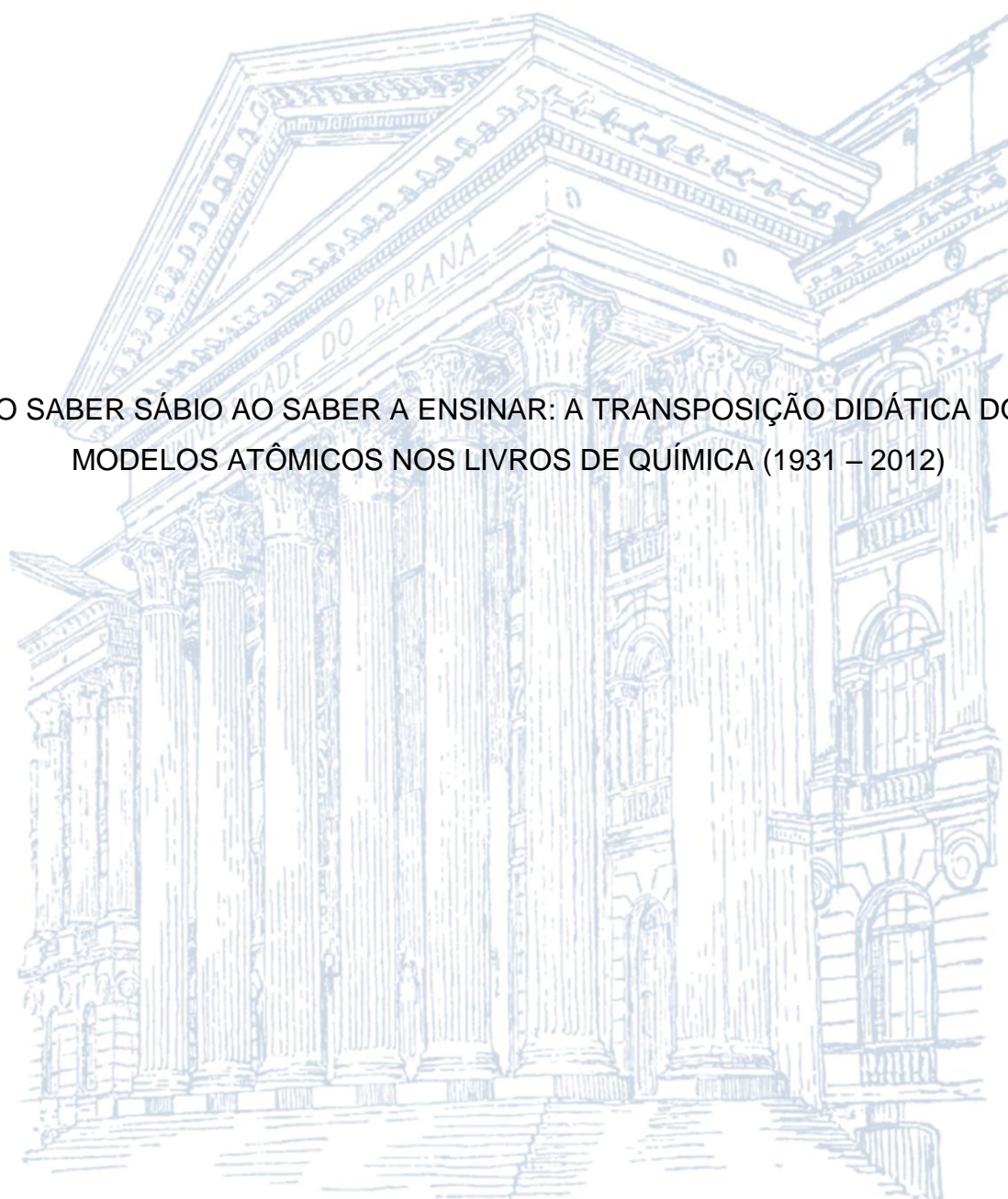


UNIVERSIDADE FEDERAL DO PARANÁ

EHRICK EDUARDO MARTINS MELZER

DO SABER SÁBIO AO SABER A ENSINAR: A TRANSPOSIÇÃO DIDÁTICA DOS
MODELOS ATÔMICOS NOS LIVROS DE QUÍMICA (1931 – 2012)



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2012

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MODELOS ATÔMICOS NOS LIVROS DE QUÍMICA (1931 – 2012)

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PARECER

Defesa de Dissertação de **EHRICK EDUARDO MARTINS MELZER**, intitulada “**DO SABER SÁBIO AO SABER A ENSINAR: A TRANSPOSIÇÃO DIDÁTICA DOS MODELOS ATÔMICOS NOS LIVROS DE QUÍMICA (1931-2012)**”, para obtenção do Título de Mestre em Educação em Ciências e em Matemática.

De acordo com o Protocolo aprovado pelo Colegiado do Programa, a Banca Examinadora composta pelos professores abaixo-assinados arguiu, nesta data, o candidato acima citado. Procedida a arguição, a Banca Examinadora é de Parecer que o candidato está **apto ao Título de MESTRE EM EDUCAÇÃO EM CIÊNCIAS E EM MATEMÁTICA**, tendo merecido as apreciações abaixo:

BANCA	ASSINATURA	APRECIÇÃO
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Coordenador do Programa de Pós-Graduação
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*Dedico este trabalho a minha companheira,
pois sem ela tudo isso seria impossível. A
você Débora, meu amor.*

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Cientistas não são dependentes de idéias de um simples homem, mas uma combinação de visões de 1000 homens, pensando sobre o mesmo problema, e cada um fazendo um pequeno pedaço e o adicionando a grande estrutura do conhecimento que gradualmente se ergue (Conn e Turner).

RESUMO

O presente trabalho tem como por objetivo fazer um levantamento e analisar como se deram as transposições didáticas em livros didáticos de química, de 1931 a 2012. Através do referencial teórico de Yves Chevallard, com a Transposição Didática e com as categorias dos elementos da *Transposição Didática: despersonalização, desincretização, descontextualização, publicidade, criações didáticas, contradição antigo/novo, programabilidade de aquisição do saber, envelhecimento moral e biológico do saber*. A técnica usada para levantamento dos dados utilizada foi a Análise de Conteúdo de Bardin (2010). Inicialmente foram analisados 55 livros didáticos de química por *leitura flutuante* e, posteriormente, 19 livros foram analisados, observando-se que estes apresentam formas distintas de *despersonalização, desincretização, descontextualização, publicidade, criações didáticas, contradição antigo/novo, programabilidade de aquisição do saber, envelhecimento moral e biológico do saber*. Compreendendo que os livros didáticos de química sofreram adaptações e modificações de suas *transposições didáticas*, enquanto manteve-se a tradição com relação ao tratamento dos Modelos Atômicos.

Palavras-Chave: Ensino de Ciências, Ensino de Química, Didática das Ciências, Transposição Didática, Livro didático, Modelo atômico.

ABSTRACT

This paper intendeds to survey and analyze how were the didactic transpositions in textbooks of chemistry from 1931 to 2012. By the theoretical reference Yves Chevallard, with the didactic transposition and categories of the elements of didactic transposition: *depersonalization, desyncretism, decontextualization, advertising, educational creations, contradiction old/new, programmability acquisition of knowledge, moral and biological aging of knowledgement*. The technique used to collect data was the analysis of Bardin (2010). Initially it was analyzed 55 text books of chemistry for floating reading and later, 19 books were reviewed, analyzing that present different ways of *depersonalization, desyncretism, decontextualization, advertising, instructional designs, contradiction old/new, programmability acquisition of knowledge, moral and biological aging of knowledgement*. Understanding that the textbooks of chemistry suffered adaptations and modifications of its didactic transposition, while maintaining the tradition regarding the treatment of Atomic Models.

Keywords: Science Teaching, Chemistry Teaching, Science Education, Didactic Transposition, Textbooks, Atomic Model.

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LISTA DE SIGLAS

- ENEM – Exame Nacional do Ensino Médio
- LDBEN – Lei de Diretrizes e Bases da Educação Nacional
- MEC – Ministério da Educação
- NCSU – North Carolina State University
- PNLEM – Plano Nacional do Livro para o Ensino Médio
- PNLD – Plano Nacional do Livro Didático
- PPGECM – Programa de Pós-Graduação em Educação em Ciências e em Matemática
- UFPR – Universidade Federal do Paraná
- UFSC – Universidade Federal de Santa Catarina

LISTA DE ABREVIATURAS

PTA - Pesquisadores da Teoria Atômica

LDQ - Livro Didático de Química

TD - Transposição Didática

HFC – História e Filosofia da Ciência

LISTA DE SÍMBOLOS

μ – Micro

e – carga do corpúsculo

ϕ – Ângulo de desvio

ρ - Curvatura dos raios em um campo magnético

π – Pi

φ – desvio das partículas

Cos – Coseno

Cosec – Cossecante

r_s – Posição da partícula no eixo x

θ_s – Posição da partícula no eixo y

Z_s – Posição da partícula no eixo z

RaBr_2 – Brometo de Rádio

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INTRODUÇÃO

Início este trabalho apresentando algumas motivações que me fizeram ingressar no mestrado, as mudanças que meu projeto sofreu até chegar a sua versão final, estrutura, objetivos e metas.

O que me motivou desenvolver esta pesquisa foi que em toda minha trajetória escolar nunca me foi elucidado o que seria o átomo ou o que seriam os Modelos Atômicos. Somente diziam que é a entidade mais importante da química, porque sem ele não é possível entender como a matéria é formada, como os compostos se ligam e estão no ambiente.

Após meu ingresso na Universidade Federal do Paraná, essa mesma questão ainda me chamava a atenção, pois a grande maioria dos professores que explicavam o Modelo Atômico, o átomo e outras entidades, usavam a mesma explicação, vista por mim no Ensino Médio, não elucidando o que realmente seria o átomo.

Recordo-me do meu primeiro dia de aula de química geral em que o professor da disciplina, na época, pediu para um aluno desenhar o modelo de átomo atual no quadro, colocando uma circunferência dentro da outra. Logo após, o professor disse: “Muito bem! Essa é a real forma do átomo. Tudo que vocês aprenderam no ensino médio está errado”. Depois daquela aula, fiquei por muito tempo abalado, cogitei até desistir do curso, mas me recompus e decidi aprender o que realmente é o átomo. E quanto mais estudava, mais aquilo me instigava e gerava dúvidas.

Nos últimos anos de faculdade, conheci a professora que atualmente me orienta recém ingressa no Departamento. Na época, eu estudava espectroscopia de luminescência na Química Inorgânica Aplicada (outra tentativa de entender o que era o átomo realmente). Como projeto de graduação na disciplina ministrada por esta professora, propus a análise do átomo no livro didático de química do PNLEM 2007, com o referencial teórico de Gaston Bachelar, sugestão desta mesma professora. Foi nas disciplinas ofertadas por ela, Projetos I e II, que comecei a compreender o quão complexa era aquela questão.

A minha motivação de pesquisa levou-me a apresentar um poster do trabalho, no ENPEC de 2009, e a fazer mestrado na área de Ensino de Química.

Durante minha atuação como profissional na área de educação, a questão sobre “como os livros didáticos selecionam e veiculam os conteúdos” sempre me chamou a atenção. E foi com ela que desenvolvi o presente trabalho. Escrevi um projeto padrão de pesquisa que envolvia uma análise de metáforas, analogias e modelos nos livros didáticos de química (LDQ), com base na dicotomia teórica entre Gaston Bachelar (escola francesa) e Mary Hesse, Max Black e Nancy Cartwright (escola inglesa).

Depois de cursar algumas disciplinas do mestrado, fui me dando conta que aquele projeto era inviável. Assim, comecei a procurar um novo referencial teórico para minha pesquisa. E foi na área de Didática das Ciências que encontrei um terreno fértil para minha proposta de análise, usando as teorias sobre *Práticas Sociais de Referência e Transposição Didática*.

Em meio aos estudos, aprofundei-me em trabalhos da sociologia, antropologia, história e filosofia das ciências, o que me fez pensar em junção com diferentes referenciais teóricos.

Fiz a disciplina Didática das Ciências na UFSC, o que me trouxe muito conhecimento sobre o assunto, além de sanar grande parte de minhas dúvidas. Depois, fiz uma disciplina no Setor de Educação da UFPR, onde tive contato com vários referenciais teóricos importantes, que me fizeram grandes reestruturações cognitivas em minha formação como pesquisador. E por fim, outra disciplina que contribuiu para mudar minha forma de pensar, em conjunto com os alunos norte americanos da North Carolina State University (NCSU). Esta experiência trouxe-me muito conhecimento interpessoal e a oportunidade de conversar com pessoas de outra realidade, o que foi muito bom e me despertaram para novos horizontes na área de pesquisa em Ensino de Ciências. Durante o estudo nas disciplinas, minha pesquisa foi sofrendo várias modificações em seu referencial teórico, passando a incorporar contribuições de autores como Ludwik Fleck, Pierre Bourdieu, Anthony Giddens, Yves Chevallard, Jean Louis Martinand e Theodor Adorno.

A proposta de incorporação da contribuição de grande parte desses autores, durante as orientações e devido a minha teimosia, conseguiu ser reduzida a um trabalho conjunto envolvendo Yves Chevallard, Jean Louis Martinand e Ludwik Fleck, que foi recortado, mais tarde, a pedido da minha banca de qualificação, focando a *Transposição Didática* para a análise do Modelo Atômico no LDQ.

Sempre tive uma grande inquietude com os recursos didáticos usados para se ensinar átomo, bem como o uso de analogias e denominações pejorativas como: “pudim de passas”, “sistema planetário”, “bola maciça”, dentre outras.

Foram estes questionamentos que deram origem ao problema de pesquisa desta dissertação, expresso pela seguinte pergunta: “Como foram transpostos os Modelos Atômicos criados pelos pesquisadores da teoria atômica (PTA) em livros didáticos de química, no período de 1931 a 2012”?

Quanto a estrutura, esta dissertação é composta por 5 capítulos. No capítulo 1, desenvolve-se um estudo bibliográfico da *Transposição Didática*, com base nos trabalhos de Yves Chevallard e interpretações teóricas de Jean Pierre Astolfi, Késia C. R. Neves, Pais, Brousseau e José de Pinho Alves Filho. Essas interpretações me permitiram separar alguns elementos da Transposição Didática para o estudo os quais são: *despersonalização, desincretização, descontextualização, publicidade, criações didáticas, contradição antigo/novo, programabilidade de aquisição do saber, envelhecimento moral e biológico do saber.*

No capítulo 2 apresenta-se uma leitura de trabalhos historiográficos e originais dos trabalhos de: John Dalton, J. J. Thomson, E. Rutherford e Niels Bohr, formando uma interpretação histórica de suas propostas atômicas.

O capítulo 3 apresenta a metodologia usada para o levantamento e depuração dos dados da pesquisa, que foi a Análise de Conteúdo de Laurence Bardin (2010). Essa escolha justifica-se pela possibilidade desta gerar uma extensa quantidade de dados. Dessa forma, analisou-se, inicialmente, 55 livros didáticos de química (LDQ), através de uma *leitura flutuante*¹, que estendeu-se de forma mais

¹ A leitura flutuante, de acordo com Bardin (2010), consiste em uma primeira análise do texto a ser pesquisado. Pode ser encarada como uma etapa de seleção de material, onde o material que é pertinente à pesquisa formará o corpo da análise.

aprofundada em 19 livros. Sendo duas coleções para cada período de reforma educacional ou programa do governo para o livro didático.

Os resultados, organizados no capítulo 4, foram levantados através de um instrumento que foi constituído através dos *elementos da Transposição Didática* de Chevallard (1991).

O capítulo 5 apresenta uma síntese dos dados da pesquisa, alguns relatos de das opções metodológicas e leituras finais sobre a *Transposição Didática* dos Modelos Atômicos nos LDQ de 1931 a 2012.

Destarte, de todas as dificuldades encontradas elenco que a pior parte da construção desta dissertação foi a busca de LDQ para análise. Pois, as bibliotecas de Curitiba carecem de material bibliográfico histórico e os Sebos que frequentei ao longo de 2 anos não tinham grande parte dos livros usados para essa análise, me forçando a recorrer a Sebos de outros estados para aguir material de pesquisa. A busca pelas fontes históricas sobre os Modelos Atômicos também não foi nada fácil, pois grande parte dos escritos não estava acessível a público, o que me ajudou muito foram os trabalhos de Vianna, Lobato e Lopes que buscaram parte dessas fontes e me sinalizaram onde buscar os artigos de Dalton, Thomson, Rutherford e Bohr.

Outro ponto crítico para o desenvolvimento desta dissertação foi a escrita, quando comecei não tinha um nível aceitável de expressão com a escrita, ao longo desses dois anos fui me desenvolvendo com a ajuda de minha namorada e os toques de minha orientadora, posso olhar para trás e ver que progredi bastante.

Mas nem tudo são lágrimas, houveram pontos positivos nesse projeto como o aumento no meu conhecimento sobre os referenciais teóricos de pesquisa que acumulei ao longo desses dois anos. As pessoas incríveis que conheci na minha jornada e a lições que elas, inconscientemente, me ensinaram sobre a vida acadêmica e sobre o que eu quero para meu futuro, me dando força para continuar e apresentar a esta banca esta dissertação.

Sobre algumas opções tomadas nesta pesquisa, gostaria de ressaltar que quase todas as sugestões feitas pela banca de qualificação foram acatadas e

implementadas. Somente uma delas não foi usada, a 6 meses atrás a banca sugeriu que meu trabalho fosse mais amplo, que ao invés de só analisar os LDQ (uma *Transposição Didática externa*), eu, analisa-se, também, como os professores pensam os Modelos Atômicos para ver como se daria a *Transposição Didática interna*.

Infelizmente, não pude acatar essa opção, devido ao fato de que os dados que os 55 e, posteriormente, os 19 LDQ geraram muitos dados que demandaram mais tempo que o imaginado na tabulação e análise. Assim, fazendo com que essa dissertação só tivesse a análise de *Transposições Didáticas externas*.

Lembrando que toda essa construção, com todas suas dificuldades, teve como objetivo central analisar como foram transpostos os Modelos Atômicos em livros didáticos de química, no período de 1931 a 2012. Com os objetivos específicos: 1) levantar as teorias dos Modelos Atômicos desenvolvidos pelos PTA; 2) examinar, ao longo da história, como os LDQ apresentam os Modelos Atômicos; 3) analisar o conteúdo referente ao Modelo Atômico presente nos LDQ, com base nos *elementos da Transposição Didática*².

Justifico a escolha do conteúdo Modelo Atômico com base nos seguintes argumentos: este conteúdo vem suscitando um maior número de discussões em pesquisas relacionadas aos livros didáticos de química, como os trabalhos de Mortimer (1988), Lopes (1990), Justi e Monteiro (2000), Gomes e Oliveira (2007), dentre outros. Outra razão é o fato de o Modelo Atômico estar entre os primeiros conteúdos de química que o aluno do Ensino Médio tem contato. Basicamente, este conteúdo contempla a parte histórica dos modelos. No entanto, pesquisas (MORTIMER, 1995) têm mostrado que os alunos, geralmente, interpretam de maneira equivocada as propostas dos modelos atômicos. Por isso, faz-se necessário uma análise e reflexão sobre como tem se dado a *transposição* desse conteúdo em livros didáticos do Ensino Médio.

Em relação ao período e ao corpus da pesquisa, recorri a trabalhos que analisam livros didáticos de química no Brasil, como Mortimer (1988) e Lopes

² Os elementos da *Transposição Didática* segundo Chevallard (1991) podem ser compreendidos como categorias que foram evidenciadas no estudo da noção matemática de distância. Tornando-se diretrizes para formação do *saber a ensinar*.

(1990). Nestes trabalhos, os autores iniciam suas análises pelo ano de 1931, data da Reforma Francisco Campos. É a partir dela que se começa a desenvolver padrões de escrita para LDQ, bem como a seleção de conteúdos socialmente relevantes. Outra questão, que instigou a análise a partir deste recorte temporal, são as mudanças das necessidades sociais, ligadas aos testes de seleção e vestibular. E, por fim, as mudanças nas leis e reformas, que permitem a compreensão de como os livros foram se adaptando a elas.

É com base nessas questões e objetivos que pretendo analisar livros didáticos de química de 1931 a 2012, buscando entender como vem se dando a *Transposição Didática*, referente ao conteúdo Modelo Atômico do *saber sábio* ao *saber a ensinar* em LDQ brasileiros. Considero que o entendimento desta questão pode vir a contribuir com novos direcionamentos no ensino de química, no que diz respeito ao conteúdo Modelo Atômico.

CAPÍTULO 1 - YVES CHEVALLARD E A TRANSPOSIÇÃO DIDÁTICA: INSTRUMENTO DE ANÁLISE DOS SABERES

Michel Verret, sociólogo, publicou em 1975 sua tese intitulada de *le temps de etudes*³ na Universidade de Paris V na França o termo *Transposição Didática* que, posteriormente, foi aprofundado, em meados dos anos 80, por Yves Chevallard na Didática das Matemáticas e posteriormente por Michel Develay e Jean Pierre Astolfi na Didática das Ciências. Defendendo que todo o conteúdo de ensino vem de um *saber* anterior, comumente produzido nas comunidades científicas, transposto para os livros didáticos e, posteriormente, inserido na sala de aula:

Um conteúdo de saber que foi designado como saber a ensinar sofre uma série de transformações e adaptações que o tornarão capaz de tomar seu lugar entre os objetos de ensino. O “trabalho” que faz a passagem de um objeto de saber a ensinar e por fim um objeto de ensino é conhecido como transposição didática (CHEVALLARD, 1991, p. 39, tradução nossa).

De acordo com Chevallard (1991) a *Transposição Didática* permite uma compreensão didática e epistemológica do percurso de formação dos *saberes* em três esferas distintas: *saber sábio*, *saber a ensinar* e *saber ensinado*, objetivando a compreensão de como um *saber* é transformado, moldado e adaptado para atender a certas demandas sociais.

Começando pelo *saber sábio* que pode ser entendido como sinônimo de *saber acadêmico*, *saber de referência*, *saber erudito* e *saber científico*. Este é fechado, restrito, altamente especializado e dotado de uma simbologia própria. Somente aqueles que são iniciados têm o grau de especialização para lidar, compreender e decodificar esse tipo de *saber*.

³ Os tempos de estudos, tese apresentada por Michel Verret à Universidade de Paris V na França.

Para Brousseau (1999) é na esfera de produção dos saberes que o matemático ou o cientista tem de lidar com inúmeras questões para constituir e formular o *saber sábio*. Porém, como frisa Brousseau, essa tarefa é complicada:

Antes de comunicar aquilo que pensa ter descoberto, um investigador, tem de começar por determiná-lo: não é fácil distinguir o labirinto das reflexões, aquelas que são suscetíveis de se transformar num saber novo e interessante para os outros (BROUSSEAU, 1999, p.36).

O pesquisador no contexto de criação de uma lei ou teoria, “despersonaliza, descontextualiza e destemporaliza o mais possível seus resultados”⁴ (BROUSSEAU, 1999, p. 37). Lembrando que esse processo é de grande valia para o leitor:

Este trabalho é indispensável para que o leitor possa tomar consciência destes detalhes e convencer-se da sua validade sem fazer ele próprio o mesmo caminho com vista à sua descoberta, se beneficiando das possibilidades que eles oferecem a sua utilização (BROUSSEAU, 1999, p.37).

Nesta visão, Brousseau (1999), subentende que no *saber sábio* se opera uma *transposição*. Necessária para que o leitor compreenda aquilo que se intenta transmitir, interpretando e adaptando um denominado *saber* de acordo com suas necessidades e expectativas, focalizando novas *transposições*.

Pinho-Alves (2000) entende que o produto *saber sábio* não reflete certas características do processo de construção da ciência:

É conveniente notar que o produto não reflete o processo, pois omite todo o contexto no qual o cientista esteve imerso, assim como não explicita a linha de pensamento durante o processo investigatório. O produto – saber sábio – apresenta-se limpo, depurado e em linguagem impessoal, não retratando os eventuais detalhes de sua construção. Esta diferença entre o processo e o produto assinala a descontextualização, a despersonalização e a reformulação que ocorre com o saber já na esfera do saber sábio (PINHO-ALVES, 2000, p. 179).

⁴ Os termos despersonaliza, descontextualiza e destemporaliza se relacionam com retirar o subjetividade, a ordem cronológica dos fatos e retirar o real tempo de desenvolvimento de um saber, posteriormente estes elementos serão melhor desenvolvidos nesta dissertação.

Nesse sentido, pode-se compreender que o produto *saber sábio* é aquele produzido no bojo da pesquisa, dentro de uma comunidade acadêmica, pelo pesquisador. Inicialmente, tem uma linguagem pessoal e é altamente codificado, um labirinto de reflexões. Estas por sua vez, passam por um processo de *despersonalização*, *desincretização* e *descontextualização*, para tornar-se o produto *saber sábio* publicável, seja em um artigo, periódico, comunicação oral, painel, ou outra forma de comunicação possível.

A segunda modalidade, compreendida como *saber a ensinar*, de acordo com Chevallard (1991), é oriunda do *saber sábio*, totalmente reorganizado e apresentado de forma mais simplificada, com o objetivo de ser um *saber* de fácil compreensão para o aluno, constituindo-se em *objetos didáticos*⁵.

Pinho-Alves (2000) faz uma distinção entre os personagens definidores do *saber a ensinar* e *saber sábio*:

Os personagens definidores do saber a ensinar não pertencem a um só grupo, como na esfera do saber sábio. Nesta última, o grupo é constituído de intelectuais e cientistas, sejam jovens e idosos, com ou sem conflitos teóricos, vinculados a esta ou aquela escola de pensamento, todavia todos são pertencentes ao mesmo nicho epistemológico em que ocorre a produção do saber (PINHO-ALVES, 2000, p. 225).

O processo de *Transposição Didática* desenvolve um novo *saber* que tem por objetivo ser ensinável a um determinado grupo de estudante, formando o que se entende por *saber a ensinar*.

O cerne da transposição didática está em se aceitar a premissa que esta esfera *não gera um saber científico* – **mas gera um novo saber!** Sua função é transformar o saber sábio, que se apresenta em forma não adequada ao ensino, em material “ensinável” inserido em um discurso didático com regras próprias. Assim como saber sábio é submetido a

⁵ *Objetos didáticos*, de acordo com Chevallard (1991), são fragmentos de *saber sábio* que foram modificados a fim de se tornar objeto de ensino, para utilização dentro do sistema didático. O objetivo dessa modificação é tornar o *saber* inteligível para o aluno, assim perde sua ligação com o *saber sábio* que o gerou.

regras e linguagem específicas, o *saber a ensinar* tem suas regras próprias (PINHO-ALVES, 2000, p.226, grifos do autor).

Portanto, de acordo com Pinho-Alves (2000) e baseando-se na *Transposição Didática*, enunciada por Chevallard (1991), o *saber a ensinar*, diferente do *saber sábio*, segue uma nova organização de crescente dificuldade, linearidade e de caráter cumulativo, possuindo uma linguagem diferente, voltada para a compreensão do aluno que está inserido na sala de aula. O caráter atemporal se manifesta de certa forma nesta linearidade, podendo encobrir muitas vezes o real tempo e as idas e vindas, como os conflitos e embates, no desenvolvimento de uma explicação científica.

O *saber a ensinar* se faz presente nos livros didáticos e outras formas de publicação destinadas ao *sistema didático*⁶, como um meio de orientar e imprimir o que deve ser ensinado em sala de aula, numa determinada ordem didática. Esse patamar de *saber*, diferentemente do *saber sábio*, traz uma idéia de que a ciência é fechada, uma verdade absoluta, encoberta por segurança e simplicidade tanto na linguagem quanto nos conceitos envolvidos.

A terceira modalidade de *saber* é denominada de *saber ensinado*. De acordo com Astolfi et al (1997) e Chevallard (1991), é aquele *saber* comunicado em sala de aula, dentro do *sistema didático*, caracterizado pela figura do professor que prepara sua aula e interpreta o *saber a ensinar*. Este, por sua vez, faz uma *Transposição Didática* ligada a seus anseios e necessidades⁷, selecionando, modificando e reorganizando os *saberes* a fim de torna-los ensináveis, dependendo de sua experiência docente e do tempo que dispõe em aula para ensinar um determinado conteúdo. Assim, é o professor que define as fontes de *saber a ensinar* que serão usadas para formar o *saber ensinado* que será apresentado ao aluno como conteúdo ensinado em sala de aula. Ou seja, essa etapa é definida como uma *transposição* ligada ao que os livros didáticos comunicam, à experiência do professor e às pressões de grupos variados, atuantes na escola, decidindo como será ensinado ao aluno.

⁶ Para Chevallard (1991) o sistema didático é uma relação ternária formada por professor-aluno-saber, constituindo todas as interações entre essas partes.

⁷ Vale lembrar que na teoria da Transposição Didática há na figura do professor uma dinâmica de mediação do saber em sala de aula, dentro do sistema didático.

Nesse sentido, Chevallard (1991) considera que existem duas etapas onde ocorrem essas modificações e transformações do *saber*: a primeira é denominada de etapa *strictu sensu* (*Externa*) que corresponde à seleção dos conteúdos que virão a se tornar *saberes* a serem ensinados, na *noosfera*⁸. A segunda etapa é definida como *lato sensu* (*Interna*), conduzida pelos atores dentro do *sistema de ensino*⁹, que formam o *saber ensinado*.

A diferenciação entre as transposições é indispensável para se compreender como um dado *saber* é modificado, a fim de se tornar um *objeto didático* veiculado no *sistema de ensino*.

Astolfi et al (1997) fazem uma sistematização dessas duas etapas da *Transposição Didática*, apresentando a figura 1:

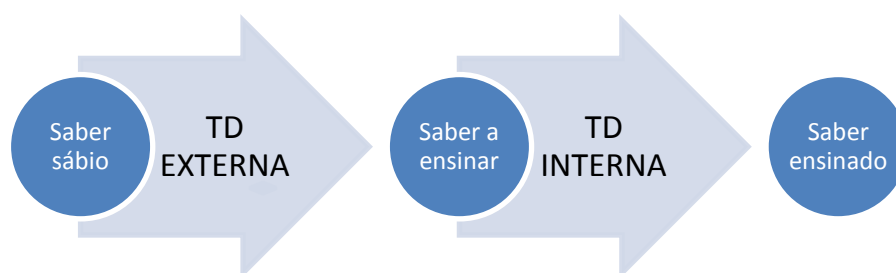


FIGURA 1 – ESQUEMA DE FUNCIONAMENTO DA TRANSPOSIÇÃO DIDÁTICA
 FONTE: O AUTOR (2012)

Na discussão da *Transposição Didática* dos diferentes patamares do *saber* (*sábio*, *a ensinar* e *ensinado*), Chevallard (1991) elenca elementos que conduzem esse processo, que são mais gerais, não diretamente ligados a *textualização*¹⁰ dos *saberes*, com maior aplicabilidade na reflexão do pesquisador (*didata*¹¹) ou professor que usa a teoria para compreender e avaliar a sua prática docente, são eles: *noosfera*, *vigilância epistemológica*, *ruptura epistemológica*, *controle social da aprendizagem*, *cronogênese* e *topogênese*¹².

⁸ *noosfera* é uma categoria desenvolvida por Chevallard (1991) e traduz, simplificadamente, a esfera que pensa e faz a Transposição Didática do *saber sábio* ao *saber a ensinar*, que será vista adiante.

⁹ Chevallard (1991) compreende que *sistema de ensino* é o conjunto de sistemas didáticos, ou seja, seria a instituição didática que receberá o *saber a ensinar*.

¹⁰ *Textualização* na compreensão de Chevallard (1991) é o *saber* traduzido na forma de um livro ou texto.

¹¹ Em sua compreensão Chevallard (1991) usa o termo *didata* que pode ser usado como sinônimo de acadêmico ou pesquisador da área educacional.

¹² Chevallard (1991) descreve outros elementos definidores da *Transposição Didática*, porém neste trabalho eles não serão abordados.

A *noosfera* de acordo com Chevallard (1991), pode ser compreendida como uma instância essencial para o funcionamento didático, sendo responsável pela interação do *sistema de ensino* com o *entorno social*¹³:

É preciso dar seu lugar a uma instância essencial para o funcionamento didático, como uma moldura do sistema de ensino e verdadeiro *tamis* por onde se opera a interação entre esse sistema e o entorno social (CHEVALLARD, 1991, p. 24, tradução nossa).

Para Chevallard (1991) a *noosfera* é o coração da *Transposição Didática*, compreendida como a “esfera onde se pensa”:

Ali se encontram todos aqueles que, para tanto ocupam os pontos principais do funcionamento didático, se enfrentam com os problemas que surgem do encontro com a sociedade e suas exigências, ali se desenvolvem os conflitos, ali se levam a cabo as negociações, ali se amadurecem as soluções (CHEVALLARD, 1991, p. 24, tradução nossa).

Chevallard (1991) entende que a *noosfera* é uma estrutura heterogênea formada por vários atores sociais, que se influenciam, disputam e negociam para formar o *saber a ensinar*. É ditada por uma hierarquia, relações dispareas entre seus integrantes e responsável pelos *saberes* presentes nos manuais didáticos¹⁴. Nas palavras do autor:

Para esta instância sugeri o nome paródico de noosfera. É na noosfera, que os representantes do sistema de ensino, com ou sem mandato (desde o presidente de uma associação de professores até o simples professor militante), se encontram, direta ou indiretamente (através de uma pesquisa, restringindo a demanda, no projeto transacional, debates ensurdecedores de projetos transacionais de uma comissão ministerial), com os representantes da sociedade (os pais de alunos, os especialistas que militam em torno do ensino, os emissários de um órgão político) (CHEVALLARD, 1982, p.28, tradução nossa).

A *noosfera* opera um delicado equilíbrio, no ato de transpor os *saberes*, em um lado, o círculo de pesquisadores e especialistas buscando maneiras de fazer *boas transposições*, do outro lado, um grupo (autores e editoras) que prega por qualidade, mas acima de tudo querendo manter a relação custo/benefício para o

¹³ Entende-se que segundo Chevallard (1991) o entorno social é um sinônimo para sociedade.

¹⁴ Para Chevallard (1991), manual didático é um sinônimo de livro didático.

saber, objetivando o lucro. Portanto, entende-se a *noosfera* como um elemento que define qual e como o *saber sábio* será transposto para *saber a ensinar*, compondo um livro didático ou similar como produto final.

A *vigilância epistemológica*, definida por Chevallard (1991), se faz no momento em que o profissional docente, pesquisador ou qualquer outro ator social questiona a natureza de um determinado *saber*, que se encontra no livro didático ou em outro texto de *saber*. Ainda vale lembrar que esta não é uma tarefa simples, pois, necessita que o ator tenha um certo conhecimento sobre a construção do *saber* que está sendo “vigiado”.

Pode-se ainda entender que a *Transposição Didática* se justifica, existe, enquanto *vigilância epistemológica* dos *saberes*, ou seja, quando o profissional se pergunta que modificações aquele *objeto didático* teve desde sua gênese no pensamento esotérico.

A *ruptura epistemológica* é quando o professor toma consciência do processo de *Transposição Didática*, através de um *processo de vigilância epistemológica*, entendendo que um determinado *objeto de ensino* não é um *saber sábio*, mas um *saber a ensinar* que foi modificado para ser didatizado em sala de aula, não correspondendo ao projeto da ciência. Nesse sentido, Chevallard (1991) lembra que o *objeto didático*, dentro de um contexto de *ruptura epistemológica*, perdeu a sua *transparência*¹⁵.

O *controle social da aprendizagem*, na visão de Chevallard (1991), se faz na figura do docente¹⁶, exercendo um controle na tarefa de ensinar um conteúdo, escolhendo aquilo que é mais relevante para o ensino e de acordo com as necessidades dos alunos, sem necessariamente ter o conhecimento da *ruptura epistemológica*.

A *cronogênese* e a *topogênese* relacionam-se a tempos de diferente natureza como argumenta Chevallard (1991). A *cronogênese* está ligada ao tempo determinado pela instituição de ensino, para o professor ensinar um determinado conteúdo. O único controle que o docente tem sobre este processo seria o de acelerá-lo ou retardá-lo e para o aluno cabe a tarefa de responder se o conteúdo foi aprendido, ou não, através de um sistema de avaliação. Já a *topogênese* seria

¹⁵ *transparencia* é um termo levantado por Chevallard (1991), traduz-se na forma que o professor observa um objeto didático, tomando-o como algo certo e irrefutável.

¹⁶ Nesta dissertação usa-se docente como sinônimo de professor.

quando ao professor é outorgado o papel de coordenador da construção de um determinado *saber*, determinando todas as etapas, que julgar necessárias, para que o aluno possa construí-lo.

Chevallard (1991) também definiu outros elementos¹⁷ como diretrizes para formação do *saber a ensinar*. É baseado neles que Astolfi et al (1997), formularam regras para melhor compreender e sistematizar os processos presentes na *Transposição Didática* constituindo-se em 5 regras básicas:

Regra 1: A modernização dos Saberes

Astolfi et al (1997) lembram que dentro de um sistema de ensino o *saber* precisa estar sendo constantemente atualizado para ficar de acordo com o avanço tecnológico da sociedade, para que este não se torne um *saber* sem utilidade dentro de um manual didático.

Regra 2: Atualização do Saber a Ensinar

A esta modernização, julgada necessária do lado do saber erudito, junta-se uma necessidade de renovação curricular, do lado do ambiente do sistema educativo (ASTOLFI et al, 1997, p. 198).

Essa atualização do *saber a ensinar* pode ocorrer devido alguns motivos, como por exemplo, tornar o *saber a ensinar* mais atual e com utilidade social ou para retirar saberes que não estão mais de acordo com o entorno social, ou seja, que se tornaram banalizados e não precisam mais ser ensinados, dando lugar a novos saberes e novas demandas sociais.

Regra 3: Articulação do saber “novo” com o “antigo”

Entre diversos “objetos” do saber erudito, suscetíveis de permitirem a modernização e de evitarem a obsolescência, alguns vão destacar-se, porque permitem uma articulação satisfatória entre o “novo” que se procura introduzir e o “antigo” que deu as suas provas no sistema e do qual será necessário conservar certos elementos reorganizados (ASTOLFI et al, 1997, p. 199).

¹⁷ Os elementos levantados por Chevallard (1991), são compreendidos como elementos de textualização dos saberes que, grosso modo, podem ser entendidos como as características que possuem os saberes, dentro de uma determinada Transposição Didática. Tais elementos serão abordados na próxima seção desta dissertação.

O *saber* “novo” nem sempre vem em substituição de um mais “antigo”, podendo ocorrer a articulação desses dois. No entanto esta articulação deve ser cuidadosa, pois o que é “novo” não pode refutar completamente o “antigo”.

Regra 4: Transformar um saber em exercícios e problemas

A seleção também se vai operar a partir da aptidão específica de certos conteúdos, para gerar um grande número de exercícios ou de actividades didáticas, mesmo quando estes estão largamente descontextualizados quanto à sua função, relativamente ao conceito original (ASTOLFI et al, 1997, p.199).

No processo de *Transposição Didática* os *saberes sábios* serão selecionados de acordo com o grau de dificuldade e da sua possibilidade de se tornar *objetos de ensino* que culminem no desenvolvimento de problemas e exercícios. Aqueles conteúdos académicos de difícil compreensão e pouca possibilidade para o desenvolvimento de exercícios serão excluídos do manual didático.

Regra 5: Tornar um conceito mais compreensível

O aluno na escola, como foi há pouco tempo letrado na língua materna, tem dificuldade em decifrar uma linguagem repleta de símbolos, códigos e matemática mais complexa, típico dos estudos presentes no meio académico. Assim, a *noosfera* no ato de fazer a *Transposição Didática*, retira esses códigos, símbolos e os substitui por sinónimos que estejam adequados a sua realidade. Neste processo alguns entraves ao entendimento de um conceito podem ser eliminados.

Pode-se compreender que a *Transposição Didática* apresenta dois contextos distintos: a etapa externa que ocorre do *saber sábio ao saber a ensinar* e a etapa interna que ocorre do *saber a ensinar ao saber ensinado*. Lembrando que a *Transposição Didática* não é responsável pelos resultados e também que esse processo não é uma mera simplificação dos *saberes* veiculados na escola, mas um conjunto de elementos que formam uma ferramenta para análise dos *saberes*.

Nesta dissertação optou-se por utilizar os elementos que Chevallard (1991) elencou para definir a *textualização dos saberes*. Na próxima seção se tem como objetivo desenvolvê-los para uso na análise de livros didáticos de química de 1931 a 2012.

1.1 INTERPRETANDO OS ELEMENTOS DA TRANSPOSIÇÃO DIDÁTICA SEGUNDO CHEVALLARD PARA O ESTUDO DO CONTEÚDO MODELO ATÔMICO

Nesta seção desenvolveu-se um estudo sobre os *elementos da Transposição Didática* como apresentados por Chevallard (1991) são eles: *despersonalização, desincretização, descontextualização, publicidade, criações didáticas, relação antigo/novo, programabilidade de aquisição do saber, envelhecimento moral e biológico do saber*¹⁸. Neves (2009) usa os mesmos *elementos* para analisar o caso das matrizes¹⁹.

A *despersonalização*, de acordo com Chevallard (1991), estaria relacionada com a retirada da subjetividade do criador de um determinado *saber*. É um dos requisitos para a comunicação do *saber* em seus diferentes patamares *saber sábio, saber a ensinar e saber ensinado*. O objetivo desse elemento é tornar o *saber* até certo ponto anônimo e universal, podendo ser aplicado nas mais diversas situações e contextos. Vale lembrar que Neves (2009), interpretando Chevallard (1991), entende que o ato de *despersonalizar* um *saber* não implica na retirada da sua história.

Neves (2009) faz uma interpretação da *desincretização* para a matemática:

A partir da desincretização dos saberes, pode-se mais facilmente designar os “lugares” que devem ocupar as noções matemáticas, paramatemáticas e protomatemáticas, pois no processo de desincretização delimita-se o que será o conceito em si, as ferramentas matemáticas e as relações do saber com outros saberes (NEVES, 2009, p. 46).

A *desincretização* pode ser compreendida como a repartição dos *saberes* e sua delimitação sob a forma de *objetos didáticos*, os quais irão compor um conteúdo de ensino. De acordo com Chevallard (1991), esse processo define como um *saber*

¹⁸ Vale lembrar que estes não são todos os elementos de textualização dos saberes elencados por Chevallard (1991), as noções matemática, protomatemática e paramatemática, também são relacionadas, pelo autor, mas por se tratar de um elemento próprio da matemática, foram retiradas para se analisar a Transposição Didática de um saber próprio da química.

¹⁹ Na dissertação de Neves (2009) analisa-se o saber matriz, desde sua gênese acadêmica (*saber sábio*) até sua inserção nos primeiros livros didáticos destinados ao ensino de matemática no ensino secundário. Nessa dissertação Neves analisa toda a estrutura do capítulo destinado ao estudo das matrizes, que na época de análise era um saber novo que estava sendo adicionado ao programa de matemática do ensino secundário brasileiro.

complexo e sincrético é dividido, formando *objetos didáticos* que possuem inúmeras delimitações, para ocupar o seu papel dentro do ensino de um determinado conteúdo.

A *descontextualização* relaciona-se com a perda de contexto do *saber*, que originalmente respondia a uma problemática específica e que agora é aplicado a qualquer problema. Chevallard (1991) apresenta a *descontextualização* por meio do conceito de distância:

Contrariamente a certos casos de transposição, que o especialista da disciplina identifica com facilidade e que procedem brutalmente de uma descontextualização dos significantes (seguida de sua recontextualização em um discurso diferente), as numerosas transferências levadas a cabo pela reforma permitiram conservar segmentos o suficiente amplos do discurso sábio como que para desviar a atenção dos matemáticos que adotaram a operação. Pois, se o contexto “discursivo” era desse modo parcialmente conservado, em relação com outro contexto, a descontextualização efetivamente novamente operada e pouco identificáveis, como tal porque transcendia o texto do saber, a rede das problemáticas no que o elemento descontextualizado falava originalmente com seu uso, seu emprego e com seu sentido. Sabemos que foram necessários alguns anos para que os matemáticos percebessem esse erro (CHEVALLARD, 1991, p. 19, tradução nossa).

Chevallard (1991) afirma que a *descontextualização* pode vir seguida de uma *recontextualização*. Nesse processo, o *saber* é retirado de sua problemática inicial que o gerou, tornando-o algo natural e universal até um certo ponto.

Neves (2009) afirma que um outro elemento que vem para contribuir com a *descontextualização* é a *desincretização*, pois quando um *saber* é *textualizado* este pode ser *desincretizado* (repartido) de forma que sua história pode ser perdida, no decorrer do processo. Entendendo que um elemento pode influenciar outro, durante o desenvolvimento da textualização do *saber a ensinar*.

Nesse sentido, pode-se compreender que a *descontextualização* é relativa a perda de contexto ou recontextualização de um *saber*, lembrando que este elemento pode ser desencadeado por uma *desincretização*.

O critério de *publicidade do saber* para Chevallard (1991) seria formas de um livro explicar como o *saber* é desenvolvido, estudado ou sistematizado e qual finalidade possui para o ensino. Esse elemento pode aparecer quando o *saber* é explicado ou quando se discorre sobre sua necessidade, aplicação ou a forma de seu estudo ao longo de uma unidade. Neves (2009) desenvolve uma interpretação desse elemento:

Já a *publicidade do saber* tem o papel de explicitar por meio de definições as compreensões e extensões do saber, é na realidade a “divulgação” do saber. Com a *publicidade do saber* se conhece quais são as finalidades dos assuntos textualizados, como por exemplo, ao divulgar sua obra em prefácios, os autores descrevem seus objetivos e tudo o mais; os prefácios seriam então as fontes de publicidade (NEVES, 2009, p. 48).

Com base nestas compreensões a *publicidade do saber* pode ser entendida como um determinado livro didático explica a relevância e como será abordado e estudado determinando *saber a ensinar*.

Programabilidade de aquisição do saber pode ser definida como:

Mais essencialmente o texto é colocado dentro dos moldes estabelecidos por M. Verret como a expressão de *programabilidade da aquisição do saber*. O texto segue um padrão de *progressão do conhecimento*. O texto tem um começo e fim (provisório), e opera com um encadeamento de razões (CHEVALLARD, 1991, p.62, tradução nossa).

Neves (2009) compreende este elemento com um exemplo:

Ao estabelecer a *programabilidade do saber*, numa textualização, está se admitindo que a aquisição do *saber* se dê de maneira progressiva e racional, seguindo o desenvolvimento do discurso utilizado no texto. Por exemplo, quando se estuda o conteúdo de geometrias não euclidianas, e vislumbra-se a possibilidade de torná-lo conteúdo ou saber escolar é porque admite-se a possibilidade de enquadrá-lo num determinado “espaço de tempo” mediante a textualização. É a textualização que permitirá pensar em temporalizar o saber. Quando se textualiza é possível pensar: “*Isto pode ser visto em uma semana, cada seção em um dia, etc.*” (NEVES, 2009, p. 47, grifos do autor).

Ou seja, a *programabilidade do saber* pode ser interpretada como a ordem em que os *objetos didáticos* são agrupados, dando a idéia lógica de linearidade e crescente complexidade dos temas abordados. Ela está presente na organização do capítulo de um livro ou sequenciamento de algum conteúdo didático. Assim, *objetos de ensino* que aparentemente não têm relação adquirem tal característica dando uma visão de ensino linear.

As *criações didáticas* podem ser entendidas como novos *objetos didáticos* que são geradas ao decorrer de uma *Transposição Didática* e introduzidos na matriz curricular, como um objeto que vem ao auxílio de um conceito. Porém, podem se

tornar um objeto mais estudado que o conceito que apoiam, figurando-se em um problema. Um exemplo, apresentado por Chevallard (1991), são os *diagramas de veen*, criados para auxiliar no ensino da teoria de conjuntos e que acabaram se tornando mais importantes do que o conceito original. Outros exemplos dessas *criações didáticas*, no domínio da matemática, são: “o ‘grande co-seno’ (Cos) e o ‘grande seno’ (Sen), os números complexos como matrizes quadradas de ordem dois, no segundo ciclo de ensino secundário” (CHEVALLARD, 1991, p.47, tradução nossa).

Pais (1999) afirma que essas criações, enquanto auxiliares, são plenamente justificáveis. O problema é que seu uso no ato de ensinar acaba sendo tão mecanizado que a própria criação perde sua aplicação e finalidade:

A escolha de conteúdos se manifesta principalmente através dos programas escolares e dos livros didáticos. Mas, embora as fontes de referências sejam preexistentes a essas escolhas e às suas publicações, é possível perceber que alguns dos conteúdos são, na realidade, verdadeiras criações didáticas incorporadas aos programas. São criações motivadas por supostas necessidades do ensino, para servirem como recurso para outras aprendizagens. A princípio, tais criações têm portanto uma finalidade educacional plenamente justificável (PAIS, 1999, p. 17).

Um outro exemplo dessas *criações didáticas* que Pais (1999) cita, são os produtos notáveis quando ensinados de maneira isolada se constituem em *objetos didáticos* que foram criados e não tem mais aplicação. Figuram-se em *objetos de ensino* em si mesmos, lembrando ainda outro ponto decisivo em torno das *criações didáticas*:

Na realidade é o conjunto das criações didáticas que evidencia a diferença que há entre o saber científico e o saber ensinado. É nesse sentido que Astolfi e Develay (1990) observam a existência de uma epistemologia do professor, que a rigor se relaciona com a epistemologia da ciência, mas que jamais pode ser identificada com ela (PAIS, 1999, p. 20).

Compreende-se que as *criações didáticas* podem de certo modo dar um caráter especial ao *saber a ensinar* e *saber ensinado*, pois se encontram como facilitadores de algum conceito e ganham um certo *status* dentro da escola. O grande problema observado é quando essas *criações* se tornam um *saber* mais

estudado do que o conceito a que se destina dar suporte, conformando um problema de nível epistemológico e didático (PAIS, 1999).

A *relação antigo/novo* se faz presente, de acordo com Chevallard (1991), quando objetos de ensino são “envelhecidos”²⁰ para compor a base de novos objetos que serão ensinados. Nesse sentido, é a relação entre um objeto “antigo” com um mais “novo”, onde o primeiro serve de pré-requisitos para a compreensão de novos conceitos.

Para Neves (2009) a *relação antigo/novo*, compreendida como *dialética antigo/novo*, se faz na relação entre *objetos didáticos*, onde:

Quando, ao iniciar um conteúdo novo, buscamos conhecimentos prévios dos alunos, estamos agindo segundo uma dialética; ou quando, ao trabalhar um conteúdo, apresentamos problemas mais atuais e que remeterão ao pensamento de novas estratégias ou à necessidade de novos conceitos, também estamos agindo conforme esta dialética (NEVES, 2009, p. 51).

A *relação antigo/novo* pode ser entendida como a forma que o *saber a ensinar* “envelhece”, tornando-se pré-requisito para a inserção de novos *saberes a ensinar* de maior grau de complexidade.

O *envelhecimento biológico* pode ser entendido como:

O envelhecimento biológico trata das definições, conceituações e conjecturas explicitadas de forma científica, por uma comunidade científica que, com o passar do tempo, ou com a mudança do paradigma, tornaram-se obsoletas. O saber científico como está parcialmente nos currículos escolares pode, dada à ocorrência deste tipo de envelhecimento, acarretar também uma mudança no paradigma científico (NEVES, 2009, p. 49).

Segundo Chevallard (1991), o *envelhecimento biológico* se dá na relação do *saber* com a atividade científica, onde, o *saber a ensinar* não é uma cópia do *saber sábio*. A diferença entre os dois está nas inovações no *saber a ensinar*. Isso se faz necessário para que o *sistema de ensino* esteja em constante adaptação sendo capaz de acompanhar os avanços sociais, podendo tornar o ensino mais ligado à realidade do aluno:

²⁰ Em seu livro Chevallard (1991) usa realmente o termo envelhecimento para explicar quando um saber fica desatualizado, ou seja, quando um saber se torna antigo.

Por um lado - envelhecimento biológico – se declara em desacordo com o desenvolvimento de saber correspondente em suas formas livres (não escolarizadas). Desacordo que pode compreender conteúdos diversos: pode ocorrer que, como corolário da investigação científica se revelem como falsos os resultados até então ensinados (CHEVALLARD, 1991, p. 26, tradução nossa).

O *saber* sofre um *envelhecimento biológico* devido ao fato de que a atividade científica não é simples e acabada. Um *saber* que é dado no livro didático como certo pode ter sido derrubado academicamente. Os autores dos livros didáticos devem estar atentos para atualizar o *saber a ensinar*, sempre mantendo uma “distância correta que o saber ensinado deve guardar a respeito do saber sábio” (CHEVALLARD, 1997, p.30, tradução nossa). Essa distância²¹ se torna necessária, pois o *saber sábio* é mais complexo e de difícil compreensão para o leigo e que deve ser de certo modo modificado para se tornar compreensível. Assim, o que deve tornar-se *saber a ensinar* são tópicos socialmente difundidos como tecnologias e outras problemáticas. Os avanços científicos mais recentes não são transpostos, pois como não tem uso cotidiano, estão longe da realidade das pessoas e do aluno.

Por *envelhecimento moral* do *saber*, Chevallard entende que:

O saber ensinado se encontrará em desacordo com a sociedade em um sentido amplo, ainda, se for o caso, e for julgada em estrita conformidade com os critérios de disciplina não seria acusado de nada. Em suma, uma questão de tempo (CHEVALLARD, 1991, p. 27, tradução nossa).

O *envelhecimento moral* que Chevallard (1991) defende pode ser entendido como um determinado *saber* que se torna socialmente difundido, tendo em vista as mudanças sociais e a necessidade que a *noosfera* tem de modificar o *saber* para atender a essas novas demandas. Ou seja, é ensinar um conteúdo ou tópico de ensino, moldado, adaptado e útil a realidade social do aluno.

Para restabelecer a compatibilidade, se torna indispensável a instauração de uma corrente de saber proveniente do saber sábio. O saber ensinado é modificado na relação com a sociedade; um novo aporte encurta a distância com o saber sábio, para os especialistas; e põe a distância aos pais. Ai se encontra a origem do processo de transposição didática (CHEVALLARD, 1991, p.27, tradução nossa).

²¹ Chevallard (1991) usa o termo distância para refletir a diferença que os diferentes patamares de saber devem ter entre si.

O *envelhecimento do saber*, segundo Chevallard (1991), explica a necessidade da *Transposição Didática*. Basicamente, o *saber a ensinar* precisa ser atualizado nos livros didáticos, para que o *sistema de ensino* não veicule *saberes* em desacordo com a sociedade, mantendo um distanciamento dos atores da sociedade e retomando o equilíbrio do *entorno social* com o *sistema de ensino*.

Todos esses elementos descritos, ao longo desta seção, são referentes aos *elementos da Transposição Didática* de Chevallard (1991) e que são usados por Neves (2009) para analisar o *saber matemático* das matrizes apresentado em livros didáticos de matemática destinados ao ensino secundário. Durante a discussão dos dados feitos por Neves (2009), um outra categoria emerge da análise dos dados de pesquisa:

Outra observação feita após a comparação entre os livros que diz respeito à contextualização e, consequentemente, diz respeito à textualização do saber, refere-se a “fidelidade” com que os conceitos são apresentados, ou seja, eles não foram burlados ou simplificados só pelo fato de serem escritos ao público do secundário. Embora os textos de Madsen e Monteiro tivesse finalidades diferentes, a fidelidade para com a escrita dos conceitos, faz subentender que o processo de transposição didática aplicado às matrizes foi de fato realizado adequadamente (NEVES, 2009, p.139) .

Neste trecho Neves (2009) analisa de forma geral a *fidelidade dos saberes textualizados* para com o conceito original (*saber sábio*). Com base nessa apresentação, desenvolve-se nesta dissertação uma outra categoria denominada *fidelidade na textualização do saber*. Assim, pode-se defini-la como uma categoria que tem por objetivo analisar um conceito no *saber sábio* em conjunto com suas *textualizações* no *saber a ensinar*, procurando identificar as modificações e adaptações feitas ou se este conceito está apresentado com certa fidelidade de informações.

Nesta dissertação optou-se analisar os livros didáticos com base nas categorias, elencadas por Chevallard (1991) e estudadas por Neves (2009), entendendo que estas não se aplicam somente ao caso da matemática, mas para vários tipos de áreas do conhecimento.

No próximo capítulo desenvolve-se uma interpretação dos artigos sobre os Modelos Atômicos de John Dalton, J. J. Thomson, E. Rutherford e Niels Bohr para formular uma visão do *saber sábio* para uso na análise dos LDQ de 1931 a 2012.

CAPÍTULO 2 – O SABER SÁBIO DOS MODELOS ATÔMICOS

Este capítulo tem por objetivo desenvolver uma leitura dos modelos atômicos no *saber sábio* presente nas produções dos seguintes autores: Dalton, Thomson, Rutherford e Bohr.

A seguir apresento uma breve contextualização da vida acadêmica de Dalton, Thomson, Rutherford e Bohr e uma leitura do *saber sábio* produzido sobre os Modelos Atômicos, fechando cada seção com uma interpretação final do modelo de cada ator.

2.1 JOHN DALTON

De acordo com Vianna (2007) e Lobato (2007) há uma certa divergência em relação a como Dalton chegou a teoria atômica, gerando várias interpretações. Em vista a essa divergência abordarei a visão de Lobato (2007) que compreende que todos os fatores destacados por esses historiadores são importantes e não podem ser amplificados ou diminuídos durante sua história.

2.1.1 A VIDA DE JOHN DALTON

Nascido em 1766, Dalton, viveu em Eaglesville, Kendal e Manchester, onde solidificou sua carreira acadêmica na *Philosophical and Literary Society de Manchester*, permanecendo até sua morte em 1844. Em sua época foi um grande pesquisador nas áreas de matemática, gramática da língua inglesa e meteorologia.

No ano de chegada a Manchester (1783), publicou o livro *Meteorological Observations and Essays*, dando a sua visão matemática à fenômenos atmosféricos como o vapor da água. Publicou inúmeros trabalhos na *Philosophical Magazine*, *Gentleman's Diary*, *Ladie's Diary* e no *Memoirs of the Philosophical and Literary Society of Manchester*. Nesses artigos há muitas resoluções de problemas matemáticos, respostas à experimentos feitos na época, leituras meteorológicas, observações de fenômenos naturais, ou seja, Dalton não era um químico de

formação, mas um matemático e meteorologista preocupado em explicar fenômenos atmosféricos (Vianna, 2007).

Segundo Vianna (2007) e Lobato (2007), Dalton teve o seu primeiro contato com a química em função da necessidade de estudá-la para ensiná-la, como professor de química no *Trinity College*. Inicialmente leu o trabalho de Lavoisier e posteriormente estudou os trabalhos de Cavendish, Ritcher e Bertholet. Esse contato com a química foi extremamente importante na formação de seu modelo de átomo, pois nessa época havia uma cisão acadêmica entre a teoria da afinidade química e uma outra explicação ancorada no mecanicismo da física newtoniana. O seu aprofundamento nas obras *Principia* e *Optica*, despertaram-no para o estudo da matéria.

Dalton, como seus contemporâneos ingleses, foi fortemente influenciado pela física de Isaac Newton, que norteou toda sua forma de pensar e compreender os fenômenos atmosféricos e gasosos. Porém, somente com essa base teórica era muito difícil dar conta de todos os fenômenos que ocorriam com os gases, fazendo-o adotar diferentes posturas teóricas, muitas vezes juntando diferentes áreas para explicar certos acontecimentos e dados experimentais. De acordo com Vianna (2007), Dalton foi duramente criticado e questionado em vários de seus trabalhos e propostas para explicar fenômenos gasosos. Dentre seus maiores críticos destacasse Bertolhet e T. Thomson. Isso era devido ao embate teórico entre os grupos de pesquisadores da época sobre a constituição da matéria e a combinação de gases e elementos. Os pesquisadores ingleses justificavam essa combinação pela lei das múltiplas proporções, enquanto que os franceses eram contra essa ideia, justificando a combinação de gases pela afinidade química. E assim, todas essas ideias controversas e conflitantes, fizeram Dalton publicar a versão total de sua obra *Novo Sistema de Química Filosófica* em 1808 e 1810.

Há uma grande dificuldade em determinar quais influências teóricas fizeram mais eco em Dalton e culminaram na sua teoria atômica. Em vista dessa dificuldade, considera-se neste trabalho a influência teórica apresentada por Lobato (2007), que levou em conta todos os acontecimentos acadêmicos e pessoais de Dalton na concepção de sua proposta atômica, como descreve:

Pode-se considerar, entretanto, que a questão do surgimento da teoria atômica não possa ser justificada apenas, e tão somente, por um simples fato, uma influência no método de trabalhar e pensar a química, ou, até mesmo, por causa da necessidade de se defender um ponto de vista mecânico da matéria. O aparecimento da teoria atômica, por ter sido um processo lento, que percorreu a primeira década do século XIX, é uma questão complexa (LOBATO, 2007, p. 19).

Assim, para compreender seu modelo atômico, na visão de Lobato (2007), se faz necessário a compreensão da construção deste, a qual pode ser retomada dos trabalhos a seguir e que constituem o *saber sábio* do modelo daltoniano²².

2.1.2 NOVO SISTEMA DE QUÍMICA FILOSÓFICA²³ (1808)

Nesse livro Dalton (1808) descreve fundamentos para a sua forma de observar os fenômenos atmosféricos e a química. Com essa compreensão são inseridos estudos sobre a natureza do *calórico*, explicando-o com bases em várias investigações feitas pelo autor, formando o capítulo 1. No capítulo 2, Dalton (1808) discorre sobre a constituição dos corpos e no capítulo 3 trata de explicar a síntese química.

Dalton (1808), trata das bases teóricas para entender as relações entre os elementos químicos e as substâncias existentes na natureza. Começando pela explicação da natureza do *calórico*. Para Dalton todos os átomos na natureza estavam rodeados por uma esfera de *calórico* que determinava a dinâmica de atração e repulsão frente a outros átomos iguais ou diferentes.

Com base na medida de temperaturas, Dalton (1808) afirma que é possível construir duas tabelas análogas, de *calores* específicos e gravidades específicas. Compreendendo que a *afinidade* pelo calor é quantificada pelo valor de calor específico, definindo assim a facilidade de atração ou repulsão da partícula:

Cada tipo de matéria tem uma peculiar atração pelo calor, pela qual requer uma certa porção desse fluido, a ponto de estar em equilíbrio com outros corpos a determinadas temperaturas (DALTON, 1808, p.1, tradução nossa).

²² DALTON, John. *New system of chemical philosophy*. Parte 1. R. Bickrstaff. Londres. 260p, 1808. e DALTON, John. *New system of chemical philosophy*. Parte 2. R. Bickrstaff. Londres. 340p, 1810

²³ *New system of chemical philosophy*.

Com base em sua compreensão o calórico seria, para Dalton (1808), uma espécie de fluido que rodeia todas as partículas, aumentando ou diminuindo suas quantidades específicas de calor de acordo com a temperatura. No decorrer do capítulo 1, Dalton descreve vários experimentos e dados que mostram valores de calor com base em comprovações experimentais de sua hipótese. Na seção 9 é que se começa a ter uma identificação do que é o átomo para Dalton. Baseando-se em suas considerações sobre os experimentos de congelamento da água, Dalton (1808) explana que durante esse processo o calor é retirado formando o aspecto sólido da água, como mostra a figura 2:

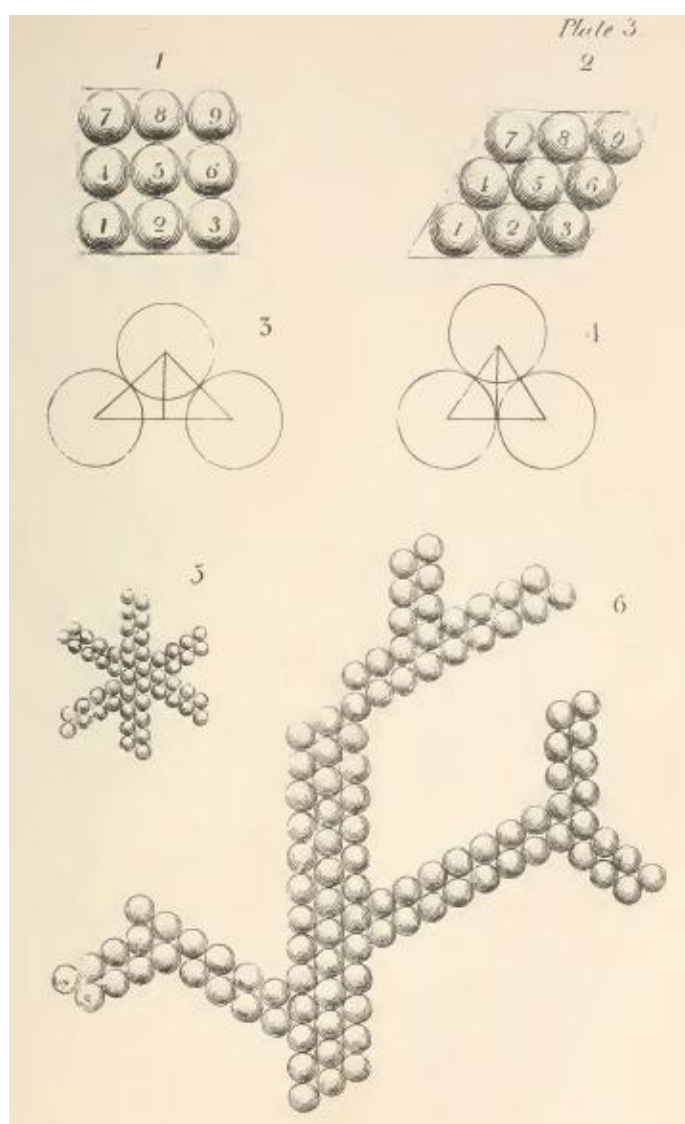


FIGURA 2 – CÁLCULO DOS ARRANJOS DE ÁTOMOS DE ÁGUA FORMANDO GELO
FONTE: Dalton (1808)

Na figura 2 é apresentada uma das representações que Dalton (1808) fez em seu livro para o congelamento da água, trazendo a visualização e cálculos dos

possíveis arranjos da água para formar cristais de gelo. Lembrando que nesta representação os átomos estão sem a atmosfera de calórico, devido ao fato de que no estado sólido ela é mínima ou completamente retirada.

No capítulo 3 do primeiro livro, Dalton (1808) adentra a compreensão da constituição da matéria e seus diferentes estados físicos. Para o autor a matéria segue três formas de arranjos específicos ou estados físicos: fluído elástico, líquidos e sólidos. Ainda lembrando que estes estados físicos tem uma certa semelhança com água, “o vapor como um fluído elástico perfeito, na água, um líquido perfeito, e no gelo um sólido completo” (DALTON, 1808, p.44, tradução nossa) e que com base no conjunto de observações pode-se chegar a uma conclusão:

Estas observações tacitamente levaram a conclusão que parece ser universalmente adotada, que todos os corpos de certa magnitude, sendo líquidos ou sólidos, são constituídos de um vasto número de pequeninas partículas, ou átomo de matéria (DALTON, 1808, p. 141, tradução nossa).

Dalton (1808) compreende que o mesmo tipo de matéria que forma o sólido é o que forma o líquido, sendo a menor partícula da matéria o átomo. Desenvolvendo sua interpretação dos átomos como sendo regidos por duas forças completamente opostas, a de coesão e repulsão.

A força de coesão é definida por Dalton (1808) como *afinidade*, *atração* ou *agregação* e a de repulsão reconhecida como *calórico*. Terminada esta compreensão, segue-se discussão nos estados da matéria e como se dão as relações entre o *calórico* e a *afinidade* no átomo. Na primeira seção, explica-se a constituição dos fluídos elásticos puros, com base na compreensão de que esses “fluídos são constituídos de partículas possuindo uma atmosfera de calor muito difusa” (DALTON, 1808, p. 145, tradução nossa). Reforçando que neste estado a força de repulsão (*calórico*) excede a força de atração (*afinidade*), dando maior expansão e elasticidade ao elemento. Com base em seus experimentos, Dalton dá uma visão geral de seu átomo no estado de fluído elástico sendo, “constituídos de um átomo de matéria extremamente pequeno, rodeado por um atmosfera de calórico” (DALTON, 1808, p. 147, tradução nossa). Entendendo que para fluídos

elásticos puros, a distância de repulsão de um átomo para outro é exatamente igual, enquanto que quando há uma mistura esse valores variam e nesta seção há uma referência a Newton sobre a atração e repulsão de partículas:

Newton demonstrou através do fenômeno de condensação e rarefação que os fluídos elásticos são constituídos por partículas, que se repelem uma as outras através de forças que crescem na proporção que a distância de seus centros diminuem (DALTON, 1808, p.168, tradução nossa).

Nesta passagem pode-se compreender a idéia de átomo de Dalton (1808), uma entidade que não é totalmente mecânica e nem totalmente química, mas um híbrido entre as duas áreas, formada por uma partícula central maciça rodeada de uma atmosfera de calor variável (*calórico*).

Na terceira seção, Dalton (1808) trata da natureza dos líquidos e suas características frente a sua organização atômica e coesão, partindo da definição:

O líquido ou fluído inelástico pode ser definido como sendo um corpo, as partes submetidas a pequenas forças, e são facilmente deslocados uns sobre os outros (DALTON, 1808, p.194, tradução nossa).

Dalton (1808) lembra que no estado líquido os átomos estão submetidos a pequenas forças desenvolvendo maleabilidade, gerando um corpo que pode ser facilmente arranjado em qualquer espaço e deslocado, fazendo uma suposição sobre a elasticidade dos fluídos e do estado líquido:

Estritamente falando, não há substância inelástica; se o calor é a causa da elasticidade, todos os corpos contém o necessário para serem elásticos (DALTON, 1808, p.194, tradução nossa).

Na visão de Dalton (1808), todos os corpos vão possuir alguma quantidade de calor em torno de seus átomos de matérias. O que vai definir sua forma química é a relação entre as forças de repulsão e coesão, rebatendo críticas de Thomson,

Bertholet, dentre outros, defendendo sua forma de enxegar a matéria e suas propriedades.

Na quarta seção do primeiro livro, Dalton explica sobre a constituição dos sólidos, começando pela seguinte interpretação:

Em um corpo sólido, as partículas estão em estado de equilíbrio entre duas grandes forças, atração e repulsão, mas de tal maneira, que nenhuma mudança em suas distâncias pode ser feita sem aplicar um força considerável (DALTON, 1808, p. 208, tradução nossa).

Então, para Dalton (1808), o estado sólido da matéria é formado pelo equilíbrio de forças que confere grande rigidez. Quando ocorre uma contração, a repulsão resiste e quando há uma força de ruptura, a força de atração é que resiste:

Se há uma aproximação das partículas por uma determinada força, o calórico resiste a isso; se há uma separação, então a força de atração é que faz resistência (DALTON, 1808, p.208, tradução nossa).

Nesse sentido, Dalton (1808) compreende que o estado sólido é obtido por um estado intermediário entre a repulsão das partículas pelo *calórico* e sua coesão pela *afinidade*. Após esta interpretação, Dalton faz uma relação entre os sólidos e líquidos:

A distinção essencial entre líquidos e sólidos, talvez consista nisso, que o calor muda o arranjo das partículas de sua formação original continuamente e gradualmente, ao mesmo tempo que ele mantém sua forma líquida, enquanto nos últimos, é provável, que a mudança de temperatura não faz mais que mudar o tamanho, e não o arranjo das partículas finais (DALTON, 1808, p.209, tradução nossa).

Com base nessa definição, Dalton (1808) pode estar atribuindo aos estados da matéria a relação de arranjo de suas partículas (átomos) e na sua interação pelas forças de atração e repulsão, ocasionando mudanças de estados físicos ou formas de uma determinada substância. Fechando a seção, apresenta-se algumas

propriedades calculadas dos sólidos, por experimentos, e há uma compreensão sobre o fenômeno da cristalização, atribuindo uma mudança no arranjo espacial de partículas para obter o aspecto de cristal.

Finalizando o primeiro livro, Dalton (1808) traz algumas noções sobre combinações e síntese em química, fazendo um estudo através da formação de compostos binários, secundários, ternários, quaternários e septenários, apresentando no decorrer do capítulo regras para os arranjos dos átomos e cálculos para a forma e peso dos mesmos. No apêndice do livro Dalton apresenta uma tabela com a representação dos átomos simples e das sínteses mencionadas no capítulo três, como apresentado na figura:

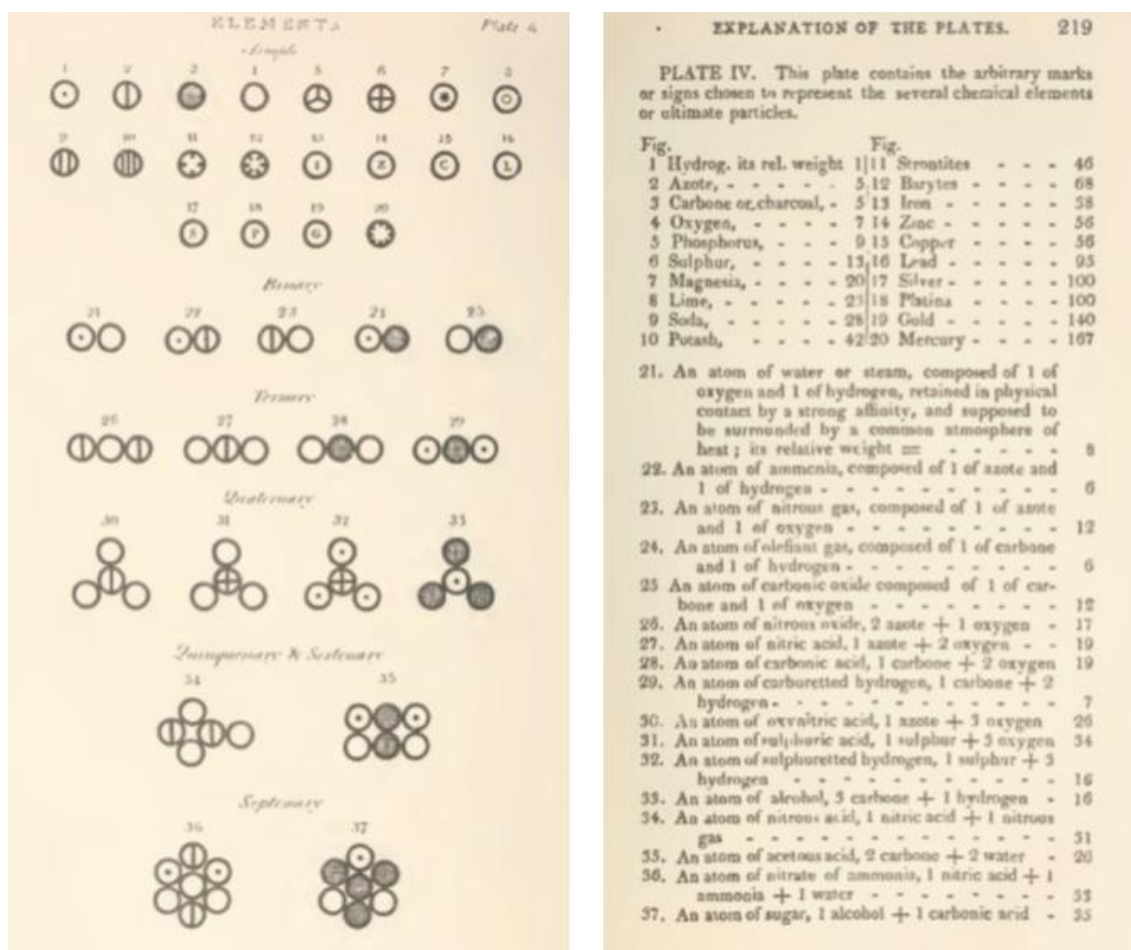


FIGURA 3 - TABELA DE NOMENCLATURA
FONTE: Dalton (1808)

Como se pode observar a figura 3 traz a visão de Dalton sobre o fenômeno atômico, além de sinalizar alguns cálculos de várias partículas atômicas. Nesse

sentido, Dalton, através de imagens desenvolve sua visão de átomo corpuscular entendendo este como uma partícula esférica indivisível que se liga a outras para formar novos compostos. Mas, é no segundo livro publicado em 1810 que Dalton dará aplicação a seu átomo e desenvolverá como a dinâmica entre forças define inúmeros compostos.

2.1.3 NOVO SISTEMA DE QUÍMICA FILOSÓFICA (1810)

Na segunda parte de sua obra, publicada em 1810, Dalton apresenta aplicações das teorias abordadas na primeira parte de seu 1º livro, dedicada a química descritiva dos compostos presentes na natureza, bem como a explicação experimental e teórica de suas propriedades.

Dalton (1810) aplica os conceitos de sua proposta atômica e síntese química para compreender as propriedades de diferentes compostos, fazendo a distinção entre átomos, para elementos líquidos, sólidos e elásticos:

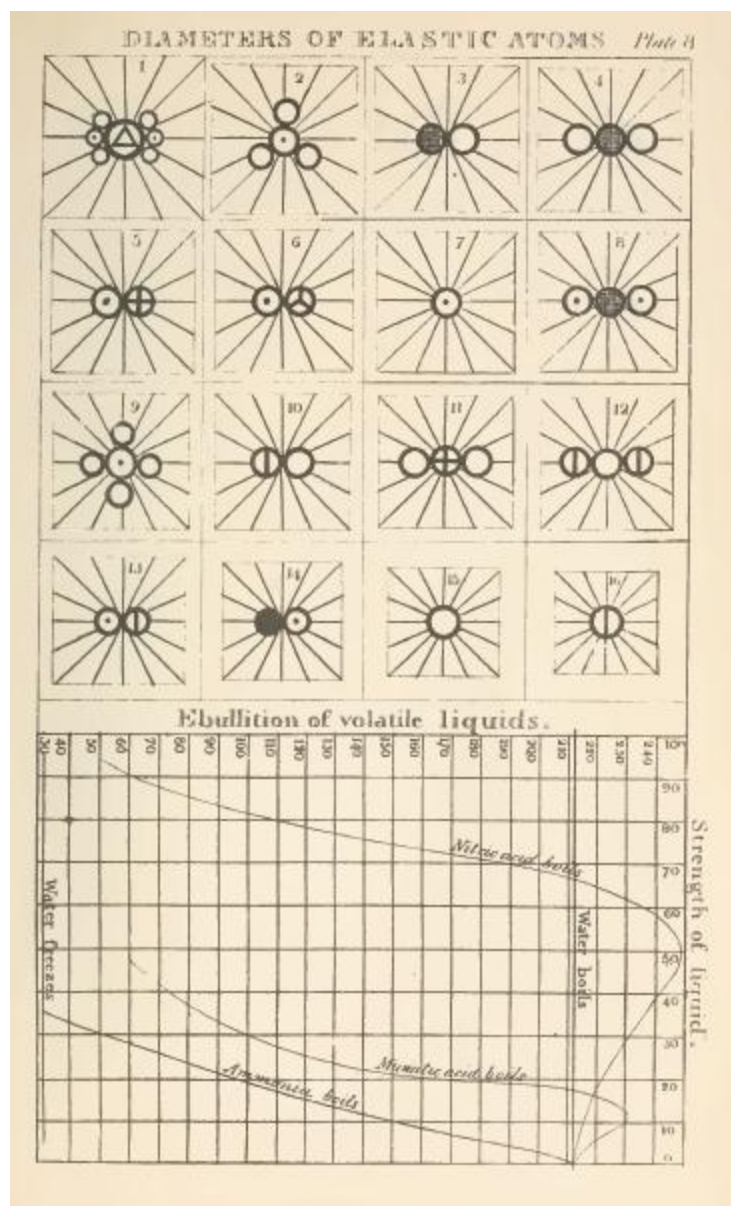


FIGURA 4 - REPRESENTAÇÃO DOS ÁTOMOS ELÁSTICOS
 FONTE: Dalton (1810)

Essa representação de Dalton (1810) ancorada nas propriedades físicas e químicas dos elementos, representados pelos seus símbolos, traz a idéia defendida no primeiro livro, onde os átomos seriam formados por atmosferas²⁴ de *calórico*.

²⁴ O termo "atmosfera" é empregado por Dalton (1810) em seu livro para significar a força que envolve a esfera indivisível.

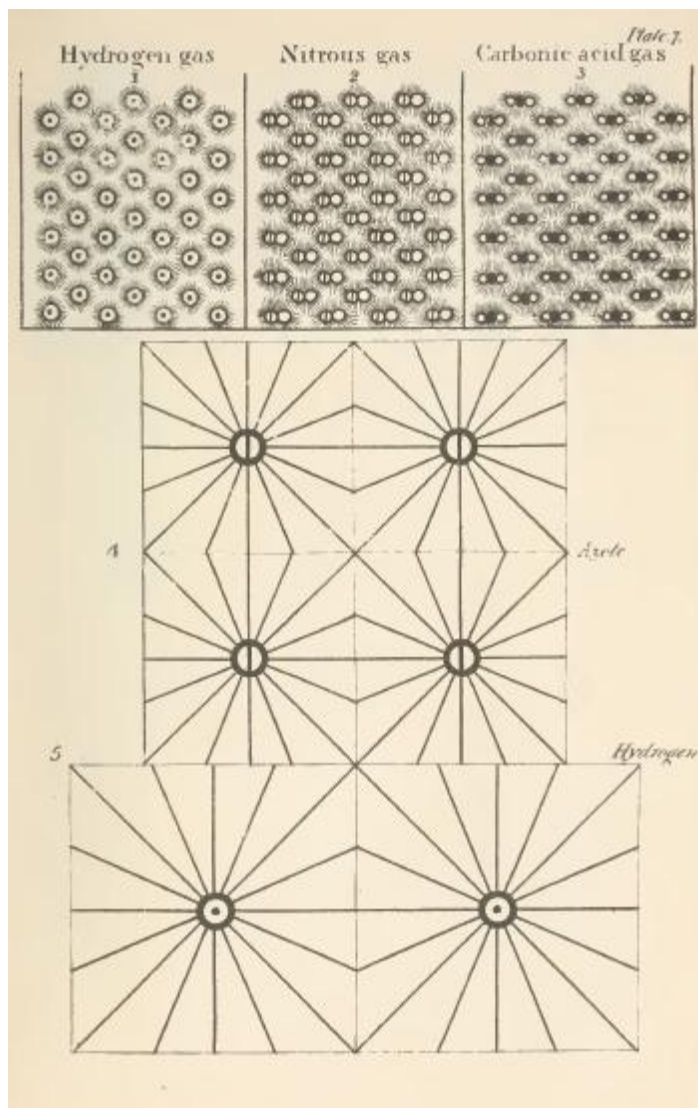


FIGURA 5 – REPRESENTAÇÃO DOS ÁTOMOS PARA DIFERENTES GASES
 FONTE: Dalton (1810)

Na figura 5, Dalton (1810) representa os átomos de diferentes substâncias gasosas combinadas e puras. Nesse estudo Dalton usa sua teoria para mostrar como se dá a repulsão dos átomos nos diferentes exemplos, compreendendo que há uma energia responsável por esse processo e que esta é que dá o aspecto de um fluido aos elementos estudados no livro de 1810.

No cerne de suas representações está o corpúsculo²⁵ de matéria, rodeado de uma atmosfera de *calórico* representado pelas linhas que saem do corpo. Portanto vale lembrar que diferentes elementos têm diferentes atmosferas de *calórico*, de acordo com o que Dalton mensurou ao longo dos experimentações.

²⁵ Dalton (1810) usa o termo corpúsculo para representar partículas esféricas perfeitas.

Tables of the elements of elastic fluids ; at a mean temperature and pressure.
(TABLE 1.)

Names of the gases.	Wt. of an atom	Wt. of 100 cubic inch. gra.	Specific gravity.	Diameter of an atom	No. of atoms in a given volume.
Atmospheric air	—	31	1.00	—	—
Hydrogen	1	2.5	.08	1.000	1000
Oxygen	7	34	1.10	.794	2000
Azote	5	30.2	.97	.747	2400
Muriatic acid	22	39.5	1.24	1.12	700
Ammonia	6	18.6	.60	.909	1330
Oxymur. acid	29	76	2.46	.981	1060
Nitrous gas	12	32.2	1.04	.980	1060
Nitrous oxide	17	50	1.60	.947	1180
Carbonic oxide	12.4	29	.94	1.020	940
Carbonic acid	19.4	47	1.52	1.00	1000
Sulphurous acid	27	71	2.30	.95	1170
Olefiant gas	6.4	29.5	.95	.81	1890
Carburetted hyd.	7.4	18.6	.60	1.00	1000
Sulphuretted hyd.	14	36	1.16	1.00	1000
Phosphur. hyd.	10	26	.84	1.03	1000
Superflu. of silex	75	130	4.20	1.15	653

FIGURA 6 – TABELA DOS ELEMENTOS FLUIDOS ELÁSTICOS: A TEMPERATURAS E PRESSÕES MÉDIAS (TABELA 1)
FONTE: Dalton (1810).

A tabela apresentada na figura 6 mostra os cálculos feitos por Dalton para vários elementos com fluidos elásticos, nessa tabela Dalton calcula qual seria a massa ocupada por um volume de 100m³ de átomos de determinados elementos e a partir deste dado calcula também a gravidade específica, o diametro de um átomo e o número de átomos dentro deste volume definido. Aqui vale lembrar que o diâmetro do átomo é baseado na medida do seu centro até a borda da atmosfera de calórico. Tomando como base empírica as representações mostradas anteriormente nas figuras 4 e 5.

2.1.4 O MODELO ATÔMICO PARA JOHN DALTON

Com base na leitura de sua produção é possível fazer uma interpretação do átomo de John Dalton. Compreendido como partículas de matéria esférica, rodeadas de atmosferas de calórico.

A dinâmica do átomo daltoniano está no balanço entre duas forças opostas denominadas: *afinidade* e *calórico*.

A *afinidade* responsável pela coesão dos átomos é que mantém todos unidos formando certas interações. O *calórico* é o oposto, uma força de repulsão que repele estes átomos separando-os, ocupando maior espaço.

Os três estados da matéria (sólido, líquido e fluido elástico) podem ser compreendidos como diferentes casos de balanço dessas forças. No estado sólido as duas forças, atração e repulsão, estão equilibradas dando rigidez e coesão aos átomos, de modo que se aplicarmos uma força para afastá-lo a *afinidade* será a força que resistirá a esta ação, e se tentarmos comprimir o material a força de repulsão, *calórico*, resistirá a ação. No estado líquido se tem a predominância da força de afinidade sobre a força do *calórico*, conferindo ao corpo líquido um certo grau de coesão e maleabilidade ou elasticidade, desenvolvida com a porção mínima de *calórico* nos átomos do composto. O estado de fluido elástico pode ser compreendido como a hegemonia da atmosfera de *calórico* sobre o composto, conferindo o maior caso de repulsão, expansão e maleabilidade.

Com base nesta interpretação, podemos entender que a figura 2, representando o congelamento da água, poderia ser atribuída ao caso do estado sólido, onde há um equilíbrio de forças. As figuras 5 e 6, representando o estado gasoso, seriam a apresentação de como o átomo estaria no estado de fluido elástico, enquanto que a figura 3, seria uma representação na forma de notação para diferenciação de compostos. Cada elemento possui propriedades singulares como evidenciado na figura 7, com os cálculos de várias características dos compostos químicos apresentados no segundo volume de sua obra.

Todos esses componentes em conjunto formam a proposta atômica de Dalton, consistindo em um sistema dinâmico regido por duas forças distintas, com um átomo corpuscular maciço e rodeado por uma atmosfera de calor. Com suas devidas representações e relações de tamanho, massa, volume e gravidade específica.

2.2 J. J. THOMSON

Físico inglês, nascido perto de Manchester em 1856, estudou engenharia no *Owens College*, onde foi despertado seu interesse pela Física nos estudos sobre o átomo. Teve contato com os trabalhos de John Dalton e veio a fazer estudos com a lei das combinações químicas e as teorias atômicas da matéria. No *Owens College*

trabalhou sob a orientação de Balfour Stewart da cadeira de Física, durante as aulas desenvolveu estudos sobre o átomo vortex de William Thomson (Lorde Kelvin), realizando experimentos sobre o comportamento dos anéis vórtices²⁶ na água (LOPES, 2009).

No ano de 1875, com a indicação de Backer, um professor do *Owens College*, Thomson tenta uma investida para entrar no *Trinity College* na Cambridge, porém é mal sucedido não passando nem da primeira fase. Como relata Lopes (2009), um ano depois tenta novamente com êxito entrando nas cátedras de Física e Matemática da instituição.

Em Cambridge assumiu a cátedra de Física Experimental de Lorde Rayleigh, tornando-se a terceira geração a presidir e gerir o laboratório de Cavendish que tinha sido inaugurado em 1874. A frente deste laboratório, Thomson, desenvolveu inúmeros estudos com eletricidade, magnetismo, conduzindo experimentos com ampolas de Crookes, raios Röntgen e raios catódicos. Todos os seus trabalhos trouxeram uma notável fama, tornando o laboratório Cavendish no centro mundial de pesquisa em física experimental. Em 1904, apresenta sua proposta para o átomo com base nos experimentos de raios catódicos e nos estudos do corpúsculo que carrega carga negativa. Trabalho este que lhe rendeu um prêmio Nobel em 1906, devido aos seus estudos com condutividade de eletricidade por gases²⁷.

Com base nestes resultados Thomson formula seu átomo e o publica pela primeira vez em 1904 em um artigo na *Philosophical Magazine*. Aqui demarca-se a ruptura entre o átomo indivisível e o átomo formado por corpúsculos negativos dentro de um corpo positivo.

Para fazer a leitura do átomo formulado por Thomson usou-se como base o *saber sábio* presente nos seguintes artigos:

(a) *Cathode Rays*, publicado na *Philosophical Magazine* em outubro de 1897²⁸.

²⁶ A teoria de Lord Kelvin, dos anéis vórtices, sugeria que os átomos de elementos químicos teriam suas cargas arranjadas em anéis coplares de localização definida. J. J. Thomson aplica essa teoria para explicar a combinação química de diferentes elementos.

²⁷ Dado obtido no site da fundação Nobel:

http://www.nobelprize.org/nobel_prizes/physics/laureates/1906/, acessado em 19 de setembro de 2011 às 22:16.

²⁸ O artigo (a) está no anexo 5 e o artigo (b) está no anexo 6, junto a uma parte extra no anexo 7.

- (b) *On the structure of the atom: an investigation of the stability and periods of oscillation of a number of corpuscles arranged at equal intervals around the circumference of a circle; with application of the results to the theory of atomic structure*, publicado na Philosophical Magazine em março de 1904.

2.2.1 O ARTIGO DE THOMSON DE 1897

No *Cathode Rays*, Thomson (1897) publica alguns aspectos metodológicos de seus experimentos com raios catódicos. Começando por uma discussão teórica entre duas linhas distintas que estudam as cargas negativas, nomeando-as como os seguidores da teoria do éter e aqueles que compreendiam que a matéria era formada por corpúsculos que carregam diversas cargas (teoria das partículas eletrificadas) atribuindo uma maior versatilidade a segunda corrente teórica, como presente no trecho:

A teoria da partícula eletrificada tem por propósito de pesquisa uma grande vantagem sobre a teoria do éter, uma vez que é definida e suas consequências podem ser preditas; com a teoria do éter é impossível de prever o que vai acontecer sob quaisquer circunstâncias, com esta teoria que estamos lidando até agora não temos fenômenos observados no éter, de cujas leis somos ignorantes. Os experimentos a seguir foram feitos para testar somente as consequências da teoria da partícula eletrificada (THOMSON, 1897, p. 25-26, tradução nossa).

No trecho apresentado se tem bem definida a posição de Thomson (1897) e de sua preferência pela linha teórica da partícula eletrificada, pelo fato desta ser passível de experimentos, enquanto que na outra abordagem teórica se torna, segundo o autor, muito complicado prever resultados. Com base nesse referencial teórico, descreve-se alguns experimentos conduzidos em Cavendish:

- (I) *Charge carried by the cathode rays* (carga carregada por raios catódicos);
- (II) *Deflexion of the cathode rays by an eletostatic field* (deflexão dos raios catódicos por um campo eletrostático);
- (III) *Coductivity of a gas through wich cathode rays are passing* (Condutividade de um gás na passagem de raios catódicos);
- (IV) *Magnetic deflexion of the cathode rays in different gases* (Deflexão magnética dos raios catódicos em diferentes gases);
- (V) *velocity of the cathode rays* (velocidade dos raios catódicos).

No experimento (I), Thomson (1897) toma como base os experimentos de Perrin, desenvolvendo o seguinte aparato para suportar a tese dos corpúsculos carregando carga negativa:

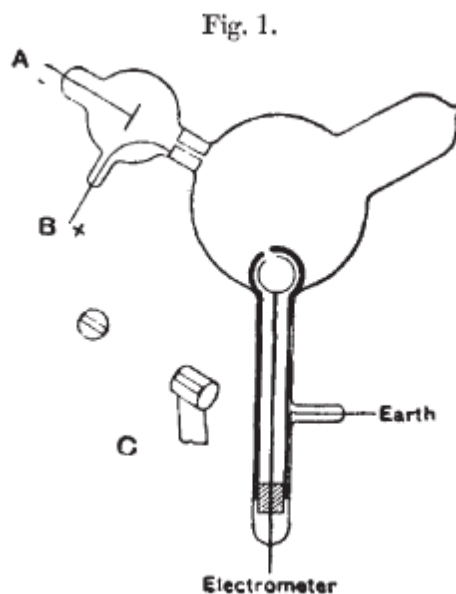


FIGURA 7 - ESQUEMA DE UM TUBO DE DESCARGA DE RAIOS CATÓDICOS
FONTE: Thomson (1897)

Na figura 7, de acordo com Thomson (1897), em “A” temos o tubo de descarga de raios catódicos. Os raios catódicos que saem do cátodo de “A” passam por um conector de metal que está ligado ao ânodo que é aterrado. O bulbo é conectado a esta primeira estrutura tendo um magneto que desvia o raio para uma terceira peça que é um cilindro conectado a terra e neste há uma segunda saída onde foi conectado um eletrômetro. A carga é mandada para este eletrômetro aferindo o seu potencial. Lembrando que a trajetória da partícula é visualizada por uma substância fosforescente no vidro. Como resultado deste experimento, Thomson, conseguiu registrar no equipamento valores que variaram de 1 a 5 μF e 20 volts.

Com base nestes resultados, Thomson (1897), conclui que:

Este experimento mostra que contudo nós agitamos e defletimos os raios catódicos por forças magnéticas, a eletrificação negativa segue o mesmo caminho dos raios, e esta eletrificação negativa está indilossuvelmente conectada aos raios catódicos (THOMSON, 1897, p. 27, tradução nossa).

Thomson (1987) sustenta sua idéia de corpos eletrificados, onde o ar dentro do aparato da figura 7 se torna um condutor de eletricidade na passagem de um raio catódico quando o bulbo está carregado positivamente. Durante as descargas o tubo anula esta carga e ganha uma carga eletrificada negativa e quando este aparato está carregado com carga negativa, este irá vaziar se o potencial inicial negativo for numericamente maior do que os valores de equilíbrio.

No experimento (II), Thomson (1987) descreve o segundo experimento conduzido em seu laboratório sobre o desvio de raios catódicos por campos eletrostáticos. Citando um experimento anterior conduzido por Hertz:

Hertz fez os raios viajarem por duas placas de metal paralelas colocadas no interior de um tubo de descarga, mas encontrou que estas não foram defletidas quando as placas eram conectadas a uma bateria de armazenamento de células; repetindo este experimento eu em primeiro lugar obtive o mesmo resultado, mas experimentos subsequentes mostraram que a ausência de deflexão é devido a condutividade conferida ao gás rarefeito pelos raios catódicos. Nas medidas de condutividade notei que ela diminui muito rapidamente enquanto a exaustão aumentava; parecia que submetendo o experimento de Hertz a uma grande exaustão possa haver a chance de detecção de deflexão dos raios catódicos por campos eletrostáticos (THOMSON, 1987, p. 28, tradução nossa).

Com base nesta possibilidade, Thomson (1987) desenvolve o experimento de raios catódicos a ponto de tentar detectar a deflexão por um campo eletrostático, usando o aparato representado na figura 8:

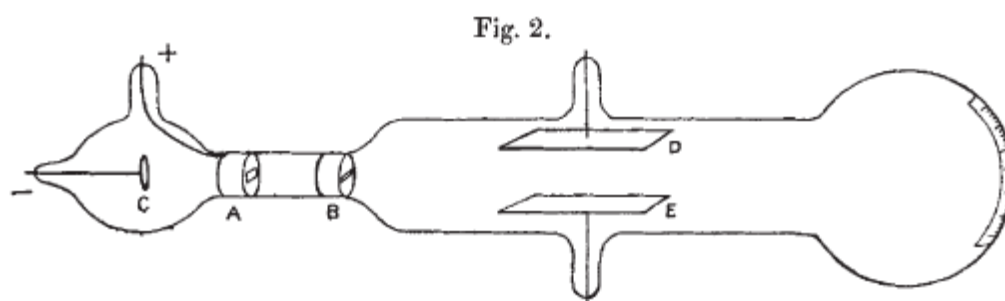


FIGURA 8 – REPRESENTAÇÃO DO TUBO DE RAIOS CATÓDICOS
 FONTE: Thomson (1987)

Na descrição do experimento, com base em Thomson (1987), os raios catódicos saem do cátodo "C", passando pelo ânodo "A" e por uma peça aterrada

representada em “A” e novamente por uma outra peça similar em “B”²⁹. Depois, o raio viaja até duas placas metálicas de alumínio paralelas de aproximadamente 5 cm separadas por 1,5 cm de distância. No final do tubo há um material fosforescente que produz uma estreita linha bem definida. Fora do tubo de descarga é colocada uma escala para medir o desvio do raio catódico disparado. Nos resultados é constatado que em uma alta exaustão os raios são defletidos por um campo formado de baterias com pequenas cargas, e a depressão do raio muda, quando coloca-se a placa de cima conectada com o polo negativo e a de baixo com o positivo e vice-versa. Lembrando também que o desvio do raio é proporcional a carga colocada nas placas. Com esse aparato foi possível mensurar valores para relação massa e energia das cargas, bem como a velocidade dos corpúsculos eletrificados negativamente, sustentando a teoria do corpo eletrificado.

Com base nestas possibilidades levantadas pelos experimentos anteriores, Thomson (1987). Desenvolve outros dois para mensurar a massa dos corpúsculos eletrificados, bem como sua carga em diferentes gases. Para essa finalidade foi usado o equipamento apresentado:

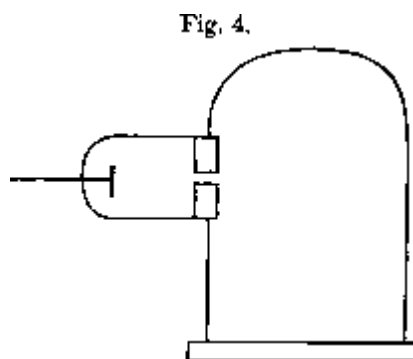


FIGURA 9 – EQUIPAMENTO USADO PARA ESTUDAR A DEFLEXÃO DOS RAIOS CATÓDICOS
 FONTE: Thomson (1987)

Neste experimento, tem-se um tubo de descarga com um anel aterrado ligado a uma cuba como apresentado no esquema. A cuba está colocada entre duas largas e paralelas bobinas, arranjadas com um galvanômetro de Helmholtz. A partir de algumas observações, Thomson (1987), cita o estudo de Birkeland com o espectro magnético, batendo fotos da fosforescência de diferentes gases, com variação na densidade de 1 a 70. De acordo com essas primeiras observações, algumas perguntas são formuladas pelo autor, bem como um reforço de sua tese:

²⁹ Observa-se que o tamanho da fenda nas duas peças muda

Eu não consigo ver uma escapatória da conclusão que essas cargas de eletricidade negativa são carregadas por partículas de matéria. As próxima questão que surge, o que são essas partículas? Elas são átomos, ou moléculas, ou matéria em estados mais finos de subdivisão? (THOMSON, 1964, p. 44, tradução nossa).

Para responder a estas questões, Thomson (1987), se propõe a arguir e calcular dados dessas partículas com base em três diferentes experimentos feitos com diferentes gases. Para fazer os cálculos, as seguintes equações foram deduzidas:

$$Ne = Q \quad (1)$$

$$\frac{1}{2}Nmv^2 = W \quad (2)$$

$$\frac{mv}{e} = H\rho = I \quad (3)$$

$$\frac{1}{2} \frac{m}{e} v^2 = \frac{W}{Q} \cdot v = \frac{2W}{QI}, \frac{m}{e} = \frac{I^2 Q}{2W} \quad (4)$$

“N” é o número de partículas que atravessam qualquer seção do raio em um tempo determinado. “Q” é a quantidade de eletricidade carregada por essas partículas, usadas na equação (1). Na equação (2), “W” é a energia cinética das partículas. Que, de acordo com Thomson (1987), podem ser calculadas pela variação do calor no impacto com um corpo sólido de capacidade térmica conhecida, “v” é a velocidade da partícula e “m” é a massa das partículas. Na equação (3) é possível calcular através do campo magnético uniforme (H), onde a relação com “Hρ” é representada por “I”, para simplificar a equação. Das equações (1), (2) e (3) é possível gerar a relação que deduz a equação (4), onde sabendo os valores de “Q”, “W” e “I”, pode-se deduzir os valores de “v” e a relação “m/e”.

Com base nestas equações Thomson (1987) usou três diferentes tubos de raios catódicos para medir os valores de “Q”, “W” e “I” e para deduzir a massa e a velocidade das partículas. O primeiro tubo usado para iniciar as medições dos valores, foi uma variação do tubo da figura 8, porém não apresentando as placas “D” e “E”, pois em seu lugar colocou-se dois cilindros coaxiais com fendas que foram

presos no final do tubo. O cilindro interno foi conectado com um eletrômetro para medir os valores de carga dos raios catódicos e com um conjunto termo elétrico, feito de finas chapas de ferro e cobre que foi colocado atrás da fenda do tubo interno. Na parte externa do tubo de descarga foi conectado um galvanômetro de baixa resistência. A passagem dos raios permitiu calcular o aumento da temperatura do tubo com o choque. Sabendo os valores da capacidade termal das juntas de ferro e cobre (5×10^{-3} , 3×10^{-3}), foi possível calcular o valor de “W” ou “ $(1/2)Nmv^2$ ”. Para determinar a curvatura dos raios catódicos, Thomson (1897), usou o seguinte princípio de cálculo, baseado na figura:

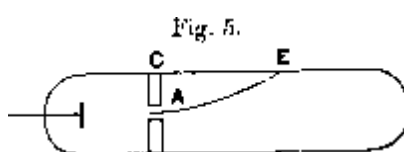


FIGURA 10 – ESQUEMA DO DESVIO DO RAIOS CATÓDICO
 FONTE: Thomson (1897)

Assim, através da medida “CA” e “CE” é possível calcular a curvatura “ ρ ” do raio catódico através da relação:

$$2\rho = CE^2 / AC + AC \quad (5)$$

O segundo tipo de tubo é uma variação do esquema da figura 9. O interior do jarro foi forrado com uma “gaze”³⁰ de cobre, que foi ligada a terra. De acordo com Thomson (1897), este tubo foi o que deu melhores resultados no cálculo do desvio, temperatura e carga dos raios catódicos. E o terceiro tubo é uma outra variação do primeiro, onde somente o tamanho das fendas é que mudou, sendo diminuídas para 1,5 milímetros de diâmetro. Os resultados dos três experimentos geraram três tabelas que estão presentes em seu artigo de 1897 (anexo 5).

A partir dos resultados, Thomson (1897) concluiu que os valores arguidos para a relação m/e no tubo três eram muito altos e para os tubos 1 e 2 eram muito pequenos. Isso o levou a proceder experimentalmente a uma outra forma de calcular esta relação.

$$(Fe/m)(l/v) \quad (6)$$

³⁰ Thomson (1897) usa o termo “gaze” para definir o material usado dentro da cuba de vidro.

Com a relação (6) é possível calcular o ângulo que os raios são desviados quando deixam o campo elétrico e entram em uma região livre da força elétrica. Esse valor é o “ θ ” dado pela equação:

$$\theta = (Fe/m)(l/v) \quad (7)$$

Os raios catódicos também sofreram a ação de campo magnético “H”, a equação que define o desvio “ φ ” e a saída do campo magnético pode ser representada pela relação:

$$(Hev/m)(l/v), \varphi = (Hev/m)(l/v) \quad (8)$$

A partir das relações (6), (7) e (8), é possível calcular a velocidade pela equação:

$$v = (\varphi/\theta)(F/H) \text{ e } m/e = H^2\theta l/F\varphi^2 \quad (9)$$

No experimento usado por Thomson (1897), o valor dos ângulos “ φ e θ ” são iguais, nesse caso:

$$v = (F/H) \text{ e } m/e = H^2l/F\theta \quad (10)$$

O aparato usado por Thomson (1897), para calcular essas relações e dar a relação “m/e” e de “v”, foi o mesmo usado da figura 8, onde o campo elétrico foi produzido por duas placas de alumínio ligadas a uma bateria. A trilha fosforescente foi observada e medida por uma escala colocada no final do tubo. Com esse aparato uma série de experimentos foram feitos com alguns gases, para ver se a deflexão eletrostática é proporcional a intensidade elétrica entre as placas. Mas, neste experimento o aparato foi ajustado de forma que a deflexão magnética fosse a mesma da elétrica gerando uma segunda tabela (anexo 5).

Com base nos resultados Thomson (1897) percebeu que o valor de “m/e” quase sempre era o mesmo, guardando pequenas diferenças e que havia a possibilidade de haver corpúsculos de massa constante, corroborando a teoria do corpúsculo que carrega carga negativa.

Assim, de posse desses resultados, Thomson (1897) procura alguma teoria que possa dar conta de elucidar como os corpúsculos de carga negativa estariam arranjados dentro do átomo. Para dar essa resposta, utiliza-se a teoria desenvolvida

por Meyer, onde magnetos que se repelem com campos magnéticos definidos tendem a manter uma distância equivalente ao campo magnético empregado, ou seja, os ímãs tendem a ficar à distâncias equidistantes de um determinado ponto, onde a distância do centro do sistema a um ímã é igual para todos.

No final do artigo Thomson (1897), relaciona essa proposta dos magnetos de Meyer com as leis periódicas, devido a variação da disposição dos magnetos terem relação com a lei periódica dos elementos e com seu agrupamento. E além disso, descreve o experimento de velocidade dos raios catódicos, com algumas ponderações e um experimento para testar outros eletrodos de metais diferentes do alumínio no cálculo do valor “m/e”.

2.2.2 O ARTIGO DE 1904 E A ELUCIDAÇÃO DA ESTRUTURA ATÔMICA

Thomson (1904) traz apontamentos gerais sobre os desdobramentos dos experimentos conduzidos com raios catódicos e cálculos teóricos para a proposição de uma nova estrutura atômica com divisão de cargas, sendo assim o seu modelo proposto para o átomo:

A visão dos átomos dos elementos consiste em um número de corpúsculos eletrificados negativamente incluso em uma esfera uniforme de eletrificação positiva, implicando, outros problemas matemáticos interessantes, a discussão deste artigo, da movimentação de um anel com n partículas eletrificadas negativamente colocadas dentro de uma esfera eletrificada uniforme (THOMSON, 1904, p.237, tradução nossa).

Neste trecho, destacado por Thomson (1904), temos a sua visão do átomo como sendo um conjunto de corpúsculos carregados eletricamente com cargas negativas e positivas. Os corpúsculos negativos, no interior de uma esfera uniforme e positiva, giram em anéis definidos.

Thomson (1904) começa supondo que os n corpúsculos dentro da esfera devem estar arranjados a iguais intervalos angulares em um anel de raio chamado a , definindo o raio da esfera que contém o sistema e a carga positiva que ela deve carregar, com base na seguinte equação:

$$\frac{ve^2a}{b^3} \quad (1)$$

Com a equação (1) é possível calcular a atração de um corpúsculo pela carga da esfera uniforme eletrificada positivamente. Após definir esta primeira equação Thomson (1904) apresenta outra que define a repulsão de partículas do centro da esfera (O) para duas partículas (A e B) no anel.

$$\frac{e^2}{AB^2} \cos OAB \quad (2)$$

Se tivermos o caso de $OA = OB$, a equação é rearranjada para:

$$\frac{e^2}{4OA^2 \sin^2 \frac{1}{2}AOB} \quad (3)$$

Com a equação (3), segundo Thomson (1904), pode-se calcular a repulsão de dois corpúsculos eletrificados negativamente a mesma distância do centro da esfera (O). Nesse sentido, lembra-se que os n corpúsculos estão arranjados em intervalos angulares iguais definidos por $2\pi/n$ em torno de uma circunferência na esfera e a repulsão radial de um corpúsculo pode ser representada pela equação (4):

$$\frac{e^2}{4a^2} \left(\operatorname{cosec} \frac{\pi}{n} + \operatorname{cosec} \frac{2\pi}{n} + \operatorname{cosec} \frac{3\pi}{n} + \dots + \operatorname{cosec} \frac{(n-1)\pi}{n} \right) \quad (4)$$

Assim, Thomson (1904), com o conjunto de equações deduz a seguinte relação entre a equação (1) e (4):

$$S_n = \operatorname{cosec} \frac{\pi}{n} + \operatorname{cosec} \frac{2\pi}{n} + \operatorname{cosec} \frac{3\pi}{n} + \dots + \operatorname{cosec} \frac{(n-1)\pi}{n},$$

$$\frac{ve^2a}{b^3} = \frac{e^2}{4a^2} S_n \text{ ou } \frac{a^3}{b^3} = \frac{S_n}{4v} \quad (5)^{31}$$

Com essas equações e a dedução de (5) é possível calcular valores de repulsão e atração para n corpúsculo eletrificados negativamente dentro da esfera eletrificada positivamente. Após o cálculo de S_n para $n= 1$ a 6 , Thomson (1904), define as equações de movimento e velocidade angular ω , desenvolvendo a condição para movimento constante como:

³¹ As variáveis a , e e b no artigo de Thomson (1904), representam: $a =$ o raio da circunferência do anel; $e =$ carga que o corpúsculo carrega e $b =$ é o raio da esfera. Lembrando que ve é a carga da esfera eletrificada positivamente.

$$\frac{ve^2a}{b^3} = ma\omega^2 + \frac{e^2}{4a^2}S_n, \text{ ou } \frac{va^3}{b^3} = \frac{m}{e^2}\omega^2 + \frac{S_n}{4} \quad (6)$$

A equação (6) define o movimento constante dos corpúsculo eletrificados negativamente dispostos em um anel a uma distância definida do centro O. Thomson (1904) prossegue sua explanação do átomo fixando as equações para o cálculo das coordenadas de cada corpúsculo eletrificado negativamente, onde r_s , θ_s, z_s são as coordenadas desse corpúsculo e as relações entre todas as fórmulas apresentadas. Descreve matematicamente o arranjo para átomo contendo: 0, 1, 2, 3, 4, 5 e 6 corpúsculos. Valida o seu modelo do ponto de vista da Física de cargas e eletricidade. Determina as condições de estabilidade de anéis para mais de 6 corpúsculos e descreve alguns valores calculados para anéis contendo 7 e 8 corpúsculos:

Eu encontrei que um simples corpúsculo é suficiente para fazer anéis com 7 e 8 corpúsculos estáveis (...) se o número de corpúsculos exceder 8 o número de corpúsculos centrais é necessário para garantir que a estabilidade aumente muito rapidamente com o número de corpúsculos no anel (THOMSON, 1904, p.253, tradução nossa).

Assim, para Thomson (1904) o aumento do número de corpúsculos no anel está ligado ao aumento do número de corpúsculos no centro do sistema atômico. Também foi constatado que ao aumentar o número de corpúsculos no anel, o raio deste aumenta e quando se faz a situação inversa, o raio do anel diminui. Com base nestas possibilidades pode-se explicar a necessidade de uma esfera uniforme positiva, elucidando a estrutura que pode ter o átomo:

Temos portanto em primeiro lugar uma esfera uniforme de eletrificação positiva, e dentro desta esfera há um número de corpúsculos arranjados em uma série de anéis paralelos, o número dos corpúsculos em um anel varia de anel para anel: cada corpúsculo está viajando a uma grande velocidade em volta da circunferência do anel que está situado, e os anéis são arranjados de forma que se contenha uma grande quantidade de corpúsculos perto da superfície da esfera, enquanto há um número menor de corpúsculos mais adentro (THOMSON, 1904, p. 255, tradução nossa).

Desse modo Thomson (1904) descreve como seria seu átomo formado por uma esfera positiva uniforme com corpúsculos negativos arranjados em anéis. Essa descrição está de acordo com a teoria do arranjo dos magnetos de Meyer, onde magnetos que flutuam tendem a se dispor de forma igualitária dentro de uma superfície com água.

Nas últimas seções, Thomson (1904) aplica seus cálculos feitos ao longo do capítulo para elementos químicos, mensurando os números de anéis para átomos com valores de corpúsculos que variam de 5 a 60. Também analisando quais propriedades esses átomos teriam para um elevado número de corpúsculos negativos, relacionando-os com várias séries de elementos químicos. Levando em conta que para o átomo ter estabilidade é necessário em alguns pontos haver um grupo secundário de corpúsculos:

Assim, pegando o caso para um anel de 30 corpúsculos; se estes forem organizados em intervalos iguais, 101 corpúsculos seriam necessários dentro do anel para fazê-lo estável. Se, talvez, 30 corpúsculos forem agrupados em dez conjuntos de três cada, somente $3 \times 3 = 9$ corpúsculos no interior seriam necessários para manter o arranjo estável (THOMSON, 1904, p. 265, tradução nossa).

Nesse sentido, Thomson (1904), para manter o arranjo estável sem ter que usar um número exagerado de corpúsculos, pensou na hipótese de se ter corpúsculos extras no centro, conferindo uma maior estabilidade a proposta atômica.

Thomson (1897) finaliza seu artigo dando uma explicação para os fenômenos radioativos que poderiam ser explicados através de sua proposta de modelo atômico, onde este estaria relacionado com a desestabilização do sistema de cargas, havendo a ejeção de corpúsculos em alta velocidade de dentro da esfera de carga positiva uniforme.

2.2.3 O MODELO ATÔMICO NA VISÃO DE THOMSON

De acordo com os escritos de Thomson (1897, 1904) sobre corpúsculos e átomos, pode-se entender que as cargas elétricas, sejam positivas ou negativas, são carregadas por corpúsculos que têm uma mesma massa, somente variando a quantidade que carregam de *eletrons* (*e*) (carga negativa). A partir deste

pressuposto, podemos compreender o átomo de Thomson como um arranjo de inúmeros corpúsculos que em equilíbrio dão estabilidade.

Assim, o átomo para Thomson (1904) seria formado por uma esfera de carga positiva uniforme, permeável, que em seu interior estariam dispostos arranjos de corpúsculos com cargas negativas, todos em equilíbrio. Esses corpúsculos estariam arranjos em forma de anéis concêntricos, onde cada um destes, carregaria um certo número fixo de corpúsculos girando com grande velocidade em movimento circular uniforme, distribuídos de acordo com a teoria dos magnetos de Meyer, ou seja, a distância dos corpúsculos no anel, do centro ao corpúsculo e de corpúsculo a corpúsculo seria a mesma.

Thomson (1904) também calculou que teríamos mais corpúsculos com carga negativa próximo a superfície da esfera de carga positiva do que no centro, estabilizando o arranjo de cargas. Junto aos corpúsculos no centro, para átomos com vários corpúsculos, teriam alguns corpúsculos extras paralelos aos existentes para conferir estabilidade. Com base neste modelo também é possível se explicar o fenômeno da radioatividade, onde o átomo desestabilizado começaria a ejetar, com grande energia cinética, corpúsculos de seu interior.

2.3 ERNEST RUTHERFORD

Ernest Rutherford nasceu na Nova Zelândia em 1871, onde estudou e se graduou. No ano de 1895, ganhou um concurso de pesquisador mais promissor neozelandês e teve a oportunidade de estudar na Inglaterra, em Cambridge, sob a tutoria de J. J. Thomson, que viria a ser seu orientador e grande amigo.

De acordo com Lopes (2009), no laboratório Cavendish, sob a tutoria de Thomson, desenvolveu estudos com partículas carregadas e adentrou a seara dos estudos radioativos. Em 1898, foi para a Universidade de McGill no Canadá, localizada em Montreal, com apoio financeiro de grandes empresas que estavam investindo no desenvolvimento científico do país. Trabalhou com o químico Zimmerman, desenvolvendo estudos aprofundados sobre radioatividade, rendendo aos dois o prêmio Nobel em Química no ano de 1908. Com ajuda de J. J. Thomson, retorna ao laboratório Cavendish em Cambridge, onde continua trabalhando com as partículas alfa, beta e gama, desenvolvendo estudos acerca de suas características

e penetrabilidade em diferentes materiais. Nesta época, pertenciam a sua equipe de laboratório Marsden, Geiger, Darwin, Royds e Crowther.

Deste grupo resultaram vários trabalhos sobre a penetração de partículas alfa e beta em diferentes materiais, culminando no desenvolvimento de uma hipótese publicada por Rutherford na *Philosophical Magazine* sobre uma possível explicação para certos graus de deflexão das partículas α e β .

Nessa seção serão abordados os seguintes artigos³²:

- (I) *The scattering of α particle by matter* (1910), publicado na Proc. Royal Society por H. Geiger;
- (II) *The scattering of α and β particles by matter and the structure of the atom* (1911), publicado na Philosophical Magazine por E. Rutherford;
- (III) *The laws of deflexion of α particles through large angles* (1913), publicado por H. Geiger e E. Marsden na Philosophical Magazine.

Nesse caso abordarei trabalhos de Geiger e Marsden (1910, 1913), pois foram estes que levaram Rutherford (1911) a publicar uma explicação para o fenômeno de deflexão de partículas α e β .

2.3.1 O PRIMEIRO ARTIGO DE GEIGER E O EXPERIMENTO DE PARTÍCULAS ALFA (1910)

Neste artigo, H. Geiger, descreve-se sucintamente a montagem do seu experimento de dispersão de partículas alfa em lâminas metálicas. Iniciando sua explanação trazendo algumas leituras de experimentos anteriores feitos por Rutherford.

Após esta apresentação inicial, Geiger (1910), desenvolve uma descrição do aparato usado no experimento como mostra a figura:

³² Esses trabalhos estão presentes em sua íntegra nos anexos 8, 9, 10, 11 e 12.

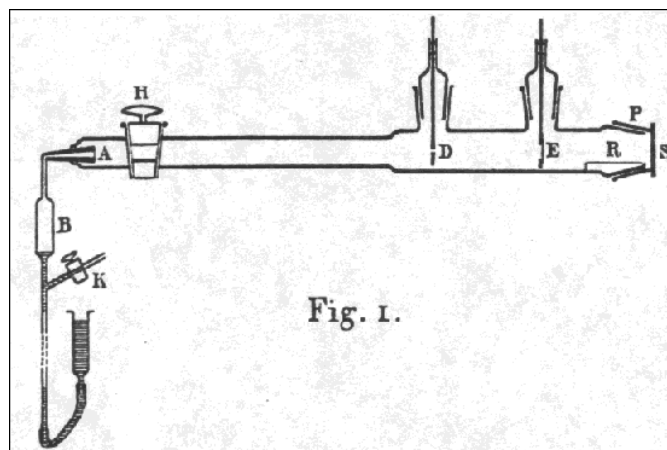


FIGURA 11 – ESQUEMA DE MONTAGEM DO EQUIPAMENTO PARA MEDIÇÃO DOS DESVIOS DE PARTÍCULAS ALFA

FONTE: Geiger (1910)

Com base na figura 12, Geiger (1910) explica cada parte do arranjo experimental: “B” representa um bulbo onde o material radioativo é colocado, a fonte usada no experimento foi de aproximadamente 50 miligramas de RaBr_2 . O dispositivo “K” é uma torneira para regular a pressão no interior do tubo com a da atmosfera. “A” é um tubo cônico de vidro, por onde passa as partículas alfa e “H” é uma torneira para conter o seu avanço. A primeira placa “D”, com uma abertura circular de 1mm de diâmetro, têm como objetivo homogenizar o feixe de partículas alfa para se poder aferir os desvios das mesmas. Entre e “E” e “D”, há uma distância de 13 cm, onde foram colocadas finas lâminas de vários metais com o intuito de se calcular o espalhamento. “S” é uma tela de sulfeto-zinco que serve para traçar as partículas desviadas. Junto a essa está acoplado um microscópio. E as medições são feitas por contagem manual. “P” e “R” são anteparos usados para se fazer correções e poder medir grandes desvios de lâminas com alto poder de espalhamento, como o ouro.

