Rencontres de physique
de l'infiniment grand à l'infiniment petit

24 juillet 2013

Histoire
de la
Physique

Joël Pouthas

L. P. C. ENSICAEN
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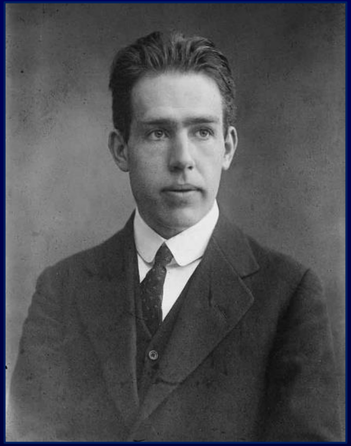
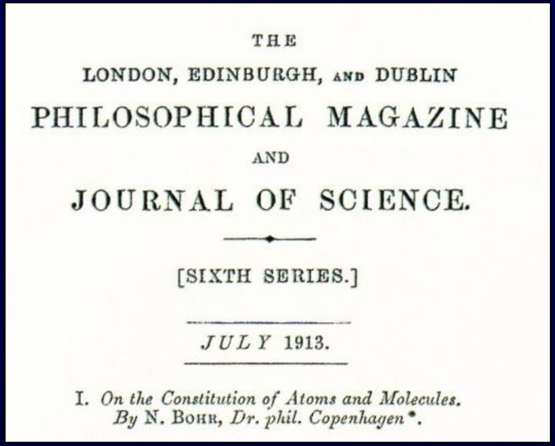
24 juillet 2013



Genèse
de
l'atome de Bohr



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**.

Joël Pouthas

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Atomisme
au dix neuvième siècle

Chimie

Théorie cinétique des gaz

Jean Perrin
1913

LES ATOMES

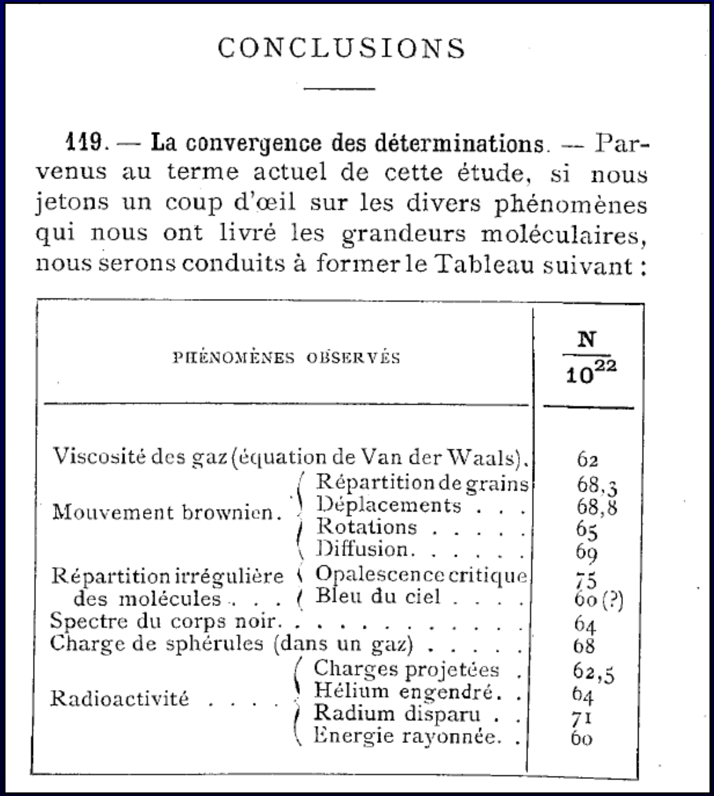
PAR

JEAN PERRIN

Professeur de chimie physique à la Faculté des Sciences de Paris.

Avec 13 figures.

LIBRAIRIE FÉLIX ALCAN
1913



CONCLUSIONS

119. — La convergence des déterminations. — Parvenus au terme actuel de cette étude, si nous jetons un coup d'œil sur les divers phénomènes qui nous ont livré les grandeurs moléculaires, nous serons conduits à former le Tableau suivant :

PHÉNOMÈNES OBSERVÉS		$\frac{N}{10^{22}}$
Viscosité des gaz (équation de Van der Waals)		62
Mouvement brownien	Répartition de grains	68,3
	Déplacements	68,8
	Rotations	65
	Diffusion	69
Répartition irrégulière des molécules	Opalescence critique	75
	Bleu du ciel	60 (?)
Spectre du corps noir		64
Charge de sphérules (dans un gaz)		68
Radioactivité	Charges projetées	62,5
	Hélium engendré	64
	Radium disparu	71
	Energie rayonnée	60

Jean Perrin (1870 – 1942)

Des phénomènes nouveaux

1895 - Rayons de Röntgen – Rayons X

1896 - Rayons uraniques de Becquerel -> Radioactivité

1897 – Corpuscules d'électricité par J.J. Thomson -> Electrons

1895 - Rayons de Röntgen (Rayons X)

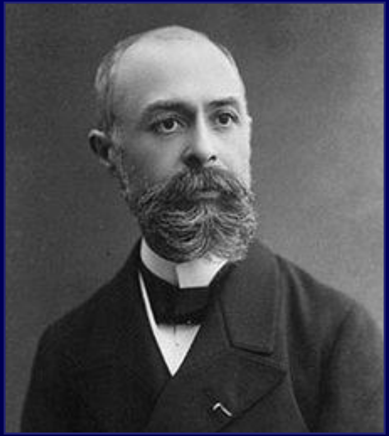
Contexte

Etude des
décharges électriques
dans les gaz

Tube de Crookes

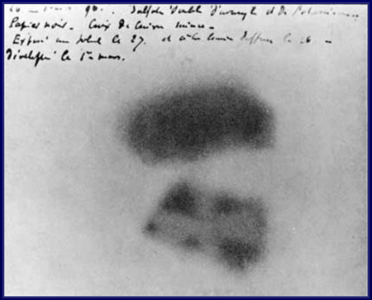
1897 – Corpuscules d'électricité par J.J. Thomson (Electrons)

1896 - Rayons uraniques de Becquerel (Radioactivité)



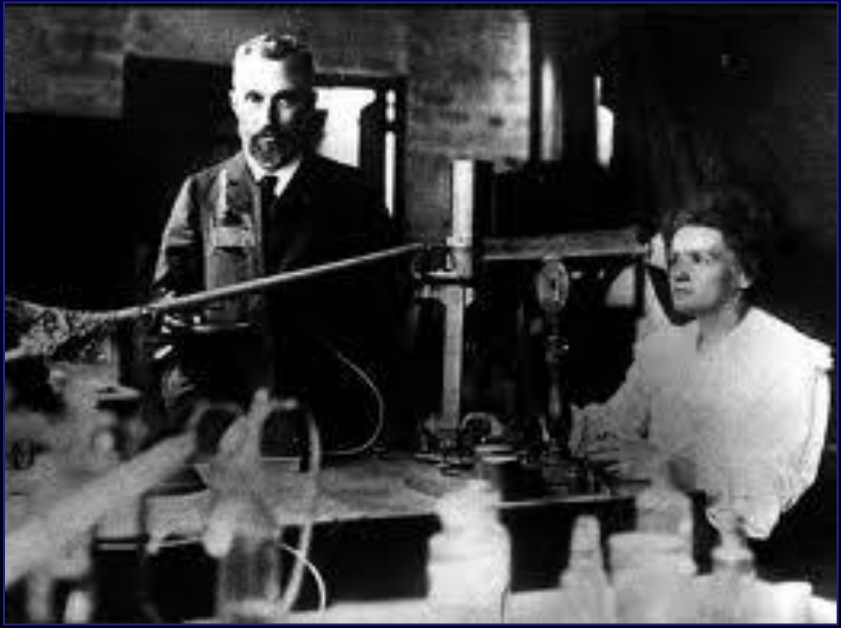
Contexte

Etude de la phosphorescence des sels d'uranium

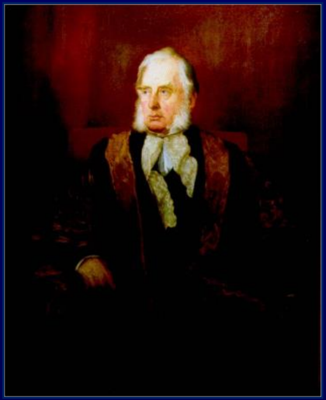


Travaux développés par Pierre et Marie Curie

Découverte du Polonium et du Radium



Cavendish Laboratory (Cambridge)



Financé par
W. Cavendish
(Chancelier de l'Université)
(7ème duc du Devenshire)

