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

27 juillet 2011

Cent ans après Rutherford

Joël Pouthas

Institut de Physique Nucléaire
CNRS/IN2P3, Université Paris-Sud 11

En 1911

Rutherford introduit un modèle d'atome

pour expliquer

les résultats expérimentaux de Geiger et Marsden

de 1909

Atomisme
au dix neuvième siècle

Chimie

Théorie cinétique des gaz

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)

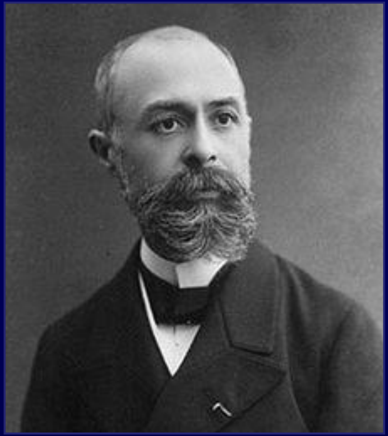
Contexte

Etude des
décharges électriques
dans les gaz

Tube de Crookes

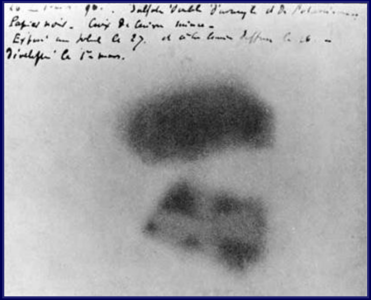
1897 – Corpuscules d'électricité par J.J. Thomson (Electrons)

1896 - Rayons uraniques de Becquerel (Radioactivité)