Geiger (1910), ressalta que o ouro foi o metal escolhido por possuir as melhores propriedades mecânicas e também os melhores valores de espalhamento dentre Alumínio, Cobre, Prata e Estanho, todos testados e com seus resultados tabelados formando a figura 12:

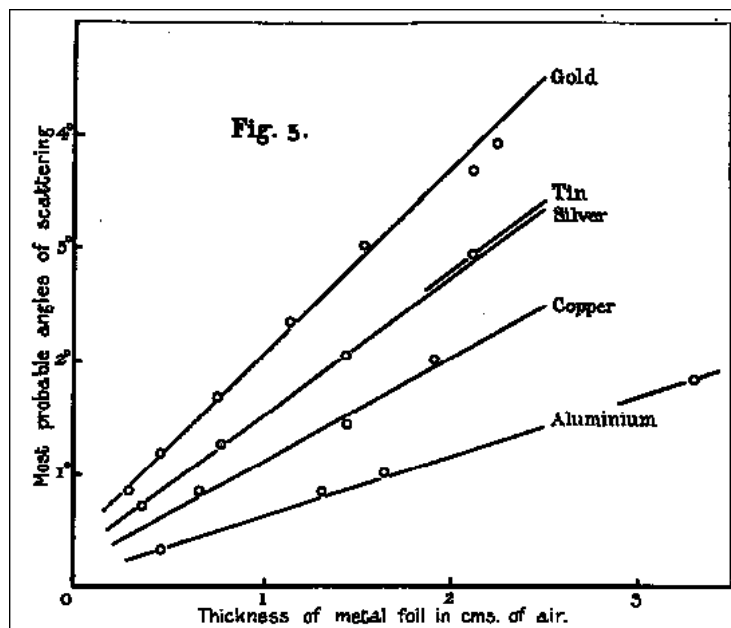


FIGURA 12 – GRÁFICO SOBRE A RELAÇÃO DE ESPESSURA DAS LÂMINAS E O SEU ESPALHAMENTO
 FONTE: Geiger (1910)

Afirma que antes de chegar ao ouro, todos os metais possíveis e mica foram testados pela equipe de Rutherford. Com base neste gráfico, o artigo apresenta somente os dados para lâmina de ouro ao longo de 32 lâminas testadas de diferentes espessuras para aferir o ângulo de espalhamento das partículas alfa.

Este artigo com seus resultados, veio ser a base para proposta do átomo de Rutherford, pois é a partir dele que sua equipe se debruça para o estudo da deflexão de partículas α e β , culminando na proposta de estudo do núcleo atômico.

2.3.2 A ELUCIDAÇÃO DA ESTRUTURA ATÔMICA POR RUTHERFORD (1911)

No artigo de Rutherford (1911), o objetivo é explicar os resultados encontrados no experimento conduzido por H. Geiger e E. Marsden sobre o espalhamento de partículas alfa em lâminas de diferentes materiais. Com base nos resultados deste experimento e em trabalhos anteriores. Inicia sua discussão dos resultados que seriam esperados para o átomo de Thomson:

Recentemente Sir J. J Thomson apresentou uma teoria que explica o espalhamento das partículas elétricas passando por pequenas partes de matéria. O átomo suposto consiste em um número de N corpúsculos negativamente carregados, acompanhado de uma igual quantidade de eletricidade positiva uniformemente distribuída na forma de uma esfera. As deflexões de partículas negativamente eletrificadas passando pelo o átomo é atribuída para dois casos – (1) a repulsão dos corpúsculos no

interior do átomo, e (2) a atração da eletricidade positiva do átomo. A deflexão das partículas que passam por dentro do átomo deveria ser supostamente pequena (RUTHERFORD, 1911, p.670, tradução nossa).

Porém, por meio dos dados obtidos nos experimentos de Geiger e Marsden, o átomo como pensado por Thomson, não estaria de acordo com os grandes ângulos de deflexão observados, já que o encontro de uma partícula alfa por um elétron seria de probabilidade infinitamente pequena e mesmo ocorrendo não seria uma deflexão tão grande. Nesse sentido, Rutherford (1911) assume algumas características que o átomo poderia ter, com base nos resultados de Geiger e Marsden:

Considero que o átomo contém uma carga $+Ze$ no seu centro rodeado por uma esfera de eletrificação contendo carga $-Ze$ supostamente uniformemente distribuída em toda uma esfera de raio R (RUTHERFORD, 1911, p. 671, tradução nossa).

Rutherford (1911) assume que o átomo tem uma área central, ou seja, inicialmente supõe que o átomo tem um núcleo e semelhantemente ao modelo de Thomson, que ainda possui uma esfera de carga uniforme, porém com carga contrária a esfera do centro. E para essa suposição, Rutherford faz alguns cálculos da força elétrica, potencial. Com base nos resultados, calcula o raio R dessa proposta de átomo, como sendo aproximadamente 10^{-10} cm, considerando que ao passar próximo ao núcleo a partícula alfa, em alta velocidade, pode ser desviada em diversos ângulos, como apresentado na figura 13:

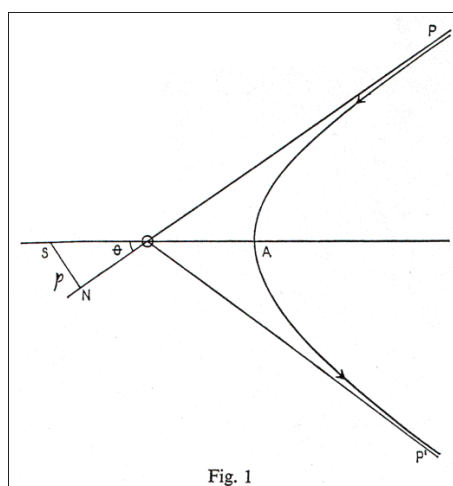


FIGURA 13 – ESQUEMA DE DEFLEXÃO DE PARTÍCULAS ALFA PRÓXIMAS AO NÚCLEO

FONTE: Rutherford (1911)

Na figura 13, Rutherford (1911) conseguiu explicar como ocorre a deflexão de partículas alfa pelo centro, ou seja, como as partículas não se chocam com o núcleo, pois são desviadas devido as forças de repulsão atuantes. Assim, a partícula entra no sistema em “P”. Ao chegar próximo ao núcleo ocorre a sua deflexão, formando o vértice da parábola em “A”, e sendo ejetada do sistema por P’. Com base na relação POA, sendo O o centro do núcleo atômico, calcula-se os ângulos de deflexão (θ), para diferentes valores de p/b ³³.

p/b	10	5	2	1	0,5	0,25	0,125
Θ	5,7°	11,4°	28°	53°	90°	127°	152°

QUADRO 1 – RELAÇÃO DE ÂNGULOS DE DEFLEXÃO

FONTE: Rutherford (1911)

Chega a algumas conclusões, através de cálculos:

1) $\text{cosec}^4 \theta/2$ ou $1/\theta^4$, se θ for pequena; 2) A espessura do espalhamento do material t é pequena; 3) A magnitude da carga central Ne ; 4) E é inversamente proporcional a $(mu^2)^2$, ou a quarta potência da velocidade se m for constante (RUTHERFORD, 1911, p. 675, tradução nossa).

Rutherford (1911) lembra que, de acordo com os últimos experimentos de Geiger, estes resultados correspondem aos ângulos encontrados experimentalmente.

O artigo prosegue com alguns cálculos para o encontro de uma partícula alfa com o núcleo, analisando o valor da velocidade das partículas com os tipos de deflexões: simples ou múltiplas e verificando tais valores teóricos com os experimentais, destacando alguns pontos de discussão:

(a) A “reflexão difusa” das partículas α , e a deflexão de partículas α em grandes ângulos (Geiger e Marsden). (b) A variação de reflexão difusa com o peso atômico do radiador (Geiger e Marsden). (c) A média de deflexão de um feixe de raios α transmitido por uma fina

³³ “b” é um valor arbitrário definido por Rutherford para fazer o cálculo do ângulo de inclinação da partícula, esse valor equivale a $b = 2 p \cot \theta$, é a partir desta relação que é possível calcular o ângulo (θ) da partícula desviada em relação ao centro do sistema atômico.

placa de metal (Geiger). (d) Os experimentos de Crowther de deflexão de raios β em diferentes velocidade e em diferentes materiais (RUTHERFORD, 1911, p. 680, tradução nossa).

Em (a), Rutherford (1911) faz uma rápida apresentação do experimento de Geiger e Marsden. Na “reflexão difusa de partículas α caindo em várias substâncias mostrou que apenas 1/8000 das partículas α do Rádio C caem sobre uma placa de platina e são defletidas de volta na direção de incidência” (RUTHERFORD, 1911, p. 680, tradução nossa). Em (b), Geiger e Marsden em um experimento similar com variação das placas metálicas obtiveram valores muito próximos para uma deflexão das partículas α . Calculando o valor teórico deste experimento, Rutherford (1911) destaca que estes valores são muito bons e próximos dos valores achados. Em (c), Geiger desenvolveu um experimento similar para finas lâminas de vários metais. Concluindo que, em uma fina folha de ouro obteve-se um resultado próximo ao do experimento apresentado em b. Nesse sentido, supôs que a carga do centro do átomo deve ser por volta de 100 e.

Com base no ponto (d), fazendo uma leitura do experimento de Crowther, Rutherford (1911) consegue desenvolver uma interpretação para o desvios das partículas α e β , compreendendo que este fator é proporcional ao valor de massa atômica, levando-o a supor que essa propriedade poderia estar relacionada ao núcleo.

Foi suposto que o átomo consiste em uma carga central provavelmente concentrada em um ponto, e as largas deflexões de partículas α e β são principalmente devido a passagem através de um forte campo central (RUTHERFORD, 1911, p. 686, tradução nossa).

Rutherford (1911) considerou que os valores de cargas do centro dos átomos são propocionais aos seus pesos atômicos. Apresentando também um parágrafo dedicado aos estudos matemáticos de Nagaoka, sobre o átomo saturniano³⁴. Finalizou com algumas considerações sobre o experimento de Geiger e Marsden, lembrando que ainda haviam muitos problemas, para o seu modelo, sem resposta que poderiam ser explicados em artigos posteriores.

³⁴ O átomo saturniano foi proposto por Hantaro Nagaoka para elucidar a estrutura atômica. Nagaoka baseou seus cálculos no artigo de Maxwell sobre os anéis de Saturno, fazendo uma analogia com o um átomo com um núcleo grande rodeado de anéis de elétrons.

2.3.3 O TRABALHO EXPERIMENTAL DE GEIGER E MARSDEN (1913)

Geiger e Marsden (1913) descrevem de forma sintética o experimento de espalhamentos de partículas α descritos em artigos anteriores de 1909 e 1910³⁵ e apresentam alguns pressupostos do mesmo:

No experimento um feixe de partículas α caem em uma tela de zinco-sulfeto em vácuo, e a distribuição das cintilações na tela são observadas com diferentes folhas de metais colocadas no caminho das partículas α (GEIGER e MARSDEN, 1913, p. 604, tradução nossa).

Neste artigo, Geiger e Marsden (1913), descrevem como foi conduzido o experimento de bombardeamento de folhas metálicas com partículas α .

Recordando alguns valores calculados no artigo de Rutherford de 1911, Geiger e Marsden (1913) apresentam algumas sugestões para o desenvolvimento de testes experimentais que constituíram pontos de discussão:

(1) variação do ângulo; (2) variação da espessura do material de espalhamento; (3) variação do peso atômico do material de espalhamento; (4) variação da velocidade das partículas α incidentes. (5) a fração de espalhamento de partículas em ângulos definidos (GEIGER e MARSDEN, 1913, p. 605, tradução nossa).

Geiger e Marsden (1913) desenvolvem o artigo com base nos 5 questionamentos feitos por Rutherford. No primeiro, constituem um aparato para o cálculo da variação do ângulo de desvio, de acordo com a figura 14:

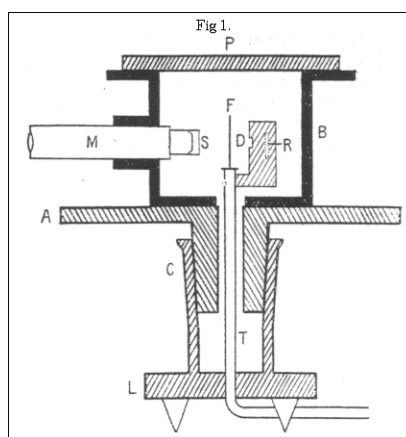


FIGURA 14 – ESQUEMA DO EQUIPAMENTO USADO PARA MEDIR OS ÂNGULOS DE DEFLEXÃO

³⁵ H. Geiger, Royal Society Proc. vol. LXXXIII. p. 492 (1910) e Geiger e Marsden, Royal Society Proc. vol. LXXXII. p. 495 (1909).

FONTE: Geiger e Marsden (1913)

Em “B” temos uma caixa cilíndrica, contendo a fonte de partículas α representado por “R”. “F” é uma folha metálica para a determinação dos espalhamentos de partículas α . O microscópio é apresentado como “M”. “A” é a plataforma móvel graduada, “S” é a tela de zinco-sulfeto, o sistema é aparado por uma junta cônica “C”, responsável pela rotação de toda a plataforma. “T” é um tubo utilizado para manter a placa constante e “P” seria uma grossa placa de vidro.

Geiger e Marsden (1913) fizeram o teste de espalhamento de partículas α para diferentes metais, em diferente ângulos de incidência das partículas. Ou seja, os dois pesquisadores lançaram partículas α sobre lâminas, observando os espalhamentos ao longo de um giro de 360° . Debruçando-se nos resultados da lâmina de prata e ouro, os autores, discorrem sobre a validade e os dados obtidos do experimento. Constataram que os valores de deflexão das partículas estavam de acordo com o que foi anteriormente descrito por Rutherford em seu artigo em 1911.

No segundo ponto levantado, Geiger e Marsden (1911), prepararam um outro aparato para fazer as mensurações experimentais. Descrevendo, sucintamente, o mesmo em três partes: na primeira dão um esquema da fonte radioativa, na segunda apresentam uma visão geral esquemática do experimento e na terceira um esquema mais simplificado do experimento.

O esquema usado para a fonte de emissão de Rádio foi composto por 80 milicuries, altamente puros e prensados em um tubo de vidro, de aproximadamente 1mm de diâmetro interno. De acordo com Geiger e Marsden (1913), essa fonte seria acoplada no esquema representado na figura 15:

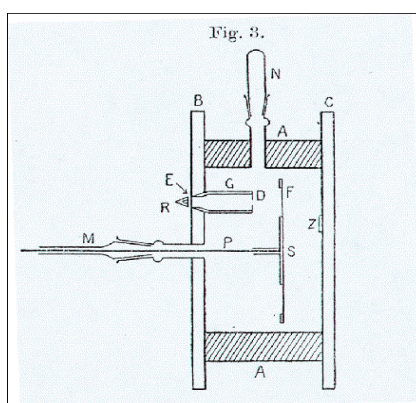


FIGURA 15 – ESQUEMA USADO NO SEGUNDO EXPERIMENTO

FONTE: Geiger e Marsden (1913)

O esquema organiza-se da seguinte forma “D” é um diafragma, “B” e “C” são placas de vidro para delimitar a área do espalhamento, em “Z” foi colocado uma placa de zinco-sulfeto para observação das partículas, “A” é um anel de latão cilíndrico que cobre as duas pontas do sistema, “S” é um conjunto de disco coberto com 6 buracos, “F” é o metal a ser testado, “P” é uma vara para dar giro ao conjunto de disco com lâmina (S + F) e “M” é uma junta para giro da vara “P”.

A figura 16 apresenta uma variação do mesmo experimento descrito anteriormente frente a dificuldade de se analisar os números de sintilações na placa de sulfeto-zinco:

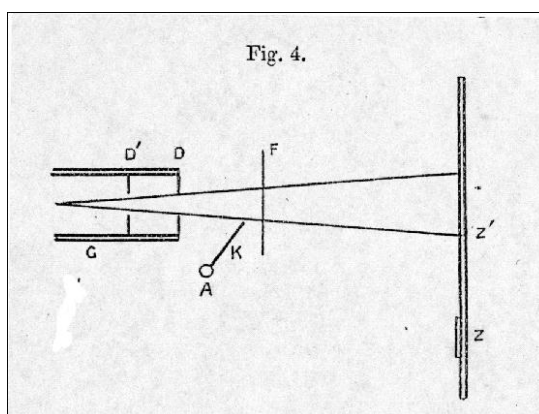


FIGURA 16 – VARIAÇÃO DO POSICIONAMENTO DO SULFETO DE ZINCO

FONTE: Geiger e Marsden (1913)

Essa alteração de “Z” para “Z'” foi necessária para observar as variedades de sintilações sofridas pela lâminas de metais diferentes. Com base neste acerto, Geiger e Marsden (1913) calcularam os valores de sintilações por número de folhas metálicas. Os resultados foram expressos de acordo com um gráfico mostrado na figura 17:

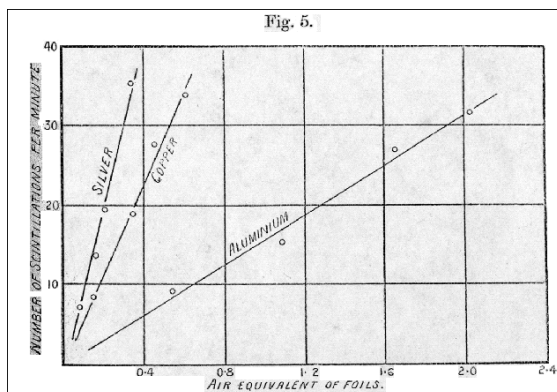


FIGURA 17 – GRÁFICO COM OS VALORES DE SINTILAÇÕES POR SEGUNDO E QUANTIDADE DE LÂMINAS

FONTE: Geiger e Marsden (1913)

A partir deste gráfico, Geiger e Marsden (1913) puderam aferir que o ouro por ter propriedades físicas intermediárias, junto aos dados de sintilação seria o metal de melhores resultados, pois registra o maior número de sintilações com uma menor espessura.

O próximo ponto analisado por Geiger e Marsden (1913) foi o espalhamento das partículas de acordo com o peso atômico, com o objetivo de calcular o valor do centro de carga dos átomos, verificando os cálculos sinalizado por Rutherford em seu artigo de 1911 e fazendo a relação entre o centro atômico e a massa relativa do átomo.

Na última seção, mostram os valores experimentais para deflexões com variações da velocidades das partículas α .

Ao final do artigo, Geiger e Marsden (1913), mostram um sumário de todos os resultados obtidos em todos os capítulos, de acordo com as proposições de pesquisa feitas por Rutherford:

Os experimentos descritos neste artigo foram realizadas para testar a teoria proposta pelo prof. Rutherford, a principal característica é que há a existência de um centro no átomo que tem uma intensa carga concentrada. A verificação é baseada nas leis de deflexão e foram deduzidos desta teoria (GEIGER E MARSDEN, 1913, p. 627, tradução nossa).

Como continuação a essa conclusão, Geiger e Marsden (1913) apresentam os valores para cada um dos pontos levantados por Rutherford: em (1), os valores

encontrados para o número de partículas e a variação dos ângulos (5 a 150°) tiveram grande proximidade com os valores teóricos. Em (2), os valores de velocidade das partículas defletidas e a sua espessura também estavam de acordo com a teoria. Em (3), os valores das deflexões, por átomo para diferentes folhas de metal, é próximo do encontrado por Rutherford, evidenciando que são relativos ao quadrado do peso atômico. No ponto (4), o valor dos desvios das partículas α são proporcionais a quarta potência inversa da velocidade incidente da partícula. E em (5), com os valores das partículas α desviadas na folha de ouro é possível calcular o número de cargas elementares compondo o centro do átomo que é igual a metade do peso atômico. Dada essas conclusões, os autores finalizam:

Nós estamos endividados com o prof. Rutherford por estes interessantes experimentos, e para colocar ao nosso dispor grandes quantidades de Rádio necessário para as emanações. Estamos em débito também com Grande Comitê Governamental da Royal Society a uma bolsa dada a um de nós, da qual parte de nossas despesas foram pagas (GEIGER E MARSDEN, 1913, p. 628, tradução nossa).

2.3.4 O MODELO ATÔMICO NA VISÃO DE RUTHERFORD

De acordo com Rutherford (1911), pode-se assumir que o átomo é formado por um núcleo pequeno, denso e carregado, envolto por uma esfera de raio definido, constituída de uma carga de valor oposto uniforme. Ou seja, a sua proposta do átomo é uma alteração da proposta anterior de J. J. Thomson, com a inserção de um núcleo denso congregando todo o peso atômico, com um determinado campo estabilizado por uma esfera que envolve todo o sistema. E que a deflexão de partículas α e β , é devido a interação do campo eletromagnético das partículas com o núcleo, ocasionando o desvio da trajetória nos mais diferentes ângulos.

2.4 NIELS BOHR

Graduou-se e pós-graduou-se em Copenhague. Em seu trabalho de mestrado e doutorado fez estudos teóricos sobre os movimentos do elétron, que não eram explicados quantitativamente. Desde 1911, época em que termina seus estudos de Doutorado, Bohr convenceu-se que era necessário uma ruptura da física clássica para uma nova física. Após o término de seu doutorado, foi para Cavendish na tentativa de trabalhar com J. J. Thomson, pesquisador que ele muito admirava.

Porém, em um jantar Bohr leva um artigo de Thomson e começa a apontar possíveis erros sem explicação, o que acaba por tumultuar a sua relação com o pesquisador. Após este episódio, Bohr vai trabalhar com Rutherford na pesquisa com partículas alfa, mensurando a variação de energia. Com os dados deste estudo, Bohr consegue desenvolver as bases de seu artigo de 1913 (LOPES, 2009).

No ano de 1913, de acordo com Lopes (2009), Bohr publica “Sobre a constituição de átomos e moléculas”, onde apresenta em três artigos as bases de sua teoria atômica, inspirada nos trabalhos anteriores de Rutherford. No primeiro artigo Bohr traz os modelos de Thomson e Rutherford fazendo várias ponderações sobre o cálculo, analisando como seu modelo era instável frente à dinâmica clássica.

Com esta trilogia de artigos, Bohr faz alusão a uma nova possibilidade, na qual a física clássica não daria conta de explicar certos fenômenos, necessitando de uma nova física. De acordo com Bohr (1963), quem sugere que ele publique uma trilogia é Rutherford, sugerindo uma simplificação de cálculos, idéias e conclusões, para se adequar a forma britânica de publicação.

Segundo Lopes (2009), Bohr também tem contato com os trabalhos de Nicholson que o ajudam a compreender a empregabilidade de cálculos que foram à base de seu modelo atômico. Mesmo assim, seguiu um caminho completamente diferente do de Nicholson no uso da Constante de Planck (h).

Assim, no ano de 1913, Bohr desenvolve e publica três artigos³⁶ na *Philosophical Magazine*, dando as bases para a compreensão de sua visão atômica:

- (I) *I. On the constitution of atoms and molecules* (1913), publicado na *Philosophical Magazine* em julho;
- (II) *Part II. – Systems containing only a single nucleus* (1913), publicado na *Philosophical Magazine* em setembro;
- (III) *Part III – Systems containing a several nucleus* (1913), publicado na *Philosophical Magazine* em novembro.

Nas próximas seções apresenta-se uma interpretação destes trabalhos buscando uma compreensão da proposta do átomo de Niels Bohr.

³⁶ Esses artigos estão presentes em sua íntegra nos anexos 14, 15 e 16.

2.4.1 I. O PRIMEIRO ARTIGO PUBLICADO EM JULHO DE 1913

Bohr (1913) inicia seu artigo apresentando uma visão geral dos átomos de Rutherford e Thomson, tecendo algumas explicações sobre as diferenças entre os dois e desenvolvendo uma base teórica para sua preferência pelo modelo de Rutherford. Começando pela explicação do modelo de Rutherford:

O prof. Rutherford criou uma teoria da estrutura do átomo. Segundo esta teoria, os átomos são constituídos por um núcleo carregado positivamente, rodeado por um sistema de elétrons ligados por forças atrativas do núcleo; a carga negativa total é igual a carga positiva do núcleo e concentra quase toda a massa do átomo com dimensões extremamente pequenas comparadas as dimensões do átomo total (BOHR, 1913, p. 95, tradução nossa).

Após a apresentação deste modelo, Bohr faz algumas considerações sobre os resultados encontrados e dilemas desta proposta. Trazendo a proposta de Thomson para o átomo:

Segundo a teoria de Thomson, o átomo é formado por uma esfera de eletrização positiva uniforme, dentro da qual elétrons se movem com órbitas circulares (BOHR, 1913, p. 96, tradução nossa).

Explicando sobre os dois modelos, Bohr (1913) explica as diferenças e limitações da proposta de Rutherford para Thomson. A diferença é que no arranjo de Thomson há uma estabilidade maior dos elétrons orbitando, enquanto a configuração sugerida por Rutherford não tem essa característica. Nesse sentido, Bohr através das teorias de radiação, espectros e outros elementos vai tentar propor uma possível explicação para a estabilidade dos elétrons no modelo de Rutherford. Partindo da suposição que o átomo possui elétrons girando em órbitas elípticas estacionárias. Com isso é possível calcular o valor da velocidade angular (w) dos elétrons, sem levar em conta que se perde energia sob forma de radiação. Após apresentar os cálculos sem perda de energia, Bohr, sugere que seja inserida essa radiação perdida explicando uma limitação do modelo proposto por Rutherford:

Neste caso, o elétron já não descreverá órbitas estacionárias. W aumentará continuamente, e o elétron aproximar-se-á do núcleo descrevendo órbitas de dimensões cada vez mais pequenas e frequência cada vez maior; em média, o elétron ganha energia cinética ao mesmo tempo que todo o sistema perde energia. O processo continuará até que as dimensões da órbita sejam da mesma ordem de grandeza que as dimensões do elétron ou do núcleo (BOHR, 1913, p. 99, tradução nossa).

A partir desta limitação começa a desenvolver sua proposta para o movimento dos elétrons baseado nos estudos de Planck, Nicholson e outros físicos. Dentro dessa discussão Bohr sintetiza as suas idéias para contornar o problema da instabilidade com dois pontos básicos:

Os principais pressupostos utilizados são: 1) Que o equilíbrio dinâmico dos sistemas nos estados estacionários pode ser discutido por meio da mecânica ordinária, enquanto a passagem dos sistemas entre diferentes estados estacionários não pode ser tratada nessa base. 2) Que este último processo é seguido pela emissão de uma radiação *homogênea*, para a qual a relação entre a frequência e a quantidade de energia emitida é dada pela teoria de Planck (BOHR, 1913, p. 104, tradução nossa).

Assumindo estas duas características e com base na teoria de Planck, Bohr (1913) faz os cálculos para as emissões de elementos que contém um elétron (hidrogênio) e encontra como resultado experimental o valor de $3,290 \times 10^{15}$, próximo ao valor teórico de $3,1 \times 10^{15}$. Com base nos valores encontrados, mostra a validade dos dois pressupostos ancorados na teoria da radiação e na constante de Planck, explicando que não seria possível aferir esses valores de emissões em tubos de descarga no vácuo. Faz os cálculos de riscas de espectros de emissão para o hidrogênio e o hélio, assumindo o átomo de Rutherford, encontrando grande similaridade nos valores encontrados.

No terceiro tópico Bohr (1913) faz algumas relações entre os cálculos para o movimento de elétrons e a teoria de Planck. Supondo que a radiação liberada é composta pela relação de $h\nu$ e que a “frequência da radiação emitida durante a passagem entre estados estacionários sucessivos coincidirá com a frequência de revolução do elétron na região das vibrações finais” (BOHR, 1913, p. 114, tradução nossa), postulando sobre o valor da órbita de um elétron:

se postularmos que a órbita do elétron nos estados estacionários é circular, o resultado do cálculo da pg. 100 pode ser expresso pela condição simples seguinte: o momento angular do elétron em torno do núcleo, em um estado estacionário do sistema, é igual a um múltiplo inteiro de um valor universal, independente da carga do núcleo. A possível importância do momento angular na discussão dos sistemas

atômicos em relação com a teoria de Planck é realçada por Nicholson (BOHR, 1913, p. 115, tradução nossa).

Nessa passagem Bohr (1913), de posse da seguinte equação de momento angular onde os valores discretos de w , W e a^{37} , indicam diferentes estados físicos para o elétron que descreve certas órbitas.

No 4º tópico são discutidas as absorções de radiação, assumindo que o que foi calculado para a liberação de energia, poderá ocorrer da mesma forma para a absorção. No 5º e último tópico, desta 1ª parte, Bohr retoma o foco principal de seu trabalho que é elucidar uma proposta de arranjo de elétrons que confira estabilidade ao modelo proposto por Rutherford.

Para atingir esta meta, Bohr (1913) faz cálculos para o movimento do elétron, com base em suas suposições iniciais, admitindo que a estabilidade de um anel contendo elétrons estaria ligada:

A hipótese que utilizamos no que segue consiste em admitir que a estabilidade de um anel de elétrons girando em torno do núcleo é assegurada pela condição antes postulada da constância universal do momento angular, acrescida da condição segundo a qual a configuração tomada pelas partículas é aquela em cuja formação é libertada a quantidade de energia máxima (BOHR, 1913, p. 127, tradução nossa).

Assim, Bohr (1913) insere um postulado de que os elétrons estão girando ao redor de um núcleo em órbitas definidas. Para este sair de sua órbita necessita da liberação de uma quantidade fixa de energia, produzindo um efeito de mobilidade de um estado a outro. Concluindo esta primeira parte, admite que:

em qualquer sistema molecular formado por núcleos positivos e elétrons no qual os núcleos estão em repouso uns relativamente aos outros, e no qual os elétrons se movem em órbitas circulares, o momento angular de cada elétron em torno do centro da sua órbita será, no estado permanente do sistema, igual a $h/2\pi$, sendo h a constante de Planck (BOHR, 1913, p. 129, grifos do autor, tradução nossa).

³⁷ Segundo Bohr (1913) w é frequência de revolução, a é o eixo da órbita e W representa a quantidade de energia que deve ser retirada ou fornecida.

Ou seja, Bohr (1913) gerou uma condição para a disposição dos elétrons dentro de uma órbita definida, tendo valores de momento angulares definidos e postulando que a relação com a teoria de Planck confere uma certa estabilidade à proposta de Rutherford.

2.4.2 O SEGUNDO ARTIGO PUBLICADO EM SETEMBRO DE 1913

No início da segunda parte, Bohr (1913), retoma os pressupostos iniciais recordando como o átomo de Rutherford seria organizado. Apresenta o postulado desenvolvido ao final do primeiro artigo e procura desenvolver alguns estudos sobre este, iniciando pela configuração de sistemas que tem vários elétrons dispostos ao longo do núcleo.

Bohr (1913) a partir de cálculos e de relações matemáticas, define que há uma diferença para o arranjo de átomos com poucos e muitos elétrons:

Admitimos em 1 que os elétrons giram nos átomos em anéis coaxiais. O cálculo indica que só no caso de sistemas contendo um grande número de elétrons, os planos dos anéis se separam, no caso de sistemas contendo um número moderado de elétrons, os anéis estarão todos situados num só plano que passa pelo núcleo (BOHR, 1913, P. 142, tradução nossa).

Com essa leitura e cálculos feitos Bohr (1913), define-se uma regra que diferencia átomos com um alto número atômico (Z) daqueles que tem um baixo Z . Assim, pode-se entender que átomos como Hidrogênio, Hélio, dentre outros, só possuem elétrons dispostos em anéis ao longo de um plano. Na medida em que o valor de Z aumenta como para o Césio, por exemplo, estes vários anéis são dispostos em diferentes planos, a ponto de conferir estabilidade a todos os elétrons em relação ao núcleo.

Com base nesta distinção, Bohr, segue a próxima etapa de seu artigo fazendo os cálculos para constituição de átomos com poucos elétrons. Aplicando seus cálculos e postulados para o: Hidrogênio ($N=1$), Hélio ($N=2$), Lítio ($N=3$), Berílio ($N=4$), onde N seria relativo ao número de elétrons, que estariam dispostos em um mesmo plano ao longo de diferentes anéis.

Na seção 4, Bohr faz o cálculo para os átomos que contém maior número de elétrons, supondo que inicialmente os anéis estariam todos no mesmo plano e que depois de um certo tempo começariam a se repelir adquirindo certos ângulos definidos, favorecendo a situação descrita na página 142 de Bohr (1913), onde átomos com muitos elétrons tem órbitas em ângulos diferentes. Fazendo a apresentação do arranjo dos elétrons em vários casos, onde o valor inicial é o número total de elétrons e os valores em parênteses são os números totais de elétrons dispostos em anéis (anexo 15).

Baseado nos cálculo de arranjo de elétrons, Bohr (1913) sintetiza essa idéia para o grupo do ferro e finaliza esta seção com a afirmação de que este sistema ainda está em formação e não responde a certos problemas encontrados.

Nas duas últimas seções desse artigo, Bohr (1913) faz um estudo dos Raios Röntgen, estudados por J. J. Thomson e sobre átomos de substâncias radioativas. Finaliza com uma leitura total do objetivo do artigo que era “aplicação da teoria da radiação de Planck ao modelo atômico de Rutherford, introduzindo a hipótese da constância universal do momento angular do elétrons ligados” (BOHR, 1913, p. 170, tradução nossa), que conduziram a resultados favoráveis com a observação experimental.

2.4.3 O TERCEIRO ARTIGO PUBLICADO EM NOVEMBRO DE 1913

Na terceira parte, Bohr (1913) introduz uma interpretação da teoria de Rutherford para a distinção de sistemas com um só núcleo:

Segundo a teoria de Rutherford sobre a estrutura dos átomos, a diferença entre o átomo de um elemento e a molécula de uma combinação química consiste em que o primeiro é formado por um grupo de elétrons rodeando um único núcleo positivo de dimensões extremamente pequenas e de massa grande em comparação com os elétrons, enquanto a última contém pelo menos dois núcleos a distâncias um do outro comparáveis com as distâncias os elétrons do enxame envolvente (BOHR, 1913, p. 171).

Na segunda seção de seu artigo, Bohr (1913) apresenta cálculos e bases teóricas para definir a configuração de estabilidade de sistemas ligados entre si, com

dois núcleos. Baseando-se em todos os cálculos e suposições usadas nas outras duas partes anteriores.

Na terceira seção, apresenta cálculos e configurações de sistemas ligados que contém poucos elétrons, como exemplo a molécula de hidrogênio, possuindo somente dois elétrons girando ao redor de seus núcleos.

Na quarta seção são abordados pressupostos para a formação destes sistemas e na quinta seção se faz a análise de como seria a formação de um sistema que contém muitos elétrons.

Na última parte desse artigo, Bohr (1913) desenvolve uma síntese de toda a sua teoria abordada ao longo dos três artigos em 5 hipóteses, ancoradas na proposta atômica de Rutherford e na teoria de Planck:

1. Que a energia radiada não é emitida (ou absorvida) da maneira contínua admitida pela eletrodinâmica clássica, por apenas durante a passagem dos sistemas de um estado “estacionário” para outro diferente. **2.** Que o equilíbrio dinâmico dos sistemas nos estados estacionários é governado pelas leis da mecânica clássica, não se verificando estas leis nas transições dos sistemas entre diferentes estados estacionários. **3.** Que é homogênea a radiação emitida durante a transição de um sistema de um estado estacionário para outro, e que a relação entre a frequência ν e a quantidade total de energia emitida é dada por $E=h\nu$, sendo h a constante de Planck. **4.** Que os diferentes estados estacionários de um sistema simples constituído por um elétron que roda em volta de um núcleo positivo são determinados pela condição de ser igual a um múltiplo inteiro de $h/2$ a razão entre a energia total emitida durante a formação da configuração e a frequência de revolução do elétron. Admitindo que a órbita do elétron é circular, esta hipótese equivale a supor que o momento angular do elétron em torno do núcleo é igual a um múltiplo inteiro de $h/2\pi$. **5.** Que o estado “permanente” de um sistema atômico – isto é, o estado no qual a energia emitida é máxima – é determinado pela condição de ser igual a $h/2\pi$ o momento angular de cada elétron em torno do centro de sua órbita (BOHR, 1913, p. 196, grifos nossos, tradução nossa).

Bohr (1913) finaliza seu artigo apresentando estas hipóteses como postulados necessários para o modelo atômico proposto por Rutherford, mostrando a possibilidade de explicação das leis de Balmer e Rydberg para os espectros dos elementos químicos. Nesta última parte, Bohr também destacou a constituição de uma teoria para formação de sistemas de moléculas com mais de um núcleo e

lembrou que é evidente a relação entre a teoria atômica e as teorias de radiação em corpo negro e de outras fontes teóricas com os movimentos dos elétrons.

2.4.4 O MODELO ATÔMICO PARA BOHR

Bohr (1913) compreende que o átomo adota a estrutura elucidada por Rutherford, com um acerto no que diz respeito ao movimento dos elétrons. Com base nisso, Bohr sistematizou algumas regras. Primeiramente uma para o arranjo de anéis de átomos com poucos e depois outra para muitos elétrons. Para poucos elétrons estes anéis estariam dispostos todos em um mesmo plano. Para arranjos com um número elevado de elétrons o sistema apresentaria anéis em diferentes ângulos, porém paralelos entre si. São eles:

- 1) A primeira está relacionada com a teoria da radiação de Planck, onde a radiação não é contínua, porém adquire um valor contínuo para passagem de um estado para outro de diferente energia.
- 2) A segunda relaciona o limite da mecânica clássica, que é descrever o movimento e a trajetória do elétron, quando há a passagem de estados estacionários.
- 3) Que a radiação de transição de um estado a outro é determinada através da teoria de Planck, onde a relação de energia é representada por: $E = h\nu$, sendo h a constante.
- 4) Nesta regra os estados estacionários de um sistema de um elétron são definidos pela razão de $h/2$ e que o momento angular desse elétron em volta do núcleo pode ser definido por $h/2\pi$.
- 5) O estado de energia máxima de uma órbita é definido como sendo o momento angular de cada elétron definido como $h/2\pi$, em torno de sua órbita.

Com base na primeira regra e nos 5 postulados é possível, de acordo com Bohr (1913), explicar os movimentos dos elétrons ao redor do núcleo e explicar os efeitos de espectros de emissão de riscas pela série de Balmer e Rydeberg.

Destarte, compreende-se que Bohr (1913) não elaborou um novo modelo atômico, mas com base em novos avanços científicos reelaborou e complementou uma proposta existente, a do seu mestre Rutherford.

De acordo com esses *saberes sábios*, desenvolve-se nos próximos capítulos um estudo dos LDQ de 1931 a 2012, por meio de uma análise de 19 exemplares, periodizados através de diferentes reformas, com base na *textualização dos saberes* de Chevallard (1991).

CAPÍTULO 3 – METODOLOGIA DA PESQUISA

Neste capítulo são apresentados o problema de pesquisa, objetivos, metodologia e instrumentos de coleta de dados.

3.1 PROBLEMA DE PESQUISA

Como foram transpostos os Modelos Atômicos em livros didáticos de química, no período de 1931 a 2012?

3.2 OBJETIVOS

3.2.1 GERAL

O objetivo desta dissertação é analisar como foram transpostos os modelos atômicos em livros didáticos de química, no período de 1931 a 2012, com base nos *elementos da transposição didática*, de acordo com a proposta da *Transposição Didática* de Yves Chevallard.

3.2.2 ESPECÍFICOS

- 1) Levantar as teorias dos Modelos Atômicos desenvolvidos pelos PTA;
- 2) Examinar ao longo da história como os LDQ apresentaram os modelos atômicos.
- 3) Analisar o conteúdo referente aos Modelos Atômicos (MA) presentes nos LDQ, com base nos elementos da *Transposição Didática* apresentados na proposta de Chevallard (1991);

3.3 A TÉCNICA DE ANÁLISE DE CONTEÚDO

A técnica de Análise de Conteúdo de acordo com Bardin (2010) tem sua gênese nos Estados Unidos. Usada como uma técnica analítica para quantificação e leitura de dados. Aplicada no Jornalismo na análise de notícias, pelos aliados, durante a segunda guerra mundial, com a intenção de filtrar notícias e propagandas de cunho nazista. Após estes episódios a Análise de Conteúdo foi utilizada em pesquisas de ciência política para leitura de dados e sua categorização. E assim,

após estes períodos a técnica se difundiu a diferentes áreas recebendo inúmeras adaptações e variações. E segundo Bardin (2010), atualmente a técnica tem sido amplamente atualizada e discutida.

De acordo com Bardin (2010), a Análise de Conteúdo é uma técnica analítica de caráter quantitativo e qualitativo, pois através de um profundo estudo lingüístico, de categorização e interpretação é possível fazer os dados literalmente “falarem”. Ou seja, é uma técnica que consiste em uma sistemática depuração de dados com o objetivo de fazer uma melhor compreensão do material de análise através de um referencial teórico adotado pelo pesquisador. Para se chegar a total depuração de informações de uma fonte de pesquisa, Bardin (2010) sistematiza o método em três etapas.

3.3.1 PRIMEIRA ETAPA

Na primeira etapa denominada de *pré-análise*, de acordo com Bardin (2010), se tem a escolha dos materiais que irão compor o *corpus* da pesquisa, através da técnica de *leitura flutuante*, gerando índices que podem compor uma futura categorização³⁸. Ou seja, é nesta etapa que toda a análise é delineada, consistindo nas seguintes etapas: *leitura flutuante*, *escolha dos documentos*, *regras do corpus*.

A *leitura flutuante*, segundo Bardin (2010), é o primeiro contato com o documento é uma leitura não precisa para reconhecimento do documento que poderá ser usado no *corpus*.

A *escolha dos documentos*, na compreensão de Bardin (2010), diz respeito a quais documentos serão usados na pesquisa, conformando o *corpus*. Se estabelece seguindo alguns critérios, destacados pela autora, os quais são: *Exaustividade*, *Representatividade*, *Homogeneidade* e *Pertinência*.

A *Exaustividade* diz respeito, segundo Bardin (2010), a seleção dos documentos que serão a base da análise, a primeira triagem, para começar a delimitar o *corpus* da pesquisa. Se junta tudo que se tem sobre o que se procura pesquisar e aplicar uma exaustiva leitura, de forma que nenhum documento que tenha relação com a pesquisa fique de fora.

A *Representatividade* relaciona-se com o que Bardin (2010) discute sobre amostragem na pesquisa, lembrando que quando há uma possibilidade de uso de

³⁸ A categorização é uma etapa importante dentro da técnica de Análise de Conteúdo, segundo Bardin (2010) refere-se ao que será analisado no documento. A categorização será aprofundada mais adiante.

técnicas de amostragem, deve-se usá-las. E quando o espaço amostral é muito pequeno e as amostras coletadas são de extrema importância, não se deve usar técnicas de amostragem.

Na *Homogeneidade* Bardin (2010), salienta que na composição do *corpus* os documentos devem ser retidos por critérios iguais de seleção com os mesmos critérios de seleção. O critério aplicado no começo da formação do espaço amostral deve ser o mesmo até o final.

E a *Pertinência* para Bardin (2010) é que os documentos analisados devem ser fontes de informação de modo que respondam à questão de pesquisa e ajudem a responder os objetivos traçados.

3.3.2 A SEGUNDA ETAPA

A segunda etapa para Bardin (2010) é denominada de *exploração de material* que consiste em administrar as técnicas da pesquisa no *corpus* de análise. Lembrando, que este *corpus* criado será exaustivamente analisado, decodificado e categorizado, a ponto de trazer o máximo possível de dados, sem uma total interpretação do material.

3.3.3 A TERCEIRA ETAPA

E a terceira etapa, como lembra Bardin (2010), é o do *tratamento dos resultados e interpretações*. Nesta etapa se tem todas as etapas que compreendem na organização dos dados argüidos e na interpretação dos mesmos com base no referencial teórico escolhido e desenvolvido na pesquisa.

Assim, a partir dessa técnica de análise de dados que se desenvolve todo o desenho metodológico para aquisição de dados dessa dissertação, apresentados em suas três etapas na seção a seguir.

3.4 METODOLOGIA DA COLETA E ANÁLISE DE DADOS

Esta pesquisa foi desenvolvida em duas etapas: a primeira correspondeu a um levantamento dos Modelos Atômicos no *saber sábio* e a segunda a uma análise dos LDQ.

Ao final, foi feita uma interpretação de todos os dados de modo a compreender como os conteúdos sobre MA foram articulados ao longo de diferentes períodos (1931 a 2012) e como se deu a *Transposição Didática* desses conteúdos.

Na primeira etapa, para fazer o levantamento do *saber sábio* dos MA, realizou-se de uma pré-análise³⁹ dos LDQ. Para montar este primeiro *corpus* de análise, foi feita uma busca em inúmeros Sebos e em buscadores especializados em livros na internet. Com base nesta busca foram encontrados 55 LDQ que foram agrupados tendo como base as datas de vigência da reforma educacional Francisco Campos (1931 – 1943), reforma educacional Gustavo Capanema⁴⁰ (1943 – 1960), Leis de Diretrizes e Bases da Educação Nacional (Nº 4.024/61, Nº 5.692/71⁴¹ e Nº 9.394/96), Constituição Federal de 1988, Plano Nacional do Livro Didático para o Ensino Médio (2007) e Plano Nacional do Livro Didático (2012). Os documentos oficiais foram somente utilizados como critério de organização dos dados, como em Mortimer (1988), não sendo usados como referencial da análise dos LDQ.

Essa pré-análise teve como objetivo levantar quais PTA mais aparecem nos LDQ, construindo um recorte da história da teoria atômica. Após este levantamento, procedeu-se um levantamento dos Modelos Atômicos no *saber sábio*. Para este levantamento foram utilizadas fontes primárias e secundárias.

As fontes primárias constituem-se de artigos dos PTA sobre a sua proposta de Modelo Atômico. As secundárias correspondem aos trabalhos acadêmicos, livros e artigos sobre a historiografia destes PTA. Com base neste conjunto de fontes foi desenvolvida uma análise bibliográfica e documental⁴² do *saber sábio*, sustentada na técnica de análise de conteúdo, Bardin (2010).

Todos os dados levantados acerca dos PTA foram organizados e constituíram o capítulo 2. Sendo este a base do *saber sábio* que subsidiou a análise dos modelos atômicos nos LDQ de acordo com um primeiro quadro (Apêndice 1).

³⁹ Essa pré-análise é a primeira etapa da técnica de Análise de Conteúdo, como enunciada por Bardin (2010) é nela que se torna possível delimitar o material que receberá uma análise mais aprofundada.

⁴⁰ De acordo com Mortimer (1988) a Reforma Capanema vigorou de 1943 a 1960, compreendendo a portaria ministerial de 1951. Está última tinha como objetivo retirar conteúdos de ciências dos LDQ, porém ela não retirou o conteúdo MA.

⁴¹ há uma divergência entre os pesquisadores se a Lei 5692/71 é LDBEN, porém que nesta dissertação este fato não é importante, pois as reformas só foram usadas para periodização do corpus de pesquisa.

⁴² De acordo com Lima e Mito (2007) a análise documental e bibliográfica não tem muitas diferenças, a sua distinção está no objeto de análise. A documental com a análise de documentos que não receberam tratamento prévio e a bibliográfica destinada a documentos e materiais que receberam um tratamento prévio.

Na segunda etapa, foram selecionados para análise 19 LDQ utilizando os seguintes critérios: o primeiro foi com base no conteúdo que estes livros apresentaram, onde os mais completos foram selecionados. O segundo critério diz respeito à data de publicação e o autor do livro, onde livros do mesmo ano e com os mesmos autores foram retirados. E o terceiro critério diz respeito à amplitude da obra, dando-se preferência aos livros de volume único e os mais completos, selecionando-se ao final duas coleções, por período, que melhor se encaixaram nos critérios apresentados de acordo com um quadro (apêndice 2).

Este material foi analisado com base na técnica de Análise de Conteúdo de Bardin (2010)⁴³. Os dados foram levantados a partir de um roteiro, baseado nos *elementos da Transposição Didática*, como apresentado por Chevallard (1991), e como foi desenvolvido por Neves (2009) na análise do *saber* das matrizes no ensino da matemática. Com base no seguinte Roteiro de Análise:

Descontextualização: O livro apresenta a história do desenvolvimento de um determinado *saber sábio* no *saber a ensinar*.

I(a). O livro faz uma abordagem da história do processo de desenvolvimento dos Modelos Atômicos?

I(b). Faz alguma menção ao fato de que nem sempre o objeto de pesquisa dos PTA era o Modelo Atômico, mas que em alguns casos acabou contribuindo para tal?

Despersonalização: Diz respeito a como o saber é tratado, se é destituído de seus criadores, tornando-se anônimo (universal) ou se possui alguma personalização.

II. Os PTA são relacionados a algum modelo, como sendo o seu criador?

Relação novo/antigo: Trata-se da observação de como se dá a articulação entre *saber novo* e antigo.

⁴³ De acordo com Bardin (2010), a técnica de análise se dá em três momentos: O primeiro é a leitura flutuante formando o *corpus* de análise, nessa etapa analisa-se todo o material disponível, selecionando o que irá compor o conjunto de análise. O segundo momento é a arguição de dados, através do *corpus*. Onde se começa a interpretar alguns dados com o referencial teórico. O terceiro momento se traduz na interpretação de todos os dados coletados nas duas etapas anteriores, usando todo o referencial. Nesta etapa se desenha as conclusões e apresenta os resultados da análise.

III. O livro desenvolve uma explicação sobre as limitações do Modelo Atômico anterior, a ponto de justificar a inserção de um novo modelo?

Criações didáticas: São novos objetos de ensino “criados” para facilitar a compreensão de conceitos mais complexos.

IV. O livro utiliza de criações didáticas para desenvolver a compreensão acerca do modelo atômico?

Publicidade do saber: É quando o livro traz em sua estrutura alguma explicação das razões para o estudo de certos conteúdos ou o apresenta como será estudado.

V. O livro faz uma introdução sobre Modelos Atômicos, ou antes de introduzir um modelo ou conceito explica sua utilidade ou a forma de seu estudo na unidade?

Fidelidade na textualização do saber: Esse elemento tem como objetivo identificar se a proposta no *saber sábio* não foi modificada no livro didático, retirando informações que podem levar a uma compreensão equivocada do modelo.

VI. Qual o nível de fidelidade que o livro aborda e explica métodos, técnicas e propostas para o Modelo Atômico?

Desincretização: Como o livro está dividido, como sistematiza o estudo do conceito em questão.

VII(a). O livro possui um capítulo específico para o Modelo Atômico?

VII(b). Além do capítulo específico sobre Modelo Atômico, este conteúdo aparece também ao longo do livro em outros capítulos?

Programabilidade de aquisição do saber: Como o autor apresenta a sequência usada no livro.

VIII(a). Para qual série este conteúdo é orientado?

VIII(b). Durante a transposição do Modelo Atômico, como são inseridos os exercícios e atividades?

Envelhecimento Moral/Biológico: Trata de como um *saber*, que se encontra desatualizado, é modificado para atender as necessidades da sociedade (Moral) e

quando há a interferência da ciência para trazer uma nova roupagem ao saber (biológico).

IX (a). Ao longo da história o saber é reestruturado (modernizado) para atender a certas demandas sociais?

IX (b). Algum conceito relacionado ao Modelo Atômico é retirado ao longo das reformas?

No próximo capítulo são apresentados os dados arguidos, utilizando a metodologia de Análise de Conteúdo de Bardin (2010). Na primeira etapa desse capítulo se apresentam os dados de *leitura flutuante* e, na segunda parte, os dados da análise do *elementos da Transposição Didática* de Chevallard (1991).

CAPÍTULO 4 – RESULTADOS E DISCUSSÃO

Neste capítulo apresenta-se os dados coletados e analisados. Estes foram constituídos em duas etapas: a primeira, por uma *leitura flutuante* (pré-análise) e, a segunda, a partir de um roteiro desenvolvido com base nos *elementos da Transposição Didática* de Chevallard (1991). Com estas duas etapas, foi desenvolvida a discussão dos dados, organizada em 10 seções buscando compreender o movimento das *noosferas* responsáveis pela *Transposição Didática* do conteúdo Modelos Atômicos em LDQ no Brasil de 1931 a 2012. A seção a seguir apresenta a primeira etapa, a qual corresponde a *leitura flutuante* dos 55 LDQ.

4.1 PRÉ-ANÁLISE DOS LDQ DE 1931 A 2012

Nesta seção desenvolve-se uma pré-análise dos 55 LDQ, compreendendo quais PTA são mais citados, quais termos são mais relacionados aos Modelos Atômicos e a quantidade de imagens acerca do mesmo, que aparecem nos LDQ. Como resultado obteve-se 3 tabelas (apêndices 3, 4 e 5).

Dos 55 livros analisados (apêndice 3), os PTA mais citados foram: E. Rutherford (38), John Dalton (37), Niels Bohr (36) e J. J. Thomson (28). Pode-se compreender que os LDQ focam o desenvolvimento do conteúdo Modelo Atômico dentro da tradição inglesa de pesquisa, onde aqueles que mais apareceram nos LDQ são os que obtiveram maior êxito experimental, excluindo outros pesquisadores para a construção do *saber*.

Também desenvolveu-se um levantamento dos termos frequentemente relacionados com os Modelos Atômicos nos LDQ, organizados sobre a forma de uma segunda tabela (apêndice 4).

De acordo com a segunda tabela (apêndice 4), pode-se compreender que, ao longo da história, alguns livros utilizaram denominações para os modelos atômicos. De todos os 55 livros analisados, há 26 ocorrências para “sistema planetário”, 16

para “pudim de passas”, 7 para “bolinha maciça” e, apenas, 2 ocorrências do termo “panetone”. Desse modo, entende-se que os LDQ, ao decorrer das reformas, se utilizaram de denominações para os modelos atômicos. A do “sistema planetário” é a mais antiga e a que mais aparece, seguida do “pudim de passas” e da “bolinha maciça”.

Alguns LDQ, dos programas mais recentes, optaram por adaptar certas denominações do átomo, com a tentativa de tornar o *saber* mais próximo da realidade do aluno, como exemplo temos Mortimer e Machado (2006 e 2011) que substituíram a denominação “pudim de passas” por “panetone”. Porém, vale lembrar que o “panetone” é um produto que não é comum em nosso cotidiano, mas somente nas épocas festivas de natal. Isso pode gerar um obstáculo epistemológico⁴⁴ similar à analogia do “pudim de passas”, recordando que no fundamento do conceito de analogia é necessário que o leitor conheça uma das partes da relação e seja instruído a igualar algumas características. O que não acontece com a analogia do “pudim de passas” e do “panetone”.

Em relação ao uso de imagens nos LDQ, desenvolveu-se um levantamento formando uma terceira tabela (apêndice 5).

De acordo com a terceira tabela (apêndice 5), aparecem 424 ocorrências de imagens para outros modelos que não os dos PTA (essas imagens que são pertencentes as propostas posteriores a de Niels Bohr no domínio da física quântica) e foram localizadas 385 ocorrências para tradição inglesa divididas em: 136 para o Modelo Atômico de Bohr, 101 para o de Rutherford, 69 para o de Thomson e 79 para o de Dalton.

É possível depreender desses dados que no decorrer das diferentes épocas de publicação de LDQ no Brasil, há um aumento na utilização de recursos imagéticos para explicar e apresentar o Modelo Atômico e há um maior apelo visual quando trata-se dos modelos de Bohr, e Rutherford, ao contrário do de Dalton e Thomson. Uma hipótese para a ocorrência desse fenômeno pode estar relacionada com a evolução no padrão editorial, onde as técnicas privilegiaram o uso de imagens

⁴⁴ Obstáculo epistemológico é um termo destacado por Bachelar (1996) para designar dificultadores do estudante para compreensão de determinados conceitos científicos, são barreiras à formação do espírito científico.

e que se deu uma maior preocupação com a questão imagética em relação aos modelos atômicos.

Assim, os LDQ se tratando do levantamento dos PTA, do uso de termos para os Modelos Atômicos e de imagens apresentam certos padrões. Citam 4 PTA como principais: Dalton, Thomson, Rutherford e Bohr, trazem os termos “pudim de passas” e “sistema planetário”. E apresentam um gradual aumento do uso de imagens. Todos esses elementos, em conjunto, caracterizam uma tradição na *Transposição Didática* dos LDQ.

4.2 ANÁLISE DOS ELEMENTOS DA TRANSPOSIÇÃO DIDÁTICA

4.2.1 DESCONTEXTUALIZAÇÃO

O elemento *descontextualização* consiste na retirada de contexto de um determinado *saber sábio*, ao ser *transposto* no LDQ. Para analisá-lo, desenvolveram-se as seguintes questões:

I(a). O livro faz uma abordagem da história do processo de desenvolvimento dos Modelos Atômicos?

I(b). O livro faz alguma menção ao fato de que nem sempre o objeto de pesquisa dos PTA era o Modelo Atômico, mas que em alguns casos acabaram contribuindo para tal?

A questão I(a) teve como objetivo levantar como os LDQ apresentam a história do desenvolvimento dos Modelos Atômicos. Dos dados arguidos, gerou-se a seguinte tabela:

TABELA 1 – DADOS RELATIVOS À QUESTÃO I(a)

Período	Livro	Sim	Não	Citações dos PTA
F. Campos (1931 – 1941)	COUTO (1938)		X	2
	SILVA (1936)	X		6
	PIMENTA (1957)	X		3
G. Capanema (1942 – 1960)	PIMENTA (1958)	X		4
	CARVALHO E SAFFIOTI (1954)	X		2
	CBA (1964a)	X		2
LDBEN 4.024 (1961 – 1970)	CBA (1964b)		X	0
	FELTRE E SETSUO (1969)	X		1
	FELTRE E SETSUO (1970)	X		3
	POLITI E REIS	X		4

- 1987)	(1979)		
	FELTRE (1988)	X	3
Constituição Federal de 1988	PERUZZO E CANTO (1996)	X	4
	NEHMI (1995)	X	4
	NOVAIS (1997)	X	4
LDBEN 9.394 (1996)	UTIMURA E LINGUANOTO (1998)	X	4
	FELTRE (2008)	X	4
PNLEM 2008	SANTOS E MOL (2006)	X	4
	MORTIMER E	X	4
PNLD 2012	MACHADO(2010)		
	REIS (2010)	X	4
	Total	17	2

FONTE: O autor (2012)

Dos 19 LDQ analisados, 17 possuem abordagem histórica do processo de desenvolvimento dos Modelos Atômicos, enquanto 2 não. Todos os 17 livros que usam a história do Modelo Atômico são focados nos 4 pesquisadores da tradição inglesa (Dalton, Thomson, Rutherford e Bohr), porém, de maneiras distintas.

Pode-se afirmar que os 17 LDQ, ao longo da história, usaram diferentes formas para apresentar a história dos Modelos Atômicos. Os livros da Reforma Francisco Campo, Gustavo Capanema e LDBEN 4.024/61 desenvolveram um recorte histórico privilegiando John Dalton, Ernest Rutherford e Niels Bohr. J. J. Thomson, não aparece como pesquisador que desenvolveu o modelo atômico e sim como estudioso dos raios catódicos, descobridor do elétron. A única exceção a essa tradição inglesa encontra-se no livro de Silva (1936), que leva em conta H. Nagaoka e Nicholson, como desenvolvedores de modelos atômicos, além de J. Dalton, J. J. Thomson, E. Rutherford, N. Bohr. Os LDQ posteriores a LDBEN 5.692/71 apresentam essa história tendo J. Dalton, J. J. Thomson, E. Rutherford e N. Bohr como atores centrais no desenvolvimento dos Modelos Atômicos, com seus estudos e experimentos, citando alguns outros coadjuvantes.

É possível inferir desses dados que dentre esses 17 livros há padrões de escrita histórica que privilegiaram aqueles pesquisadores que tiveram êxito experimental, dentro de uma visão epistemológica de um paradigma empírico-indutivista. Aqueles pesquisadores que simplesmente “fracassaram” com suas propostas são esquecidos de todo o processo, pois ao final, dentro de uma visão empirista de ciência, somente interessou o êxito experimental. É como se aqueles

outros pesquisadores, que foram suprimidos, nada tivessem cotribuido para a construção da ciência.

Essa interpretação pode corroborar uma compreensão equivocada da natureza da ciência, pois dá a idéia de que somente o acerto é aceito na academia, enquanto o erro é inadmissível. A *transposição* feita nesses 17 LDQ *contextualizaram* a história do processo de desenvolvimento dos Modelos Atômicos, dentro da idéia empirico-indutivista, deixando somente os PTA que obtiveram dados experimentais expressivos e foram aceitos como referencial de pesquisas futuras. Nesse sentido, pode-se dizer, de acordo com Chevallard (1991), houve uma *descontextualização* seguida por uma *recontextualização* dessa história em um novo discurso, onde a “nova” história é tão bem editada, à partir da história total do *saber sábio*, que acaba sendo aceita pelo docente que está lecionando a disciplina. A seguir, apresenta-se alguns exemplos de como os 17 LDQ apresentam essa história:

Para sistematizar os exemplos, os 17 LDQ foram divididos em três grupos: (a) os que abordam os 4 pesquisadores como centrais no desenvolvimento dos modelos atômicos, (b) os que tornam alguns meros coadjuvantes na história do desenvolvimento dos Modelos Atômicos e (c) os que adicionam novos pesquisadores a essa história.

Os autores que fazem parte do grupo (a), que abordam os 4 pesquisadores (Dalton, Thomson, Rutherford e Bohr) como centrais no desenvolvimento dos modelos atômicos são: Peruzzo e Canto (1996), Nehmi (1995), Novais (1997), Utimura e Linguanoto (1998), Politi e Reis (1979), Feltre (2008), Reis (2010).

Politi e Reis (1979) entendem a história do Modelo Atômico como iniciada por John Dalton, que em 1803 construiu sua proposta. Em 1898 J. J. Thomson, baseado em experimentos sobre descargas elétricas em gases, desenvolveu seu modelo atômico que levou “em conta, pela primeira vez, a existência de cargas elétricas” (POLITI e REIS, 1979, p. 10). Após o desenvolvimento de Thomson, destaca-se E. Rutherford que, em 1911, criou o modelo planetário para o átomo, seguindo os resultados da “experiência de Rutherford” (POLITI e REIS, 1979, p. 11). O experimento consistia no bombardeamento de uma lâmina de ouro com elemento

radioativo. Os desvios sofridos pela partícula dariam uma idéia da disposição espacial do átomo. Em 1913, Niels Bohr aprofundou seu estudo no movimento dos elétrons, baseado nos estudos de Planck, corrigindo as falhas do modelo atômico de Rutherford.

Feltre (2008) explica a história do átomo através de um recorte diferente. Inicia pelos estudos de John Dalton, que desenvolveu sua “hipótese atômica” (FELTRE, 2008, p. 53), segundo a qual todo o tipo de matéria era formada por átomos indivisíveis e indestrutíveis. Em 1854, ocorreu o desenvolvimento do tubo de descargas por Heinrich Geissler, e em 1875, o desenvolvimento do tubo de raios catódicos por William Crookes. Esses dois aparelhos experimentais orientaram J. J. Thomson em seu estudo sobre o modelo atômico, no ano de 1903. Em 1911, E. Rutherford, através dos resultados de seu experimento, desenvolveu o modelo atômico com núcleo positivo e elétrons orbitando em sua volta, como um sistema solar. No ano de 1913, N. Bohr guiado pelos experimentos sobre ondas, espectroscopia e luz, desenvolveu explicações para o movimento dos elétrons no átomo de Rutherford, formando o modelo Rutherford-Bohr, com 5 postulados.

Para Reis (2010), no ano de 1803, John Dalton desenvolveu uma teoria sobre a estrutura da matéria, retomando noções dos antigos gregos. Após o desenvolvimento desse modelo, em 1897, J. J. Thomson guiado pelos experimentos de descargas elétricas em tubos de raios catódicos, desenvolveu seu modelo atômico. Anos mais tarde, em 1911, Rutherford com base nos resultados obtidos do “Experimento de Rutherford” (REIS, 2010, p. 199), propôs o modelo atômico planetário. No ano de 1913, Niels Bohr desenvolveu postulados para o movimento dos elétrons, baseado no modelo de Rutherford e nos estudos de física quântica e espectroscopia.

Os autores que fazem parte do grupo (b), usam os mesmos 4 pesquisadores do grupo (a), porém, tornam alguns meros coadjuvantes na história do desenvolvimento dos Modelos Atômicos. São eles: Pimenta (1957 e 1958), Carvalho e Saffioti (1954), Feltre e Setsuo (1969 e 1970) e Feltre (1988).

Pimenta (1957 e 1958) desenvolve a história dos modelos atômicos pelos estudos de John Dalton, lembrando que, antes dele, as idéias eram muito vagas e

sem base científica, considerando o átomo daltoniano como o primeiro modelo realmente científico:

Desde épocas remotas os cientistas se têm preocupado com os estudos relacionados com a constituição íntima da matéria. (...) É quase impossível fixar-se a data em que se tenham iniciado os estudos que vieram a desfazer a crença dessa velha química. Em 1808, o nome de JOHN DALTON apareceu ligado a teoria atômica (PIMENTA, 1957, p. 21).

Após apresentar John Dalton, Pimenta (1957 e 1958) cita outros pesquisadores que trabalharam no desenvolvimento de modelos atômicos: E. Rutherford e Niels Bohr. Suas propostas atômicas são denominadas, por Pimenta (1957 e 1958), como dinâmicas, por possuírem movimentação de cargas. J. J. Thomson aparece somente como responsável pela determinação dos valores de m/e e no cálculo das cargas do átomo, não desenvolvendo uma proposta de modelo atômico.

Os autores que fazem parte do grupo (c), adicionam novos pesquisadores a história do desenvolvimento atômico, além de citar os 4 PTA da tradição inglesa (Dalton, Thomson, Rutherford e Bohr). São: Silva (1936), CBA (1964a), Santos e Mol (2006) e Mortimer e Machado (2010).

Silva (1936) apresenta o trabalho de John Dalton com o desenvolvimento da teoria atômica, seguido dos estudos de raios catódicos e do Modelo Atômico de J. J. Thomson. Cita que, anos mais tarde, H. Geiger e Marsden, mostraram que o modelo de Thomson não explicava os desvios de partículas alfa, levando Rutherford a propor um modelo nuclear, baseado em H. Nagaoka. Niels Bohr concentra-se no estudo dos movimentos dos elétrons, supondo órbitas estáveis e que, posteriormente, desenvolve seu Modelo Atômico que previa muitas das características do modelo de Rutherford.

CBA (1964a) desenvolve um histórico através de Benjamin Franklin, com os seus estudos a cerca da eletricidade. Thomson aparece em 1897 provando que o elétron é carregado negativamente. Após estes trabalhos, aparece a menção a Willian Watson provando uma melhora na condução de eletricidade em gases com a

mudança de pressão. Junto a estes estudos, encontra-se os trabalhos de Julius Plucker, que provam a incandescência de partículas gasosas através da eletricidade. Em 1883, Thomas Edison é citado com seus estudos acerca da lâmpada incandescente. No ano de 1874, G. Johnstun Stoney sugere o nome de elétron para nomear as partículas emitidas pelos raios catódicos. Em 1909, Milikan provou que o elétron tem menor massa em detrimento a outras partículas. Becquerel, em 1896, descobriu que o Urânio emite partículas radioativas. E, junto a estes estudos, encontra-se a equipe de Rutherford (Geiger e Marsden) que elucida que cargas positivas ocupam o centro do átomo, concentrando toda sua massa.

Dentre os 2 LDQ, que não fazem um recorte histórico do desenvolvimento dos Modelos Atômicos, temos: Couto (1938) e CBA (1964b). Em Couto (1938) há a citação de dois PTA. Uma de Thomson, relacionando-o ao estudo dos raios catódicos, e outra de Dalton, ligada à teoria atômica. Em CBA (1964b) somente apresenta-se o modelo atômico “atual”. Talvez, devido ao fato de que o desenvolvimento histórico é abordado no primeiro livro, CBA (1964a), o qual fala da participação de distintos grupos de pesquisa (radioatividade e eletricidade).

A questão I(b) tem como objetivo levantar quais LDQ apresentam dados, em suas textualizações, que indicam a casualidade da contribuição dos PTA para o estudo sobre modelos atômicos, já que muitas vezes este não era o objetivo central da pesquisa, além de informar a área de pesquisa de cada um:

TABELA 2 – DADOS RELATIVOS À QUESTÃO I(b)

Período	Livro	Sim	Não	Em quais PTA?
F. Campos (1931 – 1941)	COUTO (1938)		X	
	SILVA (1936)		X	
	PIMENTA (1957)		X	
G. Capanema (1942 – 1960)	PIMENTA (1958)		X	
	CARVALHO E SAFFIOTI (1954)		X	
LDBEN 4.024/1961 (1961 – 1970)	CBA (1964a)		X	
	CBA (1964b)		X	
	FELTRE E SETSUO (1969)		X	
	FELTRE E SETSUO (1970)		X	
LDBEN 5.692 (1971 – 1987)	POLITI E REIS (1979)		X	
	FELTRE (1988)		X	
	PERUZZO E CANTO (1996)		X	
Constituição Federal de 1988	NEHMI (1995)		X	
	NOVAIS (1997)		X	
LDBEN 9.394/1996	UTIMURA E LINGUANOTO		X	

	(1998)		
PNLEM 2008	FELTRE (2008)		X
	SANTOS E MOL (2006)		X
	MORTIMER E		X
PNLD 2012	MACHADO(2010)		
	REIS (2010)	X	Dalton
	Total	1	18

FONTE: O autor (2012)

De acordo com os dados, dos 19 livros pesquisados, 18 não apresentam o objetivo de pesquisa ou problemática dos PTA, enquanto que somente 1 a apresenta para John Dalton.

Depreende-se que esses 18 LDQ *descontextualizam o saber a ensinar*, não se preocupando com as reais problemáticas de pesquisa desenvolvidas pelos PTA, dando a idéia de que a única problemática estudada durante suas vidas era os fenômenos acerca da constituição da matéria e formulação de Modelos Atômicos. Essa compreensão passa a idéia de ciência ideal e despida de interesses, onde pesquisa-se somente pela vontade de conhecer. O que sabemos, dentro de um paradigma da sociologia das ciências, que não é a realidade. A ciência é social e está sobre influência⁴⁵.

O único livro que traz a informação de forma clara sobre a área de pesquisa de um PTA, bem como seu foco de trabalho é o de Reis (2010), para John Dalton:

Embora a teoria atômica de Dalton tenha surgido em um momento histórico no qual era muito grande o volume de informações sobre as quantidades de substâncias envolvidas em reações químicas, a atenção de Dalton estava voltada para outra direção. Seu interesse original e permanente sempre foi a meteorologia, o ar atmosférico e os gases que a compõem. Foram esses estudos que o levaram a desenvolver sua teoria atômica (REIS, 2010, p. 118)

Este dado, dá a entender que os LDQ, através do PNLEM e do PNLD, estão procurando formas de quebrar uma visão estereotipada de ciência, começando a fazer uma modificação nessa *descontextualização*, focalizando mudanças, mesmo que pequenas, na *Transposição Didática*.

Entre os 18 livros que não apresentam a verdadeira área de atuação dos PTA, e sim somente as formas como eles chegaram ao seu Modelo Atômico, temos

⁴⁵ Fleck (2010, 1979), epistemólogo e sociólogo da ciência, entende que a ciência não é diferente de qualquer outra atividade coletiva e social e que pode ser influenciada por outras esferas menos especializadas da sociedade.

o de Couto (1938), Silva (1936), Pimenta (1957, 1958), Carvalho e Saffioti (1954), CBA (1964b), Feltre e Setsuo (1969 e 1970), Feltre (1988) e Nehmi (1995).

Assim, pode-se sintetizar como o elemento *descontextualização* opera no LDQ. Depreende-se, a partir da questão I(a) e II(a), que os LDQ podem construir uma idéia equivocada sobre a natureza e construção da ciência, figurando-se em um problema epistemológico, onde a história do Modelo Atômico é conduzida por apenas quatro pesquisadores dotados de um inteligência acima da média (gênios), que fizeram alguns poucos experimentos, desenvolvendo sem qualquer base teórica seus modelos, onde somente lhes interessava pesquisar a constituição do átomo.

Pode-se compreender que essa foi uma *recontextualização* operada pela *Transposição Didática* que teve pelo menos duas repercursões negativas para o ensino de ciências: a primeira foi tornar uma história linear, cumulativa, onde o erro não é permitido (paradigma empirico-indutivista). E segundo, para se adequar a um tempo didático, que em geral não é suficiente ensinar todo o projeto científico, forçando o desenvolvimento de recortes históricos nos livros, que passam uma visão distorcida e limitada da natureza da ciência. Possivelmente, por esta necessidade de recorte é que outros PTA, como Nicholson e Nagaoka, não foram citados na maioria dos LDQ analisados, somente na proposta de Silva (1936).

4.2.2 DESPERSONALIZAÇÃO

O elemento *despersonalização* procura investigar se o *saber a ensinar* é anônimo (não possui um criador) ou nominal (possui um criador). Com base nele, desenvolveu-se a seguinte questão:

II. Os PTA são apontados como “criadores” de determinado Modelo Atômico?

A questão II tem como objetivo fazer o levantamento de como os Modelos Atômicos são relacionados aos PTA. A partir desta elaborou-se a tabela 3:

TABELA 3 – DADOS RELATIVOS À QUESTÃO II

Período	Livro	Pesquisadores da Teoria Atômica					Nº de PTA citados
		Dalton	Thomson	Rutherford	Nicholson	Bohr	
F. Campos (1931 – 1941)	COUTO (1938)	X					1
	SILVA (1936)	X	X	X	X	X	5

G.	PIMENTA (1957)	X		X	X	3
Capanema (1942 – 1960)	PIMENTA (1958)	X	X	X	X	4
	CARVALHO E SAFFIOTI (1954)			X	X	2
			X	X		2
	CBA (1964a)					0
LDBEN 4.024 (1961 – 1970)	CBA (1964b)					1
	FELTRE E SETSUO (1969)	X				1
	FELTRE E SETSUO (1970)	X		X	X	3
LDBEN 5.692 (1971 – 1987)	POLITI E REIS (1979)	X	X	X	X	4
	FELTRE (1988)	X		X	X	3
Constituição Federal de 1988	PERUZZO E CANTO (1996)	X	X	X	X	4
	NEHMI (1995)	X	X	X	X	4
LDBEN 9.394 (1996)	NOVAIS (1997)	X	X	X	X	4
	UTIMURA E LINGUANOTO (1998)	X	X	X	X	4
	FELTRE (2008)	X	X	X	X	4
PNLEM 2008	SANTOS E MOL (2006)	X	X	X	X	4
	MORTIMER E MACHADO(2010)	X	X	X	X	4
PNLD 2012	REIS (2010)	X	X	X	X	4

FONTE: O autor (2012)

Dos 19 livros analisados, 10 relacionam 4 PTA com os seus respectivos modelos atômicos, 3 livros relacionam 3 PTA, 3 livros relacionam 1 PTA, 1 livro relaciona 2 PTA, 1 livro relaciona 5 PTA e 1 livro não faz nenhuma relação.

Observa-se que a partir da LDBEN 5.692 de 1971, todos os 10 LDQ analisados citam os mesmos PTA, trazendo o mesmo grau de personalização. Enquanto que os livros anteriores variam de abordagens, *despersonalizando* e *personalizando* o conteúdo de diferentes formas. Os quais são: Pimenta (1958), Politi e Reis (1979), Peruzzo e Canto (1996), Nehmi (1995), Novais (1997), Utimura e Linguanoto (1998), Feltre (2008), Santos e Mol (2006), Mortimer e Machado (2010) e Reis (2010).

Destaca-se, de todos os livros analisados, Silva (1936) que é o menos *despersonalizado*, pois possui 5 Modelos Atômicos, incluindo o modelo da astroquímica de Nicholson junto a menções a Nagaoka, até então inexistentes nos LDQ.

Pode-se depreender que a partir desses 10 LDQ que relacionam 4 PTA desenvolveu-se uma tradição de trazer a *personalização* do conteúdo Modelo Atômico. Onde se privilegia os pesquisadores da tradição inglesa que, ao longo da história, conseguiram uma grande repercussão dos seus achados experimentais. Essa abordagem, traz uma visão equivocada da ciência e dos seus pesquisadores. Há um esvaziamento, pois não são levados em conta outros grupos de pesquisadores, técnicos e outros atores que foram igualmente importantes na discussão de idéias, passando a visão de uma ciência hegemônica, sem embates e discussões teóricas, onde se reina a uniformidade de pensamento. Os LDQ não trazem a possibilidade de que, naquela época, outras pessoas pensavam diferente, fazendo com que a ciência progredisse, através da troca e debate de idéias, em grupos de pesquisa distintos.

A seguir, apresenta-se como ocorreu a distribuição dos 19 LDQ analisados. Dos 10 livros que apresentam 4 PTA em suas textualizações, todos relacionam Dalton, Bohr e Rutherford aos seus modelos atômicos. Dos 3 livros que citam 3 PTA temos: Pimenta (1957), Feltre e Setsuo (1970), Feltre (1988). As três obras relacionam Dalton, Rutherford e Bohr aos seus modelo atômicos. Um livro apresenta 2 PTA ligados aos seus modelos, Carvalho e Saffioti (1954), mencionando Rutherford e Bohr. Três livros trazem menção a 1 PTA. Couto (1938) e Feltre e Setsuo (1969) relacionam John Dalton, enquanto que o livro CBA (1964a) relaciona Rutherford com o modelo de átomo nuclear. Em CBA (1964a), Thomson é lembrado pelo estudo de cargas não fazendo referência direta a sua proposta de modelo atômico. O único livro que faz menção a 5 PTA é o de Silva (1936), que relaciona os modelos de Dalton, Thomson, Rutherford, Bohr e Nicholson. CBA (1964b) não relaciona nenhum PTA a um modelo atômico, pois trata de elucidar o modelo atômico chamado de atual.

Logo, o elemento *despersonalização* aparece quando se passa uma visão individualizada da ciência. De acordo com a questão II, ele está presente, ao longo de 19 obras, na atribuição dos Modelos Atômicos a somente alguns pesquisadores, retirando outros coadjuvantes de mesma importância no processo de desenvolvimento. O que dá uma visão distorcida da ciência, sua natureza e procedimentos, ficando mais evidente em 10 LDQ que reificam uma seleção de

pesquisadores que tiveram suas idéias mais aceitas pela comunidade científica, passando uma visão distorcida, simplificada e neutra da ciência.

4.2.3 RELAÇÃO ANTIGO/NOVO

O elemento *relação antigo/novo* se faz presente na articulação de saberes (antigos e novos) em um livro didático, de forma que o antigo não entre em conflito com o novo. Com base nele, desenvolveu-se a seguinte pergunta:

III. O livro desenvolve uma explicação sobre as limitações do Modelo Atômico anterior, a ponto de justificar a inserção de um novo modelo?

TABELA 4 – DADOS RELATIVOS À QUESTÃO III

Período	Livro	Sim	Não
F. Campos (1931 – 1941)	COUTO (1938)	X	
	SILVA (1936)	X	
G. Capanema (1942 – 1960)	PIMENTA (1957)		X
	PIMENTA (1958)	X	
	CARVALHO E SAFFIOTI (1954)	X	
LDBEN 4.024 (1961 – 1970)	CBA (1964a)		X
	CBA (1964b)		X
	FELTRE E SETSUO (1969)		X
	FELTRE E SETSUO (1970)	X	
LDBEN 5.692 (1971 – 1987)	POLITI E REIS (1979)		X
	FELTRE (1988)		X
Constituição Federal de 1988	PERUZZO E CANTO (1996)	X	
	NEHMI (1995)		X
LDBEN 9.394 (1996)	NOVAIS (1997)	X	
	UTIMURA E LINGUANOTO (1998)		X
PNLEM 2008	FELTRE (2008)	X	
	SANTOS E MOL (2006)	X	
PNLD 2012	MORTIMER E MACHADO(2010)	X	
	REIS (2010)	X	
	Total	11	8

FONTE: O autor (2012)

Com base nesta tabela, pode-se observar que 11 dos 19 livros explicam as limitações de um modelo atômico, enquanto 8 livros não o fazem, dando a idéia de simples sucessões de modelos, injustificadas.

Assim, de acordo com os 11 LDQ que apresentam as limitações dos modelos, pode-se depreender que essa necessidade tornou-se mais evidente após a implementação do PNLEM 2007 e PNLD 2012, como uma forma de normatizar o que é importante que o livro didático contenha. Pois, a inserção das limitações dá uma visão de ciência que se desenvolve através de rupturas e mudanças de

paradigmas⁴⁶. Essa característica é pertinente nos LDQ, pois traz a verdadeira intenção e motivação dos PTA no desenvolvimento dos Modelos Atômicos. Os 8 livros, que não possuem essas limitações, são anteriores a esses programas e dão uma visão de ciência linear e cumulativa, além de não se explicitar a necessidade de um novo modelo.

Pode-se sintetizar essa depreensão em duas partes: na primeira, a inserção das limitações era facultativa, existindo LDQ que se preocupavam com essa questão e outros que não. Com a implementação de uma política pública do livro didático destinado ao ensino público, de certa forma instituiu-se parâmetros para a escrita de LDQ, onde a inserção das limitações nos Modelos Atômico, parece se fixar como uma norma para que este seja aceito e distribuído nacionalmente. Esse aspecto é importante, pois dá indícios de uma ruptura com um paradigma de escrita de LDQ, tendo-se agora a preocupação em trazer as necessidades e motivações da ciência em avançar e desenvolver novas áreas e referências teóricas de pesquisa. A seguir apresentam-se exemplos de como essas limitações aparecem nos LDQ.

Os 11 LDQ que trazem algumas limitações dos Modelos Atômicos são: Couto (1970), Silva (1936), Pimenta (1958), Carvalho e Saffioti (1954), Feltre e Setsuo (1970), Peruzzo e Canto (1996), Novais (1997), Feltre (2008), Santos e Mol (2006), Mortimer e Machado (2011) e Reis (2010).

Como exemplo, podemos apresentar Silva (1936):

Este tipo de estrutura explica muitos fenômenos, mas entre outras dificuldades que fizeram abandoná-lo, a principal é que ele não explica como, bombardeando um gás ou folha metálica delgada pelos raios α conseguem-se libertar elétrons algumas vezes; outras ao contrário, sofrem desvios que H. Geiger e Marsden avaliaram até em 90° (SILVA, 1936, p. 84).

Silva (1936) trabalha a limitação do Modelo Atômico de Thomson, explicando a necessidade de um novo, o de Rutherford, através do experimento de Geiger e Marsden. Essa limitação está de acordo com o *saber sabio* presente nos artigos de Rutherford (1911), pois a idéia que se tinha do átomo antes do experimento de

⁴⁶ Os termos rupturas e paradigmas são desenvolvidos por Kuhn (1970, 2004), onde entende-se que rupturas são mudanças na tradição de pesquisa, onde o novo supera, substituindo, o antigo e paradigma é a teoria (visão) científica vigente naquele determinado momento histórico.

Geiger e Marsden era a visão de Thomson. Carvalho e Saffioti também trazem essa elucidação para a ruptura entre o modelo de Thomson e Rutherford:

Com base na trajetória das partículas α , Rutherford, demonstrou que o átomo é formado por um núcleo central, carregado de eletricidade positiva, envolvido por uma nuvem de elétrons (CARVALHO E SAFFIOTI, 1954, p. 175).

De acordo com Carvaho e Saffioti (1954), Rutherford, com base nas trajetórias das partículas alfa, entende que o átomo deve ser nuclear e não homogêneo, como era defendido por Thomson, o que está de acordo com os relatos dos documentos históricos:

Mal a teoria fora lançada, ela teve que vencer diversos obstáculos. Uma forte contradição apareceu imediatamente, em relação à trajetória e energia do elétron (FELTRE E SETSUO, 1970, p. 126).

Feltre e Setsuo (1970) apresentam uma outra limitação do modelo proposto por Rutherford, utilizando o princípio da “teoria clássica de Maxwell” (FELTRE E SETSUO, 1970, p. 126). Os autores até apresentam uma imagem que explica essa limitação frente à movimentação eletrônica:

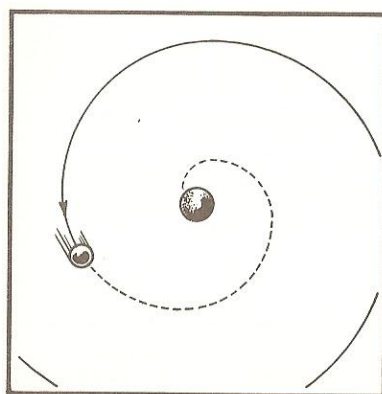


FIGURA18 – CONTRADIÇÃO DA TEORIA DE RUTHERFORD

FONTE: Feltre e Setsuo (1970)

Essa limitação é importante para a obra de Feltre e Setsuo, pois é a partir dela que se começa a desenvolver o aprimoramento do Modelo Atômico de Rutherford por Niels Bohr, culminando no “Modelo Atômico de Rutherford-Bohr” (FELTRE E SETSUO, 1970, p. 126).

Já Peruzzo e Canto (1996) explicam a limitação do modelo de Dalton e dos filósofos gregos para introduzir o modelo atômico de J. J. Thomson:

(...) Após esse feito, estava provado que um átomo não é indivisível como imaginavam os filósofos gregos ou como queria o modelo de Dalton (PERUZZO E CANTO, 1996, p. 43).

Peruzzo e Canto (1996) focam-se na questão do indivisível, firmada por Dalton, que é derrubada, posteriormente, através dos experimentos e suposições de J. J. Thomson, em seus artigos de 1897 e 1904.

Novais (1997) explica a ruptura e as limitações do modelo de Thomson frente ao de Rutherford:

Em 1911, E. Rutherford realizou uma série de experiências envolvendo radioatividade que serviram para *testar* o modelo de Thomson. Com suas experiências, Rutherford abandonou a hipótese de Thomson de que a distribuição de partículas positiva e negativa se dava de forma homogênea (NOVAIS, 1997, p. 81, grifos do autor).

Para Novais (1997), o modelo de Thomson mostrou seu limite no experimento de espalhamento de partículas α . Santos e Mol (2006) estudam essa mesma limitação, em seu livro, dando as mesmas explicações:

De acordo com o modelo atômico de Thomson, as deflexões seriam improváveis: sendo muito mais leves que as partículas alfa, os elétrons teriam dificuldade para desviar suas trajetórias quanto bolas de gude para desviar balas de canhão (...) Mas, para a surpresa de Rutherford, uma grande luminosidade continuou aparecendo do outro lado da lâmina de ouro, indicando que a radiação alfa havia atravessado sem a menor dificuldade. Além disso, ele observou o surgimento de uma pequena luminosidade em outras partes da chapa. Isso evidenciava que a trajetória de uma parte da radiação alfa era desviada por algo na lâmina de ouro (SANTOS E MOL, 2006, p. 144 – 145).

Já, Reis (2010) elucida as limitações do modelo de John Dalton frente ao de J. J. Thomson, para explicar a divisibilidade, a radioatividade e a natureza elétrica da matéria:

O modelo de Thomson explicou muitas propriedades da matéria que o modelo de Dalton não era capaz de explicar, como os fenômenos radioativos e os de natureza elétrica (REIS, 2010, p. 198).

Reis (2010) também traz uma explicação similar à de outras obras estudadas, para os limites do modelo atômico de J. J. Thomson frente ao de Rutherford, como destacado no trecho:

O máximo que se previa era que algumas partículas alfa sofreriam pequenos desvios em suas trajetórias, já que o átomo era uma esfera carregada positivamente com elétrons distribuídos uniformemente por todo seu volume (modelo de Thomson). (...) Interpretando os resultados de uma grande série de experimentos, a equipe de Rutherford chegou à conclusão de que o átomo realmente não se parecia com uma esfera positiva com elétrons incrustados (REIS, 2010, p. 199 – 200).

Os 8 livros restantes, que não trazem as limitações dos modelos, só os apresentam sem qualquer dado desta natureza.

Logo, pode-se entender que ao longo da história do LDQ existiu uma dicotomia entre a utilização das limitações, onde se podia optar por usá-las ou não. Porém, mais recentemente, com os PNLEM e PNLD, parece que a influência dos pesquisadores na área de ensino de ciências tem mudado essa visão, instituindo a necessidade de mostrar as limitações da ciência. O que se configurou num avanço nas *Transposições Didáticas* para o Modelo Atômico.

4.2.4 CRIAÇÕES DIDÁTICAS

O elemento *criações didáticas* tem como objetivo verificar se os LDQ possuem *objetos didáticos*, criados através da *Transposição Didática*, com o intuito de tornar o *saber a ensinar* melhor compreendido. Com base nesse elemento, elaborou-se a seguinte questão:

IV. O livro utiliza de criações didáticas para desenvolver a compreensão acerca do Modelo Atômico?

De acordo com a análise dos 19 LDQ, todos usam *criações didáticas* para explicar o conteúdo Modelo Atômico. Evidenciando a necessidade de facilitar sua compreensão pelos alunos, como será apresentado nos exemplos adiante.

O problema é que muitas vezes, essas *criações* usam aproximações com o cotidiano ou adicionam atributos aos Modelos Atômicos que podem resultar em obstáculos ao conhecimento.

Depreende-se que a utilização de *criações didáticas* mal formuladas pode acarretar alguns problemas a nível conceitual do aprendizado dos Modelos Atômicos, figurando-se em obstáculos epistemológicos à aprendizagem como: o desenvolvimento de uma visão distorcida dos mesmos no imaginário dos estudantes; atribuição de propriedades e características que não estão presentes na proposta original no *saber sábio*. Podendo dar a idéia de que o modelo é estático, quando na verdade ele é dinâmico, ou seja, suas partes (prótons, neutrões ou elétrons) estão em movimento desempenhando funções. Em outras palavras, as *criações* fazem com que o aluno receba um modelo pronto ao invés de participar de sua construção, sem o desenvolvimento de uma modelização adequada, figurando-se em um problema para a área de ensino de química. A seguir apresentam-se alguns exemplos de criações didáticas retiradas dos LDQ:

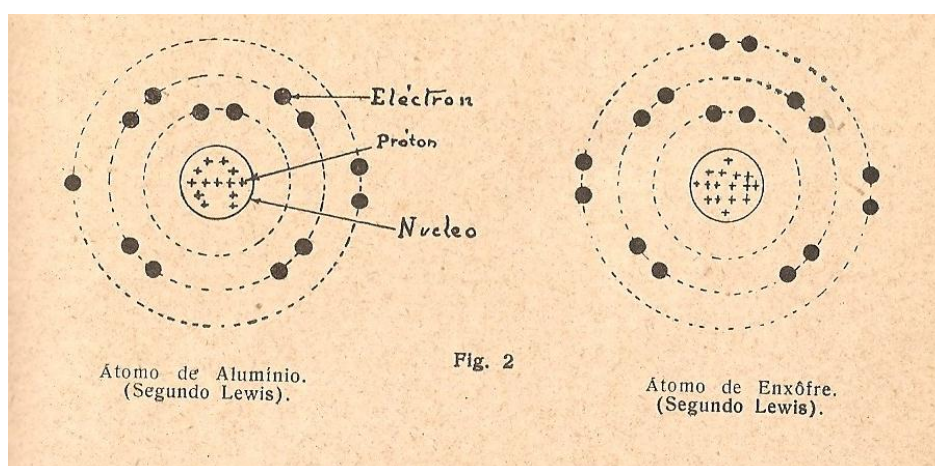


FIGURA 19 – MODELO ATÔMICO
 FONTE: Couto (1938)

Analisando a figura 19, observa-se uma *criação didática* para o átomo, que tem como objetivo explicar a organização atômica e a teoria de valência. Este tipo de *criação* é encontrada em todos os 19 LDQ analisados, remontando uma possível representação do átomo de Rutherford e Bohr. Uma informação importante no estudo do *saber sábio* dos Modelos Atômicos é que os pesquisadores desses modelos nunca representaram seus átomos sob tal forma, o que dá, assim, um aspecto de criação do autor do LDQ.

Uma outra *criação*, que pode ser observada, está presente no átomo de Thomson:

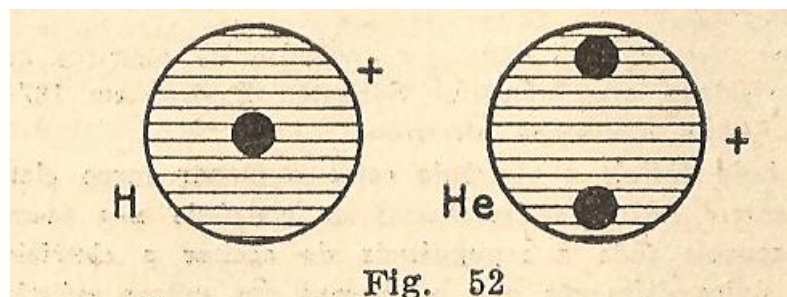


FIGURA 20 – ÁTOMO DE THOMSON PARA O HIDROGÊNIO E HÉLIO
 FONTE: Silva (1936)

Silva (1936) traz *criações didáticas* dos modelos atômicos para todos as propostas, menos a de John Dalton. A seguir, apresentam-se outras imagens do átomo de J. J. Thomson:

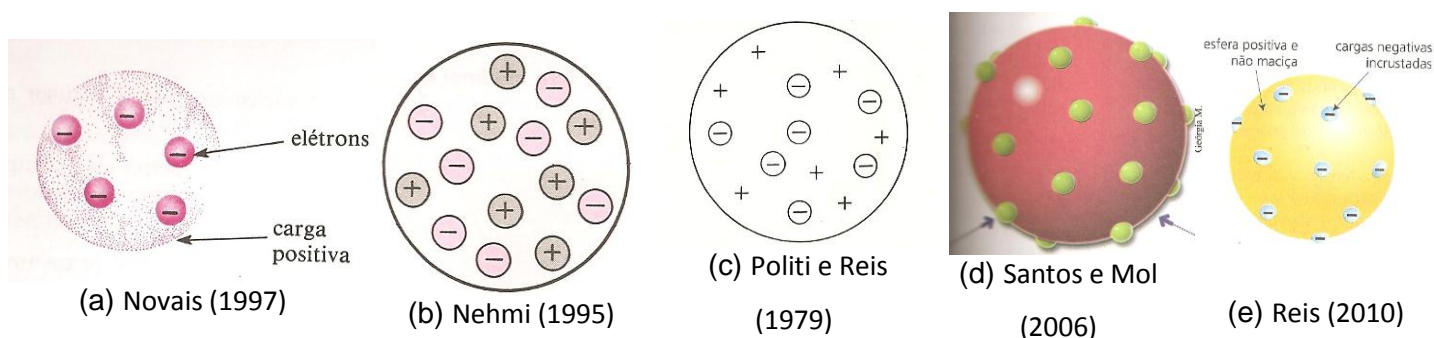


FIGURA 21 – REPRESENTAÇÕES DO ÁTOMO DE THOMSON
 FONTE: Modificado de Politi e Reis (1979), Nehmi (1995), Novais (1997), Santos e Mol (2006) e Reis (2010)

De acordo com a figura 21, percebe-se que os LDQ analisados usam a *criação didática* do átomo de Thomson, para explicar a estrutura e a disposição do mesmo, elucidando ao leitor o que seria esse átomo. Lembrando que essas representações estão equivocadas, baseando-se no *saber sábio*, pois inserem novas características ao modelo original de Thomson, podendo gerar distorções conceituais.

Para o modelo atômico de Rutherford encontram-se algumas *criações didáticas* voltadas à explicação dos experimentos de espalhamento de partículas alfa:

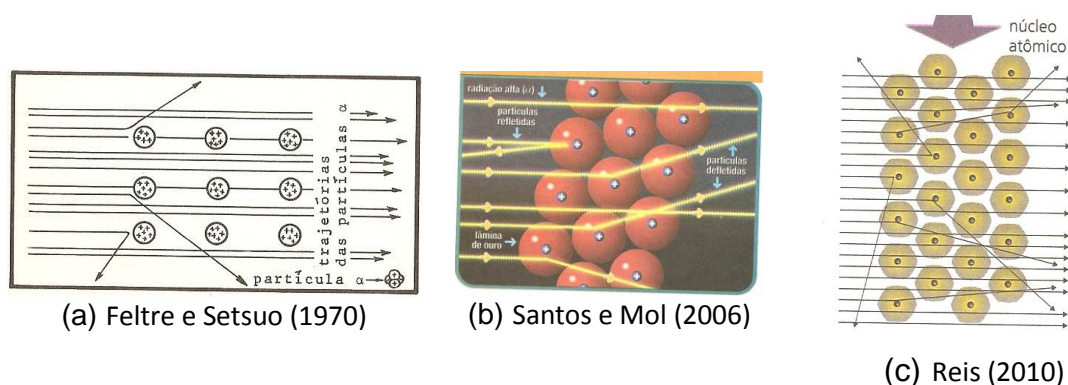


FIGURA 22 – REPRESENTAÇÃO DO EXPERIMENTO DE RUTHERFORD
 FONTE: Modificado de Feltre e Setsuo (1970), Santos e Mol (2006), Reis (2010)

Pode-se observar que as três imagens guardam a mesma função como *criação didática*. Buscam mostrar como Rutherford propôs a visão de átomo nuclear. Entendendo que estas representações elucidam o porque de Rutherford propor um modelo de átomo nuclear. Depreende-se que esta é uma representação positiva, pois ajuda o aluno a compreender o que levou Rutherford a propor um novo modelo. Há, também, *criações didáticas* para o modelo de Rutherford:

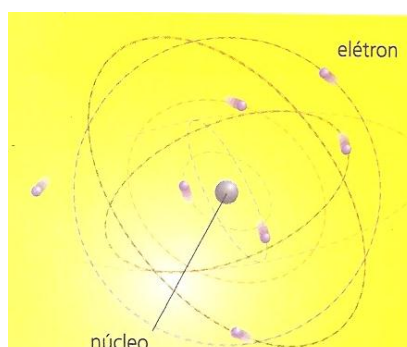


FIGURA 23 – IMAGEM DO ÁTOMO DE RUTHERFORD
 FONTE: Reis (2010)

Nesta *criação didática*, o átomo de Rutherford é representado como possuidor de um núcleo, envolto por elétrons, com o objetivo de explicar o fato experimental do espalhamento de partículas alfa pela lâmina de ouro. Outra relação, que é explorada por alguns LDQ no átomo de Rutherford, é a de extensão. O átomo é comparado a um estádio ou à uma grande distância, com o intuito de tornar mensurável o tamanho do centro para com a periferia deste, assim como na figura:



FIGURA 24 – ANALOGIA DO ÁTOMO COM UM ESTÁDIO DE FUTEBOL

FONTE: Santos e Mol (2006)

Carvalho e Saffioti (1954) trazem uma *criação didática* para o átomo de Niels Bohr:

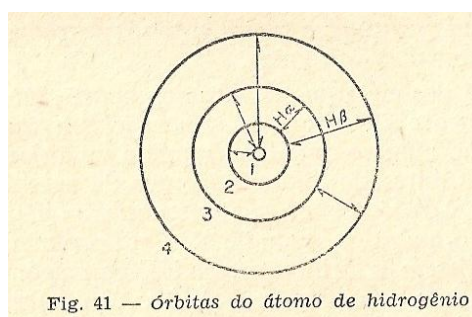


Fig. 41 — Órbitas do átomo de hidrogênio

FIGURA 25 – MODELO ATÔMICO DE BOHR PARA O HIDROGÊNIO

FONTE: Carvalho e Saffioti (1954)

Em Carvalho e Saffioti (1954), de acordo com a figura 25, pode-se observar este tipo de *criação didática* para o modelo atômico de Niels Bohr, onde representa-se os níveis energéticos para um átomo de hidrogênio com suas orbitas definidas.

Em Feltre e Setsuo (1970), há uma *criação didática* similar a da figura 26:

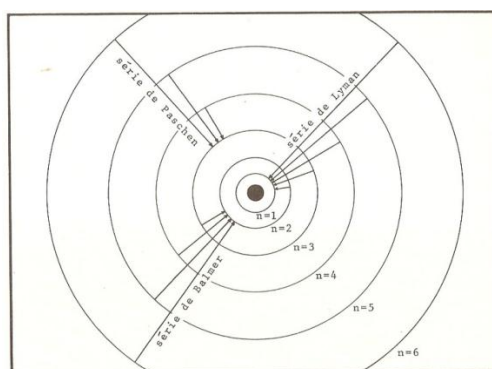


FIGURA 26 - REPRESENTAÇÃO DO ÁTOMO DE BOHR

FONTE: Feltre e Setsuo (1970)

A *criação didática*, representada nas figuras 25 e 26, tem como objetivo explicar a dinâmica de movimentação de elétrons, elucidada através dos postulados

de Niels Bohr. Feltre e Setsuo (1970) vão além para explicá-la usando outras *criações didáticas* associadas:

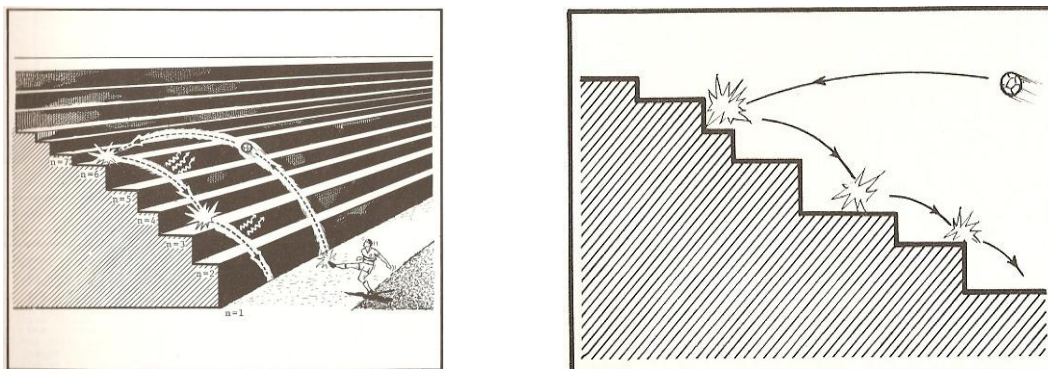


FIGURA 27 - EXPLICAÇÃO DO MOVIMENTO DE ELÉTRONS
 FONTE: MODIFICADO DE Feltre e Setsuo (1970)

Na figura 27, apresentam-se duas *criações didáticas* desenvolvidas por Feltre e Setsuo (1970) para explicar a dinâmica de movimentação do elétron. Os autores nomeiam essa criação de “exercício do craque”. Nessa *criação*, os autores usam a escadaria para representar os níveis de energia e a bola para representar o elétron, tendo como objetivo favorecer a compreensão dos níveis permitidos dos elétrons, um dos postulados de Niels Bohr.

Nehmi (1995) também traz uma *criação didática* para o modelo de Niels Bohr:

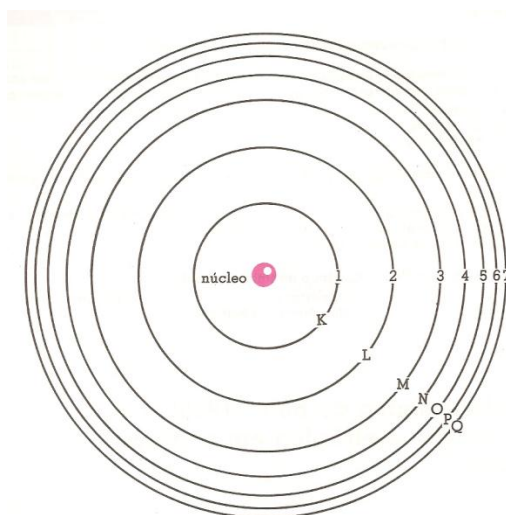


FIGURA 28 – ÁTOMO DE BOHR
 FONTE: Nehmi (1995)

Santos e Mol (2006) também trazem uma *criação didática* para o átomo de Bohr, similar a todos os LDQ analisados anteriormente:

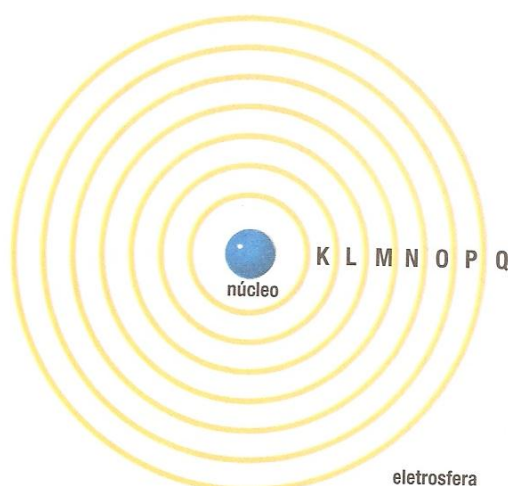


FIGURA 29 – IMAGEM DO ÁTOMO DE BOHR
 FONTE: Santos e Mol (2006)

Logo, entende-se que o elemento *criação didática* está presente em todos os 19 LDQ, para representar os Modelo Atômicos. De acordo com Chevallard (1991), essas criações podem vir a ajudar o aluno a compreender conceitos mais complexos, quando bem formuladas. O que não acontece em nenhum dos 19 LDQ analisados. Nestes, as *criações didáticas* são usadas como substitutas da explicação do Modelo Atômico, como se fossem uma cópia fiel do que se encontra no *saber sábio*, configurando-se em um obstáculo epistemológico no ensino, dando uma visão distorcida sobre sua constituição, atribuindo características que não fazem parte deles e gerando equívocos conceituais.

4.2.5 PUBLICIDADE DO SABER

O elemento *publicidade do saber* se faz presente quando o livro didático traz informações sobre a importância e a utilidade de um conteúdo. Para sua investigação, desenvolveu-se a seguinte pergunta:

V. Antes de introduzir um modelo atômico, o livro didático explica sua utilidade ou importância?

Com base na questão V, criou-se a seguinte tabela:

TABELA 5 – DADOS REFERENTES À QUESTÃO V

Período	Livro			Relaciona a textualização com uma problematização	Explica a forma de estudar o conteúdo	Faz outro tipo de relação
		Sim	Não			

F. Campos (1931 – 1941)	COUTO (1938)		X		
	SILVA (1936)	X			X
G. Capanema (1942 – 1960)	PIMENTA (1957)	X		X	
	PIMENTA (1958)	X		X	
	CARVALHO E SAFFIOTI (1954)		X		
LDBEN 4.024 (1961 – 1970)	CBA (1964a)	X		X	X
	CBA (1964b)	X			X
	FELTRE E SETSUO (1969)	X		X	
LDBEN 5.692 (1971 – 1987)	FELTRE E SETSUO (1970)	X		X	X
	POLITI E REIS (1979)	X		X	
	FELTRE (1988)	X		X	X
Constituição Federal de 1988	PERUZZO E CANTO (1996)	X		X	X
	NEHMI (1995)	X		X	
	NOVAIS (1997)	X		X	X
LDBEN 9.394 (1996)	UTIMURA E LINGUANOTO (1998)	X		X	X
	FELTRE (2008)	X		X	X
PNLEM 2008	SANTOS E MOL (2006)	X	X	X	
PNLD 2012	MORTIMER E MACHADO(2010)	X	X	X	
	REIS (2010)	X		X	X
	Total	17	2		

FONTE: O AUTOR (2012)

De acordo com a tabela 10, dos 19 LDQ analisados, 17 desenvolvem uma *publicidade do saber*, sob a forma de prefácio do livro, capítulo ou em inserções durante o texto, buscando explicitar ao leitor a utilidade de um determinado *saber* ou a forma como este será abordado ao decorrer da unidade.

Observa-se que estes 17 livros, ao longo das reformas educacionais, utilizaram a *publicidade do saber* para retomar certos conteúdos, sistematizar algum estudo e introduzir novos *saberes*. Depreende-se que este é um fator interessante, pois os LDQ não somente incluem os *saberes* dentro de uma organização, mas sim se preocupam em como inseri-lo aos seus leitores, dando explicações e possibilidades para seu estudo, apontando diretrizes para uso do *saber* Modelos Atômicos no ensino de química. A seguir, apresentam-se alguns exemplos dessa *publicidade*:

Silva (1936), no “prefácio da 1ª edição” e no “antelóquio à 1ª edição”, traz algumas motivações e explicações sobre a utilização e confecção de seu livro:

Ademais, ao professor cômico de seu papel de educador, surge outra dificuldade: em questões tão delicadas de filosofia, mais do que de ciências, qual será a verdadeira orientação filosófica católica? Que resposta dá a filosofia católica aos quesitos da ciência moderna? Foi precisamente este o primeiro motivo que nos induziu à publicação deste trabalho. Em forma simples e consisa foram expostas as doutrinas das várias escolas filosóficas sobre a constituição da matéria, seguidas das respectivas críticas, e enfim exposta mais abundantemente a doutrina verdadeira i. é o Hilemorfismo (SILVA, 1936, p. 7).

Na citação apresentada, Silva (1936) destaca uma das motivações para o desenvolvimento de seu livro, além de alguns apontamentos sobre a organização do conteúdo histórico-filosófico presente. Também, desenvolve uma orientação ao estudante sobre as seções do livro:

Sem nos coarctarmos às divisões e ordem dos programas oficiais, fomos expondo, com certa abundância a matéria Química Geral, de modo que este livro não venha a sofrer profundamente com as possíveis mudanças e ulteriores exigências dos programas. E por razão de clareza e método, usamos dois caracteres no corpo do livro: em tipo maior são exaradas as noções absolutamente necessária a todos, em corpo menor as elucidações mais amplas e outros conhecimentos para os que desejam ter uma noção mais completa da matéria (SILVA, 1936, p. 7).

Em Pimenta (1958), a *publicidade do saber* está presente quando se apresenta uma retomada dos estudos sobre matéria e átomo (1º ano), explicando a

necessidade deste estudo para a compreensão do conteúdo do capítulo 6, para o 3º ano:

Nos estudos que fizemos no primeiro ano do curso, tivemos oportunidade de mostrar as razões que levaram os estudiosos a pensar na divisibilidade da matéria. Vimos ainda algumas noções sobre a estrutura desta, a constituição dos átomos e rudimentos sobre a teoria de valência. Neste capítulo, daremos uma noção mais aprofundada sobre o assunto, principalmente no que se refere à distribuição dos elétrons na camada envolvente do átomo (PIMENTA, 1958, p. 93).

CBA (1964a), ao longo do capítulo 3, faz uma retomada dos estudos acerca de eletricidade feitos na seção 3-5, de forma a encadear estas idéias para a compreensão da natureza elétrica da matéria e do átomo:

Na seção 3-5 vimos que gases rarefeitos podem ser condutores de eletricidade. Vários detalhes deste processo de condução nos interessam particularmente quando tentamos formar uma imagem da natureza elétrica da matéria (CBA, 1964a, p. 38).

Feltre (1988), no início do capítulo 3, desenvolve uma retomada do modelo atômico de Dalton, como forma de encadear idéias para o desenvolvimento de novos modelos atômicos:

Vimos na página 14, o **modelo atômico de Dalton** como sendo uma “bolinha, extremamente pequena, maciça e indivisível”. No século passado, este modelo atômico explicou muitos fenômenos e, sem dúvida, fez a Química progredir bastante (FELTRE, 1988, p. 41, grifos do autor).

Utamura e Linguanoto (1998) trazem a *publicidade do saber* na introdução ao capítulo 3 sobre Modelos Atômicos, motivando o estudo deste *saber*:

Durante muito tempo, cientistas têm-se dedicado ao estudo da estrutura da matéria, criando modelos atômicos que vão sendo aperfeiçoados. Modelos são criados à medida que novos fatos coloquem em cheque o modelo anterior. Pelos conhecimentos atuais sabemos que a matéria é composta de átomos e estes, de partículas menores, os prótons, os

nêutrons e os elétrons que por sua vez são compostos por partículas menores, os quarks (UTIMURA E LINGUANOTO, 1998, p. 37).

Santos e Mol (2006) inserem a *publicidade do saber* ao longo do capítulo, como forma de desenvolver o espírito crítico do estudante, instigando-o com questionamentos:

Como foi possível observar, os modelos não correspondem à forma real dos objetos. Eles se aproximam dela à medida que são aperfeiçoados. Mas como reconhecemos se um modelo está próximo da realidade? (SANTOS E MOL, 2006, p. 137).

Reis (2010) utiliza a *publicidade do saber* como uma forma de introduzir e sistematizar o que será estudado no capítulo. Ou seja, a autora explica ao leitor o que e como será abordado no capítulo, ou seção em estudo:

Para evitar os raciocínios utilizados na alquimia, instituiu-se na Renascença (período que sucedeu a Idade Média) o método científico indutivo, segundo o qual a Ciência é construída a partir das etapas descritas abaixo. Os cientista que iremos estudar neste capítulo se basearam nesse método e o conhecimento que eles construíram também (REIS, 2010, p. 114).

Logo, pode-se entender, a partir da questão V, que os LDQ se valeram do elemento *publicidade do saber* com o objetivo de introduzir e adaptar o capítulo Modelos Atômicos. Outra hipótese é que esse elemento pode ter sido introduzido com um objetivo mercadológico de atrair professores e alunos, por meio de uma leitura agradável, diminuindo o trabalho docente na sistematização do estudo, mais do que por necessidade de explicitar a utilidade do *saber* no ensino de química.

4.2.6 FIDELIDADE NA TEXTUALIZAÇÃO DO SABER

O elemento *fidelidade na textualização do saber* tem como objetivo levantar a fidelidade na textualização do *saber a ensinar* nos LDQ, ou seja, o quão modificado foi um *saber* de sua proposta original por meio da *Transposição Didática*. A partir deste elemento, desenvolveu-se a seguinte questão:

VI. Qual o nível de fidelidade que o livro aborda, explicando métodos, técnicas e propostas para o Modelo Atômico?

Com base nesta questão, pode-se observar que, na abordagem dos Modelos Atômicos, todos os 19 livros analisados apresentam alguma modificação ou adaptação na passagem do *saber sábio* para o *saber a ensinar*.

Pode-se inferir, a partir da *fidelidade na textualização do saber*, que os Modelos Atômicos, geralmente, não são interpretados com total *fidelidade* ao *saber sábio* e que os LDQ não trazem informações suficientes para a sua total compreensão. Alguns exemplos que demonstram isso: os LDQ interpretam o modelo de Dalton como sendo uma esfera maciça. Outras características são suprimidas, dando uma visão limitada e equivocada. Em relação ao modelo de Thomson, os livros analisados trazem informações que não estão de acordo com o *saber sábio*, além de equívocos na nomenclatura das partículas negativas. Já o modelo de Rutherford é interpretado como um núcleo positivo rodeado de elétrons que o orbitam. Visão que não está totalmente de acordo com o *saber sábio* de Rutherford. E o modelo de Bohr foi retratado pelos LDQ com a apresentação, somente, dos 5 postulados, presente em seu terceiro artigo publicado em 1913, omitindo outras características do mesmo.

Assim, depreende-se que essa visão modificada e limitada dos Modelos Atômicos e procedimentos experimentais, passada pelos livros didáticos, é problemática e ao mesmo tempo necessária. Problemática, devido ao fato de dar uma visão equivocada da construção de cada um dos modelos, não se explicando certos fenômenos experimentais, configurando-se em obstáculos epistemológicos à aprendizagem. Necessária, pois o Modelo Atômico como apresentado no *saber sábio* é carregado de simbologia, cálculos matemáticos e linguagem, que somente os pesquisadores da área têm acesso, sendo necessária uma adaptação para seu uso no ensino de química. O grande problema é que as adaptações conduzidas nos 19 LDQ analisados, alteram o significado dos modelos, gerando distorções e compreensões errôneas de fenômenos químicos e físicos variados, podendo gerar obstáculos epistemológicos no aprendizado de outros *saberes*.

Outro ponto, que pode-se depreender, é que antes da chegada do livro CBA (1964a), os LDQ não apresentavam esquematizações do experimento de espalhamento de partículas α . Ou seja, é após a proposta de CBA (1964a) que

começam a surgir esquemas desse experimento que não tem nenhuma fidelidade com a proposta original de Geiger e Marsden (1909), descrita em seu artigo.

Os LDQ, frequentemente, interpretam os Modelos Atômicos de formas diferentes do que se apresenta no *saber sábio*, mostrando que não há muita *fidelidade na textualização do saber*.

4.2.6.1 O MODELO DE DALTON

Segundo os trabalhos apresentados por John Dalton (1808 e 1810) o seu modelo atômico poderia ser compreendido como uma esfera maciça, corpúsculo, rodeado por uma força que determina suas dinâmicas de atração e repulsão (afinidade e calórico) (anexo 1, 2, 3 e 4). Assim, o átomo daltoniano seria um corpúsculo indivisível rodeado por uma atmosfera de calórico que determina o estado de agregação da substância.

De acordo com essa interpretação do modelo de Dalton, todos os LDQ, ao realizarem a *Transposição Didática*, retiraram algumas de suas características, apresentando-o como uma esfera uniforme e maciça, que se junta a outras para formar moléculas e participar de reações químicas. Os exemplos, a seguir, ilustram adequadamente este fenômeno:

John Dalton, sugeriu a teoria atômica. Os seus pontos principais são: 1. A matéria é feita de pequenas partículas chamadas átomos. 2. Esses átomos são indivisíveis 3. Os átomos de um mesmo elemento tem o mesmo peso. 4. Os átomos de elementos diferentes tem pesos diferentes (COUTO, 1938, p.37).

No livro de Pimenta (1957):

Baseado no princípio de Avogrado-Ampère, Dalton admitiu a molécula como sendo constituída de partículas menores, denominadas átomos. Da união, resultariam as várias moléculas conhecidas. Dessa maneira, Dalton pôde explicar com base científica, as leis das combinações químicas, principalmente a das proporções fixas e proporções múltiplas (PIMENTA, 1957, p. 22).

Feltre e Setsuo (1970) também apresentam uma definição similar para o modelo atômico de Dalton:

De modo resumido, Dalton supôs que: a) Todo átomo é uma minúscula partícula material indestrutível, mantendo massa e dimensão inalteráveis. b) átomos do mesmo elemento químico são idênticos entre si. c) os diversos átomos podem combinar-se, originando diferentes espécies de matéria (FELTRE e SETSUO, 1970, p. 121).

Para Feltre e Setsuo (1970), a visão do átomo de Dalton é uma esfera maciça e indivisível, com propriedades constantes, onde átomos de um mesmo elemento químico são iguais e átomos de diferentes elementos são diferentes.

Em 1803, o cientista inglês John Dalton (1766 – 1844), baseado em resultados experimentais, enunciou a sua teoria atômica que pode ser assim resumida: a) a matéria é constituída por pequenas partículas chamadas **ÁTOMOS**. b) os átomos são considerados como esferas maciças, homogêneas, indivisíveis e indestrutíveis. c) átomos que possuem as mesmas propriedades são do mesmo tipo (POLITI e REIS, 1979, p. 10, grifos do autor).

Para Politi e Reis (1979), Dalton baseou seu modelo em dados experimentais, definindo uma regra para o seu funcionamento (átomos do mesmo elemento químico são iguais e de diferentes elementos químicos são diferentes), além de algumas características: esférico, maciço, homogêneo, indestrutível, indivisível. De certo modo, essa visão do átomo é parecida com a de outros livros:

O átomo é maciço e indivisível; moléculas de uma mesma substância são formadas pelo mesmo número de átomos dos mesmos elementos; nas transformações químicas, os átomos das moléculas separam-se e juntam-se formando moléculas (UTIMURA e LINGUANOTO, 1998, p. 38).

Para Utimura e Linguanoto (1998), o átomo também guarda as mesmas características anteriormente mencionadas, com a adição da explicação da formação de moléculas nas transformações químicas:

Para Dalton os átomos seriam partículas indivisíveis e indestrutíveis. Normalmente, utilizamos cores diferentes para representar átomos de elementos diferentes. (...) O **modelo de Dalton** baseava-se nas seguintes hipóteses: 1. A matéria é constituída de átomos, que são partículas indivisíveis e indestrutíveis. 2. Todos os átomos de um

elemento químico são idênticos em massa e propriedades. Os átomos de de diferentes elementos químicos são diferentes em massa e em propriedades. 3. As substâncias são formadas pela combinação de diferentes átomos na razão de números pequenos. 4. As reações químicas envolvem somente combinação, separação e rearranjo dos átomos, não havendo em seu curso nem a criação e destruição de átomos (SANTOS e MOL, 2006, p.139).