1871 1874

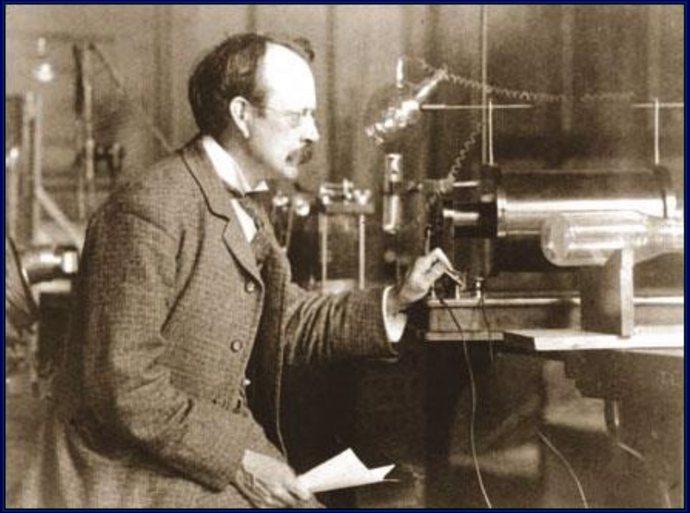
Directeur

Professeur de
physique expérimentale

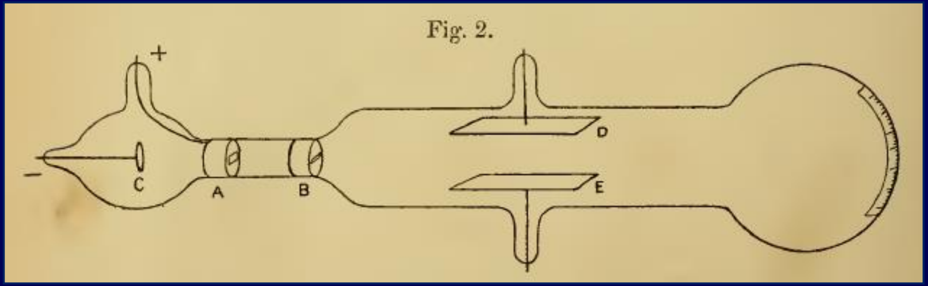
1871 – 1879	J. C. Maxwell
1879 – 1884	Lord Rayleigh
1884 – 1919	J.J. Thomson
1919 – 1937	E. Rutherford
1938 – 1954	W.L. Bragg

Rayons cathodiques ?

J.J. Thomson (1856 – 1940)



1897



Déviation des rayons cathodiques dans un champ électrique

Travaux de
Perrin, Lenard, Kaufmann, Wien, Towsend…

Les rayons cathodiques :

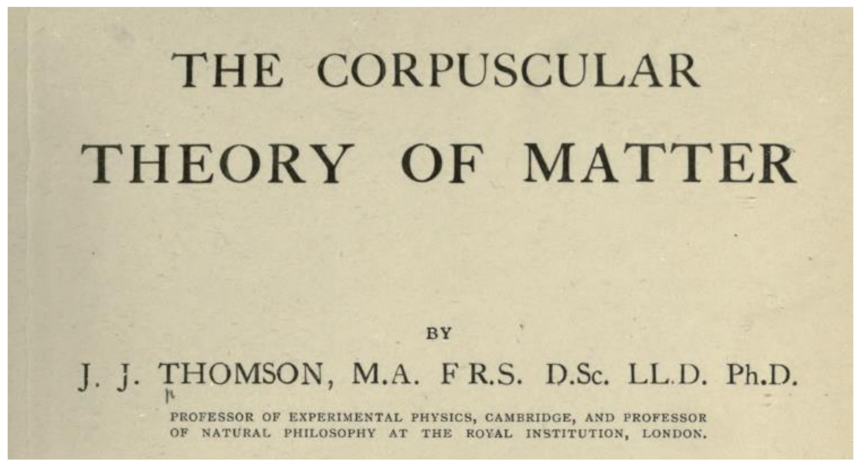
Corpuscules
d'électricité négative

(Electrons)

1906
Prix Nobel de physique

En témoignage des grands mérites de ses recherches théoriques et expérimentales sur la conduction de l'électricité dans les gaz

L'atome de Thomson



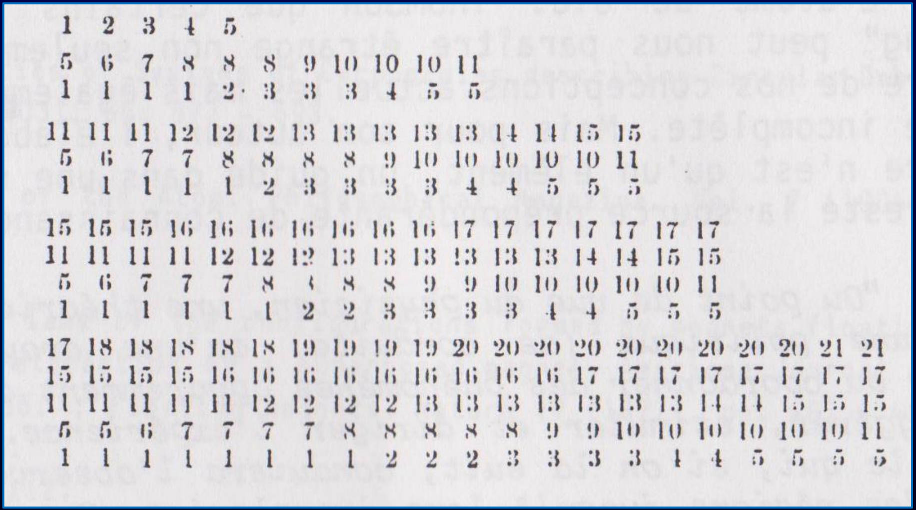
THE CORPUSCULAR
THEORY OF MATTER

BY

J. J. THOMSON, M.A. F R.S. D.Sc. LL.D. Ph.D.

PROFESSOR OF EXPERIMENTAL PHYSICS, CAMBRIDGE, AND PROFESSOR
OF NATURAL PHILOSOPHY AT THE ROYAL INSTITUTION, LONDON.

1907



1	2	3	4	5

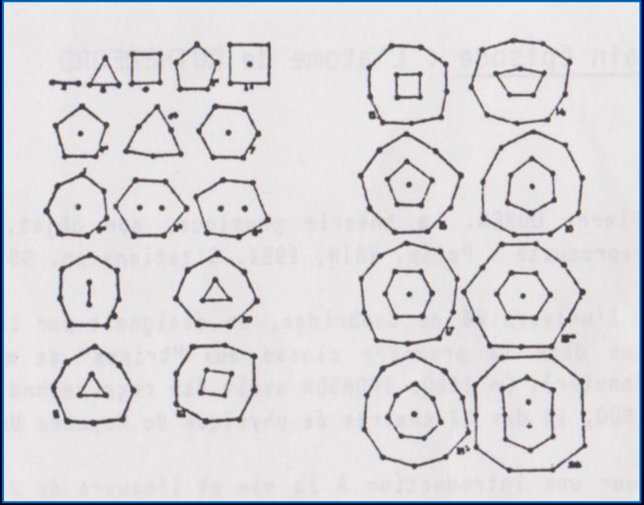
5	6	7	8	8	8	9	10	10	10	11
1	1	1	1	2	3	3	3	4	5	5

11	11	11	12	12	12	13	13	13	13	13	14	14	15	15
5	6	7	7	8	8	8	8	9	10	10	10	10	10	11
1	1	1	1	1	2	3	3	3	3	4	4	5	5	5

15	15	15	16	16	16	16	16	16	16	17	17	17	17	17	17	17
11	11	11	11	12	12	12	13	13	13	13	13	13	14	14	15	15
5	6	7	7	7	8	8	8	8	9	9	10	10	10	10	10	11
1	1	1	1	1	1	2	2	3	3	3	3	4	4	5	5	5

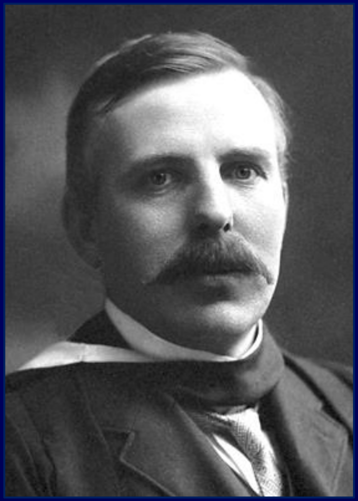
17	18	18	18	18	18	19	19	19	19	20	20	20	20	20	20	20	20	20	21	21
15	15	15	15	16	16	16	16	16	16	16	16	16	17	17	17	17	17	17	17	17
11	11	11	11	11	12	12	12	12	13	13	13	13	13	13	13	14	14	15	15	15
5	5	6	7	7	7	7	8	8	8	8	8	9	9	10	10	10	10	10	10	11
1	1	1	1	1	1	1	1	2	2	2	3	3	3	3	4	4	5	5	5	5

Distribution des corpuscules en anneaux
(Calculs de J. J. Thomson)



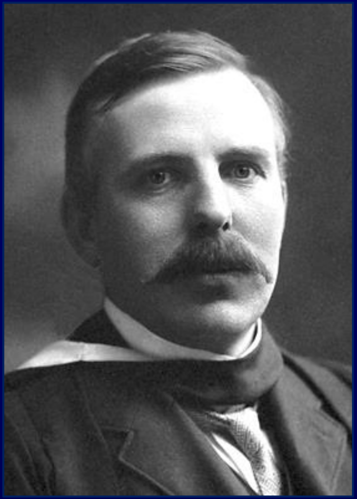
Analogie avec les expériences
de Mayer (1877)

Ernest Rutherford



1871 Naissance à Nelson (Nouvelle Zélande)
Boursier au Nelson puis au Canterbury College de Christchurch (N.Z.). B.A., M.A et B.Sc.
1895 Bourse pour le Cavendish de Cambridge
1898 Professeur à McGill, Montreal (Canada)
1908 Prix Nobel de chimie pour ses recherches sur la désintégration des éléments et la chimie des substances radioactives