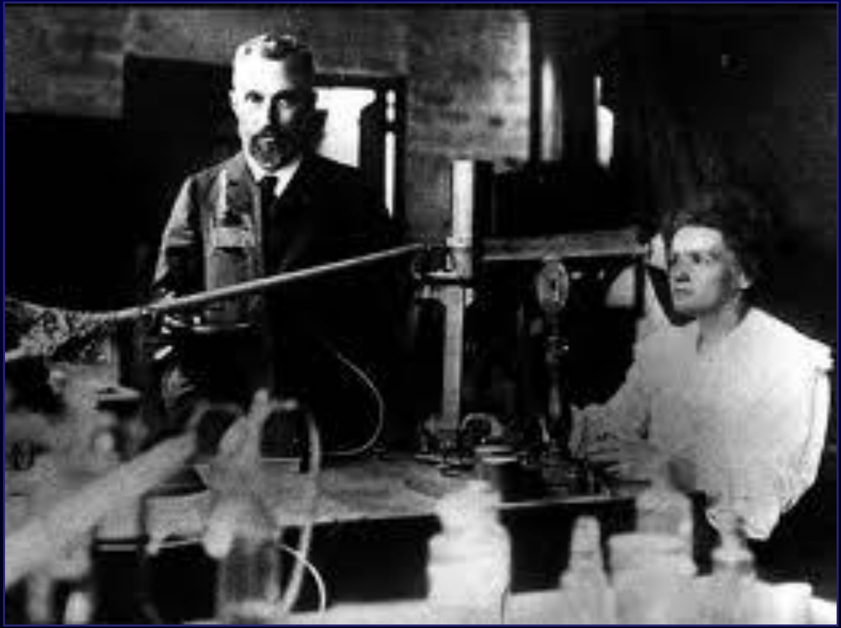
Contexte

Etude de la phosphorescence des sels d'uranium



Travaux développés par Pierre et Marie Curie

Découverte du Polonium et du Radium



L'atome en 1900

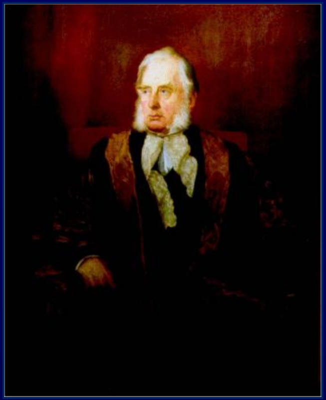
L'atome en 1900

Congrès International de Physique

1. Questions générales. Unités. Mesures	7, 9 et 11 août
2. Physique mécanique et moléculaire	7, 9 et 11 août
3. Optique et thermodynamique	8 et 10 août
4. Electricité et magnétisme	8, 10 et 11 août
5. Magnéto-optique. Rayons cathodiques. Rayonnement de l'uranium. Etc.	7, 8, 9 et 10 août
6. Physique cosmique	7, 8, 9 et 10 août
7. Physique biologique	7, 8 et 9 août

Séance générale de clôture
12 août

Cavendish Laboratory (Cambridge)

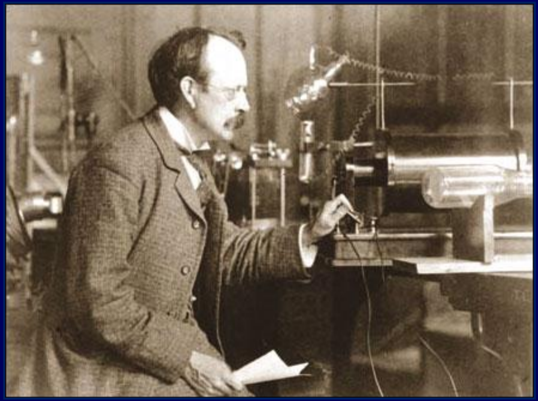


Financé par
W. Cavendish
(7ème duc of Devenshire)

1874

Directeur
Professeur de
physique expérimentale

1874 – 1879	J. C. Maxwell
1879 – 1884	Lord Rayleigh
1884 – 1919	J.J. Thomson
1919 – 1937	E. Rutherford
1938 – 1954	W.L. Bragg



Joseph John Thomson

1856 Naissance à Manchester
1870 Etudes au Owens Collège (Manchester)
1876 Boursier au Trinity Collège (Cambridge)
1880 Wrangler". Reçu 2ème au "Tripos" de mathématiques de Cambridge

1884 – 1919
Directeur du
Laboratoire Cavendish

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

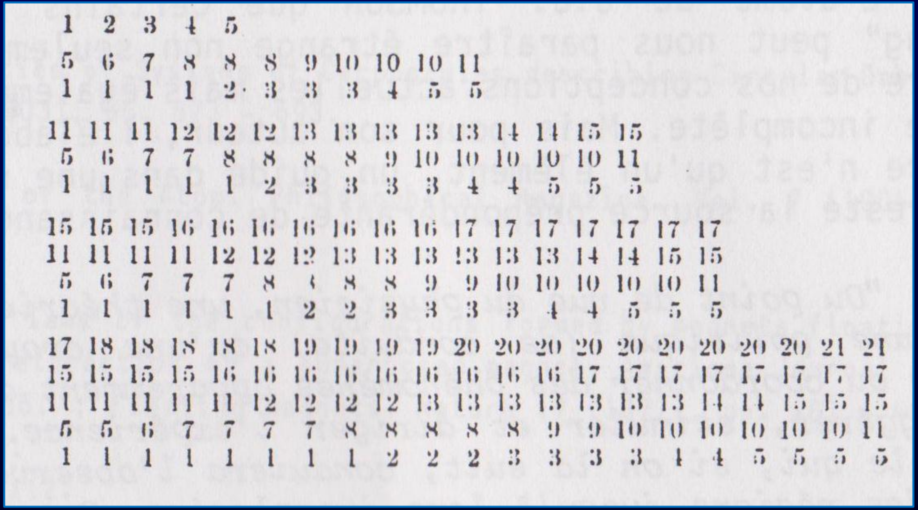
1940 Décès à Cambridge

L'atome deThomson

Contexte Conduction of Electricity through Gazes (Livre, 1903)