Santos e Mol (2006) trazem uma interpretação do átomo de Dalton em 5 regras, definindo o modelo como sendo de partículas indivisíveis, indestrutíveis, átomos de um mesmo elemento são iguais, substâncias são formadas pelas combinações de diferentes átomos e que reações químicas envolvem arranjo, união e separação de átomos. De certa maneira, o que é descrito pelos autores é parecido com que foi anteriormente trabalho em outros LDQ:

Postulados de Dalton. Utilizando seu modelo, Dalton estabeleceu os postulados a seguir: I. Todas as substâncias são constituídas de minúsculas partículas, denominadas átomos. Os átomos não podem ser criados nem destruídos. Cada substância é constituída de um único tipo de átomo. II. As substâncias simples, ou elementos, são formadas de “átomos simples” que são átomos isolados, pois átomos de um mesmo elemento químico sofrem repulsão mútua. Os “átomos simples” são **indivisíveis**. III. As substâncias compostas são formadas de “átomos compostos”, capazes de se decompor, durante as reações químicas, em “átomos simples”. IV. Todos os átomos de uma mesma substância são idênticos na forma, no tamanho, na massa e nas demais propriedades; átomos de substâncias diferentes possuem forma, tamanho, massa e propriedades diferentes. A massa de um “átomo composto” é igual à soma das massas de todos os “átomos simples” componentes. V. Os “átomos compostos” são constituídos de um pequeno número de “átomos simples”. Assim, por exemplo, duas substâncias simples, constituídas de “átomos simples” X e Y, podem formar substâncias compostas com “átomos compostos” de composição $X + Y$, ou $X + 2Y$ ou $2X + Y$ e assim por diante (REIS, 2010, p. 117).

Reis (2010), de todos os livros analisados, é o único que entende as regras para o átomo de Dalton como postulados. De forma geral, sua interpretação do átomo daltoniano é a mesma dos autores anteriores. O que muda é a denominação de “átomos simples” que seria o átomo do elemento químico puro e “átomos compostos” resultantes da união e do arranjo de mais de um átomo em uma reação química. Outro ponto destacado é a inserção da noção de atração e repulsão, porém não aprofundada no texto.

Pode-se observar, através destes exemplos, que a noção do átomo de Dalton (*saber sábio*) ao ser transposto para os LDQ (*saber a ensinar*) não sofreu severas modificações. Ou seja, manteve-se uma mesma idéia de que o átomo é uma partícula esférica, maciça, indivisível, onde cada átomo de elemento químico é diferente e que se une para formar moléculas e demais substâncias. No entanto, nota-se que uma característica desse Modelo Atômico foi deixada de lado pelos 19 LDQ analisados, exceto por Reis (2010). Estes não mencionam as duas forças opostas presentes no átomo de Dalton (1808 e 1810), a de repulsão e a de coesão. Dessa forma, o átomo daltoniano é simplificado pelos livros didáticos na realização da *Transposição Didática*.

4.2.6.2 O MODELO DE THOMSON

Thomson (1904) faz uma leitura de seu modelo atômico, explicando algumas de suas disposições e características:

Temos portanto em primeiro lugar uma esfera uniforme de eletrificação positiva, e dentro desta esfera há um número de corpúsculos arranjados em uma série de anéis paralelos, o número dos corpúsculos em um anel varia de anel para anel: cada corpúsculo está viajando a uma grande velocidade em volta da circunferência do anel que está situado, e os anéis são arranjados de forma que se contenha uma grande quantidade de corpúsculos perto da superfície da esfera, enquanto há um número menor de corpúsculos mais adentro (THOMSON, 1904, p. 255, tradução nossa).

Com base nessa explicação dada por Thomson (1904), pode-se compreender que o seu átomo seria formado por uma esfera de carga positiva uniforme, que em seu interior tem disperso corpúsculos que carregam carga negativa, dispostos em anéis concêntricos que giram em alta velocidade.

Assim, dos 19 livros analisados, 12 apresentam textualizações sobre o Modelo Atômico de Thomson. Silva (1936) apresenta uma leitura deste modelo:

O átomo é uma esfera, de densidade uniforme, de carga positiva, de dimensões normais (raio 10^{-10} m) e no interior do qual se acham os elétrons dispostos no mesmo plano, se não são em número maior que 5, ou em planos diferentes, repelindo-se mutuamente (porque elétrons negativos) e atraídos pelo centro (que é eletropositivo), e sob a ação de duas forças se mantêm em equilíbrio (SILVA, 1936, p.84).

Silva (1936) é o único autor que apresenta Thomson como proponente de um Modelo Atômico, de todos os LDQ analisados das reformas Francisco Campos, Gustavo Capanema e LDBEN 4.024/61. Na sua *transposição*, considera-se certas características levantadas por Thomson (1904), como: a esfera de carga positiva, os elétrons dispostos em planos iguais ou diferentes e as dinâmicas de repulsão que mantêm o sistema estável. Porém, não há menção aos movimentos desenvolvidos no modelo atômico. E, ainda, Silva (1936) não usa a mesma terminologia que Thomson (1904), referindo-se às partículas no interior do átomo como “corpúsculos que carregam carga negativa”. Politi e Reis (1979) também trazem uma forma de transpor o átomo de Thomson:

O modelo atômico desenvolvido por Joseph J. Thomson (1865 – 1940) é baseado em experiências realizadas sobre descargas elétricas em gases, levando-se em conta, pela primeira vez, a existência das cargas elétricas. Foi chamado “**modelo pudim de passas**”. Segundo Thomson, o átomo seria formado por matéria positiva e partículas negativas distribuídas ao acaso. As cargas elétricas devem se compensar para que o conjunto seja eletricamente neutro (POLITI e REIS, 1979, p. 11).

Na *transposição* de Politi e Reis (1979), elucida-se uma versão do modelo de Thomson. Apresentando-o com certas características modificadas. Segundo os autores, esse modelo é formado por uma matéria positiva e partículas negativas. Também, atribuem a metáfora *pudim de passas* para esse modelo, que não é desenvolvida no *saber sábio*. A sua descrição é fiel para com algumas características de forma e distribuição do modelo, estando de acordo com a versão original do *saber sábio* de Thomson (1904). Porém, outras características não são evidenciadas no *saber a ensinar*, como a nomenclatura *corpúsculo*, adotada para definir corpos que carregam carga negativa e os movimentos do átomo. Assim, esse modelo retira características do *saber sábio* e incorpora novas características na sua *Transposição Didática*.

J. J. Thomson quem o propôs. O átomo, segundo ele, seria formado por uma esfera de carga elétrica positiva, possuindo, em sua superfície, elétrons incrustados. Assim, a carga elétrica total de um átomo seria nula, pois a carga negativa dos elétrons compensaria a carga positiva da esfera que o contém. Esse modelo é conhecido como “pudim de passas” (PERUZZO e CANTO, 1996, p. 43).

A *transposição* desenvolvida por Peruzzo e Canto (1996) possui certas características que necessitam ser analisadas: a primeira, que esse átomo seria formado por uma esfera positiva, está coerente com o *saber sábio* presente na obra de Thomson (1904). A segunda, é a neutralidade do átomo pela compensação de cargas, que também se encontra coerente com a proposta do *saber sábio* de Thomson. A terceira, é o uso do termo elétron para designar cargas negativas. No artigo de Thomson (1904) não há menção a esse termo. No seu lugar, temos o corpúsculo, que carrega carga negativa. A quarta e última, é a analogia do “pudim de passas”, que não foi elaborada por Thomson, em seu artigo publicado em 1904.

Outro exemplo de *Transposição Didática* do Modelo Atômico de Thomson está em Novais (1997):

Thomson, baseado em suas pesquisas, propôs em 1898 um primeiro modelo mais detalhado do átomo. Ele supôs que o átomo fosse uma esfera de cargas positivas, na qual os elétrons estivessem espalhados como se fossem passas num pudim. A maior parte da massa do átomo estaria na esfera positiva, já que as partículas negativas têm uma massa muito pequena. Segundo Thomson, a densidade do átomo seria uniforme, isto é, a massa seria igualmente distribuída por todo o volume. O átomo como um todo seria neutro, porque: carga total positiva + carga total negativa = 0 (NOVAIS, 1997, p. 81).

De acordo com Novais (1997), o átomo de Thomson pode ser encarado como uma esfera de carga positiva com cargas negativas em seu interior, tendo carga e peso uniformemente distribuídos sobre a esfera positiva. Esta descrição guarda uma fidelidade com a proposta de Thomson (1904). Porém, quando Novais (1997) usa a analogia de *passas em um pudim*, é adicionado um elemento que não faz parte deste modelo no *saber sábio*. Outro ponto, que se pode destacar, é que Thomson não se preocupou, nesse modelo, em explicar onde estaria sua massa, já que ele seria formado por uma esfera positiva com corpúsculos que carregam cargas negativas.

Para explicar os fenômenos anteriores, Joseph John Thomson propôs, em 1903, um novo modelo de átomo, formado por uma “pasta” positiva “recheada” pelos elétrons de carga negativa, o que garantia a neutralidade elétrica do modelo atômico (esse modelo ficou conhecido como “pudim de passas”). Começava-se, então, a admitir oficialmente a

divisibilidade do átomo e a reconhecer a **natureza elétrica da matéria** (FELTRE, 2008, p.).

Feltre (2008) aborda uma outra forma de *transpor* o átomo de Thomson, porém os mesmos elementos que tiram a *fidelidade* desse modelo são apresentados: primeiro é a “pasta” positiva que está “recheada” de elétrons. Estes termos fogem a definição dada por Thomson em seu artigo de 1904. O termo elétron, como usado por Feltre (2008), está mal empregado, devido ao fato de que Thomson compreendia que o átomo era formado de *corpúsculos* com carga negativa em seu interior. E a analogia, presente em Feltre (2008), do “pudim de passas” que não faz parte do *saber sábio*. Mas, há dois pontos positivos nessa *transposição*. Feltre (2008) leva em conta que Thomson foi o PTA que definiu a divisibilidade do átomo e deu caráter elétrico ao Modelo Atômico, permitindo a aplicabilidade de novos problemas de natureza eletrodinâmica.

Thomson propôs seu modelo atômico: O átomo é uma esfera de carga elétrica positiva, não maciça, incrustada de elétrons (negativos), de modo que sua carga elétrica total é nula (REIS, 2010, p. 198).

Reis (2010) é mais direta em sua definição do Modelo Atômico de Thomson, firmando-o como uma esfera de carga positiva, não maciça. Até este ponto, há uma *fidelidade* com a proposta de Thomson (1904). Porém, Reis (2010) equivoca-se em dois aspectos: primeiro, o uso equivocado do termo elétron, já que Thomson usava uma outra denominação a essas cargas negativas (*corpúsculos*). Segundo, é a idéia de que os elétrons estão “incrustados” no átomo. Aqui há um mau uso da palavra, pois pode-se passar uma visão equivocada do modelo, onde as cargas negativas estariam somente na superfície do modelo de Thomson e não no interior, como defende o próprio Thomson (1904), em seu artigo.

Nehmi (1995) apresenta uma outra *Transposição Didática* para o modelo de Thomson, diferente das anteriormente citadas:

O inglês Thomson descobriu, experimentalmente, que, no interior do átomo, ocorrem partículas eletrizadas positivamente, às quais deu o nome de *prótons*, e partículas eletrizadas negativamente, às quais deu o nome de *elétrons*. Pelo fato de o átomo (e a matéria) ser eletricamente

neutro, concluímos que o número de prótons e de elétrons deve ser o mesmo, a fim de se neutralizarem (NEHMI, 1995, p. 54).

De acordo com esta citação, o átomo seria formado por dois tipos de partículas, prótons e elétrons, que estão em equilíbrio em seu interior. Esta relação, desenvolvida por Nehmi (1995), foge quase completamente da proposta de Thomson (1904), no *saber sábio*, na forma do átomo, na disposição de partículas e na utilização dos termos. Ou seja, este modelo apresentado por Nehmi (1995) está totalmente modificado e não mais representa de forma *fidel* o modelo de Thomson.

Utamura e Linguanoto (1998) apresentam uma *transposição* do Modelo Atômico de Thomson, inadequada de acordo com o que foi proposto por Thomson (1904), no *saber sábio*:

Nele o átomo é maciço, formado de massa positiva impregnada de partículas negativas, os elétrons (UTIMURA E LINGUANOTO, 1998, p. 38).

Esta inadequação pode ser compreendida em três aspectos: 1) o átomo, como apresentado por Utamura e Linguanoto (1998), é maciço ao invés de “permeável”, como colocado por Thomson. 2) o átomo é formado por uma “massa positiva”, de acordo com os autores, mas segundo Thomson, uma esfera de carga positiva uniforme (THOMSON, 1904). 3) Thomson entende que no interior da esfera positiva estariam *corpúsculos* negativos desenvolvendo movimentos e não “elétrons impregnados”, como defende Utamura e Linguanoto (1998).

Outra proposta para o modelo de Thomson, apresenta-se no livro de Mortimer e Machado (2011). Segundo os autores, Thomson recupera o modelo de Lorde Kelvin para montar sua proposta. Essa informação está de certa forma fidedigna com o *saber sábio*, lembrando que em determinada parte de sua carreira acadêmica, Thomson trabalhou com o modelo de girostatos de Kelvin, de acordo com Lopes (2009). Porém, a *transposição* de Mortimer e Machado (2011) traz a idéia de elétrons inscrustados na esfera de carga positiva e a metáfora do “pudim de passas”, que foge a proposta original do *saber sábio*:

Thomson recuperou o modelo proposto por Lorde Kelvin, em que as partículas com carga negativa, denominadas elétrons, se encontravam incrustadas numa esfera de carga positiva. Thomson propôs, como imagem para seu modelo, um pudim de passas, sobremesa típica do natal inglês, à época. Preferimos aqui utilizar a imagem do panetone. Nessa analogia, a massa do panetone corresponderia aquilo que Thomson descreveu como a esfera contendo a carga positiva uniformemente distribuída. As passas seriam os elétrons incrustados nessa esfera. **principais características do modelo de Thomson.** Os átomos são esféricos e o volume total do átomo é igual ao volume da esfera. A carga positiva está uniformemente distribuída na esfera. Os elétrons se movem nessa esfera sob o efeito de forças eletrostáticas (MORTIMER e MACHADO, 2011, p. 148).

Um ponto positivo da *Transposição Didática* de Mortimer e Machado (2011) é a utilização do “panetone” como analogia, já que ele faz parte da realidade brasileira. Outro ponto é o fato dos autores destacarem que os elétrons estão em movimento sob o efeito de forças, conferindo a idéia de dinâmica do modelo, não presente nas *transposições didáticas* anteriores.

4.2.6.3 O MODELO DE RUTHERFORD

Rutherford (1911), em seu artigo, faz uma interpretação de como poderia ser a disposição de partículas no átomo de acordo com os dados experimentais obtidos por Geiger e Marsden, como se apresenta:

Considero que o átomo contém uma carga +- Ne no seu centro rodeado por uma esfera de eletrificação contendo carga -+Ne supostamente uniformemente distribuída em toda uma esfera de raio R (RUTHERFORD, 1911, p. 671, tradução nossa).

Nesse sentido, o modelo atômico de Rutherford seria uma variação do modelo de Thomson, onde muda-se a disposição interna de cargas com a inserção de um pequeno núcleo e com essa modificação se torna possível explicar os resultados obtidos por Geiger, Marsden e Royds, na série de experimentos conduzidos pela equipe no laboratório Cavendish.

Dessa forma, dos 19 LDQ analisados, 18 apresentam uma textualização acerca dele. E grande parte dos livros analisados trazem uma visão comum deste modelo:

Rutherford procurou evitar esta dificuldade e aproveitando uma hipótese anterior de Nagaoka apresenta seu átomo como um sistema planetário, em que os elétrons gravitam ao redor de um centro material, pesado, dito núcleo, de carga positiva, de dimensões de ordem $1,8 \times 10^{-13}$ cm;

fazendo alguns bilhões de rotações por segundo, a uma distância do núcleo de 10 a 10 mil vezes o diâmetro do núcleo. O núcleo constitui a massa pesada do átomo (SILVA, 1936, p.85).

De acordo com a textualização de Silva (1936), o átomo é dotado de uma região central e positiva denominada núcleo, com uma outra região vazia com cargas negativas. A analogia reforçada é a de que o átomo seria semelhante a um “sistema planetário”. Essa visão de átomo foge a proposta adotada por Rutherford (1911), pois o mesmo não relaciona cargas as regiões do átomo, na verdade, somente usa a idéia de núcleo para explicar os experimentos de espalhamento de partículas alfa. Em outras palavras, essa proposta traz elementos não elucidados por Rutherford em seu artigo de 1911. Vale lembrar que as *transposições* do modelo de Rutherford não mudam nos livros. Somente há o acréscimo de informações, como apresentado em Santos e Mol (2006):

Rutherford então idealizou um outro modelo. Para ele, os espaços por onde passavam as partículas alfa eram ocupados pelos elétrons dos átomos, e a região que oferecia resistência à passagem das partículas seria constituída pela carga positiva do átomo (...) Segundo esse modelo, o átomo tem duas regiões: uma central, denominada **núcleo**, constituída por partículas carregadas positivamente, camadas **prótons**, e por partículas sem carga, denominadas **nêutrons**, que dariam estabilidade ao acúmulo de cargas positivas; e outra região ao redor da central, a **eletrosfera**, constituída por **elétrons**. Esse modelo ficou conhecido como modelo atômico de Rutherford (SANTOS e MOL, 2006, p. 145).

Santos e Mol (2006), além de apresentar as mesmas características anteriormente descritas, trazem a presença do neutron. Lembrando que a partícula neutron só foi elucidada por Chadwick e Rutherford, posteriormente a 1911, de acordo com Lopes (2009). Assim, formando mais um equívoco de *transposição*, destoando da proposta de Rutherford (1911), como apresentado no *saber sábio*.

4.2.6.4 O MODELO DE BOHR

Para Bohr (1913) o átomo teria a estrutura como elucidada por Rutherford, se preocupando em determinar qual a dinâmica de movimento dos elétrons ao redor de um núcleo:

1. Que a energia radiada não é emitida (ou absorvida) da maneira contínua admitida pela eletrodinâmica clássica, por apenas durante a passagem dos sistemas de um estado “estacionário” para outro

diferente. **2.** Que o equilíbrio dinâmico dos sistemas nos estados estacionários é governado pelas leis da mecânica clássica, não se verificando estas leis nas transições dos sistemas entre diferentes estados estacionários. **3.** Que é homogênea a radiação emitida durante a transição de um sistema de um estado estacionário para outro, e que a relação entre a frequência ν e a quantidade total de energia emitida é dada por $E=h\nu$, sendo h a constante de Planck. **4.** Que os diferentes estados estacionários de um sistema simples constituído por um elétron que roda em volta de um núcleo positivo são determinados pela condição de ser igual a um múltiplo inteiro de $h/2$ a razão entre a energia total emitida durante a formação da configuração e a frequência de revolução do elétron. Admitindo que a órbita do elétron é circular, esta hipótese equivale a supor que o momento angular do elétron em torno do núcleo é igual a um múltiplo inteiro de $h/2\pi$. **5.** Que o estado “permanente” de um sistema atômico – isto é, o estado no qual a energia emitida é máxima – é determinado pela condição de ser igual a $h/2\pi$ o momento angular de cada elétron em torno do centro de sua órbita (BOHR, 1913, p. 196, grifos nossos, tradução nossa).

Assim, pode-se entender que Bohr não elucidou um modelo atômico, mas parte da pressuposição de que o modelo proposto por Rutherford explica melhor certas dinâmicas atômicas, focando-se na movimentação de elétrons, através dos cinco postulados como enunciado.

O modelo de Bohr, de acordo com Silva (1936), apresenta-se sob uma forma mais simplificada:

No átomo de Rutherford os elétrons enquanto giram a órbita estável no emitem energia, mais só quando passam de uma órbita a outra de maior raio e assim podem dar espectros e raias perfeitamente monocromáticas e por terem camadas distintas podem dar também raias distintas e características (SILVA, 1936, p.86).

Em Mortimer e Machado (2011), o modelo de Bohr é apresentado sob a forma de postulados, maneira mais recorrentemente usada pelos LDQ:

Postulados de Bohr. 1. Um elétron, em um átomo, se move em uma órbita circular estável em torno do núcleo sob influência da atração coulombiana entre o elétron e o núcleo. Esse movimento está de acordo com as leis da mecânica clássica. 2. No lugar de um número infinito de órbitas possíveis, como previsto pela mecânica clássica, o elétron só pode se mover em órbitas determinadas, que podem ser associadas a números inteiros. Essas órbitas privilegiadas são chamadas de estados estacionários. 3. Um elétron que se move em um desses estados estacionários não emite radiação eletromagnética, apesar de estar constantemente acelerado. Sua energia total, portanto, permanece constante. 4. Quando um elétron muda de uma órbita ou estado estacionário de energia total E_i para uma outra, de energia total E_f , menor do que E_i , emite radiação eletromagnética. A radiação emitida tem

frequência igual à diferença de energia das órbitas ($E_i - E_f$) dividida por uma constante, conhecida como constante de Planck (h) (MORTIMER e MACHADO, 2011, p.167).

Feltre e Setsuo (1970) apresentam esse modelo de forma mais aprofundada usando algumas relações matemáticas e fórmulas:

Em simples palavras, os postulados de Bohr são: a) “Os elétrons giram em redor do núcleo em órbitas circulares bem definidas e, espontaneamente, ao fazê-lo, eles não irradiam energia.” b) “Quando um elétron passa de uma órbita para outra, ele emite ou absorve, determinada energia dada pela expressão: $\Delta E = h \cdot f$, sendo: h – constante de Planck = $6,6 \times 10^{-27}$ erg x seg. f – frequência da radiação absorvida ou emitida. A energia “*absorvida ou emitida por um elétron*” é sempre de “um fóton” (FELTRE e SETSUO, 1970, p.126).

Depreende-se que os LDQ desenvolvem o Modelo Atômico de Niels Bohr, porém não de forma totalmente *fiel* com o *saber sábio* apresentado nos três artigos de 1913 do pesquisador. Nas diferentes formas de *transposição*, são trabalhadas as idéias de órbitas definidas e movimentação eletrônica. Também apresentam a dinâmica de absorção e liberação de energia pelo elétron, como forma de explicar os espectros de raios de diferentes elementos químicos. De uma maneira geral, as propostas guardam uma *fidelidade* com a proposta de Bohr, no que tange à dinâmica dos elétrons e seus movimentos. O livro de Feltre e Setsuo (1970), de todos os livros analisados, é o que mais traz informações, conferindo uma maior *fidelidade* a textualização. Os demais simplificam esse modelo.

4.2.6.5 A FIDELIDADE DO SABER COM OS EXPERIMENTOS DE THOMSON, RUTHERFORD E BOHR

De acordo com o levantamento de dados, os LDQ apresentam ou fazem menção aos experimentos conduzidos por Thomson, Rutherford e Bohr. Os LDQ reproduzem os experimentos de descargas elétricas conduzidos por J. J. Thomson, exceto Couto (1938), Silva (1936), Pimenta (1957), CBA (1964a), Nehmi (1995), Politi e Reis (1979), Novais (1997) e Utimura e Linguanoto (1998). Esses livros não trazem explicações sobre fatos experimentais, apenas citam vagamente a contribuição de Thomson ou nem o fazem, como é o caso de Carvalho e Saffioti (1954), CBA (1964b), Feltre e Setsuo (1969 e 1970), Feltre (1988).

Dos LDQ que incluem as explicações dos experimentos de descargas elétricas para desenvolver o estudo do átomo, temos: Pimenta (1958), CBA (1964a), Peruzzo e Canto (1996), Feltre (2008), Santos e Mol (2006), Reis (2010) e Mortimer e Machado (2011). Pimenta (1958) possui a maior *fidelidade* para com a explicação do experimento de Thomson, trazendo detalhes de diferentes experimentos conduzidos.

Pimenta (1958) traz informações sobre os experimentos de raios catódicos, no início do capítulo 6, explicando seus fundamentos, por meio das seguintes ilustrações:

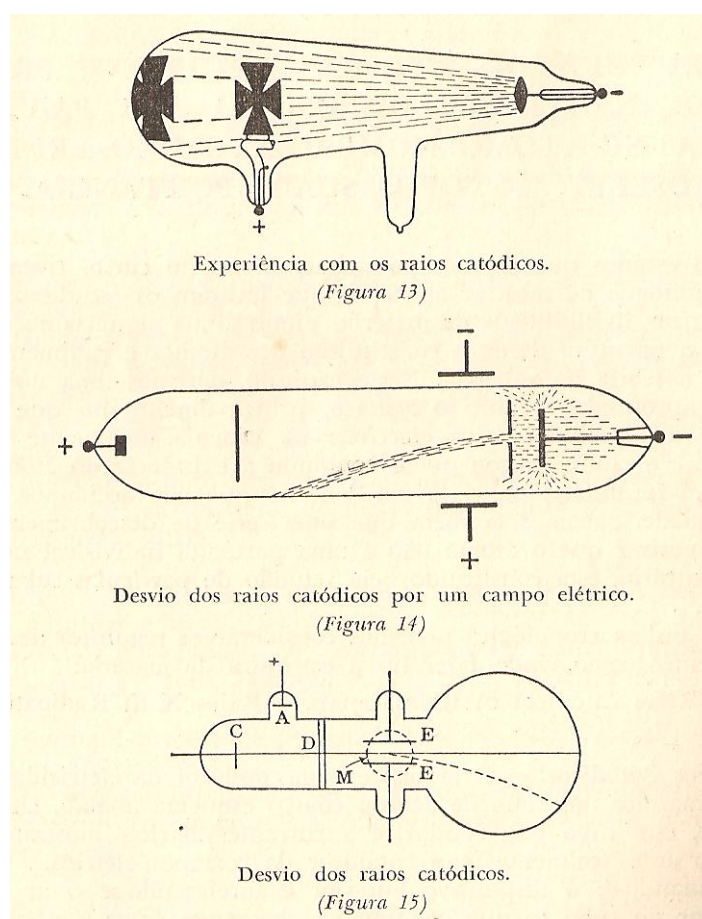


FIGURA 30 – IMAGEM DE AMPOLAS DE RAIOS CATÓDICOS

FONTE: Pimenta (1958)

Pode-se observar certa semelhança com a proposta original descrita no artigo de J. J. Thomson de 1894, que explica a formação da relação m/e através de inúmeros experimentos. Pimenta (1958) desenvolve em sua *transposição* os cálculos para essa relação:

Thompson, utilizando-se do desvio sofrido pelos raios catódicos em um campo elétrico, determinou a relação e/m entre a carga e a massa do elétron. Este valor encontrado foi $e/m = 1,7592 \times 10^8$ coulombs/g. Tendo Milikan determinado a carga do elétron como sendo $-1,602 \times 10^{-19}$ coulombs, pode-se determinar então a massa do elétron como sendo $1/1838$ da massa do átomo de hidrogênio (PIMENTA, 1958, p.95).

Nesta passagem, pode-se entender a meta do livro em explicar o motivo do elétron ter massa menor do que a do átomo, porém, há uma confusão em sua determinação. De acordo com Thomson (1894), o cálculo da relação m/e não é para o elétron e sim para o *corpúsculo* que carrega carga negativa. Nesse sentido, o livro de Pimenta (1958) confunde cálculos da relação de massa do elétron, feitos posteriormente, com cálculos da massa de *corpúsculos* carregados.

Peruzzo e Canto (1996) elucidam os experimentos com raios catódicos através dos trabalhos de Henrich Geissler (1859), Johann Hittorf (1896) e William Crookes (1886), apresentando alguns de seus dados experimentais:

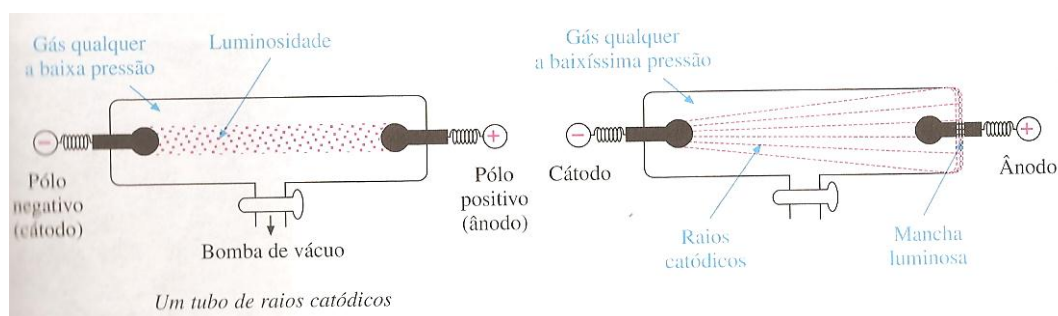


FIGURA 31 – IMAGEM DE AMPOLAS DE RAIOS CATÓDICOS

FONTE: Peruzzo e Canto (1996)

A única informação, em Peruzzo e Canto (1996), que aparece referente ao trabalho de Thomson está contida no seguinte trecho:

O cientista inglês Joseph John Thomson, refinando as experiências feitas com o tubo de raios catódicos, foi capaz de concluir, que em 1897, que os raios catódicos são, na verdade constituídos pelo fluxo de partículas menores que o átomo e dotadas de carga elétrica negativa. Estava descoberto a partícula que chamamos de elétron (PERUZZO E CANTO, 1996, p. 43).

De acordo com Peruzzo e Canto (1996), Thomson aferiu a carga e a massa do elétron através de experimentos com raios catódicos. Essa informação não está errada, porém não está fidedigna. Ou seja, faltam informações que podem dar uma

visão equivocada do trabalho de Thomson. Em primeiro lugar, Thomson não desenvolveu um único experimento de raios catódicos para aferir a massa e carga dos corpúsculos. Na verdade, foram desenvolvidos vários tipos de experimentos, de acordo com seu artigo de 1897. Outro ponto que se pode destacar é que Thomson, quando calculou essa relação, estava no paradigma do *corpúsculo* que carrega carga.

Santos e Mol (2006) também desenvolvem uma leitura do experimento de Thomson, para definição do átomo portador de diferentes cargas. Os autores trazem informações sintetizadas:

O físico inglês Joseph John Thomson realizou uma série de experiências com as ampolas de Crookes. Em uma delas ele inseriu dois pólos (positivo e negativo) na região da ampola por onde passavam os raios catódicos e observou que esses raios sofriam um desvio na direção do pólo positivo. A análise dos resultados dos experimentos de Thomson o levou a concluir que “os raios catódicos são constituídos de cargas elétricas negativas, transportadas por partículas de matéria” (SANTOS E MOL, 2006, p. 141).

De acordo com as informações prestadas por Santos e Mol (2006), há uma maior *fidelidade* com o que Thomson comunicou em seu artigo de 1897. Ou seja, apesar das informações estarem sintetizadas, há coerência entre o que é explicado por Santos e Mol (2006) e o que é conduzido por Thomson (1897) em seu artigo. Santos e Mol (2006) apresentam um esquema de um dos experimentos de raios catódicos conduzidos por Thomson, descrito em seu artigo:

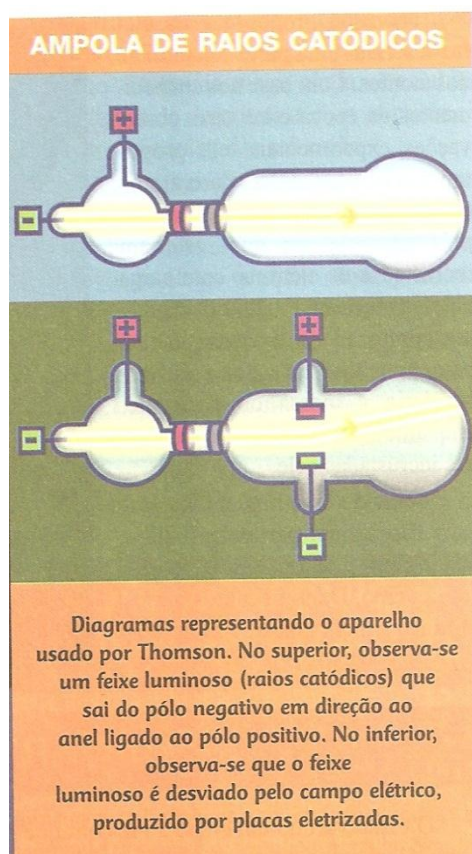


FIGURA 32 – ESQUEMA DO EXPERIMENTO DE THOMSON

FONTES: Santos e Mol (2006)

A imagem da ampola de raios catódicos, descrita e apresentada por Santos e Mol (2006), tem uma certa *fidelidade* com a proposta original do artigo de Thomson (1897). Outro livro que traz uma visualização da ampola de raios catódicos é o de Reis (2010):

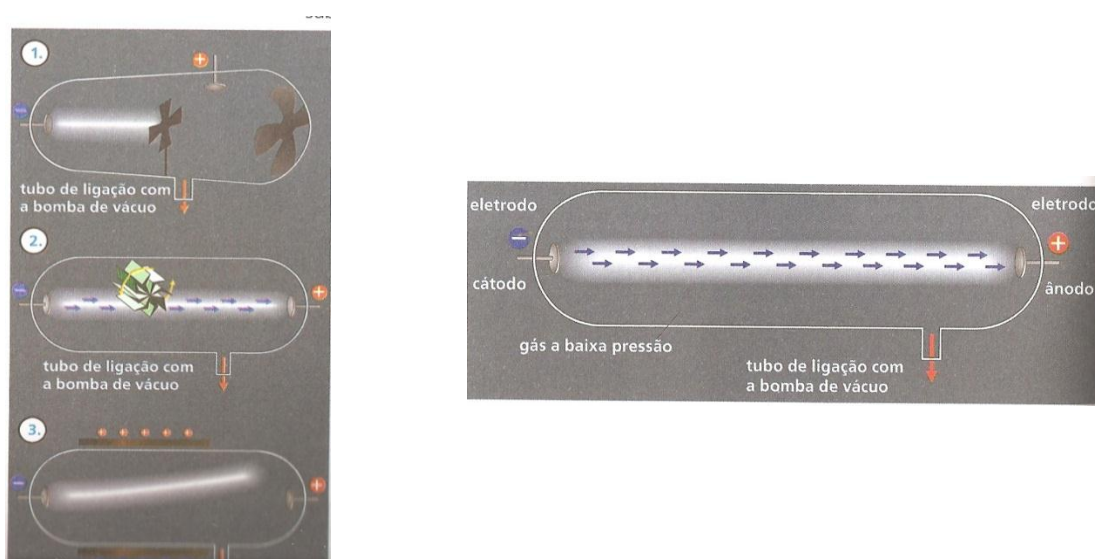


FIGURA 33 – IMAGENS DAS AMPOLAS DE RAIOS CATÓDICOS

FONTE: modificado Reis (2010)

Reis (2010) apresenta diferentes configurações para o experimento da ampola de raios catódicos, todos eles descritos e alguns esquematizados no artigo de J. J Thomson (1897). Porém, duas dessas 4 esquematizações não foram representadas por Thomson (1897), só descritas, as ampolas 1 e 2. Essas duas foram usadas por Thomson (1897) para cálculos experimentais da massa e carga dos *corpúsculos*, mas não foram representadas em seu artigo. Por outro lado, as outras ampolas representadas, por Reis (2010), foram também por Thomson (1897). Assim, pode-se entender que Reis (2010) adicionou novas representações, a partir de descrições experimentais de Thomson e com certa *fidelidade*.

Para o experimento de Rutherford, somente o livro de Couto (1938) não apresenta esquemas do experimento de dispersão das partículas alfa. Todas as outras obras analisadas apresentam alguma informação sobre esse experimento. Silva (1936) traz uma leitura geral do experimento de dispersão de partículas alfa:

(...) como, bombardeando um gás ou folha metálica delgada pelos raios α conseguem-se libertar elétrons algumas vezes; outras ao contrário, sofrem desvios que H. Geiger e Marsden avaliaram até em 90° (SILVA, 1936, p. 84).

Silva (1936) explica sucintamente o experimento de espalhamento de partículas α , não trazendo uma representação visual. De acordo com a descrição do autor, pode-se perceber uma certa *fidelidade* com o encontrado nos artigos de Rutherford (1911) e nos escritos de Geiger e Marsden (1909), trazendo informações importantes sobre o experimento e mencionando a execução de Geiger e Marsden. Em Pimenta (1958), observa-se também uma leitura do experimento:

A evidência deste fato foi dada por uma experiência executada por Rutherford, a qual consistiu no seguinte: tomou uma lâmina de ouro, muito delgada, e fez incidir sobre esta uma feixe de partículas α oriundas do Rádio. Notou que as partículas α em sua grande maioria atravessavam a lâmina de ouro. Um certo número de partículas sofria entretanto um desvio (PIMENTA, 1958, p. 100).

Pimenta (1958) apresenta informações gerais sobre o experimento, porém não levando em conta Geiger e Marsden, atribuindo toda a execução experimental a Rutherford. Outro ponto, que pode ser destacado na textualização, é o fato do autor apresentar como fonte radioativa o Brometo de Rádio. Em Rutherford (1911) e Geiger e Marsden (1909), a fonte usada era de RaBr_2 . Ou seja, Pimenta (1958), nesse aspecto, guarda uma certa *fidelidade* ao que foi comunicado no *saber sábio*.

O aparelho consistia em linhas gerais de um fragmento de polônio (que servia de fonte para as partículas alfa), uma placa espessa de chumbo com um orifício, uma lâmina fina de metal e um anteparo coberto de sulfeto de zinco (CBA, 1964a, p. 36).

CBA (1964a), dos 19 livros analisados, é o primeiro a apresentar, além da textualização, um esquema do experimento de espalhamento de partículas alfa, como mostra a figura:

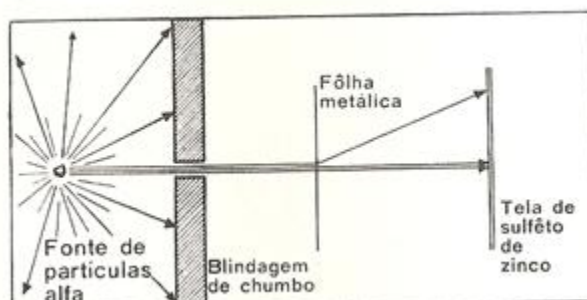


FIGURA 34– IMAGEM DO EXPERIMENTO DE ESPALHAMENTO DE PARTÍCULAS ALFA
 FONTE: CBA (1964a)

Pode-se observar, a partir da *transposição* proposta por CBA (1964a), algumas modificações da proposta original no *saber sábio* de Rutherford (1911) e Geiger e Marsden (1909). Em sua textualização, CBA (1964a) não é *fiel* com o que foi comunicado no *saber sábio*, reconstruindo alguns aspectos do experimento:

Uma fina lâmina de ouro é bombardeada com partículas **alfa**, que são **emitidas** pelo elemento radiativo Polônio (veja o capítulo radiatividade). Por trás dessa lâmina de ouro, há um anteparo recoberto de sulfeto de zinco, que tem a propriedade de detectar as partículas alfa, pois torna-se **fluorescente** sob seu impacto (POLITI e REIS, 1979, p. 11, grifos do autor).

Politi e Reis (1979) também apresentam um esquema do experimento de espalhamento de partículas alfa, como mostra a figura:

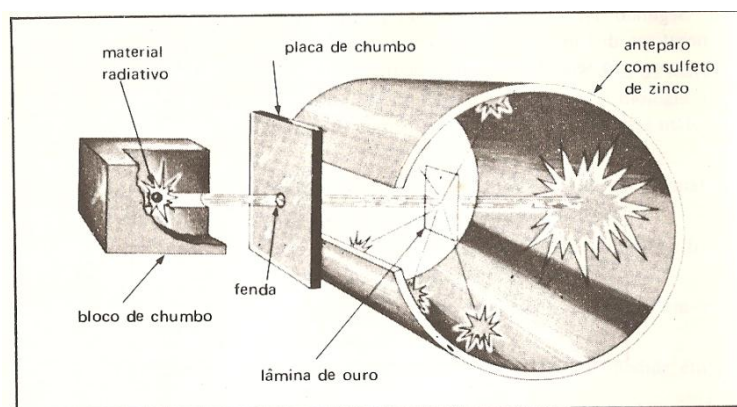


FIGURA 35 – IMAGEM DO EXPERIMENTO DE ESPALHAMENTO DE PARTÍCULAS ALFA
 FONTE: Politi e Reis (1979)

Com base na textualização e no esquema apresentado por Politi e Reis (1979), percebe-se uma reconfiguração da proposta original de Rutherford (1911) e Geiger e Marsden (1909), onde a aparelhagem do experimento e a descrição são modificados e simplificados, não retratando com *fidelidade* o experimento.

Rutherford atirou numa *finíssima* folha de ouro, cuja espessura se estima em 10 mil átomos o que corresponde a cerca de 0,0001 cm! A “metralhadora” usada por ele lançava pequenas partículas radioativas portadoras de carga elétrica positiva, chamadas de *partículas alfa*. Para saber se essas “balas” atravessaram ou ricocheteavam, ele usou uma tela feita com um material apropriado (fluorescente) que emite luminosidade instantânea quando atingidas por partícula alfa (PERUZZO e CANTO, 1996, p. 44, grifos do autor).

Peruzzo e Canto (1996), além de apresentarem a textualização, também trazem um esquema do experimento na figura 36:

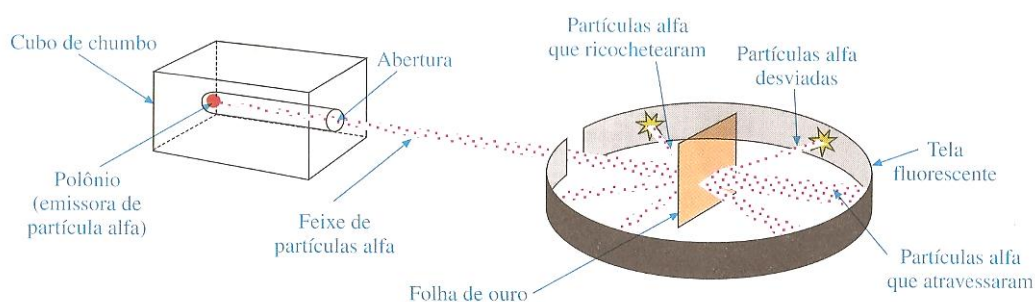


FIGURA 36 – IMAGEM DO EXPERIMENTO DE ESPALHAMENTO DE PARTÍCULAS ALFA
 FONTE: Peruzzo e Canto (1996)

Peruzzo e Canto (1996), de todos os 19 livros analisados, são os que mais modificam a proposta original do experimento. Primeiramente, retirando a participação de Geiger e Marsden na condução e execução dos experimento, delegando esse fato a Rutherford. Os autores também não retratam com *fidelidade* o experimento, trazendo informações incoerentes com o que foi apresentado por Rutherford (1911) e Geiger e Marsden (1909):

Com suas experiências, Rutherford abandonou a hipótese de Thomson de que a distribuição de partículas positivas e negativas se dava de forma homogênea (NOVAIS, 1997, p. 81).

Novais (1997), por sua vez, não descreve o experimento. Apenas fala rapidamente de seu resultado, sem trazer o processo experimental. Santos e Mol (2006) apresentam uma textualização desse experimento:

Em 1909, o aluno de doutorado em Física Johannes Hans Wilhelm Geiger (1882 – 1945) e o professor inglês Ernest Marsden (1889 – 1970), sob orientação de Rutherford, trabalharam em um aparato experimental que possibilitava a observação da trajetória da radiação alfa. Diversos experimentos foram desenvolvidos por Geiger, Marsden e Rutherford, utilizando esse equipamento, e os resultados foram espantosos (SANTOS e MOL, 2006, p. 144).

Santos e Mol (2006), trazem a textualização do experimento de espalhamento de partículas alfa, além de um esquema, representado na figura 37:

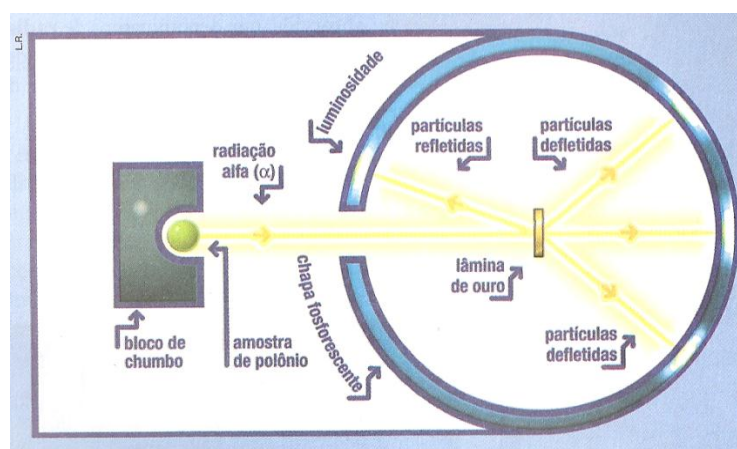


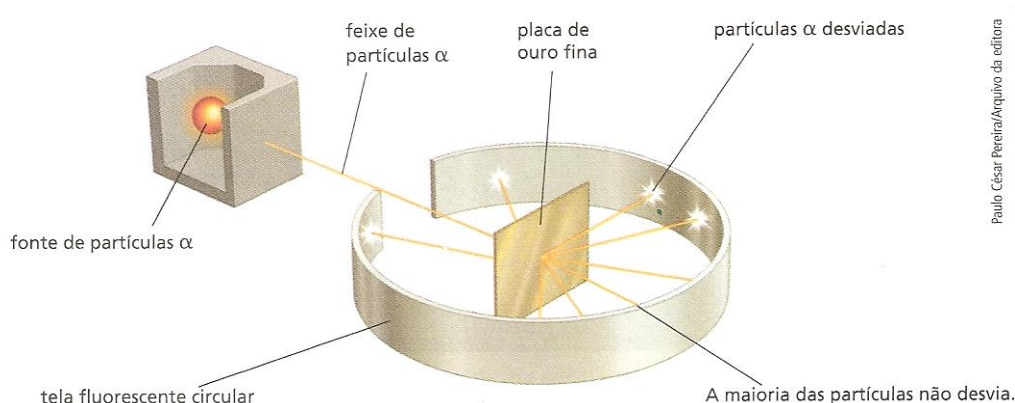
FIGURA 37 – IMAGEM DO EXPERIMENTO DE ESPALHAMENTO DE PARTÍCULAS ALFA
 FONTE: Santos e Mol (2006)

De acordo com a representação de Santos e Mol (2006), o experimento consiste em uma fonte de Polônio que emite partículas numa folha de ouro, que está rodeada por uma chapa fosforescente. Esta representação do experimento guarda pouca *fidelidade* com a proposta de Rutherford (1911) e Geiger e Marsden (1909), no que se refere ao arranjo experimental e ao material radioativo que era usado. Na leitura do *saber sábio*, o material do experimento era RaBr_2 e não Polônio, como descrito por Santo e Mol (2006).

Mortimer e Machado (2011) apresentam uma explicação do experimento de espalhamento de partículas alfa:

(...) podemos identificar uma fonte de radiação que emite partículas alfa. O feixe de partículas é dirigido a uma lâmina de ouro muito fina. O ouro, bastante maleável, pode ser transformado numa lâmina de espessura muito pequena. Era possível contar o número de partículas que exibiam cada tipo de comportamento depois de atravessar a lâmina de ouro, pois o aparato estava envolto por um anteparo constituído por um papel banhado em solução de sulfeto de zinco, que cintila ao ser atingido por uma partícula alfa. Os pesquisadores procuraram detectar as partículas alfa que atravessavam a lâmina, confirmando que a maioria das partículas alfa detectadas atravessava a lâmina sem sofrer desvio significativos (MORTIMER e MACHADO, 2011, p. 150).

Mortimer e Machado (2011), apresentam, além da textualização, uma representação do experimento conduzido por Geiger e Marsden sob orientação de E. Rutherford, como mostra a figura 38:



Paulo César Pereira/Arquivo da editora

Figura 6-19: O esquema da experiência de Geiger e Marsden. Um feixe de partículas alfa atinge a folha de ouro, sendo detectado o desvio de sua trajetória no anteparo fluorescente.

FIGURA 38 – IMAGEM DO EXPERIMENTO DE ESPALHAMENTO DE PARTÍCULAS ALFA
 FONTE: Mortimer e Machado (2011)

Mortimer e Machado (2011) não apresentam alguns dados como a fonte de radiação, o aparato experimental usado e quem conduziu o experimento. A terceira informação só fica clara na representação do experimento, quando descreve-se a experiência de Geiger e Marsden. Porém, o *saber a ensinar*, usado por Mortimer e Machado (2011) não tem nenhuma *fidelidade* com a proposta original.

Com base na questão VI, depreende-se que os 19 LDQ não retratam o Modelo Atômico com total *fidelidade*. Estas interpretações podem gerar distorções quanto ao significado e funcionamento de cada modelo. No entanto, deve-se frisar que a adaptação é inevitável, pois o aluno que estuda este conteúdo não tem o mesmo nível de compreensão que um pesquisador. Sendo assim necessário que os LDQ procurem formas de adaptar os Modelos Atômicos e relatos experimentais, sem passar idéias equivocadas que podem constituir-se em obstáculos epistemológicos. Gerando dificuldades na vida cotidiana e acadêmica do aluno.

4.2.7 DESINCRETIZAÇÃO

O elemento *desincretização* tem como objetivo levantar como os LDQ distribuem um determinado *saber a ensinar*, para formar unidades. As questões referentes a esse elemento são as seguintes:

VII(a). O livro possui um capítulo específico para o Modelo Atômico?

VII(b). Além do capítulo específico sobre Modelo Atômico, este conteúdo aparece também ao longo do livro em outros capítulos?

A questão VII(a) teve como objetivo fazer um levantamento da presença de capítulos específicos sobre Modelos Atômicos nos 19 LDQ analisados. Os dados estão agrupados na tabela a seguir:

TABELA 6 – DADOS RELATIVOS À QUESTÃO VII(a)

Período	Livro	Sim	Não	Capítulos
F. Campos (1931 – 1941)	COUTO (1938)	X		Capítulo 8 – Teoria atômica. Teoria de Avogadro
	SILVA (1936)	X		Capítulo 3 – Matéria e Energia
G. Capanema (1942 – 1960)	PIMENTA (1957)		X	-
	PIMENTA (1958)	X		Capítulo 6

	CARVALHO E SAFFIOTI (1954)	E	X		Capítulo 7 – Estrutura do átomo
	CBA (1964a)			X	-
	CBA (1964b)			X	-
LDB 4.024 (1961 – 1970)	FELTRE SETSUO (1969)	E		X	-
	FELTRE SETSUO (1970)	E	X		Capítulo 3 – Estrutura do átomo
LDB 5.692 (1971 – 1987)	POLITI REIS (1979)	E	X		Capítulo 1 – Estrutura do átomo / capítulo 5 – Estrutura atômica
	FELTRE (1988)			X	Capítulo 3 – Estrutura atômica
Constituição Federal de 1988	PERUZZO CANTO (1996)	E	X		Capítulo 3 – Estrutura atômica
	NEHMI (1995)			X	Capítulo 6 – Evolução dos modelos atômicos
	NOVAIS (1997)			X	Capítulo 4 – Noções sobre a estrutura da matéria
LDB 9.692 (1996)	UTIMURA LINGUANOTO (1998)	E	X		Capítulo 3 – O átomo: da história à sua constituição
	FELTRE (2008)			X	Capítulo 4 – A evolução dos modelos atômicos
PNLEM 2008	SANTOS E MOL (2006)			X	Capítulo 6 – Modelos atômicos / capítulo 25 – Estrutura eletrônica do átomo
	MORTIMER MACHADO(2011)	E		X	Capítulo 6 – Modelos para o átomo e um introdução a tabela periódica
PNLD 2012	REIS (2010)			X	Capítulo 12 – Evolução dos modelos atômicos
	Total			15	4

FONTE: O autor (2012)

Na tabela 6, observa-se que dos 19 LDQ, 15 apresentam um capítulo dedicado ao estudo dos Modelos Atômicos, enquanto 4 não.

Em relação aos 15 LDQ, observa-se que 12 organizam esse *saber a ensinar* na forma de um capítulo, enquanto 3 separam o estudo dos Modelos Atômicos em dois capítulos, um para a física clássica e outro para a quântica.

O fato de a maioria dos LDQ organizaram os Modelos Atômicos sob a forma de um capítulo é um aspecto positivo, pois sistematiza este conteúdo. Porém também pode ser considerada uma desvantagem, pois não favorece a relação entre diferentes *saberes*. Em outras palavras, dentro de uma ordem didática de capítulos, não há o encadeamento de *saberes*, dando a impressão que os conhecimentos são independentes no desenvolvimento da ciência.

A seguir, apresentam-se alguns exemplos de como a *desincretização* aparece no LDQ.

No livro de Silva (1936), há o estudo dos Modelos Atômicos no capítulo 3, “Matéria e energia” (SILVA, 1936, p. 78), abordando as teorias de coesão, afinidade e repulsão, os modelos atômicos de Thomson, Rutherford, Bohr e Nicholson, além de apresentar estudos sobre espectroscopia e radioatividade.

Pimenta (1958) desenvolve esse conteúdo no capítulo 6 (PIMENTA, 1958, p. 93), tratando dos modelos atômicos, divisibilidade da matéria, elétrons, prótons, neutrons, disposição de partículas no átomo, número atômico, distribuição eletrônica e isótopos.

Feltre e Setsuo (1970) apresentam esse conteúdo no capítulo 3, “estrutura do átomo” (FELTRE e SETSUO, 1970, p. 120), com o estudo do átomo de Dalton, Rutherford-Bohr, os modelos posteriores a Rutherford-Bohr, princípio da exclusão de Pauli, mecânica ondulatória, Regra de Hund e hibridação. Os capítulos 1 e 2 são destinados aos experimentos e técnicas básicas para o desenvolvimento dos Modelos Atômicos.

No livro de Nehmi (1995), este estudo está agrupado sobre o capítulo 6, “Evolução dos modelos atômicos” (NEHMI, 1995, p. 54), apresentando o modelo de Dalton, Thomson, Rutherford, número atômico, número de massa, isótopos, isótonos, isóbaros, modelo atômico de Bohr e de Sommerfeld, configuração eletrônica e diagrama de Pauling.

Em Novais (1997), o capítulo 4 “Noções sobre o estudo da matéria” (NOVAIS, 1997, p. 80) contém a “primeira idéia de átomo” (p. 80), modelo de Dalton, Thomson, Rutherford, o núcleo, número atômico, elemento químico, símbolo, número de massa, isótopos, isóbaros e distribuição eletrônica no átomo.

Feltre (2008) apresenta o capítulo 4, “A evolução dos modelos atômicos” (FELTRE, 2008, p. 74), trazendo o Modelo Atômico de Thomson, Rutherford e Bohr, radioatividade, propriedades atômicas, classificação, modelo de orbitais atômicos, estudos energéticos dos elétrons e distribuição eletrônica.

Em Mortimer e Machado (2011), no capítulo 6, “Modelos para o átomo e uma introdução à tabela periódica” (MORTIMER E MACHADO, 2011, p. 136), apresentam-se os estudos dos modelos atômicos, propriedades atômicas e estudo da tabela periódica, organizados com as seguintes seções: A Idéia de Átomo, O Átomo de Dalton, Cargas Elétricas, Modelo Atômico de Thomson, Modelo Atômico de Rutherford, Elemento Químico, Tabela Periódica, Espectroscopia, Luz, Modelo Atômico de Bohr, Modelo Quântico, Distribuição Eletrônica e Tabela Periódica Moderna.

Dentre os 3 livros que dividem esse estudo em mais de um capítulo, apresentam-se as obras de Politi e Reis (1979), Santos e Mol (2006) e Reis (2010).

Em Politi e Reis (1979), o Modelo Atômico de Bohr só é mostrado no capítulo 5, enquanto os outros modelos anteriores são trabalhados no capítulo 1. Através da análise do sumário, encontra-se o capítulo 1 dedicado ao estudo do átomo e dos Modelos Atômicos, denominado “Estrutura do átomo” (POLITI e REIS, 1979, p. 9). Nele, estão o estudo do número atômico, número de massa, isótopos, isóbaros e isótonos. Também estuda-se o histórico dos Modelos Atômicos e algumas de suas propriedades. No capítulo 5, “Estrutura atômica” (POLITI e REIS, 1979, p. 51), apresenta-se o modelo de Bohr, articulando-o com o estudo dos números quânticos e diagramas de Pauli.

Nos livros de Santos e Mol (2006) e Reis (2010) essa divisão muda. Os modelos de Dalton a Bohr, no livro de Santos e Mol (2006), são estudados no capítulo 6 e os modelos posteriores são somente desenvolvidos no capítulo 25. No capítulo 6, “Modelos atômicos” (SANTOS e MOL, 2006, p. 132), estuda-se o modelo

atômico de Dalton, Thomson, Radioatividade, modelo atômico de Rutherford, o átomo e suas partículas e o universo atômico. Também se investiga os espectros atômicos e, conseqüentemente, o modelo atômico de Niels Bohr. No capítulo 25 intitulado “Estrutura eletrônica do átomo” (SANTO e MOL, 2006, p. 683) apresentam-se os estudos relativos ao átomo através da física quântica.

No livro de Reis (2010) apresenta-se outra divisão, onde o modelo de Dalton é desenvolvido no capítulo 7. No capítulo 12 estudam-se os modelos de Thomson a Bohr. O capítulo 13 traz os modelos posteriores ao de Sommerfield. Lembrando que na organização didática sugerida pela autora, os experimentos que culminaram no desenvolvimento de Modelos Atômicos são apresentados à parte no capítulo 11.

Em Reis (2010), os capítulos são organizados da seguinte forma: capítulo 7 denominado “Átomos e Moléculas” (REIS, 2010, p. 114), contém o estudo do átomo de Dalton, a lei volumétrica de Gay Lussac, contradições à teoria de Dalton e os estudos de Avogadro. O capítulo 12, “Evolução dos Modelos Atômicos” (REIS, 2010, p. 198), apresenta os modelos de Thomson, Rutherford, estudos sobre a luz, espectroscopia e o modelo atômico de Bohr. Os estudos relativos à eletricidade e radioatividade são vistos no capítulo 11, “Eletricidade e Radioatividade” (REIS, 2010, p. 181). Os modelos posteriores a Bohr e Sommerfield são desenvolvidos no capítulo 13, “Modelo Básico para o Átomo” (REIS, 2010, p. 219).

A questão VII(b) teve como objetivo analisar se os LDQ apresentam o conteúdo Modelos Atômicos em outros capítulos não específicos sobre a temática. Assim, construiu-se a seguinte tabela:

TABELA 7 – DADOS RELATIVOS À QUESTÃO VII(b)

Período	Livro	Sim	Não	Capítulo
F. Campos (1931 – 1941)	COUTO (1938)	X		Capítulo I – A matéria e sua subdivisão / Capítulo XI – Teoria da valência
	SILVA (1936)	X		Capítulo II – Evolução e história da química
	PIMENTA (1957)	X		Capítulo 2
G. Capanema (1942 – 1960)	PIMENTA (1958)		X	-
	CARVALHO E		X	-

	SAFFIOTI (1954)				
	CBA (1964a)	X			Capítulo III – Elétrons, Prótons e reagentes químicos / capítulo IV – Estrutura a partir de prótons e eletrons
LDBEN 4.024 (1961 – 1970)	CBA (1964b)	X			Capítulo VII – Níveis de energia dos elétrons
	FELTRE E SETSUO (1969)	X			Capítulo 2 – Esboço de evolução da química
	FELTRE E SETSUO (1970)		X		-
LDBEN 5.692 (1971 – 1987)	POLITI E REIS (1979)		X		-
	FELTRE (1988)	X			Capítulo 2 – Introdução à química
Constituição Federal de 1988	PERUZZO E CANTO (1996)	X			Capítulo 2 – Propriedades gerais da matéria
	NEHMI (1995)		X		-
	NOVAIS (1997)		X		-
LDBEN 9692 (1996)	UTIMURA E LINGUANOTO (1998)		X		-
	FELTRE (2008)	X			Capítulo 3 – Explicando a matéria e suas transformações
PNLEM 2008	SANTOS E MOL (2006)		X		-
	MORTIMER E MACHADO(2010)	X			Capítulo 5 – Um modelo para os estados físicos dos materiais
PNLD 2012	REIS (2010)		X		Capítulo 7 – Átomos e moléculas
		Total	11	8	

FONTE: O autor (2012)

De acordo com a tabela 7, dos 19 livros analisados, 11 possuem o conteúdo Modelos Atômicos em outros capítulos, enquanto 8 não. Entre os primeiros estão Couto (1938), Silva (1936), Pimenta (1957), CBA (1964a, 1964b), Feltre e Setsuo (1968), Feltre (1988), Santos e Mol (2006), Feltre (2008), Reis (2010), Mortimer e Machado (2010). Já, entre os segundos estão Pimenta (1958), Carvalho e Saffioti

(1954), Feltre e Setsuo (1970), Politi e Reis (1979), Nehmi (1995), Novais (1997), Utimura e Linguanoto (1998), Santos e Mol (2006).

Depreende-se, em relação aos 11 LDQ que possuem o conteúdo Modelos Atômicos em outros capítulos, que há uma necessidade de inserir o *saber* Modelo Atômico como pré-requisito para o ensino de outros *saberes*. Essa característica garante que os LDQ façam a relação entre *saberes* buscando a integração do conteúdo. O que é válido, pois faz o aluno ver a importância deste conteúdo para o ensino de outros. É a forma encontrada nas *transposições didáticas* para dar utilidade ao *saber* dentro de uma ordem didática, dando a base para desenvolvimento de novos conceitos. Ou seja, essa intenção pode reificar uma visão linear e cumulativa dos *saberes*.

A seguir, apresentam-se alguns exemplos do uso do *saber* Modelos Atômicos em outros capítulos dos LDQ:

No livro de Couto (1938), os Modelos Atômicos são apresentados no capítulo 1 para explicar a matéria. E no capítulo 11 para explicar a teoria da valência.

No livro de Silva (1936), capítulo 2, desenvolve-se um tratamento histórico, abordando a “Evolução Química” (SILVA, 1936, p. 57), doutrinas falsas⁴⁷, críticas a essas doutrinas, doutrina hilemórfica, prática química antiga, química moderna e química hodierna, dando-se preferência ao estudo histórico da química, passando pela história do atomismo.

Pimenta (1957) apresenta no capítulo 2 um estudo sobre substâncias simples, moléculas, átomos, constituintes do átomo, número e massa atômica, massa molecular, átomo grama, molécula grama, volume molecular e alotropia e algumas noções para o cálculo de átomos e moléculas.

Na coleção CBA (1964a e 1964b) não há um capítulo específico para os Modelos Atômicos. Este conteúdo é diluído ao longo de 3 capítulos (III, IV e VII), desenvolvendo os conceitos de eletricidade, radioatividade, átomo, hibridização, configuração eletrônica, modelagem, ligação química, reação química e tabela periódica.

⁴⁷ Silva (1936) compreende como doutrinas falsas aquelas que vieram de gerações anteriores, gregas, e que não tem a base do método da ciência, como compreendido pelo autor.

Feltre e Setsuo (1969) relacionaram o conteúdo Modelos Atômicos ao capítulo que trata do recorte histórico da química, “Esboço da Evolução da Química” (FELTRE e SETSUO, 1969, p. 25), inserindo-o em subítens chamados Período anterior ao século XIX e Estudos do século XIX e XX, com a apresentação de algumas propriedades e idéias sobre o átomo e substâncias.

Já em Feltre (1988) esse conteúdo aparece no capítulo 2, “Introdução à Química” (FELTRE, 1988, p.9), mostrando noções sobre matéria, corpos, objetos, constituição da matéria, misturas, transformação da matéria, energia, desdobramento de misturas. O estudo do átomo aparece nesses capítulos com a hipótese sobre o átomo (FELTRE, 1988, p. 12) e com a apresentação da teoria atômica de Dalton (FELTRE, 1988, p. 14). Estrutura essa similarmente reproduzida no livro de Peruzzo e Canto (1996).

Feltre (2008) no capítulo 3, “Explicando a Matéria e suas Transformações” (FELTRE, 2008, p. 48), trata de aspectos sobre a ciência, matéria, a lei de Lavoisier, Proust, a hipótese de Dalton, elementos químicos, símbolos, substâncias, transformações dos materiais, propriedades das substâncias, segunda visão da química e como a ciência progride. Neste capítulo, apresenta-se o Modelo Atômico de Dalton, porém não o especificando como modelo, mas como uma hipótese, além de trazer noções básicas para a química e uma idéia sobre a ciência.

Em Reis (2010) o capítulo 7, “Átomos e Moléculas” (REIS, 2010, p. 114), apresenta o Modelo Atômico de Dalton, a lei volumétrica de Gay Lussac, contradições a teoria de Dalton e a idéia de Avogadro.

Logo, de acordo com as questão VII(a) e VII(b), os LDQ *desincretizam* os Modelos Atômicos de maneira similar, organizando-os sob a forma de um capítulo específico e distribuindo-os em outros. Essa característica revela a necessidade dos LDQ em apresentar esse *saber* organizado sob uma ordem didática, possivelmente, como pré-requisito para a compreensão de outros conteúdos, dentro da idéia de linearidade e crescente dificuldade dos *saberes*.

4.2.8 PROGRAMABILIDADE DE AQUISIÇÃO DO SABER

Neste elemento analisou-se como os LDQ apresentam a sequência de conteúdos de química. As questões usadas para este levantamento foram:

VIII(a). Para qual série o conteúdo Modelos Atômicos é orientado?

VIII(b). Durante a transposição dos Modelos Atômicos, como são inseridos os exercícios e atividades?

A questão VIII(a) tem como objetivo levantar quais LDQ indicam o conteúdo Modelo Atômico para estudo em uma série específica. A partir dela, gerou-se a tabela abaixo:

TABELA 8 – DADOS RELATIVOS À QUESTÃO VIII(a)

Período	Livro	Organização da obra	1º ano	1º e 2º ano	2º ano	2º e 3º ano	3º ano	1º, 2º e 3º ano	Não específica
F. Campos (1931 – 1941)	COUTO (1938)	3 v.				X			
	SILVA (1936)	V. único				X			
G. Capanema (1942 – 1960)	PIMENTA (1957)	3 v.	X						
	PIMENTA (1958)	3 v.					X		
	CARVALHO E SAFFIOTI (1954)	3 v.					X		
LDBEN 4.024 (1961 – 1970)	CBA (1964a)	3 v.							X
	CBA (1964b)	3 v.							X
	FELTRE E SETSUO (1969)	3 v.							X
LDBEN 5.692 (1971 – 1987)	FELTRE E SETSUO (1970)	3 v.							X
	POLITI E REIS (1979)	V. único							X
Constituição Federal de 1988	FELTRE (1988)	3 v.							X
	PERUZZO E CANTO (1996)	V. único							X
LDBEN 9.692 (1996)	NEHMI (1995)	V. único							X
	NOVAIS (1997)	3 v.							X
PNLEM	UTIMURA E LINGUANOTO (1998)	V. único							X
	FELTRE (2008)	3 v.							X

2008	SANTOS E MOL (2006)	3 v.							X
PNLD 2012	MORTIMER E MACHADO(2010)	3 v.							X
	REIS (2010)	3 v.							X
	Total		1	0	0	2	2		14

FONTE: O autor (2012)

A partir do levantamento de dados, evidenciou-se que dos 19 livros didáticos analisados, 14 não especificam o estudo do conteúdo Modelos Atômicos a uma série escolar. Em contrapartida, 5 especificam.

Depreende-se que esses 14 LDQ que não especificam a que série se destina o estudo dos Modelos Atômicos, devido ao fato de que há um currículo instituído, o qual é respeitado pelos professores. Todos esses livros são posteriores a LDB 4.024/61, dando a idéia de que nessa época já havia um currículo padrão, uma tradição do que se ensinar em cada uma das séries escolares, aparecendo sempre no volume de química geral e inorgânica. Assim, entende-se que há um currículo formal, que já vem seguido na tessitura dos LDQ, e também um *habitus*⁴⁸, formado pela tradição e formação ambiental do professor⁴⁹, onde este reproduz o ensino do jeito que ele aprendeu na escola, não necessitando que o livro publique um documento especificando onde e o que se ensinar em cada série.

Já para os LDQ que possuem um currículo impresso junto ao sumário, todos das Reformas F. Campos e G. Capanema, infere-se que naquela época ainda não havia o *habitus*, já que a inserção do ensino da química na escola era recente e o padrão de ensino era do Colégio Dom Pedro II, necessitando que os LDQ trouxessem a organização do ensino dessa ciência, aos alunos e professores do secundário, ditando onde e como cada conteúdo deveria ser ensinado.

Os 14 LDQ, que não fazem relação entre o conteúdo Modelos Atômicos e uma série específica para seu estudo, informam que o livro é orientado para o

⁴⁸ *habitus* é um termo destacado por Bourdieu (2002) que reflete o conjunto de práticas que moldam as ações do indivíduo e um determinado campo. É um conjunto de normas implícitas que moldam sua forma de proceder em determinados meios sociais.

⁴⁹ Formação ambiental é um termo usado por Maldaner (1999) entendendo como a reprodução da prática docente espelhada em antigos professores.

ensino de química em todo o secundário (ensino médio). Vale lembrar que nos LDQ divididos em três volumes, o estudo dos Modelos Atômicos aparece no 1º volume.

O livro de Santos e Mol (2006) tem uma forma distinta de organizar o conteúdo através de eixos temáticos, totalizando nove: “A Ciência, os Materiais e o Lixo; Modelos de Partículas e Poluição Atmosférica; Elementos, Interações e Agricultura; Cálculos, Soluções e Estética; Termoquímica, Cinética e Recursos Energéticos; Equilíbrio Químico e Água; A Química em Nossas Vidas; Metais, Pilhas e Baterias, Átomo, Radioatividade e Energia Nuclear” (SANTOS e MOL, 2006, p. 5 - 7).

Na coleção CBA há uma indicação de estudo da obra:

O projeto CBA é uma das duas maiores tentativas feitas por professores secundários e universitários para aperfeiçoar o ensino de química nas escolas secundárias (...) (CBA, 1964a, p. 5).

Neste trecho, entende-se que a coleção CBA foi confeccionada para o propósito de aperfeiçoar o estudo da química no ensino secundário, em três temas centrais (estrutura, ligação e energia), intercalados com práticas experimentais.

No prefácio do livro de Politi e Reis (1979) há algumas indicações de uso do livro:

O objetivo fundamental desta obra é atender a muitos alunos do 2º grau, do supletivo e do cursinho pré-vestibular que necessitam de um livro sintetizado de química. Não tivemos em absoluto a intenção de expor um curso analítico, mas abreviado, onde os alunos encontrarão partes fundamentais do programa (POLITI e REIS, 1979, p.5).

Politi e Reis (1979) orientam sua obra para o ensino secundário, supletivo e cursinhos. Explicam que este material é uma síntese do conteúdo de um curso de química, com o objetivo de recapitular e abordar os principais pontos presentes no programa.

Nehmi (1995) apresenta uma indicação para elaboração de seu livro: “elaboramos um volume único de Química para atender às crescentes solicitações dos professores de 2º grau” (NEHMI, 1995, p. 2). Nesta explicação, delimita-se somente o uso do livro no segundo grau, mas não se menciona qual série cada um dos conteúdos é destinado.

Novais (1997) explica que “é no curso de 2º grau que você terá a oportunidade de iniciar, de forma regular, seus estudos de química” (NOVAIS, 1997, p. V). Nesta passagem, deixa-se claro a orientação do estudo introdutório da química no segundo grau (ensino médio), porém sem maiores indicações de organização e estudo para o professor.

Feltre (2008) orienta o uso de seu livro no prefácio do volume 1: “em seus três volumes, esta obra procura contribuir para o ensino da química entre os alunos do Ensino Médio” (FELTRE, 2008, p. III), não especificando onde se encontrarão os conteúdos da química ao longo destas três obras.

Mortimer e Machado (2011) dão orientações acerca do uso de seu livro, porém, não especificando onde e quando se estudar um determinado conteúdo. Os autores dão mais ênfase à questões relativas ao material.

Dentre os 5 livros que fazem a relação entre os conteúdos estudados e uma série escolar, podemos citar Couto (1938), Silva (1936), Pimenta (1957 e 1958) e Carvalho e Saffioti (1954). Cada um destes apresenta uma cópia do Programa Oficial, com o intuito de justificar o estudo de todos os conteúdos, sugerindo uma organização e hierarquia de trabalho ao professor.

No livro de Couto (1938), há uma cópia do programa indicando o estudo dos modelos atômicos para 4ª e 5ª séries, como mostra a figura:

4.^a SÉRIE

I. — **Química Geral.** Leis numéricas das combinações, 32. Teoria atômica, 37. Princípio de Avogadro, 38. Volume molecular, 64. Determinação dos pesos atômicos, 66 ; e moleculares, 59. Nomenclatura, 133 ; e notação, 27. Valência, 45. Fórmulas, 69. Equações químicas, 75 e 141. Exercícios, 77 (e no fim de cada capítulo).

FIGURA 39 – PROGRAMA DA 4ª SÉRIE DE COUTO (1938)
FONTE: Couto (1938)

E também, Couto (1938) apresenta o programa de conteúdos destinados à 5ª série:

5.^a SÉRIE

I. — **Química geral.** Cinética química : Dissociação térmica, 132. Equilíbrio químico e reações reversíveis, 76 e 112. Lei das massas, 42. Catálise, 42. Afinidade química, 40. Oxidação e redução, 140. Estabilidade dos corpos ; ação da água, calor, e luz, 41. Termoquímica, 130. Radioatividade, 533. Lei periódica dos elementos, 146. Resumo das teorias modernas da química ; noções da teoria da estrutura atômica dos elementos, 48.

II. — **Metais.** Metais, propriedades, compostos naturais, minérios, processos metalúrgicos, dos metais usuais, 388. Ligas, 390. Lítio, óxidos, hidratos, sais, 392 e 393. Sódio, óxidos, hidratos e sais, 392 e 394. Potássio, óxidos, hidratos e sais, 392 e 405. Magnésio, óxido, hidratos e sais, 414 e 416. Cálcio, óxido, hidrato e sais, 414 e 421. Estrôncio, óxidos, hidratos, sais, 414 e 430. Bário, óxidos, hidrato e sais, 414 e 431. Alumínio e seus compostos, 434 e 437. Alúmens, 443. Ferro, 506 e 407. Compostos

FIGURA 40 – PROGRAMA DA 5ª SÉRIE DE COUTO (1938)
FONTE: Couto (1938)

Pimenta (1958) direciona o estudo para 1º ano e Pimenta (1958) indica o estudo mais aprofundado dos Modelo Atômicos para o 3º ano:

PROGRAMA PARA O ENSINO DE QUÍMICA

Ciclo Colegial

3.^a série do Curso Científico

1. Metais: conceito, propriedades gerais. Noções de mineração e metalurgia. Ligas metálicas.
2. Estudo sucinto dos metais e compostos metálicos mais importantes. Ferro e suas ligas. Noções de siderurgia.
3. Rudimentos de análise quantitativa. Principais métodos título-métricos.
4. Estrutura do átomo. Isótopos. Teoria da combinação química.
5. Classificação periódica dos elementos.
6. Radioatividade. Transmutação dos elementos.
7. Soluções, conceito, propriedade; analogia com o estudo gasoso. Massas moleculares e atômicas. Electrólitos; electrólise.
8. Estudo geral dos colóides.
9. Termoquímica, suas leis. Cinética das reações; conceito de velocidade de reação, fatores que a influenciam. Catálise.
10. Equilíbrio químico; equilíbrio iônico. Extensão dos conceitos de ácido e de base.

3.^a série do Curso Clássico

Primeira Parte

1. Compostos orgânicos. Caracterização do carbônio, hidrogênio e nitrogênio nos compostos orgânicos. Constituição dos compostos orgânicos. Isomeria.
2. Sinopse das funções orgânicas. Radicais. Séries.
3. Estudo geral sucinto dos hidrocarbonetos, álcoois, fenóis, aldeídos, cetonas, carboxil-ácidos, ésteres e éteres. Exemplos mais importantes. Noções sobre lipídios.
4. Noções sobre glicídios. Apresentação dos mais importantes.
5. Estudo geral sucinto dos compostos orgânicos nitrogenados.

Segunda Parte

6. Metais: conceito, propriedades gerais. Noção de mineração e metalurgia. Ligas metálicas.

Terceira Parte

7. Estrutura do átomo. Isótopos. Teoria da combinação química. Radioatividade e transmutação dos elementos.
8. Classificação periódica dos elementos.
9. Solução, conceito, propriedades. Electrólitos; electrólise.
10. Termoquímica, suas leis. Conceito de velocidade de reação, fatores que a influenciam. Catálise. Noções sobre equilíbrio químico.

FIGURA 41 – PROGRAMA DE 3ª SÉRIE CICLO COLEGIAL DE PIMENTA (1958)

FONTE: Pimenta (1958)

No livro de Carvalho de Saffioti (1954), indica-se também o estudo para 3º ano:

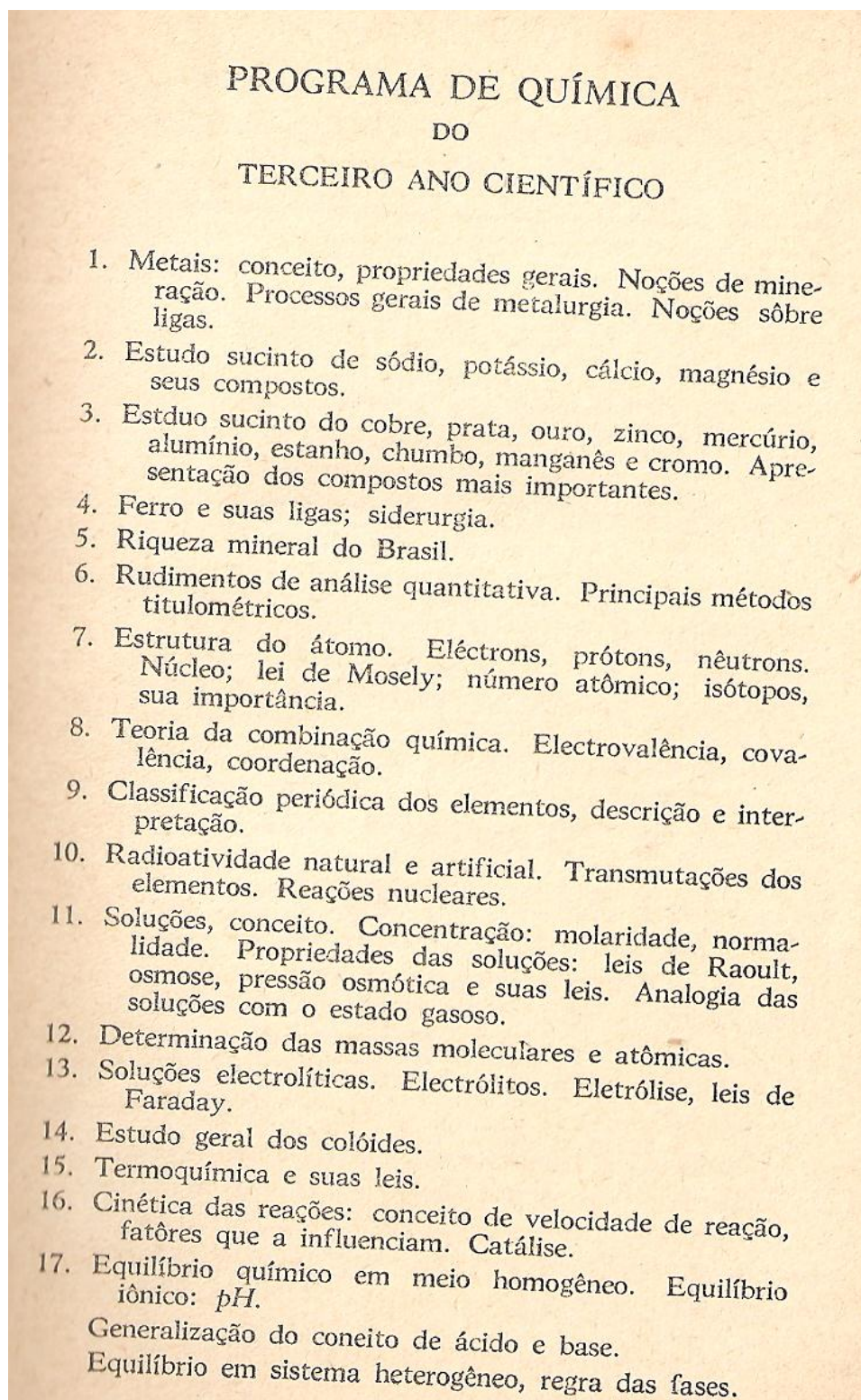


FIGURA 42 – PROGRAMA DE QUÍMICA TERCEIRO ANO DE CARVALHO E SAFFIOTI (1954)

FONTE: Carvalho e Saffioti (1954)

A questão VIII(b) teve como objetivo levantar dados referentes a como os LDQ inserem exercícios e atividades em suas *textualizações*. A partir do conjunto de dados analisados, desenvolveu-se a seguinte tabela:

TABELA 9 – DADOS RELATIVOS À QUESTÃO VIII(b)

Período	Livro	Inserir exercícios e atividades entre as seções	Inserir os exercícios no final do capítulo	Inserir exercícios e atividades entre as seções e no final do capítulo	Não inserir exercícios e atividades
F. Campos (1931 – 1941)	COUTO (1938)		X		
	SILVA (1936)				X
G.	PIMENTA (1957)				X
Capanema (1942 – 1960)	PIMENTA (1958)				X
	CARVALHO E SAFFIOTI (1954)				X
	CBA (1964a)		X		
	CBA (1964b)		X		
LDBEN 4.024 (1961 – 1970)	FELTRE E SETSUO (1969)			X	
	FELTRE E SETSUO (1970)	X			
LDBEN 5.692 (1971 – 1987)	POLITI E REIS (1979)			X	
	FELTRE (1988)	X			
Constituição Federal de 1988	PERUZZO E CANTO (1996)			X	
	NEHMI (1995)	X			
	NOVAIS (1997)			X	
LDBEN 9.692 (1996)	UTIMURA E LINGUANOTO (1998)	X			
	FELTRE (2008)			X	
PNLEM 2007	SANTOS E MOL (2006)			X	
	MORTIMER E MACHADO(2010)			X	
PNLD 2012	REIS (2010)			X	

Total	4	3	8	4
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FONTE: O autor (2012)

Com base na organização dos capítulos, a tabela 9 mostra que, dos 19 livros analisados, 15 inserem exercícios (8 inserem exercícios e atividades entre as seções e no final do capítulo, 4 inserem entre as seções, e 3 inserem no final do capítulo), enquanto 4 não inserem exercícios.

Como dito anteriormente, ao todo, 15 LDQ inserem exercícios e atividades no capítulo destinado aos Modelos Atômicos. A partir das LDBEN 4.024/61, LDBEN 5.692/71 e Constituição Federal de 1988 é muito recorrente a inserção de exercícios discursivos e de múltipla escolha, devido a necessidade de preparar para o vestibular e exames de qualificação⁵⁰. Mesclam exercícios de autoria própria, com os de múltipla escolha de vestibulares conceituados de São Paulo e do Rio de Janeiro. Depois da LDBEN 9.394/96, há uma grande preocupação com questões de contextualização de conteúdo e problematização. Fazendo com que os livros didáticos desenvolvam questões de raciocínio e problematização. Junto a estes, são inseridos exercícios de vestibular e ENEM como forma de atender às demandas sociais para preparação para testes seletivos.

No PNLEM (2008) e PNLD (2012) há uma forte preocupação em algumas obras como a de Santos e Mol (2006) e Mortimer e Machado (2011), em tornar o ensino mais cotidiano e problematizador. Nesses livros, além dos testes discursivos, de vestibular e ENEM, há também questões que buscam desenvolver o espírito crítico do aluno, trazendo a proposta de formação do cidadão. O que vai ao encontro da função do Ensino Médio, definida na LDBEN 9.394/96, artigo 35, inciso III: "o aprimoramento do educando como pessoa humana, incluindo a formação ética e o desenvolvimento da autonomia intelectual e do pensamento crítico" (BRASIL, 1996).

Pode-se depreender que os livros didáticos operaram por um delicado equilíbrio ao longo da história do ensino de química no Brasil, onde tiveram que atender os anseios da sociedade que buscava preparação para os variados exames de seleção e também atender aos anseios do MEC de tornar o ensino da química

⁵⁰ Vale lembrar que o vestibular não é uma criação recente, ele sempre existiu sobre o nome de exame de admissão ou qualificação, que era prestado pelos alunos das instituições certificadas pelo colégio Dom Pedro II, de acordo com Mortimer (1988) e Lopes (1990) esse caráter não muda, porém de reforma a reforma há algumas adaptações como tentativa de dificultar ou facilitar o acesso ao ensino superior.

mais cotidiano e problematizador, de modo a formar cidadãos críticos conforme orientação da LDBEN 9.394/96.

Com base nestes dados, pode-se inferir a forma de como as *noosferas* foram responsáveis pelo desenvolvimento desses LDQ, adaptando seus produtos de forma a tentar atender a duas demandas. De um lado, uma sociedade que consome o livro didático e, de outro, o governo fixando certos preceitos para os livros, determinando sua distribuição ou retenção.

Outro fato é que os LDQ apresentam exercícios conceituais que objetivam uma única resposta correta. Essa característica pode estar ligada com o aspecto social e epistemológico, dentro da análise da *Transposição Didática*. No aspecto social, infere-se que os LDQ trazem exercícios de provas e testes seletivos, indo ao encontro da necessidade que se tem do Ensino Médio, de formar para o vestibular, ENEM e outras formas de seleção. E com o aspecto epistemológico, onde os exercícios têm caráter de aplicação de conceitos, objetivando uma única resposta.

Nas coleções dos últimos períodos (PNLEM 2007 e PNLD 2012), há uma inserção de outros tipos de atividades. Percebe-se em Mortimer e Machado (2011) e Santos e Mol (2006), a inserção de experimentos que visam o desenvolvimento de algum conceito relacionado ao conteúdo. Nos exercícios, como levantados em Santos e Mol (2006), há a inserção de atividades que levam o aluno a algum tipo de reflexão.

Pode-se depreender que, ao longo das reformas educacionais, houve uma mudança na postura epistemológica do LDQ. Inicialmente, os exercícios e atividades possuíam um caráter confirmatório do conteúdo. Posteriormente, passaram a ter um caráter mais flexível, buscando discernir o conteúdo certo do errado e, ao mesmo tempo, objetivando fazer o aluno formular seus conceitos, respostas e a pensar sobre sua sociedade.

Dentre os 8 livros que apresentam exercícios e atividades entre as seções e ao final dos capítulos, destacam-se Feltre e Setsuo (2008), Politi e Reis (1979), Feltre (2008), Santos e Mol (2006), Mortimer e Machado (2011) e Reis (2010).

O LDQ de Santos e Mol (2006) apresenta ao longo dos capítulos, exercícios que tem o objetivo de desenvolver a discussão e a problematização do conteúdo,

com questões do tipo: “O que é energia elétrica? O que é eletricidade?” (SANTOS e MOL, 2006, p. 140). Exemplo:

considere as seguintes informações: a) de acordo com Rutherford, o desvio de partículas alfa no experimento era resultado da sua aproximação a cargas positivas. b) somente sofria desvio. Então, porque o modelo atômico de Thomson precisava ser reformulado? (SANTOS e MOL, 2006, p. 145).

Entende-se que os exercícios como aparecem em Santos e Mol (2006), tem como objetivo despertar o questionamento sobre o conteúdo estudado ao longo do capítulo, colocando exercícios variados, como mostra a figura:

EXERCÍCIOS

Atenção!
Responda as questões no seu caderno.

1. O que é modelo científico? Dê um exemplo de modelo que você já tenha estudado em Ciências.

2. Sabemos que a Terra é bastante antiga e muitos dos animais e vegetais existentes nos primórdios do planeta já não existem mais. Porém, é comum vermos em desenhos, filmes e em alguns parques modelos de dinossauros que apresentam riquezas de detalhes. Explique, com suas palavras, como os cientistas chegaram a esses modelos tão perfeitos.

3. Utilizando o modelo proposto por Thomson responda:

a) Como os elétrons e os prótons estão distribuídos nos átomos?

b) Qual a diferença entre esse modelo e o de Rutherford?

4. Durante os experimentos com raios catódicos, Thomson observou que, ao submeter o tubo de raios a um campo elétrico, os raios eram atraídos para o pólo positivo. Como você explica esse fato?

5. Por que, ao longo dos tempos, os cientistas propuseram diversos modelos diferentes para representar o átomo?

6. Comente a frase: O modelo atômico de Rutherford mostra exatamente como é o átomo, pois indica que ele tem um núcleo e uma eletrosfera ao redor deste.

7. Como seria o resultado do experimento de Rutherford se o átomo fosse como propõe o modelo de Thomson?

8. Durante a experiência realizada sobre a estrutura da matéria, Rutherford chegou às seguintes conclusões:

I – O átomo é constituído por duas regiões distintas: o núcleo e a eletrosfera.

II – O núcleo atômico é extremamente pequeno em relação ao tamanho do átomo.

III – O átomo tem uma região em que existe muito espaço vazio.

Quais fatos levaram Rutherford a chegar a essas conclusões?

9. Qual região do átomo é mais densa? Por quê?

10. Uma importante contribuição ao estudo da matéria foi a descoberta de modelos e partículas presentes no átomo. Relacione os nomes dos cientistas com as alternativas citadas.

1. Rutherford 3. Chadwick
2. Dalton 4. Thomson

a) É o descobridor do nêutron.
b) Seu modelo atômico era semelhante a uma bola de bilhar.
c) Seu modelo atômico era semelhante a um panetone.
d) Criou um modelo para o átomo semelhante ao sistema solar.

11. (ITA-SP) Em 1803, John Dalton propôs um modelo de teoria atômica. Considere que sobre a base conceitual desse modelo sejam feitas as seguintes afirmações:

I – O átomo apresenta a configuração de uma esfera rígida.
II – Os átomos caracterizam os elementos químicos e somente os átomos de um mesmo elemento são idênticos em todos os aspectos.
III – As transformações químicas consistem de combinação, separação e/ou rearranjo de átomos.
IV – Substâncias compostas são formadas de átomos de dois ou mais elementos unidos em uma razão fixa.

Qual das opções a seguir se refere a todas as afirmações CORRETAS?

a) I e IV. d) II, III e IV.
b) II e III. e) I, II, III e IV.
c) II e IV.

12. (UFSC) Na famosa experiência de Rutherford, no início do século XX, com a lâmina de ouro, o(s) fato(s) que (isoladamente ou em conjunto) indicava(m) o átomo possuir um núcleo pequeno e positivo foi(foram):

a) A maioria das partículas alfa atravessaria os átomos da lâmina sem sofrer desvio de sua trajetória.
b) Ao atravessar a lâmina, uma maioria de partículas alfa sofreria desvio de sua trajetória.
c) Um pequeno número de partículas alfa atravessando a lâmina sofreria desvio de sua trajetória.
d) Um grande número de partículas alfa não atravessaria a lâmina.
e) As partículas alfa teriam cargas negativas.

FIGURA 43 – PÁGINA DE EXERCÍCIOS DO FINAL DO CAPÍTULO SANTOS E MOL
FONTE: Santos e Mol (2006).

Santos e Mol (2006) também inserem atividades diferenciadas:

ATIVIDADE

IMAGINANDO O INVISÍVEL

Esta atividade deve ser feita em grupo na própria sala de aula. Cada equipe deverá montar um *kit* com uma caixa de papelão, pequena ou média (pode ser uma caixa de sapato), e três objetos diferentes que só devem ser conhecidos pelos componentes do grupo. Esses objetos podem ser uma esfera, um dado, uma borracha ou outro qualquer. A caixa deverá estar bem lacrada e, se possível, embrulhada com outro papel.

A atividade consiste em analisar as caixas dos outros grupos e tentar descobrir o que há dentro delas sem, é claro, abri-las.

Como é possível descobrir o conteúdo da caixa?

Para isso, vamos procurar descrever possíveis propriedades dos objetos contidos nas caixas, como: dureza, textura da superfície, tipos de material, propriedades magnéticas, densidades, formas, tamanhos, etc.

Construa em seu caderno uma tabela como a apresentada ao lado e complete-a.

Com base nas propriedades observadas, faça um desenho (modelo representativo) que melhor represente os objetos que você identificou em cada caixa.

Depois de elaborado um modelo para os objetos de uma caixa, troque de caixa com outro grupo e proceda à nova análise, até que sejam analisadas todas elas.

Depois de observadas todas as caixas, debatam as conclusões de cada grupo a respeito dos objetos e vejam o que há em comum, confrontando os modelos propostos para os objetos de cada caixa, discutindo os critérios que levaram à sua elaboração, e proponham, quando possível, um modelo comum.

Solicitem ao professor que abra as caixas e confira o que tem em cada uma.

Os modelos elaborados correspondem às características reais dos objetos? Por quê?

PROPRIEDADES DOS OBJETOS CONTIDOS NAS CAIXAS			
Número da caixa	Objeto	Características que possibilitam identificar propriedades do objeto	Propriedades do objeto
Caixa 1	1	Objeto pesado que rola	Objeto sólido, liso, esférico...
	2		
	3		
Caixa 2	1		

FIGURA 44 – PROPOSTA DE ATIVIDADE SANTOS E MOL

FONTE: Santos e Mol (2006)

Em Mortimer e Machado (2011), há a inserção de exercícios e atividades experimentais, de forma tradicional, seguindo um roteiro: apresentação dos materiais, procedimentos e algumas questões para discussão, conforme o exemplo:

ATIVIDADE 2

O teste da chama

O teste da chama é uma atividade muito usada na identificação de substâncias químicas. Sabe-se que os átomos, quando aquecidos a uma determinada temperatura, emitem luz de frequência bem definida, que é característica para cada tipo de átomo. Como cada frequência diferente de luz visível corresponde a uma cor característica, esse teste permite a identificação dos tipos de átomos presentes numa amostra de solução qualquer simplesmente pela cor que a chama adquire em contato com essa solução.

Nesta atividade, vamos realizar o teste de chama para algumas substâncias. Posteriormente, tentaremos explicar os resultados obtidos recorrendo a um outro modelo atômico: o modelo de Bohr.

Material

Quatro latas de refrigerante, um prego, areia suficiente para encher uma lata de refrigerante de 350 mL, uma rolha, uma régua, quatro béqueres (para colocar cada uma das quatro soluções a seguir), seringa ou conta-gotas ou proveta de 10 mL, álcool comercial, 25 mL de cada uma das seguintes soluções: HCl (ácido clorídrico), BaCl_2 (cloreto de bário), CaCl_2 (cloreto de cálcio) e SrCl_2 (cloreto de estrôncio).

Tenha cuidado!

Atenção: Cuidado ao manipular o HCl e o álcool. Faça isso somente sob a supervisão de seu professor.

O que fazer

A5 Peguem as quatro latas de refrigerante e façam 250 furos em cada uma delas. Para evitar que a lata amasse, coloquem areia em seu interior e tampem com a rolha. Com o auxílio do prego, façam os furos na parede lateral da lata, a partir da altura de 2 cm da base (meçam essa altura com a régua).

A6 Construam, no caderno, um quadro com duas colunas: **Nome das substâncias** e **Cor resultante da queima da substância na chama**. Esse quadro receberá os dados observados neste experimento.

A7 Adicionem 3 mL (aproximadamente 60 gotas) de etanol (álcool etílico 95%) dentro de cada lata.

A8 Coloquem, sobre a tampa da primeira lata, próximo à abertura, algumas gotas de solução de HCl (ácido clorídrico). Nas outras três latas adicionem, usando o mesmo procedimento, soluções de BaCl_2 (cloreto de bário), CaCl_2 (cloreto de cálcio) e SrCl_2 (cloreto de estrôncio).

A9 Indiquem a substância que está sobre a tampa das latas, anotando seu nome num pedaço de papel e colocando-o na frente da lata.

A10 Inflamem o conteúdo das quatro latas, jogando um palito de fósforo aceso, **com muito cuidado**, em seu interior. Observem o que ocorre e anotem no quadro no caderno.



Figura 5-38: Exemplo de lata perfurada.

FIGURA 45 – PROPOSTA DE ATIVIDADE EXPERIMENTAL DE MORTIMER E MACHADO
 FONTE: Mortimer e Machado (2011)

Mortimer e Machado (2011) apresentam exercícios, durante o capítulo, de forma a retomar os conceitos estudados, abertos e discursivos:

EXERCÍCIOS

- E1.** A ideia de átomo remonta à Grécia antiga. Duas linhas diferentes de pensamento existiam. Uma delas associada ao filósofo Aristóteles, e outra associada aos filósofos Leucipo, Demócrito e Epicuro. Explícite essas duas linhas de pensamento.
- E2.** Descreva o modelo atômico proposto por Thomson.
- E3.** Qual a diferença entre raios X e radioatividade?
- E4.** Como foram descobertos os raios X?
- E5.** Explique como foi descoberta a radioatividade.
- E6.** O que são partículas alfa?
- E7.** Em 1987, catadores encontraram, na cidade de Goiânia, uma cápsula dentro de um cilindro de metal de um aparelho hospitalar usado em tratamentos de radioterapia. Desconhecendo o sinal que indicava a presença de material radioativo, eles abriram o cilindro e a cápsula. O dono do ferro-velho que comprou as peças, fascinado pela fosforescência do material encontrado – célio 137 –, espalhou esse material entre vizinhos e amigos, provocando um desastre radioativo de graves consequências. Com base nas informações do texto 4 e em outras informações que você deverá pesquisar, responda:
- Que sinal indica presença de material radioativo?
 - Se você encontrasse esse sinal em um dispositivo qualquer abandonado num ferro-velho, que providências deveria tomar?
 - Supondo que você encontrasse um material sem nenhuma indicação de que fosse radioativo, que características desse material evidenciariam a sua radioatividade? Que providências você deveria tomar nesse caso?

FIGURA 46 – EXERCÍCIOS PROPOSTOS AO FINAL DE ATIVIDADE DE MORTIMER E MACHADO
 FONTE: Mortimer e Machado (2011)

Havendo, também, exercícios que têm por objetivo suscitar alguns debates em sala de aula: “Q8. Qual seria o resultado previsto para a experiência de Geiger e Marsden, se o modelo de Thomson estivesse correto?” (MORTIMER e MACHADO, 2011, p. 152).

Entre os 4 livros que inserem exercícios entre as seções, citamos: Feltre e Setsuo (1970), Feltre (1988), Nehmi (1995) e Utimura e Linguanoto (1998). Por meio da análise, pode-se entender que todas as 4 obras apresentam exercícios conceituais abertos e de múltipla escolha, como no exemplo de Feltre e Setsuo (1970):

FELTRE-SETSUO

- a diferença entre o número cancelado e 8 ou 18 (imediatamente inferior), deve ser escrito na camada seguinte.

c) Se ainda, a nova camada tem mais de 8 elétrons, deve-se repetir a operação do item b.

EXERCÍCIOS

(111) Seja a configuração eletrônica do átomo de cálcio de $Z = 20$. Então temos:

$\begin{array}{l} K - 2 \\ L - 8 \\ M - 10 \end{array}$ <p>1a. etapa</p>	→	$\begin{array}{l} K - 2 \\ L - 8 \\ M - 8 \\ N - 2 \end{array}$	<p>Entre 8 e 18, o número 8 é imediatamente inferior a 10.</p> <p>diferença (10 - 8)</p>
--------------------------------------------------------------------------	---	-----------------------------------------------------------------	------------------------------------------------------------------------------------------

(112) Seja a configuração eletrônica do átomo de iôdo de $Z=53$.

$\begin{array}{l} K - 2 \\ L - 8 \\ M - 18 \\ N - 25 \end{array}$ <p>1a. etapa</p>	então	$\begin{array}{l} K - 2 \\ L - 8 \\ M - 18 \\ N - 18 \\ O - 7 \end{array}$	<p>18 é imediatamente inferior a 25 na escolha entre 8 e 18.</p> <p>diferença (25 - 18)</p>
------------------------------------------------------------------------------------	-------	----------------------------------------------------------------------------	---------------------------------------------------------------------------------------------

(113) Seja a configuração eletrônica do átomo de frâncio de $Z = 87$.

$\begin{array}{l} K - 2 \\ L - 8 \\ M - 18 \\ N - 32 \\ O - 27 \end{array}$ <p>1a. etapa</p>	→	$\begin{array}{l} K - 2 \\ L - 8 \\ M - 18 \\ N - 32 \\ O - 18 \\ P - 9 \end{array}$ <p>2a. etapa</p>	então	$\begin{array}{l} K - 2 \\ L - 8 \\ M - 18 \\ N - 32 \\ O - 18 \\ P - 9 \\ Q - 1 \end{array}$ <p>(Resposta)</p>
----------------------------------------------------------------------------------------------	---	-------------------------------------------------------------------------------------------------------	-------	-----------------------------------------------------------------------------------------------------------------

diferença (27 - 18)

(114) Escreva a configuração eletrônica do átomo de alumínio de $Z = 13$, segundo suas camadas eletrônicas.

(115) Idem, para o átomo de antimônio de $Z = 51$.

(116) Quantos elétrons possui o átomo de $Z = 37$ na sua camada externa?

a) 1 b) 8 c) 9 d) 5

FIGURA 47 – EXERCÍCIOS FINAL DO CAPÍTULO FELTRE E SETSUO
 FONTE: Feltre e Setsuo (1970)

No livro de Feltre (1988) apresentam-se os exercícios:

Cap. 3 – Estrutura Atômica 55

EXERCÍCIOS PROPOSTOS

119. (E.E. MAUÁ-SP) Qual a constante que melhor caracteriza o átomo de um elemento químico? Defina-a.

120. O átomo de potássio (${}_{19}^{39}\text{K}$) em seu estado normal ou eletricamente neutro (K^0) possui:

n° de prótons: $Z =$ n° de nêutrons: $N =$
 n° de massa: $A =$ n° de elétrons: $E =$

Ao perder um elétron, esse átomo se transforma no cátion potássio, com carga elétrica ou valência $+1 (\text{K}^+)$, o qual possui:

n° de prótons: $Z =$ n° de nêutrons: $N =$
 n° de massa: $A =$ n° de elétrons: $E =$

121. O átomo de enxofre (${}_{16}^{32}\text{S}$), em seu estado normal (S^0) possui:

n° de prótons: $Z =$ n° de nêutrons: $N =$
 n° de massa: $A =$ n° de elétrons: $E =$

Ao ganhar dois elétrons, esse átomo se transforma no ânion sulfeto, com carga elétrica ou valência $-2 (\text{S}^{2-})$, o qual possui:

n° de prótons: $Z =$ n° de nêutrons: $N =$
 n° de massa: $A =$ n° de elétrons: $E =$

122. (FEI-SP) Preencha os retângulos vazios da tabela abaixo:

Elemento Químico	Número Atômico	Partículas por Átomos			Nº de Massa
		Prótons	Elétrons	Nêutrons	
Alumínio	13				27
Fósforo	15			16	
Berílio		4			9

123. (FEI/MAUÁ-SP) O íon Li^+ e o íon H^- (hidreto) têm estruturas eletrônicas idênticas, porém, o íon hidreto é muito maior que o íon de lítio. Por quê?
 Dados: números atômicos $\text{H} = 1$ $\text{Li} = 3$

124. (U.F. CE) Conhecem-se os seguintes dados referentes aos átomos A, B e C:

- a) A tem número atômico 14 e é isôbaro de B
- b) B tem número atômico 15 e número de massa 30, sendo isótopo de C
- c) A e C são isótonos entre si

Qual o número de massa de C?

125. Examine os átomos A, B, C, D e E:

${}_{11}^{24}\text{A}$ ${}_{12}^{24}\text{B}$ ${}_{13}^{25}\text{C}$ ${}_{11}^{25}\text{D}$ ${}_{12}^{26}\text{E}$

Identifique:
 isótopos: _____
 isôbaros: _____
 isótonos: _____

126. Examine, ainda, os átomos do exercício anterior. Imagine, agora, como seria o átomo X que é isótopo de B e isôbaro de D.
 O átomo X terá: $Z =$ _____ $N =$ _____ $A =$ _____

FIGURA 48 – EXERCÍCIOS DE FELTRE (1988)

FONTE: Feltre (1988)

No exemplos de Feltre e Setsuo (1970) e Feltre (1988), os exercícios são objetivos. Em Feltre e Setsuo (1970) são de múltipla escolha com uma única resposta e de aplicação do conteúdo. Na versão de Feltre (1988), são exercícios de vestibular, com a mesma característica de aplicação da teoria com uma única resposta.

No livro de Utimura e Linguanoto (1998), os exercícios são abertos, discursivos e de aplicação da teoria.

Já em Nehmi (1995), encontram-se exercícios discursivos abertos, de múltipla escolha, com uma única resposta, mesclando exercícios de autoria própria com os de vestibulares, como apresentado logo abaixo:

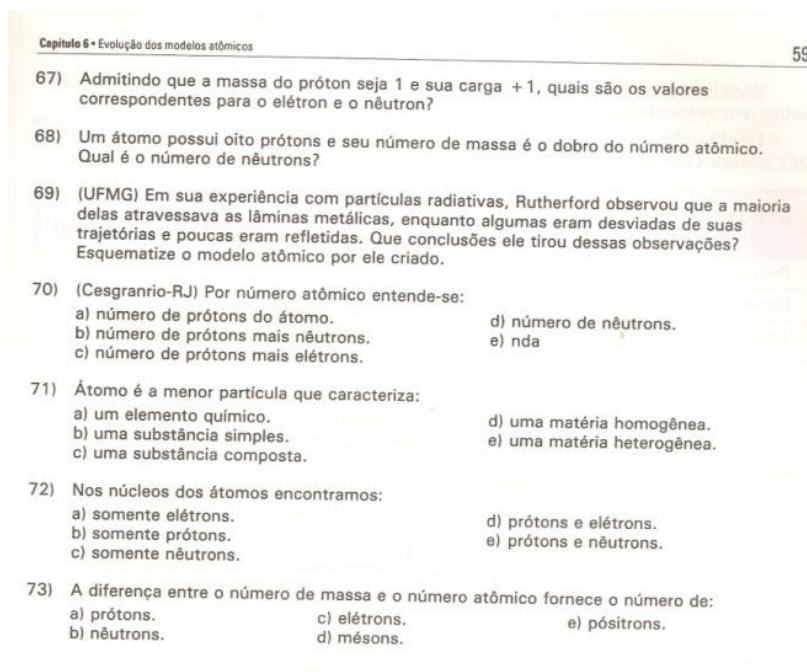


FIGURA 49 – EXERCÍCIOS DE NEHMI (1995)

FONTE: Nehmi (1995)

Assim, percebe-se que nestes livros os exercícios entre as seções têm a função de retomar o conteúdo ensinado. E em alguns exemplos como em Nehmi (1995) e Feltre (1988), apresentam teste de provas de seleção relacionando o conteúdo ensinado.

Dos 4 livros que não inserem nenhum tipo de atividade e exercícios temos as seguintes obras: Silva (1936), Pimenta (1957 e 1958) e Carvalho e Saffioti (1954). O objetivo é apenas ser fonte de consulta, tanto para o aluno como para o professor. No livro de Silva (1936), a característica dessas obras fica mais clara:

O antelóquio à 1ª edição dá a origem deste trabalho, que viu a luz a publicidade graças as solicitações dos alunos que já recebiam oralmente estas lições (SILVA, 1936, p. 5).

Dos 3 livros que inserem exercícios no final do capítulo, temos Couto (1938) e CBA (1964a e 1964b). No livro de Couto (1938), são apresentados ao final do capítulo:

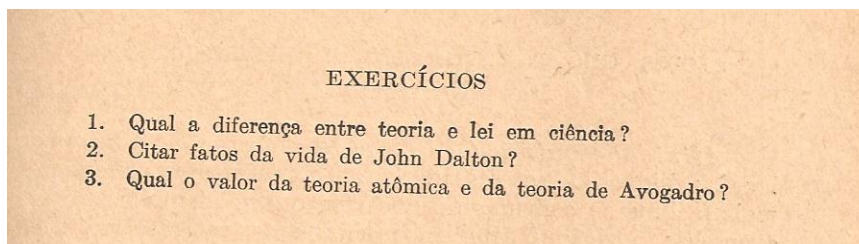


FIGURA 50 – EXERCÍCIOS DE COUTO (1938)

FONTE: Couto (1938)

Porém, os exercícios apresentados por Couto (1938) são abertos, discursivos e tem como objetivo retomar os pontos estudados ao longo do capítulo.

Nos livros da coleção CBA (1964a, 1964b) são apresentados exercícios de cunho diferenciado do pressuposto, envolvendo um estilo de raciocínio, porém, objetivando a retomada dos conteúdos estudados ao longo do capítulo, por meio de problemas:

1. Quando apresentamos os pés num tapete de lã, especialmente num dia frio e com pouca umidade, há produção de uma considerável carga elétrica nas solas de couro dos sapatos. Como se poderia determinar o sinal desta carga? Que parte do posento adquire uma carga de sinal oposto? 2. Um relâmpago é uma corrente elétrica que passa entre uma nuvem e talvez o solo ou outra nuvem. Qual deve ser a situação no momento exato antes do aparecimento do relâmpago? (...) (CBA, 1964a, p. 40).

Desse modo, a partir das questões VIII(a) e VIII(b), pode-se compreender que os LDQ se dividem em dois momentos distintos: anteriores a Reforma Gustavo Capanema e os posteriores.

Os LDQ anteriores à Reforma G. Capanema, com exceção de Couto (1938), têm a função de sistematizar as notas de aulas dos professores de química, de forma a desenvolver um livro texto que sirva de base, deixando a cargo do professor o trabalho de propor exercícios e atividades ao seus alunos. Enquanto os posteriores, tentam atender a certas demandas sociais que julgam importante (a preparação do aluno para testes de seleção).

Assim, a *programabilidade de aquisição dos saber*, modifica-se ao longo do tempo, a partir de cada nova proposta de *Transposição Didática* no LDQ. Inicialmente, apresentam-se em 3 LDQ *transposições* sem exercícios, com o programa de ensino impresso na obra, dando um caráter mais rígido ao manual e

com o objetivo de ser um livro texto apenas. Posteriormente, em 16 LDQ dos programas mais recentes, há a inserção de exercícios, no capítulo Modelos Atômicos, denotando a necessidade de preparar o estudante para testes de seleção. Porém, observa-se uma nova mudança desse elemento nos LDQ mais atuais, como em Mortimer e Machado (2006 e 2011), que trazem, além das questões de vestibular, questões que levam o aluno a desenvolver um raciocínio em torno de problemáticas da área de ensino de química e a formar o espírito crítico e cidadão.

4.2.9 ENVELHECIMENTO MORAL E BIOLÓGICO

O elemento *Envelhecimento Moral* apresenta-se quando um livro didático moderniza os exemplos usados para explicar um conteúdo. Já, o *Envelhecimento Biológico* se faz presente quando um LDQ retira ou adiciona novos *saberes* para ficar de acordo com o que a ciência comunica. A partir desses elementos, desenvolveu-se duas questões:

IX(a). Ao longo da história, o saber a ensinar é reestruturado (modernizado) para atender a certas demandas sociais?

IX(b). Algum conceito relacionado ao Modelo Atômico é retirado ao longo das reformas?

A questão IX(a) tem como objetivo levantar o *envelhecimento moral do saber* que se faz presente na modernização de exemplos apresentados nas *textualizações* do livro didático de química. Dos dados levantados, desenvolveu-se a tabela 10:

TABELA 10 – DADOS REFERENTES À QUESTÃO IX(a)

Período	Livro	Sim	Não	Tipo de exemplos
F. Campos (1931 – 1941)	COUTO (1938)		X	-
	SILVA (1936)		X	-
	PIMENTA (1957)		X	-
G. Capanema (1942 – 1960)	PIMENTA (1958)		X	-
	CARVALHO E SAFFIOTI (1954)		X	-
	CBA (1964a)	X		Cotidiano, Válvulas de Rádio e Televisão
LDBEN 4.024 (1961 – 1970)	CBA (1964b)		X	-
	FELTRE E SETSUO (1969)	X		Processo de Fermentação, Vidros coloridos, balança
	FELTRE E SETSUO (1970)	X		Homem atirando em uma tela de galinheiro, exemplo

					do jogador de futebol
LDBEN 5.692 (1971 – 1987)	POLITI E REIS (1979)		X		-
	FELTRE (1988)	X			Exemplo do bastão atritado com carga,
	PERUZZO E CANTO (1996)	X			Exemplo do bastão atritado, exemplo das caixas e balas, exemplos dos raios catódicos, exemplo da cirurgia ocular, estádio da marcanã
Constituição Federal de 1988					Relação do pão de açúcar com dedal,
	NEHMI (1995)	X			-
LDBEN 9.394 (1996)	NOVAES (1997)		X		-
	UTIMURA E LINGUANOTO (1998)	X			Exemplo do prisma
	FELTRE (2008)	X			Exemplo com escala musical, exemplo dos bastão eletrizado e de tubos de neon, exemplo da aplicação de raios catódico (TV e Raio X), radioterapia, exemplo das ondas, prisma, sinaleiro
PNLEM 2008					Relampago, raio x, Maracanã, Protetor solar, espectrofotômetro, fogos de artifício,
	SANTOS E MOL (2006)	X			Difração de raio X e imagens de microscópio de tunelamento, espectrofotometro, pente eletrizado, imagem raio x, panetone, uso de contraste para detecção de tumores, exemplo do microondas, radio e televisão, filtro solar, onda na água, arco-iris
	MORTIMER E MACHADO(2010)	X			Ambar, bastão atritado, pilha de volta, arco iris, gamafria, tomografia computadorizada, controle remoto, Fogos de artifício,
PNLD 2012					
	REIS (2010)				
	Total		11	8	

FONTE: O autor (2012)

Dos 19 livros analisados, 11 apresentam exemplos que desmonstram que o *saber a ensinar* foi reestruturado em suas textualizações, enquanto 8 não.

É possível depreender então, que os 11 LDQ procuraram atualizar (modernizar) seus exemplos de acordo com a necessidade social de se inserir tópicos que fizessem parte do cotidiano do aluno evidenciando assim o *envelhecimento moral do saber a ensinar*. Há também um aumento do número de

exemplos, que aparecem na unidade sobre Modelos Atômicos, ao longo das Reformas Educacionais no Brasil. Com base no *envelhecimento moral do saber*, observa-se a diferença dos exemplos apresentados pelos livros analisados, onde cada um é contextualizado com uma realidade social e tecnológica diferente.

Essa necessidade pode estar ligada ao critério nomeado por Chevallard (1991) de utilidade do *saber*, onde os LDQ somente apresentam *saberes* que podem ser relacionados com a realidade social do aluno, aqueles que não tem essa possibilidade de ligação são retirados do LDQ.

Outro ponto é que 8 LDQ, das reformas F. Campos e G. Capanema, não trazem exemplos que desmonstram que o *saber a ensinar* foi reestruturado em seus textos. Essa característica pode estar ligada ao caráter enciclopédico que esses LDQ tem, em relação às coleções mais recentes, buscando trazer mais *saberes* sem se preocupar com sua didatização, deixando, possivelmente, a cargo do professor a didatização e proposição de exemplos. A seguir, apresentam-se alguns exemplos desses LDQ.

Dentre os 11 que possuem exemplos que desmonstram que o *saber a ensinar* foi reestruturado, temos o CBA (1964a), que em sua textualização apresenta um único exemplo de aplicação da eletricidade nos Modelos Atômicos, citando as válvulas de rádio e televisão. Este exemplo está de acordo com o *envelhecimento moral*, pois em 1964 e posteriormente os equipamentos de som e vídeo utilizavam válvulas para seu funcionamento. Atualmente, não vemos este exemplo, pois não temos mais equipamentos que usam essa tecnologia, evidenciando uma modernização.

Feltre e Setsuo (1969 e 1970) trazem exemplos de balanças, relações do átomo com estádios de futebol e o exemplo do *craque* para explicar os níveis energéticos. Esses exemplos, ligados ao futebol, podem ser um reflexo dos triunfos no esporte pela Seleção Brasileira naquele tempo. Ilustrando a necessidade de usar exemplos que fazem parte do cotidiano do leitor, de acordo com o *envelhecimento moral*.

Já Mortimer e Machado (2011) e Feltre (2008), trazem exemplos mais recentes como televisores e rádios, que usam tecnologia advinda da eletrônica e dos

	NEHMI (1995)	X			X	X	X	X	X	X	X	X	
	NOVAIS (1997)	X			X	X	X	X	X	X	X	X	
LDBEN 9.394/1996	UTIMURA E	X			X	X	X	X			X	X	
	LINGUANO TO (1998)												
PNLEM 2008	FELTRE (2008)	X			X	X	X	X	X	X	X	X	
	SANTOS E MOL (2006)	X			X	X	X	X			X	X	
	MORTIME R E	X			X	X	X	X			X	X	
PNLD 2012	MACHADO (2011)												
REIS (2010)	X	X			X	X	X	X	X	X	X	X	X
Total		16	2	2	5	18	16	15	15	12	15	13	1

FONTE: O autor (2012)

Pode-se levantar que dos 19 LDQ, 18 apresentam as propriedades atômicas, 16 apresentam o conteúdo Matéria, subdivisões e substâncias, 16 apresentam a estrutura atômica, 15 apresentam a eletricidade, 15 apresentam a Radioatividade, 15 apresentam a tabela periódica, 13 apresentam ligações químicas, 12 apresentam as leis de combinações, 5 apresentam a teoria de valência, 2 apresentam a teoria de Avogrado, 2 apresentam a afinidade química e 1 livro apresenta a teoria de Gay-Lussac.

Infere-se, de acordo com os dados colhidos, que os 19 LDQ analisados sofreram *envelhecimento biológico do saber* a partir do momento em que retiraram *saberes* sobre afinidade química e teoria de valência, ao mesmo tempo, procurando inserir novos *saberes* para dar uma nova visão e aplicabilidade ao conteúdo Modelos Atômicos. Justificando a inserção de estudos sobre tabela periódica, ligações químicas, leis de combinações e sobre a teoria de Gay-Lussac.

Os conteúdos apresentados pelos LDQ podem ser divididos em 3 grupos distintos: (a) os que sofreram *envelhecimento biológico*; (b) os que não sofreram *envelhecimento biológico*, (c) os que foram inseridos para justificar novas demandas no ensino de química e (d) os que saem dos LDQ e depois retornam.

Dentre os conteúdos do grupo (a) temos a teoria de valência e afinidade química. A afinidade química consta nos LDQ da Reforma F. Campos (Couto (1938)

e a teoria de valência está presente nos livros da Reforma F. Campos e G. Capanema (Couto (1938) e Silva (1936)).

Dentre os conteúdos do grupo (b) temos: matéria, subdivisões, substâncias e propriedades atômicas. Eles estão presentes desde os LDQ da Reforma F. Campos. São eles: Couto (1938), Silva (1936), Pimenta (1957 e 1958), Feltre (2008), Santos e Mol (2006), Mortimer e Machado (2011) e Reis (2010).

Dentre os conteúdos do grupo (c) temos: estrutura atômica, eletricidade, Radioatividade, tabela periódica, ligações químicas, leis de combinações e a teoria de Gay-Lussac. Onde o *saber* pertinente a tabela periódica surge a partir da Reforma G. Capanema, com o livro de Pimenta (1958). As ligações químicas surgem na LDBEN 4.024 de 1961 com aparição no livro da coleção CBA (1964b). As leis das combinações químicas aparecem durante a Reforma F. Campos com o livro de Silva (1936), que de todos analisados é o primeiro a trazer esse *saber*. E a teoria de Gay Lussac aparece mais recentemente, no livro de Reis (2010), do PNLD 2012.

Dentre os conteúdos do grupo (d) temos a teoria de Avogrado, que aparece, inicialmente, em Couto (1938), estudada em conjunto com a teoria atômica de John Dalton, que é retirada, nas reformas posteriores e retorna no livro de Reis (2010), junto ao estudo da teoria atômica de Dalton.