Ernest Rutherford



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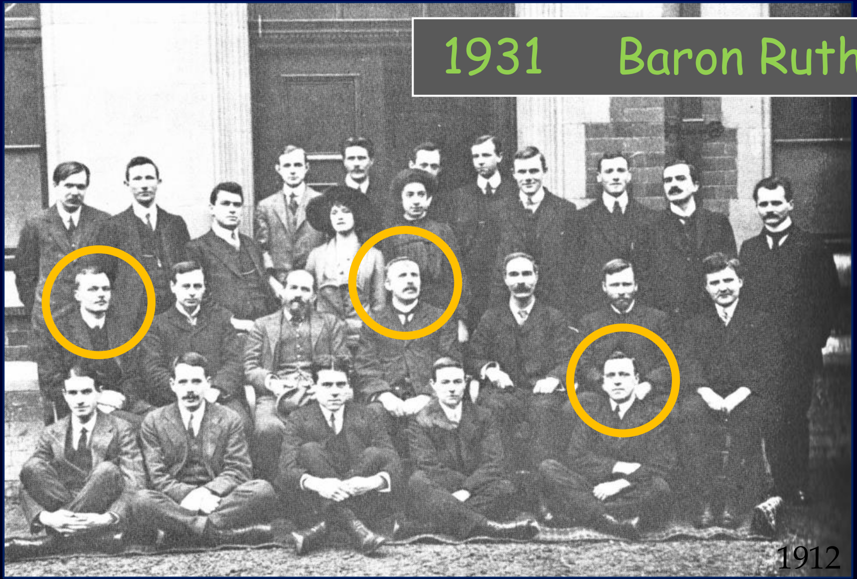
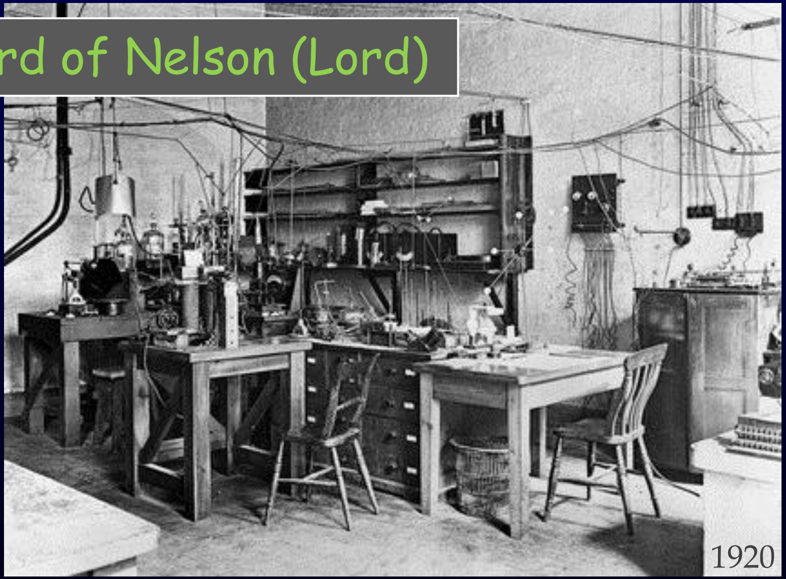
1907 Université de Manchester

1919 Cavendish Laboratory

1931 Baron Rutherford of Nelson (Lord)



1912



1920

1937 Décès à Cambridge

Les expériences de Geiger et Marsden

1909 Sur la réflexion diffuse des Particules α *

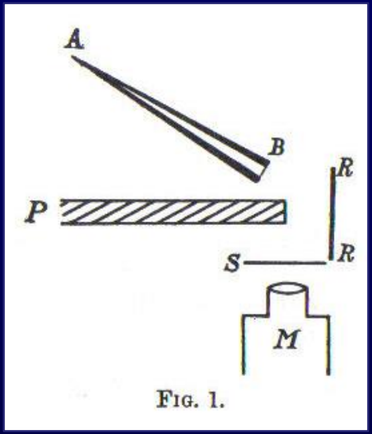
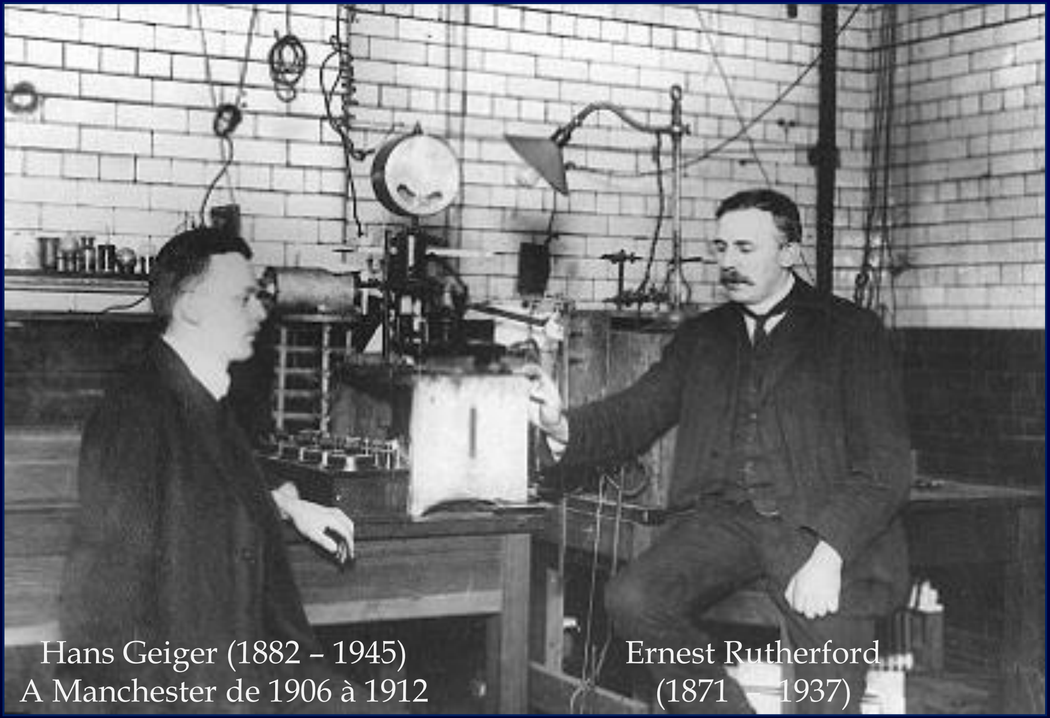


Fig. 1.



Hans Geiger (1882 – 1945)
A Manchester de 1906 à 1912

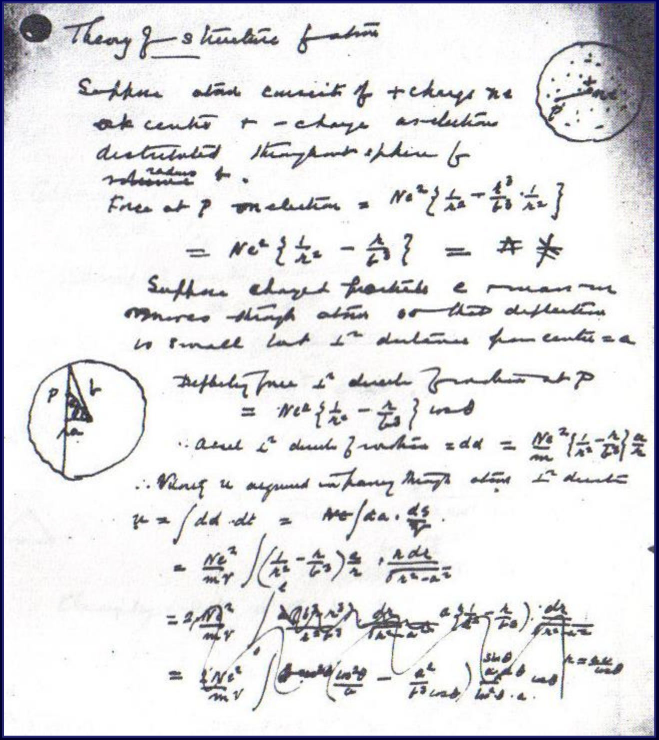
Ernest Rutherford
(1871 – 1937)

Ernest Marsden
(1889 – 1970)

* H. Geiger and E. Marsden. On a diffuse Reflection of the alpha-particles
Proceedings of the Royal Society, 1909, A82, p.495-500

Le modèle de Rutherford

1911 La diffusion des particules α et β par la matière et la structure de l'atome *



Theory of structure of atom

Suppose atom consist of + charge ne at centre & − charge as electrons distributed throughout sphere of ~~volume~~ radius b.