1903 The Magnetic Properties of Corpuscules describing Circular Orbits
1904 On the structure of the Atom

1907 (Livre) The corpuscular Theory of Matter



1	2	3	4	5

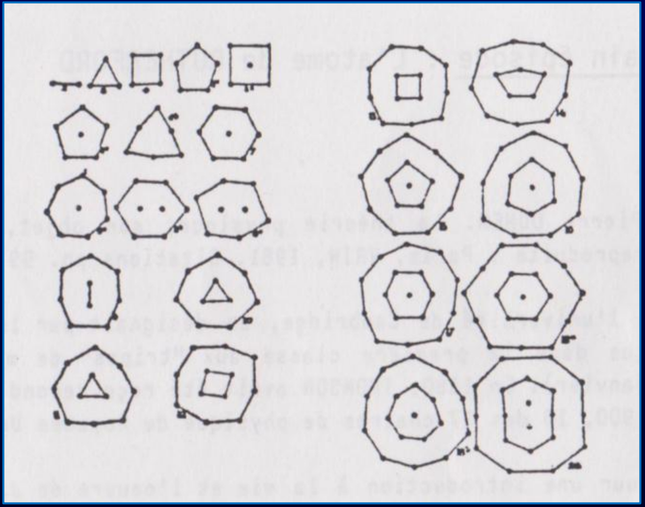
5	6	7	8	8	8	9	10	10	10	11
1	1	1	1	2	3	3	3	4	5	5

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

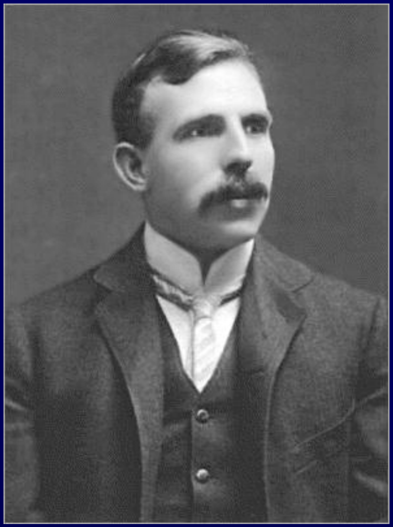
15	15	15	16	16	16	16	16	16	16	17	17	17	17	17	17	17
11	11	11	11	12	12	12	13	13	13	13	13	13	14	14	15	15
5	6	7	7	7	8	8	8	8	9	9	10	10	10	10	10	11
1	1	1	1	1	1	2	2	3	3	3	3	4	4	5	5	5

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)



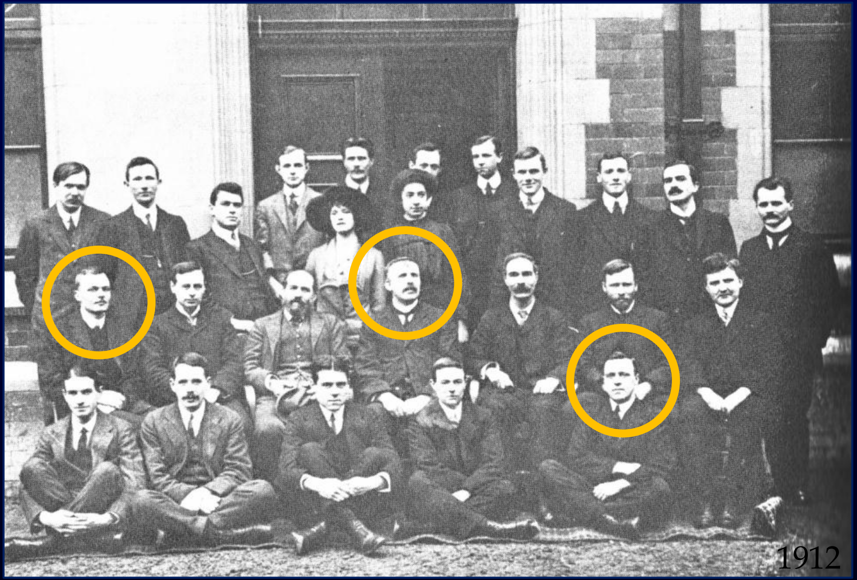
Analogie avec les expériences
de Mayer (1877)