A partir da análise do *envelhecimento moral e biológico* do saber, pode-se considerar que os LDQ modernizaram os exemplos apresentados nos capítulos destinados ao Modelo Atômico, expressando a necessidade de estar de acordo com as demandas sociais e aproximando o *saber a ensinar* da realidade do aluno. Há uma mudança dos *saberes* que integram o capítulo Modelos Atômicos, onde *saberes* como afinidade e teoria de valência, foram sendo substituídos por outros mais atualizados de acordo com o que a ciência desenvolve e comunica à sociedade. Em outras palavras, há a atualização dos *saberes* apresentados, na unidade Modelos Atômicos, mostrando que os LDQ estão de acordo com certas demandas científicas, ensinando *saberes* mais atualizados.

CONSIDERAÇÕES FINAIS

Esta pesquisa buscou investigar como ocorreu a *transposição do saber sábio ao saber a ensinar do conteúdo Modelos Atômicos em livros didáticos de química, no período de 1931 a 2012*. Foi desenvolvida em 4 capítulos. No primeiro foi realizada uma leitura e revisão bibliográfica do referencial teórico de pesquisa, a *Transposição Didática* de Yvê Chevillard, com a elucidação de seus elementos para compreender como ocorreu a passagem dos modelos atômicos de Dalton, Thomson, Rutherford e Bohr do *saber sábio ao saber a ensinar*. No segundo apresentou-se um resgate histórico das produções acadêmicas de Dalton, Thomson, Rutherford e Bohr, do *saber sábio*. No terceiro trabalhou-se todo o desenho metodológico da pesquisa, tendo como referência a proposta de Bardin (2010) e, no quarto realizou-se a coleta e discussão dos dados.

A primeira etapa do capítulo 4 foi destinada à *leitura flutuante* (pré-análise) dos 55 LDQ selecionados, na qual buscou-se levantar quais os PTA são mais citados, quais termos são mais relacionados aos Modelos Atômicos, bem como a quantidade de imagens relacionados aos Modelos Atômicos.

Os resultados apontaram que nos 55 LDQ analisados, os PTA que mais apareceram foram Rutherford com 38 ocorrências, Dalton com 37 ocorrências, Bohr com 36 ocorrências e Thomson com 28. Em relação à denominação mais usada para o Modelo Atômico, “sistema planetário” foi a mais recorrente, com 26 ocorrências, seguida de “pudim de passas”, com 15. No que se refere às imagens, foram encontradas 424 ocorrências para outros Modelos Atômicos (essas imagens que são pertencentes as propostas posteriores a de Niels Bohr no domínio da Física quântica) e foram localizadas 385 ocorrências para tradição inglesa divididas em: 136 para o modelo de Bohr; 101 para o modelo de Rutherford; 79 para o modelo de Dalton e 69 para o modelo de Thomson.

Como ao longo das Reformas Educacionais, os LDQ apresentaram o capítulo Modelos Atômicos focado em PTA da tradição inglesa, com uma maior ocorrência

para Dalton e Rutherford, foram os Modelos Atômicos desta tradição os analisados neste estudo. Outro aspecto observado é que, ao longo do tempo, os LDQ aumentaram o uso de recursos visuais para representar os Modelos Atômicos. Vale lembrar que estas características impactam diretamente na visão de ciência, na compreensão didática e epistemológica dos Modelos Atômicos no ensino de química. Lembrando que esta característica também pode estar associada com o desenvolvimento editorial dos livros, onde os avanços das técnicas de publicação possibilitaram um aumento no uso de recursos visuais na apresentação do *saber a ensinar*.

Na segunda etapa, foram selecionados 19 LDQ, de acordo com três critérios: o primeiro teve por base o conteúdo que estes livros apresentaram, onde foram selecionados os mais completos. O segundo critério correspondeu à data de publicação e o autor do livro, onde livros do mesmo ano e com os mesmos autores foram retirados. E o terceiro critério esteve relacionado à amplitude da obra, dando-se preferência aos livros de volume único e os mais completos, selecionando-se ao final duas coleções, por período e analisando-as com base nos *elementos da Transposição Didática*. Gerando as seguintes conclusões:

A partir do elemento *descontextualização*, entende-se que os LDQ trazem uma *descontextualização* seguida por uma *recontextualização* da história dos Modelos Atômicos em um novo discurso, sendo que a “nova” história é tão bem editada, a partir da história total do *saber sábio*, que acabou sendo difundida no decorrer do tempo com pequenas variações. Também entende-se que os LDQ *descontextualizam* o *saber a ensinar*, não se preocupando com as reais problemáticas de pesquisa desenvolvidas pelos PTA, dando a idéia de que a única problemática estudada durante suas vidas eram os fenômenos acerca da constituição da matéria e formulação de Modelos Atômicos. Essa compreensão passa a idéia de ciência ideal e despida de interesses, onde pesquisa-se somente pela vontade de conhecer. O que sabemos, dentro de um paradigma sociocontrutivista, da sociologia das ciências, que não é a realidade. A ciência é social e está sofre influência de múltiplos interesses.

Assim, pode-se compreender que os LDQ analisados operaram uma *recontextualização* em torno dos PTA da tradição inglesa (Dalton, Thomson,

Rutherford e Bohr). Considero que esta *recontextualização* teve duas repercussões negativas para o ensino de ciências: a primeira foi tornar a história dos Modelos Atômicos linear, cumulativa, onde o erro não é permitido (paradigma empirico-indutivista). E segundo, para se adequar a um tempo didático, que em geral não é suficiente ensinar todo o projeto científico, forçando o desenvolvimento de recortes históricos nos livros, que acabam passando uma visão distorcida e limitada da natureza da ciência.

A análise do elemento *despersonalização* apareceu nos LDQ na forma de uma *personalização*, pelo fato de passar uma visão individualizada da ciência ao longo das 19 obras, atribuindo aos Modelos Atômicos somente alguns pesquisadores, retirando outros coadjuvantes de mesma importância no processo de desenvolvimento do *saber*. Este fato também contribui para uma visão distorcida, simplificada e neutra da ciência, sem apresentar sua real natureza e reais procedimentos. Ficou mais evidente que 10 LDQ reificam uma seleção de pesquisadores que tiveram suas idéias mais aceitas pela comunidade científica.

A análise do elemento *relação antigo/novo* mostrou que ao longo da história dos LDQ existiu uma dicotomia entre a utilização das limitações, onde se podia optar por usá-las ou não. Porém, mais recentemente, com os PNLEM e PNLD, parece que a influência dos pesquisadores da área de ensino de ciências tem mudado essa visão, instituindo a necessidade de mostrar as limitações da ciência. O que se configurou num avanço nas *transposições didáticas*, de algumas obras analisadas, para o Modelo Atômico.

De acordo com a análise, o elemento *criação didática* está presente em todos os 19 LDQ, para representar os Modelos Atômicos. De acordo com Chevallard (1991), essas criações podem vir a ajudar o aluno a compreender conceitos mais complexos, quando bem formuladas. O que não acontece em nenhum dos 19 LDQ analisados. Nestes, as *criações didáticas* são usadas como substitutas da explicação do Modelo Atômico, como se fossem uma cópia fiel do que se encontra no *saber sábio*, configurando-se em um obstáculo epistemológico no ensino, dando uma visão distorcida sobre sua constituição, atribuindo características que não fazem parte deles e gerando equívocos conceituais.

O elemento *publicidade do saber* apareceu nos LDQ com o objetivo de introduzir e adaptar o capítulo Modelos Atômicos. Outra hipótese é que esse elemento pode ter sido introduzido com um objetivo mercadológico de atrair professores e alunos, por meio de uma leitura agradável, diminuindo o trabalho docente na sistematização do estudo, mais do que por necessidade de explicitar a utilidade do *saber* no ensino de química. Ou seja, de acordo com Chevallard (1991) a *publicidade do saber* pode ter diferentes utilidades em um texto de *saber a ensinar*. A primeira utilidade seria de introduzir e sistematizar o estudo; a segunda seria de introduzir um diálogo com o leitor facilitando a comunicação de um *saber*; a terceira seria usada na forma de um prefácio ou introdução para apresentar o texto de *saber a ensinar*. O que se observa dos livros analisados é que estes usam essa publicidade para tornar a comunicação do *saber* melhor e a sistematização de ensino do *saber a ensinar*, facilitando o trabalho do professor em sala de aula, visando um objetivo mercadológico na venda desses livros didáticos.

Da análise do elemento *fidelidade na textualização do saber* pode-se depreender que os 19 LDQ não retratam o Modelo Atômico com total *fidelidade*. Estas interpretações podem gerar distorções quanto ao significado e funcionamento de cada modelo. No entanto, deve-se frisar que a adaptação do *saber a ensinar* é inevitável, pois o aluno que estuda este conteúdo não tem o mesmo nível de compreensão que um pesquisador. Sendo assim necessário que os LDQ procurem formas de adaptar os Modelos Atômicos e relatos experimentais, sem passar idéias equivocadas que podem constituir-se em obstáculos epistemológicos, gerando dificuldades na vida cotidiana e acadêmica do aluno.

Do elemento *desincretização* pode-se compreender que a maioria dos LDQ organizaram os Modelos Atômicos sob a forma de um capítulo, o que pode ser considerado um aspecto positivo, pois sistematiza este conteúdo. Porém, também pode ser considerada uma desvantagem, pois não favorece a relação entre diferentes *saberes*. Em outras palavras, dentro de uma ordem didática de capítulos, não há o encadeamento de *saberes*, dando a impressão que os conhecimentos são independentes no desenvolvimento da ciência.

Também pode-se compreender que 11 LDQ possuem o conteúdo Modelos Atômicos em outros capítulos, observando-se uma necessidade de inserir o *saber*

Modelo Atômico como pré-requisito para o ensino de outros *saberes*. Essa característica pode garantir que os LDQ façam a relação entre *saberes* buscando a integração do conteúdo. O que é válido, pois faz o aluno ver a importância deste conteúdo para a aprendizagem de outros. É a forma encontrada nas *transposições didáticas* para dar utilidade ao *saber* dentro de uma ordem didática, dando a base para desenvolvimento de novos conceitos.

Assim pode-se sintetizar para o elemento *desincretização* que os LDQ organizam os Modelos Atômicos sob a forma de um capítulo específico e distribuindo-os em outros capítulos. Essa característica revela a necessidade dos LDQ em apresentar esse *saber* organizado sob uma ordem didática, possivelmente, como pré-requisito para a compreensão de outros conteúdos, dentro da idéia de crescente dificuldade dos *saberes* e utilidade do *saber*, como lembrado por Chevallard (1991).

A análise do elemento *programabilidade de aquisição do saber*, possibilitou observar que esta modifica-se ao longo do tempo, a partir de cada nova proposta de *Transposição Didática* no LDQ. Inicialmente, apresentam-se em 3 LDQ sem exercícios, com o programa de ensino impresso na obra, dando um caráter mais rígido ao manual e com o objetivo de ser um livro texto apenas. Posteriormente, em 16 LDQ, dos programas mais recentes, há a inserção de exercícios, no capítulo Modelos Atômicos, denotando a necessidade de preparar o estudante para testes de seleção. Porém, observa-se uma nova mudança desse elemento nos LDQ mais atuais, como em Mortimer e Machado (2006 e 2011), que trazem, além das questões de vestibular, questões que levam o aluno a desenvolver um raciocínio em torno de problemáticas da área de ensino de química e a formar o espírito crítico e cidadão.

Sobre o elemento *envelhecimento moral do saber*, observou-se que os 11 LDQ procuraram atualizar (modernizar) seus exemplos de acordo com a necessidade social de se inserir tópicos que fizessem parte do cotidiano do aluno. Há também um aumento do número de exemplos, que aparecem na unidade sobre Modelos Atômicos, ao longo dos diferentes períodos no Brasil. Com base no *envelhecimento moral do saber*, observa-se a diferença dos exemplos apresentados pelos livros analisados, onde cada um é contextualizado com uma realidade social e

tecnológica diferente. Sua necessidade de uso pode estar ligada ao critério nomeado por Chevallard (1991) de *utilidade do saber*, onde os LDQ somente apresentam *saberes* que podem ser relacionados com a realidade social do aluno, aqueles que não tem essa possibilidade de ligação são retirados do LDQ.

Enquanto infere-se que, de acordo com os dados colhidos, os 19 LDQ analisados sofreram *envelhecimento biológico do saber* a partir do momento em que retiraram *saberes* sobre afinidade química e teoria de valência, ao mesmo tempo, procurando inserir novos *saberes* para dar uma nova visão e aplicabilidade ao conteúdo Modelos Atômicos. Justificando a inserção de estudos sobre tabela periódica, ligações químicas, leis de combinações e sobre a teoria de Gay-Lussac.

Dessa forma, para o *envelhecimento moral e biológico do saber*, pode-se considerar que os LDQ modernizaram os exemplos apresentados nos capítulos destinados ao Modelo Atômico, expressando a necessidade de estar de acordo com as demandas sociais e aproximando o *saber a ensinar* da realidade do aluno. Há uma mudança dos *saberes* que integram o capítulo Modelos Atômicos, onde *saberes* como “afinidade e teoria de valência”, foram sendo substituídos por outros mais atualizados de acordo com o que a ciência desenvolve e comunica à sociedade. Em outras palavras, houve a atualização dos *saberes* apresentados, na unidade Modelos Atômicos, mostrando que os LDQ estão de acordo com certas demandas científicas, ensinando *saberes* mais atualizados.

Com base nas duas etapas da pesquisa, sintetizo uma visão geral dos LDQ ao longo dos diferentes períodos no Brasil, dividindo-a em três períodos distintos. No primeiro que compreende as Reformas F. Campos e G. Capanema, os livros eram mais consultivos, sem exercícios e com uma programação rígida, apresentando uma história dos Modelos Atômicos em torno de 3 PTA (Dalton, Rutherford e Bohr), sem mencionar as limitações de cada modelo e trazendo visões distorcidas sobre a atividade científica, estereótipos do cientista e da constituição dos Modelos Atômicos. No segundo período, LDBEN 4.024/61, 5.692/71 e Constituição Federal de 1988, observou-se algumas modificações como a inserção de exercícios de vestibular e testes de seleção conceituados. Os LDQ deixam de ter somente o caráter de recapitulação do conteúdo estudado em aula. Há a inserção de J. J. Thomson, formando-se uma nova história do Modelo Atômico, integrando suas contribuições

junto a Dalton, Rutherford e Bohr, continuando a visão estereotipada de cientista e linear equivocada de ciência. No terceiro período, LDBEN 9.394/96, PNLEM 2007 e PNL D 2012, observa-se uma certa modificação, onde passam a serem inseridos exercícios que trazem formação do espírito cidadão e desenvolvimento do raciocínio acerca de questões cotidianas variadas. Há uma maior preocupação em se explicitar quais eram as limitações de cada modelo e o que culminou o surgimento de novas propostas. Um dos livros analisados inova ao trazer quais eram as áreas de pesquisa de John Dalton, dado que não fazia parte do texto das obras didáticas. Outro ponto positivo dessas *transposições* está em que alguns livros estão procurando ultrapassar e retirar a visão estereotipada de ciência e cientista que permeou obras desde 1931. Mas, ainda, apresentam os mesmos equívocos conceituais ao abordarem os Modelos Atômicos apresentados em períodos anteriores com uma história centralizada em 4 pesquisadores, somente.

Considero que os LDQ passaram por diversas reestruturações, avançando no entendimento do *saber a ensinar*. Porém, esses livros ainda tem muito o que melhorar em termos de *Transposição Didática*, em relação a historiografia, construção e entendimento do que é a ciência. Outro ponto que considero necessitar maior preocupação está na compreensão de como são construídos os Modelos Atômicos, pois, todas as obras reproduziram a forma de apresentar tais propostas com equívocos conceituais e distorções nos seus significados e entendimento do seu funcionamento. Esse fato demonstra que os LDQ não ficaram parados no tempo, ao contrário, se atualizaram, modificaram inúmeras características, porém, ainda reproduzindo certos problemas para a área de ensino de química, uma fonte de concepções errôneas para os estudantes e professores(as) acerca dos Modelos Atômicos, podendo gerar obstáculos à compreensão da ciência química em sala de aula, reproduzindo um *habitus* (que pouco mudou) desde 1931.

Com relação à outras perspectivas de pesquisa que foram surgindo através deste trabalho, e que podem suscitar novas pesquisas, argumento que a primeira corresponde a possibilidade de fazer um estudo relacionado às imagens usados nos LDQ, analisando suas características com base em referenciais teóricos da Expressão Gráfica. Outra questão que surgiu foi desenvolver uma proposta didática para o ensino de Modelos Atômicos no ensino de química, abordando pressupostos de Didática, História e Filosofia das Ciências. Mais uma possibilidade de pesquisa

seria analisar como os documentos oficiais influenciaram a escrita do LDQ ao decorrer da história, e fazer um levantamento das reformas e seleções de LDQ que o país realizou, desde a implementação das disciplinas científicas na Reforma Francisco Campos. Entendo que todas essas possibilidades mencionadas podem originar fecundas pesquisas.

O que mais me preocupa, ao visualizar os resultados, é que os Modelos Atômicos não são representados com total *fidelidade ao saber sábio* e isso caracteriza um problema que a área de Ensino de Química deve buscar resolver. É preciso tomar uma decisão sobre o que fazer com este conteúdo no livro didático.

Antes de finalizar esta dissertação, apresento um questionamento a todos nós pesquisadores da área de Ensino de Ciências sobre o conteúdo Modelos Atômicos: *Será que o conteúdo Modelo Atômico é realmente necessário para se ensinar química na Educação Básica?*

Com base nesta questão penso que o conteúdo Modelos Atômicos não precisa ser necessariamente banido dos LDQ. Mas, deve ser reformulado para atender a novas demandas da área de pesquisa em ensino de química no que diz respeito à História e Filosofia das Ciências (HFC).

Essa possível reestruturação do capítulo Modelos Atômicos pode vir trazer uma nova dimensão ao desenvolvimento da HFC no LDQ, gerando novos questionamentos aos alunos e fazendo-os compreender como a ciência realmente funciona e o que a move em nosso mundo cotidiano, como lembra Quintanilha et all (2008):

Nossa pretensão é que os alunos compreendam o que e porque destas controversias, assumindo a natureza da ciência como uma atividade profundamente humana onde a construção de um novo conhecimento requer a produção de textos escolares trabalhos socialmente em sala de aula (QUINTANILHA ET ALL, 2008, p.102, tradução nossa).

Assim, podemos entender fazendo essa ligação: conteúdo, história e filosofia científica, gerando um ensino de química com cunho mais social que atinja satisfatoriamente algumas necessidades que as pesquisas no ensino de química tem apontado na formação do aluno. Entendendo-se que:

Para que a educação científica possa subsidiar o aluno no exercício de uma cidadania consciente e atuante, ela deve ir além do simples ensino-aprendizagem de fatos, leis e teorias científicas. Entre outras coisas, é

preciso também proporcionar ao estudante uma compreensão crítica da natureza da ciência e da construção do conhecimento científico. A reivindicação da implantação desses aspectos nos currículos de ciências tem sido uma das preocupações de alguns pesquisadores dessa área, e se intensifica ainda mais, tendo em vista a orientação dos Parâmetros Curriculares Nacionais. (*Köhnlein e Peduzzi, 2005, p. 62*)

Nesse sentido sustento a tese de que uma articulação histórico-filosófica da ciência no LDQ pode produzir efeitos positivos no alunos, durante o aprendizado da química, pois essa visão histórica lhe propicia uma compreensão de como a ciência funciona.

Conhecendo a ciência a partir de uma visão histórico-filosófica será possível compreender os conceitos científicos e, principalmente, usar este conhecimento para entender o mundo contemporâneo. (*Guerra et all, 1998, p.35*).

Finalizo essa dissertação fixando minha posição dentro de um tratamento histórico filosófico do episódio histórico dos modelos atômicos nos LDQ. Uma construção que propicie o aluno a compreender como a ciência funciona, procurando fazer uma maior contextualização da *Transposição Didática* sobre os modelos atômicos, embasada nos escritos originais, problemáticas e anseios de seus reais pesquisadores.

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APÊNDICE 1 – QUADRO DOS 55 LDQ ANALISADOS.

<p>Reforma F. Campos (1931 – 1943)</p> <p>PINTO, Dr. Pedro A. Noções rudimentares de farmácia química. 3ª ed. Rio de Janeiro: JYP. 1931;</p> <p>FRANCA, Leonel S. J. Apontamentos de chímical geral. 6ª ed. Rio de Janeiro: Pimenta e Mello & Cia. 1933;</p> <p>PINTO, Dr. Pedro A. Rudimentos de química. 5ª ed. Rio de Janeiro: Tipografia. 1934;</p> <p>PUIG, Inácio Pe. Curso de química geral. Porto Alegre: Edição da Livraria do Globo. 1935;</p> <p>SILVA, A. B. Alves da. Noções de Química Geral. Porto Alegre: Edição da Livraria do Globo. 1936;</p> <p>MENEZES, Luiz. Chimica 3ª série (de accordo com o programma do collegio D. Pedro II). São Paulo: Saraiva e Cia. 1937;</p> <p>MENEZES, Luiz. Chimica 4ª série (de accordo com o programma do collegio D. Pedro II). São Paulo: Saraiva e Cia. 1937;</p> <p>LIBERALLI, C. H. Elementos de química: 1ª parte 4ª série ginasial. Rio de Janeiro: J. R. De Oliveira & Cia. 1937;</p> <p>LIBERALLI, C. H. Elementos de química: 2ª parte 5ª série ginasial. Rio de Janeiro: J. R. De Oliveira & Cia. 1937;</p> <p>COUTO, A. Valente do. Química teórica e prática: para o curso ginasial. 4ª ed. São Paulo: Companhia Editora Nacional. 1938;</p>
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FONTE: O autor (2012)

APÊNDICE 2 – QUADRO COM OS 19 LDQ ANALISADOS.

<p>Reforma Francisco Campos (1931 – 1940)</p> <p>SILVA, A. B. Alves da. Noções de química geral. 2ª ed. Porto Alegre: Globo. 1936;</p> <p>COUTO, A. Valente do. Química teórica e prática: para o curso ginásial. 4ª ed. São Paulo: Companhia Editora Nacional. 1938;</p>
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<p>LDBEN 4.024/61</p> <p>CHEMICAL BOND APPROACH COMMITTEE. Química: parte I. edição preliminar. Brasília: UNB. 1964a;</p> <p>CHEMICAL BOND APPROACH COMMITTEE. Química: parte II. edição preliminar. Brasília: UNB. 1964b;</p> <p>FELTRE, Ricardo. YOSHINAGA, Setsuo. Química geral: volume 1 teoria e exercícios. São Paulo: Moderna. 1969;</p> <p>FELTRE, Ricardo. YOSHINAGFA, Setsuo. Atomística: volume 2 teoria e exercícios. São Paulo: Moderna. 1970;</p>
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⁵¹ Vale lembrar que a reforma Capanema iniciada em 1941, não trouxe mudanças significativas em relação aos conteúdos até 1950, com a portaria Ministerial nº 966 expedida em 2 de outubro de 1951, os programas foram reformulados com o intuito de se retirar o grande volume de conteúdos veiculados no ensino secundário brasileiro. Com base nesta portaria e de acordo com Mortimer (1988), optou-se por analisar somente livros que foram publicados após a portaria dos programas mínimos, entendendo que depois dessa portaria é que muitos livros didáticos de química tiveram que readaptar os seus conteúdos às novas exigências.

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<p>PNLD 2012</p> <p>MORTIMER, Eduardo F. MACHADO, Andréa H. Química: volume 1. 1ª ed. São Paulo: Scipione. 2011;</p> <p>REIS, Martha. F. Coleção química: meio ambiente, cidadania, tecnologia volume 1. 1ª ed. São Paulo: FTD. 2010;</p>

FONTE: O autor (2012)

APÊNDICE 3 – LEVANTAMENTO DOS PTA PRESENTES NOS LDQ DE 1931 A 2012.

Livro	Dalton	Thomson	Nagaoka	Rutherford	Nicholson	Bohr
Pinto (1931)	-	-	-	-	-	-
Franca (1933)	X	-	-	-	-	-
Pinto (1934)	X	-	-	-	-	-
Pe. Puig (1935)	X	-	-	X	-	-
Silva (1936)	X	X	X	X	X	X
Liberalli (1937a)	X	-	-	-	-	-
Liberalli (1937b)	-	X	-	X	X	X
Menezes (1937a)	-	-	-	-	-	-
Menezes (1937b)	-	-	-	-	-	-
Couto (1938)	X	X	-	-	-	-
Pecegheiro (1944)	-	-	-	-	-	-
Décourt (1951)	X	X	-	X	-	X
Carvalho e Saffioti (1954)	-	-	-	X	-	X
Costa e Pasquale (1956)	-	-	-	-	-	-
Pimenta (1957)	X	-	-	-	-	-
Pimenta (1958)	-	X	-	X	-	X
Amado (1959)	X	-	-	-	-	-
Carvalho e Saffioti (1961)	-	-	-	X	-	X
Costa e Pasquale (1961)	X	X	-	X	-	X
Carvalho e Saffioti (1963)	-	-	-	-	-	-
Bonato (1963)	X	-	-	X	-	X
Nehmi (1965)	-	-	-	-	-	-
Pimenta (1967)	X	-	-	X	-	X
CEMS (1967)	-	-	-	-	-	-
CBA (1964a)	-	X	-	X	-	X
CBA (1964b)	-	-	-	-	-	-
CBA (1964c)	-	-	-	-	-	-
Feltre e Setsuo (1969)	X	-	-	-	-	-
Feltre e Setsuo (1970)	X	-	-	X	-	X
Moraes (1974)	-	X	-	X	-	-
Politi e Reis (1979)	X	X	-	X	-	X
Feltre e Setesuo (1979)	X	-	-	X	-	X
Sardela (1979)	X	-	-	X	-	X
Lembo (1981)	X	-	-	X	-	X
Politi (1982)	X	X	-	X	-	X
Feltre (1988)	X	-	-	X	-	X
Politi (1990)	X	X	-	X	-	X
Nehmi (1995)	X	X	-	X	-	X
Peruzzo e Canto (1996)	X	X	-	X	-	X
Novais (1997)	X	X	-	X	-	X
Utimura et all (1998)	X	X	-	X	-	X
Usberco e Salvador (1999)	X	X	-	X	-	X
Sardela (2003)	-	X	-	X	-	X

Mortimer (2003)	X	X	-	X	-	X
Santos e Mol (2006)	X	X	-	X	-	X
Bianchi et all (2005)	X	X	-	X	-	X
Nóbrega et all (2005)		X	-	X	-	X
Feltre (2005)	X	X	-	X	-	X
Tito e Canto (2005)	X	X	-	X	-	X
Santos e Mol (2010)	X	X	-	X	-	X
Reis (2010)	X	X	X	X	-	X
Peruzzo e Canto (2010)	X	X	-	X	-	X
Mortimer (2011)	X	X	-	X	-	X
Lisboa (2010)	X	X	-	X	-	X
Kiel (S/D)	X	-	-	X	-	X
Total	37	28	2	38	1	36

FONTE: O autor (2012)

APÊNDICE 4 - LEVANTAMENTO DOS TERMOS USADOS PARA DESIGNAR O MODELO ÁTOMICO.

Livro	Bolinha maciça	Pudim de passas	Panetone	Sistema planetário
Pinto (1931)	-	-	-	-
Franca (1933)	-	-	-	-
Pinto (1934)	-	-	-	-
Pe. Puig (1935)	-	-	-	-
Silva (1936)	-	-	-	X
Liberalli (1937a)	-	-	-	-
Liberalli (1937b)	-	-	-	-
Menezes (1937a)	-	-	-	-
Menezes (1937b)	-	-	-	-
Couto (1938)	-	-	-	-
Pecegueiro (1944)	-	-	-	-
Décourt (1951)	-	-	-	X
Carvalho e Saffioti (1954)	-	-	-	-
Costa e Pasquale (1956)	-	-	-	X
Pimenta (1957)	-	-	-	-
Pimenta (1958)	-	-	-	X
Amado (1959)	-	-	-	-
Carvalho e Saffioti (1961)	-	-	-	-
Costa e Pasquale (1961)	-	-	-	X
Carvalho e Saffioti (1963)	-	-	-	-
Bonato (1963)	-	-	-	X
Nehmi (1965)	X	-	-	X
Pimenta (1967)	X	-	-	X
CEMS (1967)	-	-	-	-
CBA (1964a)	-	-	-	-
CBA (1964b)	-	-	-	-
CBA (1964c)	-	-	-	-
Feltre e Setsuo (1969)	X	-	-	-
Feltre e Setsuo (1970)	X	-	-	X
Moraes (1974)	-	-	-	X
Politi e Reis (1979)	-	X	-	X
Feltre e Setesuo (1979)	-	-	-	X
Sardela (1979)	-	-	-	X
Lembo (1981)	-	-	-	X
Politi (1982)	-	X	-	X
Feltre (1988)	X	-	-	X
Politi (1990)	X	X	-	X
Nehmi (1995)	-	X	-	X
Peruzzo e Canto (1996)	-	X	-	X
Novais (1997)	X	X	-	-
Utamura et all (1998)	-	-	-	-
Usberco e Salvador (1999)	-	X	-	-
Sardela (2003)	-	-	-	X

Mortimer (2003)	-	X	X	-
Santos e Mol (2006)	-	X	-	X
Bianchi et all (2005)	-	-	-	-
Nóbrega et all (2005)	-	X	-	X
Feltre (2005)	-	X	-	X
Tito e Canto (2005)	-	X	-	X
Santos e Mol (2010)	-	-	-	-
Reis (2010)	-	X	-	X
Peruzzo e Canto (2010)	-	X	-	-
Mortimer (2011)	-	X	X	-
Lisboa (2010)	-	X	-	-
Kiel (S/D)	-	-	-	X
Total	7	16	2	26

FONTE: O autor (2012)

APÊNDICE 5 – LEVANTAMENTO DO USO DE IMAGENS SOBRE MODELOS ATÔMICOS NOS LDQ.

Livro	Dalton	Thomson	Rutherford	Bohr	Outros	Total
Pinto (1931)	0	0	0	0	0	0
Franca (1933)	0	0	0	0	0	0
Pinto (1934)	0	0	0	0	0	0
Pe. Puig (1935)	0	0	0	0	4	4
Silva (1936)	0	1	1	1	1	4
Liberalli (1937a)	0	0	0	0	1	1
Liberalli (1937b)	0	0	6	5	0	11
Menezes (1937a)	0	0	0	0	0	0
Menezes (1937b)	0	0	0	0	0	0
Couto (1938)	1	1	0	0	7	9
Pecegueiro (1944)	0	0	0	0	2	2
Décourt (1951)	0	0	0	3	10	13
Carvalho e Saffioti (1954)	0	0	0	1	2	3
Costa e Pasquale (1956)	0	0	0	9	4	13
Pimenta (1957)	0	0	0	0	1	1
Pimenta (1958)	0	4	0	0	4	8
Amado (1959)	0	0	0	0	1	1
Costa e Pasquale (1961)	0	0	0	0	1	1
Carvalho e Saffioti (1961)	0	0	0	1	2	3
Carvalho e Saffioti (1963)	0	0	0	0	3	3
Bonato (1963)	0	0	0	0	6	6
Nehmi (1965)	0	0	0	1	7	8
Pimenta (1967)	0	0	0	0	6	6
CEMS (1967)	0	0	0	0	11	11
CBA (1964a)	0	0	2	0	21	23
CBA (1964b)	0	0	0	0	0	0
CBA (1964c)	0	0	0	0	0	0
Feltre e Setsuo (1969)	20	0	1	10	18	49

Feltre e Setsuo (1970)	4	0	6	14	0	24
Moraes (1974)	0	0	0	0	6	6
Politi e Reis (1979)	0	1	4	0	0	5
Feltre e Setesuo (1979)	1	0	4	3	32	40
Sardela (1979)	0	0	0	4	9	13
Lembo (1981)	1	0	0	1	19	21
Politi (1982)	0	1	5	1	6	13
Feltre (1988)	20	0	1	10	18	49
Politi (1990)	0	1	5	2	2	10
Nehmi (1995)	1	1	1	1	0	4
Peruzzo e Canto (1996)	0	5	8	6	0	19
Vera Novais (1997)	1	1	3	0	3	8
Utamura et all (1998)	0	1	2	2	2	7
Usberco e Salvador (1999)	6	3	4	4	29	46
Sardela (2003)	0	1	3	2	1	7
Mortimer (2003)	0	2	3	2	20	27
Santos e Mol (2006)	2	2	6	3	19	32
Bianchi et all (2005)	6	2	4	3	27	42
Nóbrega et all (2005)	0	1	2	1	8	12
Feltre (2005)	5	12	5	14	18	54
Peruzzo e Canto (2005)	3	7	4	10	15	39
Santos e Mol (2010)	1	6	7	2	20	36
Reis (2010)	2	2	3	4	12	23
Peruzzo e Canto (2010)	3	6	6	6	13	34
Mortimer (2011)	0	2	3	2	20	27
Lisboa (2010)	2	6	2	8	5	23
Kiel (s/d)	0	0	0	0	8	8
Total	79	69	101	136	424	809

FONTE: O autor (2012)

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ANEXO 1 – Livro John Dalton, Capítulo 1, 1808.

NEW SYSTEM
OF
CHEMICAL PHILOSOPHY.

CHAP. I.

ON HEAT OR CALORIC.

THE most probable opinion concerning the nature of caloric, is, that of its being an elastic fluid of great subtilty, the particles of which repel one another, but are attracted by all other bodies.

When all surrounding bodies are of one temperature, then the heat attached to them is in a quiescent state; the absolute quantities of heat in any two bodies in this case are not equal, whether we take the bodies of equal weights or of equal bulks. Each kind of matter has its peculiar affinity for heat, by which it requires a certain portion of the fluid, in order to be in equilibrium with other bodies at a certain temperature. Were the *whole*

quantities of heat in bodies of equal weight or bulk, or even the *relative quantities*, accurately ascertained, for any temperature, the numbers expressing those quantities would constitute a table of *specific heats*, analogous to a table of *specific gravities*, and would be an important acquisition to science. Attempts of this kind have been made with very considerable success.

Whether the specific heats, could they be thus obtained for one temperature, would express the relation at every other temperature, whilst the bodies retained their form, is an enquiry of some moment. From the experiments hitherto made there seems little doubt of its being nearly so; but it is perhaps more correct to deduce the specific heat of bodies from equal *bulks* than from equal *weights*. It is very certain that the two methods will not give precisely the same results, because the expansions of different bodies by equal increments of temperature are not the same. But before this subject can well be considered, we should first settle what is intended to be meant by the word temperature.

SECTION 1.

ON TEMPERATURE,

And the Instruments for measuring it.

The notion of the specific heat of bodies and of temperature, may be well conceived from a system of cylindrical vessels of different diameters connected with each other by pipes at the bottom, and a small cylindrical tube attached to the system, all capable of holding water or any other liquid, and placed perpendicular to the horizon. (See Plate 1. Fig. 1.) The cylinders are to represent the different specific heats of bodies; and the small tube, being divided into equal parts, is to represent the thermometer or measure of temperature. If water be poured into one vessel it rises to the same level in them all, and in the thermometer; if equal portions be successively poured in, there will be equal rises in the vessels and in the tube; the water is obviously intended to represent heat or caloric. According to this notion, then, it is evident that equal increments of heat in any body correspond to equal increments of temperature.

This view of the subject necessarily requires, that if two bodies be taken of any one tempe-

perature, and then be raised to any other temperature, the additional quantities of heat received by each will be exactly proportioned to the whole quantities of that fluid previously contained in them. This conclusion, though it may be nearly consistent with facts in general, is certainly not strictly true. For, in elastic fluids, it is well known, an increase of *bulk* occasions an increase of specific heat, though the weight and temperature continue the same. It is probable then that solids and liquids too, as they increase in bulk by heat, increase in their capacity or capability of receiving more. This circumstance, however, might not affect the conclusion above, provided all bodies increased in one and the same proportion by heat; but as this is not the case, the objection to the conclusion appears of validity. Suppose it were allowed that a thermometer ought to indicate the accession of *equal* increments of the fluid denominated caloric, to the body of which it was to shew the temperature;—suppose too that a measure of air or elastic fluid was to be the body; query, whether ought the air to be suffered to expand by the temperature, or to be confined to the same space of one measure? It appears to me the most likely in theory to procure a standard capacity for heat by subjecting a body to heat,

whilst its bulk is kept constantly the same. Let m = the quantity of heat necessary to raise the elastic fluid 10° in temperature in this case; then $m + d$ = the quantity necessary to raise the same 10° , when suffered to expand, d being the difference of the absolute quantities of heat contained by the body in the two cases. Now, $\frac{1}{10}m$ = the quantity of heat necessary to raise the temperature 1° in the first case; but $\frac{1}{10}(m+d)$ can not be the quantity necessary in the second case; it will be a less quantity in the lower degrees, and a greater in the higher. If these principles be admitted, they may be applied to liquids and solids; a liquid, as water, cannot be raised in temperature equally by equal increments of heat, unless it is confined within the same space by an extraordinary and perhaps incalculable force; if we suffer it to take its ordinary course of expansion, then, not equal, but increasing increments of heat will raise its temperature uniformly. If sufficient force were applied to condense a liquid or solid, there can be no doubt but heat would be given out, as with elastic fluids.

It may perhaps be urged by some that the difference of heat in condensed and rarefied air, and by analogy probably in the supposed cases of liquids and solids, is too small to have sensible influence on the capacities or affinities

of bodies for heat ; that the effects are such, as only to raise or depress the temperature a few degrees ; when perhaps the whole mass of heat is equivalent to two or three thousand such degrees ; and that a volume of air supposed to contain 2005° of temperature being rarefied till it become 2000°, or lost 5° of temperature, may still be considered as having its capacity invariable. This may be granted if the data are admissible ; but the true changes of temperature consequent to the condensation and rarefaction of air have never been determined. I have shewn, (Manchester Mem. Vol. 5, Pt. 2.) that in the process of admitting air into a vacuum, and of liberating condensed air, the inclosed thermometer is affected as if in a medium of 50° higher or lower temperature ; but the effects of instantaneously doubling the density of air, or replenishing a vacuum, cannot easily be derived from those or any other facts I am acquainted with ; they may perhaps raise the temperature one hundred degrees or more. The great heat produced in charging an air-gun is a proof of a great change of capacity in the inclosed air.— Upon the whole then it may be concluded, that the change of bulk in the same body by change of temperature, is productive of considerable effect on its capacity for heat, but

that we are not yet in possession of data to determine its effect on elastic fluids, and still less on liquids and solids. M. De Luc found, that in mixing *equal weights* of water at the freezing and boiling temperatures, 32° and 212° , the mixture indicated nearly 119° of Fahrenheit's mercurial thermometer; but the numerical mean is 122° ; if he had mixed *equal bulks* of water at 32° and 212° , he would have found a mean of 115° . Now the means determined by experiment in both these ways are probably too high; for, water of these two temperatures being mixed, loses about 1-90th of its bulk; this condensation of volume (whether arising from an increased affinity of aggregation, or the effect of external mechanical compression, is all one) must expel a quantity of heat, and raise the temperature above the true mean. It is not improbable that the true mean temperature between 32° and 212° may be as low as 110° of Fahrenheit.

It has been generally admitted that if two portions of any liquid, of equal weight but of different temperatures, be mixed together, the mixture must indicate the true mean temperature; and that instrument which corresponds with it is an accurate measure of temperature. But if the preceding observations be correct, it may be questioned whether any

two liquids will agree in giving the same mean temperature upon being mixed as above.

In the present imperfect mode of estimating temperature, the equable expansion of mercury is adopted as a scale for its measure. This cannot be correct for two reasons; 1st. the mixture of water of different temperatures is always *below* the mean by the mercurial thermometer; for instance, water of 32° and 212° being mixed, gives 119° by the thermometer; whereas it appears from the preceding remarks, that the temperature of such mixture ought to be found above the mean 122°; 2d. mercury appears by the most recent experiments to expand by the same law as water; namely, as the square of the temperature from the point of greatest density.—The apparently equal expansion of mercury arises from our taking a small portion of the scale of expansion, and that at some distance from the freezing point of the liquid.

From what has been remarked it appears that we have not yet any mode easily practicable for ascertaining what is the true mean between any two temperatures, as those of freezing and boiling water; nor any thermometer which can be considered as approximating nearly to accuracy.

Heat is a very important agent in nature; it

cannot be doubted that so active a principle must be subject to general laws. If the phenomena indicate otherwise, it is because we do not take a sufficiently comprehensive view of them. Philosophers have sought, but in vain, for a body that should expand uniformly, or in arithmetical progression, by equal increments of heat; liquids have been tried, and found to expand unequally, all of them expanding more in the higher temperatures than in the lower, but no two exactly alike. Mercury has appeared to have the least variation, or approach nearest to uniform expansion, and on that and other accounts has been generally preferred in the construction of thermometers. Water has been rejected, as the most unequally expanding liquid yet known. Since the publication of my experiments on the expansion of elastic fluids by heat, and those of Gay Lussac, immediately succeeding them, both demonstrating the perfect sameness in all permanently elastic fluids in this respect; it has been imagined by some that gases expand equally; but this is not corroborated by experience from other sources.

Some time ago it occurred to me as probable, that water and mercury, notwithstanding their apparent diversity, actually expand by the same law, and that the quantity of expansion

is as the square of the temperature from their respective freezing points. Water very nearly accords with this law according to the present scale of temperature, and the little deviation observable is exactly of the sort that ought to exist, from the known error of the equal division of the mercurial scale. By prosecuting this enquiry I found that the mercurial and water scales divided according to the principle just mentioned, would perfectly accord, as far as they were comparable; and that the law will probably extend to all other pure liquids; but not to heterogeneous compounds, as liquid solutions of salts.

If the law of the expansion of liquids be such as just mentioned, it is natural to expect that other phenomena of heat will be characteristic of the same law. It may be seen in my Essay on the Force of Steam (Man. Mem. Vol. 5, Part 2.) that the elastic force or tension of steam in contact with water, increases *nearly* in a geometrical progression to equal increments of temperature, *as measured by the common mercurial scale*; it was not a little surprising to me at the time to find such an approach to a regular progression, and I was then inclined to think, that the want of perfect coincidence was owing to inaccuracy in the division of the received thermometer; but

overawed by the authority of Crawford, who seemed to have proved past doubt that the error of the thermometer no where amounted to more than one or two degrees, I durst not venture to throw out more than a suspicion at the conclusion of the essay, on the expansion of elastic fluids by heat, that the error was probably 3 or 4°, as De Luc had determined; to admit of an error in the supposed mean, amounting to 12°, seemed unwarrantable. However it now appears that the force of steam in contact with water, increases *accurately* in geometrical progression to equal increments of temperature, provided those increments are measured by a thermometer of water or mercury, the scales of which are divided according to the above-mentioned law.

The Force of Steam having been found to vary by the above law, it was natural to expect that of air to do the same; for, air (meaning any permanently elastic fluid) and steam are essentially the same, differing only in certain modifications. Accordingly it was found upon trial that air expands in geometrical progression to equal increments of temperature, measured as above. Steam detached from water, by which it is rendered incapable of increase or diminution in quantity, was found by Gay Lussac, to have the same quantity of

expansion as the permanently elastic fluids. I had formerly conjectured that air expands as the *cube* of the temperature from absolute privation, as hinted in the essay above-mentioned; but I am now obliged to abandon that conjecture.

The union of so many analogies in favour the preceding hypothesis of temperature is almost sufficient to establish it; but one remarkable trait of temperature derived from experiments on the heating and cooling of bodies, which does not accord with the received scale, and which, nevertheless, claims special consideration, is, that *a body in cooling loses heat in proportion to its excess of temperature above that of the cooling medium*; or that the temperature descends in geometrical progression in equal moments of time. Thus if a body were 1000° above the medium; the times in cooling from 1000° to 100, from 100 to 10, and from 10 to 1°, ought all to be the same. This, though nearly, is not accurately true, if we adopt the common scale, as is well known; the times in the lower intervals of temperature are found longer than in the upper; but the new scale proposed, by shortening the lower degrees, and lengthening the higher, is found perfectly according to this remarkable law of heat.

Temperature then will be found to have four most remarkable analogies to support it.

1st. All pure homogenous liquids, as water and mercury, expand from the point of their congelation, or greatest density, a quantity always as the square of the temperature from that point.

2. The force of steam from pure liquids, as water, ether, &c. constitutes a geometrical progression to increments of temperature in arithmetical progression.

3. The expansion of permanent elastic fluids is in geometrical progression to equal increments of temperature.

4. The refrigeration of bodies is in geometrical progression in equal increments of time.

A mercurial thermometer graduated according to this principle will differ from the ordinary one with equidifferential scale, by having its lower degrees smaller and the upper ones larger; the mean between freezing and boiling water, or 122° on the new scale, will be found about 110° on the old one.—The following Table exhibits the numerical calculations illustrative of the principles inculcated above.

NEW TABLE OF TEMPERATURE.

True equal intervals of temperature.	Mercury.			Common Fahrenheit scale; or preceding column corrected for expansion of glass.	Water Expansion of water as geomet. progress. Ratio 1,0179.	Air Expansion of air in geomet. progress. Ratio 1,351.	Vapour.	
	Roots, or intervals of temperature, com. dif. = .4103	Square, or measures of temp. on merc. scale from freezing merc.	Same as preceding column, or Fahrenheit's scale.				Force of vapour of water geom. prog. ratio 1,351. In. M.	Force of vapour of ether, geom. prog. ratio 1,2178. Inch M.
-175	0	0	40			698		
-68	4 3803	18.88	21.12			837.6	.018	.75
-58	4 7908	28.94	17.06			852.5	.016	.96
-48	5 2013	39.04	12.96			867.7	.022	1.18
-38	5 6118	49.18	8.82			883.3	.028	1.45
-28	6 0223	59.34	4.76			899	.038	1.77
-18	6 4328	69.53	3.34		16	915.2	.050	2.17
-8	6 8433	79.78	6.78		16	931.5	.066	2.68
2	7 2538	89.99	12.63		16	948.2	.087	3.30
12	7 6643	99.74	18.74		16	965.2	.115	4.06
22	8 0748	109.21	25.21		16	982.4	.151	4.97
32	8 4853	118.71	32.29	32	1	1000	.200	6.1
42	8 8958	128.21	39.79	39.3	0	1017.9	.264	7.57
52	9 3063	137.71	46.6	47	1	1036.1	.348	9.26
62	9 7168	147.21	54.44	55	4	1054.7	.461	11.22
72	10 1273	156.71	62.55	63.3	9	1073.5	.609	13.77
82	10 5378	166.21	71.04	72	16	1092.7	.804	16.86
92	10 9483	175.71	79.84	81	25	1112.3	1.068	20.65
102	11 3588	185.21	89.02	90.4	36	1132.2	1.40	24.30
112	11 7693	194.71	98.49	100.1	49	1152.4	1.85	28.1
122	12 1798	204.21	108.3	110	64	1173.1	2.46	32.98
132	12 5903	213.71	118.5	120.1	81	1194	3.24	38.54
142	13 0008	223.21	129	130.4	100	1215.4	4.27	44.83
152	13 4113	232.71	139.9	141.1	121	1237.1	5.65	51.88
162	13 8218	242.21	151	152	144	1259.2	7.47	59.62
172	14 2323	251.71	162.4	163.2	169	1281.8	9.87	68.01
182	14 6428	261.21	174.4	175	196	1304.7	13.08	77.15
192	15 0533	270.71	186.5	186.9	225	1328	17.19	87.15
202	15 4638	280.21	199	199.2	256	1351.8	22.20	98.01
212	15 8743	289.71	212	212	289	1376	28.00	109.5
318	19 9793	399.1	359.1			1643	445	
412	24 0843	579.8	539.8			1962		
512	28 1893	794.7	754.7			2342		
612	32 2943	1043	1000			2797		
718	36 3993	1315	1285			3339		

Explanation of the Table.

The first column contains the degrees of temperature, of which there are supposed to be 180 between freezing and boiling water, according to Fahrenheit. The concurrence of so many analogies as have been mentioned, as well as experience, indicate that those degrees are produced by equal increments of the matter of heat, or caloric; but then it should be understood they are to be applied to a body of uniform bulk and capacity, such as air confined within a given space. If water, for instance, in its ordinary state, is to be raised successively through equal intervals of temperature, as measured by this scale, then unequal increments of heat will be requisite, by reason of its increased capacity. The first number in the column, -175° , denotes the point at which mercury freezes, hitherto marked -40° . The calculations are made for every 10° from -68° to 212° ; above the last number, for every 100° . By comparing this column with the 5th, the correspondences of the new scale and the common one are perceived: the greatest difference between 32° and 212° is observable at 122° of the new scale, which agrees with 110° of the old, the difference

being 12° ; but below 32° and above 212° , the differences become more remarkable.

The 2d and 3d columns are two series, the one of roots, and the other of their squares. They are obtained thus; opposite 32° , in the first column, is placed in the 3d, 72° , being the number of degrees or equal parts in Fahrenheit's scale from freezing mercury to freezing water; and opposite 212° in the first is placed 252° in the 3d, being $212 + 40^\circ$, the number of degrees (or rather equal parts) between freezing mercury and boiling water. The square roots of these two numbers, 72° and 252° , are found and placed opposite to them in the second column. The number 8.4853 represents the relative quantity of real temperature between freezing mercury and freezing water; and the number 15.8743 represents the like between freezing mercury and boiling water; consequently the difference 7.3890 represents the relative quantity between freezing water and boiling water, and $7.3890 \div 18 = .4105$ represents the quantity corresponding to each interval of 10° . By adding .4105 successively to 8.4853, or subtracting it from it, the rest of the numbers in the column are obtained, which are of course in arithmetical progression. The numbers in the 3d column are all obtained by squaring those of

the 2d opposite to them. The unequal differences in the 3d column mark the expansions of mercury due to equal increments of temperature, by the theory. The inconvenient length of the table prevents its being carried down by intervals of 10° to the point of freezing mercury, which however is found to be at $-17\frac{1}{2}^{\circ}$.

The 4th column is the same as the 3d, with the difference of 40° , to make it conform to the common method of numbering on Fahrenheit's scale.

The 5th column is the 4th corrected, on account of the unequal expansion of Glass:—The *apparent* expansion of mercury in glass is less than the *real*, by the expansion of the glass itself; this, however, would not disturb the law of expansion of the liquid, both apparent and real being subject to the same, *provided the glass expands equally*; this will be shewn hereafter. But it has been shewn by De Luc, that glass expands less in the lower half of the scale than the higher; this must occasion the mercury apparently to expand more in the lower half than what is dictated by the law of expansion. By calculating from De Luc's data, I find, that the mercury in the middle of the scale, or 122° , ought to be found nearly 3° higher than would be, were it

not for this increase. Not however to over-rate the effect, I have taken it only at $1^{\circ}.7$, making the number $108^{\circ}.3$ in the 4th column, 110° in the 5th, and the rest of the column is corrected accordingly. The numbers in this column cannot well be extended much beyond the interval from freezing to boiling water, for want of experiments on the expansion of glass. By viewing this column along with the 1st, the quantity of the supposed error in the common scale may be perceived; and any observations on the old thermometer may be reduced to the new.

The 6th column contains the squares of the natural series 1, 2, 3, &c. representing the expansion of water by equal intervals of temperature. Thus, if a portion of water at 42° expands a quantity represented by 289, at the boiling temperature, then at 52° it will be found to have expanded 1, at 62° , 4 parts, &c. &c. Water expands by cold or the abstraction of heat in the same way below the point of greatest density, as will be illustrated when we come to consider the absolute expansion of bodies. The apparent greatest density too does not happen at $39^{\circ}.3$ old scale; but about 42° ; and the greatest real density is at or near 36° of the same.

The 7th column contains a series of num-

bers in Geometrical Progression, denoting the expansion of air, or elastic fluids. The volume at 32° is taken 1000, and at 212° , 1376 according to Gay Lussac's and my own experiments. As for the expansion at intermediate degrees, General Roi makes the temperature at midway of total expansion, $116^{\circ}\frac{1}{2}$ old scale; from the results of my former experiments, (Manch. Mem. Vol. 5, Part 2, page 599) the temperature may be estimated at $119^{\circ}\frac{1}{4}$; but I had not then an opportunity of having air at 32° . By more recent experiments I am convinced that dry air of 32° will expand the same quantity from that to 117° or 118° of common scale, as from the last term to 212° . According to the theory in the above Table it appears, that air of 117° will be 1188, or have acquired one half its total expansion. Now if the theory accord so well with experiment in the middle of the interval, we cannot expect it to do otherwise in the intermediate points.

The 8th column contains the force of aqueous vapours in contact with water expressed in inches of mercury, at the respective temperatures. It constitutes a geometrical progression; the numbers opposite 32° and 212° , namely, .200 and 30.0 are derived from experiments, (ibid. page 559) and the rest are determined from theory. It is remarkable that

those numbers do not differ from the table just referred to, which was the result of actual experience, so much as 2° in any part; a difference that might even exist between two thermometers of the same kind.

The 9th column exhibits the force of the vapour of sulphuric ether in contact with liquid ether; which is a geometrical progression, having a less ratio than that of water. Since writing my former Essay on the Force of Steam, I am enabled to correct one of the conclusions therein contained; the error was committed by trusting to the accuracy of the common mercurial thermometer. Experience confirmed me that the force of vapour from water of nearly 212°, varied from a change of temperature as much as vapour from ether of nearly 100°. Hence I deduced this general law, namely, "that the variation of the force of vapour from all liquids is the same for the same variation of temperature, reckoning from vapour of any given force."—But I now find that 30° of temperature in the lower part of the common scale is much more than 30° in the higher: and therefore the vapours of ether and water are not subject to the same change of force by equal increments of temperature. The truth is, vapour from water, ether and other liquids, increases in force in geometri-

cal progression to the temperature; but the ratio is different in different fluids. Ether as manufactured in the large way, appears to be a very homogeneous liquid. I have purchased it in London, Edinburgh, Glasgow and Manchester, at very different times, of precisely the same quality in respect to its vapour; namely, such as when thrown up into a barometer would depress the mercury 15 inches at the temperature of 68°. Nor does it lose any of its effect by time; I have now a barometer with a few drops of ether on the mercury, that has continued with invaried efficacy for eight or nine years. The numbers in the column between the temperatures of 20° and 80°, are the results of repeated observations on the above ether barometer for many years; those above and below are obtained from direct experiment as far as from 0 to 212°; the low ones were found by subjecting the vacuum of the barometer to an artificial cold mixture; and the higher ones were found in the manner related in my former Essays: only the highest force has been considerably increased from what I formerly had it, in consequence of supplying the manometer with more ether; it having been found to leave little or no liquid when at the temperature of 212°; and in order to obtain the maximum effect it is indispen-

sible to have a portion of liquid remaining in contact with the vapour.

The 10th column shews the force of vapour from alcohol, or rather common spirit of wine, determined by experiment in the same way as the vapour of water. This is not a geometrical progression, probably because the liquid is not pure and homogeneous. I suspect the elastic fluid in this case is a mixture of aqueous and alcoholic vapour.

SECTION 2.

EXPANSION BY HEAT.

One important effect of heat is the expansion of bodies of every kind. Solids are least expanded; liquids more; and elastic fluids most of all. The quantities of increase in bulk have in many instances been determined; but partly through the want of a proper thermometer, little general information has been derived from particular experiments. The force necessary to counteract the expansion has not been ascertained, except in the case of elastic fluids; but there is no doubt it is very great. The quantity and law of expansion of all permanent elastic fluids have already

been given ; it remains then to advert to liquid and solid bodies.

In order to understand the expansion of liquids, it is expedient to premise certain propositions :

1st. Suppose a thermometrical vessel of glass, metal, &c., were filled with any liquid up to a certain mark in the stem ; and that it was known the vessel and the liquid had precisely the same expansion, bulk for bulk, with the same change of temperature ; then it must be evident upon a little consideration, that whatever change of temperature took place, the liquid must remain at the same mark.

2. Suppose as before, except that both bodies expand uniformly with the temperature, but the liquid at a greater rate than the vessel : then it is evident by an increase of temperature, the liquid would appear to ascend uniformly a quantity equal to the difference of the absolute expansion of the two bodies.

3. Suppose as in the last case, but that the liquid expands at a less rate than the vessel ; the liquid would then descend, and that uniformly by an increase of temperature, a quantity equal to the difference of the absolute expansions.

4. Suppose as before, only the vessel now expands uniformly, and the liquid with a velocity uniformly accelerated, commencing from

rest; in this case if temperature be added uniformly, the liquid will appear to descend with a velocity uniformly retarded to a certain point, there to be stationary, and afterwards to ascend with an uniformly accelerated velocity, of the same sort as the former.—For, as the velocity with which the liquid expands is uniformly accelerative, it must successively pass through all degrees from 0 to any assigned quantity, and must therefore in some moment be the same as that of the vessel, and therefore, for that moment, the liquid must appear stationary: previously to that time the liquid must have descended by the third proposition, and must afterwards ascend, by the 2d. but not uniformly. Let the absolute space expanded by the liquid at the moment of equal velocities be denoted by 1, then that of the vessel in the same time must be 2; because the velocity acquired by an uniformly accelerating force, is such as to move a body through twice the space in the same time. It follows then that the liquid must have sunk 1, being the excess of the expansion of the vessel above that of the liquid. Again, let another portion of temperature equal to the former be added, then the absolute expansion of the liquid will be 4, reckoned from the commencement; and the expansion of the vessel

also 4: the place of the liquid will be the same as at first, and therefore it must apparently ascend 1 by the 2d portion. Let a third portion of heat equal to one of the former be added, and it will make the total expansion of the liquid 9, or give 5 additional expansion, from which deducting 2, that of the vessel, there remains 3 for the apparent expansion by the 3d portion; in like manner 5 will be due for the 4th, and 7 for the 5th, &c., being the series of odd numbers. But the aggregate of these forms a series of squares, as is well known. Hence the apparent expansion will proceed by the same law as the real, only starting from a higher temperature. If the law of expansion of the liquid be such that either the addition or abstraction of temperature, that is, either heat or cold produces expansion alike, reckoned from the point of greatest density; then the apparent expansion will still be guided by the same law as the real. For, if when the liquid is at the lowest point of the scale, we withdraw a portion of heat, it ascends to 1; or is in the circumstance of greatest density, and no expansion as at the commencement; if then we withdraw another portion, it will expand 1 by hypothesis, but the vessel will contract 2, which must make the apparent expansion of the liquid 3;

by another portion it will be 5, by another 7, &c., as before.

The truth of the above proposition may be otherwise shewn thus :

Let 1, 4, 9, 16, 25, &c., represent the absolute expansions of the liquid, and p , $2p$, $3p$, $4p$, $5p$, &c., those of the vessel by equal increments of temperature, then $1-p$, $4-2p$, $9-3p$, $16-4p$, $25-5p$, &c., will represent the apparent expansion of the liquid; the differences of these last quantities, namely $3-p$, $5-p$, $7-p$, $9-p$, &c., form a series in arithmetical progression, the common difference of which is 2. But it is demonstrated by algebraists, that the differences of a series of square numbers, whose roots are in arithmetical progression, form an arithmetical progression, and that the common difference of the terms of this progression is equal to twice the square of the difference of the roots. Hence, as $2 =$ twice the square of 1, we have the above arithmetical series $3-p$, $5-p$, &c., equal to the differences of a series of squares, the common difference of the roots of which is 1.

Now to apply these principles: solid bodies are generally allowed to expand uniformly within the common range of temperature: at all events the quantity is so small compared

with the expansion of liquids, such as water, that the deviation from uniformity cannot require notice in many cases. Water being supposed to expand according to the square of the temperature from that of greatest density, we may derive the following conclusions.

Cor. 1. The laws of uniformly accelerated motion, are the same as those of the expansion of water, whether absolute or apparent, the time in one denoting the temperature in the other, and the space denoting the expansion: that is, if t = time or temperature, v = velocity, and s = space or expansion: then,

t^2 , or tv , or v^2 are as s .

$\frac{1}{2} t v = s$

v is as t

\dot{s} is as $2 t \dot{t}$

\ddot{s} is as t , \dot{t} being supposed constant, &c.

Cor. 2. The real expansion of water from maximum density for any number of degrees of temperature, is the same as the apparent expansion from apparent greatest density in any vessel for the same number of degrees. For instance, if water in a glass vessel appears to be of greatest density, or descends lowest at 42° of common scale, and appears to expand $\frac{1}{7}$ of its first volume from thence

to 212° ; then it may be inferred that the real expansion of water from greatest density by 170° is $\frac{1}{47}$ of its volume; so that the absolute expansion of water is determinable this way, without knowing either at what temperature its density is greatest, or the expansion of the vessel containing it.

Cor. 3. If the expansion of any vessel can be obtained; then may the temperature at which water is of greatest density be obtained; and *vice versú*. This furnishes us with an excellent method of ascertaining both the relative and absolute expansion of all solid bodies that can be formed into vessels capable of holding water.

Cor. 4. If the apparent expansion of water from maximum density for 180° were to be equalled by a body expanding uniformly, its velocity must be equal to that of water at 90° , or mid-way.—And if any solid body be found to have the same expansion as water at 10° from max. density; then its expansion for 180° must be $\frac{1}{9}$ of that of water, &c. Because in water v is as t , &c.

By graduating several glass thermometer vessels, filling them with water, exposing them to different temperatures, and comparing results, I have found the *apparent* expansion of water in glass for every 10° of the common

or old scale (as I shall henceforward call it) and the new one, as under.

EXPANSION OF WATER.

OLD SCALE.		NEW SCALE.	
		5°	100227
12°	100236	15	100129
22	100090	25	100057
32	100022	35	100014
42	100000	45	100000
52	100021	55	100014+
62	100083	65	100057
72	100180	75	100129
82	100312	85	100227
92	100477	95	100359
102	100672	105	100517
112	100880	115	100704
122	101116	125	100919
132	101367	135	101163
142	101638	145	101436
152	101934	155	101738
162	102245	165	102068
172	102575	175	102426
182	102916	185	102814
192	103265	195	103231
202	103634	205	103676
212	104012	215	104150
		225	104658

The whole expansion of water for 180° of temperature, reckoned from the point of greatest density, appears from the 2d Table to be $\frac{1}{17.7}$, or $21\frac{1}{4}$ parts become $22\frac{1}{4}$.

In the Edinburgh Philosophical Transactions

for 1804, Dr. Hope has given a paper on the contraction of water by heat in low temperatures. (See also Nicholson's Journal, Vol. 12.) In this paper we find an excellent history of facts and opinions relative to this remarkable question in physics, with original experiments. There appear to have been two opinions respecting the temperature at which water obtains its maximum density; the one stating it to be at the freezing point, or 32° ; the other at 40° . Previously to the publication of the above essay, I had embraced the opinion that the point was 32° , chiefly from some experiments about to be related. Dr. Hope argued from his own experiments in favour of the other opinion. My attention was again turned to the subject, and upon re-examination of facts, I found them all to concur in giving the point of greatest density at the temperature 36° , or mid-way between the points formerly supposed. In two letters inserted in Nicholson's Journal, Vol. 13 and 14, I endeavoured to shew that Dr. Hope's experiments supported this conclusion and no other. I shall now shew that my own experiments on the apparent expansion of water in different vessels, coincide with them in establishing the same conclusion.

The results of my experiments, without

those deductions, were published in Nicholson's Journal, Vol. 10. Since then some small additions and corrections have been made. It may be observed that small vessels, capable of holding one or two ounces of water, were made of the different materials, and such as that glass tubes could be cemented into them when full of water, so as to resemble and act as a common thermometer. The observations follow :

	Water stationary.	Corresponding points of expansion.
1 Brown earthen ware.....	at 38°	at 32° & 44°
2 Common white ware, and } stone ware, }	40	32 & 48+
3 Flint glass.....	42	32 & 52½
4 Iron.....	42+	32 & 53—
5 Copper	45+	32 & 59
6 Brass.....	45½	32 & 60—
7 Pewter	46	32 & 60½
8 Zinc.....	48	32 & 64+
9 Lead.....	49	32 & 67

As the expansion of earthen ware by heat has never before been ascertained, we cannot make use of the first and second experiments to find the temperature of greatest density ; all that we can learn from them is, that the point must be below 38°.

According to Smeaton, glass expands $\frac{1}{1100}$ in length for 180° of temperature ; consequently it expands $\frac{1}{600}$ in bulk. But water expands

$\frac{1}{18}$, or rather more than 18 times as much; therefore the mean velocity of the expansion of water (which is that at 90° , or half way) is 18 times more than that of glass, which is equal to the expansion of water at 42° ; this last must therefore be $\frac{1}{18}$ of the former; consequently water of 42° has passed through $\frac{1}{18}$ of the temperature to the mean, or $\frac{1}{18}$ of $90^\circ = 5^\circ$, of new scale = 4° of old scale, above the temperature at which it is absolutely of greatest density. This conclusion however cannot be accurate; for, it appears from the preceding paragraph that the temperature must be below 38° . The inaccuracy arises, I have no doubt, from the expansion of glass having been under-rated by Smeaton; not from any mistake of his, but from the peculiar nature of glass. Rods and tubes of glass are seldom if ever properly annealed; hence they are in a state of violent energy, and often break spontaneously or with a slight scratch of a file: tubes have been found to expand more than rods, and it might be expected that thin bulbs should expand more still, because they do not require annealing; hence too the great strength of thin glass, its being less brittle, and more susceptible of sudden transitions of temperature. From the above experiments it seems that the expansion due to glass, such

as the bulbs of ordinary thermometers, is very little less than that of iron.

Iron expands nearly $\frac{1}{1000}$ in length by 180° of heat, or $\frac{1}{600}$ in bulk; this is nearly $\frac{1}{12}$ of the expansion of water; hence $90 \div 12 = 7\frac{1}{2}$ of true mean temperature = 6° of common scale; this taken from $42^\circ+$, leaves 36° of common scale for the temperature at which water is of greatest density.

Copper is to iron as 3 : 2 in expansion; therefore if 6° be the allowance for iron, that for copper must be 9° ; hence $45^\circ - 9^\circ = 36^\circ$, for the temperature as before.

Brass expands about $\frac{1}{6}$ more than copper; hence we shall have $45\frac{1}{6} - 9\frac{1}{6} = 36^\circ$, for the temperature as above.

Fine pewter is to iron as 11 : 6 in expansion, according to Smeaton; hence $46^\circ - 11^\circ = 35^\circ$, for the temperature as derived from the vessel of pewter: but this being a mixed metal, it is not so much to be relied upon.

Zinc expands $\frac{1}{12}$ in bulk for 180° , if we may credit Smeaton: hence water expands $5\frac{1}{2}$ times as much as zinc; and $90 \div 5\frac{1}{2} = 17^\circ$ of new scale = $13\frac{1}{2}$ of old scale; whence $48^\circ - 13\frac{1}{2} = 34\frac{1}{2}$ for the temperature derived from zinc. It seems highly probable that in this case the expansion of the vessel is over-rated; it was found to be less than that of lead,

whereas Smeaton makes it more. The vessel was made of the patent malleable zinc of Hodson and Sylvester. Perhaps it contains a portion of tin, which will account for the deviation.

Lead expands $\frac{1}{118}$ of its bulk for 180° ; water therefore expands about $5\frac{1}{2}$ times as much; this gives $90 \div 5\frac{1}{2} = 16\frac{1}{2}$ of new scale = 13° of old scale; whence $49^\circ - 13^\circ = 36^\circ$, as before.

From these experiments it seems demonstrated, that the greatest density of water is at or near the 36° of the old scale, and 37° or 38° of the new scale: and further, that the expansion of thin glass is nearly the same as that of iron, whilst that of stone ware is $\frac{2}{3}$, and brown earthen ware $\frac{1}{2}$ of the same.

The apparent expansion of mercury in a thermometrical glass for 180° I find to be .0163 from 1. That of thin glass may be stated at .0037 = $\frac{1}{270}$, which is rather less than iron, $\frac{1}{257}$. Consequently the real expansion of mercury from 32° to 212° is equal to the sum of these = .02 or $\frac{1}{50}$. De Luc makes it, .01836, and most other authors make it less; because they have all under-rated the expansion of glass. Hence we derive this proportion, $0163 : 180^\circ :: .0037 : 41^\circ$ nearly, which expresses the effect of the expansion of glass on

the mercurial thermometer: that is, the mercury would rise 41° higher on the scale at the temperature of boiling water, if the glass had no expansion.—De Luc makes the expansion of a glass tube from 32° to $212^{\circ} = .00083$ in length, and from 32° to 122° only $.00035$. This inequality arises in part at least, I apprehend, from the want of equilibrium in the original fixation of glass tubes, the outside being hard when the inside is soft.

Liquids may be denominated pure when they are not decomposed by heat and cold. Solutions of salts in water cannot be deemed such; because their constitution is affected by temperature. Thus, if a solution of sulphate of soda in water be cooled, a portion of the salt crystallizes, and leaves the remaining liquid less saline than before; whereas water and mercury, when partially congealed, leave the remaining liquid of the same quality as before. Most acid liquids are similar to saline solutions in this respect. Alcohol as we commonly have it, is a solution of pure alcohol in a greater or less portion of water: and probably would be affected by congelation like other solutions. Ether is one of the purest liquids, except water and mercury. Oils, both fixed and volatile, are probably for the most part impure, in the sense we use it. Notwithstand-

ing these observations, it is remarkable how nearly those liquids approximate to the law of expansion observed in water and mercury. Few authors have made experiments on these subjects; and their results in several instances are incorrect. My own investigations have been chiefly directed to water and mercury; but it may be proper to give the results of my enquiries on the other liquids as far as they have been prosecuted.

Alcohol expands about $\frac{1}{7}$ of its bulk for 180° , from -8 to 172° . The relative expansions of this liquid are given by De Luc from 32° to 212° ; but the results of my experiments do not seem to accord with his. According to him alcohol expands 35 parts for the first 90° , and 45 parts for the second 90° . The strength of his alcohol was such as to fire gun-powder: but this is an indefinite test. From my experiments I judge it must have been very weak. I find 1000 parts of alcohol of .817 sp. gravity at the temperature 50° became 1079 at the temperature 170° of the common mercurial scale: at 110° the alcohol is at 1039, or half a division below the true mean. When the sp. gravity is .86, I find 1000 parts at 50° become 1072 at 170° ; at 110° the bulk is 1035+, whence the disproportion of the two parts of the scale is not so much

in this case as 35 to 37. When the sp. gravity is ,937, I find 1000 parts become 1062 at 170°, and 1029½ at 110°; hence the ratio of the expansion becomes 29½ to 32½. When the sp. gravity is ,967, answering to 75 per cent. water, I find 1000 parts at 50° become 1040 at 170°, and 1017½ at 110°, giving a ratio of 35 to 45; which is the same as De Luc gives for alcohol. It is true he takes an interval of temperature = 180°, and I take one for 120° only; but still it is impossible to reconcile our results. As the expansion of alcohol from 172° to 212° must have been conjectural, perhaps he has over-rated it. In reporting these results I have not taken into account the expansion of the glass vessel, a large thermometrical bulb, containing about 750 grains of water, and having a tube proportionally wide; consequently the real expansions must be considered as more rather than less than above stated. The graduation of the vessel having been repeatedly examined, and being the same that was used in determining the expansion of water, I can place confidence in the results. Particular care was taken in these experiments to have the bulb and stem both immersed in water of the proposed temperature.

As alcohol of .817 sp. gravity contains at

least 8 per cent. water, it is fair to infer from the above that a thermometer of pure alcohol would in no apparent degree differ from one of mercury in the interval of temperature from 50° to 170° . But when we consider that the relative expansions of glass, mercury and alcohol for this interval, are as 1, $5\frac{1}{2}$ and 22 respectively, it must be obvious that the inequality of the expansion of glass in the higher and lower parts of the scale, which tends to equalise the apparent expansion of mercury, has little influence on alcohol, by reason of its comparative insignificance. Hence it may be presumed that a spirit thermometer would be more equable in its divisions than a mercurial one, in a vessel of uniform expansion. This it ought to be by theory, because the point of greatest density or congelation of alcohol is below that of mercury.

Water being densest at 36° , and alcohol at a very remote temperature below, it was to be expected that mixtures of these would be densest at intermediate temperatures, and those higher as the water prevailed; thus we find the disproportion, so observable in the expansion of water, growing greater and greater in the mixtures as they approach to pure water.

Water saturated with common salt expands as follows: 1000 parts at 32° become 1050

at 212° ; at 122° it is nearly 1023, which gives the ratio of 23 to 27 for the corresponding equal intervals of mercury. This is nearly the same as De Luc's ratio of 36.3 to 43.7. This solution is said to congeal at -7° , and probably expands nearly as the square of the temperature from that point. It differs from most other saline solutions in regard to its expansion by temperature.

Olive and linseed oils expand about 8 per cent. by 180° of temperature; De Luc finds the expansion of olive oil nearly correspond to mercury; with me it is more disproportionate, nearly agreeing with water saturated with salt.

Oil of turpentine expands about 7 per cent. for 180° ; it expands much more in the higher than in the lower part of the scale, as it ought to do, the freezing point being stated at 14 or 16° . The ratio is somewhere about 3 to 5. Several authors have it that oil of turpentine boils at 560° ; I do not know how the mistake originated; but it boils below 212° , like the rest of the essential oils.

Sulphuric acid, sp. gravity 1.85 expands about 6 per cent. from 32° to 212° . It accords with mercury as nearly as possible in every part of the scale. Dr. Thomson says the freezing point of acid of this strength is at

—36° or below; whence it accords with the same law as water and mercury. I find that even the glacial sulphuric acid, or that of 1.78 sp. gravity, which remains congealed at 45°, expands uniformly, or nearly like the other, whilst it continues liquid.

Nitric acid, sp. gravity 1.40, expands about 11 per cent. from 32° to 212°; the expansion is nearly of the same rate as that of mercury, the disproportion not being more than 27 to 28 or thereabouts. The freezing point of acid of this strength is near the freezing point of mercury.

Muriatic acid, sp. gravity 1.137, expands about 6 per cent. from 32° to 212°; it is more disproportionate than nitric acid, as might be expected, being so largely diluted with water. The ratio is nearly 6 to 7.

Sulphuric ether expands after the rate of 7 per cent. for 180° of temperature. I have only compared the expansion of this liquid with that of mercury from 60° to 90°. In this interval it accords so nearly with mercury that I could perceive no sensible difference in their rates. It is said to freeze at —46°.

From what has been observed it may be seen that water expands less than most other liquids; yet it ought to be considered as having in reality the greatest rate of expansion.

Alcohol and nitric acid, which appear to expand so much, do not excel, or even equal water, if we estimate their expansion from the temperature of greatest density, and compare them with water in like circumstances. It is because we begin with them at 100 or 200° above the point of greatest density, and observe their expansion for 180° further, that they appear to expand so largely. Water, if it continued liquid, would expand three times as much in the *second* interval of 180° as it does in the first, reckoning from 36°.

EXPANSION OF SOLIDS.

No general law has hitherto been discovered respecting the expansion of solid bodies; but as elastic fluids and liquids appear to be subject to their respective laws in this particular, we may confidently expect that solids will be found so too. As it may be presumed that solids undergo no change of form, by the abstraction of heat, it is probable that whatever the law may be, it will respect the point at which temperature commences, or what may be called, absolute cold. It is not our present business to enquire how low this point is; but it may be observed that every phenomenon

indicates it to be very low, or much lower than is commonly apprehended. Perhaps it may hereafter be demonstrated that the interval of temperature from 32° to 212° of Fahrenheit, constitutes the 10th, 15th, or 20th interval from absolute cold. Judging from analogy, we may conjecture that the expansion of solids is progressively increasing with the temperature; but whether it is a geometrical progression as elastic fluids, or one increasing as the square of the temperature, like liquids, or as the 3d or any power of the temperature, still if it be estimated from absolute cold, it must appear to be nearly uniform, or in arithmetical progression to the temperature, for so small and remote an interval of temperature as that between freezing and boiling water. The truth of this observation will appear from the following calculation: let us suppose the interval in question to be the 15th; then the real temperature of freezing water will be 2520° , the mid-way to boiling 2610° , and boiling water 2700° , reckoned from absolute cold.

$14^1 = 196$	Dif.	$14^1 = 2744$	Dif.
$14\frac{1}{2}^1 = 210\frac{1}{4}$	— $14\frac{1}{2}$	$14\frac{1}{2}^1 = 3048\frac{1}{4}$	— $304\frac{1}{2}$
$15^1 = 225$	— $14\frac{1}{2}$	$15^1 = 3375$	— $326\frac{1}{2}$

Now the differences above represent the ratios of expansion for 90° of temperature; they are in the former case as 57 to 59, and in the latter as 14 to 15 nearly. But the temperature being supposed to be measured by the new scale, the mean is about 110° of the old scale; therefore the expansion of solids should be as 57 or 14 from 32° to 110° , and as 59 or 15 from 110° to 212° of the old scale. If these conjectures be right, the expansion of solids ought to be something greater in the lower part of the old scale, and something less in the higher part. Experience at present does not enable us to decide the question. For all practical purposes we may adopt the notion of the equable expansion of solids. Only glass has been found to expand increasingly with the temperature, and this arises probably from its peculiar constitution, as has been already observed.

Various pyrometers, or instruments for measuring the expansion of solids, have been invented, of which accounts may be seen in books of natural philosophy. Their object is to ascertain the expansion in length of any proposed subject. The longitudinal expansion being found, that of the bulk may be derived from it, and will be three times as much. Thus, if a bar of 1000 expand to 1001 by a

certain temperature ; then 1000 cubic inches of the same will become 1003 by the same temperature.

The following Table exhibits the expansion of the principal subjects hitherto determined, for 180° of temperature ; that is, from 32° to 212° of Fahrenheit. The bulk and length of the articles at 32° are denoted by 1.

SOLIDS.	EXPANSION.	
	In bulk.	In length.
Brown earthen ware.....	.0012 = $\frac{1}{83}$	$\frac{1}{220}$
Stone ware.....	.0025 = $\frac{1}{40}$	$\frac{1}{100}$
Glass—rods and tubes.....	.0025 = $\frac{1}{40}$	$\frac{1}{200}$ †
— bulbs (thin).....	.0037 = $\frac{1}{27}$	$\frac{1}{70}$
Platinum.....	.0025 = $\frac{1}{40}$	$\frac{1}{135}$ †
Steel.....	.0034 = $\frac{1}{29}$	$\frac{1}{75}$ †
Iron.....	.0038 = $\frac{1}{26}$	$\frac{1}{68}$ †
Gold.....	.0042 = $\frac{1}{24}$	$\frac{1}{72}$ *
Bismuth.....	.0042 = $\frac{1}{24}$	$\frac{1}{72}$ †
Copper.....	.0051 = $\frac{1}{20}$	$\frac{1}{74}$ †
Brass.....	.0053 = $\frac{1}{19}$	$\frac{1}{77}$ †
Silver.....	.0060 = $\frac{1}{17}$	$\frac{1}{60}$ *
Fine Pewter.....	.0068 = $\frac{1}{15}$	$\frac{1}{55}$ †
Tin.....	.0074 = $\frac{1}{14}$	$\frac{1}{50}$ †
Lead.....	.0086 = $\frac{1}{12}$	$\frac{1}{47}$ †
Zinc.....	.0093 = $\frac{1}{11}$	$\frac{1}{43}$ †
LIQUIDS.		
Mercury.....	.0200 = $\frac{1}{5}$	
Water.....	.0466 = $\frac{1}{21.5}$	
Water sat. with salt.....	.0500 = $\frac{1}{20}$	
Sulphuric acid.....	.0600 = $\frac{1}{17}$	
Muriatic Acid.....	.0600 = $\frac{1}{17}$	
Oil of turpentine.....	.0700 = $\frac{1}{14}$	
Ether.....	.0700 = $\frac{1}{14}$	
Fixed oils.....	.0800 = $\frac{1}{13}$	
Alcohol.....	.0110 = $\frac{1}{9}$	
Nitric acid.....	.0110 = $\frac{1}{9}$	
ELASTIC FLUIDS.		
Gases of all kinds.....	.376 = $\frac{1}{3}$	

† Smeaton. * Ellicott. † Borda.

Wedgwood's Thermometer.

The spirit thermometer serves to measure the greatest degrees of cold we are acquainted with, and the mercurial thermometer measures 400° above boiling water, by the old scale, or about 250° by the new one, at which temperature the mercury boils. This is short of red heat, and very far short of the highest attainable temperature. An instrument to measure high temperatures is very desirable; and Mr. Wedgwood's is the best we have yet; but there is still great room for improvement. Small cylindrical pieces of clay, composed in the manner of earthen ware, and slightly baked, are the thermometrical pieces. When used, one of them is exposed in a crucible to the heat proposed to be measured, and after cooling, it is found to be contracted, in proportion to the heat previously sustained; the quantity of contraction being measured, indicates the temperature. The whole range of this thermometer is divided into 240 equal degrees, each of which is calculated to be equal to 130° of Fahrenheit. The lowest, or 0, is found about 1077° of Fahrenheit (supposing the common scale continued above boiling mercury,) and the highest 3227°. According to the new views of temperature in the preceding

pages, there is reason to think these numbers are much too large.

The following Table exhibits some of the more remarkable temperatures in the whole range, according to the present state of our knowledge.

	Wedg.
Extremity of Wedgwood's thermometer.....	240°
Fig iron, cobalt and nickel, melt from 130° to.....	150
Greatest heat of a Smith's forge.....	125
Furnaces for glass and earthen ware, from 40 to.....	124
Gold melts	32
Settling heat of flint glass.....	29
Silver melts.....	28
Copper melts	27
Brass melts	21
Diamond burns	14
Red heat visible in day-light.....	0
	Fahrenheit.
	old scale.
Hydrogen and charcoal burn 500° to	1000°
Antimony melts.....	809
Zinc	700
Lead	612
Mercury boils	600
Linseed oil boils.....	600
Sulphuric acid boils.....	590
Bismuth.....	476
Tin	442
Sulphur burns slowly.....	303
Nitric acid boils	240
Water and essential oils boil	212
Bismuth 5 parts, tin 3 and lead 2, melt.....	210

ON SPECIFIC HEAT.

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	Fahrenheit.
Alcohol boils	174°
Bees wax melts.....	142
Ether boils.....	98
Blood heat 96° to.....	98
Summer heat in this climate 75° to.....	80
Sulphuric acid (1.78) when congealed. begins to melt	45
Mixture of ice and water.....	32
Milk freezes	30
Vinegar freezes	28
Strong wines freeze about	20
Snow 3 parts, salt 2	-7
Cold observed on the snow at Kendal, 1791.....	-10
Ditto at Glasgow, 1780	-23
Mercury freezes	-32
Greatest artificial cold observed.....	-90

SECTION 5.

ON THE

SPECIFIC HEAT OF BODIES.

If the whole quantity of heat in a measure of water of a certain temperature be denoted by 1, that in the same measure of mercury will be denoted by .5 nearly : hence the specific heats of water and mercury, *of equal bulks*, may be signified by 1 and .5 respectively.

If the specific heats be taken from *equal weights* of the two liquids ; then they will be

ANEXO 2 – Livro John Dalton Capítulo 2, 1808.

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CHAP. II

ON THE
CONSTITUTION OF BODIES.

THERE are three distinctions in the kinds of bodies, or three states, which have more especially claimed the attention of philosophical chemists; namely, those which are marked by the terms *elastic fluids, liquids, and solids*. A very familiar instance is exhibited to us in water, of a body, which, in certain circumstances, is capable of assuming all the three states. In steam we recognise a perfectly elastic fluid, in water, a perfect liquid, and in ice a complete solid. These observations have tacitly led to the conclusion which seems universally adopted, that all bodies of sensible magnitude, whether liquid or solid, are constituted of a vast number of extremely small particles, or atoms of matter bound together by a force of attraction, which is more or less powerful according to circumstances, and which as it endeavours to prevent their separation, is very

properly called in that view, *attraction of cohesion*; but as it collects them from a dispersed state (as from steam into water) it is called, *attraction of aggregation*, or more simply, *affinity*. Whatever names it may go by, they still signify one and the same power. It is not my design to call in question this conclusion, which appears completely satisfactory; but to shew that we have hitherto made no use of it, and that the consequence of the neglect, has been a very obscure view of chemical agency, which is daily growing more so in proportion to the new lights attempted to be thrown upon it.

The opinions I more particularly allude to, are those of Berthollet on the Laws of chemical affinity; such as that chemical agency is proportional to the mass, and that in all chemical unions, there exist insensible gradations in the proportions of the constituent principles. The inconsistency of these opinions, both with reason and observation, cannot, I think, fail to strike every one who takes a proper view of the phenomena.

Whether the ultimate particles of a body, such as water, are all alike, that is, of the same figure, weight, &c. is a question of some importance. From what is known, we have no reason to apprehend a diversity in these

particulars : if it does exist in water, it must equally exist in the elements constituting water, namely, hydrogen and oxygen. Now it is scarcely possible to conceive how the aggregates of dissimilar particles should be so uniformly the same. If some of the particles of water were heavier than others, if a parcel of the liquid on any occasion were constituted principally of these heavier particles, it must be supposed to affect the specific gravity of the mass, a circumstance not known. Similar observations may be made on other substances. Therefore we may conclude that *the ultimate particles of all homogeneous bodies are perfectly alike in weight, figure, &c.* In other words, every particle of water is like every other particle of water ; every particle of hydrogen is like every other particle of hydrogen, &c.

Besides the force of attraction, which, in one character or another, belongs universally to ponderable bodies, we find another force that is likewise universal, or acts upon all matter which comes under our cognisance, namely, a force of repulsion. This is now generally, and I think properly, ascribed to the agency of heat. An atmosphere of this subtile fluid constantly surrounds the atoms of all bodies, and prevents them from being drawn into

actual contact. This appears to be satisfactorily proved by the observation, that the bulk of a body may be diminished by abstracting some of its heat: But from what has been stated in the last section, it should seem that enlargement and diminution of bulk depend perhaps more on the arrangement, than on the size of the ultimate particles. Be this as it may, we cannot avoid inferring from the preceding doctrine on heat, and particularly from the section on the natural zero of temperature, that solid bodies, such as ice, contain a large portion, perhaps $\frac{2}{3}$ of the heat which the same are found to contain in an elastic state, as steam.

We are now to consider how these two great antagonist powers of attraction and repulsion are adjusted, so as to allow of the three different states of *elastic fluids, liquids, and solids*. We shall divide the subject into four Sections; namely, first, *on the constitution of pure elastic fluids*; second, *on the constitution of mixed elastic fluids*; third, *on the constitution of liquids*, and fourth, *on the constitution of solids*.

SECTION I.

ON THE CONSTITUTION OF PURE
ELASTIC FLUIDS.

A pure elastic fluid is one, the constituent particles of which are all alike, or in no way distinguishable. Steam, or aqueous vapour, hydrogenous gas, oxygenous gas, azotic gas,* and several others are of this kind. These fluids are constituted of particles possessing very diffuse atmospheres of heat, the capacity or bulk of the atmosphere being often one or two thousand times that of the particle in a liquid or solid form. Whatever therefore may be the shape or figure of the solid atom abstractedly, when surrounded by such an atmosphere it must be globular; but as all the globules in any small given volume are subject to the same pressure, they must be equal in bulk, and will therefore be arranged in horizontal strata, like a pile of shot. A volume

* The novice will all along understand that several chemical subjects are necessarily introduced before their general history and character can be discussed.

of elastic fluid is found to expand whenever the pressure is taken off. This proves that the repulsion exceeds the attraction in such case. The absolute attraction and repulsion of the particles of an elastic fluid, we have no means of estimating, though we can have little doubt but that the cotemporary energy of both is great; but the excess of the repulsive energy above the attractive can be estimated, and the law of increase and diminution be ascertained in many cases. Thus in steam, the density may be taken at $\frac{1}{1718}$ that of water; consequently each particle of steam has 12 times the diameter that one of water has, and must press upon 144 particles of a watery surface; but the pressure upon each is equivalent to that of a column of water of 34 feet; therefore the excess of the elastic force in a particle of steam is equal to the weight of a column of particles of water, whose height is $34 \times 144 = 4896$ feet. And further, this elastic force decreases as the distance of the particles increases. With respect to steam and other elastic fluids then, the force of cohesion is entirely counteracted by that of repulsion, and the only force which is efficacious to move the particles is the excess of the repulsion above the attraction. Thus, if the attraction be as 10 and the repulsion as 12, the effective repulsive force is as 2. It

appears then, that an elastic fluid, so far from requiring any force to separate its particles, it always requires a force to retain them in their situation, or to prevent their separation.

A vessel full of any pure elastic fluid presents to the imagination a picture like one full of small shot. The globules are all of the same size; but the particles of the fluid differ from those of the shot, in that they are constituted of an exceedingly small central atom of solid matter, which is surrounded by an atmosphere of heat, of great density next the atom, but gradually growing rarer according to some power of the distance; whereas those of the shot are globules, uniformly hard throughout, and surrounded with atmospheres of heat of no comparative magnitude.

It is known from experience, that the force of a mass of elastic fluid is directly as the density. Whence is derived the law already mentioned, that the repulsive power of each particle is inversely as its diameter. That is, the *apparent* repulsive power, if we may so speak; for the real or absolute force of repulsion is not known, as long as we remain ignorant of the attractive force. When we expand any volume of elastic fluid, its particles are enlarged, without any material change in the quantity of their heat; it follows then, that

the density of the atmospheres of heat must fluctuate with the pressure. Thus, suppose a measure of air were expanded into 8 measures; then, because the diameters of the elastic particles are as the cube root of the space, the distances of the particles would be twice as great as before, and the elastic atmospheres would occupy nearly 8 times the space they did before, with nearly the same quantity of heat: whence we see that these atmospheres must be diminished in density in nearly the same ratio as the mass of elastic fluid.

Some elastic fluids, as hydrogen, oxygen, &c. resist any pressure that has yet been applied to them. In such then it is evident the repulsive force of heat is more than a match for the affinity of the particles, and the external pressure united. To what extent this would continue we cannot say; but from analogy we might apprehend that a still greater pressure would succeed in giving the attractive force the superiority, when the elastic fluid would become a liquid or solid. In other elastic fluids, as steam, upon the application of compression to a certain degree, the elasticity apparently ceases altogether, and the particles collect in small drops of liquid, and fall down. This phenomenon requires explanation.

From the very abrupt transition of steam

from a volume of 1700 to that of 1, without any material increase of pressure, one would be inclined to think that the condensation of it was owing to the *breaking* of a spring, rather than to the *curbing* of one. The last however I believe is the fact. The condensation arises from the action of affinity becoming superior to that of heat, by which the latter is overruled, but not weakened. As the approximation of the particles takes place, their repulsion increases from the condensation of the heat, but their affinity increases, it should seem, in a still greater ratio, till the approximation has attained a certain degree, when an equilibrium between those two powers takes place, and the liquid, water, is the result. That this is the true explanation we may learn from what has been stated at page 131; wherein it is shewn that the heat given off by the condensation of steam, is in all probability no more than would be given off by any permanently elastic fluid, could it be mechanically condensed into the like volume, and is moreover a small portion of the whole heat previously in combination. As far then as the heat is concerned in this phenomenon, the circumstances would be the same, whether the approximation of the particles was the effect of affinity, or of external mechanical force.

The constitution of a liquid, as water, must then be conceived to be that of an aggregate of particles, exercising in a most powerful manner the forces of attraction and repulsion, but nearly in an equal degree.—Of this more in the sequel.

SECTION 2.

ON THE CONSTITUTION OF MIXED ELASTIC FLUIDS.

When two or more elastic fluids, whose particles do not unite chemically upon mixture, are brought together, one measure of each, they occupy the space of two measures, but become uniformly diffused through each other, and remain so, whatever may be their specific gravities. The fact admits of no doubt; but explanations have been given in various ways, and none of them completely satisfactory. As the subject is one of primary importance in forming a system of chemical principles, we must enter somewhat more fully into the discussion.

Dr. Priestley was one of the earliest to notice the fact: it naturally struck him with surprise,

that two elastic fluids, having apparently no affinity for each other, should not arrange themselves according to their specific gravities, as liquids do in like circumstances. Though he found this was not the case after the elastic fluids had once been thoroughly mixed, yet he suggests it as probable, that if two of such fluids could be exposed to each other without agitation, the one specifically heavier would retain its lower situation. He does not so much as hint at such gases being retained in a mixed state by affinity. With regard to his suggestion of two gases being carefully exposed to each other without agitation, I made a series of experiments expressly to determine the question, the results of which are given in the *Manch. Memoirs, Vol. 1. new series*. From these it seems to be decided that gases always intermingle and gradually diffuse themselves amongst each other, if exposed ever so carefully; but it requires a considerable time to produce a complete intermixture, when the surface of communication is small. This time may vary from a minute, to a day or more, according to the quantity of the gases and the freedom of communication.

When or by whom the notion of mixed gases being held together by chemical affinity was first propagated, I do not know; but it seems

probable that the notion of water being dissolved in air, led to that of air being dissolved in air.—Philosophers found that water gradually disappeared or evaporated in air, and increased its elasticity; but steam at a low temperature was known to be unable to overcome the resistance of the air, therefore the agency of affinity was necessary to account for the effect. In the permanently elastic fluids indeed, this agency did not seem to be so much wanted, as they are all able to support themselves; but the diffusion through each other was a circumstance which did not admit of an easy solution any other way. In regard to the solution of water in air, it was natural to suppose, nay, one might almost have been satisfied without the aid of experiment, that the different gases would have had different affinities for water, and that the quantities of water dissolved in like circumstances, would have varied according to the nature of the gas. Saussure found however that there was no difference in this respect in the solvent powers of carbonic acid, hydrogen gas, and common air.—It might be expected that at least the *density* of the gas would have some influence upon its solvent powers, that air of half density would take half the water, or the quantity of water would diminish in some proportion to

the density; but even here again we are disappointed; whatever be the rarefaction, if water be present, the vapour produces the same elasticity, and the hygrometer finally settles at extreme moisture, as in air of common density in like circumstances. These facts are sufficient to create extreme difficulty in the conception how any principle of affinity or *cohesion* between air and water can be the agent. It is truly astonishing that the same quantity of vapour should cohere to *one* particle of air in a given space, as to *one thousand* in the same space. But the wonder does not cease here; a torricellian vacuum dissolves water; and in this instance we have vapour existing independently of air at all temperatures; what makes it still more remarkable is, the vapour in such vacuum is precisely the same in quantity and force as in the like volume of any kind of air of extreme moisture.

These and other considerations which occurred to me some years ago, were sufficient to make me altogether abandon the hypothesis of air dissolving water, and to explain the phenomena some other way, or to acknowledge they were inexplicable. In the autumn of 1801, I hit upon an idea which seemed to be exactly calculated to explain the phenomena of vapour; it gave rise to a great variety of

experiments upon which a series of essays were founded, which were read before the Literary and Philosophical Society of Manchester, and published in the 5th Vol. of their memoirs, 1802.

The distinguishing feature of the new theory was, that the particles of one gas are not elastic or repulsive in regard to the particles of another gas, but only to the particles of their own kind. Consequently when a vessel contains a mixture of two such elastic fluids, each acts independently upon the vessel, with its proper elasticity, just as if the other were absent, whilst no mutual action between the fluids themselves is observed. This position most effectually provided for the existence of vapour of any temperature in the atmosphere, because it could have nothing but its own weight to support; and it was perfectly obvious why neither more nor less vapour could exist in air of extreme moisture, than in a vacuum of the same temperature. So far then the great object of the theory was attained. The law of the condensation of vapour in the atmosphere by cold, was evidently the same on this scheme, as that of the condensation of pure steam, and experience was found to confirm the conclusion at all temperatures. The only thing now wanting to completely establish

the independent existence of aqueous vapour in the atmosphere, was the conformity of other liquids to water, in regard to the diffusion and condensation of their vapour. This was found to take place in several liquids, and particularly in sulphuric ether, one which was most likely to shew any anomaly to advantage if it existed, on account of the great change of expansibility in its vapour at ordinary temperatures. The existence of vapour in the atmosphere and its occasional condensation were thus accounted for; but another question remained, how does it rise from a surface of water subject to the pressure of the atmosphere? The consideration of this made no part of the essays abovementioned, it being apprehended, that if the other two points could be obtained by any theory, this third too, would, in the sequel, be accomplished.

From the novelty, both in the theory and the experiments, and their importance, provided they were correct, the essays were soon circulated, both at home and abroad. The new facts and experiments were highly valued, some of the latter were repeated, and found correct, and none of the results, as far as I know, have been controverted; but the theory was almost universally misunderstood, and

consequently reprobated. This must have have arisen partly at least from my being too concise, and not sufficiently clear in its exposition.

Dr. Thomson was the first, as far as I know, who publicly animadverted upon the theory; this gentleman, so well known for his excellent System of Chemistry, observed in the first edition of that work, that the theory would not account for the equal distribution of gases; but that, granting the supposition of one gas neither attracting nor repelling another, the two must still arrange themselves according to their specific gravity. But the most general objection to it was quite of a different kind; it was admitted, that the theory was adapted so as to obtain the most uniform and permanent diffusion of gases; but it was urged, that as one gas was as a vacuum to another, a measure of any gas being put to a measure of another, the two measures ought to occupy the space of one measure only. Finding that my views on the subject were thus misapprehended, I wrote an illustration of the theory, which was published in the 3d Vol. of Nicholson's Journal, for November, 1802. In that paper I endeavoured to point out the conditions of mixed gases more at large, according to my hypothesis; and particularly touched upon the

discriminating feature of it, that of two particles of any gas A, repelling each other by the known stated law, whilst one or more particles of another gas B, were interposed in a direct line, without at all affecting the reciprocal action of the said two particles of A. Or, if any particle of B were casually to come in contact with one of A, and press against it, this pressure did not preclude the cotemporary action of all the surrounding particles of A upon the one in contact with B. In this respect the mutual action of particles of the same gas was represented as resembling magnetic action, which is not disturbed by the intervention of a body not magnetic.

As the subject has since received the animadversions of several authors, which it is expedient to notice more or less, it will be proper to point out the order intended to be pursued. First, I shall consider the objections to the new theory made by the several authors, with their own views on the subject; and then shall give what modifications of the theory, the experience and reflection of succeeding time have suggested to me. The authors are Berthollet, Dr. Thomson, Mr. Murray, Dr. Henry, and Mr. Gough.

Berthollet in his *Chemical Statics* (1804) has given a chapter on the constitution of the

atmosphere, in which he has entered largely into a discussion of the new theory. This celebrated chemist, upon comparing the results of experiments made by De Luc, Saussure, Volta, Lavoisier, Watt, &c. together with those of Gay Lussac, and his own, gives his full assent to the fact, that vapours of every kind increase the elasticity of each species of gas alike, and just as much as the force of the said vapours in vacuo; and not only so, but that the specific gravity of vapour in air and vapour in vacuo is in all cases the same (Vol. 1. Sect. 4.) Consequently he adopts the theorem for finding the quantity of vapour which a given volume of air can dissolve, which I have laid down; namely,

$$s = \frac{p}{p-f}$$

where p represents the pressure upon a given volume (1) of dry air, expressed in inches of mercury, f = the force of the vapour in vacuo at the temperature, in inches of mercury, and s = the space which the mixture of air and vapour occupies under the given pressure, p , after saturation. So far therefore we perfectly agree: but he objects to the theory by which I attempt to explain these phenomena, and substitutes another of his own.

The first objection I shall notice is one that

clearly shews Berthollet either does not understand, or does not rightly apply the theory he opposes; he says, "If one gas occupied the interstices of another, as though they were vacancies, there would not be any augmentation of volume when aqueous or ethereal vapour was combined with the air; nevertheless there is one proportional to the quantity of vapour added: humidity should increase the specific gravity of the air, whereas it renders it specifically lighter, as has been already noticed by Newton." This is the objection which has been so frequently urged; it has even been stated by Mr. Gough, if I understand him aright, in almost the same words (*Nicholson's Journal*, Vol. 9, page 162); yet this last gentleman is profoundly skilled in the mechanical action of fluids. Let a tall cylindrical glass vessel containing dry air be inverted over mercury, and a portion of the air drawn out by a syphon, till an equilibrium of pressure is established within and without; let a small portion of water, ether, &c. be then thrown up into the vessel; the vapour rises and occupies the interstices of the air as a void; but what is the obvious consequence? Why, the surface of the mercury being now pressed both by the dry air, and by the new raised vapour, is more pressed within than

without, and an enlargement of the volume of air is unavoidable, in order to restore the equilibrium. Again, in the open air: suppose there were no aqueous atmosphere around the earth, only an azotic one = 23 inches of mercury, and an oxygenous one = 6 inches. The air being thus perfectly dry, evaporation would commence with great speed. The vapour first formed being constantly urged to ascend by that below, and as constantly resisted by the air, must, in the first instance, dilate the other two atmospheres; (for, the ascending steam adds its force to the upward elasticity of the two gases, and in part alleviates their pressure, the necessary consequence of which is dilatation.) At last when all the vapour has ascended, that the temperature will admit of, the aqueous atmosphere attains an equilibrium; it no longer presses upon the other two, but upon the earth; the others return to their original density and pressure throughout. In this case it is true, there would not be any augmentation of volume when aqueous vapour was combined with the air; humidity would increase the weight of the congregated atmospheres, but diminish their specific gravity under a given pressure. One would have thought that this solution of the phenomenon upon my hypothesis was too obvious to escape the notice

of any one in any degree conversant with pneumatic chemistry. Berthollet indeed enquires, "Is such a division of the same pressure of the atmosphere analogous with any physical property yet known? Can it be conceived that an elastic substance exists, which adds its volume to that of another, and which nevertheless does not act on it by its expansive force?" Certainly; we can not only conceive it, but bring an instance that must be allowed to be in point. Two magnets repel each other, that is, act upon each other with an expansive force, yet they do not act upon other bodies in the same way, but merely as inelastic bodies; and this no doubt would be the same if they were reduced to atoms: So two particles of the same kind of air may act upon each other elastically, and upon other bodies inelastically, and therefore not at all, unless when in contact.

Berthollet observes, "Hydrogen gas and oxygen gas form water in a given circumstance; azotic gas, and oxygen gas, can also produce nitric acid; but the reciprocal action which decides the combinations cannot be considered as a force commencing at the precise moment at which it is manifested, it must have existed long before producing its effect, and increases gradually till it becomes preponderant." It is

no doubt true that the opposite powers of attraction and repulsion are frequently, perhaps constantly, energetic at the same instant; but the effect produced in those cases arises from the difference of the two powers. When the excess of the repulsive power above the attractive in different gases is comparatively small and insignificant, it constitutes that character which may be denominated neutral, and which I supposed to exist in the class of mixed gases which are not observed to manifest any sign of chemical union. I would not be understood to deny an energetic affinity between oxygen and hydrogen, &c. in a mixed state; but that affinity is more than counterbalanced by the repulsion of the heat, except in circumstances which it is not necessary at present to consider.

Again, "Azotic gas comports itself with oxygen gas, in the changes occasioned by temperature and pressure, precisely like one and the same gas: Is it necessary to have recourse to a supposition which obliges us to admit so great a difference of action without an ostensible cause?" It is possible this may appear an objection to a person who does not understand the theory, but it never can be any to one who does. If a mixture of gas, such as atmospheric air, containing azote pressing

with a force equal to 24 inches of mercury, and oxygen with a force equal to 6 inches, were suddenly condensed into half the compass, the azotic gas would then evidently, on my hypothesis, press with a force = 48 inches, and the oxygen with a force = 12 inches, making together 60 inches, just the same as any simple gas. And a similar change in the elasticity of each would take place by heat and cold. Will the opposite theory of Berthollet be equally free from this objection? We shall presently examine it.

Another objection is derived from the very considerable time requisite for a body of hydrogen to descend into one of carbonic acid; if one gas were as a vacuum for another, why is the equilibrium not instantly established? This objection is certainly plausible; we shall consider it more at large hereafter.

In speaking of the pressure of the atmosphere retaining water in a liquid state, which I deny, Berthollet adopts the idea of Lavoisier, "that without it the *moleculæ* would be infinitely dispersed, and that nothing would limit their separation, unless their own weight should collect them to form an atmosphere." This, I may remark, is not the language dictated by a correct notion on the subject. Suppose our atmosphere were annihilated, and the

waters on the surface of the globe were instantly expanded into steam; surely the action of gravity would collect the molecu \ddot{a} e into an atmosphere of similar constitution to the one we now possess; but suppose the whole mass of water evaporated amounted in weight to 30 inches of mercury, how could it support its own weight at the common temperature? It would in a short time be condensed into water merely by its weight, leaving a small portion, such as the temperature could support, amounting perhaps to half an inch of mercury in weight, as a permanent atmosphere, which would effectually prevent any more vapour from rising, unless there were an increase of temperature. Does not every one know that water and other liquids can exist in a Torricellian vacuum at low temperatures solely by the pressure of vapour arising from them? What need then of the pressure of the atmosphere in order to prevent an excess of vapourisation?

After having concluded that "without the pressure of the ærial atmosphere, liquids would pass to the elastic state," Berthollet proceeds in the very next paragraph to shew that the quantity of vapour in the atmosphere may in fact be much *more* than would exist if the atmosphere were suppressed, and hence infers, "that the variations of the barometer oc-

casioned by those of the humidity of the atmosphere may be much greater than was believed by Saussure and Deluc." I cannot see how the author reconciles the opposite conclusions.

The experiments of Fontana on the distillation of water and ether in close vessels containing air, are adduced to prove, that vapours do not penetrate air without resistance. This is true no doubt; vapour cannot make its way in such circumstances through a long and circuitous route without time, and if the external atmosphere keep the vessel cool, the vapour may be condensed by its sides, and fall down in a liquid form as fast as it is generated, without ever penetrating in any sensible quantity to its remote extremity.

We come now to the consideration of that theory which Berthollet adopts in his explanation of the phenomena of gaseous mixtures. According to his theory, there are two degrees of affinity. The one is strong, makes the particles of bodies approach nearer to each other, and generally expels heat: the effect of this may be called *combination*; for instance, when oxygen gas is put to nitrous gas, the two combine, give out heat, are condensed in volume, and become possessed of properties different from what they had previously. The other is weak; it

does not sensibly condense the volume of any mixture, nor give out heat, nor change the properties of the ingredients; its effect may be called *solution* or *dissolution*; for instance, when oxygen gas and azotic gas are mixed in due proportion, they constitute atmospheric air, in which they retain their distinguishing properties.

It is upon this supposed *solution* of one elastic fluid in another that I intend to make a few observations. That I have not misrepresented the author's ideas, will, I think, appear from the following quotations. "When different gases are mixed, whose action is confined to this solution, no change is observed in the temperature, or in the volume resulting from the mixture; hence it may be concluded, that this mutual action of two gases does not produce any condensation, and that it cannot surmount the effort of the elasticity, or the affinity for caloric, so that the properties of each gas are not sensibly changed—." "Although both the solution and combination of two gases are the effect of a chemical action, which only differs in its intensity, a real difference may be established between them, because there is a very material difference between the results: the combination of two gases always leads to a condensation of their volume, and

gives rise to new properties ; on their solution, the gases share in common the changes arising from compression and temperature, and preserve their individual properties, which are only diminished in the ratio of the slight action which holds them united." (Page 198.) "The mutual affinity of the gases can, therefore, produce between them an effect which is greater than their difference of specific gravity, but which is inferior to the elastic tension which belongs to each molecule of both, so that the volume is not changed by this action ; the liquids which take the elastic state, comport themselves afterwards like the gases." (Page 218.) "Solution must be distinguished from combination, not only because in the first, each of the substances is retained by an affinity so weak, that it preserves its dimensions.—" (Page 219.) Again, "It cannot be doubted, that the parts of elastic fluids are *not* endued with the force of cohesion, as the substances dissolved by them undergo an equal distribution, which could not happen but by the means of a reciprocal chemical attraction ; that which constitutes the force of cohesion." (Researches into the Laws of chemical affinity, Eng. Trans. page 57.) Here the translator has, I apprehend, mistaken the English idiom. The author means to say, that the parts of

elastic fluids *are* endued with the force of cohesion; but this he applies only to heterogeneous particles. He certainly does not mean that the particles of homogeneous elastic fluids possess the force of cohesion.

Newton has demonstrated from the phenomena of condensation and rarefaction that elastic fluids are constituted of particles, which repel one another by forces which increase in proportion as the distance of their centres diminishes: in other words, the forces are reciprocally as the distances. This deduction will stand as long as the Laws of elastic fluids continue to be what they are. What a pity it is that all who attempt to reason, or to theorise respecting the constitution of elastic fluids, should not make themselves thoroughly acquainted with this immutable Law, and constantly hold it in their view whenever they start any new project! When we contemplate a mixture of oxygenous and hydrogenous gas, what does Berthollet conceive, are the particles that repel each other according to the Newtonian Law? The mixture *must* consist of such; and he ought in the very first instance to have informed us what constitutes the *unity* of a particle in his solution. If he grants that each particle of oxygen retains its unity, and each particle of hydrogen does the

same, then we must conclude that the mutual action of two particles of oxygen is the same as that of a particle of oxygen, and one of hydrogen, namely, a repulsion according to the Law above stated, which effectually destroys the supposed solution by chemical agency. But if it be supposed that each particle of hydrogen attaches itself to a particle of oxygen, and the two particles so united form *one*, from which the repulsive energy emanates; then the new elastic fluid may perfectly conform to the Newtonian Law; in this case a true saturation will take place when the number of particles of hydrogen and oxygen in a mixture happen to be equal, or at least in the ratio of some simple numbers, such as 1 to 2, 1 to 3, &c. Now something like this does actually take place when a real combination is formed, as for instance, steam, and nitric acid formed of a mixture of oxygen and nitrous gas. Here we have new elastic fluids, the atoms of which repel one another by the common Law, heat is given out, a great condensation of volume ensues, and the new fluids differ from their constituents in their chemical relations. It remains then to determine whether, in the instance of solution, all these effects take place in a "slight" degree; that is, in so small a degree as not to be

cognisable to any of the senses. It certainly requires an extraordinary stretch of the imagination to admit the affirmative.

One great reason for the adoption of this, or any other theory on the subject, arises from the phenomena of the evaporation of water. How is water taken up and retained in the atmosphere? It cannot be in the state of vapour, it is said, because the pressure is too great: there must therefore be a true chemical solution. But when we consider that the surface of water is subject to a pressure equal to 30 inches of mercury, and besides this pressure, there is a *sensible* affinity between the particles of water themselves; how does the *insensible* affinity of the atmosphere for water overcome both these powers? It is to me quite inexplicable upon this hypothesis, the leading object of which is to account for this very phenomenon. Further, if a particle of air has attached a particle of water to it, what reason can be assigned why a superior particle of air should rob an inferior one of its property, when each particle possesses the same power? If a portion of common salt be dissolved in water and a little muriatic acid added; is there any reason to suppose the additional acid displaces that already combined with the soda, and that upon evaporation the salt is not obtained with

the identical acid it previously had? Or, if oxygen gas be confined by water, is there any reason to suppose that the hydrogen of the water is constantly giving its oxygen to the air and receiving an equal quantity from the same? Perhaps it will be said in the case of air dissolving water, that it is not the affection of one particle for one, it is that of a mass of particles for another mass; it is the united action of all the atoms in the atmosphere upon the water, which raises up a particle. But as all these energies are reciprocal, the water must have a like action on the air, and then an atmosphere over water would press downward by a force greater than its weight, which is contradicted by experience.

When two measures of hydrogen and one of oxygen gas are mixed, and fired by the electric spark, the whole is converted into steam, and if the pressure be great, this steam becomes water. It is most probable then that there is the same number of particles in two measures of hydrogen as in one of oxygen. Suppose then three measures of hydrogen are mixed with one of oxygen, and this slight affinity operates as usual; how is the union effected? According to the principle of equal division, each atom of oxygen ought to have *one atom and a half* of hydrogen at-

tached to it ; but this is impossible ; one half of the atoms of oxygen must then take two of hydrogen, and the other half, one each. But the former would be specifically lighter than the latter, and ought to be found at the top of the solution ; nothing like this is however observed on any occasion.

Much more might be advanced to shew the absurdity of this doctrine of the solution of one gas in another, and the insufficiency of it to explain any of the phenomena ; indeed I should not have dwelt so long upon it, had I not apprehended that respectable authority was likely to give it credit, more than any arguments in its behalf derived from physical principles.

Dr. Thomson, in the 3d Edition of his System of Chemistry, has entered into a discussion on the subject of mixed gases ; he seems to comprehend the excellence and defects of my notions on these subjects, with great acuteness. He does not conclude with Berthollet, that on my hypothesis, "there would not be any augmentation of volume when aqueous and ethereal vapour was combined with the air," which has been so common an objection. There is however one objection which this gentleman urges, that shews he does not completely understand the

mechanism of my hypothesis. At page 448, Vol. 3. he observes that from the principles of hydrostatics, "each particle of a fluid sustains the whole pressure. Nor can I perceive any reason why this principle should not hold, even on the supposition that Dalton's hypothesis is well founded." Upon this I would observe, that when once an equilibrium is established in any mixture of gases, each particle of gas is pressed as if by the surrounding particles *of its own kind only*. It is in the renunciation of that hydrostatical principle that the leading feature of the theory consists. The lowest particle of oxygen in the atmosphere sustains the weight of all the particles of oxygen above it, and the weight of no other. It was therefore a maxim with me, that every particle of gas is equally pressed in every direction, but the pressure arises from the particles of its own kind only. Indeed when a measure of oxygen is put to a measure of azote, at the moment the two surfaces come in contact, the particles of each gas press against those of the other with their full force; but the two gases get gradually intermingled, and the force which each particle has to sustain proportionally diminishes, till at last it becomes the same as that of the original gas dilated to twice its volume. The ratio of the forces is as the cube

root of the spaces inversely; that is, as $\sqrt{2} : 1$, or as 1.26 : 1 nearly. In such a mixture as has just been mentioned, then, the common hypothesis supposes the pressure of each particle of gas to be 1.26; whereas mine supposes it only to be 1; but the sum of the pressure of both gases on the containing vessel, or any other surface, is exactly the same on both hypotheses.

Excepting the above objection, all the rest which Dr. Thomson has made, are of a nature not so easily to be obviated;—he takes notice of the considerable time which elapses before two gases are completely diffused through each other, as Berthollet has done, and conceives this fact, makes against the supposition, that one gas is as a vacuum to another. He further objects, that if the particles of different gases are inelastic to each other; then a particle of oxygen coming into actual contact with one of hydrogen, ought to unite with it, and form a particle of water; but, on the other hand, he properly observes, that the great facility with which such combinations are effected in such instances as a mixture of nitrous and oxygen gas, is an argument in favour of the hypothesis.—Dr. Thomson finds another objection upon the facility of certain combinations, when one of the ingredients is in a *nascent form*;

that is, just upon the point of assuming the elastic state; this, he observes, "seems incompatible with the hypothesis, that gases are not mutually elastic." Upon the whole, Dr. Thomson inclines to the opinion of Berthollet, that gases have the property of dissolving each other; and admits, "however problematical it may appear at first view, that the gases not only mutually repel each other, but likewise mutually attract." I have no doubt if he had taken due time to consider this conclusion, he would, with me, have pronounced it absurd: but of this again in the sequel.

With regard to the objection, that one gas makes a more durable resistance to the entrance of another, than it ought to do on my hypothesis: This occurred to me in a very early period of my speculations; I devised the train of reasoning which appeared to obviate the objection; but it being necessarily of a mathematical nature, I did not wish to obtrude it upon the notice of chemical philosophers, but rather to wait till it was called for.—The resistance which any medium makes to the motion of a body, depends upon the surface of that body, and is greater as the surface is greater, all other circumstances being the same. A ball of lead 1 inch in diameter meets with a certain resistance in falling through the

air; but the same ball, being made into a thousand smaller ones of $\frac{1}{10}$ of an inch diameter, and falling with the same velocity, meets with 10 times the resistance it did before: because the force of gravity increases as the *cube* of the diameter of any particle, and the resistance only as the *square* of the diameter. Hence it appears, that in order to increase the resistance of particles moving in any medium, it is only necessary to divide them, and that the resistance will be a maximum when the division is a maximum. We have only then to consider particles of lead falling through air by their own gravity, and we may have an idea of the resistance of one gas entering another, *only the particles of lead must be conceived to be infinitely small*, if I may be allowed the expression. Here we shall find great resistance, and yet no one, I should suppose, will say, that the air and the lead are mutually elastic.

The other two objections of Dr. Thomson, I shall wave the consideration of at present.

Mr. Murray has lately edited a system of chemistry, in which he has given a very clear description of the phenomena of the atmosphere, and of other similar mixtures of elastic fluids. He has ably discussed the different theories that have been proposed on the subject,

and given a perspicuous view of mine, which he thinks is ingenious, and calculated to explain several of the phenomena well, but upon the whole, not equally satisfactory with that which he adopts. He does not object to the mechanism of my hypothesis in regard to the independent elasticity of the several gases entering into any mixture, but argues that the phenomena do not require so extraordinary a postulatum; and more particularly disapproves of the application of my theory to account for evaporation.

The principal feature in Mr. Murray's theory, and which he thinks distinguishes it from mine, is "that between mixed gases, which are capable, under any circumstances of combining, an attraction must always be exerted." It is unnecessary to recount the arguments on behalf of this conclusion, because it will not be controverted. Mr. Murray announces his views of the constitution of the atmosphere, as follows: "Perhaps that chemical attraction which subsists between the solid bases of these gases, but which, when they are merely mixed together, cannot, from the distance at which their particles are placed by the repulsive power of caloric, bring them into intimate union, may still be so far exerted, as to prevent their separation: or, they may be

retained in mixture by that force of adhesion, which, exerted at the surfaces of many bodies, retains them in contact with considerable force." He supports these notions at length by various observations, and repeats some of the observations of Berthollet, whose doctrine on this subject, as has been seen, is nearly the same.

Before we animadvert on these principles, it may be convenient to extend the first a little farther, and to adopt as a maxim, "that between the particles of *pure* gases, which are capable under any circumstances of combining, an attraction must always be exerted." This, Mr. Murray cannot certainly object to, in the case of steam, a pure elastic fluid, the particles of which are known in certain circumstances to combine. Nor will it be said that steam and a permanent gas are different; for he justly observes, "this distinction (between gases and vapours) is merely relative, and arises from the difference of temperature at which they are formed; the state with regard to each, while they exist in it, is precisely the same." Is steam then constituted of particles in which the attraction is so far exerted as to prevent their separation? No: they exhibit no traces of attraction, more than the like number of particles of oxygen do, when in

the gaseous form. What then is the conclusion? It is this: *notwithstanding it must be allowed, that all bodies, at all times, and in every situation, attract one another; yet in certain circumstances, they are likewise actuated by a repulsive power; the only efficient motive force is then the difference of these two powers.*

From the circumstance of gases mixing together without experiencing any sensible diminution of volume, the advocates for the agency of chemical affinity, characterise it as a "slight action," and "a weak reciprocal action." So far I think they are consistent; but when we hear of this affinity being so far exerted as to prevent the separation of elastic particles, I do not conceive with what propriety it can be called weak. Suppose this affinity should be exercised in the case of steam of 212°; then the attraction becoming equal to the repulsion, the force which any one particle would exercise must be equal to the weight of a column of water of 4896 feet high. (See page 146.)

It is somewhat remarkable that those gases which are known to combine occasionally, as azote and oxygen, and those which are never known to combine, as hydrogen and carbonic acid, should dissolve one another with equal

facility; nay, these last exercise this solvent power with more effect than the former; for, hydrogen can draw up carbonic acid from the bottom to the top of any vessel, notwithstanding the latter is 20 times the specific gravity of the former. One would have thought that a force of adhesion was more to be expected in the particles of steam, than in a mixture of hydrogen and carbonic acid. But it is the business of those who adopt the theory of the mutual solution of gases to explain these difficulties.

In a mixture where are 8 particles of oxygen for 1 of hydrogen, it is demonstrable that the central distances of the particles of hydrogen are at a medium twice as great as those of oxygen. Now supposing the central distance of two adjacent particles of hydrogen to be denoted by 12, query, what is supposed to be the central distance of any one particle of hydrogen from that one particle, or those particles of oxygen with which it is connected by this weak chemical union? It would be well if those who understand and maintain the doctrine of chemical solution would represent how they conceive this to be; it would enable those who are desirous to learn, to obtain a clear idea of the system, and those who are dissatisfied with it, to point out its defects with

more precision. The greatest possible central distance would be $8\frac{1}{2}$ in the above instance, and the least might perhaps be 1. Berthollet, who decries the diagram by which I endeavoured to illustrate my ideas on this subject, has not given us any precise information, either verbally or otherwise, relative to the collocation of the heterogeneous particles, unless it is to be gathered from the consideration that the affinity is so weak that the mixture of fluids preserves its dimensions. What can this weak affinity do, when opposed by a repulsive power of infinite superiority?