Force at P on electron = $Ne^2\left\{\frac{1}{r^2} - \frac{r^3}{b^3}\cdot\frac{1}{r^2}\right\}$

$= Ne^2\left\{\frac{1}{r^2} - \frac{r}{b^3}\right\}$ = [illegible]

Suppose charged particle e mass m moves through atom so that deflection is small but ⊥ distance from centre = a

Deflecting force ⊥ direction of motion at P

$= Ne^2\left\{\frac{1}{r^2} - \frac{r}{b^3}\right\}\cos\theta$

∴ accel ⊥ direction of motion $= \alpha = \frac{Ne^2}{m}\left\{\frac{1}{r^2}-\frac{r}{b^3}\right\}\frac{a}{r}$

∴ Velocity u acquired in passing through atom ⊥ direction =

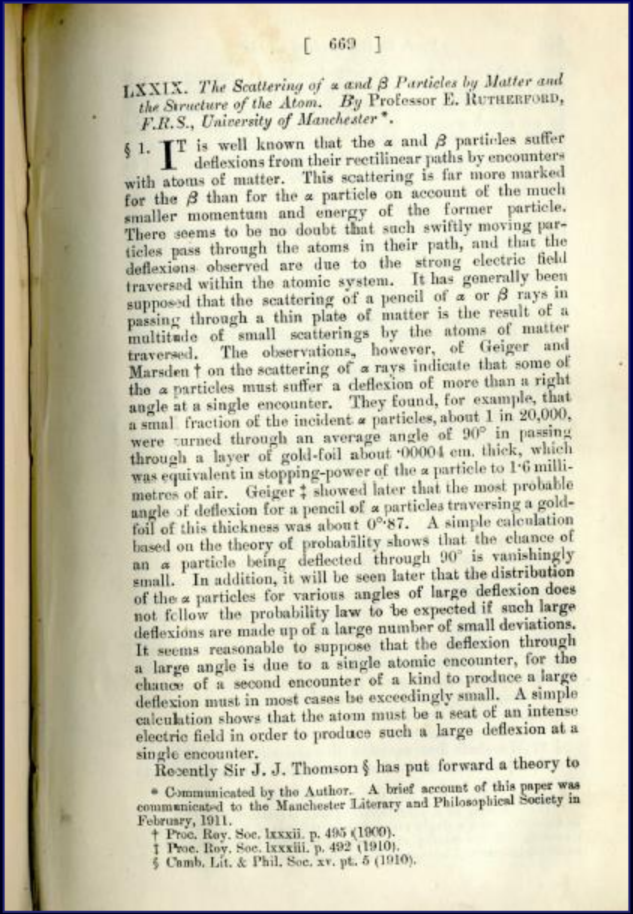
$u = \int \alpha\cdot dt = \frac{Ne}{m}\int \alpha\cdot\frac{ds}{V}$

$= \frac{Ne^2}{mV}\int\left(\frac{1}{r^2}-\frac{r}{b^3}\right)\frac{a}{r}\cdot\frac{r\,dr}{\sqrt{r^2-a^2}}$

$= 2\frac{Ne^2}{mV}\int$ [illegible]

$= \frac{2Ne^2}{mV}\int$ [illegible]

Lu le 7 mars 1911 à Manchester Literary and Philosophical Society



[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 ·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°·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

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* 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).

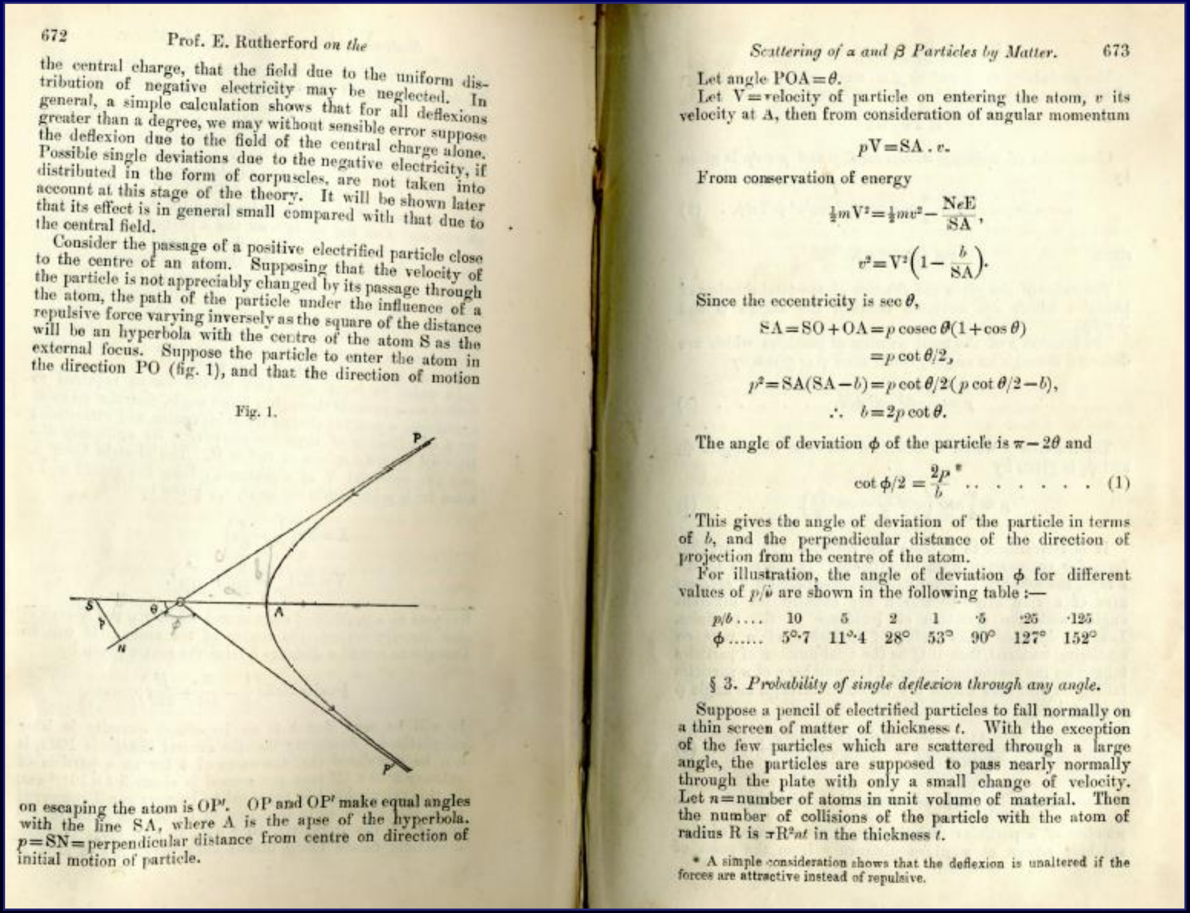
§ Camb. Lit. & Phil. Soc. xv. pt. 5 (1910).

Philosophical Magazine, Mai 1911

* The Scattering of the α and β Particles by Matter and the Structure of the Atom

Le modèle de Rutherford

1911 La diffusion des particules α et β par la matière et la structure de l'atome *



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 on escaping the atom is OP′. OP and OP′ make equal angles with the line SA, where A is the apse of the hyperbola. $p=\mathrm{SN}=$ perpendicular distance from centre on direction of initial motion of particle.

Fig. 1.

Let angle $\mathrm{POA}=\theta$.

Let $\mathrm{V}=$ velocity of particle on entering the atom, v its velocity at A, then from consideration of angular momentum

$$p\mathrm{V}=\mathrm{SA}\,.\,v.$$

From conservation of energy

$$\tfrac{1}{2}m\mathrm{V}^2=\tfrac{1}{2}mv^2-\frac{\mathrm{N}e\mathrm{E}}{\mathrm{SA}},$$

$$v^2=\mathrm{V}^2\left(1-\frac{b}{\mathrm{SA}}\right).$$

Since the eccentricity is $\sec\theta$,

$$\begin{aligned}\mathrm{SA}=\mathrm{SO}+\mathrm{OA}&=p\operatorname{cosec}\theta(1+\cos\theta)\\&=p\cot\theta/2,\end{aligned}$$

$$p^2=\mathrm{SA}(\mathrm{SA}-b)=p\cot\theta/2(p\cot\theta/2-b),$$

$$\therefore\quad b=2p\cot\theta.$$

The angle of deviation ϕ of the particle is $\pi-2\theta$ and

$$\cot\phi/2=\frac{2p}{b}\,{}^{*}\quad\ldots\ldots\ldots\quad(1)$$

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 ….	10	5	2	1	·5	·25	·125
ϕ ……	5°·7	11°·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 $\pi\mathrm{R}^2nt$ in the thickness t.

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* A simple consideration shows that the deflexion is unaltered if the forces are attractive instead of repulsive.