Ernest Rutherford

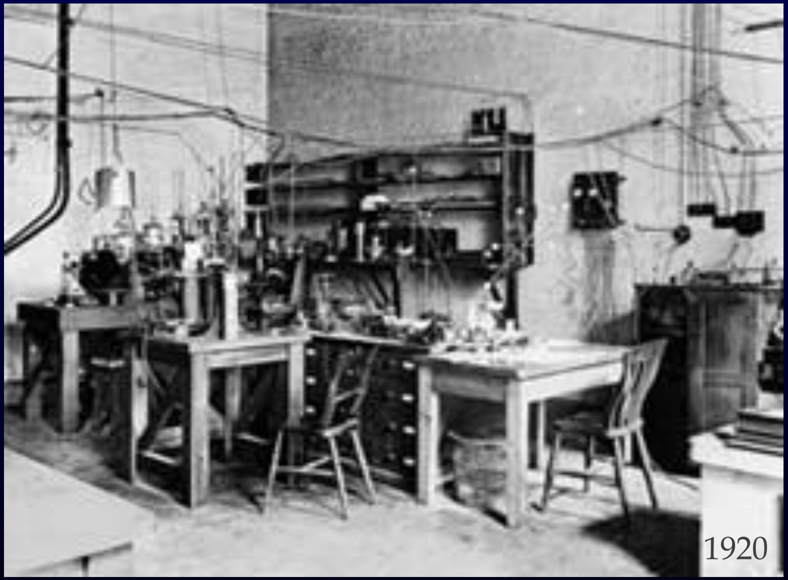
1871 Naissance à Nelson (Nouvelle Zélande)
Boursier au Nelson puis au Canterbury College de Christchurch (N.Z.). B.A., M.A et B.Sc.
1895 Bourse pour le Cavendish de Cambridge
1898 Professeur à McGill, Montreal (Canada)
1908 Prix Nobel de chimie pour ses recherches sur la désintégration des éléments et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