In discussing the doctrines of elastic fluids mixed with vapour, Mr. Murray seems disposed to question the accuracy of the fact, that the quantity of vapour is the same in vacuo as in air, though he has not attempted to ascertain in which case it more abounds. This is certainly the touchstone of the mechanical and chemical theories; and I had thought that whoever admitted the truth of the fact, must unavoidably adopt the mechanical theory. Berthollet however, convinced from his own experience, that the fact was incontrovertible, attempts to reconcile it, inimical as it is, to the chemical theory; with what success it is left to others to judge. Mr. Murray joins with Berthollet in condemning as extravagant

the position which I maintain, that if the atmosphere were annihilated, we should have little more aqueous vapour than at present exists in it. Upon which I shall only remark, that if either of those gentlemen will calculate, or give a rough estimate upon their hypothesis, of the quantity of aqueous vapour that would be collected around the earth, on the said supposition, I will engage to discuss the subject with them more at large.

In 1802, Dr. Henry announced a very curious and important discovery, which was afterwards published in the *Philosophical Transactions*; namely, *that the quantity of any gas absorbed by water is increased in direct proportion to the pressure of the gas on the surface of the water.* Previously to this, I was engaged in an investigation of the quantity of carbonic acid in the atmosphere; it was matter of surprise to me that lime water should so readily manifest the presence of carbonic acid in the air, whilst pure water by exposure for any length of time, gave not the least traces of that acid. I thought that length of time ought to compensate for weakness of affinity. In pursuing the subject I found that the quantity of this acid taken up by water was greater or less in proportion to its greater or less density in the gaseous mixture, incumbent

upon the surface, and therefore ceased to be surprised at water absorbing so insensible a portion from the atmosphere. I had not however entertained any suspicion that this law was generally applicable to the gases till Dr. Henry's discovery was announced. Immediately upon this, it struck me as essentially necessary in ascertaining the quantity of any gas which a given volume of water will absorb, that we must be careful the gas is perfectly pure or unmixed with any other gas whatever; otherwise the maximum effect for any given pressure cannot be produced. This thought was suggested to Dr. Henry, and found to be correct; in consequence of which, it became expedient to repeat some of his experiments relating to the quantity of gas absorbed under a given pressure. Upon due consideration of all these phenomena, Dr. Henry became convinced, that there was no system of elastic fluids which gave so simple, easy and intelligible a solution of them, as the one I adopt, namely, that each gas in any mixture exercises a distinct pressure, which continues the same if the other gases are withdrawn. In the 8th Vol. of Nicholson's Journal, may be seen a letter addressed to me, in which Dr. Henry has clearly pointed out his reasons for giving my theory a preference.

In the 9th Vol. is a letter from Mr. Gough, containing some animadversions, which were followed by an appropriate reply from Dr. Henry.

In the 8th, 9th, and 10th Volumes of Nicholson's Journal, and in the first Vol. of the Manchester Memoirs (*new series*) may be seen some animadversions of Mr. Gough, on my doctrine of mixed gases, with some of his own opinions on the same subject. Mr. Gough conceives the atmosphere to be a chemical compound of gases, vapour, &c. and he rests his belief chiefly upon the observance of certain hygrometrical phenomena, such as that air absorbs moisture from bodies in certain cases, and in others restores it to them, shewing that air has an affinity for water, which may be overcome by another more powerful one. This opinion, as Mr. Murray observes, is the one we have from Dr. Halley; it was supported by Le Roy, Hamilton and Franklin, and might be considered as the prevailing opinion, till Saussure, in his celebrated Essays on hygrometry, published in 1783, suggested that water was first changed into vapour, and was in that state dissolved by the air. This amphibious theory of Saussure does not seem to have gained any converts to it, though it pointed out the instability of the other. Finally, the theory

of the chemical solution of water in air, received its death blow in 1791, by the publication of Pictet's Essay on Fire, and more particularly by De Luc's paper on evaporation, published in the Philosophical Transactions for 1792. These gentlemen demonstrated, that all the train of hygrometrical phenomena takes place just as well, indeed rather quicker, in a vacuum, than in air, provided the same quantity of moisture is present. All the influence that any kind or density of air has, is to retard the effect; but in the end it becomes the same.

The only objection which Mr. Gough has presented that appears to me to raise any difficulty, is that in regard to the propagation of sound: If the atmosphere consist chiefly of two distinct elastic media, it is urged that distant sounds ought to be heard double; that is, the same sound would be heard twice, according as it was brought by one or other of the atmospheres. By calculation I find that if sound move at the rate of 1000 feet per second in an atmosphere of azotic gas, it ought to move in the other gases as follows: namely,

	Feet.
Sound moves in azotic gas	1000 per second.
———— oxygen gas	930 —————
———— carb. acid	804 —————
———— aqueous vap.	1175 —————

According to this table, if a strong and loud sound were produced 13 miles off, the first would be a weak impression of it brought by the atmosphere of aqueous vapour, in 39 seconds; the second would be the strongest of all, brought by the atmosphere of azotic gas, in $68\frac{1}{2}$ seconds; the third would be much inferior to the second, brought by the oxygenous atmosphere, in 74 seconds; the fourth and last brought by the carbonic acid atmosphere would be extremely weak, in 85 seconds.—Now though observation does not perfectly accord with the theory in this respect, it comes as near it, perhaps, as it does to that of the more simple constitution of the atmosphere which Mr. Gough maintains. Derham, who has perhaps made the greatest number of accurate observations on distant sounds, remarked that the report of a cannon fired at the distance of 13 miles from him, did not strike his ear with a single sound, but that it was repeated 5 or 6 times close to each other. “ The two first cracks were louder than the

third; but the last cracks were louder than any of the rest." Cavallo, in his experimental philosophy, after quoting the above observations, proceeds, "this repetition of the sound probably originated from the reflection of a single sound, from hills, houses, or other objects, not much distant from the cannon. But it appears from general observation, and where no echo can be suspected, that the sound of a cannon, at the distance of 10 or 20 miles, is different from the sound when near. In the latter case, the crack is loud and instantaneous, of which we cannot appreciate the height. Whereas in the former case, viz. at a distance, it is a grave sound, which may be compared to a determinate musical sound; and instead of being instantaneous, it begins softly, swells to its greatest loudness, and then dies away growling.—Nearly the same thing may be observed with respect to a clap of thunder, other sounds are likewise altered in quality by the distance." (Vol. 2. page 331.)

I shall now proceed to give my present views on the subject of mixed gases, which are somewhat different from what they were when the theory was announced, in consequence of the fresh lights which succeeding experience has diffused. In prosecuting my enquiries into the nature of elastic fluids, I

soon perceived it was necessary, if possible, to ascertain whether the atoms or ultimate particles of the different gases are of the same size or volume in like circumstances of temperature and pressure. By the size or volume of an ultimate particle, I mean in this place, the space it occupies in the state of a pure elastic fluid; in this sense the bulk of the particle signifies the bulk of the supposed impenetrable nucleus, together with that of its surrounding repulsive atmosphere of heat. At the time I formed the theory of mixed gases, I had a confused idea, as many have, I suppose, at this time, that the particles of elastic fluids are all of the same size; that a given volume of oxygenous gas contains just as many particles as the same volume of hydrogenous; or if not, that we had no data from which the question could be solved. But from a train of reasoning, similar to that exhibited at page 71, I became convinced that different gases have *not* their particles of the same size: and that the following may be adopted as a maxim, till some reason appears to the contrary: namely,—

That every species of pure elastic fluid has its particles globular and all of a size; but that no two species agree in the size of their

particles, the pressure and temperature being the same.

There was another thing concerning which I was dubious; whether heat was the cause of repulsion. I was rather inclined to ascribe repulsion to a force resembling magnetism, which acts on one kind of matter, and has no effect on another. For, if heat were the cause of repulsion, there seemed no reason why a particle of oxygen should not repel one of hydrogen with the same force as one of its own kind, especially if they were both of a size. Upon more mature consideration, I see no sufficient reason for discarding the common opinion, which ascribes repulsion to heat; and I think the phenomena of mixed gases may still be accounted for, by repulsion, without the postulatam, that their particles are mutually inelastic, and free from such of the preceding objections as I have left unanswered.

When we contemplate upon the disposition of the globular particles in a volume of pure elastic fluid, we perceive it must be analogous to that of a square pile of shot; the particles must be disposed into horizontal strata, each four particles forming a square: in a superior stratum, each particle rests upon four particles below, the points of its contact with all four

being 45° above the horizontal plane, or that plane which passes through the centres of the four particles. On this account the pressure is steady and uniform throughout. But when a measure of one gas is presented to a measure of another in any vessel, we have then a surface of elastic globular particles of one size in contact with an equal surface of particles of another: in such case the points of contact of the heterogeneous particles must vary all the way from 40° to 90° ; an intestine motion must arise from this inequality, and the particles of one kind be propelled amongst those of the other. The same cause which prevented the two elastic surfaces from maintaining an equilibrium, will always subsist, the particles of one kind being from their size unable to apply properly to the other, so that no equilibrium can ever take place amongst the heterogeneous particles. The intestine motion must therefore continue till the particles arrive at the opposite surface of the vessel against any point of which they can rest with stability, and the equilibrium at length is acquired when each gas is uniformly diffused through the other. In the open atmosphere no equilibrium can take place in such case till the particles have ascended so far as to be restrained by their own weight;

that is, till they constitute a distinct atmosphere.

It is remarkable that when two equal measures of different gases are thus diffused, and sustain an invaried pressure, as that of the atmosphere, the pressure upon each particle after the mixture is less than before. This points out the active principle of diffusion; for, particles of fluids are always disposed to move to that situation where the pressure is least. Thus, in a mixture of equal measures of oxygen and hydrogen, the common pressure on each particle before mixture being denoted by 1, that after the mixture when the gas becomes of half its density, will be denoted by $\sqrt[3]{\frac{1}{2}} = .794$.

This view of the constitution of mixed gases agrees with that which I have given before, in the two following particulars, which I consider as essential to every theory on the subject to give it plausibility.

1st. The diffusion of gases through each other is effected by means of the repulsion belonging to the homogenous particles; or to that principle which is always energetic to produce the dilatation of the gas.

2d. When any two or more mixed gases acquire an equilibrium, the elastic energy of each against the surface of the vessel or of any

liquid, is precisely the same as if it were the only gas present occupying the whole space, and all the rest were withdrawn.

In other respects I think the last view accords better with the phenomena, and obviates the objections which Dr. Thomson has brought against the former; particularly in regard to the query, why mixed gases that are known on certain occasions to combine, do not always combine; and why any gaseous particle in its nascent state is more disposed to combination than when it has already assumed the elastic form. It will also more clearly explain the reason of one gas making so powerful and durable a resistance to the entrance of another.

One difficulty still remains respecting vapour, which neither view of the subject altogether removes: though vapour may subsist in the atmosphere upon either supposition, as far as the temperature will admit, not being subject to any more pressure than would arise from its own particles, were the others removed, yet it may be enquired, how does it rise from the surface of water subject to the pressure of the atmosphere? how does vapour which ascends with an elastic force of only half an inch of mercury, detach itself from water when it has the weight of 30 inches of mercury to oppose its ascent? This difficulty

applies nearly the same to all theories of the solution of water in air, and it is therefore of consequence for every one, let him adopt what opinion he may, to remove it. Chemical solution but ill explains it; for, the affinity of air for vapour is always described as weak, and yet it is sufficient to overcome the pressure of a powerful force equal to the weight of the atmosphere. I have endeavoured to shew in another place (*Manch. Memoirs, Vol. 1. new series, page 284*) what my own ideas on the subject are. It appears to me, that it is not till the depth of 10 or 12 strata of particles of any liquid, that the pressure upon each perpendicular column becomes uniform; and that several of the particles in the uppermost stratum are in reality subject to but little pressure.

SECTION 3.

ON THE

CONSTITUTION OF LIQUIDS,

*And the Mechanical Relations betwixt Liquids
and Elastic Fluids.*

A liquid or inelastic fluid may be defined to be a body, the parts of which yield to a very small impression, and are easily moved one upon another. This definition may suffice for the consideration of liquids in an hydrostatical sense, but not in a chemical sense. Strictly speaking, there is no substance inelastic; if heat be the cause of elasticity, all bodies containing it must necessarily be elastic: but we commonly apply the word elastic to such fluids only as have the property of condensation in a very conspicuous degree. Water is a liquid or inelastic fluid; but if it is compressed by a great force, it yields a little, and again recovers its original bulk when the pressure is removed. We are indebted to Mr. Canton for a set of experiments by which the compressibility of several liquids is demonstrated. Water, he found, lost about

$\frac{1}{1774}$ th part of its bulk by the pressure of the atmosphere.

When we consider the origin of water from steam, we have no reason to wonder at its compressibility, and that in a very small degree; it would be wonderful if water had not this quality. The force of steam at 212° is equal to the pressure of the atmosphere; what a prodigious force must it have when condensed 15 or 18 hundred times? We know that the particles of steam, reduced to the state of water, still retain the greatest part of their heat. What a powerful resistance then ought they not to make against a compressing force? The truth is, water, and by analogy, other liquids, must be considered as bodies, under the controul of two most powerful and energetic agents, attraction and repulsion, between which there is an equilibrium. If any compressing force is applied, it yields, indeed, but in such a manner, as a strong spring would yield, when wound up almost to the highest pitch. When we attempt to separate one portion of liquid from another, the case is different: here the attraction is the antagonist force, and that being balanced by the repulsion of the heat, a moderate force is capable of producing the separation. But

even here we perceive the attractive force to prevail, there being a manifest cohesion of the particles. Whence does this arise? It should seem that when two particles of steam coalesce to form water, they take their station so as to effect a perfect equilibrium between the two opposite powers; but if any foreign force intervene, so as to separate the two molecules an evanescent space, the repulsion decreases faster than the attraction, and consequently this last acquires a superiority or excess, which the foreign force has to overcome. If this were not the case, why do they at first, or upon the formation of water, pass from the greater to the less distance?

With regard to the collocation and arrangement of particles in an aggregate of water or any other liquid, I have already observed (page 139) that this is not, in all probability, the same as in air. It seems highly improbable from the phenomena of the expansion of liquids by heat. The law of expansion is unaccountable for, if we confine liquids to one and the same arrangement of their ultimate particles in all temperatures; for, we cannot avoid concluding, if that were the case, the expansion would go on in a progressive way with the heat, like as in air; and there

would be no such thing observed as a point of temperature at which the expansion was stationary.

Reciprocal Pressure of Liquids and Elastic Fluids.

When an elastic fluid is confined by a vessel of certain materials, such as wood, earthenware, &c. it is found slowly to communicate with the external air, to give and receive successively, till a complete intermixture takes place. There is no doubt but this is occasioned by those vessels being porous, so as to transmit the fluids. Other vessels, as those of metal, glass, &c. confine air most completely. These therefore cannot be porous; or rather, their pores are too small to admit of the passage of air. I believe no sort of vessel has yet been found to transmit one gas and confine another; such a one is a desideratum in practical chemistry. All the gases appear to be completely porous, as might be expected, and therefore operate very temporarily in confining each other. How are liquids in this respect? Do they resemble glass, or earthen-

ware, or gases, in regard to their power of confining elastic fluids? Do they treat all gases alike, or do they confine some, and transmit others? These are important questions: they are not to be answered in a moment. We must patiently examine the facts.

Before we can proceed, it will be necessary to lay down a rule, if possible, by which to distinguish the *chemical* from the *mechanical* action of a liquid upon an elastic fluid. I think the following cannot well be objected to: *When an elastic fluid is kept in contact with a liquid, if any change is perceived, either in the elasticity or any other property of the elastic fluid, so far the mutual action must be pronounced CHEMICAL: but if no change is perceived, either in the elasticity or any other property of the elastic fluid, then the mutual action of the two must be pronounced wholly MECHANICAL.*

If a quantity of lime be kept in water and agitated, upon standing a sufficient time, the lime falls down, and leaves the water transparent: but the water takes a small portion of the lime which it permanently retains, contrary to the Laws of specific gravity. Why? Because that portion of lime is dissolved by the water. If a quantity of air be put to water

and agitated, upon standing a sufficient time, the air rises up to the surface of the water and leaves it transparent; but the water permanently retains a portion of air, contrary to the Laws of specific gravity. Why? Because that small portion of air is dissolved by the water. So far the two explanations are equally satisfactory. But if we place the two portions of water under the receiver of an air pump, and exhaust the incumbent air, the whole portion of air absorbed by the water ascends, and is drawn out of the receiver; whereas the lime remains still in solution as before. If now the question be repeated, why is the air retained in the water? The answer must be, because there is an elastic force on the surface of the water which holds it in. The water appears passive in the business. But, perhaps, the pressure on the surface of the water may have some effect upon its affinity for air, and none on that for lime? Let the air be drawn off from the surfaces of the two portions of water, and another species induced without alleviating the pressure. The lime water remains unchanged; the air escapes from the other much the same as in vacuo. The question of the relation of water to air appears by this fact to be still more difficult; at first the air seemed

to be retained by the attraction of the water ; in the second case, the water seemed indifferent ; in the third, it appears as if repulsive to the air ; yet in all three, it is the same air that has to act on the same water. From these facts, there seems reason then for maintaining three opinions on the subject of the mutual action of air and water ; namely, that water attracts air, that water does not attract it, and that water repels air. One of these must be true ; but we must not decide hastily. Dr. Priestley once imagined, that the clay of a porous earthen retort, when red hot, " destroys for a time the aerial form of whatever air is exposed to the outside of it ; which aerial form it recovers, after it has been transmitted in combination from one part of the clay to another, till it has reached the inside of the retort." But he soon discarded so extravagant an opinion.

From the recent experiments of Dr. Henry, with those of my own, there appears reason to conclude, that a given volume of water absorbs the following parts of its bulk of the several gases.

Bulk of gas absorbed.

1 = 1	Carbonic acid
1 = 1	Sulphuretted hydrogen
1 = 1	Nitrous oxide
$\frac{1}{8} = .125$	Olefant gas
$\frac{1}{27} = .037$	Oxygenous gas
$\frac{1}{27} = .037$	Nitrous gas
$\frac{1}{27} = .037$	Carburetted hydrogen
$\frac{1}{27} = .037$	Carbonic oxide ?
$\frac{1}{64} = .0156$	Azotic gas
$\frac{1}{64} = .0156$	Hydrogenous gas
$\frac{1}{64} = .0156$	Carbonic oxide ?

These fractions are the cubes of $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. this shews the distances of the gaseous particles in the water to be always same multiple of the distances without.

In a mixture of two or more gases, the rule holds the same as when the gases are alone ; that is, the quantity of each absorbed is the same as if it was the only gas present.

As the quantity of any gas in a given volume is subject to variation from pressure and temperature, it is natural to enquire whether any change is induced in the absorption of these

circumstances ; the experiments of Dr. Henry have decided this point, by ascertaining, that if the exterior gas is condensed or rarefied in any degree, the gas absorbed is condensed or rarefied in the same degree ; so that the proportions absorbed given above are absolute.

One remarkable fact, which has been hinted at is, that no one gas is capable of retaining another in water ; it escapes, not indeed instantly, like as in a vacuum, but gradually, like as carbonic acid escapes into the atmosphere from the bottom of a cavity communicating with it.

It remains now to decide whether the relation between water and the abovementioned gases is of a *chemical* or *mechanical* nature. From the facts just stated, it appears evident that the elasticity of carbonic acid and the other two gases of the first class is not at all affected by the water. It remains exactly of the same energy whether the water is present or absent. All the other properties of those gases continue just the same, as far as I know, whether they are alone or blended with water : we must therefore, I conceive, if we abide by the Law just laid down, pronounce the mutual action between these gases and water to be *mechanical*.

A very curious and instructive phenomenon

takes place when a portion of any of the above three gases is thrown up into an eudiometer tube of $\frac{1}{10}$ of an inch diameter over water; the water ascends and absorbs the gas with considerable speed; if a small portion of common air is suddenly thrown up, it ascends to the other, and is commonly separated by a fine film of water for a time. That instant the the two airs come into the above situation, the water suddenly ceases to ascend in the tube, but the film of water runs up with great speed, enlarging the space below, and proportionally diminishing that above, till it finally bursts. This seems to shew that the film is a kind of sieve through which those gases can easily pass, but not common air.

In the other gases it is very remarkable their density within the water should be such as to require the distance of the particles to be just 2, 3 or 4 times what it is without. In olefiant gas, the distance of the particles within is just twice that without, as is inferred from the density being $\frac{1}{2}$. In oxygenous gas, &c. the distance is 3 times as great, and in hydrogenous, &c. 4 times. This is certainly curious, and deserves further investigation; but at present we have only to decide whether the general phenomena denote the relation to be of a chemical or mechanical nature. In no case

whatever does it appear that the elasticity of any of these gases is affected; if water takes $\frac{1}{27}$ of its bulk of any gas, the gas so absorbed, exerts $\frac{1}{27}$ of the elasticity, that the exterior gas does, and of course it escapes from the water when the pressure is withdrawn from its surface, or when a foreign one is induced, against which it is not a proper match. As far as is known too, all the other properties of the gases continue the same; thus, if water containing oxygenous gas be admitted to nitrous gas, the union of the two gases is certain; after which the water takes up $\frac{1}{27}$ of its bulk of nitrous gas, as it would have done, if this circumstance had not occurred. It seems clear then that the relation is a *mechanical* one.*

* Dr. Thomson and Mr. Murray have both written largely in defence of the notion that *all* gases are combined with water, that a real union by means of a chemical affinity which water exercises in a greater or less degree towards all gases, takes place; this affinity is supposed to be of the *slight* kind, or of that kind which holds all gases in a state of solution, one amongst another, without any distinction. The opposite doctrine was first stated in a paper of mine, on the absorption of gases by water. (Manch. Memoirs, *new series*, Vol. 1.) Previously to the publication of that paper, Dr. Henry, who was convinced from his own experience, that the connection of gases with water was of a mechanical nature, wrote two essays in

Carbonic acid gas then presses upon water in the first instance with its whole force ; in a short time it partly enters the water, and then the reaction of the part entered, contri-

the 8th and 9th Vol. of Nicholson's Journal, in which the arguments for that opinion are clearly, and, I think, unanswerably stated. I do not intend to enter largely into a discussion of the arguments these gentlemen adopt. Dr. Thomson's leading argument seems to be, that "water will absorb such a portion of each gas, that the repulsion between the particles absorbed, just balances the affinity of water for them." He then proceeds to infer, that the affinity of carbonic acid for water is such as nearly to balance the elasticity, that the affinity of olfiant gas for water is equal to *half* its elasticity, that of oxygen, $\frac{1}{3}$, and of azote $\frac{1}{4}$, &c. Now if a particle of water attract one of carbonic acid by a force analogous to that of repulsion, it must increase directly as the distance decreases ; if so, two such particles must be in equilibrium at any distance ; and if any other force is applied to the particle of gas propelling it towards the water, the two particles must unite or come into most intimate contact. Hence, I should infer, from Dr. Thomson's principle, that each particle of water would take one of acid, and consequently 1lb. of water would combine with 2 $\frac{1}{2}$ lbs. of carbonic acid nearly. Mr. Murray mentions a great many circumstances which he conceives make against the mechanical hypothesis ; for instance, some of the acid and alkaline gases are known to be absorbed largely by water, and undoubtedly by affinity ; therefore the less absorbable gases must be under the same influence, only in an inferior degree, and that "it would be impossible to point out the line of distinction between those where the absorption might be conceived to be purely

butes to support the incumbent atmosphere. Finally, the gas gets completely diffused through the water, so as to be of the same density within as without; the gas within the water then presses on the containing vessel only, and reacts upon the incumbent gas. The water then sustains no pressure either from the gas within or without. In olefiant gas the surface of the water supports $\frac{2}{7}$ of the pressure, in oxygenous, &c. $\frac{2}{7}$, and in hydrogenous, &c. $\frac{6}{7}$.

When any gas is confined in a vessel over

mechanical, and those where the exertion of affinity must be allowed to operate." I conceive nothing is more easy than to point out the exact line of distinction: *wherever water is found to diminish or destroy the elasticity of any gas, it is a chemical agent; wherever it does neither of these, it is a mechanical agent.* Whoever undertakes to maintain the chemical theory of the absorption of gases by water, should in the outset overturn the following argument preferred by Dr. Henry: "The quantity of every gas, absorbed by water, follows exactly the ratio of the pressure; and since it is a rule in philosophizing, that effects of the same kind, though differing in degree, are produced by the same cause, it is perfectly safe to conclude, that every, even the minutest portion of any gas, in a state of absorption by water, is retained entirely by incumbent pressure. There is no occasion, therefore, to call in the aid of the law of chemical affinity, when a mechanical law fully and satisfactorily explains the appearances."

water in the pneumatic trough, so as to communicate with the atmosphere through the medium of water, that gas must constantly be filtering through the water into the atmosphere, whilst the atmospheric air is filtering through the water the contrary way, to supply its place in the vessel; so that in due time the air in the vessel becomes atmospheric, as various chemists have experienced. Water in this respect is like an earthenware retort: it admits the gases to go both ways at the same time.

It is not easy to assign a reason why water should be so permeable to carbonic acid, &c. and not to the other gases; and why there should be those differences observable in the others. The densities $\frac{1}{2}$, $\frac{1}{7}$ and $\frac{1}{14}$, have most evidently a reference to a mechanical origin, but none whatever to a chemical one. No mechanical equilibrium could take place if the densities of the gases within were not regulated by this law; but why the gases should not all agree in some one of these forms, I do not see any reason.

Upon the whole it appears that water, like earthenware, is incapable of forming a perfect barrier to any kind of air; but it differs from earthenware in one respect; the last is alike permeable to all the gases, but water is

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much more permeable to some gases than to others. Other liquids have not been sufficiently examined in this respect.

The mutual action of water, and the greater number of acid gases and alkaline gas partaking most evidently of a chemical nature, will be best considered under the heads of the respective acids and alkalis.

SECTION 4.

ON THE

CONSTITUTION OF SOLIDS.

A solid body is one, the particles of which are in a state of equilibrium betwixt two great powers, attraction and repulsion, but in such a manner, that no change can be made in their distances without considerable force. If an approximation of the particles is attempted by force, then the heat resists it; if a separation, then the attraction resists it. The notion of Boscovich of alternating planes of attraction and repulsion seems unnecessary; except that upon forcibly breaking the cohesion of any body, the newly exposed surface must receive such a modification in its atmo-

sphere of heat, as may prevent the future junction of the parts, without great force.

The essential distinction between liquids and solids, perhaps consists in this, that heat changes the figure of arrangement of the ultimate particles of the former continually and gradually, whilst they retain their liquid form; whereas in the latter, it is probable, that change of temperature does no more than change the size, and not the arrangement of the ultimate particles.

Notwithstanding the *hardness* of solid bodies, or the difficulty of moving the particles one amongst another, there are several that admit of such motion without fracture, by the application of proper force, especially if assisted by heat. The ductility and malleability of the metals, need only to be mentioned. It should seem the particles glide along each others surface, somewhat like a piece of polished iron at the end of a magnet, without being at all weakened in their cohesion. The absolute force of cohesion, which constitutes the *strength* of bodies, is an enquiry of great practical importance. It has been found by experiment, that wires of the several metals beneath, being each $\frac{1}{16}$ of an inch in diameter, were just broken by the annexed weights.

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Lead.....	29 $\frac{1}{4}$	} Pounds.
Tin.....	49 $\frac{1}{2}$	
Copper.....	299 $\frac{1}{4}$	
Brass.....	360	
Silver.....	370	
Iron.....	450	
Gold.....	500	

A piece of good oak, an inch square and a yard long, will just bear in the middle 330lbs. But such a piece of wood should not in practice be trusted, for any length of time, with above $\frac{1}{2}$ or $\frac{1}{4}$ of that weight. Iron is about 10 times as strong as oak, of the same dimensions.

One would be apt to suppose that *strength* and *hardness* ought to be found proportionate to each other; but this is not the case. Glass is harder than iron, yet the latter is much the stronger of the two.

Crystallization exhibits to us the effects of the natural arrangement of the ultimate particles of various compound bodies; but we are scarcely yet sufficiently acquainted with chemical synthesis and analysis to understand the rationale of this process. The rhomboidal form may arise from the proper position of 4, 6, 8 or 9 globular particles, the cubic form from 8 particles, the triangular form from 3,

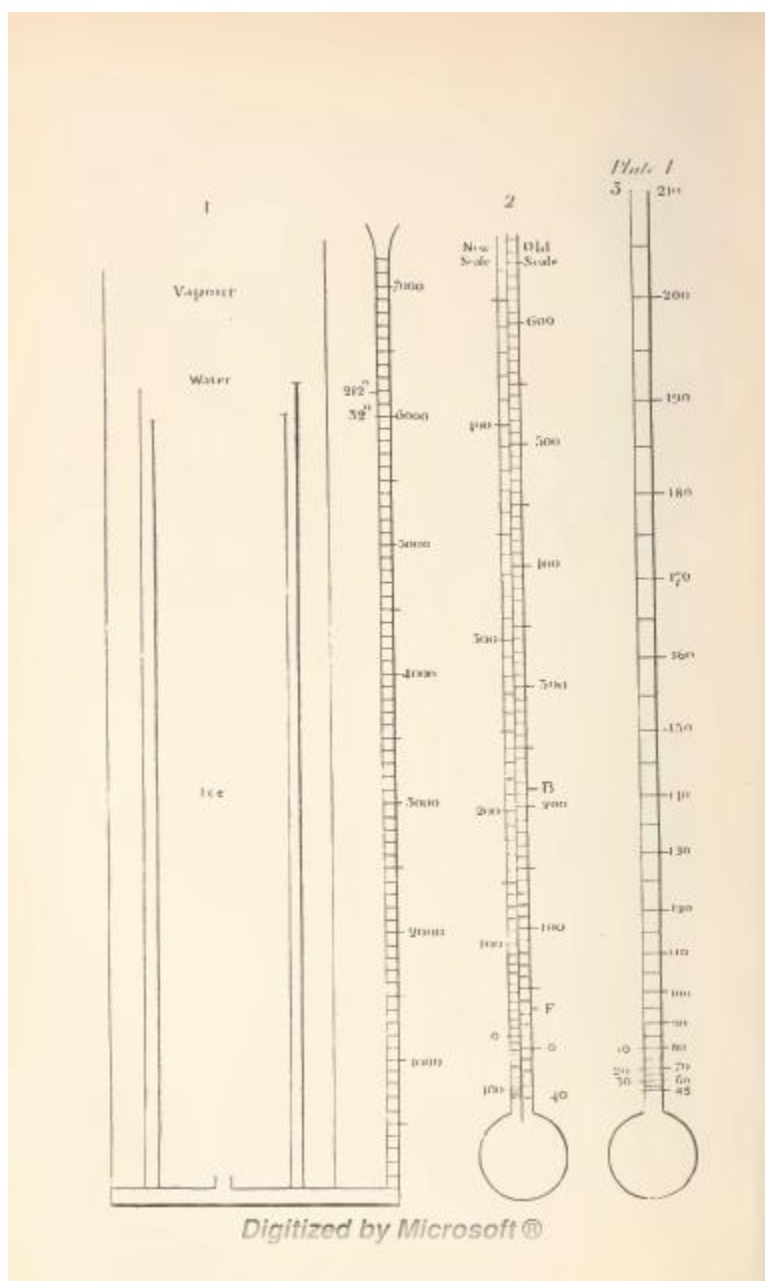
6 or 10 particles, the hexahedral prism from 7 particles, &c. Perhaps, in due time, we may be enabled to ascertain the number and order of elementary particles, constituting any given compound element, and from that determine the figure which it will prefer on crystallization, and *vice versa*; but it seems premature to form any theory on this subject, till we have discovered from other principles the number and order of the primary elements which combine to form some of the compound elements of most frequent occurrence; the method for which we shall endeavour to point out in the ensuing chapter.

CHAP. III.

ON CHEMICAL SYNTHESIS.

WHEN any body exists in the elastic state, its ultimate particles are separated from each other to a much greater distance than in any other state; each particle occupies the centre of a comparatively large sphere, and supports

ANEXO 3 – Anexo livro de John Dalton, 1810.



(217)

EXPLANATION OF THE PLATES.

PLATE I. Fig. 1. is intended to illustrate the author's ideas on the subject of the capacities of bodies for heat. See page 3. There are three cylindrical vessels placed one within another, having no communication but over their margins; the innermost is connected with a lateral and parallel tube graduated, and supposed to represent the degrees of a thermometer, the scale of which commences at absolute cold; if a liquid (supposed to represent heat) be poured into the tube, it will flow into the inner vessel, through an aperture at the bottom, and rise to the same level in the vessel and the tube. Equal increments of heat in this case are supposed to produce equal increments of temperature. When the temperature has arrived at a certain point (suppose 6000°) the body may be supposed to change its solid form to the liquid, as from ice to water, in which case its capacity for heat is increased, and is to be represented by the second vessel. A considerable portion of liquid must then be poured into the tube before any rise will be perceived, because it flows over the margin of the innermost vessel into the lateral cavity of the second; at length it reaches the level, and then a proportional rise will ensue, till the body becomes converted into an elastic fluid, when the thermometer again becomes stationary—whilst a great portion of heat is entering into the body, now assuming a new capacity.

Fig. 2. is a comparative view of the old and new divisions of the scale of the mercurial thermometer. See Table, page 14. The interval from freezing to boiling water is 180° on both scales, and the extremes are numbered 32° and 212° respectively. There are no other points of temperature in which the two scales can agree.

Fig. 3. is a view of the divisions of a water thermometer, conformably to the new scale of the mercurial; the lowest point is at 45° ; the intervals from 45° upwards, to 55° , 65° , 75° , &c. are as the numbers 1, 4, 9, &c. Also, 30° and 60° coincide, as do 20° and 70° , &c.

PLATE II. Fig. 1. represents an air thermometer, or the expansion of air by heat; the numbers are Fahrenheit's, and the intervals are such as represented in the 7th column of the table, at page 14.

Fig. 2. is the logarithmic curve, the ordinates of which are erected at equal intervals, and diminish progressively by the ratio $\frac{1}{2}$. The intervals of the absciss or base of the

curve, represent equal intervals of temperature (25° for steam or aqueous vapour, and 34° for ethereal vapour) the ordinates represent inches of mercury, the weight of which is equal to the force of steam at the temperature. See the 8th and 9th columns of table, at page 14. Thus the force of steam at 212°, and of ethereal vapour at 110°, new scale, is equal to 50 inches of mercury; at 187° the force of steam is half as much, or 15 inches, and at 76°, that of ethereal vapour is also 15 inches, &c.

Fig. 3. is a device suggested by Mr. Ewart, to illustrate the idea which I have developed in the section on the temperature of the atmosphere. It is a cylindrical vessel close at one end and open at the other, having a moveable piston sliding within it: the vessel is supposed to contain air, and a weight is connected with the piston as a counterpoise to it. There is also a thermometer supposed to pass through the side of the vessel, and to be cemented into it. Now if we may suppose the piston to move without friction, and the vessel to be taken up into the atmosphere, the piston will gradually ascend, and suffer the air within to dilate, so as to correspond every where with the exterior air in density. This dilatation tends to diminish the temperature of the air within (provided no heat is acquired from the vessel.) Such an instrument would shew what the theory requires, namely, that the temperature of the air within would every where in the same vertical column agree with that without, though the former would not receive or part with any heat absolutely, or in any manner communicate with the external air.

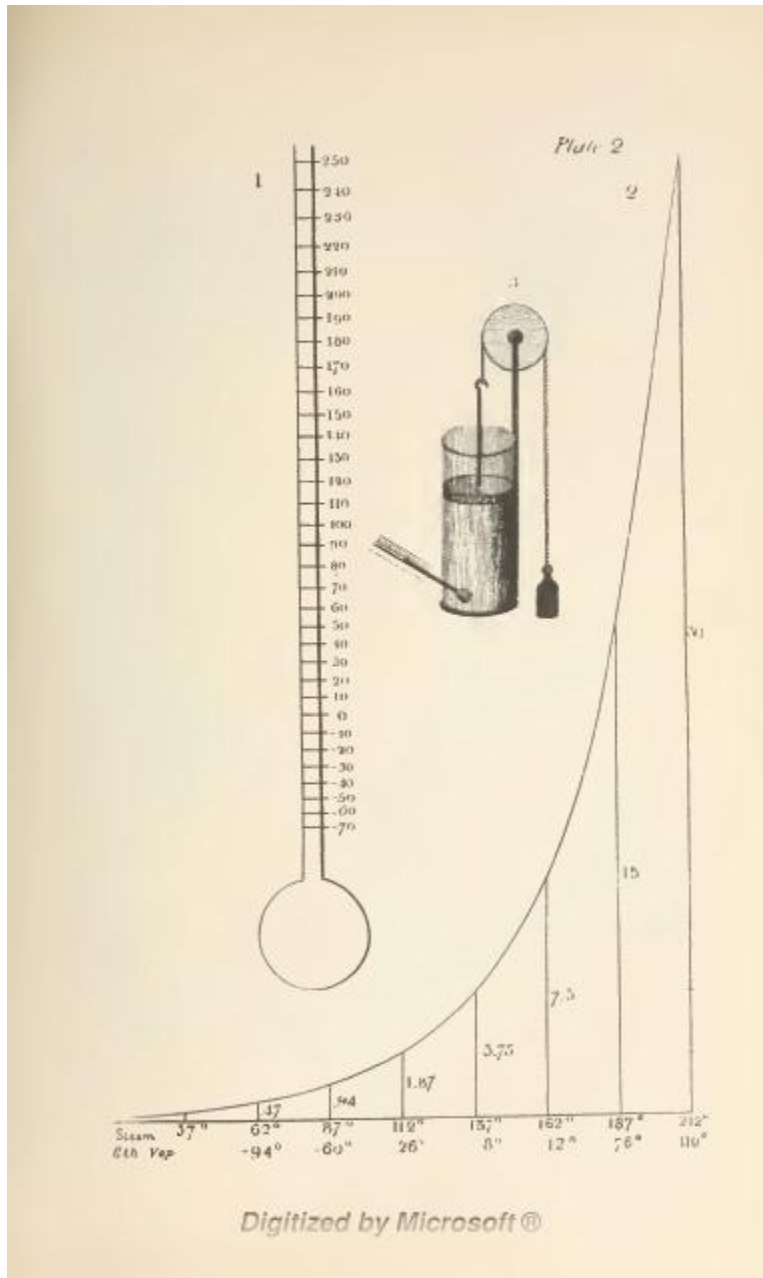
PLATE III. See page 135.—The balls in Fig. 1 and 2 represent particles of water: in the former, the square form denotes the arrangement in water, the rhomboidal form in the latter, denotes the arrangement in ice. The angle is always 60° or 120°.

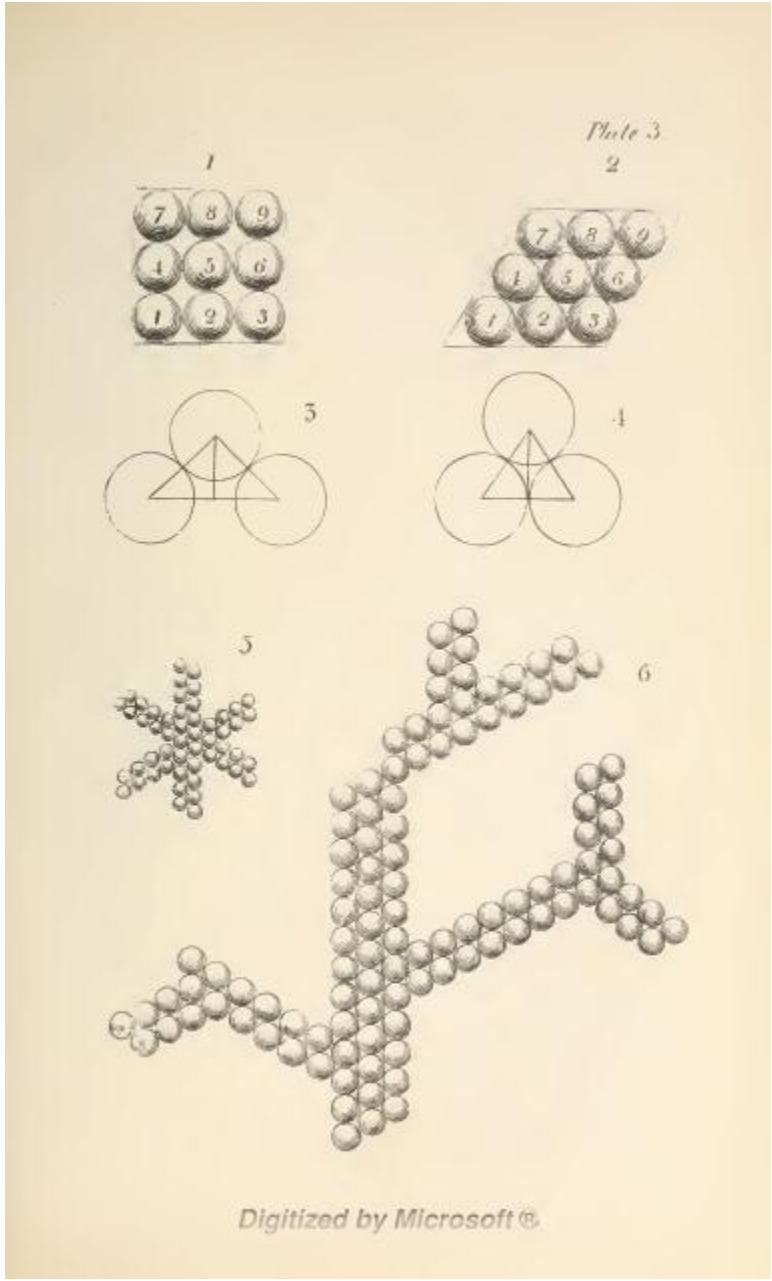
Fig. 3. represents the perpendicular section of a ball resting upon two others, as 4 and 8, Fig. 1.

Fig. 4. represents the perpendicular section of a ball resting upon two balls, as 7 and 5, Fig. 2. The perpendiculars of the triangles shew the heights of the strata in the two arrangements.

Fig. 5. represents one of the small spiculæ of ice formed upon the sudden congelation of water cooled below the freezing point. See page 134.

Fig. 6. represents the shoots or ramifications of ice at the commencement of congelation. The angles are 60° and 120°.

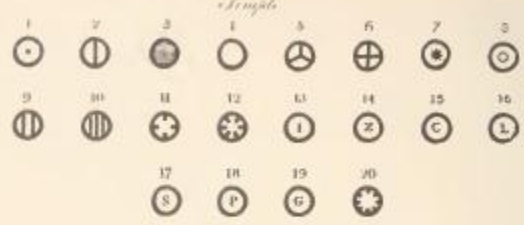




ELEMENTS

Plate 4

Simple



Binary



Ternary



Quaternary



Quinary & Sextenary



Septenary



EXPLANATION OF THE PLATES. 219

PLATE IV. This plate contains the arbitrary marks or signs chosen to represent the several chemical elements or ultimate particles.

Fig.		Fig.		
1	Hydrog. its rel. weight	11	Strontites	46
2	Azote, - - - -	5	Barytes	68
3	Carbone or charcoal, -	5	Iron	58
4	Oxygen, - - - -	7	Zinc	56
5	Phosphorus, - - - -	9	Copper	56
6	Sulphur, - - - -	13	Lead	95
7	Magnesia, - - - -	20	Silver	100
8	Lime, - - - -	23	Platina	100
9	Soda, - - - -	28	Gold	140
10	Potash, - - - -	42	Mercury	167
21.	An atom of water or steam, composed of 1 of oxygen and 1 of hydrogen, retained in physical contact by a strong affinity, and supposed to be surrounded by a common atmosphere of heat; its relative weight = - - - - 8			
22.	An atom of ammonia, composed of 1 of azote and 1 of hydrogen - - - - - 6			
23.	An atom of nitrous gas, composed of 1 of azote and 1 of oxygen - - - - - 12			
24.	An atom of olefiant gas, composed of 1 of carbone and 1 of hydrogen - - - - - 6			
25.	An atom of carbonic oxide composed of 1 of carbone and 1 of oxygen - - - - - 12			
26.	An atom of nitrous oxide, 2 azote + 1 oxygen - 17			
27.	An atom of nitric acid, 1 azote + 2 oxygen - 19			
28.	An atom of carbonic acid, 1 carbone + 2 oxygen 19			
29.	An atom of carburetted hydrogen, 1 carbone + 2 hydrogen - - - - - 7			
30.	An atom of oxynitric acid, 1 azote + 3 oxygen 26			
31.	An atom of sulphuric acid, 1 sulphur + 3 oxygen 34			
32.	An atom of sulphuretted hydrogen, 1 sulphur + 3 hydrogen - - - - - 16			
33.	An atom of alcohol, 3 carbone + 1 hydrogen - 16			
34.	An atom of nitrous acid, 1 nitric acid + 1 nitrous gas - - - - - 31			
35.	An atom of acetous acid, 2 carbone + 2 water - 20			
36.	An atom of nitrate of ammonia, 1 nitric acid + 1 ammonia + 1 water - - - - - 33			
37.	An atom of sugar, 1 alcohol + 1 carbonic acid - 35			

220 EXPLANATION OF THE PLATES.

Enough has been given to shew the method; it will be quite unnecessary to devise characters and combinations of them to exhibit to view in this way all the subjects that come under investigation; nor is it necessary to insist upon the accuracy of all these compounds, both in number and weight; the principle will be entered into more particularly hereafter, as far as respects the individual results. It is not to be understood that all those articles marked as simple substances, are necessarily such by the theory; they are only necessarily of such weights. Soda and Potash, such as they are found in combination with acids, are 28 and 42 respectively in weight; but according to Mr. Davy's very important discoveries, they are metallic oxides; the former then must be considered as composed of an atom of metal, 21, and one of oxygen, 7; and the latter, of an atom of metal, 35, and one of oxygen, 7. Or, soda contains 75 per cent. metal and 25 oxygen; potash, 83.3 metal and 16.7 oxygen. It is particularly remarkable, that according to the above-mentioned gentleman's essay on the Decomposition and Composition of the fixed alkalies, in the Philosophical Transactions (a copy of which essay he has just favoured me with) it appears that "the largest quantity of oxygen indicated by these experiments was, for potash 17, and for soda, 20 parts in 100, and the smallest 13 and 19."

DIRECTIONS TO THE BINDER.

- Plate 1 to face page 217.
 2 to face page 218.
 3 to follow plate 2.
 4 to face page 219.

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ANEXO 4 – Apêndice livro de John Dalton, 1810.

APPENDIX.



AS it is nearly two years since the printing of this second part commenced, it may be expected that in the rapid progress of chemical investigation, some addition has, in the interval, been made to the stock of facts and observations relating to the more early subjects herein discussed. The ground upon which I determine the weights of the ultimate particles of the metals, has not yet been entered upon. This will occupy a leading place in a second volume, when the metallic oxides and sulphurets come to be considered. It will be observed, that I have seen reason to change some of the metallic weights which were given in the first part; and it is probable, that in our future investigations these may be again changed; this will depend upon the precision with which the proportions of the elements of the metallic oxides, sulphurets and salts, shall be obtained. The identity of tantalium and columbium seems to have been ascertained by

Dr. Wollaston. Mr. Davy, and the French chemists Gay Lussac and Thenard, have furnished a number of facts and observations on various subjects, resulting from their application of the new metals, potassium and sodium, and Voltaic electricity, to chemical investigations. When the mind is ardently engaged in prosecuting experimental enquiries, of a new and extraordinary kind, it is not to be expected that new theoretic views can be examined in all their relations, and formed so as to be consistent with all the well known and established facts of chemistry; nor that the facts themselves can be ascertained with that precision which long experience, an acquaintance with the instruments, and the defects to which they are liable, and a comparison of like observations made by different persons, are calculated to produce. This may appear to be a sufficient apology for the differences observed in the results of the above celebrated chemists, and for the opposition, and sometimes extravagance, of their views.

All the phenomena of combustion are exhibited by heating potassium in fluoric acid gas (superfluat of silex); though this would seem to intimate that the gas contains oxygen, yet, as Mr. Davy properly observes, heat and light

are merely the results of the intense agency of combination. It is remarkable that hydrogen is given out, yet not so much as would be given by the action of potassium on water; it is variable, and amounts generally to less than $\frac{1}{4}$ th of that quantity. Mr. Davy and the French chemists agree in the belief of a decomposition of the acid; but it is doubtful whether the hydrogen is from the potassium or the acid. The fact, I have observed, page 285, of the diminution of a mixture of hydrogen and fluoric acid gas by electricity, is one of the strongest in favour of the notion that the acid gas contains oxygen.

Muriatic acid has been a great object of investigation. Mr. Davy's ideas on this subject, in his *Electrochemical Researches*, 1808, were, that the acid gas contains water in a combined state; or, to use my own phraseology, that an atom of real muriatic acid combined with one of water, formed one of the acid gas; hence, in burning potassium in the gas, the potassium decomposed the water, the hydrogen was liberated, and the oxygen joined to the potassium to form potash, with which the real or dry acid immediately united. This conclusion was plausible; but it was truly astonishing to see the French chemists draw the same conclusion

from their views of the subject. They should have viewed muriatic acid gas as the pure acid, which combined with the potash of the potassium, and liberated its hydrogen. Mr. Davy has recently written an essay on the oxymuriatic and muriatic acids, with a copy of which he has just favoured me ; in this, he discards his former opinion of the gaseous combination of acid and water, and adopts another, that muriatic acid gas is a pure elastic fluid, resulting from the union of hydrogen with oxymuriatic acid, which last he conceives to be a simple substance. This notion agrees so far with mine, as to make hydrogen the base of muriatic acid ; but I cannot adopt his constitution of the acid. Mr. Davy now considers the hydrogen liberated, by the combustion of potassium in muriatic acid gas, as proceeding from the decomposed acid, and the new compound an *oxymuriate of potassium*. The explanation I prefer is, that the hydrogen proceeds from the potassium, and the undecomposed acid gas unites to the potash.

As to oxymuriatic acid, Gay Lussac and Thenard have reported some very striking and unexpected properties of it which they have discovered. They assert, that dry oxymuriatic acid gas was not decomposed by sulphurous

acid gas, nitrous oxide, carbonic oxide, nor even nitrous gas, when these were dry; but that it was immediately decomposed by them if water was present. These *may* appear to them to be facts; but certainly they are too important, and some of them too difficultly ascertained, to be believed merely upon the assertion of any one. By what means were they found? What was the structure of the apparatus, the quantity of gases operated upon, the time they were allowed to be in contact, the means employed to investigate the results, &c. &c.? To answer all these enquiries satisfactorily, would require a volume in detail; yet, Gay Lussac and The-
nard have not said one word. Now, we know that the facts respecting the mixtures of these gases over water, are *not* as above stated. Mr. Davy observes, (Researches, page 250) that
“oxygenated muriatic acid and nitrous oxide
“were mingled in a water apparatus; there
“was a slight appearance of condensation;
“but this was most probably owing to absorp-
“tion by the water; on agitation, the oxy-
“genated muriatic acid was absorbed, and the
“greater part of the nitrous oxide remained un-
“altered.” I have repeatedly mixed carbonic oxide and nitrous gas with oxymuriatic acid in a water apparatus; the former mixture ex-

hibits no signs of chemical union for several seconds ; afterwards, if the sun shine upon it, chemical action commences, and continues somewhat slower than that of oxygen and nitrous gas ; but if the mixture be put in the dark, it will remain for days, I believe, without any change. The latter mixture, or nitrous gas and oxymuriatic acid, in equal measures, over water, produces an instantaneous union, much more rapid than that of oxygen and nitrous gas, and which to all appearance seems independent upon the water. Now, if these simple experiments give such different results in different hands, what may we expect of the complex experiments, where the gases are previously dried, and then mixed in vessels quite free from mercury and water, and lastly examined after such mixture has taken place, regard being still had to the effects which mercury and water have, or are supposed to have, upon such mixtures ?

Mr. Davy has given several experiments to shew that oxymuriatic acid combines with hydrogen to produce muriatic acid ; but none of them appears to me decisive. When equal measures of hydrogen and oxymuriatic acid were introduced into an exhausted vessel, and fired by an electric spark, the result was a

slight vapour, and a condensation of $\frac{1}{15}$ to $\frac{1}{20}$ of the volume, the gas remaining being muriatic acid. This fact, if it can be relied upon, is favourable to the notion it is to support; I should have expected a condensation of $\frac{1}{4}$ or $\frac{1}{5}$ of the total volume on the common hypothesis; if the author had described the apparatus and quantity of gases submitted to the experiment, with the mode of determining the quantity and quality of the residual gas, it would have assisted in any future enquiry on the subject; it is certainly an important experiment. Mr. Davy allows the hyperoxymuriate of potash to abound with oxygen. He supposes the oxygen to be attracted by the potassium, or the potash, rather than by the oxymuriatic acid. The facts appear to me to draw the other way much more powerfully. We find oxymuriatic acid in conjunction with much oxygen, in several other salts, but potash no where, except when joined to this acid.

Some observations on nitric acid, and the other compounds of azote and oxygen, have been made by Gay Lussac, in the 2d vol. of the *Memoires d'Arcueil*. He contends that one *measure* of oxygenous gas unites to two *measures* of nitrous gas to form nitric acid, and to three *measures* to form nitrous acid. Now

I have shewn, page 328, that 1 measure of oxygen may be combined with 1.3 of nitrous gas, or with 3.5, or with any intermediate quantity whatever, according to circumstances, which he seems to allow; what, then, is the nature of the combinations below 2, and above 3, of nitrous gas? No answer is given to this; but the opinion is founded upon an hypothesis that all elastic fluids combine in equal measures, or in measures that have some simple relation one to another, as 1 to 2, 1 to 3, 2 to 3, &c. In fact, his notion of measures is analogous to mine of atoms; and if it could be proved that all elastic fluids have the same number of atoms in the same volume, or numbers that are as 1, 2, 3, &c. the two hypotheses would be the same, except that mine is universal, and his applies only to elastic fluids. Gay Lussac could not but see (page 188, Part 1. of this work) that a similar hypothesis had been entertained by me, and abandoned as untenable; however, as he has revived the notion, I shall make a few observations upon it, though I do not doubt but he will soon see its inadequacy.

Nitrous gas is, according to Gay Lussac, constituted of equal measures of azote and oxygen, which, when combined, occupy the same volume as when free. He quotes Davy, who

found 44.05 azote, and 55.95 oxygen by weight, in nitrous gas. He converts these into volumes, and finds them after the rate of 100 azote to 108.9 oxygen. There is, however, a mistake in this; if properly reduced, it gives 100 azote to 112 oxygen, taking the specific gravities according to Biot and Arago. But that Davy has overrated the oxygen 12 per cent. he shews by burning potassium in nitrous gas, when 100 measures afforded just 50 of azote. The degree of purity of the nitrous gas, and the particulars of the experiment, are not mentioned. This one result is to stand against the mean of three experiments of Davy, (see page 318) and may or may not be more correct, as hereafter shall appear. Dr. Henry's analysis of ammonia embraces that of nitrous gas also; he finds 100 measures of ammonia require 120 of nitrous gas for their saturation. Now this will apply to Gay Lussac's theory in a very direct manner; for, according to him, ammonia is formed of 1 measure of azote and 3 of hydrogen, condensed into a volume of 2; it follows, then, that 100 ammonia require 75 oxygen to saturate the hydrogen; hence, 120 nitrous gas should contain 75 oxygen, or 100 should contain 62.5, instead of 50. Here either the theory of Gay Lussac, or the expe-

rience of Dr. Henry, must give results wide of the truth. In regard to ammonia too, it may farther be added, that neither is the rate of azote to hydrogen 1 to 3, nor is the volume of ammonia doubled by decomposition, according to the experiments of Berthollet, Davy, and Henry, made with the most scrupulous attention to accuracy, to which may be added my own.—There is another point of view in which this theory of Gay Lussac is unfortunate, in regard to ammonia and nitrous gas; 1 measure of azote with 3 of hydrogen, forms 2 of ammonia; and 1 measure of azote with 1 of oxygen, forms 2 of nitrous gas: now, according to a well established principle in chemistry, 1 measure of oxygen ought to combine with 3 of hydrogen, or with one half as much, or twice as much; but no one of these combinations takes place. If Gay Lussac adopt my conclusions, namely, that 100 measures of azote require about 250 hydrogen to form ammonia (page 433), and that 100 azote require about 120 oxygen to form nitrous gas (page 331), he will perceive that the hydrogen of the former would unite to the oxygen of the latter, and form water, leaving no excess of either, further than the unavoidable errors of experiments might produce; and thus the great

chemical law would be preserved. The truth is, I believe, that gases do not unite in equal or exact measures in any one instance ; when they appear to do so, it is owing to the inaccuracy of our experiments. In no case, perhaps, is there a nearer approach to mathematical exactness, than in that of 1 measure of oxygen to 2 of hydrogen ; but here, the most exact experiments I have ever made, gave 1.97 hydrogen to 1 oxygen.

I shall close this subject, by presenting two tables of the elements of elastic fluids ; they are collected principally from the results already given in detail, with a few small alterations or corrections ; the utility of them to practical chemistry will be readily recognised.

Tables of the elements of elastic fluids; at a mean temperature and pressure.

(TABLE 1.)

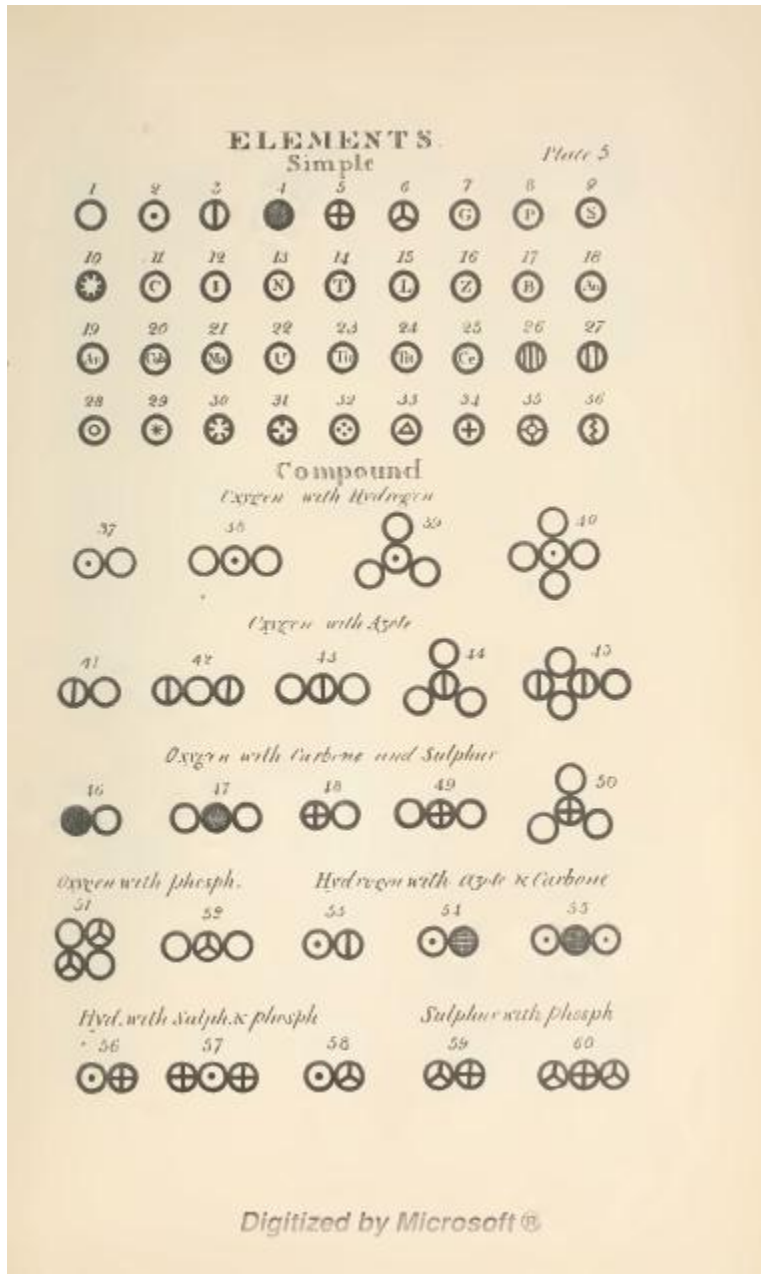
Names of the gases.	Wt. of an atom	Wt. of each cubic inch. grs.	Specific gravity.	Diameter of an atom	No. of atoms in a given volume.
Atmospheric air	—	31	1.00	—	—
Hydrogen	1	2.5	.08	1.000	1000
Oxygen	7	34	1.10	.794	2000
Nitrogen	5	30.2	.97	.747	2400
Muriatic acid	22	39.5	1.24	1.12	700
Ammonia	6	18.6	.60	.009	1530
Oxymur. acid	29	76	2.46	.981	1060
Nitrous gas	12	32.2	1.04	.950	1060
Nitrous oxide	17	50	1.60	.947	1180
Carbonic oxide	12.4	29	.94	1.020	910
Carbonic acid	19.4	47	1.52	1.00	1000
Sulphurous acid	27	71	2.30	.95	1170
Olefiant gas	6.4	29.5	.95	.81	1890
Carburetted hyd.	7.4	18.6	.60	1.00	1000
Sulphuretted hyd.	14	36	1.16	1.00	1000
Phosphur. hyd.	10	26	.84	1.00	1000
Superflu. of silic.	75	130	4.20	1.15	633

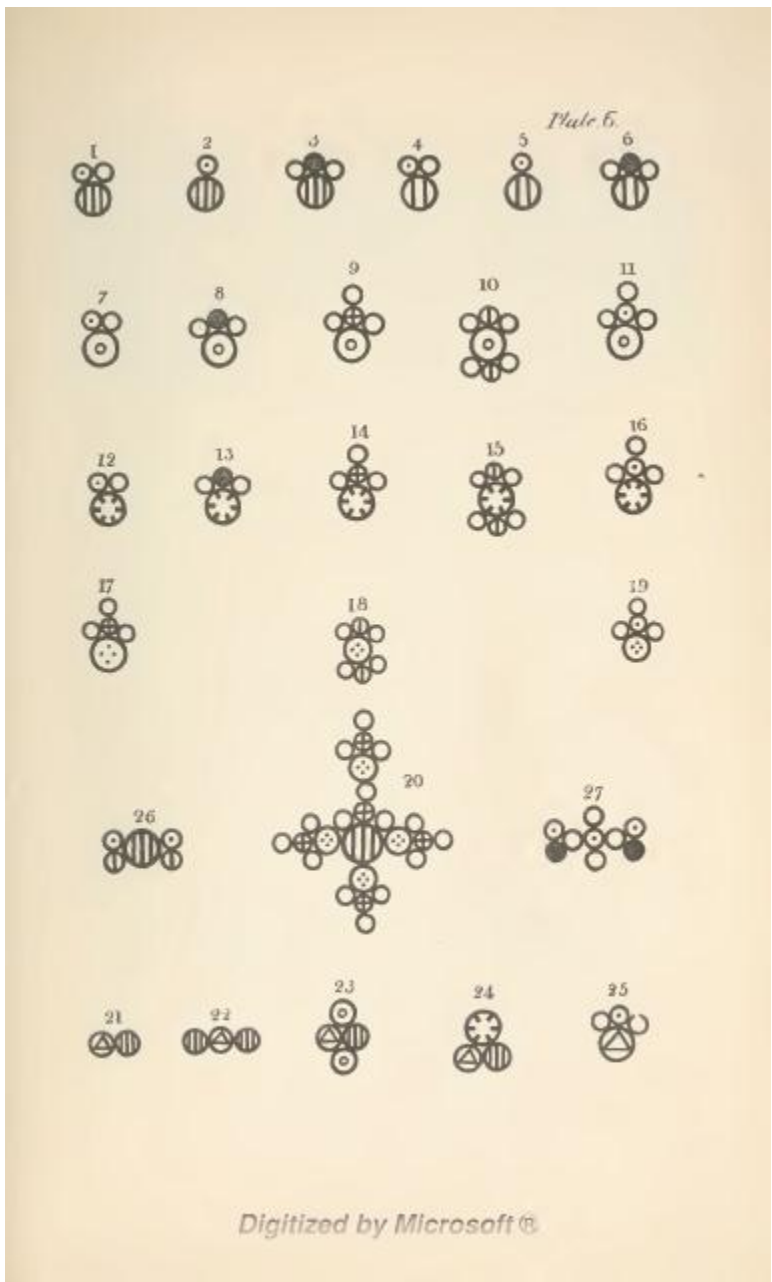
(TABLE 2.)

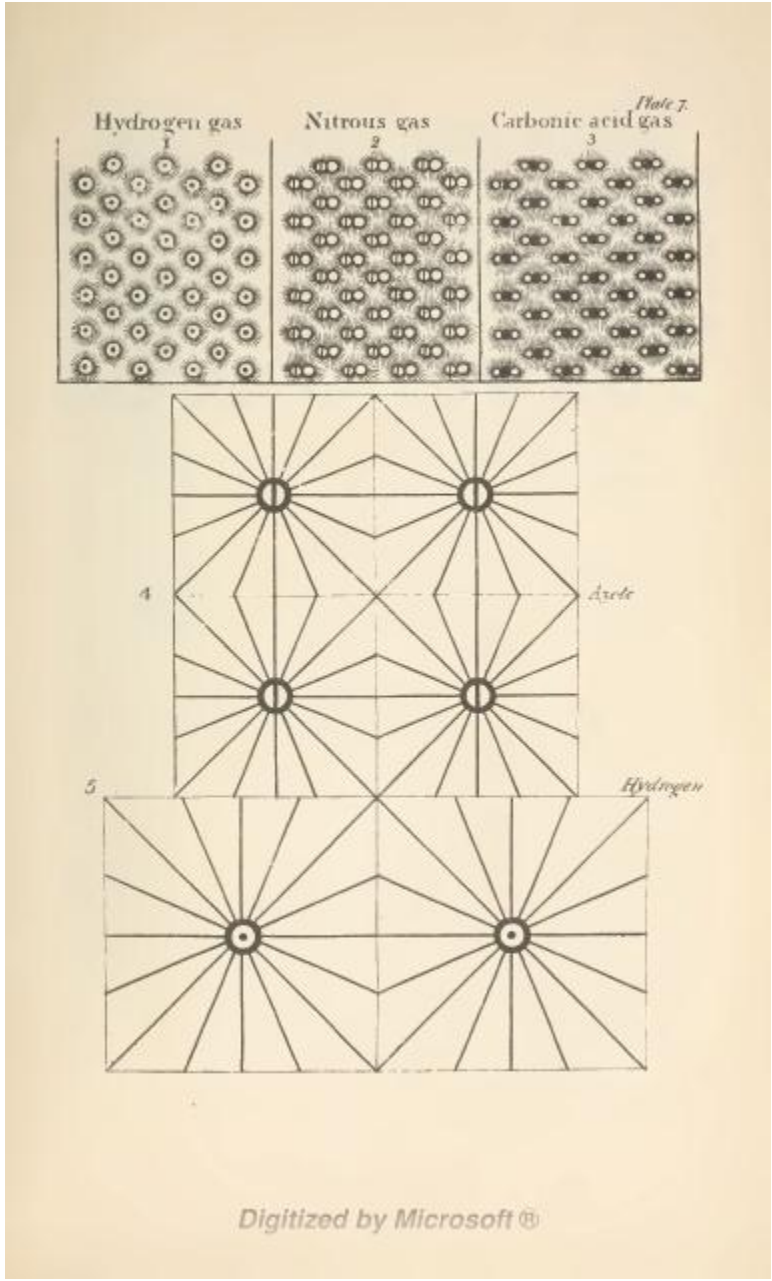
Proportions of the constituent principles of compound gases.

Names of the compound gases.	Constituent principles of 100 measures of the compound gases.		Constituent principles of 100 weight of the compound gases.	
	Measures.	Measures.	Measures.	Measures.
Ammon. gas	52 azote	+ 133 hyd.	85 azote	+ 17 hyd.
Water	100 oxyg.	+ 200 hyd.*	87 oxy.	+ 12.5 hyd.
Nitrous gas	46 azote	+ 55 oxyg.	42 azote	+ 38 oxygen
Nitr. oxide	99 azote	+ 58 oxyg.	50 azote	+ 41 oxygen
Nitric acid	150 nit. gas	+ 100 oxy.	27 azote	+ 73 oxy.
Nitrous acid	160 nit. gas	+ 100 oxy.	33 azote	+ 67 oxy.
Oxym. acid	150 mur. acid	+ 50 oxy.	76 mur. acid	+ 24 oxy.
Sulphur. acid	100 oxygen	+ sulphur	52 oxy.	+ 48 sulphur
Sulphur. acid	100 sulphur. acid	+ 50 oxy.	79½ sul. acid	+ 20½ oxy.
Carb. oxide	47 oxy.	+ charcoal	55 oxy.	+ 45 charc.
Carb. acid	100 oxy.	+ charcoal	72 oxy.	+ 28 charc.
Carbur. hyd.	200 hydr.	+ 1 part char.	27 hyd.	+ 73 charc.
Olefiant gas	200 hydr.	+ 2 parts ch.	15 hyd.	+ 85 charc.
Sulph. hyd.	100 hydr.	+ sulphur	7 hyd.	+ 93 sulph.
Mur. of am.	100 mur. acid	+ 100 am. g.	65 mur. acid	+ 35 am. gas
Carb. of am.	100 carb. acid	+ 80 am. g.	76 carb. acid	+ 24 am. gas
Subc. of am.	100 carb. acid	+ 160 am. g.	61 carb. acid	+ 39 am. gas

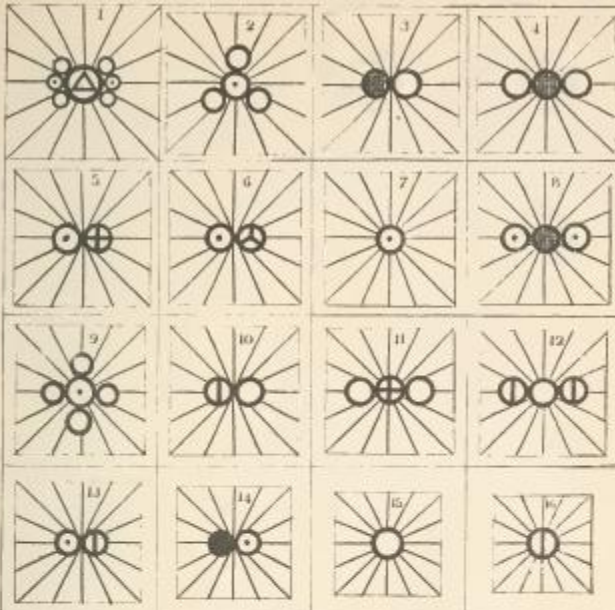
* I believe 197 is nearer the truth.



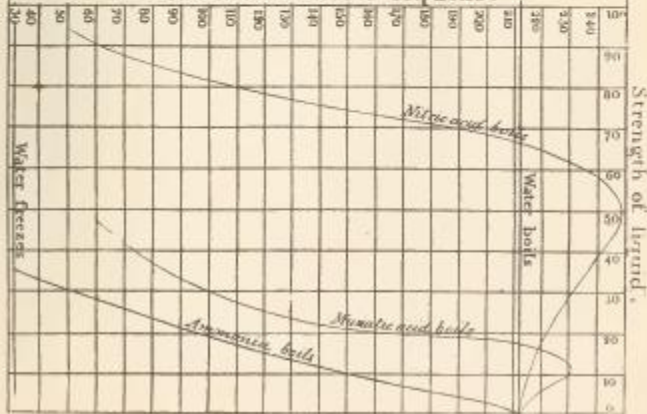




DIAMETERS OF ELASTIC ATOMS *Plate 3*



Ebullition of volatile liquids.



ANEXO 5 – Artigo J. J. Thomson. *Philosophical Magazine*, S6, 1897.

Philosophical Magazine, 44, 293 (1897). [facsimile from Stephen Wright, *Classical Scientific Papers, Physics* (Mills and Boon, 1964).]

The experiments* discussed in this paper were undertaken in the hope of gaining some information as to the nature of the Cathode Rays. The most diverse opinions are held as to these rays; according to the almost unanimous opinion of German physicists they are due to some process in the [aether](#) to which—inasmuch as in a uniform magnetic field their course is circular and not rectilinear—no phenomenon hitherto observed is analogous: another view of these rays is that, so far from being wholly aetherial, they are in fact wholly material, and that they mark the paths of particles of matter charged with negative electricity. It would seem at first sight that it ought not to be difficult to discriminate between views so different, yet experience shows that this is not the case, as amongst the physicists who have most deeply studied the subject can be found supporters of either theory.

The electrified-particle theory has for purposes of research a great advantage over the aetherial theory, since it is definite and its consequences can be predicted; with the aetherial theory it is impossible to predict what will happen under any given circumstances, as on this theory we are dealing with hitherto unobserved phenomena in the aether, of whose laws we are ignorant.

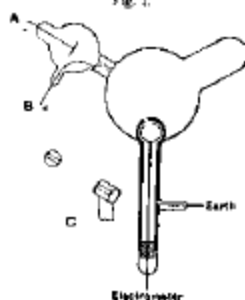
The following experiments were made to test some of the consequences of the electrified-particle theory.

Charge carried by the Cathode Rays

If these rays are negatively electrified particles, then when they enter an enclosure they ought to carry into it a charge of negative electricity. This has been proved to be the case by [Perrin](#), who placed in front of a plane cathode two coaxial metallic cylinders which were insulated from each other: the outer of these cylinders was connected with the earth, the inner with a gold-leaf electroscope. These cylinders were closed except for two small holes, one in each cylinder, placed so that the cathode rays could pass through them into the inside of the inner cylinder. Perrin found that when the rays passed into the inner cylinder the electroscope received a charge of negative electricity, while no charge went to the electroscope when the rays were deflected by a magnet so as no longer to pass through the hole.

Fig. 1.

This experiment proves that something charged with negative electricity is shot off from the cathode, travelling at right angles to it, and that this something is deflected by a magnet; it is open, however, to the objection that it does not prove that the cause of the electrification in the



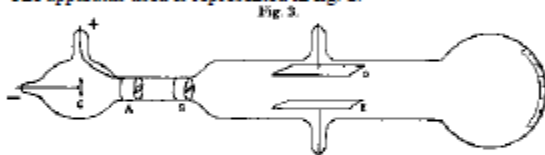
electroscope has anything to do with the cathode rays. Now the supporters of the aetherial theory do not deny that electrified particles are shot off from the cathode; they deny, however, that these charged particles have any more to do with the cathode rays than a rifle-ball has with the flash when a rifle is fired. I have therefore repeated Perrin's experiment in a form which is not open to this objection. The arrangement used was as follows:--Two coaxial cylinders (fig. 1) with slits in them are placed in a bulb connected with the discharge-tube; the cathode rays from the cathode A pass into the bulb through a slit in a metal plug fitted into the neck of the tube; this plug is connected with the anode and is put to earth. The cathode rays thus do not fall upon the cylinders unless they are deflected by a magnet. The outer cylinder is connected with the earth, the inner with the electrometer. When the cathode rays (whose path was traced by the phosphorescence on the glass) did not fall on the slit, the electrical charge sent to the electrometer when the induction-coil producing the rays was set in action was small and irregular; when, however, the rays were bent by a magnet so as to fall on the slit there was a large charge of negative electricity sent to the electrometer. I was surprised at the magnitude of the charge; on some occasions enough negative electricity went through the narrow slit into the inner cylinder in one second to alter the potential of a capacity of 1.5 microfarads by 20 volts. If the rays were so much bent by the magnet that they overshot the slits in the cylinder, the charge passing into the cylinder fell again to a very small fraction of its value when the aim was true. Thus this experiment shows that however we twist and deflect the cathode rays by magnetic forces, the negative electrification follows the same path as the rays, and that this negative electrification is indissolubly connected with the cathode rays.

When the rays are turned by the magnet so as to pass through the slit into the inner cylinder, the deflexion of the electrometer connected with this cylinder increases up to a certain value, and then remains stationary although the rays continue to pour into the cylinder. This is due to the fact that the gas in the bulb becomes a conductor of electricity when the cathode rays pass through it, and thus, though the inner cylinder is perfectly insulated when the rays are not passing, yet as soon as the rays pass through the bulb the air between the inner cylinder and the outer one becomes a conductor, and the electricity escapes from the inner cylinder to the earth. Thus the charge within the inner cylinder does not go on continually increasing; the cylinder settles down into a state of equilibrium in which the rate at which it gains negative electricity from the rays is equal to the rate at which it loses it by conduction through the air. If the inner cylinder has initially a positive charge it rapidly loses that charge and acquires a negative one; while if the initial charge is a negative one, the cylinder will leak if the initial negative potential is numerically greater than the equilibrium value.

Deflexion of the Cathode Rays by an Electrostatic Field.

An objection very generally urged against the view that the cathode rays are negatively electrified particles, is that hitherto no deflexion of the rays has been observed under a small electrostatic force, and though the rays are deflected when they pass near electrodes connected with sources of large differences of potential, such as induction-coils or electrical machines, the deflexion in this case is regarded by the supporters of the aetherial theory as due to the discharge passing between the electrodes, and not primarily to the electrostatic field. Hertz made the rays travel between two parallel plates of metal placed inside the discharge-tube, but found that they were not deflected when the plates were connected with a battery of storage-cells; on repeating this experiment I at first got the same result, but subsequent experiments showed that the absence of deflexion is due to the conductivity conferred on the rarefied gas by the cathode rays. On measuring this conductivity it was found that it diminished very rapidly as the exhaustion increased; it seemed then that on trying Hertz's experiment at very high exhaustions there might be a chance of detecting the deflexion of the cathode rays by an electrostatic force.

The apparatus used is represented in fig. 2.



The rays from the cathode C pass through a slit in the anode A, which is a metal plug fitting tightly into the tube and connected with the earth; after passing through a second slit in another earth-connected metal plug B, they travel between two parallel aluminium plates about 5 cm. long by 2 broad and at a distance of 1.5 cm. apart; they then fall on the end of the tube and produce a narrow well-defined phosphorescent patch. A scale pasted on the outside of the tube serves to measure the deflexion of this patch. At high exhaustions the rays were deflected when the two aluminium plates were connected with the terminals of a battery of small storage cells; the rays were depressed when the upper plate was connected with the negative pole of the battery, the lower with the positive, and raised when the upper plate was connected with the positive, the lower with the negative pole. The deflexion was proportional to the difference of potential between the plates, and I could detect the deflexion when the potential-difference was as small as two volts. It was only when the vacuum was a good one that the deflexion took place, but that the absence of deflexion is due to the conductivity of the medium is shown by what takes place when the vacuum has just arrived at the stage at which the deflexion begins. At this stage there is a deflexion of the rays when the plates are first

connected with the terminals of the battery, but if this connexion is maintained the patch of the phosphorescence gradually creeps back to its undeflected position. This is just what would happen if the space between the plates were a conductor, though a very bad one, for then the positive and negative ions between the plates would slowly diffuse, until the positive plate became coated with negative ions, the negative plate with positive ones; thus the electric intensity between the plates would vanish and the cathode rays be free from electrostatic force. Another illustration of this is afforded by what happens when the pressure is low enough to show the deflexion and a large difference of potential, say 200 volts, is established between the plates; under these circumstances there is a large deflexion of the cathode rays, but the medium under the large electromotive force breaks down every now and then and a bright discharge passes between the plates; when this occurs the phosphorescent patch produced by the cathode rays jumps back to its undeflected position. When the cathode rays are deflected by the electrostatic field, the phosphorescent band breaks up into several bright bands separated by comparatively dark spaces; the phenomena are exactly analogous to those observed by Birkeland when the cathode rays are deflected by a magnet, and called by him the magnetic spectrum.

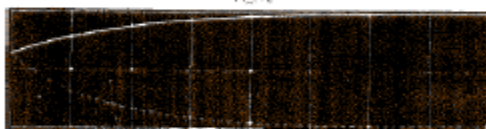
A series of measurements of the deflexion of the rays by the electrostatic force under various circumstances will be found later on in the part of the paper which deals with the velocity of the rays and the ratio of the mass of the electrified particles to the charge carried by them. It may, however, be mentioned here that the deflexion gets smaller as the pressure diminishes, and when in consequence the potential-difference in the tube in the neighbourhood of the cathode increases.

Conductivity of a Gas through which Cathode Rays are passing.

The conductivity of the gas was investigated by means of the apparatus shown in [fig. 2](#). The upper plate D was connected with one terminal of a battery of small storage-cells, the other terminal of which was connected with the earth; the other plate E was connected with one of the coatings of a condenser of one microfarad capacity, the other coating of which was to earth; one pair of quadrants of an electrometer was also connected with E, the other pair of quadrants being to earth. When the cathode rays are passing between the plates, the two pairs of quadrants of the electrometer are first connected with each other, and then the connexion between them was broken. If the space between the plates were a non-conductor, the potential of the pair of quadrants not connected with the earth would remain zero and the needle of the electrometer would be deflected. There is always a deflexion of the electrometer, showing that a current passes between the plates. The magnitude of the current depends very greatly upon the pressure of the gas; so much so, indeed, that it is difficult to obtain consistent readings in consequence of the

changes which always occur in the pressure when the discharge passes through the tube.

We shall first take the case when the pressure is only just low enough to allow the phosphorescent patch to appear at the end of the tube; in this case the relation between the current between the plates and the initial difference of potential is represented by the curve shown in fig. 3. In this figure the abscissae represent the initial difference of potential between the plates, each division representing two volts. The quantity of electricity which has passed between the plates in one minute is the quantity required to raise 1 microfarad to the potential-difference shown by the curve. The upper and lower curve relates to the case when the upper plate is connected with the negative and positive pole respectively of the battery.



Even when there is no initial difference of potential between the plates the lower plate acquires a negative charge from the impact on it of some of the cathode rays.

We see from the curve that the current between the plates soon reaches a value where it is only slightly affected by an increase in the potential-difference between the plates; this is a feature common to conduction through gases traversed by Röntgen rays, by uranium rays, by ultra-violet light, and, as we now see, by cathode rays. The rate of leak is not greatly different whether the upper plate be initially positively or negatively electrified.

The current between the plates only lasts for a short time; it ceases long before the potential of the lower plate approaches that of the upper. Thus, for example, when the potential of the upper plate was about 400 volts above that of the earth, the potential of the lower plate never rose above 6 volts: similarly, if the upper plate were connected with the negative pole of the battery, the fall in potential of the lower plate was very small in comparison with the potential-difference between the upper plate and the earth.

These results are what we should expect if the gas between the plates and the plug B (fig. 2) were a very much better conductor than the gas between the plates, for the lower plate will be in a steady state when the current coming to it from the upper plate is equal to the current going from it to the plug; now if the conductivity of the gas between the plate and the plug is much greater than that between the plates, a small difference of potential between the lower plate

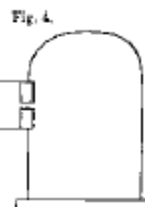
and the plug will be consistent with a large potential-difference between the plates.

So far we have been considering the case when the pressure is as high as is consistent with the cathode rays reaching the end of the tube; we shall now go to the other extreme and consider the case when the pressure is as low as is consistent with the passage of a discharge through the bulb. In this case, when the plates are not connected with the battery we get a negative charge communicated to the lower plate, but only very slowly in comparison with the effect in the previous case. When the upper plate is connected with the negative pole of a battery, this current to the lower plate is only slightly increased even when the difference of potential is as much as 400 volts: a small potential-difference of about 20 volts seems slightly to decrease the rate of leak. Potential-differences much exceeding 400 volts cannot be used, as though the dielectric between the plates is able to sustain them for some little time, yet after a time an intensely bright arc flashes across between the plates and liberates so much gas as to spoil the vacuum. The lines in the spectrum of this glare are chiefly mercury lines; its passage leaves very peculiar markings on the aluminium plates.

If the upper plate was charged positively, then the negative charge communicated to the lower plate was diminished, and stopped when the potential-difference between the plates was about 20 volts; but at the lowest pressure, however great (up to 400 volts) the potential-difference, there was no leak of positive electricity to the lower plate at all comparable with the leak of negative electricity to this plate when the two plates were disconnected from the battery. In fact at this very low pressure all the facts are consistent with the view that the effects are due to the negatively electrified particles travelling along the cathode rays, the rest of the gas possessing little conductivity. Some experiments were made with a tube similar to that shown in [fig. 2](#), with the exception that the second plug B was absent, so that a much greater number of cathode rays passed between the plates. When the upper plate was connected with the positive pole of the battery a luminous discharge with well-marked striations passed between the upper plate and the earth-connected plug through which the cathode rays were streaming; this occurred even though the potential-difference between the plate and the plug did not exceed 20 volts. Thus it seems that if we supply cathode rays from an external source to the cathode a small potential-difference is sufficient to produce the characteristic discharge through a gas.

Magnetic Deflexion of the Cathode Rays in Different Gases.

The deflexion of the cathode rays by the magnetic field was studied with the aid of the apparatus



shown in fig. 4. The cathode was placed in a side-tube fastened on to a bell-jar; the opening between this tube and the bell-jar was closed by a metallic plug with a slit in it; this plug was connected with the earth and was used as the anode. The cathode rays passed through the slit in this plug into the bell-jar, passing in front of a vertical plate of glass ruled into small squares. The bell-jar was placed between two large parallel coils arranged as a Helmholtz galvanometer. The course of the rays was determined by taking photographs of the bell-jar when the cathode rays were passing through it; the divisions on the plate enabled the path of the rays to be determined. Under the action of the magnetic field the narrow beam of cathode rays spreads out into a broad fan-shaped luminosity in the gas. The luminosity in this fan is not uniformly distributed, but is condensed along certain lines. The phosphorescence on the glass is also not uniformly distributed; it is much spread out, showing that the beam consists of rays which are not all deflected to the same extent by the magnet. The luminosity on the glass is crossed by bands along which the luminosity is very much greater than in the adjacent parts. These bright and dark bands are called by Birkeland, who first observed them, the magnetic spectrum. The brightest spots on the glass are by no means always the terminations of the brightest streaks of luminosity in the gas; in fact, in some cases a very bright spot on the glass is not connected with the cathode by any appreciable luminosity, though there may be plenty of luminosity in other parts of the gas. One very interesting point brought out by the photographs is that in a given magnetic field, and with a given mean potential-difference between the terminals, the path of the rays is independent of the nature of the gas. Photographs were taken of the discharge in hydrogen, air, [carbonic acid](#), methyl iodide, *i.e.*, in gases whose densities range from 1 to 70, and yet, not only were the paths of the most deflected rays the same in all cases, but even the details, such as the distribution of the bright and dark spaces, were the same; in fact, the photographs could hardly be distinguished from each other. It is to be noted that the pressures were not the same; the pressures in the different gases were adjusted so that the mean potential-differences between the cathode and the anode were the same in all the gases. When the pressure of a gas is lowered, the potential-difference between the terminals increases, and the deflexion of the rays produced by a magnet diminishes, or at any rate the deflexion of the rays when the phosphorescence is a maximum diminishes. If an air-break is inserted an effect of the same kind is produced.

In the experiments with different gases, the pressures were as high as was consistent with the appearance of the phosphorescence on the glass, so as to ensure having as much as possible of the gas under consideration in the tube.

As the cathode rays carry a charge of negative electricity, are deflected by an electrostatic force as if they were negatively electrified, and are acted on by a magnetic force in just the way in which this force would act on a negatively electrified body moving along the path of these rays, I can see no escape from

the conclusion that they are charges of negative electricity carried by particles of matter. The question next arises, What are these particles? are they atoms, or molecules, or matter in a still finer state of subdivision? To throw some light on this point, I have made a series of measurements of the ratio of the mass of these particles to the charge carried by it. To determine this quantity, I have used two independent methods. The first of these is as follows:--Suppose we consider a bundle of homogeneous cathode rays. Let m be the mass of each of the particles, e the charge carried by it. Let N be the number of particles passing across any section of the beam in a given time; then Q the quantity of electricity carried by these particles is given by the equation

$$Ne = Q.$$

We can measure Q if we receive the cathode rays in the inside of a vessel connected with an electrometer. When these rays strike against a solid body, the temperature of the body is raised; the kinetic energy of the moving particles being converted into heat; if we suppose that all this energy is converted into heat, then if we measure the increase in the temperature of a body of known thermal capacity caused by the impact of these rays, we can determine W , the kinetic energy of the particles, and if v is the velocity of the particles,

$$(1/2)Nmv^2 = W.$$

If ρ is the radius of curvature of the path of these rays in a uniform magnetic field H , then

$$mv/e = H\rho = I,$$

where I is written for $H\rho$ for the sake of brevity. From these equations we get

$$(1/2)(m/e)v^2 = W/Q.$$

$$v = 2W/QI,$$

$$m/e = I^2Q/2W.$$

Thus, if we know the values of Q , W , and I , we can deduce the values of v and m/e .

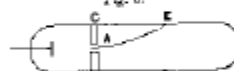
To measure these quantities, I have used tubes of three different types. The first I tried is like that represented in [fig. 2](#), except that the plates E and D are absent, and two coaxial cylinders are fastened to the end of the tube. The rays from the cathode C fall on the metal plug B , which is connected with the earth, and serves for the anode; a horizontal slit is cut in this plug. The cathode rays pass through this slit, and then strike against the two coaxial cylinders at the end of the tube; slits are cut in these cylinders, so that the cathode rays pass into the inside of the inner cylinder. The outer cylinder is connected with the earth, the inner cylinder, which is insulated from the outer one, is connected with an electrometer, the deflexion of which measures Q , the quantity of electricity brought into the inner cylinder by the rays. A thermo-electric couple is placed behind the slit in the inner cylinder; this couple is made of very thin strips of iron and copper fastened to very fine iron

and copper wires. These wires passed through the cylinders, being insulated from them, and through the glass to the outside of the tube, were they were connected with a low-resistance galvanometer, the deflexion of which gave data for calculating the rise of temperature of the junction produced by the impact against it of the cathode rays. The strips of iron and copper were large enough to ensure that every cathode ray which entered the inner cylinder struck against the junction. In some of the tubes the strips of iron and copper were placed end to end, so that some of the rays struck against the iron, and others against the copper; in others, the strip of one metal was placed in front of the other; no difference, however, could be detected between the results got with these two arrangements. The strips of iron and copper were weighed, and the thermal capacity of the junction calculated. In one set of junctions this capacity was 5×10^{-3} , in another 3×10^{-3} . If we assume that the cathode rays which strike against the junction give their energy up to it, the deflexion of the galvanometer gives us W or $(1/2)Nm v^2$.

The value of I , *i.e.*, $H\rho$, where ρ is the curvature of the path of the rays in a magnetic field of strength H was found as follows:--The tube was fixed between two large circular coils placed parallel to each other, and separated by a distance equal to the radius of either; these coils produce a uniform magnetic field, the strength of which is got by measuring with an ammeter the strength of the current passing through them. The cathode rays are thus in a uniform field, so that their path is circular. Suppose that the rays, when deflected by a magnet, strike against the glass of the tube at E (fig. 5), then, if ρ is the radius of the circular path of the rays,

$$2\rho = CE^2/AC + AC;$$

thus, if we measure CE and AC we have the means of determining the radius of curvature of the path of the rays.



The determination of ρ is rendered to some extent uncertain, in consequence of the pencil of rays spreading out under the action of the magnetic field, so that the phosphorescent patch at E is several millimetres long; thus values of ρ differing appreciably from each other will be got by taking E at different points of this phosphorescent patch. Part of this patch was, however, generally considerably brighter than the rest; when this was the case, E was taken as the brightest point; when such a point of maximum brightness did not exist, the middle of the patch was taken for E . The uncertainty in the value of ρ thus introduced amounted sometimes to about 20 per cent.; by this I mean that if we took E first at one extremity of the patch and then at the other, we should get values of ρ differing by this amount.

The measurement of Q , the quantity of electricity which enters the inner cylinder, is complicated by the cathode rays making the gas through which they pass a conductor, so that though the insulation of the inner cylinder was

perfect when the rays were off, it was not so when they were passing through the space between the cylinders; this caused some of the charge communicated to the inner cylinder to leak away so that the actual charge given to the cylinder by the cathode rays was larger than that indicated by the electrometer. To make the error from this cause as small as possible, the inner cylinder was connected to the largest capacity available, 1.5 microfarad, and the rays were only kept on for a short time, about 1 or 2 seconds, so that the alteration in potential of the inner cylinder was not large, ranging in the various experiments from about .5 to 5 volts. Another reason why it is necessary to limit the duration of the rays to as short a time as possible, is to avoid the correction for the loss of heat from the thermo-electric junction by conduction along the wires; the rise in temperature of the junction was of the order 2°C.; a series of experiments showed that with the same tube and the same gaseous pressure Q and W were proportional to each other when the rays were not kept on too long.

Tubes of this kind gave satisfactory results, the chief drawback being that sometimes in consequence of the charging up of the glass of the tube, a secondary discharge started from the cylinder to the walls of the tube, and the cylinders were surrounded by glow; when this glow appeared, the readings were very irregular; the glow could, however, be got rid of by pumping and letting the tube rest for some time. The results got with this tube are given in the Table under the heading Tube 1.

The second type of tube was like that used for photographing the path of the rays ([fig. 4](#)); double cylinders with a thermo-electric junction like those used in the previous tube were placed in the line of fire of the rays, the inside of the bell-jar was lined with copper gauze connected with the earth. This tube gave very satisfactory results; we were never troubled with any glow round the cylinders, and the readings were most concordant; the only drawback was that as some of the connexions had to be made with sealing-wax, it was not possible to get the highest exhaustions with this tube, so that the range of pressure for this tube is less than that for tube 1. The results got with this tube are given in the Table under the heading Tube 2.

The third type of tube was similar to the first, except that the openings in the two cylinders were made very much smaller; in this tube the slits in the cylinders were replaced by small holes, about 1.5 millim. in diameter. In consequence of the smallness of the openings, the magnitude of the effects was very much reduced; in order to get measurable results it was necessary to reduce the capacity of the condenser in connexion with the inner cylinder to .15 microfarad, and to make the galvanometer exceedingly sensitive, as the rise in temperature of the thermo-electric junction was in these experiments only about .5° C. on the average. The results obtained in this tube are given in the Table under the heading Tube 3.

The results of a series of measurements with these tubes are given in the following Table:--

Gas.	Value of W/Q.	I	m/e	v .
Tube 1.				
Air	4.6×10^{11}	230	$.57 \times 10^{-7}$	4×10^9
Air	1.8×10^{12}	350	$.34 \times 10^{-7}$	1×10^{10}
Air	6.1×10^{11}	230	$.43 \times 10^{-7}$	5.4×10^9
Air	2.5×10^{12}	400	$.32 \times 10^{-7}$	1.2×10^{10}
Air	5.5×10^{11}	230	$.48 \times 10^{-7}$	4.8×10^9
Air	1×10^{12}	285	$.4 \times 10^{-7}$	7×10^9
Air	1×10^{12}	285	$.4 \times 10^{-7}$	7×10^9
Hydrogen	6×10^{12}	205	$.35 \times 10^{-7}$	6×10^9
Hydrogen	2.1×10^{12}	460	$.5 \times 10^{-7}$	9.2×10^9
Carbonic acid	8.4×10^{11}	260	$.4 \times 10^{-7}$	7.5×10^9
Carbonic acid	1.47×10^{12}	340	$.4 \times 10^{-7}$	8.5×10^9
Carbonic acid	3.0×10^{12}	480	$.39 \times 10^{-7}$	1.3×10^{10}
Tube 2.				
Air	2.8×10^{11}	175	$.53 \times 10^{-7}$	3.3×10^9
Air	4.4×10^{11}	195	$.47 \times 10^{-7}$	4.1×10^9
Air	3.5×10^{11}	181	$.47 \times 10^{-7}$	3.8×10^9
Hydrogen	2.8×10^{11}	175	$.53 \times 10^{-7}$	3.3×10^9
Air	2.5×10^{11}	160	$.51 \times 10^{-7}$	3.1×10^9
Carbonic acid	2×10^{11}	148	$.54 \times 10^{-7}$	2.5×10^9
Air	1.8×10^{11}	151	$.63 \times 10^{-7}$	2.3×10^9
Hydrogen	2.8×10^{11}	175	$.53 \times 10^{-7}$	3.3×10^9
Hydrogen	4.4×10^{11}	201	$.46 \times 10^{-7}$	4.4×10^9
Air	2.5×10^{11}	176	$.61 \times 10^{-7}$	2.8×10^9
Air	4.2×10^{11}	200	$.48 \times 10^{-7}$	4.1×10^9
Tube 3.				
Air	2.5×10^{11}	220	$.9 \times 10^{-7}$	2.4×10^9
Air	3.5×10^{11}	225	$.7 \times 10^{-7}$	3.2×10^9
Hydrogen	3×10^{11}	250	1.0×10^{-7}	2.5×10^9

It will be noticed that the value of m/e is considerably greater for Tube 3, where the opening is a small hole, than for Tubes 1 and 2, where the opening is a slit of much greater area. I am of the opinion that the values of m/e got from Tubes 1 and 2 are too small, in consequence of the leakage from the inner cylinder to the outer by the gas being rendered a conductor by the passage of the cathode rays.

It will be seen from these tables that the value of m/e is independent of the nature of the gas. Thus, for the first tube the mean for air is $.40 \times 10^{-7}$, for hydrogen $.42 \times 10^{-7}$, and for carbonic acid gas $.4 \times 10^{-7}$; for the second tube the mean for air is $.52 \times 10^{-7}$, for hydrogen $.50 \times 10^{-7}$, and for carbonic acid gas $.54 \times 10^{-7}$.

Experiments were tried with electrodes made of iron instead of aluminium; this altered the appearance of the discharge and the value of v at the same pressure, the values of m/e were, however, the same in the two tubes; the effect produced by different metals on the discharge will be described later on.

In all the preceding experiments, the cathode rays were first deflected from the cylinder by a magnet, and it was then found that there was no deflexion either of the electrometer or the galvanometer, so that the deflexions observed were entirely due to the cathode rays; when the glow mentioned previously surrounded the cylinders there was a deflexion of the electrometer even when the cathode rays were deflected from the cylinder.

Before proceeding to discuss the results of these measurements I shall describe another method of measuring the quantities m/e and v of an entirely different kind from the preceding; this method is based upon the deflexion of the cathode rays in an electrostatic field. If we measure the deflexion experienced by the rays when traversing a given length under a uniform electric intensity, and the deflexion of the rays when they traverse a given distance under a uniform magnetic field, we can find the values of m/e and v in the following way:--

Let the space passed over by the rays under a uniform electric intensity F be l , the time taken for the rays to traverse this space is l/v , the velocity in the direction of F is therefore

$$(Fe/m)(l/v),$$

so that θ , the angle through which the rays are deflected when they leave the electric field and enter a region free from electric force, is given by the equation

$$\theta = (Fe/m)(l/v^2).$$

If, instead of the electric intensity, the rays are acted on by a magnetic force H at right angles to the rays, and extending across the distance l , the velocity at right angles to the original path of the rays is

$$(Hev/m)(l/v),$$

so that ϕ , the angle through which the rays are deflected when they leave the magnetic field, is given by the equation

$$\phi = (He/m)(l/v).$$

From these equations we get

$$v = (\phi/\theta)(F/H)$$

and

$$m/e = H^2 \theta / F \phi^2 .$$

In the actual experiments H was adjusted so that $\phi = \theta$; in this case the

equations become

$$v = F/H,$$

$$m/e = H^2 / F \theta .$$

The apparatus used to measure v and m/e by this means is that represented in [fig. 2](#). The electric field was produced by connecting the two aluminium plates to the terminals of a battery of storage-cells. The phosphorescent patch at the end of the tube was deflected, and the deflexion measured by a scale pasted to the end of the tube. As it was necessary to darken the room to see the phosphorescent patch, a needle coated with luminous paint was placed so that by a screw it could be moved up and down the scale; this needle could be seen when the room was darkened, and it was moved until it coincided with the phosphorescent patch. Thus, when light was admitted, the deflexion of the phosphorescent patch could be measured.

The magnetic field was produced by placing outside the tube two coils whose diameter was equal to the length of the plates; the coils were placed so that they covered the space occupied by the plates, the distance between the coils was equal to the radius of either. The mean value of the magnetic force over the length l was determined in the following way: a narrow coil C whose length was l , connected with a ballistic galvanometer, was placed between the coils; the plane of the windings of C was parallel to the planes of the coils; the cross section of the coil was a rectangle 5 cm. by 1 cm. A given current was sent through the outer coils and the kick α of the galvanometer observed when this current was reversed. The coil C was then placed at the centre of two very large coils, so as to be in a field of uniform magnetic force: the current through the large coils was reversed and the kick β of the galvanometer again observed; by comparing α and β we can get the mean value of the magnetic force over a length l ; this was found to be

$$60 \times i ,$$

where i is the current flowing through the coils.

A series of experiments was made to see if the electrostatic deflexion was proportional to the electric intensity between the plates; this was found to be the case. In the following experiments the current through the coils was adjusted so that the electrostatic deflexion was the same as the magnetic:--

Gas.	θ .	H .	F .	l .	m/e .	v .
Air	8/110	5.5	1.5×10^{10}	5	1.3×10^{-7}	2.8×10^9
Air	9.5/110	5.4	1.5×10^{10}	5	1.1×10^{-7}	2.8×10^9

Air	13/110	6.6	1.5×10^{10}	5	1.2×10^{-7}	2.3×10^9
Hydrogen	9/110	6.3	1.5×10^{10}	5	1.5×10^{-7}	2.5×10^9
Carbonic Acid	11/110	6.9	1.5×10^{10}	5	1.5×10^{-7}	2.2×10^9
Air	6/110	5	1.8×10^{10}	5	1.3×10^{-7}	3.6×10^9
Air	7/110	3.6	$1. \times 10^{10}$	5	1.1×10^{-7}	2.8×10^9

The cathode in the first five experiments was aluminium, in the last two experiments it was made of platinum; in the last experiment Sir William Crookes's method of getting rid of the mercury vapour by inserting tubes of pounded sulphur, sulphur iodide, and copper filings between the bulb and the pump was adopted. In the calculation of m/e and v no allowance has been made for the magnetic force due to the coil in the region outside the plates; in this region the magnetic force will be in the opposite direction to that between the plates, and will tend to bend the cathode rays in the opposite direction: thus the effective value of H will be smaller than the value used in the equations, so that the values of m/e are larger, and those of v less than they would be if this correction were applied. This method of determining the values of m/e and v is much less laborious and probably more accurate than the former method; it cannot, however, be used over so wide a range of pressures.

From these determinations we see that the value of m/e is independent of the nature of the gas, and that its value 10^{-7} is very small compared with the value 10^{-4} , which is the smallest value of this quantity previously known, and which is the value for the hydrogen ion in electrolysis.

Thus for the carriers of the electricity in the cathode rays m/e is very small compared with its value in electrolysis. The smallness of m/e may be due to the smallness of m or the largeness of e , or to a combination of these two. That the carriers of the charges in the cathode rays are small compared with ordinary molecules is shown, I think, by Lenard's results as to the rate at which the brightness of the phosphorescence produced by these rays diminishes with the length of path travelled by the ray. If we regard this phosphorescence as due to the impact of the charged particles, the distance through which the rays must travel before the phosphorescence fades to a given fraction (say $1/e$, where $e = 2.71$) of its original intensity, will be some moderate multiple of the mean free path. Now Lenard found that this distance depends solely upon the density of the medium, and not upon its chemical nature or physical state. In air at atmospheric pressure the distance was about half a centimetre, and this must be comparable with the mean free path of the carriers through air at atmospheric pressure. But the mean free path of the molecules of air is a quantity of quite a different order. The carrier, then, must be small compared with ordinary molecules.

The two fundamental points about these carriers seem to me to be (1) that these carriers are the same whatever the gas through which the discharge

passes, (2) that the mean free paths depend upon nothing but the density of the medium traversed by these rays.

It might be supposed that the independence of the mass of the carriers of the gas through which the discharge passes was due to the mass concerned being the quasi mass which a charged body possesses in virtue of the electric field set up in its neighbourhood; moving the body involves the production of a varying electric field, and, therefore, of a certain amount of energy which is proportional to the square of the velocity. This causes the charged body to behave as if its mass were increased by a quantity, which for a charged sphere is $(1/5)e^2/\mu a$ ('Recent Researches in Electricity and Magnetism'), where e is the charge and a the radius of the sphere. If we assume that it is this mass which we are concerned with in the cathode rays, since m/e would vary as e/a , it affords no clue to the explanation of either of the properties (1 and 2) of these rays. This is not by any means the only objection to this hypothesis, which I only mention to show that it has not been overlooked.

The explanation which seems to me to account in the most simple and straightforward manner for the facts is founded on a view of the constitution of the chemical elements which has been favourably entertained by many chemists: this view is that the atoms of the different chemical elements are different aggregations of atoms of the same kind. In the form in which this hypothesis was enunciated by Prout, the atoms of the different elements were hydrogen atoms; in this precise form the hypothesis is not tenable, but if we substitute for hydrogen some unknown primordial substance X, there is nothing known which is inconsistent with this hypothesis, which is one that has been recently supported by Sir Norman Lockyer for reasons derived from the study of the stellar spectra.

If, in the very intense electric field in the neighbourhood of the cathode, the molecules of the gas are dissociated and are split up, not into the ordinary chemical atoms, but into these primordial atoms, which we shall for brevity call [corpuscles](#); and if these corpuscles are charged with electricity and projected from the cathode by the electric field, they would behave exactly like the cathode rays. They would evidently give a value of m/e which is independent of the nature of the gas and its pressure, for the carriers are the same whatever the gas may be; again, the mean free paths of these corpuscles would depend solely upon the density of the medium through which they pass. For the molecules of the medium are composed of a number of such corpuscles separated by considerable spaces; now the collision between a single corpuscle and the molecule will not be between the corpuscles and the molecule as a whole, but between this corpuscle and the individual corpuscles which form the molecule; thus the number of collisions the particle makes as it moves through a crowd of these molecules will be proportional, not to the number of the molecules in the crowd, but to the number of the individual

corpuscles. The mean free path is inversely proportional to the number of collisions in unit time, and so is inversely proportional to the number of corpuscles in unit volume; now as these corpuscles are all of the same mass, the number of corpuscles in unit volume will be proportional to the mass of unit volume, that is the mean free path will be inversely proportional to the density of the gas. We see, too, that so long as the distance between neighbouring corpuscles is large compared with the linear dimensions of a corpuscle the mean free path will be independent of the way they are arranged, provided the number in unit volume remains constant, that is the mean free path will depend only on the density of the medium traversed by the corpuscles, and will be independent of its chemical nature and physical state: this from Lenard's very remarkable measurements of the absorption of the cathode rays by various media, must be a property possessed by the carriers of the charges in the cathode rays.

Thus on this view we have in the cathode rays matter in a new state, a state in which the subdivision of matter is carried very much further than in the ordinary gaseous state: a state in which all matter--that is, matter derived from different sources such as hydrogen, oxygen, &c.--is of one and the same kind; this matter being the substance from which all the chemical elements are built up.

With appliances of ordinary magnitude, the quantity of matter produced by means of the dissociation at the cathode is so small as to almost preclude the possibility of any direct chemical investigation of its properties. Thus the coil I used would, I calculate, if kept going uninterruptedly night and day for a year, produce only about one three-millionth part of a gramme of this substance.

The smallness of the value of m/e is, I think, due to the largeness of e as well as the smallness of m . There seems to me to be some evidence that the charges carried by the corpuscles in the atom are large compared with those carried by the ions of an electrolyte. In the molecule of HCl, for example, I picture the components of the hydrogen atoms as held together by a great number of tubes of electrostatic force; the components of the chlorine atom are similarly held together, while only one stray tube binds the hydrogen atom to the chlorine atom. The reason for attributing this high charge to the constituents of the atom is derived from the values of the specific inductive capacity of gases: we may imagine that the specific inductive capacity of a gas is due to the setting in the electric field of the electric doublet formed by the two oppositely electrified atoms which form the molecule of the gas. The measurements of the specific inductive capacity show, however, that this is very approximately an additive quantity: that is, that we can assign a certain value to each element, and find the specific inductive capacity of HCl by adding the value for hydrogen to the value for chlorine; the value of H_2O by

adding twice the value for hydrogen to the value for oxygen, and so on. Now the electrical moment of the doublet formed by a positive charge on one atom of the molecule and a negative charge on the other atom would not be an additive property; if, however, each atom had a definite electrical moment, and this were large compared with the electrical moment of the two atoms in the molecule, then the electrical moment of any compound, and hence its specific inductive capacity, would be an additive property. For the electrical moment of the atom, however, to be large compared with that of the molecule, the charge on the corpuscles would have to be very large compared with those on the ion.

If we regard the chemical atom as an aggregation of a number of primordial atoms, the problem of finding the configurations of stable equilibrium for a number of equal particles acting on each other according to some law of force--whether that of Boscovich, where the force between them is a repulsion when they are separated by less than a certain critical distance, and an attraction when they are separated by less than a certain critical distance, and an attraction when they are separated by a greater distance, or even the simpler case of a number of mutually repellent particles held together by a central force--is of great interest in connexion with the relation between the properties of an element and its atomic weight. Unfortunately the equations which determine the stability of such a collection of particles increase so rapidly in complexity with the number of particles that a general mathematical investigation is scarcely possible. We can, however, obtain a good deal of insight into the general laws which govern such configurations by the use of models, the simplest of which is the floating magnets of Professor Mayer. In this model the magnets arrange themselves in equilibrium under the mutual repulsions and a central attraction caused by the pole of a large magnet placed above the floating magnets.

A study of the forms taken by these magnets seems to me to be suggestive in relation to the periodic law. Mayer showed that when the number of floating magnets did not exceed 5 they arranged themselves at the corners of a regular polygon--5 at the corners of a pentagon, 4 at the corners of a square, and so on. When the number exceeds 5, however, this law no longer holds: thus 6 magnets do not arrange themselves at the corners of a hexagon, but divide into two systems, consisting of 1 in the middle surrounded by 5 at the corners of a pentagon. For 8 we have two in the inside and 6 outside; this arrangement in two systems, an inner and an outer, lasts up to 18 magnets. After this we have three systems: an inner, a middle, and an outer; for a still larger number of magnets we have four systems, and so on.

Mayer found the arrangement of magnets was as follows:--

1.	2.	3.	4.	5.
1.5	2.6	3.7	4.8	5.9
1.6	2.7	3.8	4.9	
1.7				
1.5.9	2.7.10	3.7.10	4.8.12	5.9.12
1.6.9	2.8.10	3.7.11	4.8.13	5.9.13
1.6.10	2.7.11	3.8.10	4.9.12	
1.6.11		3.8.11	4.9.13	
		3.8.12		
		3.8.13		
1.5.9.12	2.7.10.13	3.7.12.13	4.9.13.14	
1.6.9.13	2.7.12.14	3.7.12.14	4.9.13.15	
1.6.9.12		3.7.13.14	4.9.14.15	
1.6.10.12		3.7.13.15		
1.6.10.13				
1.6.11.12				
1.6.11.13				
1.6.11.14				
1.6.11.15				
1.7.12.14				

where, for example, 1.6.10.12 means an arrangement with one magnet in the middle, then a ring of six, then a ring of ten, and a ring of twelve outside.

Now suppose that a certain property is associated with two magnets forming a group by themselves; we should have this property with 2 magnets, again with 8 and 9, again with 19 and 20, and again with 34, 35, and so on. If we regard the system of magnets as a model of an atom, the number of magnets being proportional to the atomic weight, we should have this property occurring in elements of atomic weight 2, (8,9), 19, 20, (34, 35). Again, any property conferred by three magnets forming a system by themselves would occur with atomic weights 3, 10, and 11; 20, 21, 22, 23, and 24; 35, 36, 37 and 39; in fact, we should have something quite analogous to the periodic law, the first series corresponding to the arrangement of the magnets in a single group, the second series to the arrangement in two groups, the third series in three groups, and so on.

Velocity of the Cathode Rays.

The velocity of the cathode rays is variable, depending upon the potential-difference between the cathode and anode, which is a function of the pressure of the gas--the velocity increases as the exhaustion improves; the measurements given above show, however, that at all the pressures at which experiments were made the velocity exceeded 10^9 cm./sec. This velocity is much greater than the value of 2×10^8 which I previously obtained (Phil. Mag. Oct. 1894) by measuring directly the interval which separated the appearance

of luminosity at two places on the walls of the tube situated at different distances from the cathode.

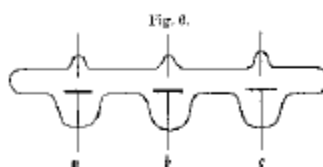
In my earlier experiments the pressure was higher than in the experiments described in this paper, so that the velocity of the cathode rays would on this account be less. The difference between the two results is, however, too great to be wholly explained in this way, and I attribute the difference to the glass requiring to be bombarded by the rays for a finite time before becoming phosphorescent, this time depending upon the intensity of the bombardment. As this time diminishes with the intensity of bombardment, the appearance of phosphorescence at the piece of glass most removed from the cathode would be delayed beyond the time taken for the rays to pass from one place to the other by the difference in time taken by the glass to become luminous; the apparent velocity measured in this way would thus be less than the true velocity. In the former experiments endeavours were made to diminish this effect by making the rays strike the glass at the greater distance from the cathode less obliquely than they struck the glass nearer to the cathode; the obliquity was adjusted until the brightness of the phosphorescence was approximately equal in the two cases. In view, however, of the discrepancy between the results obtained in this way and those obtained by the later method, I think that it was not successful in eliminating the lag caused by the finite time required by the gas to light up.

Experiments with Electrodes of Different Materials.

In the experiments described in this paper the electrodes were generally made of aluminium. Some experiments, however, were made with iron and platinum electrodes.

Though the value of m/e came out the same whatever the material of the electrode, the appearance of the discharge varied greatly; and as the measurements showed, the potential-difference between the cathode and anode depended greatly upon the metal used for the electrode; the pressure being the same in all cases.

To test this point further I used a tube like that shown in fig. 6, where a , b , c are cathodes made of different metals, the anodes being in all cases platinum wires. The cathodes were disks of aluminium, iron, lead, tin, copper, mercury, sodium amalgam, and silver chloride; the potential-difference between the cathode and anode was measured by Lord Kelvin's vertical voltmeter, and also by measuring the length of spark in air which, when placed in parallel with the anode and



cathode, seemed to allow the discharge to go as often through the spark-gap as through the tube. With this arrangement the pressures were the same for all the cathodes. The potential-difference between the anode and cathode and the equivalent spark-length depended greatly upon the nature of the cathode. The extent of the variation in potential may be estimated from the following table:-

Cathode. Mean Potential-Difference between Cathode and Anode.

Aluminium	1800 volts.
Lead	2100 "
Tin	2400 "
Copper	2600 "
Iron	2900 "

The potential-difference when the cathode was made of sodium amalgam or silver chloride was less even than that of aluminium.

The order of many of the metals changed about very capriciously, experiments made at intervals of a few minutes frequently giving quite different results. From the abrupt way in which these changes take place I am inclined to think that gas absorbed by the electrode has considerable influence on the passage of the discharge.

I have much pleasure in thanking Mr. Everitt for the assistance he has given me in the preceding investigation.

Cambridge, Aug. 7, 1897.

ANEXO 6 – Artigo J. J. Thomson. *Philosophical Magazine*, S6, 1904.

THE
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AND
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[SIXTH SERIES.]

MARCH 1904.

XXIV. *On the Structure of the Atom: an Investigation of the Stability and Periods of Oscillation of a number of Corpuscles arranged at equal intervals around the Circumference of a Circle; with Application of the results to the Theory of Atomic Structure.* By J. J. THOMSON, F.R.S., Cavendish Professor of Experimental Physics, Cambridge*.

THE view that the atoms consist of a number of negatively electrified corpuscles enclosed in a sphere of uniform positive electrification, suggests, among other interesting mathematical problems, the one discussed in this paper, that of the motion of a ring of n negatively electrified particles placed inside a uniformly electrified sphere. Suppose when in equilibrium the n corpuscles are arranged at equal angular intervals round the circumference of a circle of radius a , each corpuscle carrying a charge e of negative electricity. Let the charge of positive electricity contained within the sphere be ve , then if b is the radius of this sphere, the radial attraction on a corpuscle due to the positive electrification is equal to ve^2a/b^3 ; if the corpuscles are at rest this attraction must be balanced by the repulsion exerted by the other corpuscles. Now the repulsion along OA, O being the centre of the sphere, exerted on a corpuscle at A by one at B, is equal to $\frac{e^2}{AB^2} \cos OAB$, and, if $OA=OB$, this is equal to $\frac{e^2}{4OA^2 \sin^2 \frac{1}{2}AOB}$: hence, if we have n corpuscles arranged at equal angular intervals $2\pi/n$ round the circumference of a circle, the radial repulsion on one corpuscle

* Communicated by the Author.

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due to the other $(n-1)$ is equal to

$$\frac{e^2}{4a^2} \left(\operatorname{cosec} \frac{\pi}{n} + \operatorname{cosec} \frac{2\pi}{n} + \operatorname{cosec} \frac{3\pi}{n} + \dots + \operatorname{cosec} \frac{(n-1)\pi}{n} \right).$$

If the corpuscles are at rest this must be equal to the radial attraction. Hence, if

$$S_n = \operatorname{cosec} \frac{\pi}{n} + \operatorname{cosec} \frac{2\pi}{n} + \dots + \operatorname{cosec} \frac{(n-1)\pi}{n},$$

$$\frac{ve^2\alpha}{b^2} = \frac{e^2}{4a^2} S_n,$$

or
$$\frac{a^3}{b^3} = \frac{S_n}{4v} \dots \dots \dots (1)$$

The following are the values of S_n from $n=2$ to $n=6$.

$S_2=1$, $S_3=2.3094$, $S_4=3.8284$, $S_5=5.5056$, $S_6=7.3094$.

In the important case when $v=n$, i. e. when the positive charge on the sphere is equal to the sum of all the negative charges in the ring of corpuscles, we get by (1) the following values for a/b :—

n .	$\frac{a}{b}$.
2 1.5
3 1.5773
4 1.6208
5 1.6505
6 1.6726

If the ring of corpuscles, instead of being at rest, is rotating with an angular velocity ω , the condition for steady motion is

$$\frac{ve^2\alpha}{b^2} = m\omega^2 + \frac{e^2}{4a^2} S_n,$$

or
$$\frac{va^3}{b^2} = \frac{m}{e^2} \omega^2 + \frac{S_n}{4};$$

here m is the mass of a corpuscle.

We shall now proceed to find the forces acting on a corpuscle when the corpuscles are slightly displaced from their positions of equilibrium. Let the position of the corpuscles be fixed by the polar coordinates r and θ in the plane of the undisturbed orbit, and by the displacement z at right angles to this plane; let r_s, θ_s, z_s be the coordinates of the s th corpuscle; then, since the corpuscles are but slightly displaced from their positions of equilibrium, $r_s = a + \rho_s$, where ρ_s is small compared with a , z_s is also small compared with a , and $\theta_s - \theta_{s-1} = \frac{2\pi}{n} + \phi_s - \phi_{s-1}$, where n is the number of corpuscles and the ϕ 's are small quantities.

The radial repulsion exerted by the s th corpuscle on the p th is equal to

$$-e^2 \frac{d}{dr_p} \frac{1}{(r_p^2 + r_s^2 - 2r_p r_s \cos(\theta_s - \theta_p) + (z_p - z_s)^2)^{\frac{3}{2}}};$$

expanding this, retaining only the first powers of ρ , ϕ , and z , we find that if R_{ps} is this repulsion

$$R_{ps} = \frac{e^2}{4a^2 \sin \psi} \left\{ 1 - \frac{\rho_s}{a} \left(\frac{3}{2} - \frac{1}{2 \sin^2 \psi} \right) - \frac{\rho_s}{a} \left(\frac{1}{2} + \frac{1}{2 \sin^2 \psi} \right) - \frac{1}{2} (\phi_s - \phi_p) \cot \psi \right\},$$

where $\psi = (p-s) \frac{\pi}{n}$.