* The Scattering of the α and β Particles by Matter and the Structure of the Atom

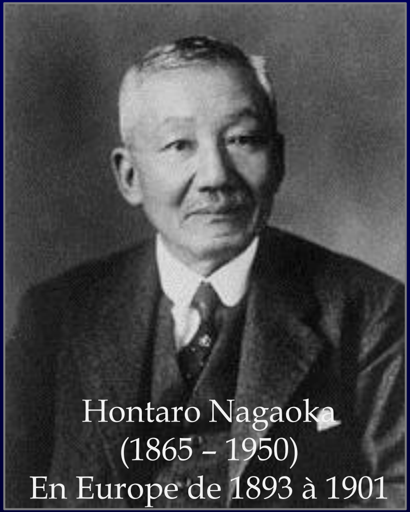
Philosophical Magazine, Mai 1911

Le modèle de Rutherford

Difficultés d'un "Atome saturnien"

1901 Perrin (Conférence, sans développement)

1904 Nagaoka (Professeur de physique à l'Université impériale de Tokyo)



Hontaro Nagaoka
(1865 – 1950)
En Europe de 1893 à 1901

Cinétique d'un système de particules qui explique les spectres de lignes et bandes et les phénomènes de la radioactivité

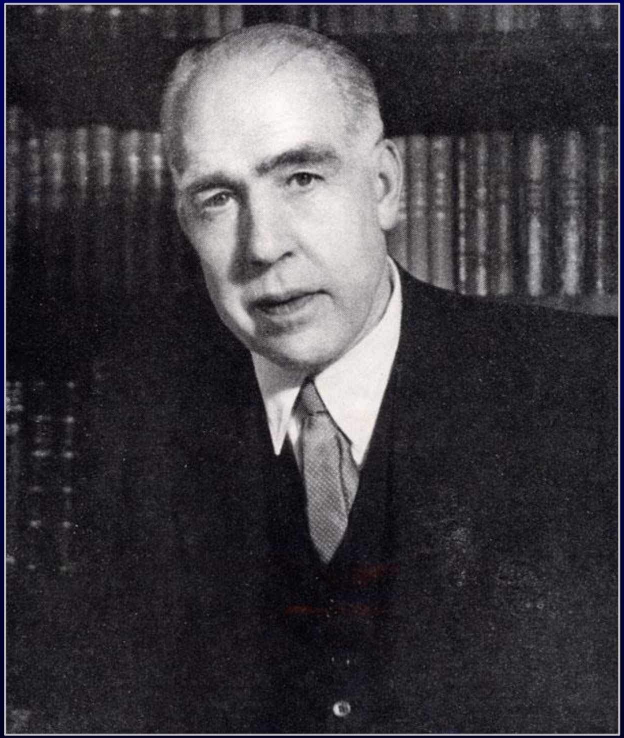
Lu le 5 décembre 1903 à Tokyo
Physico-mathematical Society

Philosophical Magazine, 1904

* Kinetics of a System of Particles illustrating the Line and the Band Spectrum and the Phenomena of Radioactivity

Le modèle d'atome de Rutherford n'est pas stable !!!

L'atome de Bohr



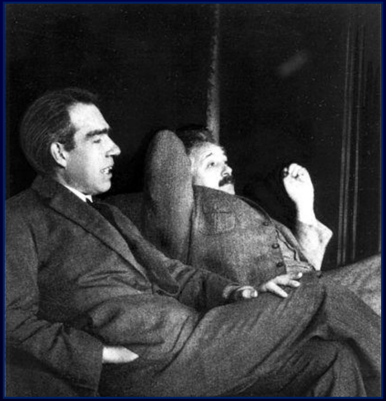
Niels Bohr

1885 Naissance à Copenhague
Fils de C. Bohr, professeur de médecine, recteur
1903 Etudes à l'Université de Copenhague
1911 Thèse (Copenhague) sur "la théorie électronique des métaux"

1916 Professeur à Copenhague
1921 Institut de physique théorique

1922
Prix Nobel
de physique

pour ses contributions à la recherche de la structure des atomes et sur le rayonnement qu'ils émettent



1962 Décès à Copenhague

Niels Bohr

13 mai 1911 à Copenhague
Thèse : la théorie électronique des métaux

Début octobre 1911
Laboratoire Cavendish à Cambridge

16 mars au 3 mai 1912 à Manchester
Introduction aux méthodes
expérimentales en radioactivité

Fin juillet 1912 Retour au Danemark
Mariage le 1^er^ août

Septembre 1912 : Cambridge, Manchester… Ecosse

Automne 1912, Contrat temporaire d'assistant de Knudsen à Copenhague
En juillet 1913, Professeur à Copenhague (Etudiants en médecine)

Sur proposition de Rutherford (mai 1914)
Professeur à Manchester (octobre 1914 à juillet 1916)

Bohr à Manchester en 1912

Georg von Hevesy
(1885 - 1966)

Chimiste hongrois

A Manchester de 1910 à 1913

Bohr à Manchester en 1912

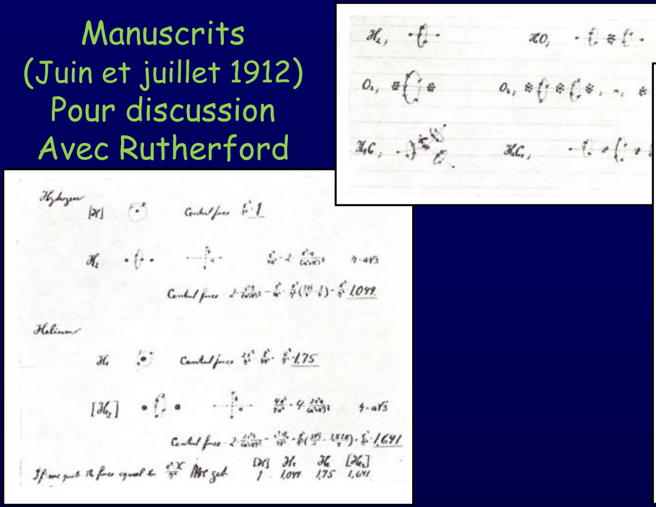
Intérêt pour les travaux théoriques de Charles Galton Darwin (1887-1962) sur la perte d'énergie des particules α dans la matière

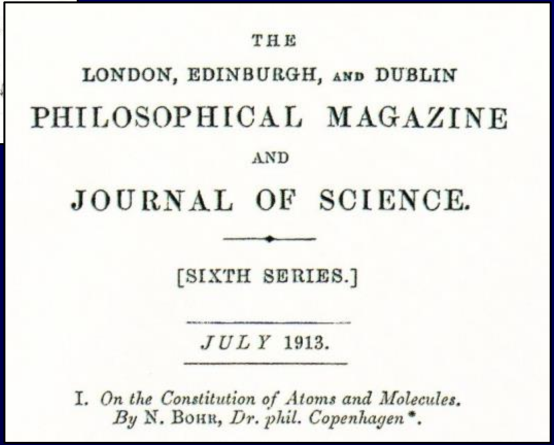
"Sur la théorie de la perte de vitesse de Particules chargées traversant la matière"

Manuscrit prêt en aout 1912, publié dans Philosophical Magazine en janvier 1913

L'atome de Bohr

Manuscrits
(Juin et juillet 1912)
Pour discussion
Avec Rutherford





THE
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AND
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[SIXTH SERIES.]

JULY 1913.

I. *On the Constitution of Atoms and Molecules.*
By N. BOHR, *Dr. phil. Copenhagen**.

* Communicated by Prof. E. Rutherford, F.R.S.

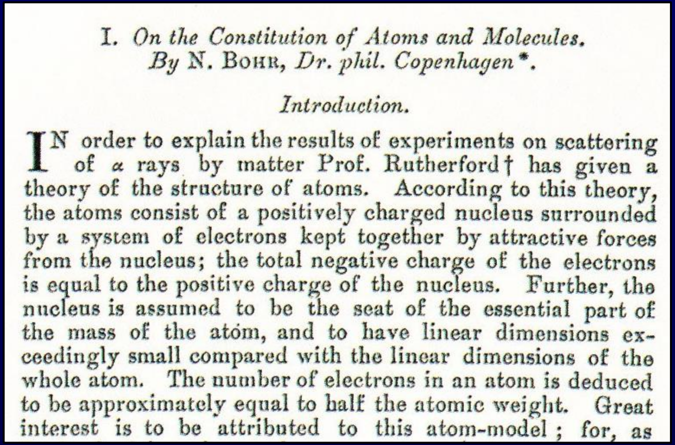
On the Constitution of Atoms and Molecules

Philosophical Magazine Juillet 1913

Part II. – Systems containing only a Single Nucleus Septembre 1913

Part III. – Systems containing Several Nuclei Novembre 1913

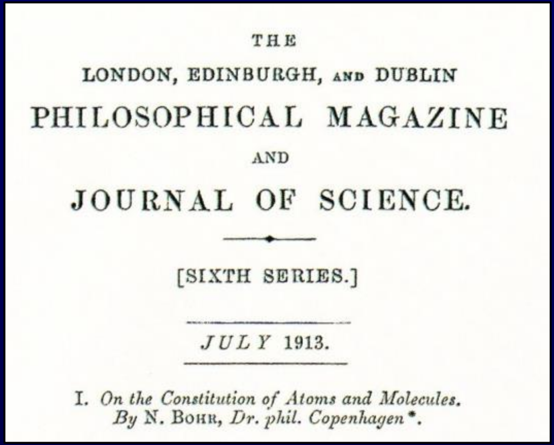
L'atome de Bohr



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



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**.

* Communicated by Prof. E. Rutherford, F.R.S.

On the Constitution of Atoms and Molecules

Philosophical Magazine Juillet 1913

Part II. – Systems containing only a Single Nucleus Septembre 1913

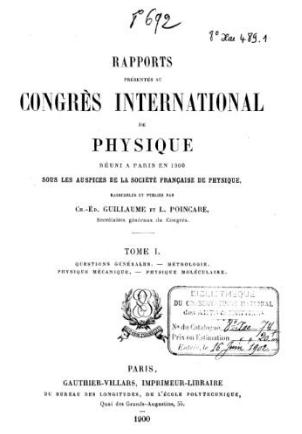
Part III. – Systems containing Several Nuclei Novembre 1913

Congrès international de physique – Paris - 1900

Lundi 6 au dimanche 12 aout 1900

Environ 1000 participants

Tome II
Optique - Electricité - Magnétisme



RAPPORTS
PRÉSENTÉS AU
CONGRÈS INTERNATIONAL
DE
PHYSIQUE
RÉUNI A PARIS EN 1900
SOUS LES AUSPICES DE LA SOCIÉTÉ FRANÇAISE DE PHYSIQUE,
RASSEMBLÉS ET PUBLIÉS PAR
CH.-ÉD. GUILLAUME ET L. POINCARÉ,
Secrétaires généraux du Congrès.