1907 Université de Manchester



1912

1919 Cavendish Laboratory

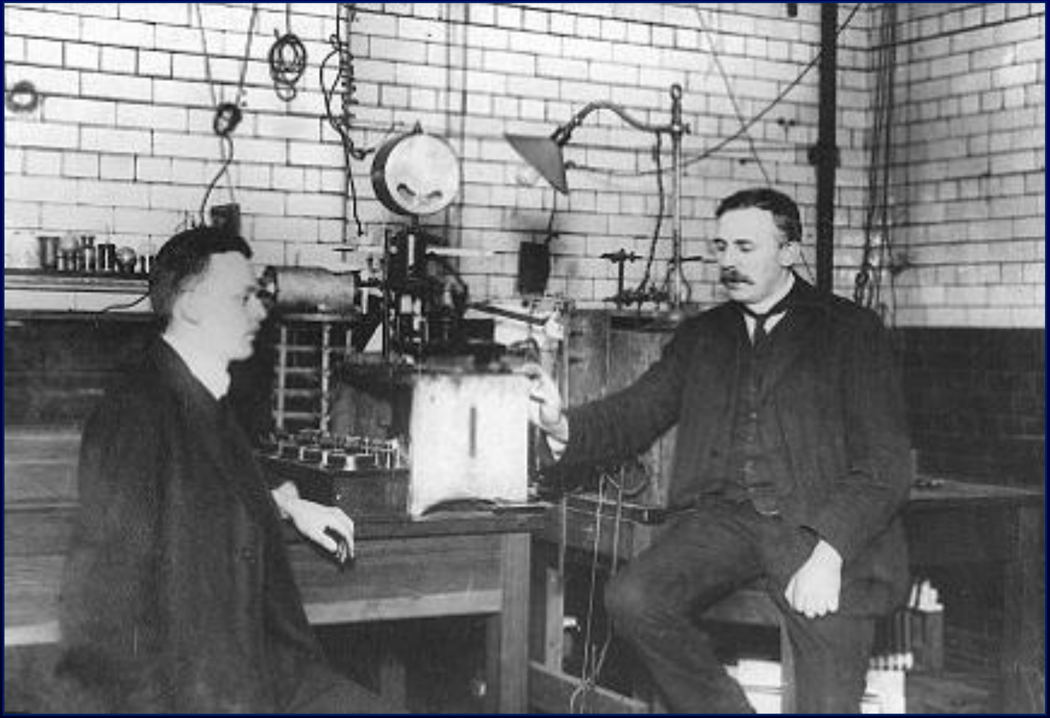


1920

1937 Décès à Cambridge

Les expériences de Geiger et Marsden

1909 On a Diffuse Reflexion of the α-Particles



Les expériences de Geiger et Marsden

1909 On a Diffuse Reflexion of the α-Particles

Source gazeuse
(Tube conique AB)

Plaque de plomb B

Détecteur S
Microscope M

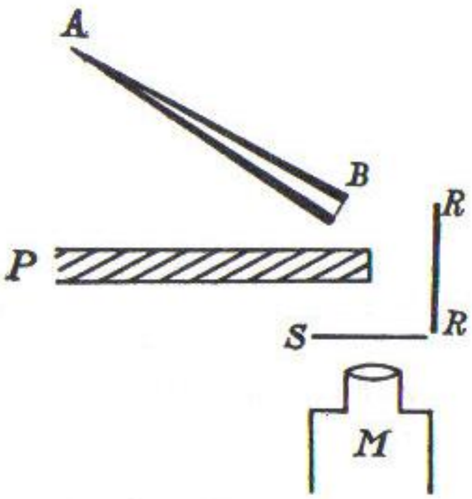


FIG. 1.

Réflecteur
RR

Source
en A

Réflecteur
en platine R

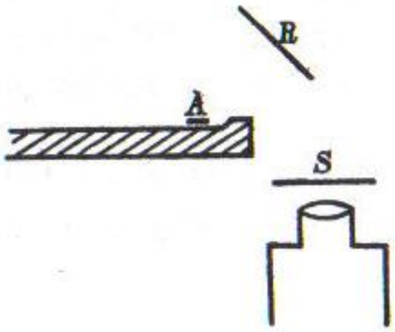
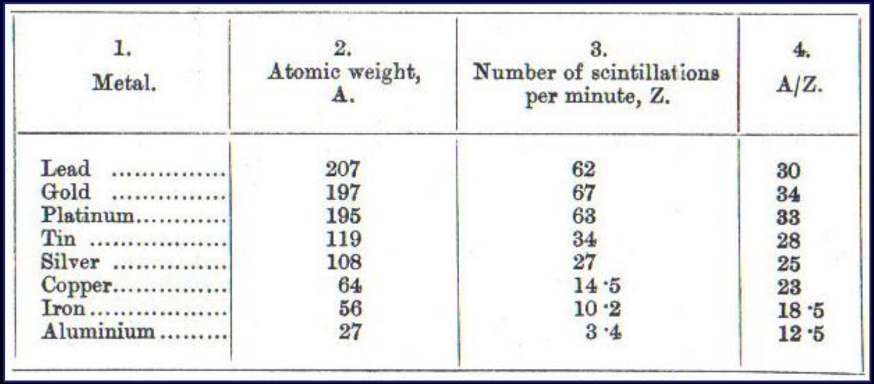