The tangential force Θ_{ps} tending to increase θ_p is equal to

$$- \frac{e^2}{r_p} \frac{d\theta_p}{dr_p} \frac{1}{(r_p^2 + r_s^2 - 2r_p r_s \cos(\theta_s - \theta_p) + (z_p - z_s)^2)^{\frac{3}{2}}};$$

expanding this and retaining only the first powers of the small quantities, we get

$$\Theta_{ps} = - \frac{e^2 \cos \psi}{4a^2 \sin^2 \psi} \left\{ 1 - \frac{3}{2} \frac{\rho_p}{a} - \frac{1}{2} \frac{\rho_s}{a} - (\phi_s - \phi_p) (\cot \psi + \frac{1}{2} \tan \psi) \right\}.$$

Z_{ps} , the force at right angles to the undisturbed plane of the orbit, is easily seen to be given by the equation

$$Z_{ps} = \frac{e^2}{8a^2 \sin^3 \psi} (z_p - z_s).$$

The total radial force R_p exerted on the p th corpuscle by all the other corpuscles, is equal to

$$\frac{e^2}{4a^2} S - \rho_p A' - \sum \rho_{p+s} A_{p,p+s} - a \sum \phi_{p+s} B_{p,p+s},$$

where $S = \frac{1}{\sin \frac{\pi}{n}} + \frac{1}{\sin \frac{2\pi}{n}} + \dots + \frac{1}{\sin \frac{(n-1)\pi}{n}}$;

$$A' = \frac{e^2}{4a^2} \left(\frac{3}{2} \left(\frac{1}{\sin \frac{\pi}{n}} + \frac{1}{\sin \frac{2\pi}{n}} + \dots + \frac{1}{\sin \frac{(n-1)\pi}{n}} \right) - \frac{1}{2} \left(\frac{1}{\sin^2 \frac{\pi}{n}} + \frac{1}{\sin^2 \frac{2\pi}{n}} + \dots + \frac{1}{\sin^2 \frac{(n-1)\pi}{n}} \right) \right);$$

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$$A_{p,p+s} = \frac{e^2}{8a^3} \left(\frac{1}{\sin \frac{s\pi}{n}} + \frac{1}{\sin^2 \frac{s\pi}{n}} \right);$$

$$B_{p,p+s} = \frac{e^2}{8a^2} \frac{\cos \frac{s\pi}{n}}{\sin^2 \frac{s\pi}{n}}.$$

The coefficient of ϕ_p in the expression for R_p vanishes, since

$$\sum \frac{\cos \frac{s\pi}{n}}{\sin^2 \frac{s\pi}{n}} = 0.$$

As $A_{p,p+s}$ $B_{p,p+s}$ do not involve p , it is more convenient to use the symbols A_s and B_s for these quantities, and to write

$$R_p = \frac{e^2}{4a^2} S - \rho_p A' - \sum \rho_{p+s} A_s - a \sum \phi_{p+s} B_s.$$

The tangential force Θ_p acting on the p 'th particle may similarly be written

$$\Theta_p = \sum \rho_{p+s} B_s - a \phi_p C + a \sum \phi_{p+s} C_s$$

where

$$C = \frac{e^2}{4a^3} \left(\frac{\cos \frac{\pi}{n}}{\sin^2 \frac{\pi}{n}} \left(\cot \frac{\pi}{n} + \frac{1}{2} \tan \frac{\pi}{n} \right) + \frac{\cos \frac{2\pi}{n}}{\sin^2 \frac{2\pi}{n}} \left(\cot \frac{2\pi}{n} + \frac{1}{2} \tan \frac{2\pi}{n} \right) + \dots \right),$$

$$C_s = \frac{e^2}{4a^3} \frac{\cos \frac{s\pi}{n}}{\sin^2 \frac{s\pi}{n}} \left(\cot \frac{s\pi}{n} + \frac{1}{2} \tan \frac{s\pi}{n} \right);$$

while Z_p , the force at right angles to the plane of the orbit, is given by the equation

$$Z_p = z_p D - \sum z_{p+s} D_s$$

where

$$D = \frac{e^2}{8a^3} \left(\frac{1}{\sin^2 \frac{\pi}{n}} + \frac{1}{\sin^2 \frac{2\pi}{n}} + \dots + \frac{1}{\sin^2 \frac{(n-1)\pi}{n}} \right),$$

and

$$D_s = \frac{e^2}{8a^3} \frac{1}{\sin^2 \frac{s\pi}{n}}.$$

The equations of motion of the p th corpuscle are

$$m \left(\frac{d^2 r_p}{dt^2} - r_p \left(\frac{d\theta_p}{dt} \right)^2 \right) = - \frac{v^2 r_p}{b^3} + R_p; \dots (\alpha)$$

$$m \left(r_p \frac{d^2 \theta_p}{dt^2} + 2 \frac{dr_p}{dt} \frac{d\theta_p}{dt} \right) = \Theta_p; \dots (\beta)$$

$$m \frac{d^2 z_p}{dt^2} = - \frac{v^2 z_p}{b^3} + Z_p \dots (\gamma)$$

Retaining only the first powers of small quantities, we get from these equations, if ω is the value of $\frac{d\theta}{dt}$ when the motion is steady,

$$\frac{v^2 a}{l^3} = m a \omega^2 + \frac{e^2}{4a^2} S,$$

$$m \frac{d^2 \rho_p}{dt^2} - 2 m a \omega \frac{d\theta_p}{dt} = \rho_p \left(m \omega^2 - \frac{v^2}{b^3} \right) + R_p - \frac{e^2}{4a^2} S.$$

If ρ_p and θ_p vary as $e^{i p t}$, this equation may be written

$$(A - m q^2) \rho_p + A_1 \rho_{p+1} + A_2 \rho_{p+2} + \dots - 2 m a \omega q \phi_p + a B_1 \phi_{p+1} + a B_2 \phi_{p+2} + \dots = 0,$$

where

$$A = \frac{e^2}{4a^2} S + A' = \frac{e^2}{8a^2} \left\{ \tilde{\delta} \left(\frac{1}{\sin \frac{\pi}{n}} + \frac{1}{\sin \frac{2\pi}{n}} + \dots \right) - \left(\frac{1}{\sin^2 \frac{\pi}{n}} + \frac{1}{\sin^2 \frac{2\pi}{n}} + \dots \right) \right\}$$

Writing 1, 2, 3 for p we get

$$\left. \begin{aligned} (A - m q^2) \rho_1 + A_1 \rho_2 + A_2 \rho_3 + \dots + A_{n-1} \rho_n - 2 m a \omega q \phi_1 + a B_1 \phi_2 + a B_2 \phi_3 + \dots &= 0 \\ (A - m q^2) \rho_2 + A_1 \rho_3 + A_2 \rho_4 + \dots - 2 m a \omega q \phi_2 + a B_1 \phi_3 + a B_2 \phi_4 + \dots &= 0 \\ \dots & \dots \\ (A - m q^2) \rho_n + A_1 \rho_1 + A_2 \rho_2 + \dots - 2 m a \omega q \phi_n + a B_1 \phi_1 + a B_2 \phi_2 + \dots &= 0 \end{aligned} \right\} (A)$$

By equation β we have

$$2 m a \omega q \frac{\rho_p}{a} - B_1 \frac{\rho_{p+1}}{a} - B_2 \frac{\rho_{p+2}}{a} + \dots (C - m q^2) \phi_p - C_1 \phi_{p+1} - C_2 \phi_{p+2} - \dots = 0.$$

Writing 1, 2, 3 in succession for p we get

$$\left. \begin{aligned} 2 m a \omega q \frac{\rho_1}{a} - B_1 \frac{\rho_2}{a} - B_2 \frac{\rho_3}{a} \dots + (C - m q^2) \phi_1 - C_1 \phi_2 - C_2 \phi_3 - \dots &= 0 \\ 2 m a \omega q \frac{\rho_2}{a} - B_1 \frac{\rho_3}{a} - B_2 \frac{\rho_4}{a} \dots + (C - m q^2) \phi_2 - C_2 \phi_3 - C_3 \phi_4 - \dots &= 0 \\ \dots & \dots \\ 2 m a \omega q \frac{\rho_n}{a} - B_1 \frac{\rho_1}{a} - B_2 \frac{\rho_2}{a} \dots + (C - m q^2) \phi_n - C_1 \phi_1 - C_2 \phi_2 - \dots &= 0 \end{aligned} \right\} (B)$$

To solve equations A and B we notice that if ω be any root of the equation $x^n=1$, i. e. if ω be one of the n th roots of unity, equations A will be satisfied by

$\rho_2 = \omega\rho_1, \rho_3 = \omega^2\rho_1, \rho_4 = \omega^3\rho_1 \dots \phi_2 = \omega\phi_1, \phi_3 = \omega^2\phi_1, \phi_4 = \omega^3\phi_1 \dots$ provided

$$\rho_1(A - m\omega^2 + \omega A_1 + \omega^2 A_2 + \dots + \omega^{n-1} A_{n-1}) + \phi_1 a(-2im\omega\omega^2 + \omega B_1 + \omega^2 B_2 + \omega^{n-1} B_{n-1}) = 0; \quad (1)$$

while equations B will be satisfied by the same values provided

$$\rho_1(2im\omega\omega^2 - \omega B_1 - \omega^2 B_2 - \omega^{n-1} B_{n-1}) + \phi_1 a(C - m\omega^2 - \omega C_1 - \omega^2 C_2 - \omega^{n-1} C_{n-1}) = 0. \quad (2)$$

Hence, if both sets of equations are satisfied by these values, we have, eliminating ρ_1 and ϕ_1 from (1) and (2),

$$\begin{aligned} & ((A - m\omega^2) + \omega A_1 + \omega^2 A_2 + \dots + \omega^{n-1} A_{n-1}) \\ & (C - m\omega^2 - \omega C_1 - \omega^2 C_2 - \omega^{n-1} C_{n-1}) \\ & = -(-2im\omega\omega^2 + \omega B_1 + \omega^2 B_2 + \dots + \omega^{n-1} B_{n-1})^2, \quad (1) \end{aligned}$$

a biquadratic equation to determine g the frequency of the oscillations of the system. Now ω is of the form

$$\cos \frac{2k\pi}{n} + i \sin \frac{2k\pi}{n},$$

where k is an integer between 0 and $n-1$. Substituting this value for ω , we find

$$\begin{aligned} \omega A_1 + \omega^2 A_2 + \omega^{n-1} A_{n-1} &= \frac{e^2}{8a^2} \left\{ \cos \frac{2k\pi}{n} \left(\frac{1}{\sin \frac{\pi}{n}} + \frac{1}{\sin^3 \frac{\pi}{n}} \right) \right. \\ & \dots \dots \dots \\ & \left. + \cos \frac{4k\pi}{n} \left(\frac{1}{\sin \frac{2\pi}{n}} + \frac{1}{\sin^3 \frac{2\pi}{n}} \right) + \cos \frac{6k\pi}{n} \left(\frac{1}{\sin \frac{3\pi}{n}} + \frac{1}{\sin^3 \frac{3\pi}{n}} \right) + \dots \right\} \end{aligned}$$

We shall denote this by L_k ; it will be noticed that L_k contains no imaginary terms. We find also that

$$\begin{aligned} \omega C_1 + \omega^2 C_2 + \omega^3 C_3 + \omega^{n-1} C_{n-1} &= \frac{e^2}{4a^2} \left(\cos \frac{2k\pi}{n} \frac{\cos \frac{\pi}{n}}{\sin^2 \frac{\pi}{n}} \left(\cot \frac{\pi}{n} + \frac{1}{2} \tan \frac{\pi}{n} \right) \right. \\ & \dots \dots \dots \\ & \left. + \cos \frac{4k\pi}{n} \frac{\cos \frac{2\pi}{n}}{\sin^2 \frac{2\pi}{n}} \left(\cot \frac{2\pi}{n} + \frac{1}{2} \tan \frac{2\pi}{n} \right) \right. \\ & \left. + \dots \right). \end{aligned}$$

We shall denote this by N_k .

Again,

$$\begin{aligned} \omega B_1 + \omega^2 B_2 + \omega^{n-1} B_{n-1} &= \frac{t \cdot e^2}{8a^3} \left(\sin \frac{2k\pi}{n} \frac{\cos \frac{\pi}{n}}{\sin^2 \frac{\pi}{n}} + \sin \frac{4k\pi}{n} \frac{\cos \frac{2\pi}{n}}{\sin^2 \frac{2\pi}{n}} \right. \\ &\quad \left. + \sin \frac{6k\pi}{n} \frac{\cos \frac{3\pi}{n}}{\sin^2 \frac{3\pi}{n}} + \dots \right) \\ &= M_k, \text{ say.} \end{aligned}$$

Substituting these values, equation (1) becomes

$$(A - mg^2) + L_k)(C - mq^2 - N_k) = (M_k - 2m\omega g)^2. \quad (2)$$

From the value of C given on p. 240 we see that C is the value of N_k when $k=0$, and so may be denoted by N_0 , and that $A = \frac{3}{4} \frac{e^2}{a^2} S - L_0$; hence equation (2) may be written

$$\left(\frac{3}{4} \frac{e^2}{a^2} S + L_k - L_0 - mg^2 \right) (N_0 - N_k - mq^2) = (M_k - 2m\omega g)^2. \quad (3)$$

k in this equation may have any value from 0 to $(n-1)$; but we see that if we write $n-k$ for k , the values of g given by the two equations differ only in sign, and so give the same frequencies; thus all the values of g can be got by putting $k=0, 1, \dots, \frac{n-1}{2}$, if n be odd, or $k=0, 1, \frac{n}{2}$ if n be even; thus if n be odd there are $\frac{n+1}{2}$ equations of the type (3). When $k=0$, $M_k=0$, and (3) reduces to a quadratic equation; so that the number of roots of these $\frac{n+1}{2}$ equations is $4 \times \frac{n+1}{2} - 2 = 2n$; if n be even there are $\frac{n}{2} + 1$ equations; but as $M_k=0$ when $k=0$ and $k=\frac{n}{2}$, two of these reduce to quadratics; so that the number of roots of these equations is $4 \left(\frac{n}{2} + 1 \right) - 4 = 2n$. Thus in each case the number of roots is equal to $2n$, the number of degrees of freedom of the corpuscles in the plane of their undisturbed orbit.

Let us now consider the motion at right angles to this plane. By equation 7 we have

$$m \frac{d^2 z_p}{dt^2} = - \frac{v_0^2}{l^2} z_p + D z_p - \Sigma D_k z_{p+k};$$

$$T_k = \sum_1^{n-1} \cos \frac{2ks\pi}{n} \frac{1}{\sin^2 \frac{s\pi}{n}},$$

$$U_k = \sum_1^{n-1} \sin \frac{2ks\pi}{n} \frac{\cos \frac{s\pi}{n}}{\sin^2 \frac{s\pi}{n}};$$

for we have

$$L_k = (S_k + T_k) \frac{e^2}{8a^3}, \quad N_k = (2T_k - S_k) \frac{e^2}{8a^3},$$

$$M_k = U_k \frac{e^2}{8a^3}, \quad P_k = T_k \frac{e^2}{8a^3}.$$

Case of two corpuscles.

When $n=2$ we have

$$L_0 = \frac{2e^2}{8a^3}, \quad M_0 = 0, \quad N_0 = \frac{e^2}{8a^3}, \quad P_0 = \frac{e^2}{8a^3},$$

$$L_1 = -\frac{2e^2}{8a^3}, \quad M_1 = 0, \quad N_1 = -\frac{e^2}{8a^3}, \quad P_1 = -\frac{e^2}{8a^3}.$$

Hence for vibrations in the plane of the orbit we have, when $k=0$,

$$\left(\frac{3}{4} \frac{e^2}{a^3} - mq^2\right)(-mq^2) = 4m^2\omega^2q^2;$$

the roots of this equation are

$$q=0, \quad q = \sqrt{\frac{3}{4} \frac{e^2}{ma^3} + 4\omega^2} = \sqrt{\frac{3ve^2}{mb^3} + \omega^2}.$$

When $k=1$, the frequency equation is

$$\left(\frac{1}{4} \frac{e^2}{a^3} - mq^2\right)^2 = 4m^2\omega^2q^2;$$

the roots of this equation are

$$q = \omega \pm \sqrt{\frac{1}{4} \frac{e^2}{ma^3} + \omega^2} = \omega \pm \sqrt{\frac{ve^2}{mb^3}}$$

and

$$q = -\omega \pm \sqrt{\frac{1}{4} \frac{e^2}{ma^3} + \omega^2} = -\omega \pm \sqrt{\frac{ve^2}{mb^3}},$$

the second set of values only differing in sign from the first.

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For the vibrations perpendicular to the plane of the orbit, we have for $k=0$,

$$q = \sqrt{\frac{ve^2}{mb^3}}$$

for $k=1$,

$$q = \sqrt{\frac{ve^2}{mb^3} - \frac{e^2}{4ma^3}} = \omega.$$

Thus the six frequencies corresponding to the six degrees of freedom of the two corpuscles are

$$0, \omega, \sqrt{\frac{ve^2}{mb^3}}, \sqrt{\frac{ve^2}{mb^3}} - \omega, \sqrt{\frac{ve^2}{mb^3}} + \omega, \sqrt{\frac{3ve^2}{mb^3} + \omega^2}.$$

When the corpuscles are not rotating round the circle, two of these roots are zero, three equal to $\sqrt{\frac{ve^2}{mb^3}}$ and the sixth equal to $\sqrt{\frac{3ve^2}{mb^3}}$. Thus the effect of rotation on the triple frequency $\sqrt{\frac{ve^2}{mb^3}}$ is to separate the roots, one remaining unaltered, one increasing, and the other diminishing.

Case of three corpuscles.

When $n=3$.

$$\begin{aligned} S_0 &= \frac{4}{\sqrt{3}}, & T_0 &= \frac{16}{3\sqrt{3}}, & U_0 &= 0, & L_0 &= \frac{28}{3\sqrt{3}} \frac{e^2}{8a^3}, \\ N_0 &= \frac{20}{3\sqrt{3}} \frac{e^2}{8a^3}, & M_0 &= 0, & P_0 &= \frac{16}{3\sqrt{3}} \frac{e^2}{8a^3}, \\ S_1 &= -\frac{2}{\sqrt{3}}, & T_1 &= -\frac{8}{3\sqrt{3}}, & U_1 &= \frac{2}{\sqrt{3}}, & L_1 &= -\frac{14}{3\sqrt{3}} \frac{e^2}{8a^3}, \\ N_1 &= -\frac{10}{3\sqrt{3}} \frac{e^2}{8a^3}, & M_1 &= \frac{2}{\sqrt{3}} \frac{e^2}{8a^3}, & P_1 &= -\frac{8}{3\sqrt{3}} \frac{e^2}{8a^3}, \\ S_2 &= S_0, & T_2 &= T_0, & U_2 &= -U_0, & L_2 &= L_0, & N_2 &= N_0, \\ & & M_2 &= -M_0, & P_2 &= P_0. \end{aligned}$$

For the vibrations in the plane of the orbit, when $k=0$, the frequency equation is

$$\left(\sqrt{3} \frac{e^2}{a^3} - mg^2\right)(-mj^2) = 4m^2 \omega^2 j^2;$$

the solution of this is

$$q=0 \text{ and } q = \left\{ \sqrt{3} \frac{e^2}{ma^3} + 4\omega^2 \right\}^{\frac{1}{2}} = \left\{ \frac{3ve^2}{mb^3} + \omega^2 \right\}^{\frac{1}{2}}.$$

When $k=1$, the frequency equation is

$$\left(\frac{5}{4\sqrt{3}} \frac{e^2}{a^3} - m\omega^2\right)^2 = \left(\frac{2}{\sqrt{3}} \frac{e^2}{8a^3} - 2m\omega\eta\right)^2.$$

The solution of this equation is

$$q = \omega \pm \sqrt{\frac{1}{\sqrt{3}} \frac{e^2}{ma^3} + \omega^2} = \omega \pm \sqrt{\frac{ve^2}{mb^3}},$$

$$q = -\omega \pm \sqrt{\frac{\sqrt{3}}{2} \frac{e^2}{ma^3} + \omega^2} = -\omega \pm \sqrt{\frac{3}{2} \frac{ve^2}{mb^3} - \frac{1}{2}\omega^2}.$$

When $k=2$ the frequencies are the same as when $k=1$; we have thus six frequencies corresponding to the six degrees of freedom of the three corpuscles in the plane of their undisturbed orbit.

For the vibration at right angles to the plane of this orbit, when $k=0$ the frequency equation is

$$\frac{ve^2}{b^3} - m\omega^2 = 0,$$

or

$$q = \sqrt{\frac{ve^2}{mb^3}}.$$

When $k=1$, the frequency equation is

$$\frac{ve^2}{b^3} - \frac{e^2}{\sqrt{3}a^3} - m\omega^2 = 0,$$

or

$$q = \pm \omega.$$

In the case of three corpuscles, as in that of two, we see that when there is no rotation three of the periods are equal; these are separated when the corpuscles are in rotation.

Case of four corpuscles.

When $n=4$,

$$S_0 = 1 + 2\sqrt{2}, \quad T_0 = 4\sqrt{2} + 1, \quad U_0 = 0, \quad L_0 = (6\sqrt{2} + 2) \frac{e^2}{8a^3},$$

$$N_0 = (6\sqrt{2} + 1) \frac{e^2}{8a^3}, \quad M_0 = 0, \quad P_0 = (4\sqrt{2} + 1) \frac{e^2}{8a^3},$$

$$S_1 = -1, \quad T_1 = -1, \quad U_1 = 2\sqrt{2}, \quad L_1 = -2 \frac{e^2}{8a^3},$$

$$N_1 = -\frac{e^2}{8a^3}, \quad M_1 = 2\sqrt{2} \frac{e^2}{8a^3}, \quad P_1 = -\frac{e^2}{8a^3},$$

$$S_2 = -2\sqrt{2} + 1, \quad T_2 = -4\sqrt{2} + 1, \quad U_2 = 0, \quad L_2 = (-6\sqrt{2} + 2) \frac{e^2}{8a^3},$$

$$N_2 = (-6\sqrt{2} + 1) \frac{e^2}{8a^3}, \quad M_2 = 0, \quad P_2 = (-4\sqrt{2} + 1) \frac{e^2}{8a^3}.$$

When $k=0$, the frequency equation is

$$\left(\frac{3}{4} \frac{e^2}{a^3} (1+2\sqrt{2}) - mq^2\right) (-mq^2) = 4m^2\omega^2 q^2;$$

the solution of which is

$$q=0, \quad q = \sqrt{\frac{3}{4} \frac{e^2}{a^3} (1+2\sqrt{2}) + 4\omega^2} = \sqrt{\frac{3ve^2}{mb^3} + \omega^2}.$$

When $k=1$, the frequency equation is

$$\left((6\sqrt{2}+2) \frac{e^2}{8a^3} - mq^2\right)^2 = \left(2\sqrt{2} \frac{e^2}{8a^3} - 2m\omega q\right)^2;$$

the solution of this is

$$q = \omega \pm \sqrt{\frac{2\sqrt{2}+1}{4} \frac{e^2}{ma^3} + \omega^2} = \omega \pm \sqrt{\frac{ve^2}{mb^3}},$$

$$q = -\omega \pm \sqrt{\frac{4\sqrt{2}+1}{4} \frac{e^2}{ma^3} + \omega^2} = -\omega \pm \sqrt{\frac{4\sqrt{2}+1}{2\sqrt{2}+1} \frac{ve^2}{mb^3} - \frac{2\sqrt{2}\omega^2}{2\sqrt{2}+1}}.$$

When $k=2$, the frequency equation is

$$\left(\frac{3}{4} \frac{e^2}{a^3} - mq^2\right) \left(\frac{3}{\sqrt{2}} \frac{e^2}{a^3} - mq^2\right) = 4m^2\omega^2 q^2.$$

Regarding this as a quadratic in q^2 , we see that the roots are positive, so that the values of q are real and the arrangement is stable. The roots of the equation are

$$q^2 = \frac{3}{8\sqrt{2}} (4 + \sqrt{2}) \frac{e^2}{ma^3} + 2\omega^2 \\ \pm \sqrt{\frac{9(4-\sqrt{2})^2}{128} \frac{e^4}{m^2a^6} + \frac{3(\sqrt{2}+4)}{2\sqrt{2}} \frac{e^2}{ma^3} \omega^2 + 4\omega^4}.$$

Let us now consider the motion at right angles to the plane of the orbit. When $k=0$, the frequency equation is

$$\frac{ve^2}{b^3} - mq^2 = 0,$$

or

$$q = \sqrt{\frac{ve^2}{mb^3}}.$$

When $k=1$, the frequency equation is

$$\frac{ve^2}{b^3} - (\frac{1}{2}\sqrt{2}+2) \frac{e^2}{8a^3} - mq^2 = 0,$$

or

$$q = \pm \omega.$$

When $k=2$, the frequency equation is

$$\frac{ve^2}{b^3} - \frac{8\sqrt{2}e^2}{8a^3} - m\omega^2 = 0,$$

or
$$y^2 = \frac{8\sqrt{2}}{4\sqrt{2}+2} \omega^2 - \frac{(4\sqrt{2}-2)}{4\sqrt{2}+2} \frac{ve^2}{mb^3}.$$

Thus, unless

$$\omega^2 > \frac{4\sqrt{2}-2}{8\sqrt{2}} \frac{ve^2}{mb^3} > 325 \frac{ve^2}{mb^3}, \quad \dots (1)$$

q^2 is negative, and the equilibrium is unstable, the four corpuscles then arranging themselves at the corner of a regular tetrahedron. When, however, ω is large enough to satisfy condition (1), four corpuscles will be in equilibrium when in steady motion in one plane at the corners of a square.

Case of five corpuscles.

When $n=5$, we have

$$S_0 = 5 \cdot 5056, \quad T_0 = 12 \cdot 1732, \quad U_0 = 0, \quad L_0 = \frac{e^2}{8a^3} (17 \cdot 6788),$$

$$N_0 = \frac{e^2}{8a^3} (18 \cdot 8408), \quad M_0 = 0, \quad P_0 = \frac{e^2}{8a^3} (12 \cdot 1732),$$

$$S_1 = -0 \cdot 65, \quad T_1 = 1 \cdot 1609, \quad U_1 = 4 \cdot 856, \quad L_1 = \frac{e^2}{8a^3} (511),$$

$$N_1 = \frac{e^2}{8a^3} (2 \cdot 9716), \quad M_1 = \frac{e^2}{8a^3} 4 \cdot 856, \quad P_1 = \frac{e^2}{8a^3} (1 \cdot 1609),$$

$$S_2 = -2 \cdot 103, \quad T_2 = -7 \cdot 249, \quad U_2 = 2 \cdot 103, \quad L_2 = -\frac{e^2}{8a^3} (9 \cdot 352),$$

$$N_2 = -\frac{e^2}{8a^3} 12 \cdot 4, \quad M_2 = \frac{e^2}{8a^3} 2 \cdot 103, \quad P_2 = -\frac{e^2}{8a^3} 7 \cdot 249.$$

The frequency equation when $k=0$ is

$$\left(\frac{3}{4} 5 \cdot 5056 \frac{e^2}{a^3} - m\omega^2 \right) (-m\omega^2) = 4m^2 \omega^6 y^2,$$

the solution of which is

$$y = 0, \quad y = \sqrt{\frac{3ve}{b^3} + \omega^2}.$$

When $k=1$, the frequency equation is

$$\left(15 \cdot 87 \frac{e^2}{8a^3} - m\omega^2 \right)^2 = \left(\frac{e^2}{8a^3} 4 \cdot 856 - 2m\omega y \right)^2,$$

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or

$$q = \omega \pm \sqrt{10 \cdot 918 \frac{e^2}{8a^3} + \omega^2} = \omega \pm \sqrt{\frac{ve^2}{mb^3}},$$

$$q = -\omega \pm \sqrt{20 \cdot 726 \frac{e^2}{8a^3} + \omega^2}.$$

When $k=2$,

$$\left(6 \frac{e^2}{8a^3} - mg^2\right) \left(31 \cdot 24 \frac{e^2}{8a^3} - mg^2\right) = \left(2 \cdot 103 \frac{e^2}{8a^3} - 2m\omega q\right)^2.$$

By applying the usual methods we find that all the roots of this equation are real, so that the steady motion of the five particles is stable for displacements in the plane of the orbit.

Let us now consider displacements at right angles to the plane of the orbit. When $k=0$ the frequency equation is

$$\frac{ve^2}{b^3} - mg^2 = 0,$$

the solution of which is

$$q = \sqrt{\frac{ve^2}{mb^3}}.$$

When $k=1$, the frequency equation is

$$m\omega^2 - mg^2 = 0,$$

hence

$$q = \omega.$$

When $k=2$, the frequency equation is

$$\frac{ve^2}{b^3} - 19 \cdot 42 \frac{e^2}{8a^3} - mg^2 = 0,$$

or

$$\frac{19 \cdot 42}{11} m\omega^2 + \frac{ve^2}{b^3} - \frac{19 \cdot 42}{11} \frac{ve^2}{b^3} - mg^2 = 0,$$

$$\frac{19 \cdot 42}{11} m\omega^2 - \frac{8 \cdot 42}{11} \frac{ve^2}{b^3} - mg^2 = 0.$$

Hence, in order that the equilibrium may be stable,

$$\omega^2 \text{ must be } > \frac{8 \cdot 42}{19 \cdot 42} \frac{ve^2}{b^3} > \cdot 433 \frac{ve^2}{mb^3}.$$

Thus the five corpuscles are unstable when in one plane unless the angular velocity exceeds a certain value; the arrangement is stable, however, when the angular velocity is large.

Case of six corpuscles.

When $n=6$,

$$\begin{aligned} S_0 &= 5 + \frac{4}{\sqrt{3}}, T_0 = 17 + \frac{16}{3\sqrt{3}}, U_0 = 0, L_0 = \left(22 + \frac{28}{3\sqrt{3}}\right) \frac{e^2}{8a^2}, \\ N_0 &= \left(29 + \frac{20}{3\sqrt{3}}\right) \frac{e^2}{8a^2}, M_0 = 0, P_0 = \left(17 + \frac{16}{3\sqrt{3}}\right) \frac{e^2}{8a^2}, \\ S_1 &= 1 - \frac{2}{\sqrt{3}}, T_1 = 7 - \frac{8}{3\sqrt{3}}, U_1 = 6 + \frac{2}{\sqrt{3}}, L_1 = \left(8 - \frac{14}{3\sqrt{3}}\right) \frac{e^2}{8a^2}, \\ N_1 &= \left(13 - \frac{10}{3\sqrt{3}}\right) \frac{e^2}{8a^2}, M_1 = \left(7 - \frac{8}{3\sqrt{3}}\right) \frac{e^2}{8a^2}, P_1 = \left(7 - \frac{8}{3\sqrt{3}}\right) \frac{e^2}{8a^2}, \\ S_2 &= -1 - \frac{2}{\sqrt{3}}, T_2 = -7 - \frac{8}{3\sqrt{3}}, U_2 = 6 - \frac{2}{\sqrt{3}}, L_2 = \left(-8 - \frac{14}{3\sqrt{3}}\right) \frac{e^2}{8a^2}, \\ N_2 &= \left(-13 - \frac{10}{3\sqrt{3}}\right) \frac{e^2}{8a^2}, M_2 = \left(6 - \frac{2}{\sqrt{3}}\right) \frac{e^2}{8a^2}, P_2 = \left(-7 - \frac{8}{3\sqrt{3}}\right) \frac{e^2}{8a^2}, \\ S_3 &= -5 + \frac{4}{\sqrt{3}}, T_3 = -17 + \frac{16}{3\sqrt{3}}, U_3 = 0, L_3 = \left(-22 + \frac{28}{3\sqrt{3}}\right) \frac{e^2}{8a^2}, \\ N_3 &= \left(-29 + \frac{20}{3\sqrt{3}}\right) \frac{e^2}{8a^2}, M_3 = 0, P_3 = \left(-17 + \frac{16}{3\sqrt{3}}\right) \frac{e^2}{8a^2}. \end{aligned}$$

It is not necessary to write down all the frequency equations because, as we shall show, the arrangement of six corpuscles is unstable. For when $k=3$ the frequency equation is

$$\begin{aligned} &\left(\frac{6}{8} \left(5 + \frac{4}{\sqrt{3}}\right) \frac{e^2}{8a^2} - 44 \frac{e^2}{8a^2} - mg^2\right) \left(58 \frac{e^2}{8a^2} - mg^2\right) = 4m^2\omega^2q^2, \\ \text{or} \quad &\left(-\frac{(14 - 8\sqrt{3})e^2}{8} - mg^2\right) \left(58 \frac{e^2}{8a^2} - mg^2\right) = 4m^2\omega^2q^2. \quad (1) \end{aligned}$$

As $14 - 8\sqrt{3}$ is positive, we see that one of the roots of this equation for q^2 is negative, so that q is imaginary; this shows that the steady motion of 6 corpuscles in a ring is unstable, however rapid the rotation. We can, however, make the motion stable by putting a corpuscle at the centre; if we have a negative charge equal to that of p corpuscles at the centre of the ring the radial force it exerts on the s th corpuscle is $\frac{pe^2}{(a+\rho)^2}$, or $\frac{pe^2}{a^2} - \frac{2pe^2\rho}{a^3}$. Introducing this term into the expression for the radial force we find the frequency

equation becomes

$$\left(\frac{3}{4} \frac{e^2}{a^2} S_0 + \frac{3pe^2}{a^2} + I_0 - L_0 - m\dot{q}^2\right)(N_0 - N_k - m\dot{q}^2) = (M_k - 2m\omega\dot{q})^2.$$

Using this frequency equation, and supposing that $p=1$, i. e. that there is only one corpuscle at the centre of the hexagon, we get instead of (1),

$$\left(\frac{10 + 8\sqrt{3}}{8} \frac{e^2}{a^2} - m\dot{q}^2\right) \left(\frac{58}{8a^2} e^2 - m\dot{q}^2\right) = 4m^2\omega^2\dot{q}^2. \quad (2)$$

The roots of this equation in \dot{q}^2 are both positive, so that q is real and the equilibrium is stable.

Let us now investigate the conditions for stability for displacements at right angles to the plane of the orbit.

For the motion at right angles to the plane of the ring, the frequency equation when $k=3$ is

$$\frac{ve^2}{b^2} - \frac{pe^2}{a^2} - \frac{34}{8a^2} e^2 - m\dot{q}^2 = 0.$$

For this to represent the displacement of a stable system \dot{q}^2 must be positive, so that if $p=1$

$$\frac{ve^2}{b^2} - \frac{e^2}{a^2} - \frac{34}{8a^2} e^2$$

must be positive; we have, however,

$$\frac{ve^2}{b^2} = m\omega^2 + \frac{e^2}{a^2} + \frac{e^2}{4a^2} \left(5 + \frac{4}{\sqrt{3}}\right);$$

so that for

$$\frac{ve^2}{b^2} - \frac{e^2}{a^2} - \frac{34}{8a^2} e^2$$

to be positive

$$m\omega^2 \text{ must be greater than } \frac{12 - 4/\sqrt{3}}{21} \frac{ve^2}{b^2}, \text{ i. e. } \cdot 46 \frac{ve^2}{b^2}.$$

Let us now consider the stability of the corpuscle at the centre of the ring: if it is displaced through a distance z at right angles to the ring, the equation of motion of the corpuscles is

$$m \frac{d^2z}{dt^2} = - \frac{ve^2}{b^2} z + \frac{6e^2}{a^3} z.$$

Thus if the motion is stable

$$\frac{ve^2}{b^2} > \frac{6e^2}{a^3},$$

or
$$m\omega^2 > \frac{15-4\sqrt{3}}{24} \frac{ve^2}{b^2}, \text{ i. e. } .53 \frac{ve^2}{b^2}.$$

This value of ω^2 is greater than that required to make the equilibrium of the ring stable for displacements at right angles to its plane; if the central corpuscle, instead of being in the plane of the ring, was one side of the centre of the sphere of positive electrification while the ring was on the other side, the rotation required to make the equilibrium of the detached corpuscle stable would be less than when it was in the plane of the ring; for equilibrium the distance of the detached corpuscle from the centre of the sphere must be six times the distance of the plane of the ring from that point.

Conditions for the stability of rings containing more than six corpuscles.

I find that a single corpuscle in the centre is sufficient to make rings of 7 and 8 corpuscles stable; in the latter case, however, one of the values of q^2 though positive is exceedingly small. When the number of corpuscles exceeds 8 the number of central corpuscles required to ensure stability increases very rapidly with the number of corpuscles in the ring.

The frequency equation is

$$\left(\frac{3}{4} \frac{e^2 S_0}{a^3} + \frac{3pe^2}{a^3} - (L_0 - L_k) - mg^2 \right) (N_0 - N_k - mg^2) = (M_k - 2m\omega g)^2.$$

Now $N_0 - N_k$ is always positive and M is small compared with L and N ; hence this equation will have real roots if

$$\frac{3}{4} \frac{e^2 S_0}{a^3} + \frac{3pe^2}{a^3} - (L_0 - L_k)$$

is positive. The greatest value of $L_0 - L_k$ is got by putting $k = n/2$ when n is even, and $=(n-1)/2$ when n is odd: hence the condition that the values of q should be real, i. e. that the equilibrium of the ring should be stable, is

$$\frac{3pe^2}{a^3} > (L_0 - L_{\frac{n}{2}}) - \frac{3}{4} \frac{e^2 S_0}{a^3} \text{ when } n \text{ is even,}$$

and

$$\frac{3pe^2}{a^3} > (L_0 - L_{\frac{n-1}{2}}) - \frac{3}{4} \frac{e^2 S_0}{a^3} \text{ when } n \text{ is odd.}$$

From this equation we can calculate the least value of p which will make a ring of n corpuscles stable. The values of *Phil. Mag. S. 6. Vol. 7. No. 39. March 1904.* T

p for a series of values of n are given in the following table:—

n ...	5	6	7	8	9	10	15	20	30	40
p ...	0	1	1	1	2	3	15	39	101	232

For large values of n the values of p are proportional to n^2 . When p is greater than one, the internal corpuscles necessary to produce equilibrium cannot all be at the centre of the sphere, they will separate until their repulsions are balanced by the attraction of the positive electricity in the sphere. Thus when there are two internal corpuscles, as when $n=9$, these two will separate and will form a pair with the line joining them parallel to the plane of the ring. If we assume, as is approximately the case, that the pair of equal corpuscles exerts at external points the same force as a double charge placed at a point midway between them, the preceding theory will apply, and the system consisting of the ring of 9 and the pair of corpuscles will be in stable equilibrium. When $n=10$, the internal corpuscles must be three in number; these three will arrange themselves at the corners of an equilateral triangle, and the system of 13 corpuscles will consist of a ring of 10 and a triangle of 3, the planes of the ring and triangle being parallel but not coincident; the corpuscles are all supposed to be in rapid rotation round the diameter of the sphere drawn at right angles to the planes of the ring. For a ring of 12 corpuscles we require 7 inside, but 7 corpuscles, as we have seen, cannot form a single ring, but will arrange themselves as a ring of 6 with one at the centre. Thus the system of 19 corpuscles will consist of an outer ring of 12, an inner ring of 6 in a plane parallel to the outer ring, and one corpuscle along the axis of rotation.

In this way we see that when we have a large number of corpuscles in rapid rotation they will arrange themselves as follows:—The corpuscles form a series of rings, the corpuscles in one ring being approximately in a plane at right angles to the axis of rotation, the number of particles in the rings diminishing as the radius of the ring diminishes. If the corpuscles can move at right angles to the plane of their orbit, the rings will be in different planes adjusting themselves so that the repulsion between the rings is balanced by the attraction exerted by the positive electrification of the sphere in which they are placed. We have thus in the first place a sphere of uniform positive electrification, and inside this sphere a number of corpuscles arranged in a series of parallel rings, the number of corpuscles in a ring varying from ring to ring: each corpuscle is travelling at a high speed round

the circumference of the ring in which it is situated, and the rings are so arranged that those which contain a large number of corpuscles are near the surface of the sphere, while those in which there are a smaller number of corpuscles are more in the inside.

If the corpuscles, like the poles of the little magnets in Mayer's experiments with the floating magnets, are constrained to move in one plane, they would, even if not in rotation, be in equilibrium when arranged in the series of rings just described. The rotation is required to make the arrangement stable when the corpuscles can move at right angles to the plane of the ring.

Application of the preceding Results to the Theory of the Structure of the Atom.

We suppose that the atom consists of a number of corpuscles moving about in a sphere of uniform positive electrification: the problems we have to solve are (1) what would be the structure of such an atom, *i. e.* how would the corpuscles arrange themselves in the sphere; and (2) what properties would this structure confer upon the atom. The solution of (1) when the corpuscles are constrained to move in one plane is indicated by the results we have just obtained—the corpuscles will arrange themselves in a series of concentric rings. This arrangement is necessitated by the fact that a large number of corpuscles cannot be in stable equilibrium when arranged as a single ring, while this ring can be made stable by placing inside it an appropriate number of corpuscles. When the corpuscles are not constrained to one plane, but can move about in all directions, they will arrange themselves in a series of concentric shells; for we can easily see that, as in the case of the ring, a number of corpuscles distributed over the surface of a shell will not be in stable equilibrium if the number of corpuscles is large, unless there are other corpuscles inside the shell, while the equilibrium can be made stable by introducing within the shell an appropriate number of other corpuscles.

The analytical and geometrical difficulties of the problem of the distribution of the corpuscles when they are arranged in shells are much greater than when they are arranged in rings, and I have not as yet succeeded in getting a general solution. We can see, however, that the same kind of properties will be associated with the shells as with the rings; and as our solution of the latter case enables us to give definite results, I shall confine myself to this case, and endeavour to show that the properties conferred on the

atom by this ring structure are analogous in many respects to those possessed by the atoms of the chemical elements, and that in particular the properties of the atom will depend upon its atomic weight in a way very analogous to that expressed by the periodic law.

Let us suppose, then, that we have N corpuscles each carrying a charge e of negative electricity, placed in a sphere of positive electrification, the whole charge in the sphere being equal to Ne ; let us find the distribution of the corpuscles when they are arranged in what we may consider to be the simplest way, *i. e.* when the number of rings is a minimum, so that in each ring there are as nearly as possible as many corpuscles as it is possible for the corpuscles inside to hold in equilibrium. Let us suppose that the number of internal corpuscles required to make the equilibrium of a ring of n corpuscles stable is $f(n)$. The value of $f(n)$ for a series of values of n is given in the table on page 254; in that table $f(n)$ is denoted by ρ . The number of corpuscles in the outer ring n_1 will then be determined by the condition that $N - n_1$, the number of corpuscles inside, must be just sufficient to keep the ring of n_1 corpuscles in equilibrium, *i. e.*, n_1 will be determined by the equation

$$N - n_1 = f(n_1), \dots \dots \dots (1)$$

If the value of n_1 got from this equation is not an integer we must take the integral part of the value.

To get n_2 , the number of corpuscles in the second ring, we notice that there must be $N - n_1 - n_2$ corpuscles inside; hence n_2 is given by the equation

$$N - n_1 - n_2 = f(n_2).$$

Similarly, n_3, n_4, \dots , the number of corpuscles in the 3rd, 4th, &c. rings reckoned from the outside, are given by

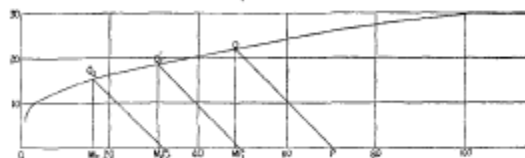
$$\begin{aligned} N - n_1 - n_2 - n_3 &= f(n_3), \\ N - n_1 - n_2 - n_3 - n_4 &= f(n_4). \end{aligned}$$

These equations can be solved very rapidly by a graphical method. Draw the graph whose abscissa = $f(n)$ and whose ordinate is n . The values of $f(n)$ for a series of values of n are given on page 254; from these values the curve fig. 1 has been constructed.

To find how a number of corpuscles equal to N will arrange themselves, measure off on the axis of abscissae a distance from O equal to N . Let OP be this distance, through P draw PQ inclined at an angle of 135° to the horizontal axis,

cutting the curve in Q , draw the ordinate QM ; then the integral part of QM will be the value of n_1 , the number of

Fig. 1.



corpuses in the first ring reckoned from the outside. For evidently

$$OM = f(QM),$$

and $OM = ON - NM$, and since PQ is inclined at 45° to the axis, $NM = OM$; hence

$$ON - QM = f(QM).$$

Comparing this with equation (1) we see that the integral part of QM is the value of n_1 .

To get the value of n_2 , the number of corpuses in the second ring, we mark off the abscissa $OP_1 = N - n_1$ (if QM is an integer P_1 will coincide with M), then from P_1 draw P_1Q_1 parallel to PQ cutting the curve in Q_1 ; the integral part of Q_1M_1 will be the value of n_2 . To get n_3 mark off the abscissa $OP_2 = N - n_1 - n_2$, and draw P_2Q_2 parallel to PQ ; the integral part of Q_2M_2 will be the value of n_3 . In this way we can in a very short time find the configuration.

The following table, which gives the way in which various numbers of corpuses group themselves, has been calculated in this way; the numbers range downwards from 60 at intervals of 5.

Number of corpuses	60.	55.	50.	45.	40.	35.
Number in successive rings...	20	19	18	17	16	16
	14	16	15	14	13	12
	13	12	11	10	8	6
	8	7	5	4	3	1
	3	1	1			
Number of corpuses	30.	25.	20.	15.	10.	5.
Number in successive rings...	15	13	12	10	8	5
	10	9	7	5	2	
	5	3	1			

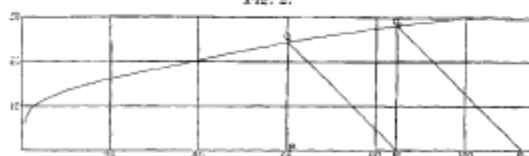
We give also the entire series of arrangement of corpuscles for which the outer ring consists of 20 corpuscles.

Number of corpuscles	59.	60.	61.	62.	63.	64.	65.	66.	67.
Number in successive rings...	20	20	20	20	20	20	20	20	20
	16	16	16	17	17	17	17	17	17
	13	13	13	13	13	13	14	14	15
	8	8	9	9	10	10	10	10	10
	2	3	3	5	3	4	4	5	5

59 is the smallest number of corpuscles which can have an outer ring of 20, while when the number of corpuscles is greater than 67 the outer ring will contain more than 20 corpuscles.

Let us now consider the connexion between these results and the properties possessed by the atoms of the chemical elements. We suppose that the mass of an atom is the sum of the masses of the corpuscles it contains, so that the atomic weight of an element is measured by the number of corpuscles in its atom. An inspection of the results just given will show that systems built up of rings of corpuscles in the way we have described, will possess properties analogous to some of those possessed by the atom. In the first place, we see that the various arrangements of the corpuscles can be classified in families, the grouping of the corpuscles in the various members of the family having certain features in common. Thus, for example, we see that the group of 60 corpuscles consists of the same rings of corpuscles as the group of 40 with an additional ring of 20 corpuscles round it, while the group of 40 consists of the same series of rings as the group of 24 with an additional ring outside, while 24 is the group 11 with an additional ring. To continue the series for larger numbers of corpuscles, take the curve $x=f(y)$ when $f(n)$ is the number of corpuscles that must be placed

Fig. 2.



inside a ring of n corpuscles to make it stable. Let Q be the point on this curve corresponding to 60 corpuscles, *i. e.* $OP=60$, from Q draw QP_1 inclined at an angle of 135° to

the axis of x ; then the number of corpuscles represented by OP_1 will be arranged like the 60 corpuscles with an addition ring of Q_1P_1 corpuscles (fig. 2). To find the next member of the family, draw Q_1P_2 parallel to QP_1 cutting the axis of x in P_2 , then OP_2 will represent the number of corpuscles in the next member of the family; and by continuing the process we can find the successive members. Thus we see that we can divide the various groups of atoms into series such that each member of the series is derived from the preceding member (*i. e.* the member next below it in atomic weight) by adding to it another ring of corpuscles. We should expect the atoms formed by a series of corpuscles of this kind to have many points of resemblance. Take, for example, the vibrations of the corpuscles; these may be divided into two sets:—(1) Those arising from the rotation of the corpuscles around their orbits: if all the corpuscles in one atom have the same angular velocity, the frequency of the vibrations produced by the rotation of the ring of corpuscles is proportional to the number of corpuscles in the ring; and thus in the spectrum of each element in the series there would be a series of frequencies bearing the same ratio to each other, the ratio of the frequencies being the ratios of the numbers in the various rings.

The second system of vibrations are those arising from the displacement of the ring from its circular figure. If now the distance of a corpuscle in the outer ring from a corpuscle in the collection of rings inside it is great compared with the distance of the second corpuscle from its nearest neighbour on its own ring, the effect of the outer ring of corpuscles on the inner set of rings will only "disturb" the vibrations of the latter without fundamentally altering the character of their vibrations. Thus for these vibrations, as well as for those due to the rotations, the sequence of frequencies would present much the same features for the various elements in the series; there would be in the spectrum corresponding groups of associated lines. We regard a series of atoms formed in this way, *i. e.* when the atom of the p th member is formed from that of the $(p-1)$ th by the addition of a single ring of corpuscles, as belonging to elements in the same group in the arrangement of the elements according to the periodic law; *i. e.*, they form a series which, if arranged according to Mendeléef's table, would all be in the same vertical column.

The gradual change in the properties of the elements which takes place as we travel along one of the horizontal rows in Mendeléef's arrangement of the elements, is also illustrated by the properties possessed by these groups of corpuscles. Thus

consider the series of arrangements of the corpuscles given on p. 258, in all of which the outer ring contains 20 corpuscles. An outer row of 20 corpuscles first occurs with 59 corpuscles; in this case the number of corpuscles inside is only just sufficient to make the outer ring stable; this ring will therefore be on the verge of instability, and when the corpuscles in this ring are displaced the forces of restitution urging them back to their original position will be small. Thus when this ring is subjected to disturbances from an external source, one or more corpuscles may easily be detached from it; such an atom therefore will easily lose a negatively electrified corpuscle, and thus acquire a charge of positive electricity; such an atom would behave like the atom of a strongly electropositive element. When we pass from 59 to 60 corpuscles the outer ring is more stable, because there is an additional corpuscle inside it; the corresponding atom will thus not be so electropositive as that containing only 59 corpuscles. The addition of each successive corpuscle will make it more difficult to detach corpuscles from the outer ring, and will therefore make the atom less electropositive. When the stability of the outer ring gets very great, it may be possible for one or more corpuscles to be on the surface of the atom without breaking up the ring; in this case the atom could receive a charge of negative electricity, and would behave like the atom of an electronegative element. The increase in the stability of the ring, and consequently in the electronegative character of the atom, would go on increasing until we had as many as 67 corpuscles, when the stability of the outer ring would be at a maximum. A great change in the properties of the atom would occur with 68 corpuscles, for now the number of corpuscles in the outer ring increases to 21; these 21 corpuscles are, however, only just stable, and would, like the outer ring of 20 in the arrangement of the 59 corpuscles, readily lose a corpuscle and so make the atom strongly electropositive.

The properties of the groups of 59 and 67 corpuscles, which are respectively at the beginning and end of the series which has an outer ring of 20 corpuscles, deserve especial consideration. The arrangement of corpuscles in the group of 59, although very near the verge of instability, and therefore very liable to lose a corpuscle and thereby acquire a positive charge, would not be able to retain this charge. For when it had lost a corpuscle, the 58 corpuscles left would arrange themselves in the grouping corresponding to 58 corpuscles which is the last to have an outer ring of 19 corpuscles; this ring is therefore exceedingly stable so that no further cor-

puscles would escape from it, while the positive charge on the system due to the escape of the 59th corpuscle would attract the surrounding corpuscles. Thus this arrangement could not remain permanently charged; for as soon as one corpuscle had escaped it would be replaced by another. An atom constituted in this way would be neither electropositive nor electronegative, but one incapable of receiving permanently a charge of electricity.

The group containing 60 corpuscles would be the most electropositive of the series; but this could only lose one corpuscle; *i. e.* acquire a charge of one unit of positive electricity; for if it lost two we should have 58 corpuscles—as when the group of 59 had lost one corpuscle—and in this case the system would be even more likely than the other to attract external corpuscles, for it would have a charge of two units of positive electricity instead of one. Thus the system containing 60 corpuscles would get charged with one, but only one, unit of positive electricity: it would therefore act like the atom of a monovalent electropositive element.

The group containing 61 corpuscles would not part with its corpuscles so readily as the group of 60, but on the other hand it could afford to lose two, as it is not until it has lost three that its corpuscles are reduced to 58, when, as we have seen, it begins to acquire fresh corpuscles. Thus this system might get charged with two units of positive electricity, and would act like the atom of a divalent electropositive element. Similarly the group of 62, though less liable even than the 61 to lose its corpuscles, could, on the other hand, lose 3 without beginning to recover its corpuscles; it could thus acquire a charge of 3 units of positive electricity, and would act like the atom of a trivalent electropositive element.

Let us now go to the groups at the other end of the series and consider the properties of the last of the series, the group of 67 corpuscles. The outer ring would be very stable, but if the system acquired another corpuscle, the 68 corpuscles would arrange themselves with a ring of 21 corpuscles on the outside; as 68 is the smallest number of corpuscles with an outer ring of 21, the ring is very nearly unstable and easily loses a corpuscle. Thus the group of 67 corpuscles, as soon as it acquires a negative charge, would lose it again, and the system, like the group of 59, would be incapable of being permanently charged with electricity—it would act like the atom of an element of no valency.

The group of 66 would be the most electronegative of the series, but this would only be able to retain a charge of one unit of negative electricity; for if it acquired 2 units there

would be 68 corpuscles, an arrangement which, as we have seen, rapidly loses its corpuscles. This group of 66 would therefore act like the atom of a monovalent electronegative element.

The group of 65 would be less liable than that of 66 to acquire negative corpuscles, but, on the other hand, it would under suitable circumstances be able to retain 2 corpuscles, and thus be charged with 2 units of negative electricity, and would act like the atom of a divalent electronegative element.

Similarly, the group of 64 would act like the atom of a trivalent electronegative element, and so on.

Thus, if we consider the series of arrangements of corpuscles having on the outside a ring containing a constant number of corpuscles, we have at the beginning and end systems which behave like the atoms of an element whose atoms are incapable of retaining a charge of either positive or negative electricity; then (proceeding in the order of increasing number of corpuscles) we have first a system which behaves like the atom of a monovalent electropositive element, next one which behaves like the atom of a divalent electropositive element, while at the other end of the series we have a system which behaves like an atom with no valency, immediately preceding this, one which behaves like the atom of a monovalent electronegative element, while this again is preceded by one behaving like the atom of a divalent electronegative element.

This sequence of properties is very like that observed in the case of the atoms of the elements.

Thus we have the series of elements :

He	Li	Be	B	C	N	O	F	Ne.
Ne	Na	Mg	Al	Si	P	S	Cl	Arg.

The first and last element in each of these series has no valency, the second is a monovalent electropositive element, the last but one is a monovalent electronegative element, the third is a divalent electropositive element, the last but two a divalent electronegative element, and so on.

When atoms like the electronegative ones, in which the corpuscles are very stable, are mixed with atoms like the electropositive ones, in which the corpuscles are not nearly so firmly held, the forces to which the corpuscles are subject by the action of the atoms upon each other may result in the detachment of corpuscles from the electropositive atoms and their transference to the electronegative. The electronegative atoms will thus get a charge of negative electricity, the electropositive atoms one of positive, the oppositely charged atoms will attract each other, and a chemical

compound of the electropositive and electronegative atoms will be formed.

Just as an uncharged conducting sphere will by electrostatic induction attract a corpuscle in its neighbourhood, so a corpuscle outside an atom will be attracted, even though the atom has not become positively charged by losing a corpuscle. When the outside corpuscle is dragged into the atom there will be a diminution in the potential energy, the amount of this diminution depending on the number of corpuscles in the atom. If now we have an atom A such that loss of potential energy due to the fall into the atom of a corpuscle from outside is greater than the work required to drag a corpuscle from an atom B of a different kind, then an intimate mixture of A and B atoms will result in the A atoms dragging corpuscles from the B atoms, thus the A atoms will get negatively, the B atoms positively electrified, and the oppositely electrified atoms will combine, forming a compound such as $A_{-}B_{+}$; in such a case as this chemical combination might be expected whenever the atoms were brought into contact. Even when the loss of potential energy when a corpuscle falls into A is less than the work required to drag a corpuscle right away from B, the existence of a suitable physical environment may lead to chemical combination between A and B. For when a corpuscle is dragged out of and away from an atom a considerable portion of the work is spent on the corpuscle after it has left the atom, while of the work gained when a corpuscle falls into an atom, the proportion done outside to that done inside the atom is smaller than the proportion for the corresponding quantities when the corpuscle is dragged out of an atom. Thus, though the work required to move a corpuscle from B to an infinite distance may be greater than that gained when a corpuscle moves from an infinite distance into A, yet the work gained when a corpuscle went from the surface of A into its interior might be greater than the work required to move a corpuscle from the interior to the surface of B. In this case anything which diminished the forces on the corpuscle when they got outside the atom, as, for example, the presence of a medium of great specific inductive capacity such as water, or contact with a metal such as platinum black, would greatly increase the chance of chemical combination.

The Existence of Secondary Groups of Corpuscles within the Atom.

The expression given on p. 238 for the radius of a ring of corpuscles shows that it depends on ve/v^2 , where ve is the

amount of positive electrification within a sphere of radius b : thus ve/b^3 is equal to $\frac{4\pi}{3}\rho$, where ρ is the density of the positive electrification in the sphere: thus, if the density of the electrification be kept constant, the radius of the ring will be independent of the size of the sphere. Now let us take a large sphere and place within it a ring of such a size that the ring would be in stable equilibrium if its centre were at the centre of the sphere. To fix our ideas, let us take the case of three corpuscles at the corners of an equilateral triangle, and place this triangle so that its centre O' is no longer at the centre of the sphere: we can easily see that the corpuscles will remain at the corners of an equilateral triangle of the same size, and that the triangle will move like a rigid body acted upon by a force proportional to the distance of its centre from O the centre of the sphere. To prove this we notice that the repulsion between the corpuscles is the same as when the centre of the triangle is at O . The attraction of the sphere on a corpuscle P is proportional to OP , and so may be resolved into two forces, one proportional to $O'P$ along PO' (O' is the centre of the triangle) and the other proportional to OO' acting along $O'O$. Now the corpuscles are by hypothesis in equilibrium under their mutual repulsions, and the attraction to the centre proportional to $O'P$: thus the relative position of the corpuscles will remain unaltered, and the system of three corpuscles will move as a rigid body under a central force acting on its centre of gravity proportional to the distance of that point from the centre of the sphere.

The three corpuscles will, at a point whose distance from their centre is large compared with a side of the triangle, produce the same effect as if the charges on the three corpuscles were condensed at the centre of the triangle: they will thus at such points act like a unit, and the results we have previously obtained for single corpuscles may be extended to the case when the single corpuscles are replaced by rings of corpuscles which would by themselves be in equilibrium. It should be noted that the atom in which these systems are placed must be large enough to allow these rings of corpuscles—sub-atoms we may call them, to be separated by distances considerably greater than the distance between the corpuscles in one of the rings.

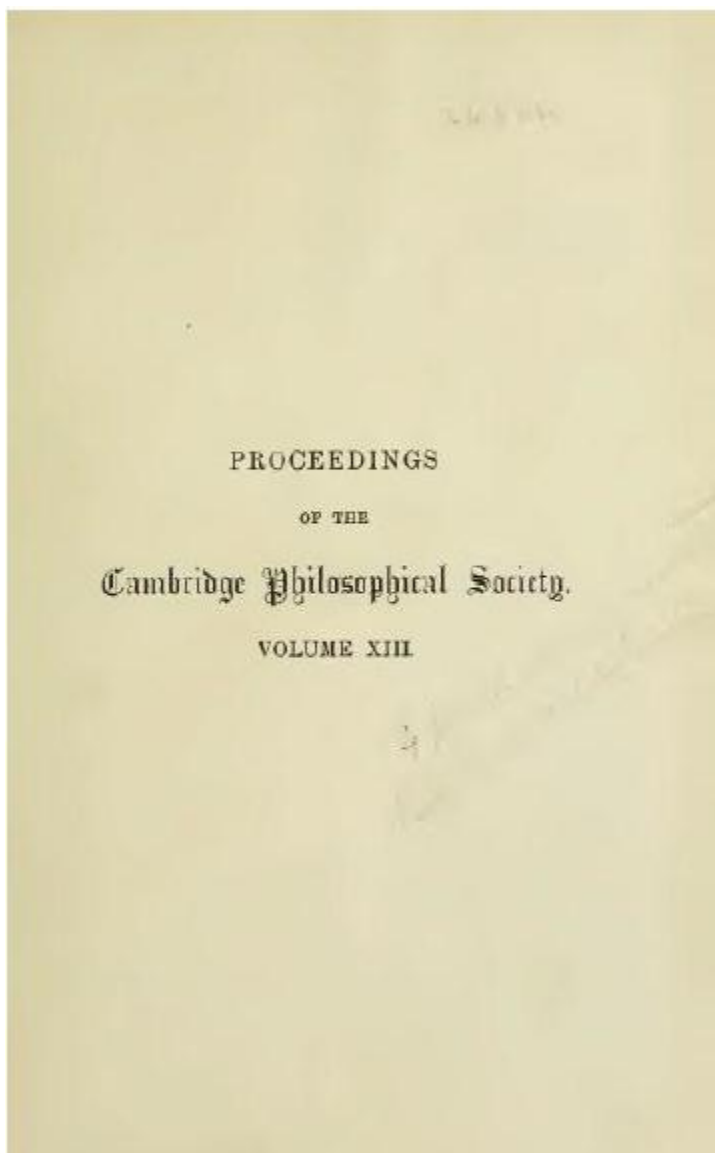
If we regard the atoms of the heavier elements as produced by the coalescence of lighter atoms, it is reasonable to suppose that the corpuscles in the heavier atoms may be arranged in secondary groups or sub-atoms, each of these groups acting

as a unit. When the corpuscles are done up in bundles in this way, it is possible to have stability when these bundles are arranged in a ring with a smaller number of corpuscles inside than when the corpuscles in the bundles are arranged at equal intervals round the circumference of the ring. Thus, take the case of a ring of 30 corpuscles; if these were arranged at equal intervals, 101 corpuscles would be required inside the ring to make it stable. If, however, the 30 corpuscles were grouped in ten sets of three each, only $3 \times 3 = 9$ corpuscles in the interior would be required to make the arrangement stable.

Constitution of the Atom of a Radioactive Element.

Our study of the stability of systems of corpuscles has made us acquainted with systems which are stable when the corpuscles are rotating with an angular velocity greater than a certain value, but which become unstable when the velocity falls below this value. Thus, to take an instance, we saw (p. 249) that four corpuscles can be stable in one plane at the corners of a square, if they are rotating with an angular velocity greater than $\cdot 325v^2/ml^2$, but become unstable if the velocity falls below this velocity, the corpuscles in this case tending to place themselves at the corners of a tetrahedron. Consider now the properties of an atom containing a system of corpuscles of this kind, suppose the corpuscles were originally moving with velocities far exceeding the critical velocity; in consequence of the radiation from the moving corpuscles, their velocities will slowly—very slowly—diminish; when, after a long interval, the velocity reaches the critical velocity, there will be what is equivalent to an explosion of the corpuscles, the corpuscles will move far away from their original positions, their potential energy will decrease, while their kinetic energy will increase. The kinetic energy gained in this way might be sufficient to carry the system out of the atom, and we should have, as in the case of radium, a part of the atom shot off. In consequence of the very slow dissipation of energy by radiation the life of the atom would be very long. We have taken the case of the four corpuscles as the type of a system which, like a top, requires for its stability a certain amount of rotation. Any system possessing this property would, in consequence of the gradual dissipation of energy by radiation, give to the atom containing it radioactive properties similar to those conferred by the four corpuscles.

ANEXO 7 – Artigo J. J. Thomson. *Proceedings of the Royal Society*. 1904.



On the vibrations of atoms containing 4, 5, 6, 7, and 8 corpuscles and on the effect of a magnetic field on such vibrations. By J. J. THOMSON, M.A., F.R.S., Cavendish Professor of Experimental Physics, Cambridge.

[Received 27 December 1904.]

The paper contains an investigation of the time of vibration of model atoms of some complexity, it was undertaken in the hope that the properties of these models might throw some light on the effect of a magnetic field on the lines in the spectra of luminous bodies.

Case of Four Corpuscles.

We suppose that we have four equal corpuscles with equal charges of negative electricity placed within a sphere of uniform positive electrification; when in equilibrium the corpuscles will be situated at the corners of a regular tetrahedron with its centre at the centre of the sphere. We can easily show that if b is the radius of the sphere of positive electrification, and a the distance of any one of the corpuscles from the centre of the sphere, then when the attraction of the positive sphere on the corpuscle is equal and opposite to the repulsion exerted by the other three corpuscles

$$\frac{a^2}{b^2} = \frac{3\sqrt{3}}{16\sqrt{2}}$$

the positive charge in the sphere being equal in magnitude to the sum of the negative charges on the four corpuscles. This result may be expressed by saying that when in equilibrium the distance between two corpuscles is equal to b .

Let us call the equilibrium positions of the four particles 1, 2, 3, 4 and let us take as our axes of coordinates the lines joining the middle points of opposite sides of the tetrahedron. The line joining the middle points of (12), (34), (13), (24), (14), (23) being taken as the axes of x , y , z respectively; the coordinates of the points 1, 2, 3, 4 are respectively (a, a, a) , $(a, -a, -a)$, $(-a, a, -a)$, $(-a, -a, a)$, where $3a^2 = b^2$.

If (ξ_r, η_r, ζ_r) are the displacements of the r th particle from its position of equilibrium, m the mass and e the charge on a corpuscle, we can show that the vibrations of the system are given by the equations:

$$(1) \quad m \frac{d^2 p}{dt^2} = -kp, \quad m \frac{d^2 q}{dt^2} = -kq, \quad m \frac{d^2 r}{dt^2} = -kr,$$

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where

$$p = \xi_1 + \xi_2 + \xi_3 + \xi_4, \quad q = \eta_1 + \eta_2 + \eta_3 + \eta_4, \quad r = \zeta_1 + \zeta_2 + \zeta_3 + \zeta_4,$$

and
$$k = \frac{4e^2}{b^3},$$

thus p, q, r which are proportional to the coordinates of the centre of gravity of the four corpuscles are principal coordinates and their vibrations give three periods each equal to $2\pi \sqrt{\frac{m}{k}}$.

If

$$p_1 = \xi_1 + \xi_2 - (\xi_3 + \xi_4), \quad q_1 = \eta_1 + \eta_2 - (\eta_3 + \eta_4), \quad r_1 = \zeta_1 + \zeta_2 - (\zeta_3 + \zeta_4),$$

$$p_2 = \xi_1 + \xi_3 - (\xi_2 + \xi_4), \quad q_2 = \eta_1 + \eta_3 - (\eta_2 + \eta_4), \quad r_2 = \zeta_1 + \zeta_3 - (\zeta_2 + \zeta_4),$$

$$p_3 = \xi_1 + \xi_4 - (\xi_2 + \xi_3), \quad q_3 = \eta_1 + \eta_4 - (\eta_2 + \eta_3), \quad r_3 = \zeta_1 + \zeta_4 - (\zeta_2 + \zeta_3),$$

we find

$$m \frac{d^2}{dt^2} (p_1 - q_1) = 0, \quad m \frac{d^2}{dt^2} (p_1 - r_1) = 0, \quad m \frac{d^2}{dt^2} (q_1 - r_1) = 0,$$

$$m \frac{d^2}{dt^2} (p_2 + q_2) = -k_1 (p_2 + q_2), \quad m \frac{d^2}{dt^2} (p_2 + r_2) = -k_1 (p_2 + r_2),$$

$$m \frac{d^2}{dt^2} (q_2 + r_2) = -k_1 (q_2 + r_2), \quad m \frac{d^2}{dt^2} (p_3 + q_3 + r_3) = -k_1 (p_3 + q_3 + r_3),$$

$$m \frac{d^2}{dt^2} (p_1 - q_3) = -k_1 (p_1 - q_3), \quad m \frac{d^2}{dt^2} (p_1 - r_3) = -k_1 (p_1 - r_3),$$

where

$$k_1 = \frac{6e^2}{b^3} = \frac{3}{2}k,$$

$$k_2 = \frac{12e^2}{b^3} = 3k,$$

$$k_3 = \frac{3e^2}{b^3} = \frac{3}{4}k.$$

Thus the remaining nine principal coordinates of the system, which has twelve degrees of freedom, are

$p_1 - q_1, p_2 - r_2, q_2 - r_2$, the three corresponding periods of vibration are infinite;

$p_2 + q_2, p_3 + r_3, q_3 + r_3$, the three corresponding periods of vibration are $2\pi \sqrt{\frac{m}{k} \frac{2}{3}}$;

containing 4, 5, 6, 7, and 8 corpuscles, etc.

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$$p_1 + q_1 + r_1 \text{ with a period } 2\pi \sqrt{\frac{m}{3k}};$$

$$p_1 - q_1, p_1 - r_1 \text{ with two periods } 2\pi \sqrt{\frac{m}{k}} \frac{1}{3};$$

Thus there are four different periods the squares of which are in the proportion of 1, 2, 3, 4.

Effect of a magnetic field on the vibrations of the tetrahedron. If α, β, γ are the components of the external magnetic field, there will be terms in the expression for $m \frac{d^2 \zeta_i}{dt^2}$, equal to $e\beta \frac{d^2 \zeta_i}{dt^2} - e\gamma \frac{d^2 \eta_i}{dt^2}$, in addition to the terms independent of the magnetic field, and corresponding terms in the expressions for $\frac{d^2 \eta_i}{dt^2}, \frac{d^2 \xi_i}{dt^2}$.

Hence instead of the equations

$$m \frac{d^2 p}{dt^2} = -kp, \text{ etc.},$$

we have

$$m \frac{d^2 p}{dt^2} = -kp + e\beta \frac{d}{dt} (\zeta_1 + \zeta_2 + \zeta_3 + \zeta_4) - e\gamma \frac{d}{dt} (\eta_1 + \eta_2 + \eta_3 + \eta_4)$$

$$\text{or } m \frac{d^2 p}{dt^2} = -kp + e\beta \frac{dx}{dt} - e\gamma \frac{dq}{dt}.$$

Similarly

$$m \frac{d^2 q}{dt^2} = -kq + e\gamma \frac{dy}{dt} - e\alpha \frac{dz}{dt},$$

$$m \frac{d^2 r}{dt^2} = -kr + e\alpha \frac{dz}{dt} - e\beta \frac{dx}{dt},$$

or if p, q, r vary as $e^{\mu t}$, we have

$$(m\mu^2 - k)^2 - (m\mu^2 - k) \mu^2 e^i (\alpha^2 + \beta^2 + \gamma^2) = 0.$$

The roots of this are

$$\mu_0 = \sqrt{\frac{k}{m}},$$

$$\mu_1 = \mu_0 + \frac{1}{2} \frac{He}{m},$$

$$\mu_2 = \mu_0 - \frac{1}{2} \frac{He}{m},$$

where $H = \sqrt{\alpha^2 + \beta^2 + \gamma^2}$.

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The changes in the periods of this oscillation are the same as those of the single particle investigated by Lorentz.

The effects on the other principal coordinates are more complex.

$$\begin{aligned} \text{Let } p_2 + q_1 &= \psi_1, & p_2 + r_1 &= \phi_2, & q_2 + r_1 &= \theta_1, \\ p_1 - q_1 &= \psi_1', & p_2 - r_1 &= \phi_1', & q_2 - r_1 &= \theta_1', \\ p_1 + q_2 + r_1 &= \alpha, \\ p_1 - q_1 &= \lambda_1, \\ p_1 - r_1 &= \lambda_2. \end{aligned}$$

Then the equation

$$m \frac{d^2 \psi_2}{dt^2} = -k_1 \psi_2$$

becomes when there is a magnetic field

$$\begin{aligned} m \frac{d^2 \psi_2}{dt^2} &= -k_1 \psi_2 + e\beta \frac{d}{dt} (\xi_1 + \xi_2 - (\zeta_2 + \zeta_4)) - e\gamma \frac{d}{dt} (\eta_1 + \eta_2 - (\eta_3 + \eta_4)) \\ &\quad + e\gamma \frac{d}{dt} (\xi_1 + \xi_2 - (\xi_3 + \xi_4)) - e\alpha \frac{d}{dt} (\zeta_1 + \zeta_2 - (\zeta_3 + \zeta_4)), \end{aligned}$$

$$\text{or } m \frac{d^2 \psi_2}{dt^2} = -k_1 \psi_2 + e\beta \frac{1}{2} \frac{d}{dt} (\theta_1 - \theta_1') + e\gamma \frac{d\lambda_1}{dt} - e\alpha \frac{1}{2} \frac{d}{dt} (\phi_1 - \phi_2).$$

Now if the vibrations are only slightly disturbed we need only retain on the right-hand side the variables whose free periods are the same as that of ψ_2 , i.e. we need only retain the terms in θ_1 and ϕ_2 , hence we have

$$m \frac{d^2 \psi_1}{dt^2} = -k \psi_1 + \frac{1}{2} e\beta \frac{d\theta_1}{dt} - \frac{1}{2} e\alpha \frac{d\phi_2}{dt}.$$

$$\text{Similarly } m \frac{d^2 \phi_2}{dt^2} = -k \phi_2 + \frac{1}{2} e\alpha \frac{d\psi_2}{dt} - \frac{1}{2} e\gamma \frac{d\theta_1}{dt},$$

$$m \frac{d^2 \theta_1}{dt^2} = -k \theta_1 + \frac{1}{2} e\gamma \frac{d\phi_2}{dt} - \frac{1}{2} e\beta \frac{d\psi_2}{dt}.$$

From the form of these equations we see that they differ from those for a single particle in that the terms involving the magnetic force are multiplied by the factor $\frac{1}{2}$, hence the effect of the magnetic force on this vibration is only $\frac{1}{2}$ the normal effect, while the effect on the vibration corresponding to p, q, r is as we have seen normal. The magnetic field has, to a first approximation, no effect on the vibrations of the coordinates $\delta, \lambda_1, \lambda_2$.

Case of Five Corpuscles

One position of equilibrium is when four of the corpuscles are at the corners of a regular tetrahedron while the fifth is at the centre of the tetrahedron.

Let x, y, z be the coordinates of the centre of gravity of the five corpuscles, $\xi_1, \eta_1, \zeta_1, \xi_2, \eta_2, \zeta_2, \xi_3, \eta_3, \zeta_3, \xi_4, \eta_4, \zeta_4$ the coordinates of the four outer corpuscles relative to the central corpuscle, the direction of the axes being the same as in the last example.

Then if

$$\begin{aligned} \xi_1 + \xi_2 + \xi_3 + \xi_4 &= p, & \eta_1 + \eta_2 + \eta_3 + \eta_4 &= q, & \zeta_1 + \zeta_2 + \zeta_3 + \zeta_4 &= r, \\ \xi_1 + \xi_2 - (\xi_3 + \xi_4) &= p_1, & \eta_1 + \eta_2 - (\eta_3 + \eta_4) &= q_1, & \zeta_1 + \zeta_2 - (\zeta_3 + \zeta_4) &= r_1, \\ \xi_1 + \xi_3 - (\xi_2 + \xi_4) &= p_2, & \eta_1 + \eta_3 - (\eta_2 + \eta_4) &= q_2, & \zeta_1 + \zeta_3 - (\zeta_2 + \zeta_4) &= r_2, \\ \xi_1 + \xi_4 - (\xi_2 + \xi_3) &= p_3, & \eta_1 + \eta_4 - (\eta_2 + \eta_3) &= q_3, & \zeta_1 + \zeta_4 - (\zeta_2 + \zeta_3) &= r_3, \end{aligned}$$

we have

$$m \frac{d^2x}{dt^2} = -kx, \quad m \frac{d^2y}{dt^2} = -ky, \quad m \frac{d^2z}{dt^2} = -kz.$$

Thus, x, y, z are principal coordinates, the time of vibration being $2\pi \sqrt{\frac{m}{k}}$.

We have also

$$m \frac{d^2}{dt^2} (p_1 + q_2 + r_3) = -k_1 (p_1 + q_2 + r_3),$$

$$m \frac{d^2}{dt^2} (p_2 - q_3) = -k_2 (p_2 - q_3) \text{ and } m \frac{d^2}{dt^2} (p_3 - r_1) = -k_3 (p_3 - r_1),$$

where $k_1 = 3k, \quad k_2 = \frac{3}{\frac{1}{3\sqrt{3}} + \frac{1}{4\sqrt{2}}} k.$

Thus $p_1 + q_2 + r_3, p_2 - q_3, p_3 - r_1$ are principal coordinates. Again

$$m \frac{d^2}{dt^2} (p_2 - q_1) = 0, \quad m \frac{d^2}{dt^2} (p_3 - r_2) = 0, \quad m \frac{d^2}{dt^2} (q_3 - r_1) = 0.$$

Thus $p_2 - q_1, p_3 - r_2, q_3 - r_1$ are also principal coordinates.

The remaining six principal coordinates are

$$\begin{aligned} r + \lambda_1 (p_2 + q_3), & \quad r + \lambda_2 (p_3 + q_1), \\ q + \lambda_3 (r_1 + p_2), & \quad q + \lambda_4 (r_2 + p_3), \\ p + \lambda_5 (q_3 + r_1), & \quad p + \lambda_6 (q_1 + r_2). \end{aligned}$$

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where λ_1, λ_2 are the roots of the equation

$$\lambda^2 = \lambda \left(\frac{1}{2} - \frac{3\sqrt{3}}{8\sqrt{8}} \right) + 1,$$

or approximately

$$\lambda_1 = \frac{9}{8},$$

$$\lambda_2 = -\frac{1}{4}.$$

The corresponding periods are

$$2\pi \sqrt{\frac{m}{k_1}}, \quad 2\pi \sqrt{\frac{m}{k_2}},$$

where

$$k_1 = 7.3k, \quad k_2 = .938k.$$

Effect of a magnetic field on the periods. The effects on the vibrations corresponding to x, y, z are normal, that on

$$p_1 + q_2 + r_3, \quad p_2 - q_3, \quad p_3 - r_1,$$

is zero, while the effects on the coordinates

$$r + \lambda_1(p_2 + q_3), \quad r + \lambda_2(p_1 + q_2),$$

are respectively about $\frac{1}{3}\frac{1}{2}$ and $\frac{1}{3}\frac{1}{2}$ of the normal.

Case of Six Corpuscles.

The six particles when in equilibrium will be at the corners of a regular octahedron. Denoting the positions of the corpuscles when in equilibrium by the symbols 1, 2, 3, 4, 5, 6, let us take the line joining 1 and 6 as the axis of x , that joining 2 and 5 as the axis of y and that joining 3 and 4 as the axis of z . If a is the distance of any one of the corpuscles in its undisturbed position from the centre of the sphere of positive electrification then the coordinates of the points 1, 2, 3, 4, 5, 6 are as follows 1 ($a, 0, 0$), 2 ($0, a, 0$), 3 ($0, 0, a$), 4 ($0, 0, -a$), 5 ($0, -a, 0$), 6 ($-a, 0, 0$); let ξ_r, η_r, ζ_r be the displacement of the r th corpuscle from its position of equilibrium, then, m being the mass and e the charge on a corpuscle, the oscillations of the corpuscles will be given by the following equations

$$m \frac{d^2 p}{dt^2} = -kp, \quad m \frac{d^2 q}{dt^2} = -kq, \quad m \frac{d^2 r}{dt^2} = -kr,$$

where

$$p = \xi_1 + \xi_2 + \xi_3 + \xi_4 + \xi_5 + \xi_6,$$

$$q = \eta_1 + \eta_2 + \eta_3 + \eta_4 + \eta_5 + \eta_6,$$

$$r = \zeta_1 + \zeta_2 + \zeta_3 + \zeta_4 + \zeta_5 + \zeta_6.$$

containing 4, 5, 6, 7, and 8 corpuscles, etc. 47

one plane at the corners of a pentagon, the other two on opposite sides of the plane, the line joining them passing perpendicularly to the plane through the centre of the pentagon, the distance of either of these from the centre is about $\frac{23}{30}$ of the distance of the other five from the same point.

Case of Eight Corpuscles.

Those when in equilibrium will be arranged at the corners of a cube. Take as the axes of x, y, z the lines through the centre of this cube parallel to its sides. Denoting the eight corpuscles by the symbols (1), (2), (3), (4), (5), (6), (7), (8), let the coordinates of these when in equilibrium be given by the scheme

(1) (a, a, a) , (2) $(-a, a, a)$, (3) $(a, -a, a)$, (4) $(a, a, -a)$,
(5) $(-a, -a, -a)$, (7) $(a, -a, -a)$, (6) $(-a, a, -a)$, (8) $(-a, -a, a)$.

Let the displacement of the r th particle from its position of equilibrium be ξ_r, η_r, ζ_r .

For the sake of brevity denote $\xi_r + \xi_{2-r}$ by X_r , $\xi_r - \xi_{2-r}$ by X'_r , $\eta_r + \eta_{2-r}$ by Y_r , $\eta_r - \eta_{2-r}$ by Y'_r , $\zeta_r + \zeta_{2-r}$ by Z_r , $\zeta_r - \zeta_{2-r}$ by Z'_r , then we may show that

$$m \frac{d^2}{dt^2} (X_1 + X_2 + X_3 + X_4) = -k(X_1 + X_2 + X_3 + X_4),$$

$$m \frac{d^2}{dt^2} (Y_1 + Y_2 + Y_3 + Y_4) = -k(Y_1 + Y_2 + Y_3 + Y_4),$$

$$m \frac{d^2}{dt^2} (Z_1 + Z_2 + Z_3 + Z_4) = -k(Z_1 + Z_2 + Z_3 + Z_4),$$

where $k = \frac{8e^2}{b^3}$, and b is the radius of the sphere of positive electrification. Thus ΣX , ΣY , ΣZ are principal coordinates, they are proportional to the coordinates of the centre of gravity; the time of vibration corresponding to these coordinates is $2\pi \sqrt{\frac{m}{k}}$.

$$\begin{aligned} \text{If } X_1 + X_2 - (X_3 + X_4) + Y_1 + Y_2 - (Y_3 + Y_4) &= \psi_1, \\ X_1 + X_2 - (X_3 + X_4) - (Y_1 + Y_2) + Y_3 + Y_4 &= \psi_2, \\ X_1 + X_2 - (X_3 + X_4) + Z_1 + Z_2 - (Z_3 + Z_4) &= \phi_1, \\ X_1 + X_2 - (X_3 + X_4) - (Z_1 + Z_2) + Z_3 + Z_4 &= \phi_2, \\ Y_1 + Y_2 - (Y_3 + Y_4) + (Z_1 + Z_2) - (Z_3 + Z_4) &= \theta_1, \\ Y_1 + Y_2 - (Y_3 + Y_4) - (Z_1 + Z_2) + (Z_3 + Z_4) &= \theta_2, \end{aligned}$$

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then

$$m \frac{d^2\psi_1}{dt^2} = -k_1\psi_1, \quad m \frac{d^2\phi_1}{dt^2} = -k_1\phi_1, \quad m \frac{d^2\theta_1}{dt^2} = -k_1\theta_1,$$

$$m \frac{d^2\psi_2}{dt^2} = -k_2\psi_2, \quad m \frac{d^2\phi_2}{dt^2} = -k_2\phi_2, \quad m \frac{d^2\theta_2}{dt^2} = -k_2\theta_2,$$

where

$$k_1 = \frac{4 + \frac{4}{\sqrt{2}} + \frac{2}{3\sqrt{3}}}{2 + \sqrt{2} + \frac{2}{3\sqrt{3}}} k,$$

$$k_2 = \frac{4 + \frac{1}{\sqrt{2}} + \frac{2}{3\sqrt{3}}}{2 + \sqrt{2} + \frac{2}{3\sqrt{3}}} k.$$

The arrangement of eight corpuscles at the corners of a cube is however unstable, for, if

$$p = X_1 + X_2 - (X_3 + X_4),$$

$$q = Y_1 + Y_2 - (Y_3 + Y_4),$$

$$r = Z_1 + Z_2 - (Z_3 + Z_4),$$

we find

$$m \frac{d^2}{dt^2}(p-q) = \left(2 - \frac{3}{2\sqrt{2}} - \frac{2}{3\sqrt{3}}\right) \frac{e^2}{a^2}(p-q),$$

and, since $2 - \frac{3}{2\sqrt{2}} - \frac{2}{3\sqrt{3}}$ is positive, the cubical arrangement is unstable for a displacement when $p-q$ has a finite value. We can show also that the cubical arrangement is unstable, even although a corpuscle is placed at the centre.

The stable arrangement for eight particles is when we have six particles at the corners of an octahedron and two others at equal distances from the centre on one of the lines joining opposite corners of the octahedron; the octahedron will no longer be regular, the axis along which the two extra particles are placed being longer than the other two, approximately in the proportion of 4 to 3, the distance of the inner particles from the centre is about $\frac{2}{3}$ of the distance of the furthest corner of the octahedron from the centre.

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On the positive electrification of α rays, and the emission of slowly moving cathode rays by radioactive substances. By J. J. THOMSON, M.A., F.R.S.

[Read 14 November 1904.]

The experiments described below were undertaken with the object of detecting the positive charge on the α rays. Rutherford

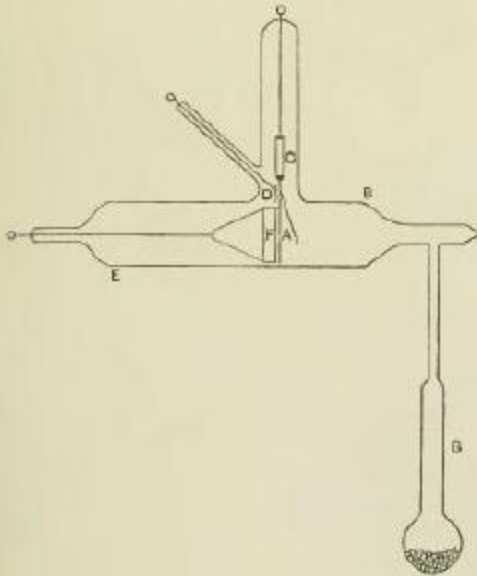


FIG. 1.

has shown that the α rays are deflected by electric and magnetic forces in the same direction as a positively electrified body, but I

am not aware of any experiments in which the positive electricity carried by these rays has been transferred to a conductor and detected by the electrification of the conductor. I only succeeded in doing this after a lengthy investigation in the course of which some properties of polonium and radium, which seem interesting and important, came to light.

The first experiments were made with polonium. This body is supposed only to give out α rays so that it seemed especially suitable for this purpose; it was found however that polonium gives out in addition to α rays large quantities of slowly moving cathode rays.

The polonium (obtained from Sthamer) was deposited on two discs, one bismuth, the other copper. The method used was as follows. A gold-leaf electroscope *A* (Fig. 1) was placed in *B*, a large glass vessel coated with tinfoil, connected with the earth. The leaves of the electroscope were supported by a stick of fused quartz *C*, and were charged by the wire *D*. The polonium discs were placed in the side tube *E*; in the earlier experiments the disc was about 4 cm. from the electroscope. *G* is a tube containing hard charcoal, it was added for the purpose of obtaining high vacuum by Devar's method of immersing charcoal in liquid air; for the experiments we are describing to succeed the vacuum has to be exceedingly good, and I have found Dewar's method of the greatest possible assistance, giving in a few hours better vacuum than I previously obtained by several days' pumping.

The vessel containing the electroscope and polonium was set up between the poles of a powerful electro-magnet which when excited gave a field of about 1200 c.o.s. units between the polonium and the electroscope.

In these experiments the electroscope was charged alternately with positive and negative electricity, and the rate of collapse of the leaves measured by a reading microscope provided with a micrometer eye-piece. The potential to which the electroscope was charged was ± 180 volts. If the polonium gave out only α rays we should expect the rate of leak to be much more rapid when the electroscope is charged with negative electricity than when charged with positive. It was found however that exactly the opposite effect occurred, the leak being almost negligible when the charge in the electroscope is negative and very appreciable when the charge is positive. The following observations are samples of a large number all showing the same effect.

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Distance of polonium from electroscope 4 cm.

Leak in five minutes in scale divisions of microscope eye-piece	Charge on electroscope	Magnet
70	+	off
2.5	+	on
5	-	off
5	-	on

*Distance of polonium from electroscope 5 cm. (this was
a different tube).*

50	+	off
1	+	on
1	-	off
1	-	on

Thus we see that when the electroscope is charged with positive electricity there is a large leak which is practically stopped by a magnetic field, while when the charge is negative there is very little leak. This shows that the polonium gives out streams of negative electricity, we have however as yet no indication of any emission of positive. I was never able to get an increase in the negative charge of the electroscope, this I attribute to the velocity of the cathode rays given out by the polonium being so low that they are not able to make their way against the repulsion exerted by the negatively electrified electroscope. In order to be sure that the effect was due to the polonium I had the polonium disc mounted on swivels so that by tapping the disc could be made to rotate about a vertical axis and the face on which the polonium is deposited made to face towards or away from the electroscope. When the polonium-coated face of the disc was towards the electroscope, the leak, when the latter was charged positively, was 45 divisions when the magnet was off, six divisions when the magnet was on; when the electroscope was charged negatively the leak was seven divisions when the magnet was off, three when it was on; the disc was then tapped until it turned through 180 degrees, the polonium-coated face now facing down the tube *E*, and away from the electroscope, the leak when the electroscope was positively charged was now only three when the magnet was off, and it was too small to detect when the magnet was on. When the electroscope was negatively charged the leak was one with the magnet off, zero with it on. This shows that the leak observed is due to the polonium. There is however a considerable leak when the disc is so placed that rays proceeding normally from the disc could not

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strike against the electroscope, thus when the disc was tapped so that it turned through an angle of 90° , from the position in which the polonium faced the electroscope, the leak in the electroscope for a positive charge with the magnet off only fell from 45 to 22, although in the new position no rays at right angles to the disc could reach the electroscope. The negative particles which discharge the disc in this case come from the walls of the vessel and are either diffusely reflected cathode rays originating from the polonium or are due to secondary radiation excited by the rays from the polonium.

The absence of any appreciable leak in the preceding experiments, when the electroscope is charged negatively, even when the negatively charged cathode rays are prevented by the magnetic field from reaching the electroscope, shows that the α rays must lose their positive charge, or rather have it neutralized by the negative charge on the cathode rays, as they pass through the swarm of cathode rays. These experiments have given no indication of the positive charge on the α rays. I will now pass on to some experiments by which the positive charge on these rays can be detected. In these the polonium disc instead of being at a distance of 4 or 5 cm. from the electroscope is placed as close to it as possible: the distance in the experiments in which the following results were obtained was 1 millimetre.

Leak in scale divisions in five minutes	Charge on electroscope	Magnet
31	+	off
0	+	on
9	-	off
5	-	on

It will be noticed that although with the magnet off the leak is as before much greater when the electroscope is charged positively than when it is charged negatively, owing to the copious emission of slow cathode rays by the polonium, yet now when the magnetic field is on the negatively electrified body shows by far the bigger leak, in fact there is no appreciable leak with the positive charge. We see that now the α particles are able to reach the electroscope and give up their charge to it, these particles are but little affected by the magnetic field, while the cathode particles are almost entirely stopped by it. The leak when the electroscope is charged negatively cannot be wholly due to secondary cathode rays emitted by the electroscope when bombarded by the α rays from the polonium, for these cathode rays unless moving with a velocity of about 10^9 cm./sec. would be stopped by the magnetic field, although it is probable that when no magnetic field acts upon the vessel, part of the leak, when the

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electroscope is negative, may be due to this cause. A series of measurements were made varying the distance between the polonium and the electroscope, and it was found that as the distance increased the leak increased, when the charge in the electroscope was positive, and diminished when it was negative.

Experiments with Radium.

Similar experiments were made using radium instead of polonium, the radium used was one of the earlier samples procured from de Haen and was not very strong. The radium was spread over a horizontal disc placed about 2 millimetres below a similar disc fastened to the electroscope, the results obtained with this were the same as with the polonium. Thus when the electroscope was charged positively the leak was 39 in 10 minutes with the magnet off, 7 with the magnet on, while when the electroscope was charged negatively the leak was 11 with the magnet off, 10 with the magnet on. Thus we have again the positive leak larger than the negative when the magnet is off, and smaller when it is on. The negative leak diminishes as the distance of the radium from the electroscope increases, and when this distance is a few centimetres the negative leak is very small compared with the positive.

The preceding experiments show that polonium and radium emit copious streams of slowly moving negative corpuscles, these streams only differ in the velocity of the particles from the β rays hitherto investigated, and it is to be observed that they would escape detection by the methods hitherto used to investigate β rays, for such methods only detect β rays able to traverse a considerable thickness of aluminium foil, i.e. β rays of great velocity, in fact the ability to penetrate this foil has been taken as the definition of a β ray. We see too that if we define an α ray as one absorbed by a thin layer of aluminium foil, that α rays may be of two kinds, one carrying positive, the other negative charges. The existence of these slow negative rays may have a very important bearing on the transformations which radio-active matter undergoes, it may also be the explanation why the radium emanation which does not emit the fast β rays, yet seems to acquire a positive charge and be attracted by negatively electrified bodies; this would be the case if the emanation like polonium gave out the slow β rays. Investigations are in progress at the Cavendish Laboratory to see whether the emission of these slow cathode rays is a general property of radio-active substances.

Another point brought out by these experiments is the way in which these slow β rays tend to neutralize the positive charge on the α rays. This tendency for the α rays to lose their charge has

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an important bearing on the determination of e/m for the α rays. In these determinations it has been assumed that the α ray retained its positive charge during the whole of its path under the electric and magnetic forces, in the light of the above experiments it seems by no means certain that this is the case. The point could be tested by making experiments with different lengths of paths; if the α ray retains its charge, alteration in the length of path would not affect e/m , if the ray lost its charge it would.

I wish to acknowledge my obligation to my assistant, Mr E. Everett, for the help he has given me with these experiments.

ANEXO 8 – Artigo E. Rutherford e T. Royds. *Philosophical Magazine*, 1909.**Ernest Rutherford (1871-1937) and T. Royds****The Nature of the α Particle from Radioactive Substances.**

E. Rutherford and T. Royds[1]. *Phil. Mag.* 17, 281-6 (1909) [from Stephen Wright, ed., *Classical Scientific Papers--Physics* (New York: American Elsevier, 1964)]

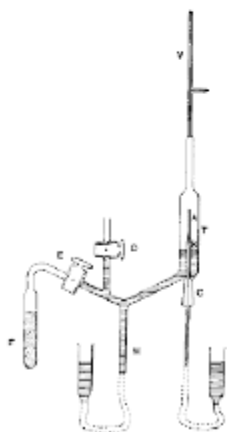
The experimental evidence collected during the last few years has strongly supported the view that the α particle is a charged helium atom, but it has been found exceedingly difficult to give a decisive proof of the relation. In recent papers, Rutherford and Geiger[2] have supplied still further evidence of the correctness of this point of view. The number of α particles from one gram of radium have been counted, and the charge carried by each determined. The values of several radioactive quantities, calculated on the assumption that the α particle is a helium atom carrying two unit charges, have been shown to be in good agreement with the experimental numbers. In particular, the good agreement between the calculated rate of production of helium by radium and the rate experimentally determined by Sir James Dewar[3], is strong evidence in favour of the identity of the α particle with the helium atom.

The methods of attack on this problem have been largely indirect, involving considerations of the charge carried by the helium atom and the value of e/m of the α particle. The proof of the identity of the α particle with the helium atom is incomplete until it can be shown that the α particles, accumulated quite independently of the matter from which they are expelled,

consist of helium. For example, it might be argued that the appearance of helium in the radium emanation was a result of the expulsion of the α particle, in the same way that the appearance of radium A is a consequence of the expulsion of an α particle from the emanation. If one atom of helium appeared for each α particle expelled, calculation and experiment might still agree, and yet the α particle itself might be an atom of hydrogen or of some other substance.

We have recently made experiments to test whether helium appears in a vessel into which the α particles have been fired, the active matter itself being enclosed in a vessel sufficiently thin to allow the α particles to escape, but impervious to the passage of helium or other radioactive products.

The experimental arrangement is clearly seen in the figure. The equilibrium quantity of emanation from



about 140 milligrams of radium was purified and compressed by means of a mercury-column into a fine glass tube A about 1.5 cms. long. This fine tube, which was sealed on a larger capillary tube B, was sufficiently thin to allow the α particles from the emanation and its products to escape, but sufficiently strong to withstand atmospheric pressure. After some trials, Mr. Baumbach succeeded in blowing such fine tubes very uniform in thickness. The thickness of the wall of the tube employed in most of the experiments was less than 1/100 mm., and was equivalent in stopping power of the α particle to about 2 cms. of air. Since the ranges of the α particles from the emanation and its products radium A and [radium C](#) are 4.3, 4.8, and 7 cms. respectively, it is seen that the great majority[4] of the α particles expelled by the active matter escape through the walls of the tube. The ranges of the α particles after passing through the glass were determined with the aid of a zinc-sulphide screen. Immediately after the introduction of the emanation the phosphorescence showed brilliantly when the screen was close to the tube, but practically disappeared at a distance of 5 cms. Such a result is to be expected. The phosphorescence initially observed was due mainly to the α particles of the emanation and its product radium A (period 3 mins.). In the course of time the amount of radium C, initially zero, gradually increased, and the α radiations from it of range 7 cms. were able to cause phosphorescence at a greater distance.

The glass tube A was surrounded by a cylindrical glass tube T, 7.5 cms. long and 1.5 cms. diameter, by means of a ground-glass joint C. A small vacuum-tube V was attached to the upper end of T. The outer glass tube T was exhausted by a pump through the stopcock D, and the exhaustion completed with the aid of the charcoal tube F cooled by liquid air. By means of a mercury column H attached to a reservoir, mercury was forced into the tube T until it reached the bottom of the tube A.

Part of the α particles which escaped through the walls of the fine tube were stopped by the outer glass tube and part by the mercury surface. If the α particle is a helium atom, helium should gradually diffuse from the glass and mercury into the exhausted space, and its presence could then be detected spectroscopically by raising the mercury and compressing the gases into the vacuum-tube.

In order to avoid any possible contamination of the apparatus with helium, freshly distilled mercury and entirely new glass apparatus were used. Before introducing the emanation into A, the absence of helium was confirmed experimentally. At intervals after the introduction of the emanation the mercury was raised, and the gases in the outer tube spectroscopically examined. After 24 hours no trace of the helium yellow line was seen; after 2 days the helium yellow was faintly visible; after 4 days the helium yellow and green lines were bright; and after 6 days all the stronger lines of the helium

spectrum were observed. The absence of the neon spectrum shows that the helium present was not due to a leakage of air into the apparatus.

There is, however, one possible source of error in this experiment. The helium may not be due to the α particles themselves, but may have *diffused* from the emanation through the thin walls of the glass tube. In order to test this point the emanation was completely pumped out of A, and after some hours a quantity of helium, about 10 times the previous volume of the emanation, was compressed into the same tube A.

The outer tube T and the vacuum-tube were removed and a fresh apparatus substituted. Observations to detect helium in the tube T were made at intervals, in the same way as before, but no trace of the helium spectrum was observed over a period of eight days.

The helium in the tube A was then pumped out and a fresh supply of emanation substituted. Results similar to the first experiment were observed. The helium yellow and green lines showed brightly after four days.

These experiments thus show conclusively that the helium could not have diffused through the glass walls, but must have been derived from the α particles which were fired through them. In other words, the experiments give a decisive proof that the α particle after losing its charge is an atom of helium.

Other Experiments.

We have seen that in the experiments above described helium was not observed in the outer tube in sufficient quantity to show the characteristic yellow line until two days had elapsed. Now the equilibrium amount of emanation from 100 milligrams of radium should produce helium at the rate of about .03 c. mm. per day. The amount produced in one day, if present in the outer tube, should produce a bright spectrum of helium under the experimental conditions. It thus appeared probable that the helium fired into the glass must escape very slowly into the exhausted space, for if the helium escaped at once, the presence of helium should have detected a few hours after the introduction of the emanation.

In order to examine this point more closely the experiments were repeated, with the addition that a cylinder of thin sheet lead of sufficient thickness to stop the α particles was placed over the fine emanation tube. Preliminary experiments, in the manner described later, showed that the lead-foil did not initially contain a detectable amount of helium. Twenty-four hours after the introduction into the tube A of about the same amount of emanation as before, the yellow and green lines of helium in this case after one day was of about the same intensity as that after the fourth day in the experiments without the

lead screen. It was thus clear that the lead-foil gave up the helium fired into it far more readily than the glass.

In order to form an idea of the rapidity of escape of the helium from the lead some further experiments were made. The outer cylinder T was removed and a small cylinder of lead-foil placed round the thin emanation-tube surrounded the air at atmospheric pressure. After exposure for a definite time to the emanation, the lead screen was removed and gested [sic--tested?] for helium as follows. The lead-foil was placed in a glass tube between two stopcocks. In order to avoid a possible release of the helium present in the lead by pumping out the air, the air was displaced by a current of pure electrolytic oxygen [5]. The stopcocks were closed and the tube attached to a subsidiary apparatus similar to that employed for testing for the presence of neon and helium in the gases produced by the action of the radium emanation on water (Phil. Mag. Nov. 1908). The oxygen was absorbed by charcoal and the tube then heated beyond the melting-point of lead to allow the helium to escape. The presence of helium was then spectroscopically looked for in the usual way. Using this method, it was found possible to detect the presence of helium in the lead which had been exposed for only four hours to the α rays from the emanation. After an exposure of 24 hours the helium yellow and green lines came out brightly. These experiments were repeated several times with similar results.

A number of blank experiments were made, using samples of the lead-foil which had not been exposed to the α rays, but in no case was any helium detected. In a similar way, the presence of helium was detected in a cylinder of tinfoil exposed for a few hours over the emanation-tube.

These experiments show that the helium does not escape at once from the lead, but there is on the average a period of retardation of several hours and possible longer.

The detection of helium in the lead and tin foil, as well as in the glass, removes a possible objection that the helium might have been in some way present in the glass initially, and was liberated as a consequence of its bombardment by the α particles.

The use of such thin glass tubes containing emanation affords a simple and convenient method of examining the effect on substances of an intense α radiation quite independently of the radioactive material contained in the tube.

We can conclude with certainty from these experiments that the α particle after losing its charge is a helium atom. Other evidence indicates that the charge is twice the unit charge carried by the hydrogen atom set free in the electrolysis of water.

University of Manchester,
Nov. 13, 1908

[1] Communicated by the Authors.

[2] Proc. Roy. Soc. A. lxxxix, pp. 141-173 (1908).

[3] Proc. Roy. Soc. A. lxxxix, p. 280 (1908).

[4] The α particles fired at a very oblique angle to the tube would be stopped in the glass. The fraction stopped in this way would be small under the experimental conditions.

[5] That the air was completely displaced was shown by the absence of neon in the final spectrum.

ANEXO 9 – Artigo Geiger, H. Marsden, E. *Proceedings of the Royal Society*, 1909.**On a Diffuse Reflection of the α -Particles**

Proc. Roy. Soc. 1909 A
vol. 82, p. 495-500

By H. GEIGER, Ph.D., John Harling Fellow, and E. MARSDEN, Hatfield
Scholar, University of Manchester.

(Communicated by Prof. E. Rutherford, F.R.S. Received May 19, -- Read
June 17, 1909.)

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When β -particles fall on a plate, a strong radiation emerges from the same side of the plate as that on which the β -particles fall. This radiation is regarded by many observers as a secondary radiation, but more recent experiments seem to show that it consists mainly of primary β -particles, which have been scattered inside the material to such an extent that they emerge again at the same side of the plate.* For α -particles a similar effect has not previously been observed, and is perhaps not to be expected on account of the relatively small scattering which α -particles suffer in penetrating matter.**

In the following experiments, however, conclusive evidence was found of the existence of a diffuse reflection of the α -particles. A small fraction of the α -particles falling upon a metal plate have their directions changed to such an extent that they emerge again at the side of incidence. To form an idea of the way in which this effect takes place, the following three points were investigated:

- (I) The relative amount of reflection from different metals.
- (II) The relative amount of reflection from a metal of varying thickness.
- (III) The fraction of the incident α -particles which are reflected.

* See Schmidt, 'Jahrbuch der Radioaktivität und Elektronik,' vol. 5, p. 471, 1908.

** Rutherford, 'Phil. Mag.,' vol. 12, p. 143, 1906; H. Geiger, 'Roy. Soc. Proc.,' A, vol. 81, p. 174, 1908.

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For the observation of the reflected particles the scintillation method was used in all experiments. With regard to the details of the method we refer to the papers of Regener* and of Rutherford and Geiger.**

On account of the fact that the amount of reflection is very small, it was necessary to use a very intense source of α -rays. A tube was employed similar to that which has been proved to be a suitable source in the scattering experiments of one of us.*** This source consisted of a glass tube AB (fig. 1),

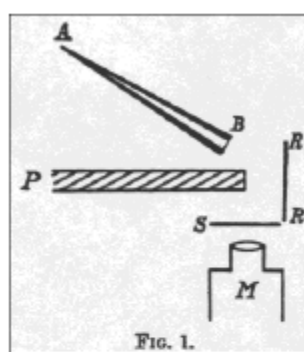


FIG. 1.

drawn down conically and filled with radium emanation, the end B of the tube being closed airtight by means of a mica window. The thickness of the mica was equivalent to about 1 cm. of air, so that the α -particles could easily pass through it.

Since it is of importance that the gas pressure inside this tube should be as low as possible, the emanation was purified according to the methods developed by Prof. Rutherford.**** The tube contained an amount of emanation equivalent to about 20 milligrammes RaBr_2 at a pressure of a few centimetres. The number of α -particles expelled per second through the window

was, therefore, very great, and, on account of the small pressure inside the tube, the different ranges of the α -particles from the three products (i.e. emanation, RaA, and RaC) were sharply defined.

The zinc sulphide screen S (fig. 1) was fixed behind the lead plate P, in such a position that no α -particles could strike it directly. When a reflector was placed in the position RR at about 1 cm. from the end of the tube, scintillations were at once observed. At the same time the screen brightened up appreciably on account of the reflected β -particles.

By means of a low power microscope, the number of scintillations per minute on a definite square millimetre of the screen was counted for reflectors of different materials. Care was taken that the different reflectors were always placed in exactly the same position.

It is, of course, to be expected that the number of α -particles reflected from the plate would be different in different directions, and would also depend on the angle of incidence. In our arrangement, however, no appreciable difference was found for different angles. This is due to the fact that,

* *Verh. d. D. Phys. Ges.*, vol. 10, p. 78, 1908.
 ** *Roy. Soc. Proc. A*, vol. 81, p. 141, 1908.
 *** *Geiger, Roy. Soc. Proc. A*, vol. 81, p. 174, 1908.
 **** *Phil. Mag.*, August p. 300, 1908.

owing to the necessity of having the tube very near to the reflector, the angle of incidence varied very much. An investigation of the variation of the effect

with the angles of incidence and emergence would necessitate a parallel and very intense source of homogeneous α -rays, which can, however, not easily be realised.

In the following table the number of scintillations observed per minute are given in column 3; in column 4 the ratio to the atomic weight is calculated, and it can be seen that this ratio decreases with decreasing atomic weight. The case of lead appears to be an exception which may be due to slight impurities in the lead.

1. Metal	2. Atomic weight, A	3. Number of scintillations per minute, Z.	4. A/Z.
Lead	207	62	30
Gold	197	67	34
Platinum	195	63	33
Tin	119	34	28
Silver	108	27	25
Copper	64	14.5	23
Iron	56	10.2	18.5
Aluminium	27	3.4	12.5

Even in the absence of any reflector about one scintillation per minute was observed. It was easy to show that this was due to a reflection from the air through which the α -particles passed. The numbers on the table are corrected for this effect. It is interesting to note here that for β -particles the number of reflected particles also decreases with the atomic weight of the reflector.* But while for β -particles the number reflected from gold is only about twice as great as for aluminium, for α -particles the same ratio amounts to about twenty.

(II) We have already pointed out that the diffuse reflection of the α -particles is a consequence of their scattering. According to this point of view, the number of particles reflected must vary with the thickness of the reflecting screen. Since gold can be obtained in very thin and uniform foils, different numbers of these foils were used as reflectors. Each foil was equivalent in stopping power to about 0.4 mm. of air. It was necessary to mount the foils on glass plates, but the number reflected from the glass itself was found to be very small compared even with the number from one gold foil. The curve, fig. 2, gives the result of the measurements.

* McClelland, Dublin Trans., vol. 9, p. 9, 1906.

The number of scintillations which were due to the reflection from the air is subtracted from each reading. The first point on the curve represents the number of scintillations observed for a glass plate alone as reflector; the last point (marked 30) gives the number of scintillations when a thick gold plate was used.

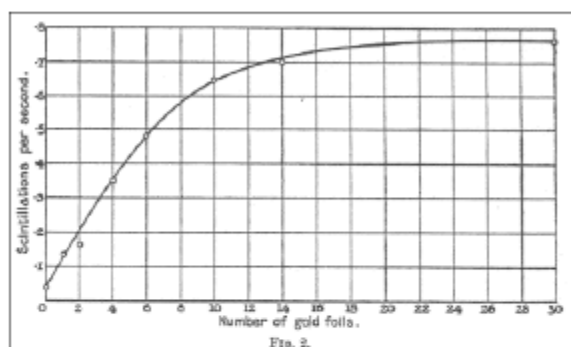


FIG. 2.

The curve is similar to those which have been obtained for the reflection of the β -particles.* It brings out clearly that the reflection is not a surface but a volume effect.

Compared, however, with the thickness of gold which an α -particle can penetrate, the effect is confined to a relatively thin layer. In our experiment, about half of the reflected particles were reflected from a layer equivalent to about 2 min. of air. If the high velocity and mass of the α -particle be taken into account, it seems surprising that some of the α -particles, as the experiment shows, can be tamed within a layer of 6×10^{-3} cm. of gold through an angle of 90° , and even more. To produce a similar effect by a magnetic field, the enormous field of 10^6 absolute units would be required.

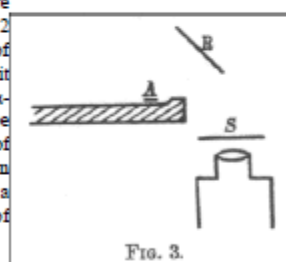


FIG. 3.

(III) In the next experiment, an estimate of the total number of particles reflected was aimed at. For this purpose the emanation tube used in the previous experiments was unsuitable, firstly, on account of the difficulty of correctly ascertaining the number of α -particles emerging from the tube; and secondly, on account of the different ranges of the α -particles from the

* McClelland, 'Phil. Mag.', vol. 9, p. 230, 1905; 'Ann. d. Phys.', vol. 18, p. 974, 1905; Schmidt, 'Ann. d. Phys.', vol. 23, p. 671, 1907; 'Phys. Zeit.', vol. 8, p. 737, 1907.

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three products: emanation, radium A, and radium C. Consequently, as radiating source, radium C, deposited on a plate of small dimensions, was used. The arrangement, which is sketched in fig. 3, was such that the α -particles from the plate A fell upon the platinum reflector R, of about 1 square centimetre area, at an average angle of 90° . The reflected particles were counted on different points of the screen S.

No appreciable variation of the number was found with different angles of emergence, the reason of which has already been explained above.

The amount of radium C deposited on the plate was determined by its γ -ray activity. Assuming that 3.4×10^{10} particles are expelled per second from an amount of RaC equivalent to 1 gramme Ra,* the number of α -particles expelled per second from the active plate was determined. The number falling on the platinum reflector was then easily calculated from its known distance and area. To find the whole number of reflected particles, it was assumed that they were distributed uniformly round a half sphere with the middle of the reflector as centre.

Three different determinations showed that of the incident α -particles about 1 in 8000 was reflected, under the described conditions.

A special experiment conducted at low pressure showed that in the case of grazing incidence the number of particles reflected at a very small angle to the reflector is largely in excess of the number calculated from the above ratio. This tangential scattering is of considerable importance in some experiments; for instance, if α -particles from a radio-active source are fired along a glass tube of appreciable length the conditions are very favourable for this effect. The number of scintillations counted on a screen sealed to the other end of the tube is made up not only of the particles striking the screen directly, but also of those which have been reflected from the glass walls of the tube.

The correction for the latter effect may be appreciable, and would be still greater in the case of a metal tube. In the counting experiments of Rutherford and Geiger this effect did not influence the final result, the arrangement being such that the reflected particles were prevented from entering the opening of the ionisation vessel by the narrow constriction of a stopcock.

It appears probable that the number of reflected particles depends also upon the velocity of the α -particles falling on the reflector. In our case

* Rutherford and Geiger, 'Roy. Soc. Proc.,' A, vol. 81, p. 162, 1906.

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the particles from the radium C had to travel through a little over a centimetre of air before reaching the reflector. The reflected particles had still an appreciable velocity, since, by interposing an aluminium foil of thickness equivalent in stopping power to 1/2 cm. of air, the number of scintillations counted was not changed. This might be expected from Experiment (II), which showed that the α -particles are reflected from a relatively thin surface layer of the reflector.

We are indebted to Prof. Rutherford for his kind interest and advice throughout this research.

ANEXO 10 – Artigo Geiger, H. *Proceedings of the Royal Society*, 1910.

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The Scattering of the α -Particles by Matter

By H. GEIGER, Ph.D.
Proceedings of the Royal Society
vol. A83, p. 492-504

(Communicated by Prof. E. Rutherford, F.R.S. Received February 1, --
Read February 17, 1910.)

In a preliminary note (Roy. Soc. Proc., A, vol. 81, p. 174, 1908) on the above subject, experiments were described which gave direct evidence of the scattering of the α -particles.* In those experiments a strong source of α -radiation was placed at one end of a long exhausted tube, and the α -particles, after passing through a narrow slit, fell upon a zinc sulphide screen sealed to the other end of the tube. When the pressure inside the tube was very low, the narrow line of scintillations which marked the place of incidence of the α -particles, on the screen was well defined, but, when the rays on their way to the screen passed through gas or through thin metal foils the edges of this line of scintillations became indistinct. The amount of scattering could be estimated for different foils by placing them in the path of the rays and noting the distribution of the scintillations on the screen.

The present investigation was undertaken with a view to obtain quantitative measurement of the scattering by determining the most probable angle through which an α -particle of definite range is turned by passing through a given thickness of matter. The following are the chief points investigated: --

- (1) Determination of the amount of scattering produced in different thicknesses of the same material.
- (2) Comparison of the amounts of scattering produced in different materials.
- (3) Relation between the velocity of the α -particles and the amount of their scattering.

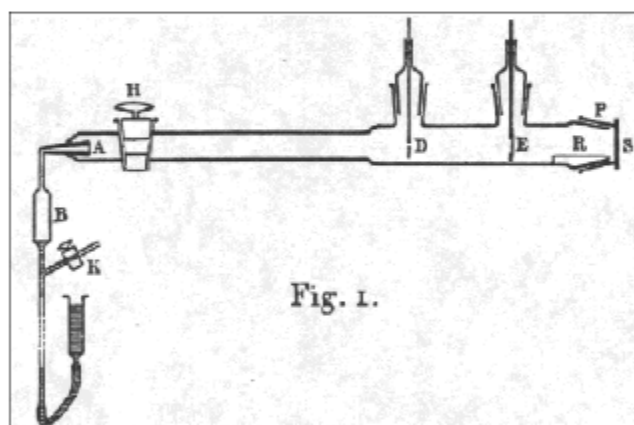
Experimental Arrangements

Since the amount by which the α -particles are scattered is comparatively small, accurate measurements could only be obtained in the way outlined above by the use of a very narrow beam of α -particles. In consequence it was necessary to employ a very small and intense source. In the early experiments the radiating source consisted of a short glass tube drawn down * The phenomenon of the scattering of the α -particles was first observed by

Rutherford (Phil. Mag., vol. 12, p. 143, 1906), and discussed later by Kucera and Masek, W. H. Bragg, L. Meitner, and E. Meyer.

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conically at one end and closed tightly at the other end by a very thin sheet of mica. The tube was filled with radium emanation and the α -particles expelled from it and its active deposit, could easily pass through the mica window. Although this source fulfilled the conditions of being intense and narrow, it was not suitable for quantitative measurements, as its radiation was not homogeneous, firstly, on account of the different α -ray products present, and, secondly, owing to the absorption by the gas inside the tube. For these reasons the radiating source was modified in a way which will be understood from fig. 1. The conical glass tube A (of less than 2 mm.



diameter at its wider end) was sealed by its narrow end to a glass tube, of very fine bore, leading to the bulb B. A quantity of radium emanation corresponding to about 50 milligrammes RaBr, which had been partially purified by the methods developed by Prof. Rutherford (Phil. Mag. vol. 16, p. 300, 1908), was introduced into the exhausted bulb B through the stopcock K. The whole emanation was then compressed into the conical tube by means of mercury. During this process the pressure increased, usually becoming nearly atmospheric. After three hours the active deposit formed from the emanation on the walls of the conical tube had reached nearly its maximum value. At this stage the emanation was expanded again into the bulb B.

On account of the volume of the bulb B being about 200 times that of the conical tube, the pressure on expanding decreased to less than 4 mm., and the amount of α -radiation from the emanation remaining in A was negligible compared with that from the active deposit present on the walls.

Fifteen minutes after the expansion of the emanation the first product of the active deposit, viz., Radium A, had decayed to an inappreciable value, and

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the whole α -radiation passing through the window was homogeneous, consisting only of the α -particles expelled from Radium C. This radiation decays to half its value in about one hour, but since the law of decay accurately known, corrections could easily be applied for measurement taken at different times after expansion.

A small fraction of the α -particles emitted from the source A passed through the narrow circular opening D (of less than 1 mm. diameter), and produced a luminous spot of scintillations on the zinc sulphide screen S. The scattering foils could be brought into the path of the rays, either at E at a distance of 13 cm. from the screen, or at D directly, in front of the diaphragm. Foils of higher scattering power could be introduced through the joint P and fixed in position on the slide R at any point near to the screen.

The scintillations were counted by means of a suitable microscope which could be moved vertically by means of a screw along a millimetre scale fitted with a vernier. The field visible through the microscope had a diameter of 1.1 mm.

Determination of the most probable Angle of Scattering

Provided that the tube through which the α -particles had to pass was completely exhausted, the spot of scintillations produced by the impact of the α -particles on the screen had a diameter of 1.2 mm., and was clearly visible with the unaided eye. When a sheet of metal, equivalent in stopping power to a few millimetres of air, was placed in the path of the rays at a point close to the screen, the brightness of the spot of scintillations remained practically undiminished. But when the same sheet was placed at a greater distance from the screen, say at D (fig. 1), the bright spot disappeared completely, the scintillations being distributed over a much greater area than formerly.

A microscopic examination of the screen showed that the density of scintillations was still greatest in the centre, but decreased steadily with increasing distance from the centre. By counting the number of scintillations at different distances

from the centre, the most probable angle through which an α -particle is turned by passing through the scattering material could be determined as follows:--

Denoting the distance of the scattering foil to the screen by s , the angle through which the α -particles observed at a distance r from the centre been turned is approximately r/s . The whole number of α -particles turned through this angle r/s is then represented by $2[\pi]nrdr$, where n is the density of the α -particles striking the screen at the distance r from the centre. If we plot the number of particles $2[\pi]nrdr$ turned through the angle r/s against

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that angle we obtain a curve which gives the probability of the occurrence of any scattering angle r/s . This curve is, in many respects, similar to Maxwell's distribution curve of the velocities of the gas molecules. Its maximum corresponds to the most probable angle through which an α -particle is turned by passing through the scattering foil.

In order to determine experimentally the most probable angle of scattering in this way, it is necessary that the distance r at which the scintillations produced by the α -particles are counted should be large, compared with the field of the microscope and large also compared with the area covered by the scintillations when no scattering foil is interposed. These conditions could not be fully realised in the experimental arrangement. This was mainly due to the fact that on account of the limited intensity of the source the distance of the scattering foil from the screen had to be adjusted so that the greater part of the scintillations should be confined within an area of 3 to 4 mm. diameter. If the distance was increased further, although the amount of scattering would appear greater on the screen, yet the scintillations would be spread out too much for reliable countings to be made. In most of the experiments observations could only be taken up to a distance of about 5 to 7 mm. from the centre. It would be difficult to assign a definite value for the correction which had to be applied, but the magnitude of the probable error could easily be estimated by comparing separate determinations of the most probable angle of scattering for the same foil placed at different distances from the screen.