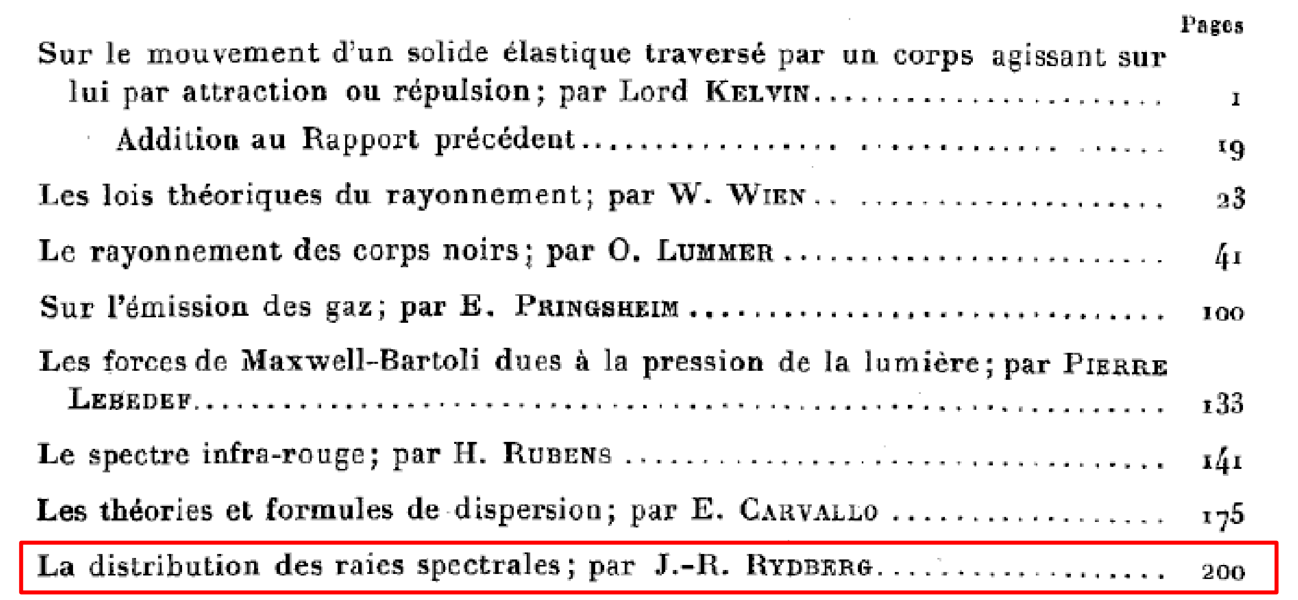
TOME I.
QUESTIONS GÉNÉRALES. — MÉTROLOGIE.
PHYSIQUE MÉCANIQUE. — PHYSIQUE MOLÉCULAIRE.

PARIS,
GAUTHIER-VILLARS, IMPRIMEUR-LIBRAIRE
DU BUREAU DES LONGITUDES, DE L'ÉCOLE POLYTECHNIQUE,
Quai des Grands-Augustins, 55.
1900

Rapports
Publiés en 1900

Tome I : 1 et 2
Tome II : 3 et 4
Tome III : 5, 6 et 7

Tome IV : Travaux
(Procès verbaux)



Pages
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Addition au Rapport précédent 19
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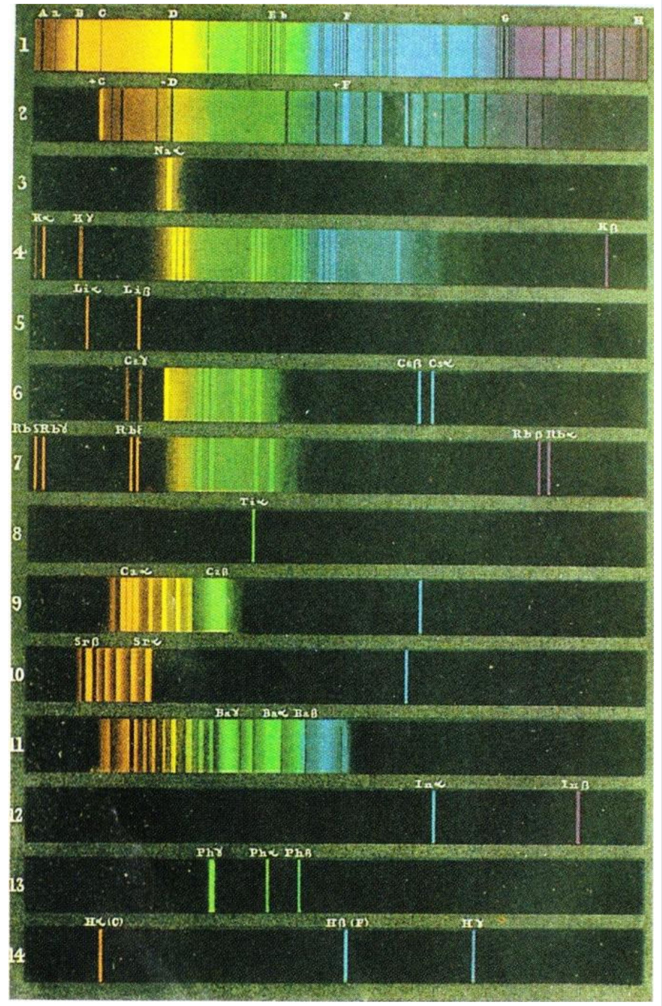
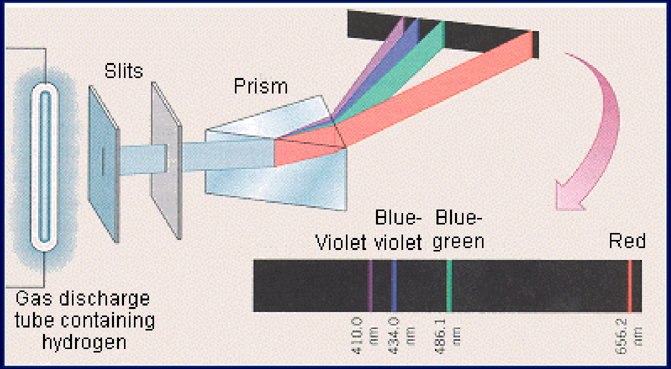
La distribution des raies spectrales; par J.-R. Rydberg 200

Spectres de sources lumineuses

Soleil
Couronne solaire
Sodium
Potassium
Lithium
Césium
Rubidium
Thallium
Calcium
Strontium
Baryum
Indium
Phosphore
Hydrogène



Spectre de l'hydrogène



410	434	486	656
m=6	m=5	m=4	m=3

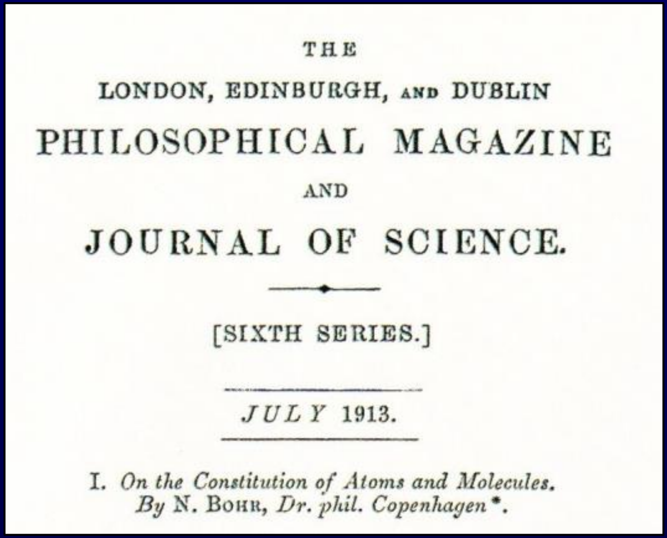
$$\lambda = k \frac{m^2}{m^2 - 4}$$

Formule de
Johann Balmer (1825-1898)

$$\frac{1}{\lambda} = R_H \left(\frac{1}{2^2} - \frac{1}{m^2} \right)$$

Généralisation
Johannes Rydberg (1854-1919)

L'atome de Bohr



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JULY 1913.

I. *On the Constitution of Atoms and Molecules.*
By N. BOHR, *Dr. phil. Copenhagen**.

Discontinuité

Constante de Planck
(Quantum élémentaire d'action)

?