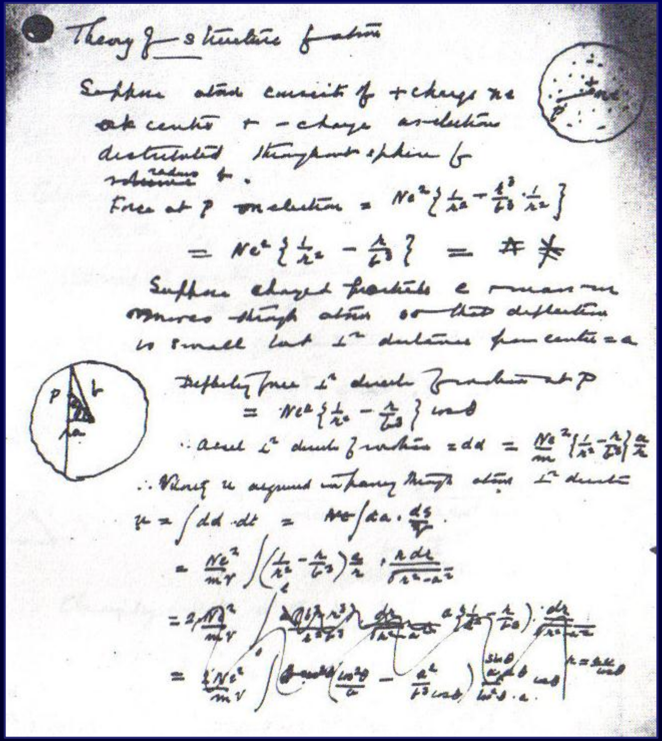
FIG. 3.



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

Le modèle de Rutherford

1911 The Scattering of the α and β Particles by Matter and the Structure of the Atom



Theory of structure of atom

Suppose atom consists 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 $= \alpha = \frac{Ne^2}{m}\left\{\frac{1}{r^2}-\frac{r}{b^3}\right\}\frac{a}{r}$

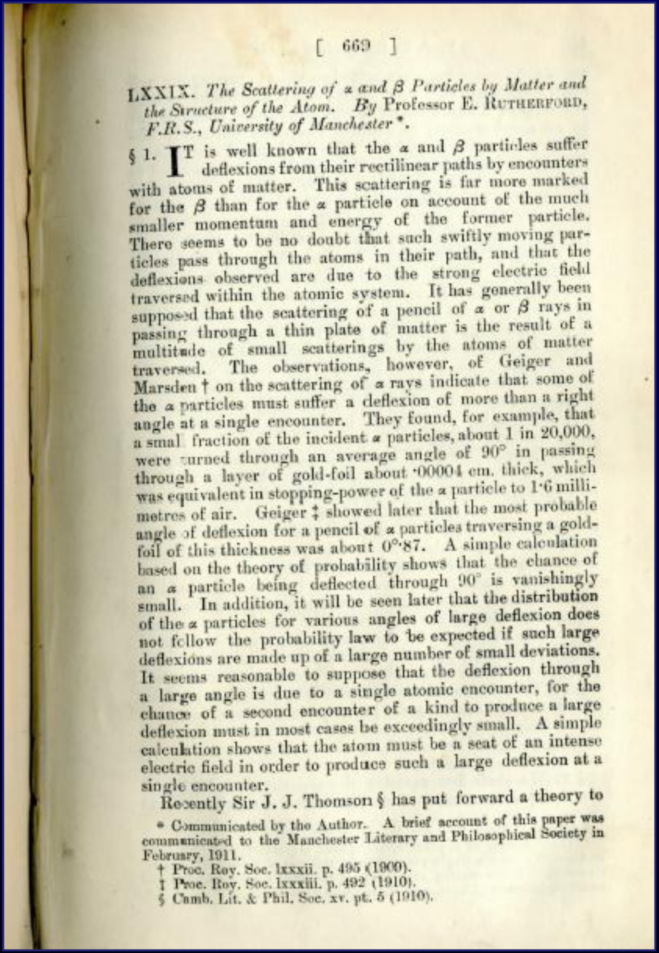
∴ Velocity u acquired in passing through atom ⊥ direction

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

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

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

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



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).