Several comparative measurements of this kind were made and their agreement showed that the error was negligible. For instance, the distribution of the scintillations over the screen was determined, firstly, when a piece of tinfoil was placed at a distance of 6.4 cm. from the screen: secondly, when the same foil was placed at a distance of 2.72 cm. The two curves showed a maximum at 3.1 and 1.4 mm. from the centre respectively which correspond to most probable angles of scattering of 2.8° and 3° .

In describing the procedure of an experiment it will be of advantage to take a special case. In one experiment, for instance, 35 gold foils, which were equivalent in stopping power to 3.68 cm. of air, were placed at a distance of 1.64 cm. from the screen. After introducing the foils the whole apparatus was exhausted by means of a Fleuss pump and finally by charcoal dipping in liquid air. Meanwhile the emanation, which had been kept compressed in the tube A for sufficient time for the active deposit to reach the equilibrium value was expanded into the bulb B. Usually 1.5 minutes after expansion the counting of scintillations was entered upon. In this special case, however measurements could be started at once, since the mica window of the tube A

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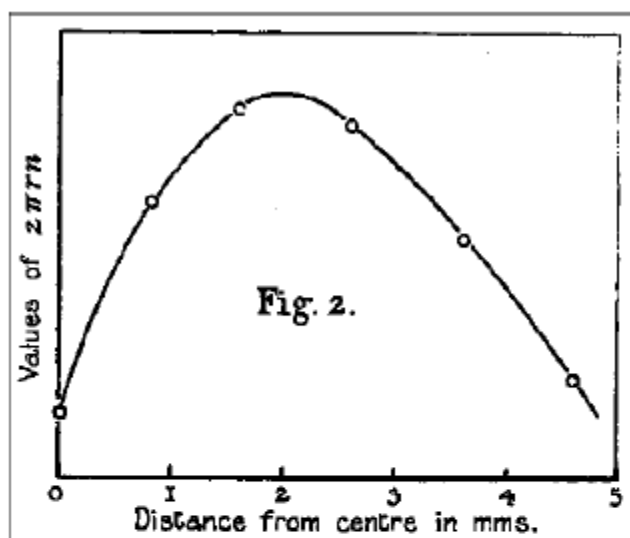
and the gold foils were sufficient to stop all the α -particles emitted from Radium A.

As a rule the number of scintillations at points farthest away from the centre, was determined first, in order to take advantage of the high initial intensity of the α -ray radiation. The counting experiments were continued for about 70 minutes. After that time the activity of the source became too small to allow reliable measurements to be made. The emanation was then again compressed to permit another set of readings to be taken after three hours' interval. The numerical results obtained for 35 gold foils are given in the table below

1.	2.	3.		4.	5.
Distance r from centre in mm.	Time of observation in minutes after expansion	Number n of scintillations per minute.		Corrected for decay.	$2(\pi r)^n$
		Observed.			
4.6	7	3.3		3.4	98
3.6	16	8.5		9.4	212
2.6	24	16.1		19.4	316
1.6	38	22.1		33.0	330
0.8	49	27.2		49.3	247
(centre)	58	25.2		55.0	55

Whole number of scintillations counted in this experiment 803.

Column 1 shows the distance from the centre at which scintillations were counted. The number of scintillations observed per minute are entered in Column 3, and those corrected for decay in Column 4. The calculated values of $2(\pi r)^n$ (Column 5) are plotted in fig. 2 against the distance from the



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centre. The maximum of the curve, which occurs at 2 mm. from the centre, corresponds to the most probable deflection. Since the distance from scattering foil to screen was 1.64 cm., the most probable angle through which the α -particles were turned in passing through the 35 gold foils was nearly 7° .

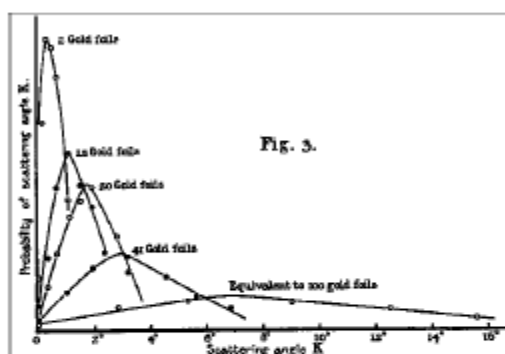
The average angle through which an α -particle is turned will be somewhat greater than the most probable angle. In the following, reference is always made to the most probable angle, the determination of which can be obtained with greater accuracy than that of the average angle which involves a determination of the area of the curve. Since, however, the distribution curves, found for different metals and varying thicknesses were similar in shape, it appears probable that the ratio between the average and most probable angle is the same in all cases.

The Scattering produced by different Thicknesses of the same Material

As in the experiment described above, the most probable angle through which the α -particles were turned was measured for different thicknesses of gold. Gold appeared to be the most suitable substance for such comparative measurements, since it can be obtained in very thin and uniform foils, and in

addition its scattering power is higher than that of any other material available. Two different types of gold foil were used: the thinner foil corresponded to 0.038 cm. of air, the thicker foil to 0.108 cm.

Some of the probability curves are plotted in fig. 3 after reducing them



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to such a scale that their areas were equal. This reduction was necessary as the total intensity of the radiation was not the same in different experiments.

In the following Table, Column 3 gives the distances from the screen, at which the foils were placed, and Column 4 gives the corresponding distance from the centre of the maximum in the distribution curve. From these figures the most probable angle of scattering is calculated and given in Column 5. The curve which connects the probable angle of scattering with the thickness of gold through which the α -particles had to pass is shown, in fig. 4. The values obtained for the thin type of gold foils are denoted by circles, those for the thick type by dots. The thick gold foils were not so uniform as the thin ones, this probably being the reason that the points obtained for thick gold foil fall slightly higher than the corresponding ones for the thin foils.

Table II.

1.	2.	3.	4.	5.
Number of gold foils	Stopping power expressed in cm. of air	Distance of foil from screen	Most probable deflection	Most probable scattering angle
	cm.	cm.	cm.	° '

1 thin gold foil	0.04	32.0	0.09	0	10
2 thin gold foils	0.08	30.5	0.20	0	23
4 " "	0.15	30.5	0.32	0	36
8 " "	0.29	14.1	0.20	0	49
12 " "	0.46	13.8	0.28	1	10
20 " "	0.76	13.8	0.41	1	40
30 " "	1.14	6.2	0.25	2	20
41 " "	1.53	4.72	0.25	3	0
56 " "	2.12	4.11	0.26	3	40
60 " "	2.25	5.67	0.39	3	55
15 thick gold foils	1.62	2.72	0.16	3	25
20 " "	2.16	1.87	0.14	4	15
25 " "	2.64	2.72	0.26	5	30
25 " "	2.64	1.65	0.15	5	10
30 " "	3.20	1.64	0.18	6	20
30 " "	3.68	1.64	0.20	7	0

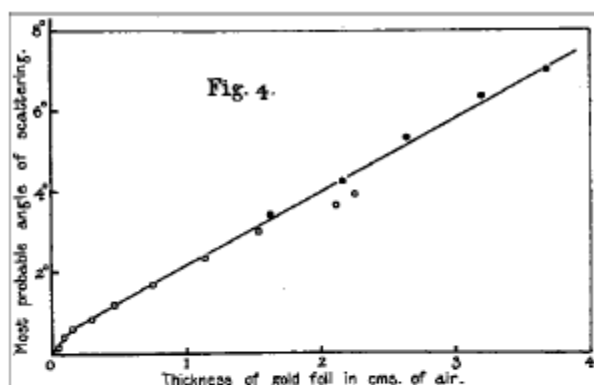
The curve (fig. 4) extends over a wide range, the last point of the curve corresponding to a thickness of gold nearly 100 times as great as that of the first. With the exception of the initial portion, where the scattering increases somewhat more rapidly, the curve appears to a first approximation to be a straight line. Later experiments showed that a similar law, for other metals.

The results obtained above for different thicknesses of matter need, a few words of discussion. Let us assume that an α -particle in passing through

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each atom is deflected from its path through a small constant angle w . Since the angle of deflection may have any orientation, the resulting deflection of such an α -particle after passing through n atoms may have any value between zero and $n \times w$. Now, if a great number of α -particles were allowed to pass through n atoms and the resulting angle measured for each of them, there would be one value which is more likely to occur than any other.

In his 'Theory of Sound' (Second Edition, p. 39, 1894), Lord Rayleigh treats a related problem, namely the composition of unit vectors whose directions are accidental. Applying the deductions given there to our case, it would follow that the most probable deflection varies as the square root of the number of atoms traversed. In other words, the most probable angle of



scattering ought to increase at a rate proportional to the square root, of the thickness of matter traversed.

A close examination of the curve (fig. 4) shows that for small thicknesses of gold (up to an equivalent thickness of about 5 mm. of air) the scattering increases approximately at that rate, but for greater thicknesses the increase becomes practically proportional to the thickness itself. This quick increase can be explained as due to an increase of the scattering angle w , on account of the decrease of velocity of the α -particle in passing through successive atoms. As will be shown later, the angle w is, to a first approximation, inversely proportional to the third power of the velocity,

The most probable angle through which an α -particle will be turned by

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passing through a layer of gold equivalent to 1. cm. of air is 2.1° . This angle, which gives us a direct conception of the scattering power, may be denoted as the scattering coefficient. It is to be expected that this coefficient will vary with different materials and will also depend on the velocity of the α -particles. Experiments in this direction will be described in the two following sections of this paper.

By an extrapolation from our curve (fig. 4), we are enabled to form an estimate of the most probable angle through which an α -particle is turned by the encounter with a single atom. Taking the diameter of an atom as 2×10^{-8} cm., the number of atoms through which it will pass in penetrating one gold foil of 8.6×10^{-15} cm. actual thickness will be about 160. If we assume

that the square root law holds accurately for small thicknesses, we find by extrapolation that the most probable angle through which the α -particle is turned in passing through 1 atom of gold is of the order of $1/200$ of a degree. This angle may be denoted as the atomic scattering coefficient of gold.

It is also of interest to refer here to experiments made by E. Marsden and myself (see 'Roy. Soc. Proc.,' A, vol. 82, p. 495, 1909) on the diffuse reflection of the α -particles. It was found that some of the α -particles falling upon a metal plate appear to be reflected, *i.e.* they are scattered to such an extent that they emerge again on the side of incidence. It was shown that from gold 1 in about 8000 of the incident α -particles suffers reflection, and that reflection takes place within a relatively thin surface layer equivalent to about 5 mm. of air. According to the curve (fig. 4), the probable angle through which the α -particles are turned in passing through this equivalent thickness of gold is only about 1° , and a simple calculation, assuming ordinary probability law, shows that the probability of an α -particle scattered through an angle exceeding 90° is extremely small, and of a different order from that which the reflection experiment suggests.

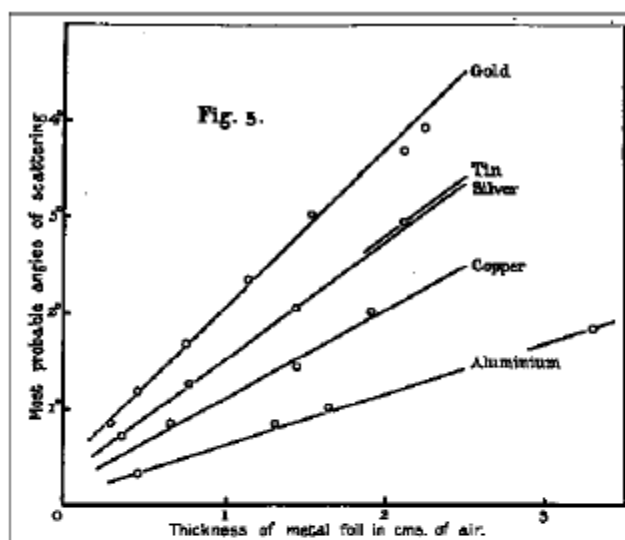
It does not appear profitable at present to discuss the assumption which might be made to account for this difference.

Comparison of the Amount of Scattering produced in different Metals.

It appeared of interest to extend the measurements to other metals in order to make a comparison of their relative scattering powers. Since thin and uniform sheets could only be obtained for gold, tin, silver, copper, and aluminium, the experiments were confined to these metals. With the exception of tin, which was only available in one thickness, equivalent to 2.12 cm. of air, measurements were carried out for several thicknesses of each metal. The most probable angles of scattering obtained for different metals

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from the maxima in the distribution curves are plotted in fig. 5 against the respective stopping powers. The points belonging to the same metal lie approximately on straight lines, which all seem to cut the negative X axis at nearly the same distance from the origin. Thus the law which gives the most probable angle of scattering for varying thicknesses of matter appears to be similar for different metals.



The most probable angle through which an α -particle is turned in passing through a layer equivalent to 1 cm. of air has been defined above as the scattering coefficient for the material considered. These coefficients, taken from the curves (fig. 5), are entered in Column 3 of the following table. Their ratios to the square root of the atomic weight are approximately constant (see Column 4).

Remembering that the coefficients refer to equivalent thicknesses of the scattering metals, this result may be stated somewhat more clearly from the following consideration. The experiments of Bragg and Kleeman ('Phil. Mag.', vol. 10, p. 318, 1905) have shown that the stopping power of an atom of atomic weight A is proportional to [square root of] A . Consequently the numbers of

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Table III

1.	2.	3.	4.	5.	6.
Scattering material.	Atomic Weight,	Scattering coefficient, $^{\circ}$ K.	$K / [\text{square root of}] A$	Relative atomic	(K_0 / A) times 10^2

	A	θ	K_0	scattering coefficient,**	K_0
Gold	197	2.1	0.150	1.00	0.51
Tin	119	1.5	0.138	0.56	0.47
Silver	108	1.5	0.144	0.53	0.49
Copper	64	1.1	0.138	0.30	0.47
Aluminium	27	0.6	0.115	0.106	0.39

* The scattering coefficient is measured by the most probable angle through which α -particle is turned in passing through a thickness of the metal equivalent to 1 cm. of air.

** Atomic scattering coefficient denotes the most probable angle through which an α -particle is turned in passing through 1 atom of the metal.

atoms which are contained in equivalent thicknesses of different metals are, inversely proportional to [the square root of] A. Approximate values for the relative atomic scattering coefficients are therefore obtained by multiplying the figures in Column 3 by the square root of the atomic weight of the metal to which they refer. These coefficients are entered in Column 5, the coefficient for gold being taken as unity. It follows that they will be approximately proportional to the atomic weight itself.

We may therefore conclude that the most probable angle through which an α -particle is turned when passing through an atom is proportional to its atomic weight.

Variation of the Scattering Coefficient with the Velocity of the α -Particles.

All the previous experiments were made with homogeneous α -rays of one definite velocity. In the following set of experiments the velocity of the α -particle was varied as much as possible, while in each experiment the same thin gold foil served to scatter the α -particles.

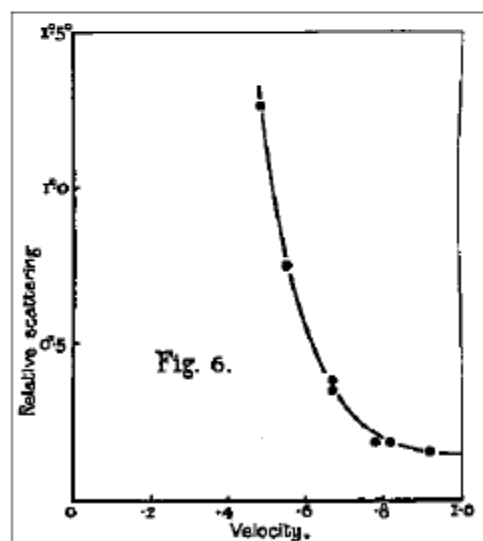
The velocity of the α -particles was diminished by interposing in their path sheets of mica or aluminium of known stopping power. These sheets were placed directly in front of the mica window of the radiating source. The distribution curves of the scintillations on the screen were then determined in the same way as before.

In the following table, Column 2 gives the range which the α -particles still possessed after passing through the absorbing screen, and Column 3 their corresponding velocities expressed in terms of the initial velocity of the

α -particles from Radium C. The observed probable angles of scattering which are seen in Column 4 give the relative scattering coefficients for different speeds of the α -particle. The curve (fig. 6) shows the rapid increase of the scattering coefficient with the decreasing velocity of the α -particle.

Table IV.

1.	2.	3.	4.	5.
Sheets interposed in addition to mica window.	Range	Velocity, V.	Relative scattering coefficient, K	K times V^3
	cm.			
(Mica window alone)	5.60	0.92	0.15	0.12
Sheet of aluminium	4.00	0.82	0.18	0.10
" mica	3.40	0.78	0.18	0.08
" aluminium	2.21	0.67	0.35	0.11
" mica	2.21	0.67	0.38	0.11
" "	1.20	0.55	0.75	0.12
" aluminium	0.89	0.48	1.27	0.14



Although the accuracy of the coefficients obtained for low velocity suffered from the difficulties in counting scintillations under such conditions, it may be of interest to state that the coefficient appears to be inversely proportional

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to the third power of the velocity. This is demonstrated by the ratios tabulated in Column 5.

This rapid increase of the scattering coefficient with decreasing velocity suggests that scattering plays an important part in the apparent stoppage of the α -particles at the end of their range.

Results

In all the foregoing experiments the scattering was measured by the most probable angle through which an α -particle was turned in passing through the scattering foil under investigation.

(1) The most probable angle of scattering increases for small thicknesses approximately proportional to the square root of the thickness of matter traversed by the α -particle. For greater thicknesses the scattering angle increases more rapidly.

(2) The probable angle through which an α -particle is turned in passing through an atom is proportional to its atomic weight. The actual value of this angle in the case of gold is about 1/200 of a degree.

(3) The most probable angle of scattering increases rapidly with decreasing velocity of the α -particle, being, to a first approximation, inversely proportional to the third power of the velocity.

In conclusion, I desire to express my thanks to Prof. Rutherford for his kind interest in this research.

ANEXO 11 – Artigo Geiger, H. Marsden, E. *Philosophical Magazine*, S6, 1913.

LXI. The Laws of Deflexion of α Particles through Large Angles¹

By Dr. H. GEIGER and E. MARSDEN²

Philosophical Magazine

Series 6, Volume 25, Number 148

April 1913

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In a former paper³ one of us has shown that in the passage of α particles through matter the deflexions are, on the average, small and of the order of a few degrees only. In the experiments a narrow pencil of α particles fell on a zinc-sulphide screen in vacuum, and the distribution of the scintillations on the screen was observed when different metal foils were placed in the path of the α particles. From the distribution obtained, the most probable angle of scattering could be deduced, and it was shown that the results could be explained on the assumption that the deflexion of a single α particle is the resultant of a large number of very small deflexions caused by the passage of the α particle, through the successive individual atoms of the scattering substance.

¹Communicated to *k. d. k. Akad. d. Wiss. Wien*.

²Communicated by Prof. E. Rutherford, F.R.S.

³H. Geiger, *Roy. Soc. Proc.* vol lxxxiii. p. 492 (1910); vol lxxx p. 235 (1912).

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In an earlier paper¹, however, we pointed out that α particles are sometimes turned through very large angles. This was made evident by the fact that when α particles fall on a metal plate, a small fraction of them, about 1/1800 in the case of platinum, appears to be diffusely reflected. This amount of reflection, although small, is, however, too large to be explained on the above simple theory of scattering. It is easy to calculate from the experimental data that the probability of α deflection through an angle of 90° is vanishingly small and different order to the value found experimentally.

Professor Rutherford² has recently developed a theory to account for the scattering of α particles through these large angles, the assumption being that the deflexions are the result of an intimate encounter of an α particle with a single atom of the matter traversed. In this theory an atom is supposed to consist of a strong positive or negative central charge

concentrated within a sphere of less than about 3×10^{-12} cm. radius, and surrounded by electricity of the opposite sign distributed throughout the remainder of the atom of about 10^{-8} cm. radius. In considering the deflection of an α particle directed against such an atom, the main deflection - effect can be supposed to be due to the central - concentrated charge which will cause the α particle to describe an hyperbola with the center of the atom as one focus.

The angle between the directions of the α particle before and after deflection will depend on the perpendicular instance of the initial trajectory from the center of the atom. The fraction of the α particles whose paths are sufficiently near to the center of the atom will, however, be small, so that the probability of an α particle suffering a large deflection of this nature will be correspondingly small. Thus, assuming a narrow pencil of α particles directed against a thin sheet of matter containing atoms distributed at random throughout its volume, if the scattered particles are counted by the scintillation's they produce on a zinc-sulfide screen distance from the point of incidence of the pencil in a direction making an angle ϕ with it, the number of α particles falling on unit area of the screen per second is deduced to be equal to

$$\frac{Qntb^2 \operatorname{cosec}^4 \phi / 2}{16 r^2}$$

where Q is the number of α particles per second in the

¹H. Geiger and E. Marsden, *Roy. Soc. Proc.* vol. lxxxii. p. 495 (1909).
²E. Rutherford, *Phil. Mag.* vol. xxi. p. 669 (1911).

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original pencil, n the number of atoms in unit volume of the material, and t the thickness of the foil. The quantity $b = 2NeE / mu^2$ where Ne is the central charge of the atom, and m , E , and u are the respective mass, charge, and velocity of the α particle. The number of deflected α particles is thus proportional to (1) $\operatorname{cosec}^4 \phi / 2$, (2) thickness of scattering material t if the thickness is small, (3) the square of the central charge Ne of the atoms of the particular matter employed to scatter the particles, (4) the inverse fourth power of the velocity u of the incident α particles. At the suggestion of Prof. Rutherford, we have carried out experiments to test the main conclusions of the above theory. The following points were investigated

- (1) Variation with angle.
- (2) Variation with thickness of scattering material.

- (3) Variation with atomic weight of scattering material.
- (4) Variation with velocity of incident α particles.
- (5) The fraction of particles scattered through a definite angle.

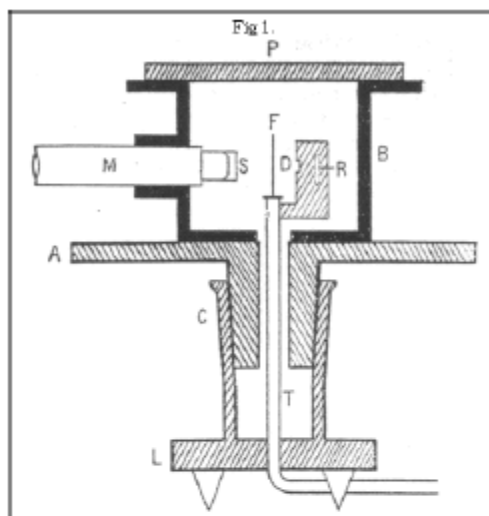
The main difficulty of the experiments has arisen from the necessity of using a very intense and narrow source of α particles owing to the smallness of the scattering effect. All the measurements have been carried out by observing the scintillations due to the scattered α particles on a zinc-sulphide screen, and during the course of the experiments over 100,000 scintillations have been counted. It may be mentioned in anticipation that all the results of our investigation are in good agreement with the theoretical deductions of Prof. Rutherford, and afford strong evidence of the correctness of the underlying assumption that an atom contains a strong charge at the centre of dimensions, small compared with the diameter of the atom.

(1) Variation of Scattering with Angle.

We have already pointed out that to obtain measurable effects an intense pencil of α particles is required. It is further necessary that the path of the α particles should be in an evacuated chamber to avoid complications due to the absorption and scattering of the air. The apparatus used is shown in fig. 1 and mainly consisted of a strong cylindrical metal box B, which contained the source of α particles R,

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the scattering foil F and a microscope M to which the zinc-sulphide screen S was rigidly attached. The box was fastened down to a graduated circular platform A, which could be rotated by means of a conical airtight joint C. By rotating the platform the box and microscope moved with it, whilst the scattering foil and radiating source remained in position, being attached to the tube T, which was fastened to the standard L. The box B was closed by the ground-glass plate P, and could be exhausted through the tube T.



The source of particles employed was similar to that used originally by Rutherford and Royds¹ in their experiments on the nature of the α particle. It consisted of a small thin-walled glass tube about 1 mm. in diameter, containing a large quantity of well purified radium emanation. The α particles emitted by the emanation and its active deposit could pass through the glass walls without much reduction in range. For these experiments the unhomogeneity of the source, due to the different α particles from the emanation, RaA and RaC, does not interfere with the application of the law of scattering with angle as deduced from the theory, as each group of α particles is scattered according to the same law.

By means of a diaphragm placed at D, a pencil of particles was directed normally on to the scattering foil F. By

¹E. Rutherford and T. Royds, *Phil. Mag.*, vol. xvii, p. 261 (1909).

rotating the microscope the α particles scattered in different directions could be observed on the screen S. Although over 100 millicuries of radium emanation were available for the experiments, the smallness of the effect for the larger angles of deflexion necessitated short distances of screen and source

from the scattering foil. In some experiments the distance between the source and scattering foil was 2.5 cm and the screen moved in a circle of 1.6 cm. radius, while in other experiments these distances were increased.

Observations were taken in various experiments for angles of deflexion from 5° to 150° . When measuring the scattering through large angles the zinc-sulphide screen had to be turned very near to the source, and the β and γ rays produced a considerable luminescence on it, thus making countings of the scintillations difficult. The effect of the β rays was reduced as far as possible by enclosing the source in a lead box shaded in the diagram. The amount of lead was, however, limited by considerations of the space taken up by it, and consequently observations could not be made for angles of deflexion between 150° and 180° .

In the investigation of the scattering through relatively small angles the distances of source and screen from the scattering foil were increased considerably in order to obtain beams of smaller solid angle.

The number of particles scattered through different angles was found to decrease extremely rapidly with increase of angle, and as it is not possible to count with certainty more than 90 scintillations per minute or less than about 5 per minute, measurements could only be made over a relatively small range of angles at the same time. The number of α particles scattered through large angles was first measured, and as the emanation decayed it was possible to take measurements for smaller and smaller angles, and from the known decay of the emanation measurements taken at different times could be corrected for the decrease of activity.

Even when no scattering foil was used a few scintillations were always observed on the screen. They were obviously due to scattered radiation from the walls of the vessel and from the edge of the diaphragm limiting the beam. The effect was reduced as far as possible by lining the box with paper and by using a substance of low atomic weight, viz. aluminium, for the diaphragm. The number of stray α particles was determined for different positions of the microscope by removing the scattering foil so that the necessary corrections could be applied with certainty.

In order to make the best use of the emanation available,

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measurements were made simultaneously with different foils. These foils were attached to frames which fitted into a slot in the tube T in such a way that they could be exchanged and accurately replaced in position. Table 1. gives an example of a particular set of countings, when a silver foil was used to scatter the α particles.

TABLE I. -- Variation of Scattering with Angle. (Example of a set of measurements.) Silver Foil. Time elapsed since filling of emanation tube, 51 hours. Correction for decay, 0.683.

Angle ϕ	Scintillations per minute.					
	Without foil.	With foil.	Corrected for effect without foil.	Corrected for decay, N.	$\frac{1}{\sin^2 \phi}$	$N \times (\sin^2 \phi / 2)$
150	0.2	4.95	4.75	6.95	1.15	6.0
135	2.6	8.3	5.7	8.35	1.38	6.1
120	3.8	10.3	6.5	9.5	1.79	5.3
105	0.6	10.6	10.0	14.6	2.53	5.8
75	0.0	28.6	28.6	41.9	7.25	5.8
60	0.3	69.2	68.9	101	16.0	6.3

In this set about 2500 scintillations were counted. After a few days had elapsed the measurements for the smaller angles were repeated and the range of angles extended. Proceeding in this way the whole range of angles was investigated in the course of a few weeks. When measuring relatively large angles of deflexion a wide beam of about 15° radius had to be used in order to obtain a suitable number of scintillations, but for the smaller angles the aperture of the diaphragm confining the beam was reduced considerably, so that the angle at which the scintillations were counted was always large compared with the angular radius of the beam. When changing over from one diaphragm to another comparative measurements for different angles were made so as to obtain an accurate value of the reduction constant.

Table II. gives the collected results for two series of experiments with foils of silver and gold. The thicknesses of the foils were in the first series equivalent to 0.45 and 0.3 c.m. air, and in the second series 0.45 and 0.1 cm. air for silver and gold respectively. Col. I. gives the values of the

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TABLE II
Variation of Scattering with Angle, (Collected results.)

I Angle of deflexion, ϕ	II $\frac{1}{\sin^2 \alpha / 2}$	SILVER.		GOLD.	
		III Number of scintil- lations, N	IV. N $\sin^2 \phi / 2$	V. Number of scintil- lations, N	VI. N $\sin^2 \phi / 2$

150	1.15	22.2	19.3	33.1	28.8
135	1.38	27.4	19.8	43.0	31.2
120	1.79	33.0	18.4	51.9	29.0
105	2.53	47.3	18.7	69.5	27.5
75	7.25	136	18.8	211	29.1
60	16.0	320	20.0	477	29.8
45	46.6	989	21.2	1435	30.8
37.5	93.7	1760	18.8	3300	35.3
30	223	5260	23.6	7800	35.0
22.5	690	20300	29.4	27300	39.6
15	3445	105400	30.6	132000	38.4
30	223	5.3	0.024	3.1	0.014
22.5	690	16.6	0.024	8.4	0.012
15	3445	93.0	0.027	48.2	0.014
10	17330	508	0.029	200	0.0115
7.5	54650	1710	0.031	607	0.011
5	276300	3320	0.012

angles ϕ between the direction of the beam and the direction in which the scattered α particles were counted. Col. II gives the values of $1 / (\sin^4 \alpha / 2)$. In Cols. III. and V. the numbers of scintillations are entered which were observed for the silver and gold respectively. Corrections are made for the decay of the emanation, for the natural effect, and for change of diaphragm. For the smaller angles corrections have been applied (in no case exceeding 20 per cent.) owing to the fact that the beam of α particles was of finite dimensions and not negligible compared with the angle of deflexion. These corrections were calculated from geometrical considerations. In Cols. IV. and VI. the ratios of the number of scintillations to $1 / (\sin^4 \alpha / 2)$ are entered. It will be seen that in both sets the values are approximately constant. The deviations are somewhat systematic, the ratio increasing with decreasing angle. However, any slight asymmetry in the apparatus and other causes would affect the results in a systematic way so that, fitting on the two sets of observations and considering the enormous variation in the numbers scattered particles, from 1 to 250,000, the deviations from constancy of the ratio are probably well within the experimental

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error. The experiments, therefore, prove that the number of α particles scattered in a definite direction varies as $\text{cosec}^4 \phi / 2$.



Variation with Thickness of Material.

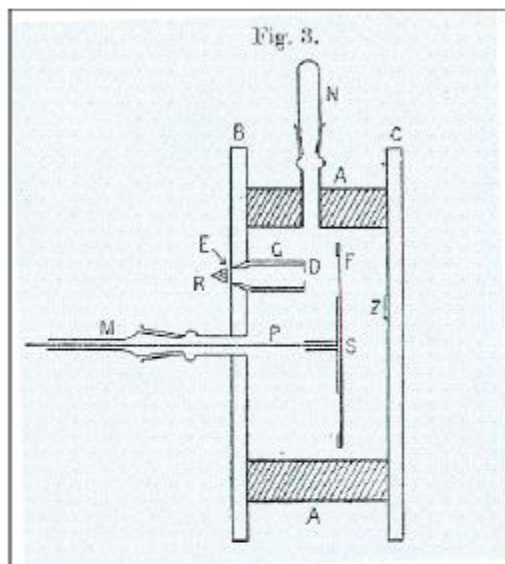
In investigating the variation of scattering with thickness of material, it seemed necessary to use a homogeneous source of α particles, for according to the theory the effect of the change of velocity with increasing thickness will be very appreciable for α particles of low velocity. In the experiments on "compound scattering" by one of us, a source was used consisting of Ra C, deposited from radium emanation *in situ* in a small conical tube fitted with a mica window, the emanation being withdrawn when measurements were taken by expanding into a large volume connected to it. In our first experiments we used such a source, but the observations eventually showed it to be unsuitable. After expansion some emanation remains clinging to the walls of the glass tube. This emanation and the Ra A associated with it gives α particles of considerably lower velocity than the α particles of Ra C, and although the number of α particles so contributed was of the order of only a few per cent. of the number from the Ra C, yet owing to the fact that the amount of scattering increases very rapidly with decreasing velocity, the disturbances caused by the slower α particles were so large as to render the source unsuitable for the present work.

The source finally adopted was prepared as shown in fig. 2. About 80 millicuries of radium emanation were very highly purified and pressed into the conical end of the glass tube T of about 1 mm. internal diameter. After the emanation had remained in position for a sufficient time to attain equilibrium with Ra C, it was expanded into a bulb below, and a small part of the capillary tube was drawn off at *b*. About 1 mm. of the end of the tube which was coated with the Ra C was then cut off (at *a*) and freed from occluded emanation by washing with alcohol and by heating. The resulting source of Ra C was used in the experiments, and with due care its decay was found to be in agreement with theory, at least for the first 80 minutes. The arrangement used for the comparison of the scattering

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of different thicknesses of metal foils is shown diagrammatically in fig. 3. It consists essentially of a source of α radiation R, a diaphragm D, a scattering foil F, and a zinc-sulphide screen Z on which the scattered α particles were observed. The main part of the apparatus was enclosed in a cylindrical brass ring A, the ends of which were planed so that they could be closed airtight by the two glass B and C. The depth of the ring was 3.5 cm., internal and external diameters 5.5 and 7.5 cm. respectively. Two holes were drilled through the glass plate B, one in the centre and the other 1.65 cm. excentric. The source of radiation R was placed directly against a sheet of mica which was waxed over and closed the opening E. By placing the source outside the apparatus, any

small amount of emanation associated with it was prevented from entering the chamber and disturbing the measurements.



By means of the diaphragm D a narrow pencil of α particles could be directed on to the scattering foil. The different foils were attached to the disk S and covered five of six holes drilled through it at equal distances from its centre. The uncovered opening was used to determine the natural effect. The disk could be fitted on to the rod P , which was fastened to the ground-glass joint M so that it could be rotated and the different foils brought in front of the diaphragm. The scattered α particles were observed by means of a microscope on the zinc-sulphide screen Z fixed inside the glass plate.

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In making the observations the disk carrying the foils was placed in position about 1.2 cm. from the glass plate C . The apparatus was then completely exhausted through a tube not shown in the diagram, charcoal cooled by liquid air being used for the final exhaustion. After the source of radiation had been placed in position, the microscope was adjusted at that part of the zinc-sulphide screen where the scintillations appeared at a rate convenient for

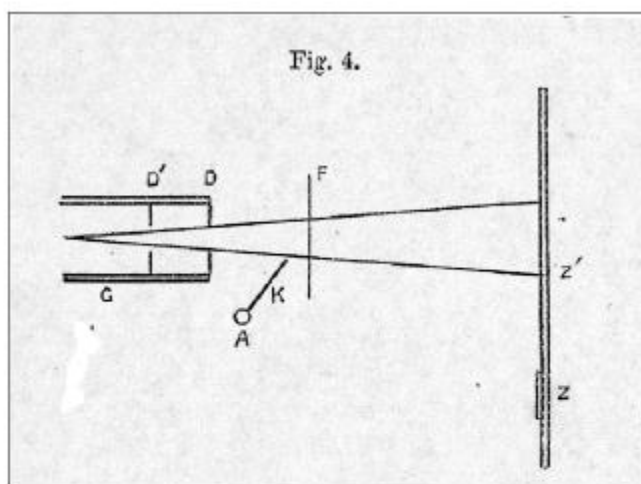
counting. With a source of 30 millicuries of Ra C this was usually the case for an angle of deflexion of from 20° to 30° degrees. The area of the screen visible through the microscope was about 1 sq. mm., whilst the main beam of a particles covered an area of about 2 sq. mm.

As soon as the Ra A in the source had decayed completely (i.e. after 20 minutes) countings were commenced. Measurements were first taken with the layers of foils of smaller thickness, and as the source decayed they were extended to the thicker foils. From the known decay of the active deposit of radium the measurements could all be corrected for the variation in activity of the source, the results being verified by making observations on the same foils at different times. An experiment generally extended for about 80 minutes. After that time the decay corrections for the source were not always reliable owing to small quantities of radium emanation associated with it, as has been mentioned above. Owing to the relatively short time available in each experiment for the completion of the measurements, only about 100 to 200 scintillations could be counted with each foil.

As in the experiments on the variation of scattering with angle, some scintillations appeared on the zinc-sulphide screen even when no scattering foil was interposed. It was found that these scintillations were due to α particles which had been scattered from the edges of the diaphragm limiting the beam. Experiments were made with paper diaphragms and with aluminium diaphragms of only 1/10 mm. thickness, whilst a diaphragm D' (fig. 4) was also introduced to prevent scattering from the inside of the glass tube G carrying the main diaphragm D. Even with these precautions the effect was still so large that accurate experiments with foils of low atomic weight would have been impossible. The difficulty was, however, successfully overcome by intercepting the stray α particles by a screen K, which could be turned by means of a ground-glass joint (N in fig. 3) about a vertical axis passing through A so as to be just outside the main pencil. The adjustment was made by observation of the scintillations produced by the main beam of the zinc-sulphide

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screen Z, which was temporarily placed at Z'. The magnitude of the effect may be judged from the following figures obtained in a particular experiment with an aluminium diaphragm: -- The number of scintillations without both the screen K and the scattering foil F was 60 per minute, whilst by bringing the screen K into position the number was reduced 0.5 per minute. With the screen K in position and an aluminium foil equivalent to 0.5 cm. air as scattering foil, the number of scintillations was 14 per minute, or about one quarter the effect without screen or scattering foil.



In the following table the results of an experiment with gold foils are tabulated. Column I. gives the number of foils and column II. the thicknesses expressed as the stopping power of α particles in centimetres of air as determined by the scintillation method. The figures given in column III represent the number of scintillations observed on the zinc-sulphide screen. These figures are corrected for the variation of activity with time of the source. A slight correction has been made due to the increase of scattering on account of the decrease of velocity of the α particles in passing through the foils. The magnitude of this correction could be calculated from the results given in the last section of the present paper and amounted to 9 per cent. in this experiment for the thickest foil used. The last column of the table gives the ratio of the corrected number of scintillations to the thickness. The values are constant within the limits of the experimental error. The variations exhibited by the figures are well within the probability errors, owing to the relatively small number of scintillations which could be counted in the time available.

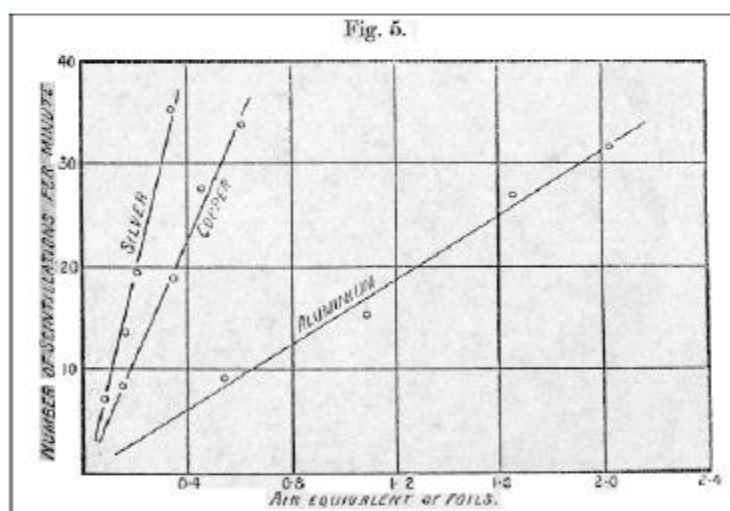
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Table III.
Gold. — Variation of Scattering with Thickness.

I.	II.	III.	IV.
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Number of Foils	Air equivalent T in cm.	Number N of scintillations per minute.	Ratio N/T
1	0.11	21.9	200
2	0.22	38.4	175
5	0.51	84.3	165
8	0.81	121.5	150
9	0.90	145	160

Similar experiments were carried out with foils of tin, silver, copper, and aluminum. In each set about 1000 scintillations were counted. The results are plotted in fig. 5, where the abscissae represent the thickness of the scattering foil expressed in centimetres of air equivalent and the ordinates the number of scattered particles. Similar corrections to the above have been introduced in each case.



For all the metals examined the points lie on straight lines which pass through the origin. The experiments therefore prove that for small thicknesses of matter the scattering is proportional to the thickness. If there is any appreciable

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diminution in velocity of the α particles in passing through the foils, the number of scattered particles increases somewhat more rapidly than the thickness.

Variation with Atomic Weight.

Assuming that the magnitude of the central charge of the atom is proportional to the atomic weight A , Professor Rutherford has shown that the number of α particles scattered by different foils containing the same number of atoms should be proportional to A^2 . With the thin foils which had to be used experimentally, it was found impracticable to calculate the number of atoms per unit area by weighing the foils. It proved much more reliable to deduce the required number of atoms from the air equivalent as found by the reduction of the range of α particles by the scintillation method. This method had the advantage that the thickness was determined at the exact part of the foil which served to scatter the α particles, thus eliminating any errors due to variations in the thickness of the foils. Bragg and others have given numbers connecting the thicknesses of foils of various materials and their stopping power, and it has been shown that for different foils of the same air equivalent the numbers of atoms per unit area are inversely proportional to the square roots of the atomic weights. Consequently if the scattering per atom of atomic weight A is proportional to A^2 , the scattering per centimetre air equivalent will be proportional to $A^2 \times A^{-1/2}$, i.e. to $A^{3/2}$.

In the experimental investigation the same apparatus was used as in the previous experiments on the variation of scattering with thickness of material. The openings in the disk S were covered with thin foils of different materials, and their thicknesses chosen in such a way that they gave approximately the same effect of scattering. A number of different sets of experiments were made, the foils being varied in each experiment. The results in a particular experiment are given in Table IV. Columns I. and II. give the foils used and their respective atomic weights. In column III. the air equivalents of the foils are entered. Column IV. gives the number of scintillations observed after correction for the variation in activity of the source and the loss of velocity of the α particles in the foil. Column V. gives the number of scintillations per unit air equivalent of material. In column VI. the values of $A^{3/2}$ are given, and in column VII. the ratios of the numbers of scintillations to $A^{3/2}$ are calculated. The figures are constant within the experimental error.

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Table IV.
Variation of Scattering with Atomic Weight. (Example of
a set of measurements.)

I. Substance.	II. Atomic weight. A.	III. Air equivalent in cm.	IV. Number of scintillations per minute corrected for decay	V. Number N of scintillations per cm. air equivalent.	VI. $A^{3/2}$.	VII. $N \times A^{3/2}$.
Gold.....	197	0.229	133	581	2770	0.21
Tin.....	119	0.441	119	270	1300	0.21
Silver.....	107.9	0.262	51.7	198	1120	0.18
Copper....	63.6	0.616	71	115	507	0.23
Aluminium.	27.1	2.05	71	34.6	141	0.24

The combined results of four experiments are given in Table V. In the last column are given the ratios of the numbers of scintillations per centimetre equivalent to $A^{3/2}$. This ratio should be constant according to theory. The experimental values show a slight increase with decreasing atomic weight.

Table V.
Variation of Scattering with Atomic Weight. (Collected
results using Ra C.)

Substance.	Total number of scintillations counted for each material.	$A^{3/2}$.	Ratio of scintillations per cm. air equivalent to $A^{3/2}$.
Gold.....	850	2770	95
Platinum...	200	2730	99
Tin.....	700	1300	96
Silver.....	800	1120	98
Copper.....	600	507	104
Aluminium...	700	144	110

*Note 1. -- Since these experiments were carried out, Richardson and one of us (Phil. Mag. vol. xxv. p.184 (1913)) have determined the masses per unit area per cm. air equivalent for different metals, using the scintillation method. Introducing the results, and calculating the values of the ratio of the scattering per atom divided by $A^{3/2}$, the following are obtained: -- Au 3.4, Pt 3.2, Sn 3.3, Ag 3.6, Cu 3.7, Al 3.6. These numbers show better agreement than those in the last column above, which are calculated on the assumption of Bragg's law.

On account of the importance of these experiments further measurements were made under somewhat different conditions. The main difficulty in the previous experiments arose from the fact, that owing to the rapid decay of the source it was impossible to count in each case a sufficient number of scintillations to obtain a true average value. In the following set of measurements radium emanation in equilibrium with its active deposit was used as source of radiation. The source consisted of a conical glass tube (fig. 6) of about 1 1/2 mm. internal diameter at its widest part, the height of the cone being about 2.5 mm. The end of the tube was closed airtight by a sheet of mica of 0.62 cm. air equivalent. This tube was filled with about 30 millicuries of highly purified emanation and placed at R (fig. 3, p. 612) directly against the mica window E, the air equivalent of which was also 0.62 cm.

The difficulty introduced by the employment of a particles of different velocities (emanation, Ra A, and Ra C) was eliminated by using foils of approximately the same air equivalent. The α particles therefore suffered the same reduction in velocity in each foil, and the numbers of scattered particles were therefore directly comparable. It was of course impossible to obtain foils of exactly the same air equivalent, but this difficulty was easily overcome by determining the scattering for two foils of the same material, one slightly smaller and the other slightly larger than a standard thickness of 0.6 cm. air equivalent.

Owing to the large variation with atomic weight of the amount of scattering, the foils could not be all directly compared with each other at the same angle. They were therefore compared in sets, the angle being chosen smaller for the sets of lower atomic weight. Column VI in the following table gives the mean results of the ratio of the number of scattered particles to $A^{3/2}$.

The scattering of carbon was obtained by using thin sheets of paraffin wax which contained about 85.2 per cent. carbon and 14.8 per cent. hydrogen. The air equivalent of the carbon was calculated from Bragg's law to be about 78 per cent. of the whole stopping power, and on account of the low atomic weight of hydrogen all the scattering effect was assumed due to the carbon. The measurements of the scattering were made by comparison with that due to aluminum foils of the same air equivalent.

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Table VI
Variation of Scattering with Atomic Weight. (Collected results using Radium emanation)

I.	II.	III.	IV.	V.	VI.
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Substance.	Air equivalents of foils used	Total number of scintillations counted for each substance.	Number N of scintillations at same angle and for same air equivalent.	$A^{1/2}$.	$N \times A^{1/2}$.
Gold.....	.52, .68	1200	2400	2770	.85
Platinum...	.54, .625	1000	2900	2730	1.08
Tin.....	.51, 1.15	1400	1290	1300	.99
Silver.....	.38, .435	600	1060	1120	.95
Copper.....	.495, .61	1300	570	507	1.12
Aluminium...	.45, .52, 1.06	1600	151	144	1.05
Carbon.....	.55, .57	400	57	41.6	1.37

Note 2. -- Introducing the new data for the mass per unit area of foils of the same air equivalent, as in note 1, the following are the values for the ratio of the scattering per atom divided by $A^{1/2}$: -- Au 3.1, Pt 3.4, Sn 3.4, Ag 3.4, Cu 3.95, Al 3.4.

It will be seen from the table that, although the experimental conditions were very different from those in the previous experiments, the results are similar, and indicate the essential correctness of the assumption that the scattering per atom is proportional to the square of the atomic weight. The deviations from constancy of the ratio (see notes 1 and 2) are nearly within the experimental error.

The measurements have not so far been extended to substances of lower atomic weight than carbon. When the atomic weight is small and comparable with the mass of the α particle, the laws of scattering will require some modification to take into account the relative motion of the atom itself when a collision occurs.

Variation of Scattering with Velocity

In order to determine the variation of scattering with velocity that apparatus was somewhat modified. A conical glass tube coated with active deposit was again used as source of radiation. This source was placed about 1 mm. from the mica window (E, fig 3), so that it was possible to insert additional sheets of mica between the source and the window to reduce the velocity of the α particles. Mica sheets were used for this purpose on account of their uniformity of

thickness in comparison with metal foils. The micas were attached to a cardboard disk, which could be rotated to bring the different sheets successively in position. The α particles were scattered by a foil of gold or silver, of stopping power about 3 mm. of air, which was attached to a rod passing through the ground glass N. This made it possible to turn the foil away from the main beam during an experiment in order to test the natural effect. The disk S, in this case, rotated in a plane very close to the glass plate, C and carried sheets of mica of different thicknesses. By rotating the ground-glass joint the micas could be placed directly in front of the zinc-sulphide screen, making it, possible to test the homogeneity of the α particles after they had been scattered.

The results are given in Table VII. Column I. gives the number of mica sheets which were interposed in addition to the mica window, and column II. the ranges of the α particles incident on the scattering foil. The values of the velocities v were calculated from these ranges by use of the formula $\alpha^3 = aR$ previously found by one of us *. The relative values

TABLE VII.
Variation of Scattering with Velocity.

I Number of sheets of mica	II Range R. of α particles after leaving mica	III Relative values of $1/v^4$	IV. Number N of scintillations per minute.	V. Nv^4
0	5.5	1.0	24.7	25
1	4.76	1.21	29.0	24
2	4.05	1.50	33.4	22
3	3.32	1.91	44	23
4	2.51	2.84	81	28
5	1.84	4.32	101	23
6	1.04	9.22	255	28

of $1/v^4$ are given in column III. The number of scintillations per minute N are entered in column IV., and in column V. relative values of $N \times v^4$ are given. Over the range examined the number of scintillations varies in the ratio 1 : 10, while it will be seen that the product Nv^4 remains sensibly constant. Several experiments were made, and in every case

* H. Geiger, Roy. Soc. Proc. A. vol. lxxxiii p. 506 (1910)

the scattering was found to vary at a rate more nearly proportional to the inverse fourth power of the velocity than to any other integral power. Owing

to the comparative uncertainty of the values of the velocity for the small ranges, however, the error of experiment may be somewhat greater than appears from column V. of the table.

In these experiments it proved essential to use a source possessing a high degree of homogeneity. In earlier experiments, where we were not able to fulfill this condition, the scattering apparently increased much more rapidly than the inverse fourth power of the velocity of the Ra C α particles. Even with the source of the Ra C with which only a small quantity of emanation was associated, the amount of scattering first rapidly increased on interposing the sheets of mica, then showed a slight decrease, and finally increased again. This irregularity was due to the α particles of the emanation and Ra A, which are of shorter range than those of Ra C, and therefore more easily scattered.

The measurements could not easily be extended to α particles of a lower velocity than corresponds to a range of about 1 centimeter, owing to the difficulty of observing the faint scintillations at lower ranges. However, in one particular experiment, by adding sheets of mica to cut down the velocity the number of scattered α particles appearing on the screen was increased 25 times, showing how easily the α particles of low velocity are scattered.

The results of the examination of the homogeneity of the scattered α particles showed that at least in the case of gold they remained practically homogenous after the scattering. Experiments of this nature in the case of scattering foils of low atomic weight would be very interesting, but are somewhat difficult.

Determination of Absolute Number of Scattered α Particles.

In the previous sections we have completely verified the theory given by Prof. Rutherford. Since, according to this theory, the large deflexion of an α particle is the result of a close encounter with a single atom of matter, it is possible to calculate the magnitude of the central charge of the atom when the fraction of α particles scattered under definite conditions is determined. We have made several attempts under different conditions to obtain a quantitative estimate of the scattered particles, but the results so far have only given us an approximate value. The main difficulty arises from the fact that the scattered particles consist of such a small

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fraction of the original beam that different methods of measurements have to be employed in the two cases. The number of scattered α particles was determined from the number of scintillations observed on the zinc-sulphide screen, a correction being necessary owing to the fact that with the particular screens used only about 85 percent of the incident α particles in the main

beam was in one case in which an emanation tube was used (as shown in fig. 1, p. 607) determined directly by the scintillation method, several weeks being allowed to elapse, so that the emanation had decayed to a small value. In other experiments Ra C deposited in the inside of a conical glass tube (as in fig. 2 p. 611) was used, and the number of α particles was calculated from its γ -ray activity and the distance and area of the diaphragm determining the beam.

The results showed that, using a gold foil of air equivalent 1 mm. (actual thickness 2.1×10^{-5} cm.), the fraction of incident Ra C α particles ($v=2.06 \times 10^9$ cm./sec.) scattered through an angle of 45° and observed on an area of 1 sq. mm. Placed normally at a distance of 1 cm. from the point of incidence of the beam, was 3.7×10^{-7} . Substituting this value in the equation given at the commencement of this paper, it can be calculated that the value of the number of elementary electrical charges composing the central charge of the gold atom is about half the atomic weight. This result is probably correct to 20 percent, and agrees with the deduction of Prof. Rutherford from the less definite data given in our previous paper.

From the results of this and the previous sections it is possible to calculate the probability of an α particle being scattered through any angle under any specified conditions. For materials of atomic weight greater than that of aluminum, it is sufficiently accurate to put N equal to half the atomic weight in the equation given at the commencement of the paper.

It will be seen that the laws of "single scattering" found in this paper are quite distinct from the laws of "compound scattering" previously deduced by Geiger. It must be remembered, however, that the experiments are not directly comparable. In the present paper we are dealing with very thin sheets of matter, and are measuring the very small fraction of α particles which are deflected by single collisions through very large angles. The experiments of Geiger, however, deal with larger thicknesses of scattering foils and angles of deflexion of a few degrees only. Under these conditions the scattering is due to the combination of a large number of deflexions not only by the central charges of the

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atoms, but probably also by the electronic charges distributed throughout the remainder of their volumes.

Summary.

The experiments described in the foregoing paper were carried out to test a theory of the atom proposed by Prof. Rutherford, the main feature of which is that there exists at the centre of the atom an intense highly concentrated

electrical charge. The verification is based on the laws of scattering which were deduced from this theory. The following relations have been verified experimentally : --

- (1) The number of α particles emerging from a scattering foil at an angle ϕ with the original beam varies as $1/\sin^4\phi / 2$, when the α particles are counted on a definite area at a constant distance from the foil. This relation has been tested for angles varying from 5° to 150° , and over this range the number of α particles varied from 1 to 250,000 in good agreement with the theory.
- (2) The number of α particles scattered in a definite direction is directly proportional to the thickness of the scattering foil for small thicknesses. For larger thicknesses the decrease of velocity of the α particles in the foil causes a somewhat more rapid increase in the amount of scattering.
- (3) The scattering per atom of foils of different materials varies approximately as the square of the atomic weight. This relation was tested for foils of atomic weight from that of carbon to that of gold.
- (4) The amount of scattering by a given foil is approximately proportional to the inverse fourth power of the velocity of the incident α particles. This relation was tested over a range of velocities such that the number of scattered particles varied as 1 : 10.
- (5) Quantitative experiments show that the fraction of particles of Ra C, which is scattered through an angle of 45° by a gold foil of 1 mm. air equivalent (2.1×10^{-5} cm.), is 3.7×10^{-7} when the scattered particles are counted on a screen of 1 sq. mm. area placed at a distance of 1 cm. from the scattering foil. From this figure and the foregoing results, it can be calculated that the number of elementary charges composing the centre of the atom is equal to half the atomic weight.

We are indebted to Prof. Rutherford for his kind interest in these experiments, and for placing at our disposal the large quantities of radium emanation necessary. We are also indebted to the Government Grant Committee of the Royal Society for a grant to one of us, out of which part of the expenses has been paid.

ANEXO 12 – Artigo E. Rutherford, *Philosophical Magazine*, S6, 1911.

[669]

LXXIX. *The Scattering of α and β Particles by Matter and the Structure of the Atom.* By Professor E. RUTHERFORD, F.R.S., University of Manchester*.

§ 1. IT is well known that the α and β particles suffer deflexions from their rectilinear paths by encounters with atoms of matter. This scattering is far more marked for the β than for the α particle on account of the much smaller momentum and energy of the former particle. There seems to be no doubt that such swiftly moving particles pass through the atoms in their path, and that the deflexions observed are due to the strong electric field traversed within the atomic system. It has generally been supposed that the scattering of a pencil of α or β rays in passing through a thin plate of matter is the result of a multitude of small scatterings by the atoms of matter traversed. The observations, however, of Geiger and Marsden † on the scattering of α rays indicate that some of the α particles must suffer a deflexion of more than a right angle at a single encounter. They found, for example, that a small fraction of the incident α particles, about 1 in 20,000, were turned through an average angle of 90° in passing through a layer of gold-foil about $\cdot 00004$ cm. thick, which was equivalent in stopping-power of the α particle to 1.6 millimetres of air. Geiger ‡ showed later that the most probable angle of deflexion for a pencil of α particles traversing a gold-foil of this thickness was about $0^\circ\cdot 87$. A simple calculation based on the theory of probability shows that the chance of an α particle being deflected through 90° is vanishingly small. In addition, it will be seen later that the distribution of the α particles for various angles of large deflexion does not follow the probability law to be expected if such large deflexions are made up of a large number of small deviations. It seems reasonable to suppose that the deflexion through a large angle is due to a single atomic encounter, for the chance of a second encounter of a kind to produce a large deflexion must in most cases be exceedingly small. A simple calculation shows that the atom must be a seat of an intense electric field in order to produce such a large deflexion at a single encounter.

Recently Sir J. J. Thomson § has put forward a theory to

* Communicated by the Author. A brief account of this paper was communicated to the Manchester Literary and Philosophical Society in February, 1911.

† Proc. Roy. Soc. lxxxii. p. 495 (1909).

‡ Proc. Roy. Soc. lxxxiii. p. 492 (1910).

§ Camb. Lit. & Phil. Soc. xv. pt. 5 (1910).

explain the scattering of electrified particles in passing through small thicknesses of matter. The atom is supposed to consist of a number N of negatively charged corpuscles, accompanied by an equal quantity of positive electricity uniformly distributed throughout a sphere. The deflexion of a negatively electrified particle in passing through the atom is ascribed to two causes—(1) the repulsion of the corpuscles distributed through the atom, and (2) the attraction of the positive electricity in the atom. The deflexion of the particle in passing through the atom is supposed to be small, while the average deflexion after a large number m of encounters was taken as $\sqrt{m} \cdot \theta$, where θ is the average deflexion due to a single atom. It was shown that the number N of the electrons within the atom could be deduced from observations of the scattering of electrified particles. The accuracy of this theory of compound scattering was examined experimentally by Crowther* in a later paper. His results apparently confirmed the main conclusions of the theory, and he deduced, on the assumption that the positive electricity was continuous, that the number of electrons in an atom was about three times its atomic weight.

The theory of Sir J. J. Thomson is based on the assumption that the scattering due to a single atomic encounter is small, and the particular structure assumed for the atom does not admit of a very large deflexion of an α particle in traversing a single atom, unless it be supposed that the diameter of the sphere of positive electricity is minute compared with the diameter of the sphere of influence of the atom.

Since the α and β particles traverse the atom, it should be possible from a close study of the nature of the deflexion to form some idea of the constitution of the atom to produce the effects observed. In fact, the scattering of high-speed charged particles by the atoms of matter is one of the most promising methods of attack of this problem. The development of the scintillation method of counting single α particles affords unusual advantages of investigation, and the researches of H. Geiger by this method have already added much to our knowledge of the scattering of α rays by matter.

§ 2. We shall first examine theoretically the single encounters † with an atom of simple structure, which is able to

* Crowther, Proc. Roy. Soc. lxxxiv. p. 226 (1910).

† The deviation of a particle through a considerable angle from an encounter with a single atom will in this paper be called "single" scattering. The deviation of a particle resulting from a multitude of small deviations will be termed "compound" scattering.

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produce large deflexions of an α particle, and then compare the deductions from the theory with the experimental data available.

Consider an atom which contains a charge $\pm Ne$ at its centre surrounded by a sphere of electrification containing a charge $\mp Ne$ supposed uniformly distributed throughout a sphere of radius R . e is the fundamental unit of charge, which in this paper is taken as 4.65×10^{-10} e.s. unit. We shall suppose that for distances less than 10^{-12} cm. the central charge and also the charge on the α particle may be supposed to be concentrated at a point. It will be shown that the main deductions from the theory are independent of whether the central charge is supposed to be positive or negative. For convenience, the sign will be assumed to be positive. The question of the stability of the atom proposed need not be considered at this stage, for this will obviously depend upon the minute structure of the atom, and on the motion of the constituent charged parts.

In order to form some idea of the forces required to deflect an α particle through a large angle, consider an atom containing a positive charge Ne at its centre, and surrounded by a distribution of negative electricity Ne uniformly distributed within a sphere of radius R . The electric force X and the potential V at a distance r from the centre of an atom for a point inside the atom, are given by

$$X = Ne \left(\frac{1}{r^2} - \frac{r}{R^3} \right)$$

$$V = Ne \left(\frac{1}{r} - \frac{3}{2R} + \frac{r^2}{2R^3} \right).$$

Suppose an α particle of mass m and velocity u and charge E shot directly towards the centre of the atom. It will be brought to rest at a distance b from the centre given by

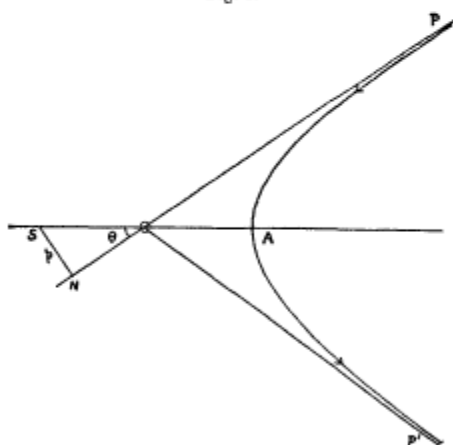
$$\frac{1}{2}mu^2 = NeE \left(\frac{1}{b} - \frac{3}{2R} + \frac{b^2}{2R^3} \right).$$

It will be seen that b is an important quantity in later calculations. Assuming that the central charge is $100e$, it can be calculated that the value of b for an α particle of velocity 2.09×10^9 cms. per second is about 3.4×10^{-12} cm. In this calculation b is supposed to be very small compared with R . Since R is supposed to be of the order of the radius of the atom, viz. 10^{-8} cm., it is obvious that the α particle before being turned back penetrates so close to

the central charge, that the field due to the uniform distribution of negative electricity may be neglected. In general, a simple calculation shows that for all deflexions greater than a degree, we may without sensible error suppose the deflexion due to the field of the central charge alone. Possible single deviations due to the negative electricity, if distributed in the form of corpuscles, are not taken into account at this stage of the theory. It will be shown later that its effect is in general small compared with that due to the central field.

Consider the passage of a positive electrified particle close to the centre of an atom. Supposing that the velocity of the particle is not appreciably changed by its passage through the atom, the path of the particle under the influence of a repulsive force varying inversely as the square of the distance will be an hyperbola with the centre of the atom S as the external focus. Suppose the particle to enter the atom in the direction PO (fig. 1), and that the direction of motion

Fig. 1.



on escaping the atom is OP' . OP and OP' make equal angles with the line SA , where A is the apse of the hyperbola. $p = SN =$ perpendicular distance from centre on direction of initial motion of particle.

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Let angle POA = θ .

Let V = velocity of particle on entering the atom, v its velocity at A, then from consideration of angular momentum

$$pV = SA \cdot v.$$

From conservation of energy

$$\frac{1}{2}mV^2 = \frac{1}{2}mv^2 - \frac{NeE}{SA},$$

$$v^2 = V^2 \left(1 - \frac{b}{SA}\right).$$

Since the eccentricity is $\sec \theta$,

$$\begin{aligned} SA &= SO + OA = p \operatorname{cosec} \theta (1 + \cos \theta) \\ &= p \cot \theta / 2, \end{aligned}$$

$$p^2 = SA(SA - b) = p \cot \theta / 2 (p \cot \theta / 2 - b),$$

$$\therefore b = 2p \cot \theta.$$

The angle of deviation ϕ of the particle is $\pi - 2\theta$ and

$$\cot \phi / 2 = \frac{2p}{b} \quad \dots \quad (1)$$

This gives the angle of deviation of the particle in terms of b , and the perpendicular distance of the direction of projection from the centre of the atom.

For illustration, the angle of deviation ϕ for different values of p/b are shown in the following table:—

$p/b \dots$	10	5	2	1	.5	.25	.125
$\phi \dots\dots$	$5^\circ.7$	$11^\circ.4$	28°	53°	90°	127°	152°

§ 3. Probability of single deflexion through any angle.

Suppose a pencil of electrified particles to fall normally on a thin screen of matter of thickness t . With the exception of the few particles which are scattered through a large angle, the particles are supposed to pass nearly normally through the plate with only a small change of velocity. Let n = number of atoms in unit volume of material. Then the number of collisions of the particle with the atom of radius R is $\pi R^2 nt$ in the thickness t .

* A simple consideration shows that the deflexion is unaltered if the forces are attractive instead of repulsive.

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The probability m of entering an atom within a distance p of its centre is given by

$$m = \pi p^2 nt.$$

Chance dm of striking within radii p and $p + dp$ is given by

$$dm = 2\pi pnt \cdot dp = \frac{\pi}{4} ntb^2 \cot \phi/2 \operatorname{cosec}^2 \phi/2 d\phi, \quad (2)$$

since $\cot \phi/2 = 2p/b$.

The value of dm gives the fraction of the total number of particles which are deviated between the angles ϕ and $\phi + d\phi$.

The fraction ρ of the total number of particles which are deflected through an angle greater than ϕ is given by

$$\rho = \frac{\pi}{4} ntb^2 \cot^2 \phi/2. \quad \dots \quad (3)$$

The fraction ρ which is deflected between the angles ϕ_1 and ϕ_2 is given by

$$\rho = \frac{\pi}{4} ntb^2 \left(\cot^2 \frac{\phi_1}{2} - \cot^2 \frac{\phi_2}{2} \right). \quad \dots \quad (4)$$

It is convenient to express the equation (2) in another form for comparison with experiment. In the case of the α rays, the number of scintillations appearing on a constant area of a zinc sulphide screen are counted for different angles with the direction of incidence of the particles. Let r = distance from point of incidence of α rays on scattering material, then if Q be the total number of particles falling on the scattering material, the number y of α particles falling on unit area which are deflected through an angle ϕ is given by

$$y = \frac{Qdm}{2\pi r^2 \sin \phi \cdot d\phi} = \frac{ntb^2 \cdot Q \cdot \operatorname{cosec}^4 \phi/2}{16r^2}. \quad \dots \quad (5)$$

Since $b = \frac{2NeE}{mu^2}$, we see from this equation that the number of α particles (scintillations) per unit area of zinc sulphide screen at a given distance r from the point of

incidence of the rays is proportional to

- (1) $\text{cosec}^4 \phi/2$ or $1/\phi^4$ if ϕ be small ;
- (2) thickness of scattering material t provided this is small ;
- (3) magnitude of central charge Ne ;
- (4) and is inversely proportional to $(mv^2)^2$, or to the fourth power of the velocity if m be constant.

In these calculations, it is assumed that the α particles scattered through a large angle suffer only one large deflexion. For this to hold, it is essential that the thickness of the scattering material should be so small that the chance of a second encounter involving another large deflexion is very small. If, for example, the probability of a single deflexion ϕ in passing through a thickness t is $1/1000$, the probability of two successive deflexions each of value ϕ is $1/10^6$, and is negligibly small.

The angular distribution of the α particles scattered from a thin metal sheet affords one of the simplest methods of testing the general correctness of this theory of single scattering. This has been done recently for α rays by Dr. Geiger*, who found that the distribution for particles deflected between 30° and 150° from a thin gold-foil was in substantial agreement with the theory. A more detailed account of these and other experiments to test the validity of the theory will be published later.

§ 4. Alteration of velocity in an atomic encounter.

It has so far been assumed that an α or β particle does not suffer an appreciable change of velocity as the result of a single atomic encounter resulting in a large deflexion of the particle. The effect of such an encounter in altering the velocity of the particle can be calculated on certain assumptions. It is supposed that only two systems are involved, viz., the swiftly moving particle and the atom which it traverses supposed initially at rest. It is supposed that the principle of conservation of momentum and of energy applies, and that there is no appreciable loss of energy or momentum by radiation.

* Manch. Lit. & Phil. Soc. 1910.

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Let m be mass of the particle,
 v_1 = velocity of approach,
 v_2 = velocity of recession,
 M = mass of atom,
 V = velocity communicated to atom as result of encounter.

Let OA (fig. 2) represent in magnitude and direction the momentum mv_1 of the entering particle, and OB the momentum of the receding particle which has been turned through an angle $AOB = \phi$. Then BA represents in magnitude and direction the momentum MV of the recoiling atom.

$$(MV)^2 = (mv_1)^2 + (mv_2)^2 - 2m^2v_1v_2 \cos \phi. \quad (1)$$

By the conservation of energy

$$MV^2 = mv_1^2 - mv_2^2. \quad (2)$$

Suppose $M/m = K$ and $v_2 = \rho v_1$, where ρ is < 1 .

From (1) and (2),

$$(K+1)\rho^2 - 2\rho \cos \phi = K-1,$$

$$\text{or } \rho = \frac{\cos \phi}{K+1} + \frac{1}{K+1} \sqrt{K^2 - \sin^2 \phi}.$$

Consider the case of an α particle of atomic weight 4, deflected through an angle of 90° by an encounter with an atom of gold of atomic weight 197.

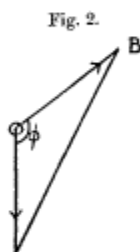
Since $K = 49$ nearly,

$$\rho = \sqrt{\frac{K-1}{K+1}} = \cdot 979,$$

or the velocity of the particle is reduced only about 2 per cent. by the encounter.

In the case of aluminium $K = 27/4$ and for $\phi = 90^\circ$ $\rho = \cdot 86$.

It is seen that the reduction of velocity of the α particle becomes marked on this theory for encounters with the lighter atoms. Since the range of an α particle in air or other matter is approximately proportional to the cube of the velocity, it follows that an α particle of range 7 cms. has its range reduced to 4.5 cms. after incurring a single



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deviation of 90° in traversing an aluminium atom. This is of a magnitude to be easily detected experimentally. Since the value of K is very large for an encounter of a β particle with an atom, the reduction of velocity on this formula is very small.

Some very interesting cases of the theory arise in considering the changes of velocity and the distribution of scattered particles when the α particle encounters a light atom, for example a hydrogen or helium atom. A discussion of these and similar cases is reserved until the question has been examined experimentally.

§ 5. *Comparison of single and compound scattering.*

Before comparing the results of theory with experiment, it is desirable to consider the relative importance of single and compound scattering in determining the distribution of the scattered particles. Since the atom is supposed to consist of a central charge surrounded by a uniform distribution of the opposite sign through a sphere of radius R , the chance of encounters with the atom involving small deflexions is very great compared with the chance of a single large deflexion.

This question of compound scattering has been examined by Sir J. J. Thomson in the paper previously discussed (§ 1). In the notation of this paper, the average deflexion ϕ_1 due to the field of the sphere of positive electricity of radius R and quantity Ne was found by him to be

$$\phi_1 = \frac{\pi}{4} \cdot \frac{NeE}{mu^2} \cdot \frac{1}{R}.$$

The average deflexion ϕ_2 due to the N negative corpuscles supposed distributed uniformly throughout the sphere was found to be

$$\phi_2 = \frac{16}{5} \frac{eE}{mu^2} \cdot \frac{1}{R} \sqrt{\frac{3N}{2}}.$$

The mean deflexion due to both positive and negative electricity was taken as

$$(\phi_1^2 + \phi_2^2)^{1/2}.$$

In a similar way, it is not difficult to calculate the average deflexion due to the atom with a central charge discussed in this paper.

Since the radial electric field X at any distance r from the

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centre is given by

$$X = Ne \left(\frac{1}{r^2} - \frac{r}{R^3} \right),$$

it is not difficult to show that the deflexion (supposed small) of an electrified particle due to this field is given by

$$\theta = \frac{b}{p} \left(1 - \frac{p^2}{R^2} \right)^{3/2},$$

where p is the perpendicular from the centre on the path of the particle and b has the same value as before. It is seen that the value of θ increases with diminution of p and becomes great for small values of ϕ .

Since we have already seen that the deflexions become very large for a particle passing near the centre of the atom, it is obviously not correct to find the average value by assuming θ is small.

Taking R of the order 10^{-8} cm., the value of p for a large deflexion is for α and β particles of the order 10^{-11} cm. Since the chance of an encounter involving a large deflexion is small compared with the chance of small deflexions, a simple consideration shows that the average small deflexion is practically unaltered if the large deflexions are omitted. This is equivalent to integrating over that part of the cross section of the atom where the deflexions are small and neglecting the small central area. It can in this way be simply shown that the average small deflexion is given by

$$\phi_1 = \frac{3\pi}{8} \frac{b}{R}.$$

This value of ϕ_1 for the atom with a concentrated central charge is three times the magnitude of the average deflexion for the same value of Ne in the type of atom examined by Sir J. J. Thomson. Combining the deflexions due to the electric field and to the corpuscles, the average deflexion is

$$(\phi_1^2 + \phi_2^2)^{1/2} \quad \text{or} \quad \frac{b}{2R} \left(5.54 + \frac{15.4}{N} \right)^{1/2}.$$

It will be seen later that the value of N is nearly proportional to the atomic weight, and is about 100 for gold. The effect due to scattering of the individual corpuscles expressed by the second term of the equation is consequently small for heavy atoms compared with that due to the distributed electric field.

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Neglecting the second term, the average deflexion per atom is $\frac{3\pi b}{8R}$. We are now in a position to consider the relative effects on the distribution of particles due to single and to compound scattering. Following J. J. Thomson's argument, the average deflexion θ_t after passing through a thickness t of matter is proportional to the square root of the number of encounters and is given by

$$\theta_t = \frac{3\pi b}{8R} \sqrt{\pi R^2 \cdot n \cdot t} = \frac{3\pi b}{8} \sqrt{\pi n t},$$

where n as before is equal to the number of atoms per unit volume.

The probability p_1 for compound scattering that the deflexion of the particle is greater than ϕ is equal to $e^{-\phi^2/\theta_t^2}$.

Consequently
$$\phi^2 = -\frac{9\pi^2}{64} b^2 n t \log p_1.$$

Next suppose that single scattering alone is operative. We have seen (§ 3) that the probability p_2 of a deflexion greater than ϕ is given by

$$p_2 = \frac{\pi}{4} b^2 \cdot n \cdot t \cot^2 \phi/2.$$

By comparing these two equations

$$p_2 \log p_1 = -\cdot 181 \phi^2 \cot^2 \phi/2,$$

ϕ is sufficiently small that

$$\tan \phi/2 = \phi/2,$$

$$p_2 \log p_1 = -\cdot 72.$$

If we suppose $p_2 = \cdot 5$, then $p_1 = \cdot 24$.

If $p_2 = \cdot 1$, $p_1 = \cdot 0004$.

It is evident from this comparison, that the probability for any given deflexion is always greater for single than for compound scattering. The difference is especially marked when only a small fraction of the particles are scattered through any given angle. It follows from this result that the distribution of particles due to encounters with the atoms is for small thicknesses mainly governed by single scattering. No doubt compound scattering produces some effect in equalizing the distribution of the scattered particles; but its effect becomes relatively smaller, the smaller the fraction of the particles scattered through a given angle.

§ 6. Comparison of Theory with Experiments.

On the present theory, the value of the central charge Ne is an important constant, and it is desirable to determine its value for different atoms. This can be most simply done by determining the small fraction of α or β particles of known velocity falling on a thin metal screen, which are scattered between ϕ and $\phi + d\phi$ where ϕ is the angle of deflexion. The influence of compound scattering should be small when this fraction is small.

Experiments in these directions are in progress, but it is desirable at this stage to discuss in the light of the present theory the data already published on scattering of α and β particles.

The following points will be discussed:—

- (a) The "diffuse reflexion" of α particles, *i. e.* the scattering of α particles through large angles (Geiger and Marsden).
- (b) The variation of diffuse reflexion with atomic weight of the radiator (Geiger and Marsden).
- (c) The average scattering of a pencil of α rays transmitted through a thin metal plate (Geiger).
- (d) The experiments of Crowther on the scattering of β rays of different velocities by various metals.

(a) In the paper of Geiger and Marsden (*loc. cit.*) on the diffuse reflexion of α particles falling on various substances it was shown that about 1/8000 of the α particles from radium C falling on a thick plate of platinum are scattered back in the direction of the incidence. This fraction is deduced on the assumption that the α particles are uniformly scattered in all directions, the observations being made for a deflexion of about 90° . The form of experiment is not very suited for accurate calculation, but from the data available it can be shown that the scattering observed is about that to be expected on the theory if the atom of platinum has a central charge of about $100e$.

(b) In their experiments on this subject, Geiger and Marsden gave the relative number of α particles diffusely reflected from thick layers of different metals, under similar conditions. The numbers obtained by them are given in the table below, where z represents the relative number of scattered particles, measured by the number of scintillations per minute on a zinc sulphide screen.

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Metal.	Atomic weight.	z .	$z/A^{3/2}$.
Lead	207	62	208
Gold	197	67	242
Platinum	185	63	252
Tin	119	34	226
Silver	108	27	241
Copper	64	14.5	225
Iron	56	10.2	200
Aluminium ...	27	3.4	243
Average			233

On the theory of single scattering, the fraction of the total number of α particles scattered through any given angle in passing through a thickness t is proportional to $n \cdot A^{3/2} t$, assuming that the central charge is proportional to the atomic weight A . In the present case, the thickness of matter from which the scattered α particles are able to emerge and affect the zinc sulphide screen depends on the metal. Since Bragg has shown that the stopping power of an atom for an α particle is proportional to the square root of its atomic weight, the value of nt for different elements is proportional to $1/\sqrt{A}$. In this case t represents the greatest depth from which the scattered α particles emerge. The number z of α particles scattered back from a thick layer is consequently proportional to $A^{3/2}$ or $z/A^{3/2}$ should be a constant.

To compare this deduction with experiment, the relative values of the latter quotient are given in the last column. Considering the difficulty of the experiments, the agreement between theory and experiment is reasonably good*.

The single large scattering of α particles will obviously affect to some extent the shape of the Bragg ionization curve for a pencil of α rays. This effect of large scattering should be marked when the α rays have traversed screens of metals of high atomic weight, but should be small for atoms of light atomic weight.

(c) Geiger made a careful determination of the scattering of α particles passing through thin metal foils, by the scintillation method, and deduced the most probable angle

* The effect of change of velocity in an atomic encounter is neglected in this calculation.

through which the α particles are deflected in passing through known thicknesses of different kinds of matter.

A narrow pencil of homogeneous α rays was used as a source. After passing through the scattering foil, the total number of α particles deflected through different angles was directly measured. The angle for which the number of scattered particles was a maximum was taken as the most probable angle. The variation of the most probable angle with thickness of matter was determined, but calculation from these data is somewhat complicated by the variation of velocity of the α particles in their passage through the scattering material. A consideration of the curve of distribution of the α particles given in the paper (*loc. cit.* p. 496) shows that the angle through which half the particles are scattered is about 20 per cent greater than the most probable angle.

We have already seen that compound scattering may become important when about half the particles are scattered through a given angle, and it is difficult to disentangle in such cases the relative effects due to the two kinds of scattering. An approximate estimate can be made in the following way:—From (§ 5) the relation between the probabilities p_1 and p_2 for compound and single scattering respectively is given by

$$p_2 \log p_1 = -\cdot721.$$

The probability q of the combined effects may as a first approximation be taken as

$$q = (p_1^2 + p_2^2)^{1/2}.$$

If $q = \cdot5$, it follows that

$$p_1 = \cdot2 \quad \text{and} \quad p_2 = \cdot46.$$

We have seen that the probability p_2 of a single deflexion greater than ϕ is given by

$$p_2 = \frac{\pi}{4} n \cdot t \cdot b^2 \cot^2 \phi / 2.$$

Since in the experiments considered ϕ is comparatively small

$$\frac{\phi \sqrt{p_2}}{\sqrt{\pi n t}} = b = \frac{2NeE}{mu^2}.$$

Geiger found that the most probable angle of scattering of the α rays in passing through a thickness of gold equivalent in stopping power to about $\cdot76$ cm. of air was $1^\circ 40'$. The angle ϕ through which half the α particles are turned thus corresponds to 2° nearly.

$$t = \cdot00017 \text{ cm. ; } n = 6\cdot07 \times 10^{22} ;$$

$$u \text{ (average value)} = 1\cdot8 \times 10^9.$$

$$E/m = 1\cdot5 \times 10^{14} \text{ e.s. units ; } e = 4\cdot65 \times 10^{-10}.$$

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Taking the probability of single scattering =.46 and substituting the above values in the formula, the value of N for gold comes out to be 97.

For a thickness of gold equivalent in stopping power to 2.12 cms. of air, Geiger found the most probable angle to be $3^{\circ} 40'$. In this case $t = .00047$, $\phi = 4^{\circ} 4'$, and average $u = 1.7 \times 10^9$, and N comes out to be 114.

Geiger showed that the most probable angle of deflexion for an atom was nearly proportional to its atomic weight. It consequently follows that the value of N for different atoms should be nearly proportional to their atomic weights, at any rate for atomic weights between gold and aluminium.

Since the atomic weight of platinum is nearly equal to that of gold, it follows from these considerations that the magnitude of the diffuse reflexion of α particles through more than 90° from gold and the magnitude of the average small angle scattering of a pencil of rays in passing through gold-foil are both explained on the hypothesis of single scattering by supposing the atom of gold has a central charge of about $100e$.

(d) *Experiments of Crowther on scattering of β rays.*— We shall now consider how far the experimental results of Crowther on scattering of β particles of different velocities by various materials can be explained on the general theory of single scattering. On this theory, the fraction of β particles p turned through an angle greater than ϕ is given by

$$p = \frac{\pi}{4} n \cdot t \cdot b^2 \cot^2 \phi/2.$$

In most of Crowther's experiments ϕ is sufficiently small that $\tan \phi/2$ may be put equal to $\phi/2$ without much error. Consequently

$$\phi^2 = 2\pi n \cdot t \cdot b^2 \quad \text{if } p = 1/2.$$

On the theory of compound scattering, we have already seen that the chance p_1 that the deflexion of the particles is greater than ϕ is given by

$$\phi^2 \log p_1 = -\frac{9\pi^2}{64} n \cdot t \cdot b^2.$$

Since in the experiments of Crowther the thickness t of matter was determined for which $p_1 = 1/2$,

$$\phi^2 = .96\pi n t b^2.$$

For a probability of $1/2$, the theories of single and compound

scattering are thus identical in general form, but differ by a numerical constant. It is thus clear that the main relations on the theory of compound scattering of Sir J. J. Thomson, which were verified experimentally by Crowther, hold equally well on the theory of single scattering.

For example, if t_m be the thickness for which half the particles are scattered through an angle ϕ , Crowther showed that $\phi/\sqrt{t_m}$ and also $\frac{mu^2}{E} \cdot \sqrt{t_m}$ were constants for a given material when ϕ was fixed. These relations hold also on the theory of single scattering. Notwithstanding this apparent similarity in form, the two theories are fundamentally different. In one case, the effects observed are due to cumulative effects of small deflexions, while in the other the large deflexions are supposed to result from a single encounter. The distribution of scattered particles is entirely different on the two theories when the probability of deflexion greater than ϕ is small.

We have already seen that the distribution of scattered α particles at various angles has been found by Geiger to be in substantial agreement with the theory of single scattering, but cannot be explained on the theory of compound scattering alone. Since there is every reason to believe that the laws of scattering of α and β particles are very similar, the law of distribution of scattered β particles should be the same as for α particles for small thicknesses of matter. Since the value of mu^2/E for the β particles is in most cases much smaller than the corresponding value for the α particles, the chance of large single deflexions for β particles in passing through a given thickness of matter is much greater than for α particles. Since on the theory of single scattering the fraction of the number of particles which are deflected through a given angle is proportional to kt , where t is the thickness supposed small and k a constant, the number of particles which are undeflected through this angle is proportional to $1-kt$. From considerations based on the theory of compound scattering, Sir J. J. Thomson deduced that the probability of deflexion less than ϕ is proportional to $1-e^{-\mu t}$ where μ is a constant for any given value of ϕ .

The correctness of this latter formula was tested by Crowther by measuring electrically the fraction I/I_0 of the scattered β particles which passed through a circular opening subtending an angle of 36° with the scattering material. If

$$I/I_0 = 1 - e^{-\mu t},$$

the value of I should decrease very slowly at first with

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increase of t . Crowther, using aluminium as scattering material, states that the variation of I/I_0 was in good accord with this theory for small values of t . On the other hand, if single scattering be present, as it undoubtedly is for α rays, the curve showing the relation between I/I_0 and t should be nearly linear in the initial stages. The experiments of Madsen* on scattering of β rays, although not made with quite so small a thickness of aluminium as that used by Crowther, certainly support such a conclusion. Considering the importance of the point at issue, further experiments on this question are desirable.

From the table given by Crowther of the value $\phi/\sqrt{t_m}$ for different elements for β rays of velocity 2.68×10^{10} cms. per second, the values of the central charge Ne can be calculated on the theory of single scattering. It is supposed, as in the case of the α rays, that for the given value of $\phi/\sqrt{t_m}$ the fraction of the β particles deflected by single scattering through an angle greater than ϕ is .46 instead of .5.

The values of N calculated from Crowther's data are given below.

Element.	Atomic weight.	$\phi/\sqrt{t_m}$.	N .
Aluminium	27	4.25	22
Copper	63.2	10.0	42
Silver	108	15.4	78
Platinum	194	29.0	138

It will be remembered that the values of N for gold deduced from scattering of the α rays were in two calculations 97 and 114. These numbers are somewhat smaller than the values given above for platinum (viz. 138), whose atomic weight is not very different from gold. Taking into account the uncertainties involved in the calculation from the experimental data, the agreement is sufficiently close to indicate that the same general laws of scattering hold for the α and β particles, notwithstanding the wide differences in the relative velocity and mass of these particles.

As in the case of the α rays, the value of N should be most simply determined for any given element by measuring

* Phil. Mag. xviii. p. 909 (1909).

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the small fraction of the incident β particles scattered through a large angle. In this way, possible errors due to small scattering will be avoided.

The scattering data for the β rays, as well as for the α rays, indicate that the central charge in an atom is approximately proportional to its atomic weight. This falls in with the experimental deductions of Schmidt*. In his theory of absorption of β rays, he supposed that in traversing a thin sheet of matter, a small fraction α of the particles are stopped, and a small fraction β are reflected or scattered back in the direction of incidence. From comparison of the absorption curves of different elements, he deduced that the value of the constant β for different elements is proportional to nA^2 where n is the number of atoms per unit volume and A the atomic weight of the element. This is exactly the relation to be expected on the theory of single scattering if the central charge on an atom is proportional to its atomic weight.

§ 7. General Considerations.

In comparing the theory outlined in this paper with the experimental results, it has been supposed that the atom consists of a central charge supposed concentrated at a point, and that the large single deflexions of the α and β particles are mainly due to their passage through the strong central field. The effect of the equal and opposite compensating charge supposed distributed uniformly throughout a sphere has been neglected. Some of the evidence in support of these assumptions will now be briefly considered. For concreteness, consider the passage of a high speed α particle through an atom having a positive central charge Ne , and surrounded by a compensating charge of N electrons. Remembering that the mass, momentum, and kinetic energy of the α particle are very large compared with the corresponding values for an electron in rapid motion, it does not seem possible from dynamic considerations that an α particle can be deflected through a large angle by a close approach to an electron, even if the latter be in rapid motion and constrained by strong electrical forces. It seems reasonable to suppose that the chance of single deflexions through a large angle due to this cause, if not zero, must be exceedingly small compared with that due to the central charge.

It is of interest to examine how far the experimental evidence throws light on the question of the extent of the

* *Annal. d. Phys.* iv. 23. p. 671 (1907).

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distribution of the central charge. Suppose, for example, the central charge to be composed of N unit charges distributed over such a volume that the large single deflexions are mainly due to the constituent charges and not to the external field produced by the distribution. It has been shown (§ 3) that the fraction of the α particles scattered through a large angle is proportional to $(NeE)^2$, where Ne is the central charge concentrated at a point and E the charge on the deflected particle. If, however, this charge is distributed in single units, the fraction of the α particles scattered through a given angle is proportional to Ne^2 instead of N^2e^2 . In this calculation, the influence of mass of the constituent particle has been neglected, and account has only been taken of its electric field. Since it has been shown that the value of the central point charge for gold must be about 100, the value of the distributed charge required to produce the same proportion of single deflexions through a large angle should be at least 10,000. Under these conditions the mass of the constituent particle would be small compared with that of the α particle, and the difficulty arises of the production of large single deflexions at all. In addition, with such a large distributed charge, the effect of compound scattering is relatively more important than that of single scattering. For example, the probable small angle of deflexion of a pencil of α particles passing through a thin gold foil would be much greater than that experimentally observed by Geiger (§ *b-c*). The large and small angle scattering could not then be explained by the assumption of a central charge of the same value. Considering the evidence as a whole, it seems simplest to suppose that the atom contains a central charge distributed through a very small volume, and that the large single deflexions are due to the central charge as a whole, and not to its constituents. At the same time, the experimental evidence is not precise enough to negative the possibility that a small fraction of the positive charge may be carried by satellites extending some distance from the centre. Evidence on this point could be obtained by examining whether the same central charge is required to explain the large single deflexions of α and β particles; for the α particle must approach much closer to the centre of the atom than the β particle of average speed to suffer the same large deflexion.

The general data available indicate that the value of this central charge for different atoms is approximately proportional to their atomic weights, at any rate for atoms heavier than aluminium. It will be of great interest to examine

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experimentally whether such a simple relation holds also for the lighter atoms. In cases where the mass of the deflecting atom (for example, hydrogen, helium, lithium) is not very different from that of the α particle, the general theory of single scattering will require modification, for it is necessary to take into account the movements of the atom itself (see § 4).

It is of interest to note that Nagaoka* has mathematically considered the properties of a "Saturnian" atom which he supposed to consist of a central attracting mass surrounded by rings of rotating electrons. He showed that such a system was stable if the attractive force was large. From the point of view considered in this paper, the chance of large deflexion would practically be unaltered, whether the atom is considered to be a disk or a sphere. It may be remarked that the approximate value found for the central charge of the atom of gold ($100e$) is about that to be expected if the atom of gold consisted of 49 atoms of helium, each carrying a charge $2e$. This may be only a coincidence, but it is certainly suggestive in view of the expulsion of helium atoms carrying two unit charges from radioactive matter.

The deductions from the theory so far considered are independent of the sign of the central charge, and it has not so far been found possible to obtain definite evidence to determine whether it be positive or negative. It may be possible to settle the question of sign by consideration of the difference of the laws of absorption of the β particle to be expected on the two hypotheses, for the effect of radiation in reducing the velocity of the β particle should be far more marked with a positive than with a negative centre. If the central charge be positive, it is easily seen that a positively charged mass if released from the centre of a heavy atom, would acquire a great velocity in moving through the electric field. It may be possible in this way to account for the high velocity of expulsion of α particles without supposing that they are initially in rapid motion within the atom.

Further consideration of the application of this theory to these and other questions will be reserved for a later paper, when the main deductions of the theory have been tested experimentally. Experiments in this direction are already in progress by Geiger and Marsden.

University of Manchester,
April 1911.

* Nagaoka, *Phil. Mag.* vii. p. 445 (1904).

ANEXO 13 – Artigo E. Rutherford, *Philosophical Magazine*, S6, 1919.

Philosophical Magazine
31–37



LIV. *Collision of α Particles with Light Atoms. IV. An Anomalous Effect in Nitrogen.* By Professor Sir E. RUTHERFORD, F.R.S.*

It has been shown in paper I. that a metal source, coated with a deposit of radium C, always gives rise to a number of scintillations on a zinc sulphide screen far beyond the range of the α particles. The swift atoms causing these scintillations carry a positive charge and are deflected by a magnetic field, and have about the same range and energy as the swift H atoms produced by the passage of α particles through hydrogen. These "natural" scintillations are believed to be due mainly to swift H atoms from the radioactive source, but it is difficult to decide whether they are expelled from the radioactive source itself or are due to the action of α particles on occluded hydrogen.

The apparatus employed to study these "natural" scintillations is the same as that described in paper I. The intense source of radium C was placed inside a metal box about 3 cm. from the end, and an opening in the end of the box was covered with a silver plate of stopping power equal to about 6 cm. of air. The zinc sulphide screen was mounted outside, about 1 mm. distant from the silver plate, to admit of the introduction of absorbing foils between them. The whole apparatus was placed in a strong magnetic field to deflect the β rays. The variation in the number of these "natural" scintillations with absorption in terms of cms. of air is shown in fig. 1, curve A. In this case, the air in the box was exhausted and absorbing foils of aluminium were used. When dried oxygen or carbon dioxide was admitted into the vessel, the number of scintillations diminished to about the amount to be expected from the stopping power of the column of gas.

A surprising effect was noticed, however, when dried air was introduced. Instead of diminishing, the number of scintillations was increased, and for an absorption corresponding to about 19 cm. of air the number was about twice that observed when the air was exhausted. It was clear from this experiment that the α particles in their passage through air gave rise to long-range scintillations which appeared to the eye to be about equal in brightness to H scintillations. A systematic series of observations was undertaken to account for the origin of these scintillations. In the first place we have seen that the passage of α particles through nitrogen and

* Communicated by the Author.

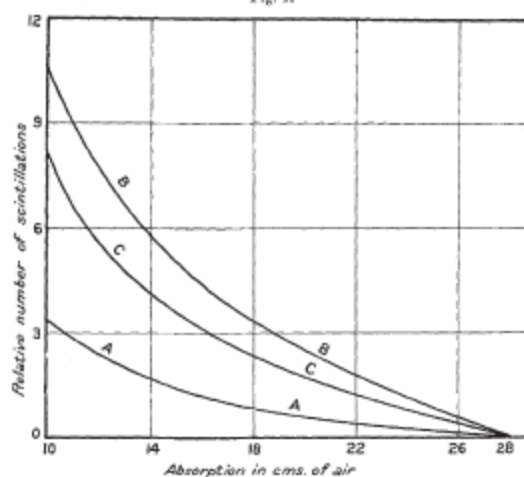
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Sir E. Rutherford on Collision of

oxygen gives rise to numerous bright scintillations which have a range of about 9 cm. in air. These scintillations have about the range to be expected if they are due to swift N or O atoms, carrying unit charge, produced by collision with α particles.

Fig. 1.



All experiments have consequently been made with an absorption greater than 9 cm. of air, so that these atoms are completely stopped before reaching the zinc sulphide screen.

It was found that these long-range scintillations could not be due to the presence of water vapour in the air; for the number was only slightly reduced by thoroughly drying the air. This is to be expected, since on the average the number of the additional scintillations due to air was equivalent to the number of H atoms produced by the mixture of hydrogen at 6 cm. pressure with oxygen. Since on the average the vapour pressure of water in air was not more than 1 cm., the effects of complete drying would not reduce the number by more than one sixth. Even when oxygen and carbon dioxide saturated with water vapour at 20° C.

α Particles with Light Atoms.

were introduced in place of dry air, the number of scintillations was much less than with dry air.

It is well known that the amount of hydrogen or gases containing hydrogen is normally very small in atmospheric air. No difference was observed whether the air was taken directly from the room or from outside the laboratory or was stored for some days over water.

There was the possibility that the effect in air might be due to liberation of H atoms from the dust nuclei in the air. No appreciable difference, however, was observed when the dried air was filtered through long plugs of cotton-wool, or by storage over water for some days to remove dust nuclei.

Since the anomalous effect was observed in air, but not in oxygen, or carbon dioxide, it must be due either to nitrogen or to one of the other gases present in atmospheric air. The latter possibility was excluded by comparing the effects produced in air and in chemically prepared nitrogen. The nitrogen was obtained by the well-known method of adding ammonium chloride to sodium nitrite, and stored over water. It was carefully dried before admission to the apparatus. With pure nitrogen, the number of long-range scintillations under similar conditions was greater than in air. As a result of careful experiments, the ratio was found to be 1.25, the value to be expected if the scintillations are due to nitrogen.

The results so far obtained show that the long-range scintillations obtained from air must be ascribed to nitrogen, but it is important, in addition, to show that they are due to collision of α particles with atoms of nitrogen through the volume of the gas. In the first place, it was found that the number of the scintillations varied with the pressure of the air in the way to be expected if they resulted from collision of α particles along the column of gas. In addition, when an absorbing screen of gold or aluminium was placed close to the source, the range of the scintillations was found to be reduced by the amount to be expected if the range of the expelled atom was proportional to the range of the colliding α particles. These results show that the scintillations arise from the volume of the gas and are not due to some surface effect in the radioactive source.

In fig. 1 curve A the results of a typical experiment are given showing the variation in the number of natural scintillations with the amount of absorbing matter in their path measured in terms of centimetres of air for α particles. In these experiments carbon dioxide was introduced at a pressure calculated to give the same absorption of the α rays as ordinary air. In curve B the corresponding curve is given when air

Sir E. Rutherford on *Collision of*

at N.T.P. is introduced in place of carbon dioxide. The difference curve C shows the corresponding variation of the number of scintillations arising from the nitrogen in the air. It was generally observed that the ratio of the nitrogen effect to the natural effect was somewhat greater for 19 cm. than for 12 cm. absorption.

In order to estimate the magnitude of the effect, the space between the source and screen was filled with carbon dioxide at diminished pressure and a known pressure of hydrogen was added. The pressure of the carbon dioxide and of hydrogen were adjusted so that the total absorption of α particles in the mixed gas should be equal to that of the air. In this way it was found that the curve of absorption of H atoms produced under these conditions was somewhat steeper than curve C of fig. 1. As a consequence, the amount of hydrogen mixed with carbon dioxide required to produce a number of scintillations equal to that of air, increased with the increase of absorption. For example, the effect in air was equal to about 4 cm. of hydrogen at 12 cm. absorption, and about 8 cm. at 19 cm. absorption. For a mean value of the absorption, the effect was equal to about 6 cm. of hydrogen. This increased absorption of H atoms under similar conditions indicated either that (1) the swift atoms from air had a somewhat greater range than the H atoms, or (2) that the atoms from air were projected more in the line of flight of the α particles.

While the maximum range of the scintillations from air using radium C as a source of α rays appeared to be about the same, viz. 28 cm., as for H atoms produced from hydrogen, it was difficult to fix the end of the range with certainty on account of the smallness of the number and the weakness of the scintillations. Some special experiments were made to test whether, under favourable conditions, any scintillations due to nitrogen could be observed beyond 28 cm. of air absorption. For this purpose a strong source (about 60 mg. Ra activity) was brought within 2.5 cm. of the zinc sulphide screen, the space between containing dry air. On still further reducing the distance, the screen became too bright to detect very feeble scintillations. No certain evidence of scintillations was found beyond a range of 28 cm. It would therefore appear that (2) above is the more probable explanation.

In a previous paper (III.) we have seen that the number of swift atoms of nitrogen or oxygen produced per unit path by collision with α particles is about the same as the corresponding number of H atoms in hydrogen. Since the number of long-range scintillations in air is equivalent to that produced under similar conditions in a column of hydrogen at 6 cm.

α Particles with Light Atoms.

pressure, we may consequently conclude that only one long-range atom is produced for every 12 close collisions giving rise to a swift nitrogen atom of maximum range 9 cm.

It is of interest to give data showing the number of long-range scintillations produced in nitrogen at atmospheric pressure under definite conditions. For a column of nitrogen 3.3 cm. long, and for a total absorption of 19 cm. of air from the source, the number due to nitrogen per milligram of activity is .6 per minute on a screen of 3.14 sq. mm. area.

Both as regards range and brightness of scintillations, the long-range atoms from nitrogen closely resemble H atoms, and in all probability are hydrogen atoms. In order, however, to settle this important point definitely, it is necessary to determine the deflexion of these atoms in a magnetic field. Some preliminary experiments have been made by a method similar to that employed in measuring the velocity of the H atom (see paper II.). The main difficulty is to obtain a sufficiently large deflexion of the stream of atoms and yet have a sufficient number of scintillations per minute for counting. The α rays from a strong source passed through dry air between two parallel horizontal plates 3 cm. long and 1.6 mm. apart, and the number of scintillations on the screen placed near the end of the plates was observed for different strengths of the magnetic field. Under these conditions, when the scintillations arise from the whole length of the column of air between the plates, the strongest magnetic field available reduced the number of scintillations by only 30 per cent. When the air was replaced by a mixture of carbon dioxide and hydrogen of the same stopping power for α rays, about an equal reduction was noted. As far as the experiment goes, this is an indication that the scintillations are due to H atoms; but the actual number of scintillations and the amount of reduction was too small to place much reliance on the result. In order to settle this question definitely, it will probably prove necessary to employ a solid nitrogen compound, free from hydrogen, as a source, and to use much stronger sources of α rays. In such experiments, it will be of importance to discriminate between the deflexions due to H atoms and possible atoms of atomic weight 2. From the calculations given in paper III., it is seen that a collision of an α particle with a free atom of mass 2 should give rise to an atom of range about 32 cm. in air, and of initial energy about .89 of that of the H atom produced under similar conditions. The deflexion of the pencil of these rays in a magnetic field should be about .6 of that shown by a corresponding pencil of H atoms.

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*Collision of α Particles with Light Atoms.**Discussion of results.*

From the results so far obtained it is difficult to avoid the conclusion that the long-range atoms arising from collision of α particles with nitrogen are not nitrogen atoms but probably atoms of hydrogen, or atoms of mass 2. If this be the case, we must conclude that the nitrogen atom is disintegrated under the intense forces developed in a close collision with a swift α particle, and that the hydrogen atom which is liberated formed a constituent part of the nitrogen nucleus. We have drawn attention in paper III. to the rather surprising observation that the range of the nitrogen atoms in air is about the same as the oxygen atoms, although we should expect a difference of about 19 per cent. If in collisions which give rise to swift nitrogen atoms, the hydrogen is at the same time disrupted, such a difference might be accounted for, for the energy is then shared between two systems.

It is of interest to note, that while the majority of the light atoms, as is well known, have atomic weights represented by $4n$ or $4n+3$ where n is a whole number, nitrogen is the only atom which is expressed by $4n+2$. We should anticipate from radioactive data that the nitrogen nucleus consists of three helium nuclei each of atomic mass 4 and either two hydrogen nuclei or one of mass 2. If the H nuclei were outriders of the main system of mass 12, the number of close collisions with the bound H nuclei would be less than if the latter were free, for the α particle in a collision comes under the combined field of the H nucleus and of the central mass. Under such conditions, it is to be expected that the α particle would only occasionally approach close enough to the H nucleus to give it the maximum velocity, although in many cases it may give it sufficient energy to break its bond with the central mass. Such a point of view would explain why the number of swift H atoms from nitrogen is less than the corresponding number in free hydrogen and less also than the number of swift nitrogen atoms. The general results indicate that the H nuclei, which are released, are distant about twice the diameter of the electron (7×10^{-10} cm.) from the centre of the main atom. Without a knowledge of the laws of force at such small distances, it is difficult to estimate the energy required to free the H nucleus or to calculate the maximum velocity that can be given to the escaping H atom. It is not to be expected, *a priori*, that the velocity or range of the H atom released from the nitrogen atom should be identical with that due to a collision in free hydrogen.

Taking into account the great energy of motion of the α particle expelled from radium C, the close collision of such

Rotational Oscillation of Cylinder in a Viscous Liquid.

an α particle with a light atom seems to be the most likely agency to promote the disruption of the latter; for the forces on the nuclei arising from such collisions appear to be greater than can be produced by any other agency at present available. Considering the enormous intensity of the forces brought into play, it is not so much a matter of surprise that the nitrogen atom should suffer disintegration as that the α particle itself escapes disruption into its constituents. The results as a whole suggest that, if α particles—or similar projectiles—of still greater energy were available for experiment, we might expect to break down the nucleus structure of many of the lighter atoms.

I desire to express my thanks to Mr. William Kay for his invaluable assistance in counting scintillations.

University of Manchester,
April 1919.

ANEXO 14 – A constituição de átomos e moléculas, parte 1.

THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[SIXTH SERIES.]

JULY 1913.

I. *On the Constitution of Atoms and Molecules.*
By N. BOHR, Dr. phil. Copenhagen.*

Introduction.

IN order to explain the results of experiments on scattering of α rays by matter Prof. Rutherford† has given a theory of the structure of atoms. According to this theory, the atoms consist of a positively charged nucleus surrounded by a system of electrons kept together by attractive forces from the nucleus; the total negative charge of the electrons is equal to the positive charge of the nucleus. Further, the nucleus is assumed to be the seat of the essential part of the mass of the atom, and to have linear dimensions exceedingly small compared with the linear dimensions of the whole atom. The number of electrons in an atom is deduced to be approximately equal to half the atomic weight. Great interest is to be attributed to this atom-model; for, as Rutherford has shown, the assumption of the existence of nuclei, as those in question, seems to be necessary in order to account for the results of the experiments on large angle scattering of the α rays‡.

In an attempt to explain some of the properties of matter on the basis of this atom-model we meet, however, with difficulties of a serious nature arising from the apparent

* Communicated by Prof. E. Rutherford, F.R.S.

† E. Rutherford, *Phil. Mag.* xxi. p. 669 (1911).

‡ See also Geiger and Marsden, *Phil. Mag.* April 1913.

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instability of the system of electrons: difficulties purposely avoided in atom-models previously considered, for instance, in the one proposed by Sir J. J. Thomson*. According to the theory of the latter the atom consists of a sphere of uniform positive electrification, inside which the electrons move in circular orbits.

The principal difference between the atom-models proposed by Thomson and Rutherford consists in the circumstance that the forces acting on the electrons in the atom-model of Thomson allow of certain configurations and motions of the electrons for which the system is in a stable equilibrium; such configurations, however, apparently do not exist for the second atom-model. The nature of the difference in question will perhaps be most clearly seen by noticing that among the quantities characterizing the first atom a quantity appears—the radius of the positive sphere—of dimensions of a length and of the same order of magnitude as the linear extension of the atom, while such a length does not appear among the quantities characterizing the second atom, viz. the charges and masses of the electrons and the positive nucleus; nor can it be determined solely by help of the latter quantities.

The way of considering a problem of this kind has, however, undergone essential alterations in recent years owing to the development of the theory of the energy radiation, and the direct affirmation of the new assumptions introduced in this theory, found by experiments on very different phenomena such as specific heats, photoelectric effect, Röntgen-rays, &c. The result of the discussion of these questions seems to be a general acknowledgment of the inadequacy of the classical electrodynamics in describing the behaviour of systems of atomic size†. Whatever the alteration in the laws of motion of the electrons may be, it seems necessary to introduce in the laws in question a quantity foreign to the classical electrodynamics, *i. e.* Planck's constant, or as it often is called the elementary quantum of action. By the introduction of this quantity the question of the stable configuration of the electrons in the atoms is essentially changed, as this constant is of such dimensions and magnitude that it, together with the mass and charge of the particles, can determine a length of the order of magnitude required.

This paper is an attempt to show that the application of the above ideas to Rutherford's atom-model affords a basis

* J. J. Thomson, *Phil. Mag.* vii. p. 237 (1904).

† See *f. inst.*, 'Théorie du rayonnement et les quanta.' *Rapports de la réunion à Bruxelles*, Nov. 1911. Paris, 1912.

for a theory of the constitution of atoms. It will further be shown that from this theory we are led to a theory of the constitution of molecules.

In the present first part of the paper the mechanism of the binding of electrons by a positive nucleus is discussed in relation to Planck's theory. It will be shown that it is possible from the point of view taken to account in a simple way for the law of the line spectrum of hydrogen. Further, reasons are given for a principal hypothesis on which the considerations contained in the following parts are based.

I wish here to express my thanks to Prof. Rutherford for his kind and encouraging interest in this work.

PART I.—BINDING OF ELECTRONS BY POSITIVE NUCLEI.

§ 1. *General Considerations.*

The inadequacy of the classical electrodynamics in accounting for the properties of atoms from an atom-model as Rutherford's, will appear very clearly if we consider a simple system consisting of a positively charged nucleus of very small dimensions and an electron describing closed orbits around it. For simplicity, let us assume that the mass of the electron is negligibly small in comparison with that of the nucleus, and further, that the velocity of the electron is small compared with that of light.

Let us at first assume that there is no energy radiation. In this case the electron will describe stationary elliptical orbits. The frequency of revolution ω and the major-axis of the orbit $2a$ will depend on the amount of energy W which must be transferred to the system in order to remove the electron to an infinitely great distance apart from the nucleus. Denoting the charge of the electron and of the nucleus by $-e$ and E respectively and the mass of the electron by m , we thus get

$$\omega = \frac{\sqrt{2}}{\pi} \frac{W^{\frac{1}{2}}}{eE\sqrt{m}}, \quad 2a = \frac{eE}{W}. \quad \dots (1)$$

Further, it can easily be shown that the mean value of the kinetic energy of the electron taken for a whole revolution is equal to $\frac{1}{2}W$. We see that if the value of W is not given, there will be no values of ω and a characteristic for the system in question.

Let us now, however, take the effect of the energy radiation into account, calculated in the ordinary way from the acceleration of the electron. In this case the electron will

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no longer describe stationary orbits. W will continuously increase, and the electron will approach the nucleus describing orbits of smaller and smaller dimensions, and with greater and greater frequency; the electron on the average gaining in kinetic energy at the same time as the whole system loses energy. This process will go on until the dimensions of the orbit are of the same order of magnitude as the dimensions of the electron or those of the nucleus. A simple calculation shows that the energy radiated out during the process considered will be enormously great compared with that radiated out by ordinary molecular processes.

It is obvious that the behaviour of such a system will be very different from that of an atomic system occurring in nature. In the first place, the actual atoms in their permanent state seem to have absolutely fixed dimensions and frequencies. Further, if we consider any molecular process, the result seems always to be that after a certain amount of energy characteristic for the systems in question is radiated out, the systems will again settle down in a stable state of equilibrium, in which the distances apart of the particles are of the same order of magnitude as before the process.

Now the essential point in Planck's theory of radiation is that the energy radiation from an atomic system does not take place in the continuous way assumed in the ordinary electrodynamics, but that it, on the contrary, takes place in distinctly separated emissions, the amount of energy radiated out from an atomic vibrator of frequency ν in a single emission being equal to $\tau h\nu$, where τ is an entire number, and h is a universal constant*.

Returning to the simple case of an electron and a positive nucleus considered above, let us assume that the electron at the beginning of the interaction with the nucleus was at a great distance apart from the nucleus, and had no sensible velocity relative to the latter. Let us further assume that the electron after the interaction has taken place has settled down in a stationary orbit around the nucleus. We shall, for reasons referred to later, assume that the orbit in question is circular: this assumption will, however, make no alteration in the calculations for systems containing only a single electron.

Let us now assume that, during the binding of the electron, a homogeneous radiation is emitted of a frequency ν , equal to half the frequency of revolution of the electron in its final

* See f. inst., M. Planck, *Ann. d. Phys.* xxxi. p. 758 (1910); xxxvii. p. 642 (1912); *Verh. deutsch. Phys. Ges.* 1911, p. 138.

orbit; then, from Planck's theory, we might expect that the amount of energy emitted by the process considered is equal to $\tau h\nu$, where h is Planck's constant and τ an entire number. If we assume that the radiation emitted is homogeneous, the second assumption concerning the frequency of the radiation suggests itself, since the frequency of revolution of the electron at the beginning of the emission is 0. The question, however, of the rigorous validity of both assumptions, and also of the application made of Planck's theory, will be more closely discussed in § 3.

Putting
$$W = \tau h \frac{\omega}{2}, \quad \dots \dots \dots (2)$$

we get by help of the formula (1)

$$W = \frac{2\pi^2 m e^3 E^2}{\tau^2 h^2}, \quad \omega = \frac{4\pi^2 m e^2 E^2}{\tau^2 h^2}, \quad 2a = \frac{\tau^2 h^2}{2\pi^2 m e E}. \quad (3)$$

If in these expressions we give τ different values, we get a series of values for W , ω , and a corresponding to a series of configurations of the system. According to the above considerations, we are led to assume that these configurations will correspond to states of the system in which there is no radiation of energy; states which consequently will be stationary as long as the system is not disturbed from outside. We see that the value of W is greatest if τ has its smallest value 1. This case will therefore correspond to the most stable state of the system, *i. e.* will correspond to the binding of the electron for the breaking up of which the greatest amount of energy is required.

Putting in the above expressions $\tau=1$ and $E=e$, and introducing the experimental values

$$e = 4.7 \cdot 10^{-10}, \quad \frac{e}{m} = 5.31 \cdot 10^{17}, \quad h = 6.5 \cdot 10^{-27},$$

we get

$$2a = 1.1 \cdot 10^{-8} \text{ cm.}, \quad \omega = 6.2 \cdot 10^{15} \frac{1}{\text{sec.}}, \quad \frac{W}{e} = 13 \text{ volt.}$$

We see that these values are of the same order of magnitude as the linear dimensions of the atoms, the optical frequencies, and the ionization-potentials.

The general importance of Planck's theory for the discussion of the behaviour of atomic systems was originally pointed out by Einstein*. The considerations of Einstein

* A. Einstein, *Ann. d. Phys.* xvii. p. 152 (1905); xx. p. 199 (1906); xxii. p. 180 (1907).

have been developed and applied on a number of different phenomena, especially by Stark, Nernst, and Sommerfeld. The agreement as to the order of magnitude between values observed for the frequencies and dimensions of the atoms, and values for these quantities calculated by considerations similar to those given above, has been the subject of much discussion. It was first pointed out by Haas*, in an attempt to explain the meaning and the value of Planck's constant on the basis of J. J. Thomson's atom-model, by help of the linear dimensions and frequency of an hydrogen atom.

Systems of the kind considered in this paper, in which the forces between the particles vary inversely as the square of the distance, are discussed in relation to Planck's theory by J. W. Nicholson†. In a series of papers this author has shown that it seems to be possible to account for lines of hitherto unknown origin in the spectra of the stellar nebulae and that of the solar corona, by assuming the presence in these bodies of certain hypothetical elements of exactly indicated constitution. The atoms of these elements are supposed to consist simply of a ring of a few electrons surrounding a positive nucleus of negligibly small dimensions. The ratios between the frequencies corresponding to the lines in question are compared with the ratios between the frequencies corresponding to different modes of vibration of the ring of electrons. Nicholson has obtained a relation to Planck's theory showing that the ratios between the wave-length of different sets of lines of the coronal spectrum can be accounted for with great accuracy by assuming that the ratio between the energy of the system and the frequency of rotation of the ring is equal to an entire multiple of Planck's constant. The quantity Nicholson refers to as the energy is equal to twice the quantity which we have denoted above by W . In the latest paper cited Nicholson has found it necessary to give the theory a more complicated form, still, however, representing the ratio of energy to frequency by a simple function of whole numbers.

The excellent agreement between the calculated and observed values of the ratios between the wave-lengths in question seems a strong argument in favour of the validity of the foundation of Nicholson's calculations. Serious

* A. E. Haas, *Jahrb. d. Rad. u. El.* vii. p. 261 (1910). See further, A. Schidlof, *Ann. d. Phys.* xxxv. p. 90 (1911); E. Wertheimer, *Phys. Zeitschr.* xii. p. 409 (1911), *Verh. deutsch. Phys. Ges.* 1912, p. 431; F. A. Lindemann, *Verh. deutsch. Phys. Ges.* 1911, pp. 482, 1107; F. Haber, *Verh. deutsch. Phys. Ges.* 1911, p. 1117.

† J. W. Nicholson, *Month. Not. Roy. Astr. Soc.* lxxii. pp. 49, 130, 677, 693, 729 (1912).

objections, however, may be raised against the theory. These objections are intimately connected with the problem of the homogeneity of the radiation emitted. In Nicholson's calculations the frequency of lines in a line-spectrum is identified with the frequency of vibration of a mechanical system in a distinctly indicated state of equilibrium. As a relation from Planck's theory is used, we might expect that the radiation is sent out in quanta; but systems like those considered, in which the frequency is a function of the energy, cannot emit a finite amount of a homogeneous radiation; for, as soon as the emission of radiation is started, the energy and also the frequency of the system are altered. Further, according to the calculation of Nicholson, the systems are unstable for some modes of vibration. Apart from such objections—which may be only formal (see p. 23)—it must be remarked, that the theory in the form given does not seem to be able to account for the well-known laws of Balmer and Rydberg connecting the frequencies of the lines in the line-spectra of the ordinary elements.

It will now be attempted to show that the difficulties in question disappear if we consider the problems from the point of view taken in this paper. Before proceeding it may be useful to restate briefly the ideas characterizing the calculations on p. 5. The principal assumptions used are :

- (1) That the dynamical equilibrium of the systems in the stationary states can be discussed by help of the ordinary mechanics, while the passing of the systems between different stationary states cannot be treated on that basis.
- (2) That the latter process is followed by the emission of a *homogeneous* radiation, for which the relation between the frequency and the amount of energy emitted is the one given by Planck's theory.

The first assumption seems to present itself; for it is known that the ordinary mechanics cannot have an absolute validity, but will only hold in calculations of certain mean values of the motion of the electrons. On the other hand, in the calculations of the dynamical equilibrium in a stationary state in which there is no relative displacement of the particles, we need not distinguish between the actual motions and their mean values. The second assumption is in obvious contrast to the ordinary ideas of electrodynamics, but appears to be necessary in order to account for experimental facts.

In the calculations on page 5 we have further made use

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of the more special assumptions, viz. that the different stationary states correspond to the emission of a different number of Planck's energy-quanta, and that the frequency of the radiation emitted during the passing of the system from a state in which no energy is yet radiated out to one of the stationary states, is equal to half the frequency of revolution of the electron in the latter state. We can, however (see § 3), also arrive at the expressions (3) for the stationary states by using assumptions of somewhat different form. We shall, therefore, postpone the discussion of the special assumptions, and first show how by the help of the above principal assumptions, and of the expressions (3) for the stationary states, we can account for the line-spectrum of hydrogen.

§ 2. Emission of Line-spectra.

Spectrum of Hydrogen.—General evidence indicates that an atom of hydrogen consists simply of a single electron rotating round a positive nucleus of charge e^* . The re-formation of a hydrogen atom, when the electron has been removed to great distances away from the nucleus—*e. g.* by the effect of electrical discharge in a vacuum tube—will accordingly correspond to the binding of an electron by a positive nucleus considered on p. 5. If in (3) we put $E=e$, we get for the total amount of energy radiated out by the formation of one of the stationary states,

$$W_r = \frac{2\pi^2 m e^4}{h^2 \tau^2}.$$

The amount of energy emitted by the passing of the system from a state corresponding to $\tau = \tau_1$ to one corresponding to $\tau = \tau_2$, is consequently

$$W_{r_2} - W_{r_1} = \frac{2\pi^2 m e^4}{h^2} \left(\frac{1}{\tau_2^2} - \frac{1}{\tau_1^2} \right).$$

If now we suppose that the radiation in question is homogeneous, and that the amount of energy emitted is equal to $h\nu$, where ν is the frequency of the radiation, we get

$$W_{r_2} - W_{r_1} = h\nu,$$

* See *f. inst.* N. Bohr, *Phil. Mag.* xxv. p. 24 (1913). The conclusion drawn in the paper cited is strongly supported by the fact that hydrogen, in the experiments on positive rays of Sir J. J. Thomson, is the only element which never occurs with a positive charge corresponding to the loss of more than one electron (*comp. Phil. Mag.* xxiv. p. 672 (1912)).

and from this

$$\nu = \frac{2\pi^2 m e^4}{h^3} \left(\frac{1}{\tau_2^2} - \frac{1}{\tau_1^2} \right) \dots \dots \dots (4)$$

We see that this expression accounts for the law connecting the lines in the spectrum of hydrogen. If we put $\tau_2=2$ and let τ_1 vary, we get the ordinary Balmer series. If we put $\tau_2=3$, we get the series in the ultra-red observed by Paschen* and previously suspected by Ritz. If we put $\tau_2=1$ and $\tau_1=4, 5, \dots$, we get series respectively in the extreme ultra-violet and the extreme ultra-red, which are not observed, but the existence of which may be expected.

The agreement in question is quantitative as well as qualitative. Putting

$$e=4.7 \cdot 10^{-10}, \quad \frac{e}{m}=5.31 \cdot 10^{17}, \quad \text{and} \quad h=6.5 \cdot 10^{-27},$$

we get

$$\frac{2\pi^2 m e^4}{h^3} = 3.1 \cdot 10^{16}.$$

The observed value for the factor outside the bracket in the formula (4) is

$$3.290 \cdot 10^{15}.$$

The agreement between the theoretical and observed values is inside the uncertainty due to experimental errors in the constants entering in the expression for the theoretical value. We shall in § 3 return to consider the possible importance of the agreement in question.