See f.inst., ''Théorie du rayonnement et les quanta.'' Rapports de la réunion à Bruxelles, Nov. 1911 Paris 1912

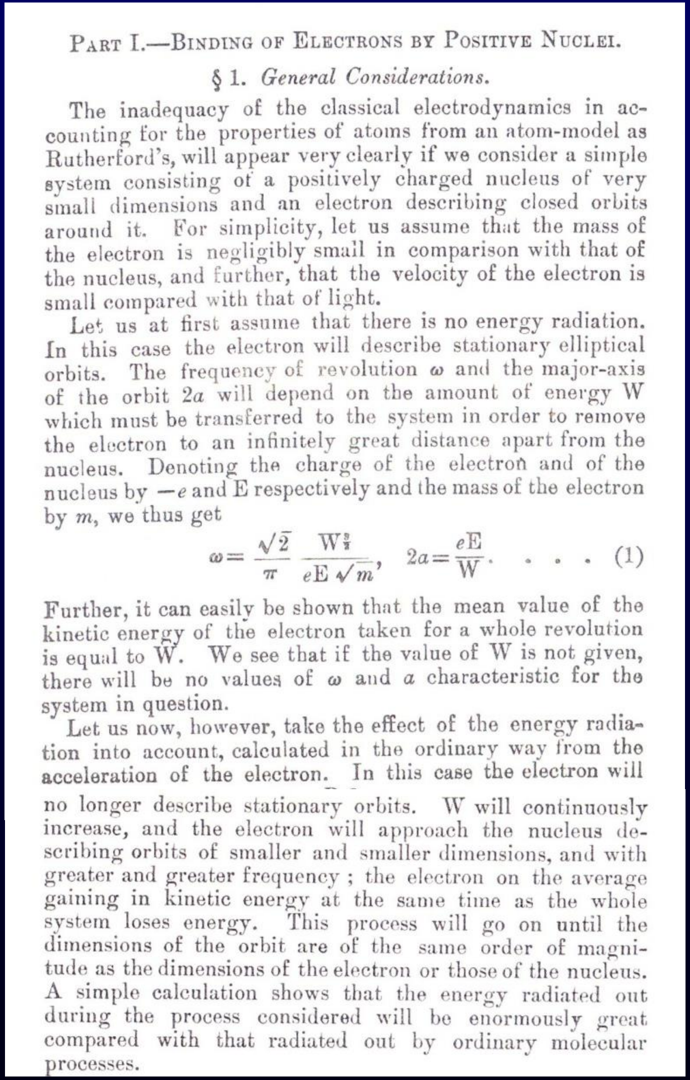
On the Constitution of Atoms and Molecules

Philosophical Magazine Juillet 1913

1910	Calculs de Erich Haas (Autrichien, 1884-1941) avec le modèle de Thomson (Cités par Lorentz au Conseil Solvay de 1911)
1911 et 1912	Travaux à Cambridge de John William Nicholson (1881 - 1955) avec le "modèle planétaire" (Oscillations transversales des orbites)

On the Constitution of Atoms and Molecules

Philosophical Magazine   Juillet 1913



PART I.—BINDING OF ELECTRONS BY POSITIVE NUCLEI.

§ 1. *General Considerations.*

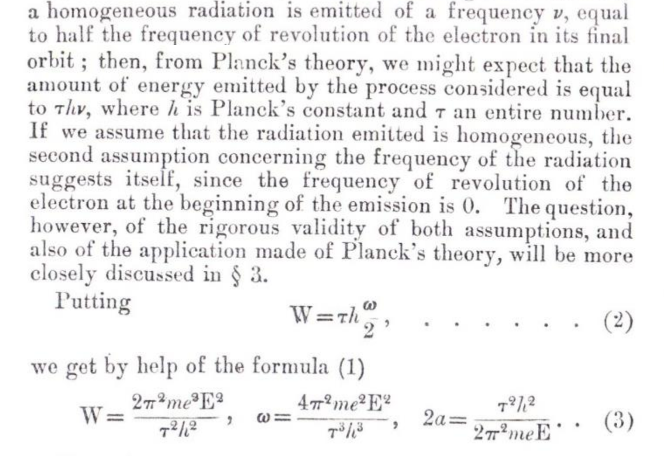
The inadequacy of the classical electrodynamics in accounting for the properties of atoms from an atom-model as Rutherford's, will appear very clearly if we consider a simple system consisting of a positively charged nucleus of very small dimensions and an electron describing closed orbits around it. 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

$$\omega = \frac{\sqrt{2}}{\pi} \frac{W^{\frac{3}{2}}}{eE\sqrt{m}}, \quad 2a = \frac{eE}{W}. \quad . \quad . \quad . \quad (1)$$

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 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 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.



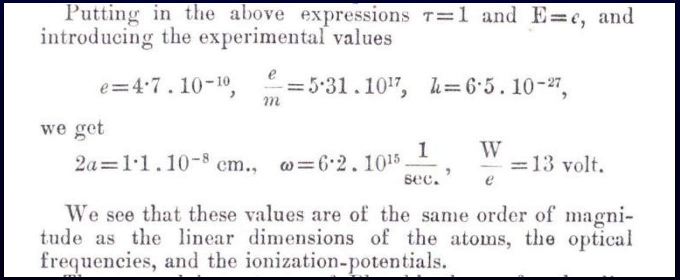
Let us now assume that, during the binding of the electron, a homogeneous radiation is emitted of a frequency ν, equal to half the frequency of revolution of the electron in its final orbit; then, from Planck's theory, we might expect that the amount of energy emitted by the process considered is equal 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

$$W = \tau h \frac{\omega}{2}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

we get by help of the formula (1)

$$W = \frac{2\pi^2 me^2E^2}{\tau^2 h^2}, \quad \omega = \frac{4\pi^2 me^2E^2}{\tau^3 h^3}, \quad 2a = \frac{\tau^2 h^2}{2\pi^2 meE}. \quad . \quad (3)$$



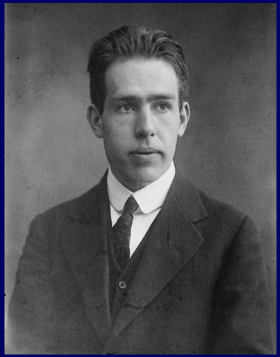
Putting in the above expressions $\tau=1$ and $E=e$, and introducing the experimental values

$$e = 4{\cdot}7 \, . \, 10^{-10}, \quad \frac{e}{m} = 5{\cdot}31 \, . \, 10^{17}, \quad h = 6{\cdot}5 \, . \, 10^{-27},$$

we get

$$2a = 1{\cdot}1 \, . \, 10^{-8} \text{ cm.}, \quad \omega = 6{\cdot}2 \, . \, 10^{15} \frac{1}{\text{sec.}}, \quad \frac{W}{e} = 13 \text{ volt.}$$

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.



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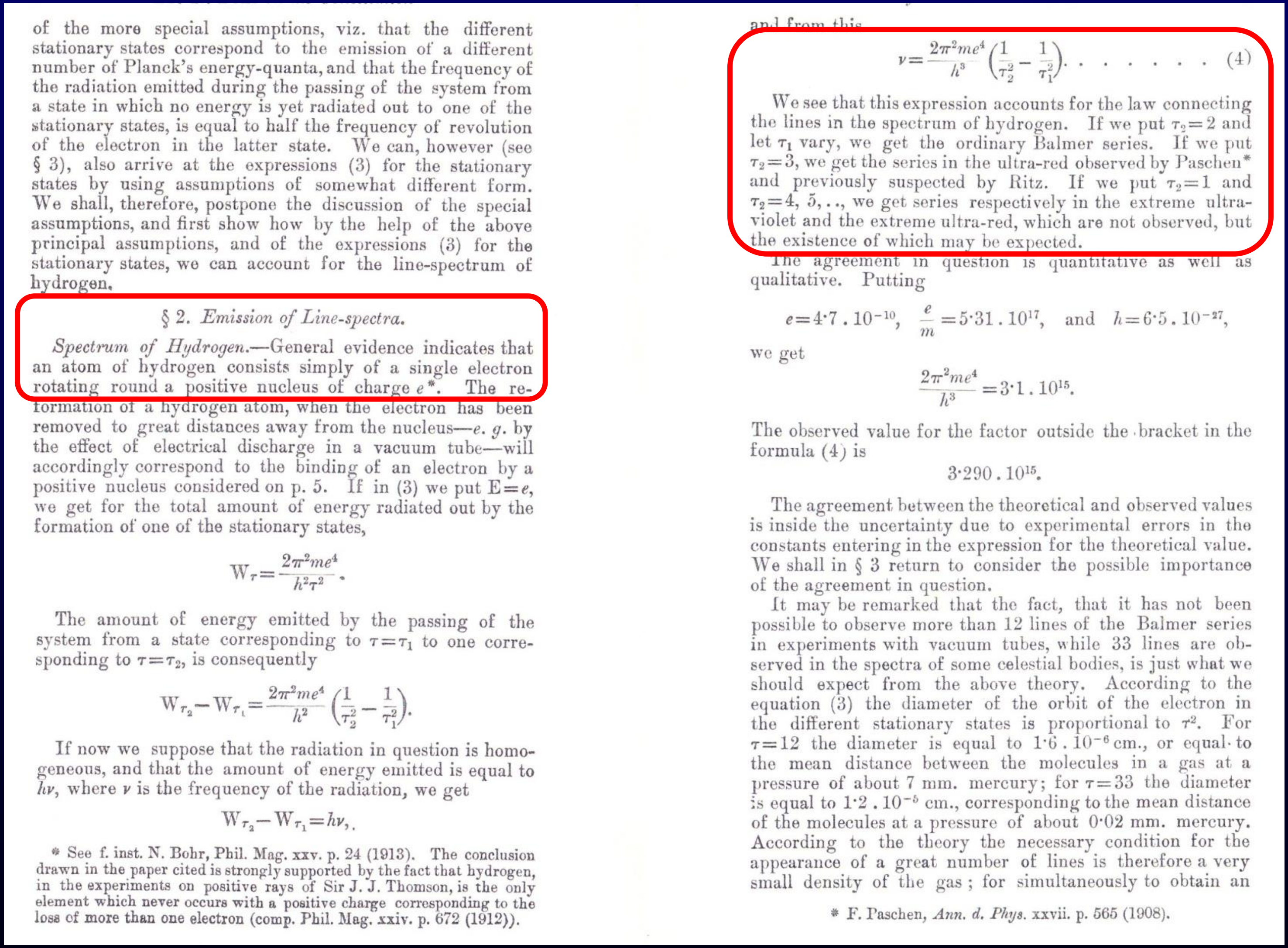
Philosophical Magazine Juillet 1913