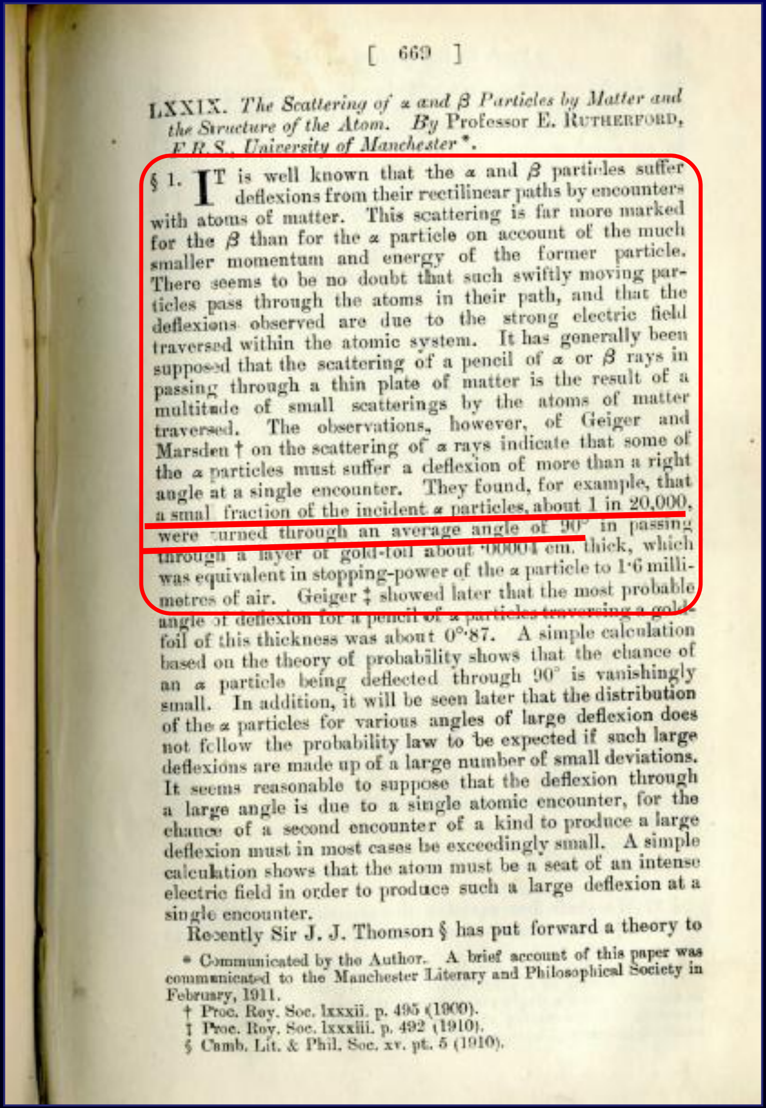
‡ Proc. Roy. Soc. lxxxiii. p. 492 (1910).

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

Article lu le 7 mars 1911 à Manchester Literary and Philosophical Society

1911

Le modèle de Rutherford



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*[*].