It may be remarked that the fact, that it has not been possible to observe more than 12 lines of the Balmer series in experiments with vacuum tubes, while 33 lines are observed in the spectra of some celestial bodies, is just what we should expect from the above theory. According to the equation (3) the diameter of the orbit of the electron in the different stationary states is proportional to τ^2 . For $\tau=12$ the diameter is equal to $1.6 \cdot 10^{-6}$ cm., or equal to the mean distance between the molecules in a gas at a pressure of about 7 mm. mercury; for $\tau=33$ the diameter is equal to $1.2 \cdot 10^{-5}$ cm., corresponding to the mean distance of the molecules at a pressure of about 0.02 mm. mercury. According to the theory the necessary condition for the appearance of a great number of lines is therefore a very small density of the gas; for simultaneously to obtain an

* F. Paschen, *Ann. d. Phys.* xxvii. p. 565 (1908).

intensity sufficient for observation the space filled with the gas must be very great. If the theory is right, we may therefore never expect to be able in experiments with vacuum tubes to observe the lines corresponding to high numbers of the Balmer series of the emission spectrum of hydrogen; it might, however, be possible to observe the lines by investigation of the absorption spectrum of this gas (see § 4).

It will be observed that we in the above way do not obtain other series of lines, generally ascribed to hydrogen; for instance, the series first observed by Pickering* in the spectrum of the star ζ Puppis, and the set of series recently found by Fowler† by experiments with vacuum tubes containing a mixture of hydrogen and helium. We shall, however, see that, by help of the above theory, we can account naturally for these series of lines if we ascribe them to helium.

A neutral atom of the latter element consists, according to Rutherford's theory, of a positive nucleus of charge $2e$ and two electrons. Now considering the binding of a single electron by a helium nucleus, we get, putting $E=2e$ in the expressions (3) on page 5, and proceeding in exactly the same way as above,

$$\nu = \frac{8\pi^2me^4}{k^3} \left(\frac{1}{\tau_2^2} - \frac{1}{\tau_1^2} \right) = \frac{2\pi^2me^4}{k^3} \left(\frac{1}{\left(\frac{\tau_2}{2}\right)^2} - \frac{1}{\left(\frac{\tau_1}{2}\right)^2} \right).$$

If we in this formula put $\tau_2=1$ or $\tau_2=2$, we get series of lines in the extreme ultra-violet. If we put $\tau_2=3$, and let τ_1 vary, we get a series which includes 2 of the series observed by Fowler, and denoted by him as the first and second principal series of the hydrogen spectrum. If we put $\tau_2=4$, we get the series observed by Pickering in the spectrum of ζ Puppis. Every second of the lines in this series is identical with a line in the Balmer series of the hydrogen spectrum; the presence of hydrogen in the star in question may therefore account for the fact that these lines are of a greater intensity than the rest of the lines in the series. The series is also observed in the experiments of Fowler, and denoted in his paper as the Sharp series of the hydrogen spectrum. If we finally in the above formula put $\tau_2=5, 6, \dots$, we get series, the strong lines of which are to be expected in the ultra-red.

The reason why the spectrum considered is not observed in

* E. C. Pickering, *Astrophys. J.* iv. p. 369 (1896); v. p. 92 (1897).

† A. Fowler, *Month. Not. Roy. Astr. Soc.* lxxiii. Dec. 1912.

ordinary helium tubes may be that in such tubes the ionization of helium is not so complete as in the star considered or in the experiments of Fowler, where a strong discharge was sent through a mixture of hydrogen and helium. The condition for the appearance of the spectrum is, according to the above theory, that helium atoms are present in a state in which they have lost both their electrons. Now we must assume that the amount of energy to be used in removing the second electron from a helium atom is much greater than that to be used in removing the first. Further, it is known from experiments on positive rays, that hydrogen atoms can acquire a negative charge; therefore the presence of hydrogen in the experiments of Fowler may effect that more electrons are removed from some of the helium atoms than would be the case if only helium were present.

Spectra of other substances.—In case of systems containing more electrons we must—in conformity with the result of experiments—expect more complicated laws for the line-spectra than those considered. I shall try to show that the point of view taken above allows, at any rate, a certain understanding of the laws observed.

According to Rydberg's theory—with the generalization given by Ritz*—the frequency corresponding to the lines of the spectrum of an element can be expressed by

$$\nu = F_r(\tau_1) - F_s(\tau_2),$$

where τ_1 and τ_2 are entire numbers, and F_1, F_2, F_3, \dots are functions of τ which approximately are equal to $\frac{K}{(\tau + a_1)^2}$, $\frac{K}{(\tau + a_2)^2}, \dots$ K is a universal constant, equal to the factor outside the bracket in the formula (4) for the spectrum of hydrogen. The different series appear if we put τ_1 or τ_2 equal to a fixed number and let the other vary.

The circumstance that the frequency can be written as a difference between two functions of entire numbers suggests an origin of the lines in the spectra in question similar to the one we have assumed for hydrogen; *i. e.* that the lines correspond to a radiation emitted during the passing of the system between two different stationary states. For systems containing more than one electron the detailed discussion may be very complicated, as there will be many different configurations of the electrons which can be taken into consideration as stationary states. This may account for the different sets of series in the line spectra emitted from the

* W. Ritz, *Phys. Zeitschr.* ix, p. 521 (1908).

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substances in question. Here I shall only try to show how, by help of the theory, it can be simply explained that the constant K entering in Rydberg's formula is the same for all substances.

Let us assume that the spectrum in question corresponds to the radiation emitted during the binding of an electron; and let us further assume that the system including the electron considered is neutral. The force on the electron, when at a great distance apart from the nucleus and the electrons previously bound, will be very nearly the same as in the above case of the binding of an electron by a hydrogen nucleus. The energy corresponding to one of the stationary states will therefore for τ great be very nearly equal to that given by the expression (3) on p. 5, if we put $E=e$. For τ great we consequently get

$$\lim (\tau^2 \cdot F_1(\tau)) = \lim (\tau^2 \cdot F_2(\tau)) = \dots = \frac{2\pi^2 m e^4}{h^3},$$

in conformity with Rydberg's theory.

§ 3. General Considerations continued.

We shall now return to the discussion (see p. 7) of the special assumptions used in deducing the expressions (3) on p. 5 for the stationary states of a system consisting of an electron rotating round a nucleus.

For one, we have assumed that the different stationary states correspond to an emission of a different number of energy-quanta. Considering systems in which the frequency is a function of the energy, this assumption, however, may be regarded as improbable; for as soon as one quantum is sent out the frequency is altered. We shall now see that we can leave the assumption used and still retain the equation (2) on p. 5, and thereby the formal analogy with Planck's theory.

Firstly, it will be observed that it has not been necessary, in order to account for the law of the spectra by help of the expressions (3) for the stationary states, to assume that in any case a radiation is sent out corresponding to more than a single energy-quantum, $h\nu$. Further information on the frequency of the radiation may be obtained by comparing calculations of the energy radiation in the region of slow vibrations based on the above assumptions with calculations based on the ordinary mechanics. As is known, calculations on the latter basis are in agreement with experiments on the energy radiation in the named region.

Let us assume that the ratio between the total amount of

energy emitted and the frequency of revolution of the electron for the different stationary states is given by the equation $W=f(\tau) \cdot h\omega$, instead of by the equation (2). Proceeding in the same way as above, we get in this case instead of (3)

$$W = \frac{\pi^2 m e^2 E^2}{2h^2 f^2(\tau)}, \quad \omega = \frac{\pi^2 m e^2 E^2}{2h^2 f^3(\tau)}.$$

Assuming as above that the amount of energy emitted during the passing of the system from a state corresponding to $\tau = \tau_1$ to one for which $\tau = \tau_2$ is equal to $h\nu$, we get instead of (4)

$$\nu = \frac{\pi^2 m e^2 E^2}{2h^2} \left(\frac{1}{f^2(\tau_2)} - \frac{1}{f^2(\tau_1)} \right).$$

We see that in order to get an expression of the same form as the Balmer series we must put $f(\tau) = c\tau$.

In order to determine c let us now consider the passing of the system between two successive stationary states corresponding to $\tau = N$ and $\tau = N - 1$; introducing $f(\tau) = c\tau$, we get for the frequency of the radiation emitted

$$\nu = \frac{\pi^2 m e^2 E^2}{2c^2 h^2} \cdot \frac{2N - 1}{N^2(N - 1)^2}.$$

For the frequency of revolution of the electron before and after the emission we have

$$\omega_N = \frac{\pi^2 m e^2 E^2}{2c^2 h^3 N^3} \quad \text{and} \quad \omega_{N-1} = \frac{\pi^2 m e^2 E^2}{2c^2 h^3 (N - 1)^3}.$$

If N is great the ratio between the frequency before and after the emission will be very near equal to 1; and according to the ordinary electrodynamics we should therefore expect that the ratio between the frequency of radiation and the frequency of revolution also is very nearly equal to 1. This condition will only be satisfied if $c = \frac{1}{2}$. Putting $f(\tau) = \frac{\tau}{2}$, we, however, again arrive at the equation (2) and consequently at the expression (3) for the stationary states.

If we consider the passing of the system between two states corresponding to $\tau = N$ and $\tau = N - n$, where n is small compared with N , we get with the same approximation as above, putting $f(\tau) = \frac{\tau}{2}$,

$$\nu = n\omega.$$

The possibility of an emission of a radiation of such a frequency may also be interpreted from analogy with the ordinary electrodynamics, as an electron rotating round a nucleus in an elliptical orbit will emit a radiation which according to Fourier's theorem can be resolved into homogeneous components, the frequencies of which are $n\omega$, if ω is the frequency of revolution of the electron.

We are thus led to assume that the interpretation of the equation (2) is not that the different stationary states correspond to an emission of different numbers of energy-quanta, but that the frequency of the energy emitted during the passing of the system from a state in which no energy is yet radiated out to one of the different stationary states, is equal to different multiples of $\frac{\omega}{2}$, where ω is the frequency of revolution of the electron in the state considered. From this assumption we get exactly the same expressions as before for the stationary states, and from these by help of the principal assumptions on p. 7 the same expression for the law of the hydrogen spectrum. Consequently we may regard our preliminary considerations on p. 5 only as a simple form of representing the results of the theory.

Before we leave the discussion of this question, we shall for a moment return to the question of the significance of the agreement between the observed and calculated values of the constant entering in the expressions (4) for the Balmer series of the hydrogen spectrum. From the above consideration it will follow that, taking the starting-point in the form of the law of the hydrogen spectrum and assuming that the different lines correspond to a homogeneous radiation emitted during the passing between different stationary states, we shall arrive at exactly the same expression for the constant in question as that given by (4), if we only assume (1) that the radiation is sent out in quanta $h\nu$, and (2) that the frequency of the radiation emitted during the passing of the system between successive stationary states will coincide with the frequency of revolution of the electron in the region of slow vibrations.

As all the assumptions used in this latter way of representing the theory are of what we may call a qualitative character, we are justified in expecting—if the whole way of considering is a sound one—an absolute agreement between the values calculated and observed for the constant in question, and not only an approximate agreement. The formula (4) may therefore be of value in the discussion of the results of experimental determinations of the constants e , m , and h .

While there obviously can be no question of a mechanical foundation of the calculations given in this paper, it is, however, possible to give a very simple interpretation of the result of the calculation on p. 5 by help of symbols taken from the ordinary mechanics. Denoting the angular momentum of the electron round the nucleus by M , we have immediately for a circular orbit $\pi M = \frac{T}{\omega}$, where ω is the frequency of revolution and T the kinetic energy of the electron; for a circular orbit we farther have $T = W$ (see p. 3) and from (2), p. 5, we consequently get

$$M = \tau M_0,$$

where

$$M_0 = \frac{h}{2\pi} = 1.04 \times 10^{-37}.$$

If we therefore assume that the orbit of the electron in the stationary states is circular, the result of the calculation on p. 5 can be expressed by the simple condition: that the angular momentum of the electron round the nucleus in a stationary state of the system is equal to an entire multiple of a universal value, independent of the charge on the nucleus. The possible importance of the angular momentum in the discussion of atomic systems in relation to Planck's theory is emphasized by Nicholson*.

The great number of different stationary states we do not observe except by investigation of the emission and absorption of radiation. In most of the other physical phenomena, however, we only observe the atoms of the matter in a single distinct state, *i. e.* the state of the atoms at low temperature. From the preceding considerations we are immediately led to the assumption that the "permanent" state is the one among the stationary states during the formation of which the greatest amount of energy is emitted. According to the equation (3) on p. 5, this state is the one which corresponds to $\tau = 1$.

§ 4. Absorption of Radiation.

In order to account for Kirchhoff's law it is necessary to introduce assumptions on the mechanism of absorption of radiation which correspond to those we have used considering the emission. Thus we must assume that a system consisting of a nucleus and an electron rotating round it under certain circumstances can absorb a radiation of a frequency equal to the frequency of the homogeneous radiation emitted during

* J. W. Nicholson, *loc. cit.* p. 679.

the passing of the system between different stationary states. Let us consider the radiation emitted during the passing of the system between two stationary states A_1 and A_2 , corresponding to values for τ equal to τ_1 and τ_2 , $\tau_1 > \tau_2$. As the necessary condition for an emission of the radiation in question was the presence of systems in the state A_1 , we must assume that the necessary condition for an absorption of the radiation is the presence of systems in the state A_2 .

These considerations seem to be in conformity with experiments on absorption in gases. In hydrogen gas at ordinary conditions for instance there is no absorption of a radiation of a frequency corresponding to the line-spectrum of this gas; such an absorption is only observed in hydrogen gas in a luminous state. This is what we should expect according to the above. We have on p. 9 assumed that the radiation in question was emitted during the passing of the systems between stationary states corresponding to $\tau \geq 2$. The state of the atoms in hydrogen gas at ordinary conditions should, however, correspond to $\tau=1$; furthermore, hydrogen atoms at ordinary conditions combine into molecules, *i. e.* into systems in which the electrons have frequencies different from those in the atoms (see Part III.). From the circumstance that certain substances in a non-luminous state, as, for instance, sodium vapour, absorb radiation corresponding to lines in the line-spectra of the substances, we may, on the other hand, conclude that the lines in question are emitted during the passing of the system between two states, one of which is the permanent state.

How much the above considerations differ from an interpretation based on the ordinary electrodynamics is perhaps most clearly shown by the fact that we have been forced to assume that a system of electrons will absorb a radiation of a frequency different from the frequency of vibration of the electrons calculated in the ordinary way. It may in this connexion be of interest to mention a generalization of the considerations to which we are led by experiments on the photo-electric effect, and which may be able to throw some light on the problem in question. Let us consider a state of the system in which the electron is free, *i. e.* in which the electron possesses kinetic energy sufficient to remove to infinite distances from the nucleus. If we assume that the motion of the electron is governed by the ordinary mechanics and that there is no (sensible) energy radiation, the total energy of the system—as in the above considered stationary states—will be constant. Further, there will be perfect continuity between the two kinds of states, as the difference between

frequency and dimensions of the systems in successive stationary states will diminish without limit if τ increases. In the following considerations we shall for the sake of brevity refer to the two kinds of states in question as "mechanical" states; by this notation only emphasizing the assumption that the motion of the electron in both cases can be accounted for by the ordinary mechanics.

Tracing the analogy between the two kinds of mechanical states, we might now expect the possibility of an absorption of radiation, not only corresponding to the passing of the system between two different stationary states, but also corresponding to the passing between one of the stationary states and a state in which the electron is free; and as above, we might expect that the frequency of this radiation was determined by the equation $E=h\nu$, where E is the difference between the total energy of the system in the two states. As it will be seen, such an absorption of radiation is just what is observed in experiments on ionization by ultra-violet light and by Röntgen rays. Obviously, we get in this way the same expression for the kinetic energy of an electron ejected from an atom by photo-electric effect as that deduced by Einstein*, i. e. $T=h\nu - W$, where T is the kinetic energy of the electron ejected, and W the total amount of energy emitted during the original binding of the electron.

The above considerations may further account for the result of some experiments of R. W. Wood† on absorption of light by sodium vapour. In these experiments, an absorption corresponding to a very great number of lines in the principal series of the sodium spectrum is observed, and in addition a continuous absorption which begins at the head of the series and extends to the extreme ultra-violet. This is exactly what we should expect according to the analogy in question, and, as we shall see, a closer consideration of the above experiments allows us to trace the analogy still further. As mentioned on p. 9 the radii of the orbits of the electrons will for stationary states corresponding to high values for τ be very great compared with ordinary atomic dimensions. This circumstance was used as an explanation of the non-appearance in experiments with vacuum-tubes of lines corresponding to the higher numbers in the Balmer series of the hydrogen spectrum. This is also in conformity with experiments on the emission spectrum of sodium; in the principal series of the emission spectrum of this substance

* A. Einstein, *Ann. d. Phys.* xvii. p. 146 (1905).

† R. W. Wood, *Physical Optics*, p. 513 (1911).

rather few lines are observed. Now in Wood's experiments the pressure was not very low, and the states corresponding to high values for τ could therefore not appear; yet in the absorption spectrum about 50 lines were detected. In the experiments in question we consequently observe an absorption of radiation which is not accompanied by a complete transition between two different stationary states. According to the present theory we must assume that this absorption is followed by an emission of energy during which the systems pass back to the original stationary state. If there are no collisions between the different systems this energy will be emitted as a radiation of the same frequency as that absorbed, and there will be no true absorption but only a scattering of the original radiation; a true absorption will not occur unless the energy in question is transformed by collisions into kinetic energy of free particles. In analogy we may now from the above experiments conclude that a bound electron—also in cases in which there is no ionization—will have an absorbing (scattering) influence on a homogeneous radiation, as soon as the frequency of the radiation is greater than W/h , where W is the total amount of energy emitted during the binding of the electron. This would be highly in favour of a theory of absorption as the one sketched above, as there can in such a case be no question of a coincidence of the frequency of the radiation and a characteristic frequency of vibration of the electron. It will further be seen that the assumption, that there will be an absorption (scattering) of any radiation corresponding to a transition between two different mechanical states, is in perfect analogy with the assumption generally used that a free electron will have an absorbing (scattering) influence on light of any frequency. Corresponding considerations will hold for the emission of radiation.

In analogy to the assumption used in this paper that the emission of line-spectra is due to the re-formation of atoms after one or more of the lightly bound electrons are removed, we may assume that the homogeneous Röntgen radiation is emitted during the settling down of the systems after one of the firmly bound electrons escapes, *e. g.* by impact of cathode particles*. In the next part of this paper, dealing with the constitution of atoms, we shall consider the question more closely and try to show that a calculation based on this assumption is in quantitative agreement with the results of experiments: here we shall only mention briefly a problem with which we meet in such a calculation.

* Compare J. J. Thomson, *Phil. Mag.* xxiii. p. 456 (1912).

Experiments on the phenomena of X-rays suggest that not only the emission and absorption of radiation cannot be treated by the help of the ordinary electrodynamics, but not even the result of a collision between two electrons of which the one is bound in an atom. This is perhaps most clearly shown by some very instructive calculations on the energy of β -particles emitted from radioactive substances recently published by Rutherford*. These calculations strongly suggest that an electron of great velocity in passing through an atom and colliding with the electrons bound will loose energy in distinct finite quanta. As is immediately seen, this is very different from what we might expect if the result of the collisions was governed by the usual mechanical laws. The failure of the classical mechanics in such a problem might also be expected beforehand from the absence of anything like equipartition of kinetic energy between free electrons and electrons bound in atoms. From the point of view of the "mechanical" states we see, however, that the following assumption—which is in accord with the above analogy—might be able to account for the result of Rutherford's calculation and for the absence of equipartition of kinetic energy: two colliding electrons, bound or free, will, after the collision as well as before, be in mechanical states. Obviously, the introduction of such an assumption would not make any alteration necessary in the classical treatment of a collision between two free particles. But, considering a collision between a free and a bound electron, it would follow that the bound electron by the collision could not acquire a less amount of energy than the difference in energy corresponding to successive stationary states, and consequently that the free electron which collides with it could not lose a less amount.

The preliminary and hypothetical character of the above considerations needs not to be emphasized. The intention, however, has been to show that the sketched generalization of the theory of the stationary states possibly may afford a simple basis of representing a number of experimental facts which cannot be explained by help of the ordinary electrodynamics, and that the assumptions used do not seem to be inconsistent with experiments on phenomena for which a satisfactory explanation has been given by the classical dynamics and the wave theory of light.

* E. Rutherford, *Phil. Mag.* xxiv, pp. 453 & 893 (1912).

§ 5. *The permanent State of an Atomic System.*

We shall now return to the main object of this paper—the discussion of the “permanent” state of a system consisting of nuclei and bound electrons. For a system consisting of a nucleus and an electron rotating round it, this state is, according to the above, determined by the condition that the angular momentum of the electron round the nucleus is equal to $\frac{h}{2\pi}$.

On the theory of this paper the only neutral atom which contains a single electron is the hydrogen atom. The permanent state of this atom should correspond to the values of a and ω calculated on p. 5. Unfortunately, however, we know very little of the behaviour of hydrogen atoms on account of the small dissociation of hydrogen molecules at ordinary temperatures. In order to get a closer comparison with experiments, it is necessary to consider more complicated systems.

Considering systems in which more electrons are bound by a positive nucleus, a configuration of the electrons which presents itself as a permanent state is one in which the electrons are arranged in a ring round the nucleus. In the discussion of this problem on the basis of the ordinary electrodynamics, we meet—apart from the question of the energy radiation—with new difficulties due to the question of the stability of the ring. Disregarding for a moment this latter difficulty, we shall first consider the dimensions and frequency of the systems in relation to Planck's theory of radiation.

Let us consider a ring consisting of n electrons rotating round a nucleus of charge E , the electrons being arranged at equal angular intervals around the circumference of a circle of radius a .

The total potential energy of the system consisting of the electrons and the nucleus is

$$P = -\frac{ne^2}{a} (E - \epsilon s_n),$$

where

$$s_n = \frac{1}{4} \sum_{\epsilon=1}^{\epsilon=n-1} \operatorname{cosec} \frac{\epsilon\pi}{n}.$$

For the radial force exerted on an electron by the nucleus and the other electrons we get

$$F = -\frac{1}{n} \frac{dP}{da} = -\frac{e}{a^2} (E - \epsilon s_n).$$

Denoting the kinetic energy of an electron by T and neglecting the electromagnetic forces due to the motion of the electrons (see Part II.), we get, putting the centrifugal force on an electron equal to the radial force,

$$\frac{2T}{a} = \frac{e}{a^2} (E - es_n),$$

or

$$T = \frac{e}{2a} (E - es_n).$$

From this we get for the frequency of revolution

$$\omega = \frac{1}{2\pi} \sqrt{\frac{e(E - es_n)}{ma^3}}.$$

The total amount of energy W necessary transferred to the system in order to remove the electrons to infinite distances apart from the nucleus and from each other is

$$W = -P - nT = \frac{ne}{2a} (E - es_n) = nT,$$

equal to the total kinetic energy of the electrons.

We see that the only difference in the above formula and those holding for the motion of a single electron in a circular orbit round a nucleus is the exchange of E for $E - es_n$. It is also immediately seen that corresponding to the motion of an electron in an elliptical orbit round a nucleus, there will be a motion of the n electrons in which each rotates in an elliptical orbit with the nucleus in the focus, and the n electrons at any moment are situated at equal angular intervals on a circle with the nucleus as the centre. The major axis and frequency of the orbit of the single electrons will for this motion be given by the expressions (1) on p. 3 if we replace E by $E - es_n$ and W by $\frac{W}{n}$. Let us now suppose

that the system of n electrons rotating in a ring round a nucleus is formed in a way analogous to the one assumed for a single electron rotating round a nucleus. It will thus be assumed that the electrons, before the binding by the nucleus, were at a great distance apart from the latter and possessed no sensible velocities, and also that during the binding a homogeneous radiation is emitted. As in the case of a single electron, we have here that the total amount of energy emitted during the formation of the system is equal to the final kinetic energy of the electrons. If we now suppose that during the

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formation of the system the electrons at any moment are situated at equal angular intervals on the circumference of a circle with the nucleus in the centre, from analogy with the considerations on p. 5 we are here led to assume the existence of a series of stationary configurations in which the kinetic energy per electron is equal to $\tau h \frac{\omega}{2}$, where τ is an entire number, h Planck's constant, and ω the frequency of revolution. The configuration in which the greatest amount of energy is emitted is, as before, the one in which $\tau=1$. This configuration we shall assume to be the permanent state of the system if the electrons in this state are arranged in a single ring. As for the case of a single electron we get that the angular momentum of each of the electrons is equal to $\frac{h}{2\pi}$. It may be remarked that instead of considering the single electrons we might have considered the ring as an entity. This would, however, lead to the same result, for in this case the frequency of revolution ω will be replaced by the frequency $n\omega$ of the radiation from the whole ring calculated from the ordinary electrodynamics, and T by the total kinetic energy nT .

There may be many other stationary states corresponding to other ways of forming the system. The assumption of the existence of such states seems necessary in order to account for the line-spectra of systems containing more than one electron (p. 11); it is also suggested by the theory of Nicholson mentioned on p. 6, to which we shall return in a moment. The consideration of the spectra, however, gives, as far as I can see, no indication of the existence of stationary states in which all the electrons are arranged in a ring and which correspond to greater values for the total energy emitted than the one we above have assumed to be the permanent state.

Further, there may be stationary configurations of a system of n electrons and a nucleus of charge E in which all the electrons are not arranged in a single ring. The question, however, of the existence of such stationary configurations is not essential for our determination of the permanent state, as long as we assume that the electrons in this state of the system are arranged in a single ring. Systems corresponding to more complicated configurations will be discussed on p. 24.

Using the relation $T=h \frac{\omega}{2}$ we get, by help of the above expressions for T and ω , values for a and ω corresponding to

the permanent state of the system which only differ from those given by the equations (3) on p. 5, by exchange of E for $E - es_n$.

The question of stability of a ring of electrons rotating round a positive charge is discussed in great detail by Sir J. J. Thomson*. An adaption of Thomson's analysis for the case here considered of a ring rotating round a nucleus of negligibly small linear dimensions is given by Nicholson†. The investigation of the problem in question naturally divides in two parts: one concerning the stability for displacements of the electrons in the plane of the ring; one concerning displacements perpendicular to this plane. As Nicholson's calculations show, the answer to the question of stability differs very much in the two cases in question. While the ring for the latter displacements in general is stable if the number of electrons is not great; the ring is in no case considered by Nicholson stable for displacements of the first kind.

According, however, to the point of view taken in this paper, the question of stability for displacements of the electrons in the plane of the ring is most intimately connected with the question of the mechanism of the binding of the electrons, and like the latter cannot be treated on the basis of the ordinary dynamics. The hypothesis of which we shall make use in the following is that the stability of a ring of electrons rotating round a nucleus is secured through the above condition of the universal constancy of the angular momentum, together with the further condition that the configuration of the particles is the one by the formation of which the greatest amount of energy is emitted. As will be shown, this hypothesis is, concerning the question of stability for a displacement of the electrons perpendicular to the plane of the ring, equivalent to that used in ordinary mechanical calculations.

Returning to the theory of Nicholson on the origin of lines observed in the spectrum of the solar corona, we shall now see that the difficulties mentioned on p. 7 may be only formal. In the first place, from the point of view considered above the objection as to the instability of the systems for displacements of the electrons in the plane of the ring may not be valid. Further, the objection as to the emission of the radiation in quanta will not have reference to the calculations in question, if we assume that in the coronal spectrum we are not dealing with a true emission but only with a scattering of radiation. This assumption seems probable if we consider

* *Loc. cit.*

† *Loc. cit.*

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the conditions in the celestial body in question; for on account of the enormous rarefaction of the matter there may be comparatively few collisions to disturb the stationary states and to cause a true emission of light corresponding to the transition between different stationary states: on the other hand there will in the solar corona be intense illumination of light of all frequencies which may excite the natural vibrations of the systems in the different stationary states. If the above assumption is correct, we immediately understand the entirely different form for the laws connecting the lines discussed by Nicholson and those connecting the ordinary line-spectra considered in this paper.

Proceeding to consider systems of a more complicated constitution, we shall make use of the following theorem, which can be very simply proved:—

“In every system consisting of electrons and positive nuclei, in which the nuclei are at rest and the electrons move in circular orbits with a velocity small compared with the velocity of light, the kinetic energy will be numerically equal to half the potential energy.”

By help of this theorem we get—as in the previous cases of a single electron or of a ring rotating round a nucleus—that the total amount of energy emitted, by the formation of the systems from a configuration in which the distances apart of the particles are infinitely great and in which the particles have no velocities relative to each other, is equal to the kinetic energy of the electrons in the final configuration.

In analogy with the case of a single ring we are here led to assume that corresponding to any configuration of equilibrium a series of geometrically similar, stationary configurations of the system will exist in which the kinetic energy of every electron is equal to the frequency of revolution multiplied by $\frac{\tau}{2}h$ where τ is an entire number and h

Planck's constant. In any such series of stationary configurations the one corresponding to the greatest amount of energy emitted will be the one in which τ for every electron is equal to 1. Considering that the ratio of kinetic energy to frequency for a particle rotating in a circular orbit is equal to π times the angular momentum round the centre of the orbit, we are therefore led to the following simple generalization of the hypotheses mentioned on pp. 15 and 22.

“In any molecular system consisting of positive nuclei and electrons in which the nuclei are at rest relative to each other and the electrons move in circular orbits, the angular momentum

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of every electron round the centre of its orbit will in the permanent state of the system be equal to $\frac{h}{2\pi}$, where h is Planck's constant**.

In analogy with the considerations on p. 23, we shall assume that a configuration satisfying this condition is stable if the total energy of the system is less than in any neighbouring configuration satisfying the same condition of the angular momentum of the electrons.

As mentioned in the introduction, the above hypothesis will be used in a following communication as a basis for a theory of the constitution of atoms and molecules. It will be shown that it leads to results which seem to be in conformity with experiments on a number of different phenomena.

The foundation of the hypothesis has been sought entirely in its relation with Planck's theory of radiation; by help of considerations given later it will be attempted to throw some further light on the foundation of it from another point of view.

April 5, 1913.

II. *On the Formation of the Molecules of the Elements and their Compounds, with Atoms as constituted on the Corpuscular-Ring Theory.* By ALBERT C. CREHORE, Ph.D.†

[Plates I. & II.]

PART I.

REASONS have been given that make it seem very probable that the atoms are constituted, as suggested by Sir J. J. Thomson, of masses of positive electrification within which negative electrons are revolving. The electrons take positions of dynamical equilibrium due to their mutual action upon each other, and upon the positive electricity. The present investigation aims, first, to obtain more exact information concerning these atoms themselves, and, second, to examine the manner in which two or more such atoms, either of the same or of different kinds, must act upon each other when brought within molecular range. To anticipate the results which are later described it is found that such atoms come to definite positions of stable equilibrium

* In the considerations leading to this hypothesis we have assumed that the velocity of the electrons is small compared with the velocity of light. The limits of the validity of this assumption will be discussed in Part II.

† Communicated by the Author.

ANEXO 15 – A constituição de átomos e moléculas, parte 2.

N. Bohr, *Philos. Mag.* **26**, 476

1913

On the Constitution of Atoms and Molecules

N. Bohr,
Dr. phil. Copenhagen
(Received July 1913)

*Part II. – Systems containing only a
Single Nucleus*

1

§ 1 *General Assumptions*

Following the theory of Rutherford, we shall assume that the atoms of the elements consist of a positively charged nucleus surrounded by a cluster of electrons. The nucleus is the seat of the essential part of the mass of the atom, and has linear dimensions exceedingly small compared with the distance apart of the electrons in the surrounding cluster.

As in the previous paper, we shall assume that the cluster of electrons is formed by the successive binding by the nucleus of electrons initially nearly at rest, energy at the same time being radiated away. This will go on until, when the total negative charge on the bound electrons is numerically equal to the positive charge on the nucleus, the system will be neutral and no longer able to exert sensible forces on electrons at distances from the nucleus great in comparison with the dimensions of the orbits of the bound electrons. We may regard the formation of helium from α rays as an observed example of

¹Part I was published in *Phil. Mag.* XXVI. p. 1 (1913).

a process of this kind, an α particle on this view being identical with the nucleus of a helium atom.

On account of the small dimensions of the nucleus, its internal structure will not be of sensible influence on the constitution of the cluster of electrons, and consequently will have no effect on the ordinary physical and chemical properties of the atom. The latter properties on this theory will depend entirely on the total charge and mass of the nucleus; the internal structure of the nucleus will be of influence only on the phenomena of radioactivity.

From the result of experiments on large-angle scattering of α -rays, Rutherford² found an electric charge on the nucleus corresponding per atom to a number of electrons approximately equal to half the atomic weight. This result seems to be in agreement with the number of electrons per atom calculated from experiments on scattering of Röntgen radiation.³ The total experimental evidence supports the hypothesis⁴ that the actual number of electrons in a neutral atom with a few exceptions is equal to the number which indicated the position of the corresponding element in the series of element arranged in order of increasing atomic weight. For example on this view, the atom of oxygen which is the eighth element of the series has eight electrons and a nucleus carrying eight unit charges.

We shall assume that the electrons are arranged at equal angular intervals in coaxial rings rotating round the nucleus. In order to determine the frequency and dimensions of the rings we shall use the main hypothesis of the first paper, viz.; that in the permanent state of an atom the angular momentum of every electron round the centre of its orbit is equal to the universal value $h/2\pi$, where h is Planck's constant. We shall take as a condition of stability, that the total energy of the system in the configuration in question is less than in any neighbouring configuration satisfying the same condition of the angular momentum of the electrons.

If the charge on the nucleus and the number of electrons in the different rings is known, the condition in regard to the angular momentum of the electrons will, as shown in § 2, completely determine the configuration of the system. i.e., the frequency of revolution and the linear dimensions of the rings. Corresponding to different distributions of the electrons in the rings, however, there will, in general, be more than one configuration which will satisfy the condition of the angular momentum together with the condition of stability.

²Comp. also Geiger and Marsden, *Phil. Mag.* XXV. p. 604 (1913).

³Comp. C.G. Barkla, *Phil. Mag.* XXI. p. 648 (1911).

⁴Comp. A.v.d. Broek, *Phys. Zeitschr.* XIV. p. 32 (1913).

In § 3 and § 4 it will be shown that, on the general view of the formation of the atoms, we are led to indications of the arrangement of the electrons in the rings which are consistent with those suggested by the chemical properties of the corresponding element.

In § 5 will be shown that it is possible from the theory to calculate the momentum velocity of cathode rays necessary to produce the characteristic Röntgen radiation from the element, and that this is in approximate agreement with the experimental values.

In § 6 the phenomena of radioactivity will be briefly considered in relation of the theory.

§ 2 Configuration and Stability of the System

Let us consider an electron of charge e and mass m which moves in a circular orbit of radius a with a velocity v small compared with the velocity of light. Let us denote the radial force acting on the electrons by e^2/a^2F ; F will in general be dependent on a . The condition of dynamical equilibrium gives

$$\frac{mv^2}{a} = \frac{e^2}{a^2}F.$$

Introducing the condition of universal constancy of the angular momentum of the electron, we have

$$mva = \frac{h}{2\pi}.$$

From these two conditions we now get

$$a = \frac{h^2}{4\pi^2 e^2 m} \cdot F^{-1} \quad \text{and} \quad v = \frac{2\pi e^2}{h} \cdot F; \quad (1)$$

and for the frequency of revolution w consequently

$$\omega = \frac{4\pi^2 e^2 m}{h^2} \cdot F^2. \quad (2)$$

If F is known, the dimensions and frequency of the corresponding orbit are simply determined by (1) and (2). For a ring of n electrons rotating round a nucleus of charge ne we have (comp. Part I., p. 20)????

$$F = N - s_n, \quad \text{where} \quad s_n = \frac{1}{4} \cdot \sum_{s=1}^{s=n-1} \operatorname{cosec} \frac{s\pi}{n}.$$

The values for s_n from $n = 1$ to $n = 16$ are given in the table 1.

For systems consisting of nuclei and electrons in which the first are at rest and the latter move in circular orbits with a velocity small compared with the velocity of light, we have shown (see part I., p. 21)???? that the total kinetic energy of the electrons is equal to the total amount of energy emitted during the formation of the system from an original configuration in which all the particles are at rest and at infinite distances from each other. Denoting this amount of energy by W , we consequently get

$$W = \sum \frac{m}{2} v^2 = \frac{2\pi^2 e^4 m}{h^2} \sum F^2. \quad (3)$$

Putting in (1), (2), and (3) $e = 4.7 \cdot 10^{-10}$, $\frac{e}{m} = 5.31 \cdot 10^{-17}$, and $h = 6.5 \cdot 10^{-27}$ we get

$$\begin{aligned} a &= 0.55 \cdot 10^{-8} F^{-1}, & v &= 2.1 \cdot 10^8 F, \\ \omega &= 6.2 \cdot 10^{15} F^2, & W &= 2.0 \cdot 10^{-11} \sum F^2. \end{aligned} \quad (4)$$

In neglecting the magnetic forces due to the motion of the electrons we have in Part I. assumed that the velocities of the particles are small compared with the velocity of light. The above calculations show that for this to hold, F must be small compared with 150. As will be seen, the latter condition will be satisfied for all the electrons in the atoms of elements of low atomic weight and for a greater part of the electrons contained in the atoms of the other elements.

If the velocity of the electrons is not small compared with the velocity of light, the constancy of the angular momentum no longer involved a constant ratio between the energy and the frequency of revolution. Without introducing new assumptions, we cannot therefore in this case determine the configuration of the systems on the basis of the consideration in Part I. Considerations given later suggest, however, that the constancy of the angular momentum is the principal condition. applying this condition for velocities not small compared with the velocity of light, we get the same expression for v as that given by (1), while the quantity m in the expressions for a and ω is replaced by $m/\sqrt{(1-v^2/c^2)}$, and in the expression for W by

$$m \cdot 2 \frac{c^2}{v^2} \cdot \left(1 - \sqrt{1 - \frac{v^2}{c^2}} \right).$$

As stated in Part I., a calculation based on the ordinary mechanics given the result, that a ring of electrons rotating round a positive nucleus in general is unstable for displacement of the electrons in the plane of the ring. In order

to escape from this difficulty, we have assumed that the ordinary principles of mechanics cannot be used in the discussion of the problem in question, any more than in the discussion of the connected problem of the mechanism of binding of electrons. We have also assumed that the stability for such displacement is secured through the introduction of the hypothesis of the universal constancy of the angular momentum of the electrons.

As is easily shown, the latter assumption is included in the condition of stability in § 1. Consider a ring of electrons rotation round a nucleus, and assume that the system is in dynamical equilibrium and that the radius of the ring is a_0 , the v_0 , the total kinetic energy T_0 , and the potential energy P_0 . As shown in Part I. (p. 21) we have $P_0 = -2T_0$. Next consider a configuration of the system in which the electrons, under influence of extraneous forces, rotate with the same angular momentum round the nucleus in a ring of radius $a = \alpha a_0$. In this case we have $P = \frac{1}{\alpha} P_0$, and on account of the uniformity of the angular momentum $v = 1/\alpha \cdot v_0$ and $T = 1/\alpha^2 \cdot T_0$. Using the relation $P_0 = -2T_0$, we get

$$P + T = \frac{1}{\alpha} \cdot P_0 + \frac{1}{\alpha^2} T_0 = P_0 + T_0 + T_0 \cdot \left(1 - \frac{1}{\alpha}\right)^2.$$

We see that the total energy of the new configuration is greater than in the original. according to the condition of stability in § 1 the system is consequently stable for the displacement considered. In this connexion, it may be remarked that in Part I. we have assumed that the frequency of radiation emitted or absorbed by the systems cannot be determined from the frequencies of vibration of the electrons in the plane of the orbits, calculated by help of the ordinary mechanics. We have, on the contrary, assumed that the frequency of the radiation is determined by the condition $h\nu = E$, where ν is the frequency, h Planck's constant, and E the difference in energy corresponding to two different "stationary" states of the system.

In considering the stability of a ring of electrons rotating round a nucleus for displacements of the electrons perpendicular to the plane of the ring, imagine a configuration of the system in which the electrons are displaced by $\delta z_1, \delta z_2, \dots, \delta z_n$ respectively, and suppose that the electrons, under influence of extraneous forces, rotate in circular orbits parallel to the original plane with the same radial and the same angular momentum round the axis of the system as before. The kinetic energy is unaltered by the displacement, and neglecting powers of the quantities $\delta z_1, \dots, \delta z_n$ higher than the second, the increase of the potential energy of the system is given by

$$\frac{1}{2} \cdot \frac{e^2}{a^3} \cdot N \sum (\delta z)^2 - \frac{1}{32} \cdot \frac{e^2}{a^2} \cdot \sum \sum \left| \operatorname{cosec}^3 \frac{\pi(r-s)}{n} \right| (\delta z_r - \delta z_s)^2,$$

where a is the radius of the ring, Ne the charge on the nucleus, and n the number of electrons. According to the condition of stability in § 1 the system is stable for the displacement considered, if the above expression is positive for arbitrary values of $\delta z_1, \dots, \delta z_n$. By a simple calculation it can be shown that the latter condition is equivalent to the condition

$$N > P_{n,0} - P_{n,m}, \quad (5)$$

where m denotes the whole number (smaller than n) for which

$$P_{n,k} = \frac{1}{8} \sum_{s=1}^{s=n-1} \cos 2k \cdot \frac{s\pi}{n} \operatorname{cosec}^3 \frac{s\pi}{n}$$

has its smallest value. This condition is identical with the condition of stability for displacements of the electrons perpendicular to the plane of the ring, deduced by help of ordinary mechanical considerations.⁵

A suggestive illustration is obtained by imagining that the displacements considered are produced by the effect of extraneous forces acting on the electrons in a direction parallel to the axis of the ring. If the displacements are produced infinitely slowly the motion of the electrons will at any moment be parallel to the original plane of the ring, and the angular momentum of each of the electrons round the centre of its orbit will obviously be equal to its original value; the increase in the potential energy of the system will be equal to the work done by the extraneous forces during the displacements we are led to assume that the ordinary mechanics can be used in calculating the vibrations of the electrons perpendicular to the plane of the ring – contrary to the ease of vibrations in the plane of the ring. This assumption is supposed by the apparent agreement with observations obtained by Nicholson in his theory of the origin of lines in the spectra of the solar corona and stellar nebulae (see Part I. pp. 6 & 23). In addition it will be shown later that the assumption seems to be in agreement with experiments on dispersion.

The following table gives the values of s_n and $P_{n,0} - P_{n,m}$ from $n = 1$ to $n = 16$.

Table 1.

⁵Comp. J.W. Nicholson, Month. Not. Roy. Astr. Soc. 72. p. 52 (1912).

n	θ_n	$p_{n,0} - p_{n,m}$	n	θ_n	$p_{n,0} - p_{n,m}$
1	0	0	9	3.328	13.14
2	0.25	0.25	10	3.863	18.13
3	0.577	0.58	11	4.416	23.60
4	0.957	1.41	12	4.984	30.80
5	1.377	2.43	13	5.565	38.57
6	1.828	4.25	14	6.159	48.38
7	2.305	6.35	15	6.764	58.83
8	2.805	9.56	16	7.379	71.65

We see from the table that the number of electrons which can rotate in a single ring round a nucleus of charge Ne increases only very slowly for increasing N ; for $N = 20$ the maximum value is $n = 10$; for $N = 13$; for $N = 60$, $n = 15$. We see, further, that a ring of n electrons cannot rotate in a single ring round a nucleus of charge ne unless $n < 8$.

In the above we have supposed that the electrons move under the influence of a stationary radial force and that their orbits are exactly circular. The first condition will not be satisfied if we consider a system containing several rings of electrons which rotate with different frequencies. If, however, the distance between the rings is not small in comparison with their radii, if the ratio between their frequency is not near to unity, the deviation from circular orbits may be very small and the motion of the electrons to a close approximation may be identical with that obtained on the assumption that the charge on the electrons is uniformly distributed along the circumference of the rings. If the ratio between the radii of the rings is not near to unity, the conditions of stability on this assumption may also be considered sufficient.

We have assumed in § 1 that the electrons in the atoms rotate in coaxial rings. The calculation indicated that only in the case of systems containing a great number of electrons will the planes of the rings separate; in the case of systems containing a moderate number of electrons, all the rings will be situated in a single plane through the nucleus. For the sake of brevity, we shall therefore here only consider the latter case.

Let us consider an electric charge E uniformly distributed along the circumference of a circle of radius a .

At a point distant z from the plane of the ring, and at a distance r from

the axis of the ring, the electrostatic potential is given by

$$U = \frac{1}{\pi} \cdot E \int_0^\pi \frac{d\vartheta}{\sqrt{a^2 + r^2 + z^2 - 2ar \cos \vartheta}}.$$

Putting in this expression $z = 0$ and $\frac{r}{a} = \tan^2 \alpha$, and using the notation

$$K(\alpha) = \int_0^{\pi/2} \frac{d\vartheta}{\sqrt{1 - \sin^2 \alpha \cos^2 \vartheta}},$$

we get for the radial force exerted on an electron in a point in the plane of the ring

$$e \frac{\partial U}{\partial r} = \frac{Ee}{r^2} Q(\alpha),$$

where

$$Q(\alpha) = \frac{1}{\pi} \sin^4 \alpha [K(2\alpha) - \cot \alpha \cdot K'(2\alpha)].$$

The corresponding force perpendicular to the plane of the ring at a distance r from the center of the ring and at a small distance δz from its plane is given by

$$e \frac{\partial U}{\partial z} = \frac{Ee \delta z}{r^3} R(\alpha),$$

where

$$R(\alpha) = \frac{2}{\pi} \sin^6 \alpha [K(2\alpha) + \tan(2\alpha) \cdot K'(2\alpha)].$$

A short table of the functions $Q(\alpha)$ and $R(\alpha)$ is given on p. 485.???

Next consider a system consisting of a number of concentric rings of electrons which rotate in the same plane round a nucleus of charge Ne . Let the radial of the rings be a_1, a_2, \dots , and the number of electrons on the different rings n_1, n_2, \dots .

Putting $a_r/a_s = \tan^2(\alpha_{r,s})$ we get for the radial force acting on an electron in the r th ring $e^2/a_r^2 F_r$ where

$$F_r = N - s - \sum n_s Q(\alpha_{r,s}).$$

the summation is to be taken over all the rings except the one considered.

If we know the distribution of the electrons in the different rings, from the relation (1) on p. 478,???? we can, by help of the above, determine a_1, a_2, \dots . The calculation can be made by successive approximations, starting from a set of values for the α 's, and from them calculating the F 's, and then

redetermining the α s by the relation (1) which gives $F_s/F_r = a_r/a_s = \tan^2(\alpha_{r,s})$, and so on.

As in the case of a single ring it is supposed that the systems are stable for displacements of the electrons in the plane of their orbits. In a calculation such as that on p. 480,???? the interaction of the rings ought strictly to be taken into account. This interaction will involve that the quantities F are not constant, as for a single ring rotating round a nucleus, but will vary with the radii of the rings; the variation in F , however, if the ratio between the radii of the rings is not very near to unity, will be too small to be of influence on the result of the calculation.

Considering the stability of the systems for a displacement of the electrons perpendicular to the plane of the rings, it is necessary to distinguish between displacements in which the centres of gravity of the electrons in the single rings are unaltered, and displacements in which all the electrons inside the same ring are displaced in the same direction. The condition of stability for the first kind of displacements is given by the condition (5) on p. 481,???? if for every ring we replace N by a quantity G_r determined by the condition that $e^2/a^3 G_r \delta z$ is equal to the component perpendicular to the plane of the ring of the force - due to the nucleus and the electrons in the other rings - acting on one of the electrons if it has received a small displacement δz . Using the same notation as above, we get

$$G_r = N - \sum n_s R(\alpha_{r,s}).$$

If all the electrons in one of the rings are displaced in the same direction by help of extraneous forces, the displacement will produce corresponding displacements of the electrons in the other rings; and this interaction will be of influence on the stability. For example, consider a system of m concentric rings rotating in a plane round a nucleus of charge Ne , and let us assume that the electrons in the different rings are displaced perpendicular to the plane by $\delta z_1, \delta z_2, \dots, \delta z_m$ respectively. With the above notation the increase in the potential energy of the system is given by

$$\frac{1}{2} \cdot N \sum n_r \frac{e^2}{a_r^3} (\delta z_r)^2 - \frac{1}{4} \cdot \sum \sum n_r n_s \frac{e^2}{a_r^3} R(\alpha_{r,s}) (\delta z_r - \delta z_s)^2.$$

The condition of stability is that this expression is positive for arbitrary values $\delta z_1, \dots, \delta z_m$. This condition can be worked out simply in the usual way. It is not of sensible influence compared with the condition of stability for the displacements considered above, except in cases where the system contains several rings of few electrons.

The following Table, containing the values of $Q(\alpha)$ and $R(\alpha)$ for every fifth degree from $\alpha = 20^\circ$ to $\alpha = 70^\circ$, gives an estimate of the order of magnitude of these functions: -

Table 2.

α	$\tan^2\alpha$	$Q(\alpha)$	$R(\alpha)$
20	0.132	0.001	0.002
25	0.217	0.005	0.011
30	0.333	0.021	0.048
35	0.490	0.080	0.217
40	0.704	0.373	1.549
45	1.000	-	-
50	1.420	1.708	4.438
55	2.040	1.233	1.839
60	3.000	1.093	1.301
65	4.599	1.037	1.115
70	7.548	1.013	1.041

$\tan^2\alpha$ indicated the ratio between the radii of the rings ($\tan^2(\alpha_{r,s}) = \frac{a_r}{a_s}$). The values of $Q(\alpha)$ show that unless the ratio of the radii of the rings is nearly unity the effect of outer rings on the dimensions of inner rings is very small, and that the corresponding effect of inner rings on outer is to neutralize approximately the effect of a part of the charge on the nucleus corresponding to the number of electrons on the ring. The values of $R(\alpha)$ show that the effect of outer rings on the stability of inner - though greater than the effect on the dimensions - is small, but that unless the ratio between the radii is very great, the effect of inner rings on the stability of outer is considerably greater than to neutralize a corresponding part of the charge of the nucleus.

The maximum number of electrons which the innermost ring can contain being unstable is approximately equal to that calculated on p. 482 for a single ring rotating round a nucleus. For the outer rings, however, we get considerably smaller numbers than those determined by the condition (5) if

we replace Ne by the total charge on the nucleus and on the electrons of inner rings.

If system of rings rotating round a nucleus in a single plane is stable for small displacements of the electrons perpendicular to this plane, there will in general be no stable configurations of the rings, satisfying the condition of the constancy of the angular momentum of the electrons, in which all the rings are not situated in the plane. An exception occurs in the special case of two rings containing equal numbers of electrons; in this case there may be a stable configuration in which the two rings have equal radii and rotate in parallel planes at equal distances from the nucleus, the electrons in the one ring being situated just opposite the intervals between the electrons in the other ring. The latter configuration, however, is unstable if the configuration in which all the electrons in the two rings are arranged in a single ring is stable.

§ 3 *Constitution of Atoms containing very few Electrons*

As stated in § 1, the condition of the universal constancy of the angular momentum of the electrons, together with the condition of stability, is in most cases not sufficient to determine completely the constitution of the system. On the general view of formation of atoms, however, and by making use of the knowledge of the properties of the corresponding elements, it will be attempted, in this section and the next, to obtain indications of what configurations of the electrons may be expected to occur in the atoms. In these considerations we shall assume that the number of electrons in the atom is equal to the number which indicates the position of the corresponding element in the series of elements arranged in order of increasing atomic weight.

Exceptions to this rule will be supposed to occur only at such places in the series where deviation from the periodic law of the chemical properties of the elements are observed. In order to show clearly the principles used we shall first consider with some detail those atoms containing very few electrons.

Forsake of brevity we shall, by the symbol $N(n_1, n_2 \dots)$, refer to a plane system of rings of electrons rotating round a nucleus of charge Ne , satisfying the condition of the angular momentum of the electrons with the approximation used in § 2. $n_1, n_2 \dots$ are the numbers of electrons in the rings,

starting from inside. By a_1, a_2, \dots and $\omega_1, \omega_2, \dots$ we shall denote the radii and frequency of the rings taken in the same order. The total amount of energy W emitted by the formation of the system shall simply be denoted by $W[N(n_1, n_2, \dots)]$.

$N = 1$ *Hydrogen.*

In Part I. we have considered the binding of an electron by a positive nucleus of charge e , and have shown that it is possible to account for the Balmer spectrum of hydrogen on the assumption of the existence of a series of stationary states in which the angular momentum of the electron round the nucleus is equal to entire multiples of the value $h/2\pi$, where h is Planck's constant. The formula found for the frequencies of the spectrum was

$$\nu = \frac{2\pi^2 e^4 m}{h^3} \cdot \left(\frac{1}{\tau_2^2} - \frac{1}{\tau_1^2} \right),$$

where τ_1 and τ_2 are entire numbers. Introducing the values for e , m , and h used on p. 479, we get for the factor before the bracket $3.1 \cdot 10^{15}$,⁶ the value observed for the constant in the Balmer spectrum is $3.290 \cdot 10^{15}$.

For the permanent state of a neutral hydrogen atom we get from the formula (1) and (2) in § 2, putting $F = 1$,

$$\begin{aligned} 1(1): \quad \alpha &= \frac{h^2}{4\pi e^2 m} = 0.55 \cdot 10^{-8}, \quad \omega = \frac{4\pi^2 e^4 m}{h^3} = 6.2 \cdot 10^{15}, \\ W &= \frac{2\pi^2 e^4 m}{h^2} = 2.0 \cdot 10^{-11}. \end{aligned}$$

These values are of the order of magnitude to be expected. For W/e we get 0.043, which corresponds to 13 volts; the value for the ionizing potential of a hydrogen atom, calculated by Sir J.J. Thomson from experiments on positive rays, is 11 volt.⁷ No other definite data, however are available for hydrogen atoms. For sake of brevity, we shall in the following denote the values for α , ω and W corresponding to the configuration 1(1) by α_0 , ω_0 , and W_0 .

⁶This value is that calculated in the first part of the paper. Using the values $e = 4.78 \cdot 10^{-10}$ (see R.A. Millikan, Brit. Assoc. Rep. 1912, p. 410), $e/m = 5.31 \cdot 10^{17}$ (see P. Gmelin, Ann. d. Phys. XXVIII p. 1086 (1909) and A.H. Bucherer, Ann. d. Phys. XXXVII p. 597 (1912)), and $e/h = 7.27 \cdot 10^{18}$ calculated by Planck's theory from the experiments of E. Warburg G. Leithauser, E. Hupka, and C. Muller, Ann.d.Phys. XL. p. 611 (1913)) we get $2\pi^2 e^4 m/h^3 = 3.26 \cdot 10^{15}$ in very close agreement with observations.

⁷J.J. Thomson, Phil. Mag. XXIV. p. 218 (1912).

At distance from the nucleus, great in comparison with a_0 , the system 1(1) will not exert sensible forces on free electrons. Since, however, the configuration:

$$1(2) \quad a = 1.33a_0, \quad \omega = 0.563\omega_0, \quad W = 1.13W_0.$$

corresponds to a greater value for W than the configuration 1(1), we may expect that a hydrogen atom under certain conditions can acquire a negative charge. This is in agreement with experiments on positive rays. Since $W[1(3)]$ is only 0.54, a hydrogen atom cannot be expected to be able to acquire a double negative charge.

$$N = 2 \qquad \text{Helium.}$$

As shown in Part I, using the same assumptions as for hydrogen, we must expect that during the binding of an electron by a nucleus of charge $2e$, a spectrum is emitted, expressed by

$$\nu = \frac{2\pi^2me^4}{h^3} \cdot \left(\frac{1}{(\frac{2}{3})^2} - \frac{1}{(\frac{1}{3})^2} \right).$$

This spectrum includes the spectrum observed by Pickering in the star *xi Puppis* and the spectra recently observed by Folwer in experiments with vacuum tubes filled with a mixture of hydrogen and helium. These spectra are generally ascribed to hydrogen.

For the permanent state of a positively charge helium atom, we get

$$2(1) \quad a = \frac{1}{2}a_0, \quad \omega = 4\omega_0, \quad W = 4W_0.$$

At distances from the nucleus great compared with the radius of the bound electron, the system 2(1) will, to a close approximation, act as an electron as a simple nucleus of charge e . For a system consisting of two electrons and a nucleus of charge $2e$, we may therefore assume the existence of a series of stationary states in which the electron most lightly bound moves approximately in the same way as the electron in the stationary states of a hydrogen atom. Such an assumption has already been used in Part I. in an attempt to explain the appearance of Rydberg's constant in the formula for the line-spectrum of any element. We can, however, hardly assume the existence of a stable configuration in which the two electrons have the same angular momentum round the nucleus and move in different orbits, the one outside the other. In such a configuration the electrons would be so near to

each other that the deviations from circular orbits would be very great. For the permanent state of a neutral helium atom, we shall therefore adopt the configuration

$$2(2) \quad a = 0.571a_0, \quad \omega = 3.06\omega_0, \quad W = 6.13W_0.$$

Since

$$W[2(2)] - W[2(1)] = 2.13W_0,$$

we see that both electrons in a neutral helium atom are more firmly bound than the electron in a hydrogen atom. Using the values on p. 488,???? we get

$$2.13 \cdot \frac{W_0}{e} = 27, \quad 2.13 \cdot \frac{W_0}{h} = 6.6 \cdot 10^{15} \text{ 1/sec.}$$

these values are of the same order of magnitude as the value observed for the ionization potential in helium, 20.5 volt,⁸ and the value for the frequency of the ultra-violet absorption in helium determined by experiments on dispersion $5.9 \cdot 10^{15}$ 1/sec.⁹

The frequency in question may be regarded as corresponding to vibrations in the plane of the ring (see p. 480).???? The frequency of vibration of the whole ring perpendicular to the plane, calculated in the ordinary way (see p. 482), is given by $\nu = 3.27\omega_0$. The fact that the latter frequency is great compared with that observed might explain that the number of electrons in a helium atom, calculated by help of Drude's theory from the experiments on dispersion, is only about two-thirds of the number to be expected. (Using $\frac{e}{m} = 5.31 \cdot 10^{17}$ the value calculated is 1.2.)

For a configuration of a helium nucleus and three electrons, we get

$$2(3) \quad a = 0.703a_0, \quad \omega = 2.02\omega_0, \quad W = 6.07W_0.$$

Since W for this configuration is smaller than for the configuration 2(2), the theory indicates that a helium atom cannot acquire a negative charge. This is in agreement with experimental evidence, which shows that helium atoms have no "affinite" for free electrons.¹⁰

⁸J.Franck u. G. Hertz, Verh. d. Deutsch. Phys. Ges. XV. p. 34 (1913).

⁹C. and M. Cuthbertson, Proc. Roy. Soc. A. LXXXIV. p. 13 (1910). In a previous paper (Phil. Mag. Jan. 1913) the author took the values for the refractive index in helium, given by M. and C. Cuthbertson, as corresponding to atmosphere pressure; these values, however, refer to double atmosphere pressure. Consequently the value there given for the number of electrons in a helium atom calculated from Drude's theory has to be divided by 2.)

¹⁰See J. Franck, Verh. d. Deutsch. Phys. Ges. XII p. 613 (1910).

In a later paper it will be shown that the theory offers a simple explanation of the marked in the tendency of hydrogen and helium atoms to combine into molecules.

$N = 3$

Lithium.

In analogy with the cases of hydrogen and helium we must expect that during the binding of an electron by a nucleus of charge $3e$, a spectrum is emitted, given by

$$\nu = \frac{2\pi^2 m e^4}{h^3} \cdot \left(\frac{1}{(\frac{2}{3})^2} - \frac{1}{(\frac{1}{3})^2} \right).$$

On account of the great energy to be spent in removing all the electrons bound in a lithium atom (see below) the spectrum considered can only be expected to be observed in extraordinary cases.

In a recent note Nicholson¹¹ has drawn attention to the fact that in the spectra of certain stars, which show the Pickering spectrum with special brightness, some lines occur the frequencies of which to a close approximation can be expressed by the formula

$$\nu = K \cdot \left(\frac{1}{4} - \frac{1}{(m \pm 1/3)^2} \right).$$

where K is the same constant as in the Balmer spectrum of hydrogen. From analogy with the Balmer- and Pickering-spectra, Nicholson has suggested that the lines in question are due to hydrogen.

It is seen that the lines discussed by Nicholson are given by the above formula if we put $\tau_2 = 6$. The lines in question correspond to $\tau_1 = 10, 13$ and 14 ; if we for $\tau_2 = 6$ put $\tau_1 = 9, 12$ and 15 , we get lines coinciding with lines of the ordinary Balmer-spectrum of hydrogen. If we in the above formula put $\tau = 1, 2$, and 3 , we get series of lines in the ultra-violet. If we put $\tau_2 = 4$ we get only a single line in visible spectrum, viz.: for $\tau_1 = 5$ which gives $\nu = 6.662 \cdot 10^{14}$, or a wave-length $\lambda = 4.503 \cdot 10^{-8}$ cm closely coinciding with the wave-length $4.504 \cdot 10^{-8}$ cm of one of the lines of unknown origin in the table quoted by Nicholson. In this table, however, no lines occur corresponding to $\tau_2 = 5$.

For the permanent state of a lithium atom with two positive charges we get a configuration

$$\mathbf{3}(1) \quad a = \frac{1}{3} a_0, \quad \omega = 9\omega_0, \quad W = 9W_0.$$

¹¹J.W. Nicholson, Month. Not. Roy. Astr. Soc. LXXIII. 382 (1913).

The probably of a permanent configuration in which two electrons move in different orbits around each other must for lithium be considered still less probable than for helium, as the ratio between the radii of the orbits would be still nearer to unity. For a lithium atom with a single positive charge we shall, therefore, adopt the configuration:

$$\mathbf{3}(2) \quad a = 0.364a_0, \quad \omega = 7.56\omega_0, \quad W = 15.13W_0.$$

Since $W[\mathbf{3}(2)] - W[\mathbf{3}(1)] = 6.13W_0$ we see that the first two electrons in a lithium atom very strongly bound compared with the electron in a hydrogen atom; they are still more rigidly bound than the electrons in a helium atom.

From a consideration of the chemical properties we should expect the following configuration for the electrons in a neutral lithium atom:

$$\begin{aligned} \mathbf{3}(2,1) \quad a_1 &= 0.362a_0, \quad \omega_1 = 7.65\omega_0, & W &= 16.02W_0 \\ a_2 &= 1.182a_0, \quad \omega_2 = 0.716\omega_0, \end{aligned}$$

This configuration may be considered as highly probable also from a dynamical point view. The deviation of the outermost electron from a circular orbit will be very small, partly on account of the great values of the ratio between the radii, and of the ratio between the frequencies of the orbits of the inner and outer electrons, partly also on account of the symmetrical arrangement of the inner electrons. accordingly, it appears probable that the three electrons will not arrange themselves in a single ring and from the system:

$$\mathbf{3}(3) \quad a = 0.413a_0, \quad \omega = 5.87\omega_0, \quad W = 17.61W_0,$$

although W for this configuration is greater than for $\mathbf{3}(2,1)$.

Since $W[\mathbf{3}(2,1)] - W[\mathbf{3}(2)] = 0.89W_0$, we see that the outer electron in the configuration $\mathbf{3}(2,1)$ is bound even more lightly than the electron in a hydrogen atom. the difference in the firmness of the binding corresponds to a difference of 1.4 volts in the ionization potential. A marked difference between the electron in hydrogen and the outermost electron in lithium lies also in the greater tendency of the latter electron to leave the plane of this orbits. The quantity G considered in § 2, which gives a kind of measure for the stability for displacements perpendicular to this plane, is thus for the outer electron in lithium only 0.55, while for hydrogen it is 1. This may have a bearing on the explanation of the apparent tendency of lithium atoms to take a positive charge in chemical combinations with other elements.

For a possible negatively charged lithium atom we may expect the configuration:

$$\begin{aligned} 3(2,2) \quad a_1 = 0.362a_0, \quad \omega_1 = 7.64\omega_0, \quad W = 16.16W_0 \\ a_2 = 1.516a_0, \quad \omega_2 = 0.436\omega_0, \end{aligned}$$

it should be remarked that we have no detailed knowledge of the properties in the atomic state, either for lithium or hydrogen, or for most of the electrons considered below.

$N = 4$ *Beryllium.*

For reasons analogous to those considered for helium and lithium we may for the formation of a neutral beryllium atom assume the following states:

$$\begin{aligned} 4(1) \quad a = 0.25a_0, \quad \omega = 16\omega_0, \quad W = 16W_0, \\ 4(2) \quad a = 0.267a_0, \quad \omega = 14.06\omega_0, \quad W = 28.13W_0, \\ 4(2,1) \quad a_1 = 0.263a_0, \quad \omega_1 = 14.46\omega_0, \quad W = 31.65W_0, \\ a_2 = 0.605a_0, \quad \omega_2 = 2.74\omega_0, \\ 4(2,2) \quad a_1 = 0.262a_0, \quad \omega_1 = 14.60\omega_0, \quad W = 33.61W_0, \\ a_2 = 0.673a_0, \quad \omega_2 = 2.21\omega_0, \end{aligned}$$

although the configurations:

$$\begin{aligned} 4(3) \quad a = 0.292a_0, \quad \omega = 11.71\omega_0, \quad W = 35.14W_0, \\ 4(4) \quad a = 0.329a_0, \quad \omega = 9.26\omega_0, \quad W = 37.04W_0, \end{aligned}$$

correspond to less values for the total energy than the configuration 4(2,1) and 4(2,2).

From analogy we get further for the configuration of a possible negatively charged atom,

$$\begin{aligned} 4(2,3) \quad a_1 = 0.263a_0, \quad \omega_1 = 14.51\omega_0, \quad W = 33.66W_0 \\ a_2 = 0.803a_0, \quad \omega_2 = 1.55\omega_0, \end{aligned}$$

Comparing the outer ring of the atom considered with the ring of a helium atom, we see that the presence of the inner ring of two electrons in the beryllium atom markedly changes the properties of the outer ring;

partly because the outer electrons in the configuration adopted for a neutral beryllium atom are more lightly bound than the electrons in a helium atom, and partly because the quantity G , which for helium is equal to 2, for the outer ring in the configuration 4(2,2) is only equal 1.12.

Since $W[4(2,3)] - W[4(2,2)] = 0.05W_0$, the beryllium atom will further have a definite, although very small affinity for free electrons.

§ 4 *Atoms containing greater numbers of electrons*

From the examples discussed in the former section it will appear that the problem of the arrangement of the electrons in the atoms is intimately connected with the question of the confluence of two rings of electrons rotating round a nucleus outside each other, and satisfying the condition of the universal constancy of the angular momentum. apart from the necessary conditions of stability for displacements of the electrons perpendicular to the plane of the orbits, the present theory gives very little information on this problem. It seems, however, possible by the help of simple considerations to throw some light on the question.

Let us consider two rings rotating round a nucleus in a single plane, the one outside the other. Let us assume that the electrons in the one ring act upon the electrons in the other as if the electric charge were uniformly distributed along the circumference of the ring, and that the ring with this approximation satisfy the condition of the angular momentum of the electrons and stability for displacements perpendicular to their plane.

Now suppose that, by help of suitable imaginary extraneous forces acting parallel to the axis of the rings, we pull the inner ring slowly to one side. During this process, on account of the repulsion from the inner ring, the outer will move to the opposite side of the original plane of the rings. During the displacements of the rings angular momentum of the electrons round the axis of the system will remain constant, and the diameter of the inner ring will increase while that of the outer will diminish. At the beginning of the displacement the magnitude of the extraneous forces to be applied to the original inner ring will increase but thereafter decrease, and at a certain distance between the plane of the rings the system will be in a configuration of equilibrium. This equilibrium, however, will not be stable. If we let the rings slowly return they will either reach their original position, or they arrive at a position in which the ring, which originally was the outer, is now

the inner, and *vice versa*.

If the charge of the electrons were uniformly distributed along the circumference of the rings, we could by the process considered at most obtain an interchange of the rings, but obviously not a junction of them. Taking, however, the discrete distribution of the electrons into account, it can be shown that in the special case when the number of electrons on the two rings are equal, and when the rings rotate in the same direction, the rings will unite by the process, provided that the final configuration is stable. In this case the radii and the frequency of the rings will be equal in the unstable configuration of equilibrium mentioned above. In reaching this configuration the electrons in the one ring will further be situated just opposite the intervals between the electrons in the outer, since such an arrangement will correspond to the smallest total energy. If now we let the rings return to their original plane, the electrons in the one ring will pass into the intervals between the electrons in the other, and from a single ring. Obviously the ring thus formed will satisfy the same condition of the angular momentum of the electrons as the original rings.

If the two rings contain unequal numbers of electrons the system will during a process such as that considered behave very differently, and, contrary to the former case, we cannot expect that the rings will flow together, if by help of extraneous forces acting parallel to the axis of the system they are displaced slowly from their original plane. It may in this connexion be noticed that the characteristic for the displacements considered is not the special assumption about the extraneous forces, but only invariance of the angular momentum of the electrons round the centre of the rings; displacements of this kind take in the present theory a similar position to arbitrary displacements in the ordinary mechanics.

The above considerations may be taken as an indication that there is greater tendency for the confluence of two rings when each contains the same number of electrons. Considering the successive binding of electrons by a positive nucleus, we conclude from this that, unless the charge on the nucleus is very great, rings of electrons will only join together if they contain equal numbers of electrons; and that accordingly the numbers of electrons on inner rings will only be 2, 4, 8, If the charge of the nucleus is very great the rings of electrons first bound, if few in number, will be very close together, and we must expect that the configuration will be very unstable, and that a gradual interchange of electrons between the rings will be greatly facilitated.

This assumption in regard to the number of electrons in the rings is strongly supported by the fact that the chemical properties of the elements

of low atomic weight vary with a period of 8. Further, it follows that the number of electrons on the outermost ring will always be odd or even, according as the total number of electrons in the atom is odd or even. This has a suggestive relation to the fact that the valency of an element of low atomic weight always is odd or even according as the number of the element in the periodic series is odd or even.

For the atoms of the elements considered in the former section we have assumed that the two electrons first bound are arranged in a single ring, and, further, that the two next electrons are arranged in another ring. If $N \geq 4$ the configuration $N(4)$ will correspond to a smaller value for the total energy than the configuration $N(2,2)$. The greater the value of N the closer will the ratio between the radii of the rings in the configuration $N(2,2)$ approach unity, and the greater will be the energy emitted by an eventual confluence of the rings. The particular member of the series of the elements for which the four innermost electrons will be arranged for the first time in a single ring cannot be determined from the theory. From a consideration of the chemical properties we can hardly expect that it will have taken place before boron ($N = 5$) or carbon ($N = 6$), on account of the observed trivalency and tetravalency respectively of these elements; on the other hand, the periodic system of the elements strongly suggests that already in neon ($N = 10$) an inner ring of eight electrons will occur. Unless $N > 14$ the configuration $N(4,4)$ corresponds to smaller value for the total energy than the configuration $N(8)$; already for $N \geq 10$ the latter configuration, however, will be stable for displacements of the electrons perpendicular to the plane of their orbits. A ring of 16 electrons will not be stable unless N is very great; but in such a case the simple considerations mentioned do not apply.

The confluence of two rings of equal number of electrons, which rotate round a nucleus of charge Ne outside a ring of n electrons already bound, must be expected to take place more easily than the confluence of two similar rings rotating round a nucleus of charge $(N - n) \cdot e$; for the stability of the rings for a displacement perpendicular to their plane will (see § 2) be smaller in the first than the latter case. This tendency for stability to decrease for displacements perpendicular to the plane of the ring will be especially marked for the outer rings of electrons of a neutral atom. In the latter case we must expect the confluence of rings to be greatly facilitated and in certain cases it may even happen that the number of electrons in the outer ring may be greater than in the next, and that the outer ring may show deviations from the assumption of 1, 2, 4, 8 electrons in the rings, e.g. the configurations $5(2,3)$ and $6(2,4)$ instead of the configuration $5(2,2,1)$ and $6(2,2,2)$. We shall here not discuss further the intricate question of the

arrangement of the electrons in the outer ring. In the scheme given below the number of electrons in this rings is arbitrary put equal to the normal valency of the corresponding element; i.e. for electronegative and electropositive elements respectively the number of hydrogen atoms and twice the number of oxygen atoms with which one atom of the element combines.

Such an arrangement of the outer electrons is suggested by considerations of atomic volumes. As is well known, the atomic volume of the elements is a periodic function of the atomic weights. If arranged in the usual way according to the periodic system, the elements inside the same column have approximately the same atomic volume, while this volume changes considerably from one column to another, being greatest for columns corresponding to the smallest valency 1 and smallest for the greatest valency 4. An approximate estimate of the radius of the outer ring of a neutral atom can be obtained by assuming that the total forces due to the nucleus and the inner electrons is equal to that from a nucleus of charge ne , where n is the number of electrons in the ring. Putting $F = n - s_n$ in the equation (1) on p. 478, ?????? and denoted the value of a for $n = 1$ by a_0 , we get for $n = 2$, $a = 0.41a_0$; and for $n = 4$, $a = 0.33a_0$. According the arrangement chosen for the electrons will involve a variation in the dimensions of the outer ring similar to the variation in the atomic volumes of the corresponding elements. It must, however, be borne in mind that the experimental determinations of atomic volumes in most cases are deduced from consideration of molecules rather than atoms.

From the above we are led to the following possible scheme for the arrangement of the electrons in light atoms: -

1(1)	9(4,4,1)	17(8,4,4,1)
2(2)	10(8,2)	18(8,8,2)
3(2,1)	11(8,2,1)	19(8,8,2,1)
4(2,2)	12(8,2,2)	20(8,8,2,2)
5(2,3)	13(8,2,3)	21(8,8,2,3)
6(2,4)	14(8,2,4)	22(8,8,2,4)
7(4,3)	15(8,4,3)	23(8,8,4,3)
8(4,2,2)	16(8,4,2,2)	24(8,8,4,2,2)

Without any fuller discussion it seems not unlikely that this constitution of the atoms will correspond to properties of the elements similar with those observed.

In the first place there will be a marked periodicity with a period of 8. Further, the binding of the outer electrons in every horizontal series of the

above scheme will become weaker with increasing number of electrons per atom, corresponding to the observed increase of the electropositive character for an increase of atomic weight of the elements in every single group of the periodic system. A corresponding agreement holds for the variation of the atomic volumes.

In the case of atoms of higher atomic weight the simple assumptions used do not apply. A few indications, however, are suggested from consideration of the variations in the chemical properties of the elements. At the end of the 3rd period of 8 elements we meet with the iron-group. This group takes a particular position in the system of the elements, since it is the first time that elements of neighbouring atomic weight show similar chemical properties. This circumstance indicates that the configurations of the electrons in the elements of this group differ only in the arrangement of the inner electrons. The fact that the period in the chemical properties of the elements after the iron-group is no longer 8, but 18, suggests that elements of higher atomic weight contain a recurrent configuration of 18 electrons in the innermost rings. The deviation from 2, 4, 8, 16 may be due to a gradual interchange of electrons between the rings, such as is indicated on p. 495. Since a ring of 18 electrons will not be stable the electrons may be arranged in two parallel rings (see p. 486). ?????? Such a configuration of the inner electrons will act upon the outer electrons in very nearly the same way as nucleus of charge $(N - 18) \cdot e$. It might therefore be possible that with increase of N another configuration of the same type will be formed outside the first, such as is suggested by the presence of a second period of 18 elements.

On the same lines, the presence of the group of the rare earths indicates that for still greater values of N another gradual alteration of the innermost rings will take place. Since, however, for elements of higher atomic weight than those of this group, the laws connection the vibration of the chemical properties with the atomic weight are similar to these between the elements of low atomic weight, we may conclude that the configuration of the innermost electrons will be again repeated. The theory, however, is not sufficiently complete to give a definite answer to such problems.

§ 5 *Characteristic Röntgen Radiation*

According to the theory of emission of radiation given in Part I., the ordinary line-spectrum of an element is emitted during the reformation of an atom

when one or more of the electrons in the other rings are removed. In analogy it may be supposed that the characteristic Röntgen radiation is sent out during the setting down of the system if electrons in inner rings are removed by some agency, e.g. by impact of cathode particles. This view of the origin of the characteristic Röntgen radiation has been proposed by Sir. J.J. Thomson.

Without any special assumption in regard to the constitution of the radiation, we can from this view determine the minimum velocity of the cathode rays necessary to produce the characteristic Röntgen radiation of a special type by calculating the energy necessary to remove one of the electrons from the different rings. Even if we know the numbers of electrons in the rings, a rigorous calculation of this momentum energy might still be complicated, and the result largely dependent on the assumptions used; for, as mentioned in Part I, p. 19, ?????????? the calculation cannot be performed entirely on the basis of the ordinary mechanics. We can, however, obtain very simply an approximate comparison with experiments if we consider the innermost ring and as a first approximation neglect the repulsion from the electrons in comparison with the attraction of the nucleus. Let us consider a simple system consisting of a bound electron rotating in a circular orbit round a positive nucleus of charge Ne . From the expressions (1) on p. 478 ?????????? we get for the velocity of the electron, putting $F = N$,

$$v = \frac{2\pi e^2}{h} N = 2.1 \cdot 10^8 \cdot N.$$

The total energy to be transferred to the system in order to remove the electron to an infinite distance from the nucleus is equal to the kinetic energy of the bound electron. If, therefore, the electron is removed to a great distance from the nucleus by impact of another rapidly moving electron, the smallest kinetic energy possessed by the latter when at a great distance from the nucleus must necessarily be equal to the kinetic energy of the bound electron before the collision. The velocity of the free electron therefore must be at least equal to e .

According to Whiddington's experiments¹² the velocity of cathode rays just able to produce the characteristic Röntgen radiation of the so-called *K*-type—the hardest type of radiation observed—from an element of atomic weight A is for elements from Al to Se approximately equal to $A \cot 10^8$ cm/sec. As seen this is equal to the above calculated value for v , if we put $N = A/2$.

¹²R. Whiddington, Proc. Roy. Soc. A. LXXXV. p. 323 (1911).

Since we have obtained approximate agreement with experiment by ascribing the characteristic Röntgen radiation of the K -type to the innermost ring, it is to be expected that no harder type of characteristic radiation will exist. This is strongly indicated by observations of the penetrating power of γ rays.¹³

It is worthy of remark that the theory gives not only nearly the right value for the energy required to remove an electron from the outer ring, but also the energy required to remove an electron from the innermost ring. The approximate agreement between the calculated and experimental values is all the more striking it is recalled that the energies required in the two cases for an element of atomic weight 70 differ by a ratio of 1000.

In connexion with this it should be emphasized that the remarkable homogeneity of the characteristic Röntgen radiation – indicated by experiments on absorption of the rays, as well as by the interference observed in recent experiments on diffraction of Röntgen rays in crystals – is in agreement with the main assumption used in part I. (see p. 7) in considering the emission of line-spectra, viz. that the radiation emitted during the passing of the systems between different stationary states is homogeneous.

Putting in (4) $F = N$, we get for the diameter of the innermost ring approximately $2a = 1/N \cdot 10^{-8}$ cm. For $N = 100$ this gives $2a = 10^{-10}$ cm, a value which is very small in comparison with ordinary atomic dimensions but still very great compared with the dimensions to be expected for the nucleus. according to Rutherford's calculation the dimensions of the latter are of the same order of magnitude as 10^{-12} cm.

§ 6 *Radioactive Phenomena*

According to the present theory the cluster of electrons surrounding the nucleus is formed with emission of energy, and the configuration is determined by the condition that the energy emitted is a maximum. The stability involved by these assumptions seems to be in agreement with the general properties of matter. It is, however, in striking opposition to the phenomena of radioactivity, and according to the theory the origin of the latter phenomena may therefore be sought elsewhere than in the electronic distribution round the nucleus.

¹³Comp. E. Rutherford, Phil. Mag. XXIV. p. 453 (1912).

A necessary consequence of Rutherford's theory of the structure of atoms is that the α -particles have their origin in the nucleus. On the present theory it seems also necessary that the nucleus is the seat of the expulsion of the high-speed β -particles. In the first place, the spontaneous expulsion of a β -particle from the cluster of electrons surrounding the nucleus would be something quite foreign to the assumed properties of the system. further, the expulsion of an α -particle can hardly be expected to produce a lasting effect on the stability of the cluster of electrons. The effect of the expulsion will be of two different kinds. Partly the particle may collide with the bound electrons during its passing through the atom. This effect will be analogous to that produced by bombardment of atoms of other substances by α -rays and cannot be expected to give rise to a subsequent expulsion of β -rays. Partly the expulsion of the particle will involve an alteration in the configuration of the bound electrons, since the charge remaining on the nucleus is different from the original. In order to consider the latter effect let us regard a single ring of electrons rotating round a nucleus of charge Ne , and let us assume that an α -particle is expelled from the nucleus in a direction perpendicular to the plane of the ring. The expulsion of the particle will obviously not produce any alteration in the angular momentum of the electrons; and if the velocity of the α -particle is small compared with the velocity of the electrons – as it will be if we consider inner rings of an atom of high atomic weight – the ring during the expulsion will expand continuously, and after the expulsion will take the position claimed by the theory for a stable ring rotating round a nucleus of charge $(N - 2) \cdot e$. The consideration of this simple case strongly indicates that the expulsion of an α -particle will not have a lasting effect on the stability of the internal rings of electrons in the residual atom.

The question of the origin of β -particles may also be considered from another point of view, based on a consideration of the chemical and physical properties of the radioactive substances. As is well known, several of these substances have very similar chemical properties and have hitherto resisted every attempt to separate them by chemical means. There is also some evidence that the substances in question show the same line-spectrum.¹⁴ It has been suggested by several writers that the substances are different only in radio-active properties and atomic weight but identical in all other physical and chemical respects. according to the theory, this would mean that the charge on the nucleus, as well as the configuration of the surrounding electrons, was identical in some of the elements, the only difference being

¹⁴see A.S. Russel and R. Rossi, Proc. Roy. Soc. A. LXXXVII. p. 478 (1912).

the mass and the internal condition of the nucleus. From the considerations of § 4 this assumption is already strongly suggested by the fact that the number of radioactive substances is greater than the number of places at our disposal in the periodic system. If, however, the assumption is right, the fact that two apparently identical elements emit β -particles of different velocities, shows that the β -rays as well as the α -rays have their origin in the nucleus.

This view of the origin of α - and β -particles explains very simply the way in which the change in the chemical properties of the radioactive substances is connected with the nature of the particles emitted. The results of experiments are expressed in the two rules:¹⁵

1. Whenever an α -particle is expelled the group in the periodic system to which the resultant product belongs is two units less than that to which the parent body belongs.

2. Whenever a β -particle is expelled the group of the resultant body is 1 unit greater than that of the parent.

As will be seen this is exactly what is to be expected according to the considerations of § 4.

In escaping from the nucleus, the β -rays may be expected to collide with the bound electrons in the inner rings. This will give rise to an emission of a characteristic radiation of the same type as the characteristic Röntgen radiation emitted from elements of lower atomic weight by impact of cathode-rays. The assumption that the emission of γ -rays is due to collisions of β -rays with bound electrons is proposed by Rutherford¹⁶ in order to account for the numerous groups of homogeneous β -rays expelled from certain radioactive substances.

In the present paper it has been attempted to show that the application of Planck's theory of radiation to Rutherford's atom-model through the introduction of the hypothesis of the universal constancy of the angular momentum of the bound electrons, leads to results which seem to be in agreement with experiments.

In a later paper the theory will be applied to systems containing more than one nucleus.

¹⁵See A.S. Russell, Chem. News, CVII. p. 49 (1913); G.v. Hevesy, Phys. Zeitschr. XIV. p. 49 (1913); K. Fajans, Phys. Zeitschr. XIV. pp. 131 & 136 (1913); Verh. d. deutsch. Phys. Ges. XV. p. 240 (1913); F. Soddy, Chem. News, CVII. p. 97 (1913).

¹⁶E. Rutherford, Phil. Mag. XXIV. pp. 453&893 (1912).

ANEXO 16 – A constituição de átomos e moléculas, parte 3.

stated that cases exist in which the field makes that potential increase.

That is just what occurs with the tubes having a lateral anode used for the experiments dealt with in the present paper.

An electrometer of convenient sensibility is enough to show that, when the magnetic field generates the magnetic rays, the deviation of the *electrometer* is much greater than before, often more than double. Now, the new explanation proposed by the authors named has, as starting point, a supposed diminution of the cathode fall of potential produced by the field. I can therefore refrain from discussing it.

I shall then point out lastly, in connexion with the remark on p. 266, that it is necessary to prove the legitimacy of the application to the case of rarefied gases of the result obtained by Sir J. J. Thomson dealing with the question of the transport of ions in a magnetic field, as such statement is based on the hypothesis that the viscosity of the medium in which an ion moves, is such as to render its speed proportional to the force acting on it; which does not seem always admissible in the case of a rarefied gas.

Bologna, August 1913.

LXXIII. *On the Constitution of Atoms and Molecules.*
By N. BOHR, *Dr. phil., Copenhagen* *.

PART III.—SYSTEMS CONTAINING SEVERAL NUCLEI †.

§ 1. *Preliminary.*

ACCORDING to Rutherford's theory of the structure of atoms, the difference between an atom of an element and a molecule of a chemical combination is that the first consists of a cluster of electrons surrounding a single positive nucleus of exceedingly small dimensions and of a mass great in comparison with that of the electrons, while the latter contains at least two nuclei at distances from each other comparable with the distances apart of the electrons in the surrounding cluster.

The leading idea used in the former papers was that the atoms were formed through the successive binding by the nucleus of a number of electrons initially nearly at rest.

* Communicated by Prof. E. Rutherford, F.R.S.

† Part I. and Part II. were published in *Phil. Mag.* xxvi. p. 1 & p. 476 (1913).

Such a conception, however, cannot be utilized in considering the formation of a system containing more than a single nucleus; for in the latter case there will be nothing to keep the nuclei together during the binding of the electrons. In this connexion it may be noticed that while a single nucleus carrying a large positive charge is able to bind a small number of electrons, on the contrary, two nuclei highly charged obviously cannot be kept together by the help of a few electrons. We must therefore assume that configurations containing several nuclei are formed by the interaction of systems—each containing a single nucleus—which already have bound a number of electrons.

§ 2 deals with the configuration and stability of a system already formed. We shall consider only the simple case of a system consisting of two nuclei and of a ring of electrons rotating round the line connecting them; the result of the calculation, however, gives indication of what configurations are to be expected in more complicated cases. As in the former papers, we shall assume that the conditions of equilibrium can be deduced by help of the ordinary mechanics. In determining the absolute dimensions and the stability of the systems, however, we shall use the main hypothesis of Part I. According to this, the angular momentum of every electron round the centre of its orbit is equal to a universal value $\frac{h}{2\pi}$, where h is Planck's constant; further, the stability is determined by the condition that the total energy of the system is less than in any neighbouring configuration satisfying the same condition of the angular momentum of the electrons.

In § 3 the configuration to be expected for a hydrogen molecule is discussed in some detail.

§ 4 deals with the mode of formation of the systems. A simple method of procedure is indicated, by which it is possible to follow, step by step, the combination of two atoms to form a molecule. The configuration obtained will be shown to satisfy the conditions used in § 2. The part played in the considerations by the angular momentum of the electrons strongly supports the validity of the main hypothesis.

§ 5 contains a few indications of the configurations to be expected for systems containing a greater number of electrons.

§ 2. Configurations and Stability of the Systems.

Let us consider a system consisting of two positive nuclei of equal charges and a ring of electrons rotating round the line connecting them. Let the number of electrons in the ring be n , the charge of an electron $-e$, and the charge on each nucleus Ne . As can be simply shown, the system will be in equilibrium if the nuclei are the same distance apart from the plane of the ring and if the ratio between the diameter of the ring $2a$ and the distance apart of the nuclei $2b$ is given by

$$b = a \left(\left(\frac{4n}{N} \right)^{\frac{1}{2}} - 1 \right)^{-\frac{1}{2}}. \quad \dots \quad (1)$$

provided that the frequency of revolution ω is of a magnitude such that for each of the electrons the centrifugal force balances the radial force due to the attraction of the nuclei and the repulsion of the other electrons. Denoting this force by $\frac{e^2}{a^2} F$, we get from the condition of the universal constancy of the angular momentum of the electrons, as shown in Part II. p. 478,

$$a = \frac{h^2}{4\pi^2 e^2 m} F^{-1} \quad \text{and} \quad \omega = \frac{4\pi^2 e^4 m}{h^3} F^2. \quad \dots \quad (2)$$

The total energy necessary to remove all the charged particles to infinite distances from each other is equal to the total kinetic energy of the electrons and is given by

$$W = \frac{2\pi^2 e^4 m}{h^3} \Sigma F^2. \quad \dots \quad (3)$$

For the system in question we have

$$F = \frac{N^2}{2a} \left(\left(\frac{4n}{N} \right)^{\frac{1}{2}} - 1 \right)^{\frac{1}{2}} - s_n. \quad \dots \quad (4)$$

where

$$s_n = \sum_{s=1}^{s=n-1} \operatorname{cosec} \frac{s\pi}{n};$$

a table of s_n is given in Part II. on p. 482.

To test the stability of the system we have to consider displacements of the orbits of the electrons relative to the nuclei, and also displacements of the latter relative to each other.

A calculation based on the ordinary mechanics gives that

the systems are unstable for displacements of the electrons in the plane of the ring. As for the systems considered in Part II., we shall, however, assume that the ordinary principles of mechanics cannot be used in discussing the problem in question, and that the stability of the systems for the displacements considered is secured through the introduction of the hypothesis of the universal constancy of the angular momentum of the electrons. This assumption is included in the condition of stability stated in § 1. It should be noticed that in Part II. the quantity F was taken as a constant, while for the systems considered here, F , for fixed positions of the nuclei, varies with the radius of the ring. A simple calculation, however, similar to that given in Part II. on p. 480, shows that the increase in the total energy of the system for a variation of the radius of the ring from a to $a + \delta a$, neglecting powers of δa greater than the second, is given by

$$\delta(P+T) = T \left(1 + \frac{a}{F} \frac{\partial F}{\partial a} \right) \left(\frac{\delta a}{a} \right)^2,$$

where T is the total kinetic energy and P the potential energy of the system. Since for fixed positions of the nuclei F increases for increasing a ($F=0$ for $a=0$; $F=2N - \epsilon_n$ for $a=\infty$), the term dependent on the variation of F will be positive, and the system will consequently be stable for the displacement in question.

From considerations exactly corresponding to those given in Part II. on p. 481, we get for the condition of stability for displacements of the electrons perpendicular to the plane of the ring

$$G > p_{n,o} - p_{n,n}, \dots \dots \dots (5)$$

where $p_{n,o} - p_{n,n}$ has the same signification as in Part II., and $\frac{e^2}{a^3} G \delta z$ denotes the component, perpendicular to the plane of the ring, of the force due to the nuclei, which acts upon one of the electrons in the ring when it has suffered a small displacement δz perpendicular to the plane of the ring. As for the systems considered in Part II., the displacements can be imagined to be produced by the effect of extraneous forces acting upon the electrons in direction parallel to the axis of the system.

For a system of two nuclei each of charge Ne and with a ring of n electrons, we find

$$G = \frac{N^2}{2n} \left(\left(\frac{4a}{N} \right)^{\frac{1}{2}} - 1 \right)^2 \left(1 - 3 \left(\frac{N}{4n} \right)^{\frac{1}{2}} \right). \dots \dots (6)$$

By help of this expression and using the table for $p_{n,c} - p_{n,\infty}$ given on p. 482 in Part II., it can be simply shown that the system in question will not be stable unless $N=1$ and a equal to 2 or 3.

In considering the stability of the systems for a displacement of the nuclei relative to each other, we shall assume that the motions of the nuclei are so slow that the state of motion of the electrons at any moment will not differ sensibly from that calculated on the assumption that the nuclei are at rest. This assumption is permissible on account of the great mass of the nuclei compared with that of the electrons, which involves that the vibrations resulting from a displacement of the nuclei are very slow compared with those due to a displacement of the electrons. For a system consisting of a ring of electrons and two nuclei of equal charge, we shall thus assume that the electrons at any moment during the displacement of the nuclei move in circular orbits in the plane of symmetry of the latter.

Let us now imagine that, by help of extraneous forces acting on the nuclei, we slowly vary the distance between them. During the displacement the radius of the ring of electrons will vary in consequence of the alteration of the radial force due to the attraction of the nuclei. During this variation the angular momentum of each of the electrons round the line connecting the nuclei will remain constant. If the distance apart of the nuclei increases, the radius of the ring will obviously also increase; the radius, however, will increase at a slower rate than the distance between the nuclei. For example, imagine a displacement in which the distance as well as the radius are both increased to α times their original value. In the new configuration the radial force acting on an electron from the nuclei and the other electrons is $\frac{1}{\alpha^2}$ times that in the original configuration. From the constancy of the angular momentum of the electrons during the displacement, it further follows that the velocity of the electrons in the new configuration is $\frac{1}{\alpha}$ times, and the centrifugal force $\frac{1}{\alpha^3}$ times that in the original. Consequently, the radial force is greater than the centrifugal force.

On account of the distance between the nuclei increasing faster than the radius of the ring, the attraction on one of the nuclei due to the ring will be greater than the repulsion from the other nucleus. The work done during the displacement by the extraneous forces acting on the nuclei will therefore

be positive, and the system will be stable for the displacement. Obviously the same result will hold in the case of the distance between the nuclei diminishing. It may be noticed that in the above considerations we have not made use of any new assumption on the dynamics of the electrons, but have only used the principle of the invariance of the angular momentum, which is common both for the ordinary mechanics and for the main hypothesis of § 1.

For a system consisting of a ring of electrons and two nuclei of unequal charge, the investigation of the stability is more complicated. As before, we find that the systems are always stable for displacements of the electrons in the plane of the ring; also an expression corresponding to (5) will hold for the condition of stability for displacements perpendicular to the plane of the ring. This condition, however, will not be sufficient to secure the stability of the system. For a displacement of the electrons perpendicular to the plane of the ring, the variation of the radial force due to the nuclei will be of the same order of magnitude as the displacement; therefore, in the new configuration the radial force will not be in equilibrium with the centrifugal force, and, if the radius of the orbits is varied until the radial equilibrium is restored, the energy of the system will decrease. This circumstance must be taken into account in applying the condition of stability of § 1. Similar complications arise in the calculation of stability for displacements of the nuclei. For a variation of the distance apart of the nuclei not only will the radius of the ring vary but also the ratio in which the plane of the ring divides the line connecting the nuclei. As a consequence, the full discussion of the general case is rather lengthy; an approximate numerical calculation, however, shows that the systems, as in the former case, will be unstable unless the charges on the nuclei are small and the ring contains very few electrons.

The above considerations suggest configurations of systems, consisting of two positive nuclei and a number of electrons, which are consistent with the arrangement of the electrons to be expected in molecules of chemical combinations. If we thus consider a neutral system containing two nuclei with great charges, it follows that in a stable configuration the greater part of the electrons must be arranged around each nucleus approximately as if the other nucleus were absent; and that only a few of the outer electrons will be arranged differently rotating in a ring round the line connecting the nuclei. The latter ring, which keeps the system together, represents the chemical "bond."

A first rough approximation of the possible configuration of such a ring can be obtained by considering simple systems consisting of a single ring rotating round the line connecting two nuclei of minute dimensions. A detailed discussion, however, of the configuration of systems containing a greater number of electrons, taking the effect of inner rings into account, involves elaborate numerical calculations. Apart from a few indications given in § 5, we shall in this paper confine ourselves to systems containing very few electrons.

§ 3. *Systems containing few Electrons. The Hydrogen Molecule.*

Among the systems considered in § 2 and found to be stable the system formed of a ring of two electrons and of two nuclei of charge e is of special interest, as it, according to the theory, may be expected to represent a neutral hydrogen molecule.

Denoting the radius of the ring by a and the distances apart of the nuclei from the plane of the ring by b , we get from (1), putting $N=1$ and $n=2$,

$$b = \frac{1}{\sqrt{3}} a;$$

from (4) we further get

$$F = \frac{3\sqrt{3}-1}{4} = 1.049.$$

From (2) and (3) we get, denoting as in Part II. the values of α , ω , and W for a system consisting of a single electron rotating round a nucleus of charge e (a hydrogen atom) by α_0 , ω_0 , and W_0 ,

$$\alpha = 0.95 \alpha_0, \quad \omega = 1.10 \omega_0, \quad W = 2.20 W_0.$$

Since $W > 2W_0$, it follows that two hydrogen atoms combine into a molecule with emission of energy. Putting $W_0 = 2.0 \cdot 10^{-12}$ erg (comp. Part II, p. 488) and $N = 6.2 \cdot 10^{23}$, where N is the number of molecules in a gram-molecule, we get for the energy emitted during the formation of a gram-molecule of hydrogen from hydrogen atoms $(W - 2W_0)N = 2.5 \cdot 10^{12}$, which corresponds to $6.0 \cdot 10^4$ cal. This value is of the right order of magnitude; it is, however, considerably less than the value $13 \cdot 10^4$ cal. found by Langmuir* by measuring the heat conduction through the gas from an incandescent wire in hydrogen. On account of the indirect

* I. Langmuir, Journ. Amer. Chem. Soc. xxxiv. p. 800 (1912).

method employed it seems difficult to estimate the accuracy to be ascribed to the latter value. In order to bring the theoretical value in agreement with Langmuir's value, the magnitude of the angular momentum of the electrons should be only $2/3$ of that adopted; this seems, however, difficult to reconcile with the agreement obtained on other points.

From (6) we get $G = \frac{3\sqrt{3}}{16} = 0.325$. For the frequency of vibration of the whole ring in the direction parallel to the axis of the system we get

$$\nu = \omega_0 \sqrt{G \frac{a_0^3}{a^3}} = 0.61\omega_0 = 3.8 \cdot 10^{13} \text{ 1/sec.}$$

We have assumed in Part I. and Part II. that the frequency of radiation absorbed by the system and corresponding to vibrations of the electrons in the plane of the ring cannot be calculated from the ordinary mechanics, but is determined by the relation $h\nu = E$, where h is Planck's constant, and E the difference in energy between two different stationary states of the system. Since we have seen in § 2 that a configuration consisting of two nuclei and a single electron rotating round the line between them is unstable, we may assume that the removing of one of the electrons will lead to the breaking up of the molecule into a single nucleus and a hydrogen atom. If we consider the latter state as one of the stationary states in question we get

$$E = W - W_0 = 1.20 W_0, \quad \text{and} \quad \nu = 1.2 \frac{W_0}{h} = 3.7 \cdot 10^{14} \text{ 1/sec.}$$

The value for the frequency of the ultra-violet absorption line in hydrogen calculated from experiments on dispersion is $\nu = 3.5 \cdot 10^{15}$ 1/sec.* Further, a calculation from such experiments based on Drude's theory gives a value near two for the number of electrons in a hydrogen molecule. The latter result might have connexion with the fact that the frequencies calculated above for the radiation absorbed corresponding to vibrations parallel and perpendicular to the plane of the ring are nearly equal. As mentioned in Part II., the number of electrons in a helium atom calculated from experiments on dispersion is only about $2/3$ of the number of electrons to be expected in the atom, viz. two. For a helium atom, as for a hydrogen molecule, the frequency determined by the relation $\nu \cdot h = E$ agrees closely with the frequency observed from dispersion; in the helium system, however, the frequency

* C. and M. Guthbertson, Proc. Roy. Soc. lxxxiii. p. 151 (1910).

corresponding to vibrations perpendicular to the plane of the ring is more than three times as great as the frequency in question, and consequently of negligible influence on the dispersion.

In order to determine the frequency of vibration of the system corresponding to displacement of the nuclei relative to each other, let us consider a configuration in which the radius of the ring is equal to y , and the distance apart of the nuclei $2x$. The radial force acting on one of the electrons and due to the attraction from the nuclei and the repulsion from the other electron is

$$R = \frac{2e^2y}{(y^2+x^2)^{\frac{3}{2}}} - \frac{e^2}{4y^3}.$$

Let us now consider a slow displacement of the system during which the radial force balances the centrifugal force due to the rotation of the electrons, and the angular momentum of the latter remains constant. Putting $R = \frac{e^2}{y^3}F$, we have seen on p. 859 that the radius of the ring is inversely proportional to F . Therefore, during the displacement considered, Ry^3 remains constant. This gives by differentiation

$$(8y^3 + 32y^2x^2 - (x^2+y^2)^{\frac{3}{2}})dy - 24xy^2dx = 0.$$

Introducing $x=b$ and $y=a$, we get

$$\frac{dy}{dx} = \frac{27}{21\sqrt{3-4}} = 0.834.$$

The force acting on one of the nuclei due to the attraction from the ring and the repulsion from the other nucleus is

$$Q = \frac{2e^2x}{(x^2+y^2)^{\frac{3}{2}}} - \frac{e^2}{4x^2}.$$

For $x=b$, $y=a$ this force is equal to 0.

Corresponding to a small displacement of the system for which $x=a+\delta x$ we get, using the above value for $\frac{dy}{dx}$ and putting $Q = \frac{e^2}{a^3}H\delta x$,

$$H = \frac{27}{16} \left(\sqrt{3} - \frac{dy}{dx} \right) = 1.515.$$

For the frequency of vibration corresponding to the displacement in question we get, denoting the mass of one of
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the nuclei by M ,

$$\nu = \omega_0 \sqrt{\frac{m}{M}} \frac{a_0^2}{a^3} = 1.32 \omega_0 \sqrt{\frac{m}{M}}$$

Putting $\frac{M}{m} = 1835$ and $\omega_0 = 6.2 \cdot 10^{15}$, we get

$$\nu = 1.91 \cdot 10^{14}.$$

This frequency is of the same order of magnitude as that calculated by Einstein's theory from the variation of the specific heat of hydrogen gas with temperature*. On the other hand, no absorption of radiation in hydrogen gas corresponding to this frequency is observed. This is, however, just what we should expect on account of the symmetrical structure of the system and the great ratio between the frequencies corresponding to displacements of the electrons and of the nuclei. The complete absence of infra-red absorption in hydrogen gas might be considered as a strong argument in support of a constitution of a hydrogen molecule like that adopted here, compared with model-molecules in which the chemical bond is assumed to have its origin in an opposite charge of the entering atoms.

As will be shown in § 5, the frequency calculated above can be used to estimate the frequency of vibration of more complicated systems for which an infra-red absorption is observed.

The configuration of two nuclei of charge e and a ring of three electrons rotating between them will, as mentioned in § 2, also be stable for displacements of the electrons perpendicular to the plane of the ring. A calculation gives

$$\frac{b}{a} = 0.486, \quad G = 0.623, \quad \text{and} \quad F = 0.879;$$

and further,

$$a = 1.14a_0, \quad \omega = 0.77\omega_0, \quad W = 2.32W_0.$$

Since W is greater than for the system consisting of two nuclei and two electrons, the system in question may be considered as representing a negatively charged hydrogen molecule. Proof of the existence of such a system has been obtained by Sir J. J. Thomson in his experiments on positive rays †.

A system consisting of two nuclei of charge e and a single

* See N. Bjerrum, *Zeitschr. f. Electrochem.* xvii. p. 731 (1911); xviii. p. 101 (1912).

† J. J. Thomson, *Phil. Mag.* xxiv. p. 253 (1912).

electron rotating in a circular orbit round the line connecting the nuclei, is unstable for a displacement of the electron perpendicular to its orbit, since in the configuration of equilibrium $G < 0$. The explanation of the appearance of positively charged hydrogen molecules in experiments on positive rays may therefore at first sight be considered as a serious difficulty for the present theory. A possible explanation, however, might be sought in the special conditions under which the systems are observed. We are probably dealing in such a case not with the formation of a stationary system by a regular interaction of systems containing single nuclei (see the next section), but rather with a delay in the breaking up of a configuration brought about by the sudden removal of one of the electrons by impact of a single particle.

Another stable configuration containing a few electrons is one consisting of a ring of three electrons and two nuclei of charges e and $2e$. A numerical calculation gives

$$\frac{b_1}{a} = 1.446, \quad \frac{b_2}{a} = 0.137, \quad F = 1.552,$$

where a is the radius of the ring and b_1 and b_2 the distances apart of the nuclei from the plane of the ring. By help of (2) and (3) we further get

$$\alpha = 0.644\alpha_0, \quad \omega = 2.41\omega_0, \quad W = 7.22W_0,$$

where ω is the frequency of revolution and W the total energy necessary to remove the particles to infinite distances from each other. In spite of the fact that W is greater than the sum of the values of W for a hydrogen and a helium atom ($W_H + 6.13W_0$; comp. Part II, p. 489), the configuration in question cannot, as will be shown in the next section, be considered to represent a possible molecule of hydrogen and helium.

The vibration of the system corresponding to a displacement of the nuclei relative to each other shows features different from the system considered above of two nuclei of charge e and two electrons. If, for example, the distance between the nuclei is increased, the ring of electrons will approach the nucleus of charge $2e$. Consequently, the vibration must be expected to be connected with an absorption of radiation.

§ 4. Formation of the Systems.

As mentioned in § 1, we cannot assume that systems containing more than one nucleus are formed by successive binding of electrons, such as we have assumed for the

systems considered in Part II. We must assume that the systems are formed by the interaction of others, containing single nuclei, which already have bound electrons. We shall now consider this problem more closely, starting with the simplest possible case, viz., the combination of two hydrogen atoms to form a molecule.

Consider two hydrogen atoms at a distance apart great in comparison with the linear dimensions of the orbits of the electrons, and imagine that by help of extraneous forces acting on the nuclei, we make these approach each other; the displacements, however, being so slow that the dynamical equilibrium of the electrons for every position of the nuclei is the same as if the latter were at rest.

Suppose that the electrons originally rotate in parallel planes perpendicular to the straight line connecting the nuclei, and that the direction of rotation is the same and the difference in phase equal to half a revolution. During the approach of the nuclei, the direction of the planes of the orbits of the electrons and the difference in phase will be unaltered. The planes of the orbits, however, will at the beginning of the process approach each other at a higher rate than do the nuclei. By the continued displacement of the latter the planes of the orbits of the electrons will approach each other more and more, until finally for a certain distance apart of the nuclei the planes will coincide, the electrons being arranged in a single ring rotating in the plane of symmetry of the nuclei. During the further approach of the nuclei the ratio between the diameter of the ring of electrons and the distance apart of the nuclei will increase, and the system will pass through a configuration in which it will be in equilibrium without the application of extraneous forces on the nuclei.

By help of a calculation similar to that indicated in § 2, it can be simply shown that at any moment during this process the configuration of the electrons is stable for a displacement perpendicular to the plane of the orbits. In addition, during the whole operation the angular momentum of each of the electrons round the line connecting the nuclei will remain constant, and the configuration of equilibrium obtained will therefore be identical with the one adopted in § 3 for a hydrogen molecule. As there shown, the configuration will correspond to a smaller value for the total energy than the one corresponding to two isolated atoms. During the process, the forces between the particles of the system will therefore have done work against the extraneous forces acting on the nuclei; this fact may be expressed by

saying that the atoms have "attracted" each other during the combination. A closer calculation shows that for any distance apart of the nuclei greater than that corresponding to the configuration of equilibrium, the forces acting on the nuclei, due to the particles of the system, will be in such a direction as to diminish the distance between the nuclei; while for any smaller distance the forces will have the opposite direction.

By means of these considerations, a possible process is indicated for the combination of two hydrogen atoms to form a molecule. This operation can be followed step by step without introducing any new assumption on the dynamics of the electrons, and leads to the same configuration adopted in § 3 for a hydrogen molecule. It may be recalled that the latter configuration was deduced directly by help of the principal hypothesis of the universal constancy of the angular momentum of the electrons. These considerations also offer an explanation of the "affinity" of two atoms. It may be remarked that the assumption in regard to the slowness of the motion of the nuclei relative to those of the electrons is satisfied to a high degree of approximation in a collision between two atoms of a gas at ordinary temperatures. In assuming a special arrangement of the electrons at the beginning of the process, very little information, however, is obtained by this method on the chance of combination due to an arbitrary collision between two atoms.

Another way in which a neutral hydrogen molecule may be formed is by the combination of a positively and a negatively charged atom. According to the theory a positively charged hydrogen atom is simply a nucleus of vanishing dimensions and of charge e , while a negatively charged atom is a system consisting of a nucleus surrounded by a ring of two electrons. As shown in Part II., the latter system may be considered as possible, since the energy emitted by the formation of it is greater than the corresponding energy for a neutral hydrogen atom. Let us now imagine that, by a slow displacement of the nuclei, as before, a negatively and a positively charged atom combine. We must assume that, when the nuclei have approached a distance equal to that in the configuration adopted for a hydrogen molecule, the electrons will be arranged in the same way, since this is the only stable configuration for this distance in which the angular momentum of the electrons has the value prescribed by the theory. The state of motion of the electrons will, however, not vary in a continuous way with the displacement

of the nuclei as in the combination of two neutral atoms. For a certain distance apart of the nuclei the configuration of the electrons will be unstable and suddenly change by a finite amount; this is immediately deduced from the fact that the motion of the electrons by the combination of two neutral hydrogen atoms considered above, passes through an uninterrupted series of stable configurations. The work done by the system against the extraneous forces acting on the nuclei will therefore, in the case of the combination of a negatively and a positively charged atom, not be equal to the difference in energy between the original and the final configuration; but in passing through the unstable configurations a radiation of energy must be emitted, corresponding to that emitted during the binding of electrons by a single nucleus and considered in Parts I. and II.

On the above view, it follows that in the breaking up of a hydrogen molecule by slowly increasing the distance apart of the nuclei, we obtain two *neutral* hydrogen atoms and not a positively and a negatively charged one. This is in agreement with deductions drawn from experiments on positive rays*.

Next imagine that instead of two hydrogen atoms we consider two helium atoms, *i. e.* systems consisting of a nucleus of charge $2e$ surrounded by a ring of two electrons, and go through a similar process to that considered on p. 868. Assume that the helium atoms at the beginning of the operation are orientated relatively to each other like the hydrogen atoms, but with the exception that the phases of the electrons in the helium atoms differ by one quarter of a revolution instead of one half revolution as in the case of hydrogen. By the displacement of the nuclei, the planes of the rings of electrons will, as in the former case, approach each other at a higher rate than the nuclei, and for a certain position of the latter the planes will coincide. During the further approach of the nuclei, the electrons will be arranged at equal angular intervals in a single ring. As in the former case, it can be shown that at any moment during this operation the system will be stable for a displacement of the electrons perpendicular to the plane of the rings. Contrary, however, to what took place in the case of hydrogen, the extraneous forces to be applied to the nuclei in order to keep the system in equilibrium will always be in a direction to diminish the distance apart of the nuclei, and the system will never pass through a configuration of equilibrium; the helium atoms

* Comp. J. J. Thomson, Phil. Mag. xxiv. p. 248 (1912).

will, during the process, "repel" each other. The consideration offers an explanation of the refusal of helium atoms to combine into molecules by a close approach of the atoms.

Instead of two hydrogen or two helium atoms, next consider a hydrogen and a helium atom, and let us slowly approach the nuclei to each other in a similar way. In this case, contrary to the former cases, the electrons will have no tendency to flow together in a single ring. On account of the great difference in the radii of the orbits of the electrons in hydrogen and helium, the electron of the hydrogen atom must be expected to rotate always outside the helium ring, and if the nuclei are brought very close together, the configuration of the electrons will coincide with that adopted in Part II. for a lithium atom. Further, the extraneous forces to be applied to the nuclei during the process will be in such a direction as to diminish the distance apart. In this way, therefore, we cannot obtain a combination of the atoms.

The stable configuration considered in § 3, consisting of a ring of three electrons and two nuclei of charge e and $2e$, cannot be expected to be formed by such a process, unless the ring of electrons were bound originally by one of the nuclei. Neither a hydrogen nor a helium nucleus will, however, be able to bind a ring of three electrons, since such a configuration would correspond to a greater total energy than the one in which the nucleus has bound two electrons (comp. Part II. pp. 488 and 490). As mentioned in § 3, such a configuration cannot therefore be considered as representing a possible combination of hydrogen and helium, in spite of the fact that the value of W is greater than the sum of the values of W for a hydrogen and a helium atom. As we shall see in the next section, the configuration may, however, give indications of the possible structure of the molecules of a certain class of chemical combinations.

§ 5. *Systems containing a greater number of Electrons.*

From the considerations of the former section we are led to indications of the configuration of the electrons in systems containing a greater number of electrons, consistent with those obtained in § 2.

Let us imagine that, in a similar way to that considered on p. 868 for two hydrogen atoms, we make two atoms containing a large number of electrons approach each other. During the beginning of the process the effect on the configuration of the inner rings will be very small compared with the effect on the electrons in the outer rings, and the

final result will mainly depend on the number of electrons in these rings. If, for example, the outer ring in both atoms contains only one electron, we may expect that during the approach these two electrons will form a single ring as in the case of hydrogen. By a further approach of the nuclei, the system will arrive at a state of equilibrium before the distance apart of the nuclei is comparable with the radii of the inner rings of electrons. If the distance be decreased still further, the repulsion of the nuclei will predominate and tend to prevent an approach of the systems.

In this way we are led to a possible configuration of a molecule of a combination of two monovalent substances—such as HCl—in which the ring of electrons representing the chemical bond is arranged in a similar way to that assumed for a hydrogen molecule. Since, however, as in the case of hydrogen, the energy emitted by a combination of the atoms is only a small part of the kinetic energy of the outer electrons, we may expect that small differences in the configuration of the ring, due to the presence of inner rings of electrons in the atoms, will be of great influence on the heat of combination and consequently on the affinity of the substances. As mentioned in § 2, a detailed discussion of these questions involves elaborate numerical calculations. We may, however, make an approximate comparison of the theory with experiment, by considering the frequency of vibration of the two atoms in the molecule relative to each other. In § 3, p. 866, we have calculated this frequency for a hydrogen molecule. Since now the binding of the atoms is assumed to be similar to that in hydrogen, the frequency of another molecule can be simply calculated if we know the ratio of the mass of the nuclei to be that of a hydrogen nucleus. Denoting the frequency of a hydrogen molecule by ν_0 and the atomic weights of the substances entering in the combination in question by A_1 and A_2 respectively, we get for the frequency

$$\nu = \nu_0 \sqrt{\frac{A_1 + A_2}{2 A_1 A_2}}$$

If the two atoms are identical the molecule will be exactly symmetrical, and we cannot expect an absorption of radiation corresponding to the frequency in question (comp. p. 866). For HCl gas an infra-red absorption band corresponding to a frequency of about $8.5 \cdot 10^{13}$ is observed*. Putting in the above formula $A_1=1$ and $A_2=35$ and using the value for ν_0

* See H. Kayser, *Handb. d. Spectr.* iii. p. 306 (1905).

on p. 866, we get $\nu = 13.7 \cdot 10^{13}$. On account of the approximation introduced the agreement may be considered as satisfactory.

The molecules in question may also be formed by the combination of a positively and a negatively charged atom. As in the case of hydrogen, however, we shall expect to obtain two *neutral* atoms by the breaking up of the molecule. There may be another type of molecule, for which this does not hold, viz., molecules which are formed in a manner analogous to the system consisting of a ring of three electrons and two nuclei of charges e and $2e$, mentioned in the former section. As we have seen, the necessary condition for the formation of a configuration of this kind is that one of the atoms in the molecule is able to bind three electrons in the outer ring. According to the theory, this condition is not satisfied for a hydrogen or a helium atom, but is for an oxygen atom. With the symbols used in Part II, the configuration suggested for the oxygen atom was given by 8 (4, 2, 2). From a calculation, as that indicated in Part II, we get for this configuration $W = 228.07 W_0$, while for the configuration 8 (4, 2, 3) we get $W = 228.18 W_0$. Since the latter value for W is greater than the first, the configuration 8 (4, 2, 3) may be considered as possible and as representing an oxygen atom with a single negative charge. If now a hydrogen nucleus approaches the system 8 (4, 2, 3) we may expect a stable configuration to be formed in which the outer electrons will be arranged approximately as in the system mentioned above. In a breaking up of this configuration the ring of three electrons will remain with the oxygen atom.

Such considerations suggest a possible configuration for a water molecule, consisting of an oxygen nucleus surrounded by a small ring of 4 electrons and 2 hydrogen nuclei situated on the axis of the ring at equal distances apart from the first nucleus and kept in equilibrium by help of two rings of greater radius each containing three electrons; the latter rotate in parallel planes round the axis of the system, and are situated relatively to each other so that the electrons in the one ring are placed just opposite the interval between the electrons in the other. If we imagine that such a system is broken up by slowly removing the hydrogen nuclei we should obtain two positively charged hydrogen atoms and an oxygen atom with a double negative charge, in which the outermost electrons will be arranged in two rings of three electrons each, rotating in parallel planes. The assumption of such a configuration for a water molecule offers a possible explanation of the great absorption of water for rays in the

infra-red and for the high value of its specific inductive capacity.

In the preceding we have only considered systems which possess an axis of symmetry around which the electrons are assumed to rotate in circular orbits. In systems such as the molecule CH_4 we cannot, however, assume the existence of an axis of symmetry, and consequently we must in such cases omit the assumption of exactly circular orbits. The configuration suggested by the theory for a molecule of CH_4 is of the ordinary tetrahedron type; the carbon nucleus surrounded by a very small ring of two electrons being situated in the centre, and a hydrogen nucleus in every corner. The chemical bonds are represented by 4 rings of 2 electrons each rotating round the lines connecting the centre and the corners. The closer discussion of such questions, however, is far out of the range of the present theory.

Concluding remarks.

In the present paper an attempt has been made to develop a theory of the constitution of atoms and molecules on the basis of the ideas introduced by Planck in order to account for the radiation from a black body, and the theory of the structure of atoms proposed by Rutherford in order to explain the scattering of α -particles by matter.

Planck's theory deals with the emission and absorption of radiation from an atomic vibrator of a constant frequency, independent of the amount of energy possessed by the system in the moment considered. The assumption of such vibrators, however, involves the assumption of quasi-elastic forces and is inconsistent with Rutherford's theory, according to which all the forces between the particles of an atomic system vary inversely as the square of the distance apart. In order to apply the main results obtained by Planck it is therefore necessary to introduce new assumptions as to the emission and absorption of radiation by an atomic system.

The main assumptions used in the present paper are:—

1. That energy radiation is not emitted (or absorbed) in the continuous way assumed in the ordinary electrodynamics, but only during the passing of the systems between different "stationary" states.
2. That the dynamical equilibrium of the systems in the stationary states is governed by the ordinary laws of mechanics, while these laws do not hold for the passing of the systems between the different stationary states.

3. That the radiation emitted during the transition of a system between two stationary states is homogeneous, and that the relation between the frequency ν and the total amount of energy emitted E is given by $E = h\nu$, where h is Planck's constant.

4. That the different stationary states of a simple system consisting of an electron rotating round a positive nucleus are determined by the condition that the ratio between the total energy, emitted during the formation of the configuration, and the frequency of revolution of the electron is an entire multiple of $\frac{h}{2}$. Assuming that the orbit of the electron is circular, this assumption is equivalent with the assumption that the angular momentum of the electron round the nucleus is equal to an entire multiple of $\frac{h}{2\pi}$.

5. That the "permanent" state of any atomic system—i. e., the state in which the energy emitted is maximum—is determined by the condition that the angular momentum of every electron round the centre of its orbit is equal to $\frac{h}{2\pi}$.

It is shown that, applying these assumptions to Rutherford's atom model, it is possible to account for the laws of Balmer and Rydberg connecting the frequency of the different lines in the line-spectrum of an element. Further, outlines are given of a theory of the constitution of the atoms of the elements and of the formation of molecules of chemical combinations, which on several points is shown to be in approximate agreement with experiments.

The intimate connexion between the present theory and modern theories of the radiation from a black body and of specific heat is evident; again, since on the ordinary electrodynamics the magnetic moment due to an electron rotating in a circular orbit is proportional to the angular momentum, we shall expect a close relation to the theory of magnetons proposed by Weiss. The development of a detailed theory of heat radiation and of magnetism on the basis of the present theory claims, however, the introduction of additional assumptions about the behaviour of bound electrons in an electromagnetic field. The writer hopes to return to these questions later.