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 reformation 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,

$$W_\tau=\frac{2\pi^2me^4}{h^2\tau^2}.$$

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

$$W_{\tau_2}-W_{\tau_1}=\frac{2\pi^2me^4}{h^2}\left(\frac{1}{\tau_2^2}-\frac{1}{\tau_1^2}\right).$$

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

$$W_{\tau_2}-W_{\tau_1}=h\nu,.$$

---

* 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

$$\nu=\frac{2\pi^2me^4}{h^3}\left(\frac{1}{\tau_2^2}-\frac{1}{\tau_1^2}\right). \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

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 $\tau_2=4, 5, ..,$ we get series respectively in the extreme ultraviolet 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

$$e=4{\cdot}7\,.\,10^{-10},\quad \frac{e}{m}=5{\cdot}31\,.\,10^{17},\quad \text{and}\quad h=6{\cdot}5\,.\,10^{-27},$$

we get

$$\frac{2\pi^2me^4}{h^3}=3{\cdot}1\,.\,10^{15}.$$

The observed value for the factor outside the bracket in the formula (4) is

$$3{\cdot}290\,.\,10^{15}.$$

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 $1{\cdot}6\,.\,10^{-6}$ 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 $1{\cdot}2\,.\,10^{-5}$ 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

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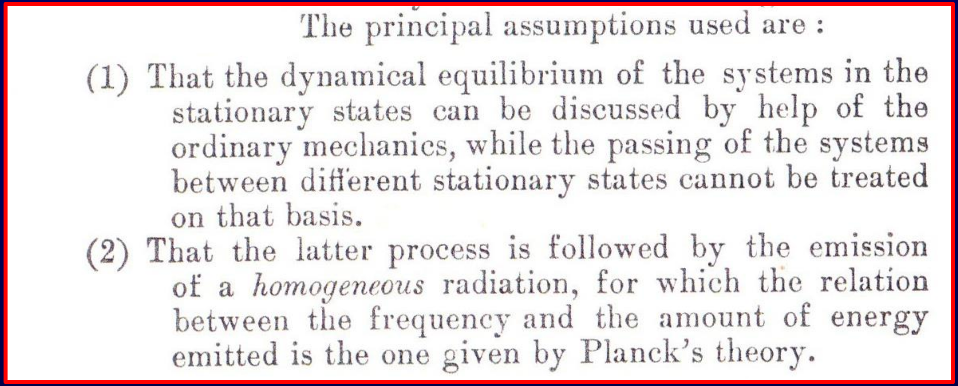
* F. Paschen, *Ann. d. Phys.* xxvii. p. 565 (1908).

On the Constitution of Atoms and Molecules

Philosophical Magazine Juillet 1913



The principal assumptions used are :

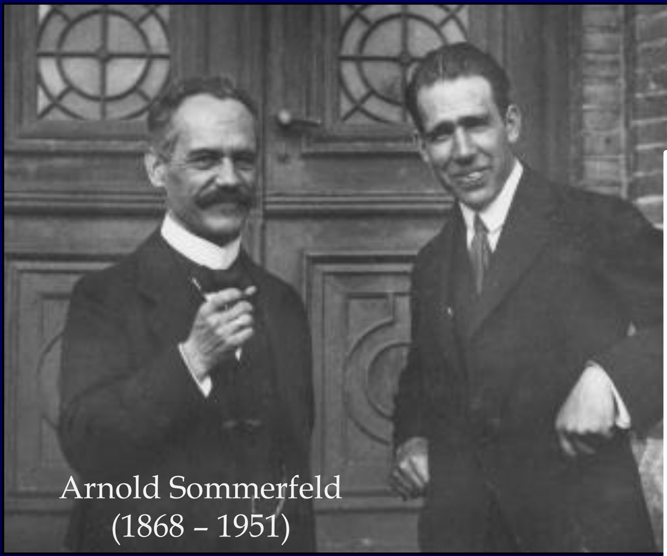
(1) That the dynamical equilibrium of the systems in the stationary states can be discussed by help of the ordinary mechanics, while the passing of the systems between different stationary states cannot be treated on that basis.

(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.

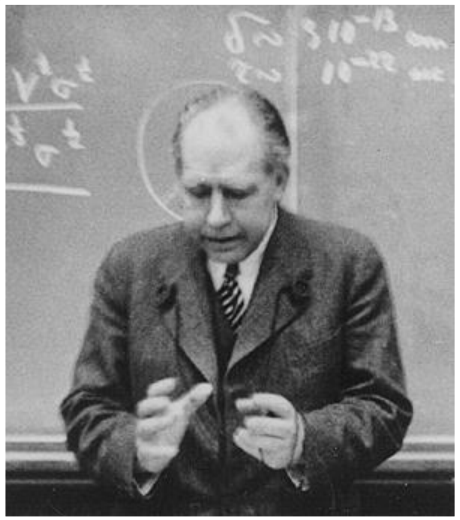
Part II. – Systems containing only a Single Nucleus Septembre 1913

Part III. – Systems containing Several Nuclei Novembre 1913

L'atome de Bohr après 1913

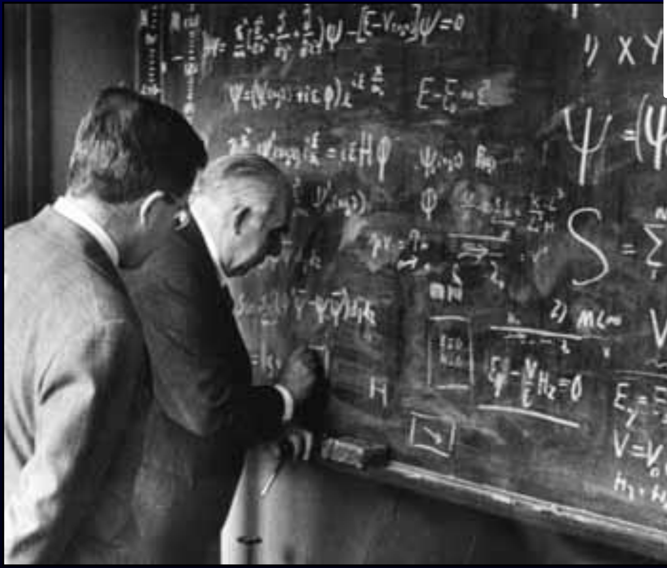


Arnold Sommerfeld
(1868 – 1951)



Werner Heisenberg
(1901 – 1976)

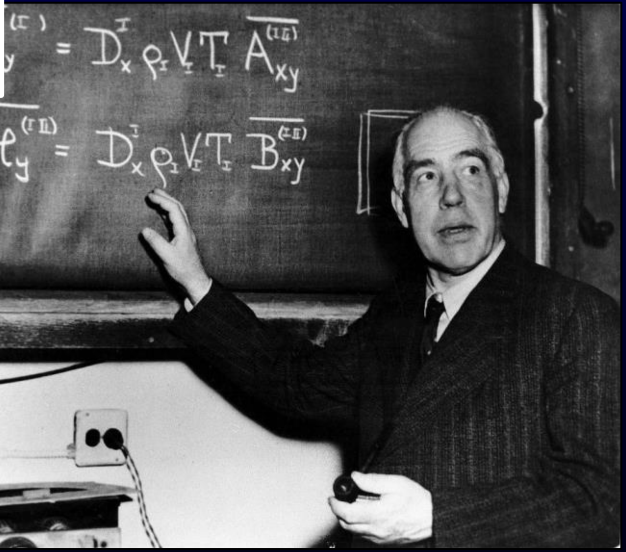
Wolfgang Pauli
(1900 – 1958)



Niels BOHR
A l'aube
de la physique
atomique

Giulio Peruzzi

Les génies de la
science (pour la
science.com)
N°34 en 2008



L'atome de

Bohr
1913


1923

Rutherford
1911

Michel Serres
Préface
Eléments d'histoire des sciences
(Ouvrage collectif, Bordas, 1989)

Conseil de Physique

Institut International de Physique Solvay

La théorie du rayonnement et les quanta

GOLDSCHMIDT PLANCK RUBENS LINDEMANN HASENOHRL
NERNST BRILLOUIN SOMMERFELD DE BROGLIE HOSTELET
SOLVAY KNUDSEN HERZEN JEANS RUTHERFORD
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Bruxelles du 30 octobre au 3 novembre 1911

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La structure de la matière

Bruxelles du 27 au 31 octobre 1913