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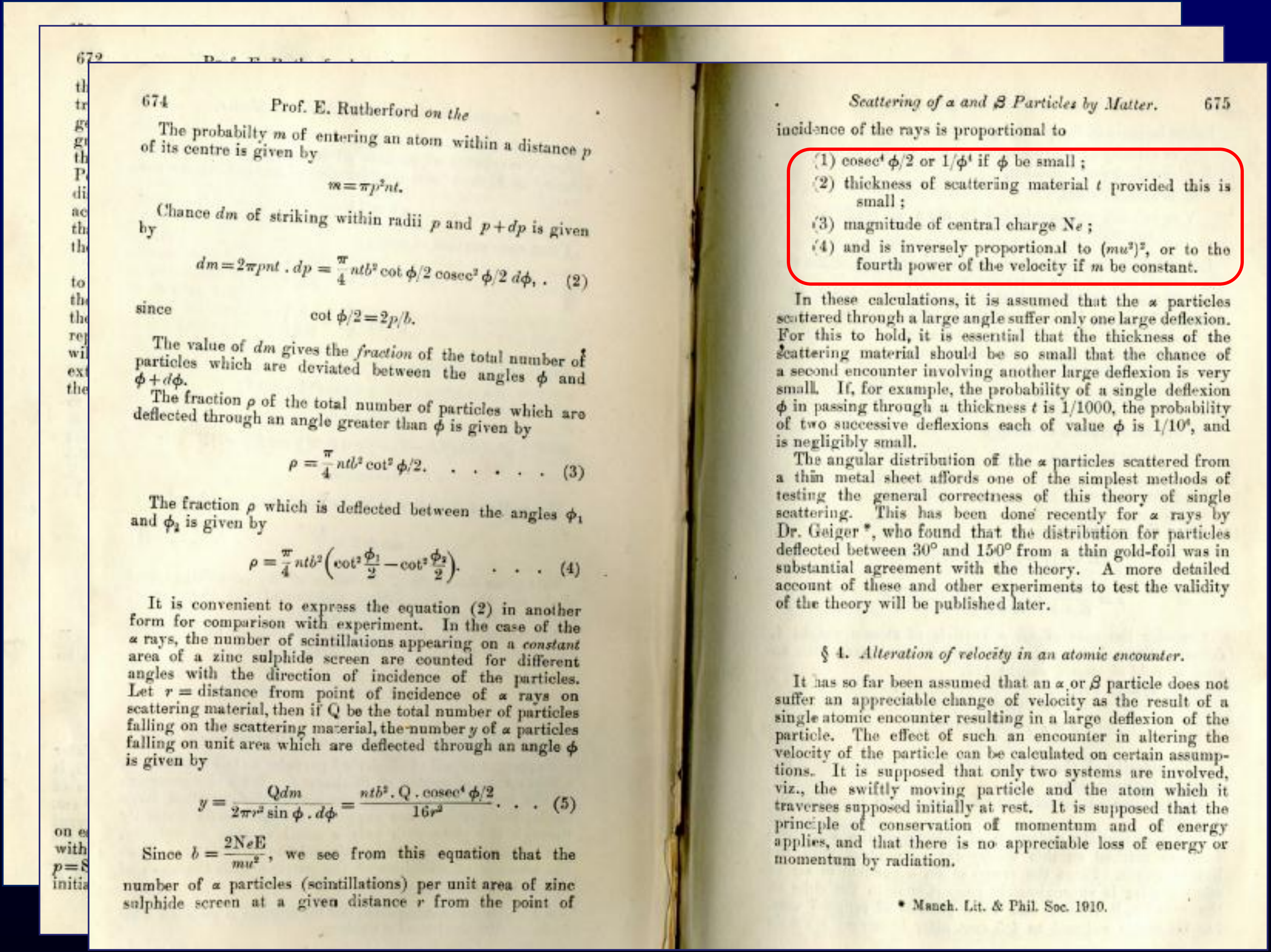
1911

Le modèle de Rutherford



674 Prof. E. Rutherford *on the*

The probabilty 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

$$dm=2\pi pnt\,.\,dp=\frac{\pi}{4}ntb^2\cot\phi/2\,\mathrm{cosec}^2\,\phi/2\,d\phi,\,. \qquad (2)$$

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

$$\rho=\frac{\pi}{4}ntb^2\cot^2\phi/2. \quad .\ .\ .\ .\ .\ . \quad (3)$$

The fraction ρ which is deflected between the angles ϕ_1 and ϕ_2 is given by

$$\rho=\frac{\pi}{4}ntb^2\left(\cot^2\frac{\phi_1}{2}-\cot^2\frac{\phi_2}{2}\right). \quad .\ .\ .\ . \quad (4)$$

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

$$y=\frac{Qdm}{2\pi r^2\sin\phi\,.\,d\phi}=\frac{ntb^2\,.\,Q\,.\,\mathrm{cosec}^4\,\phi/2}{16r^2}. \quad .\ .\ . \quad (5)$$

Since $b=\dfrac{2NeE}{mu^2}$, 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

Scattering of α and β Particles by Matter. 675

incidence of the rays is proportional to

(1) $\mathrm{cosec}^4\,\phi/2$ 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 $(mu^2)^2$, 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.

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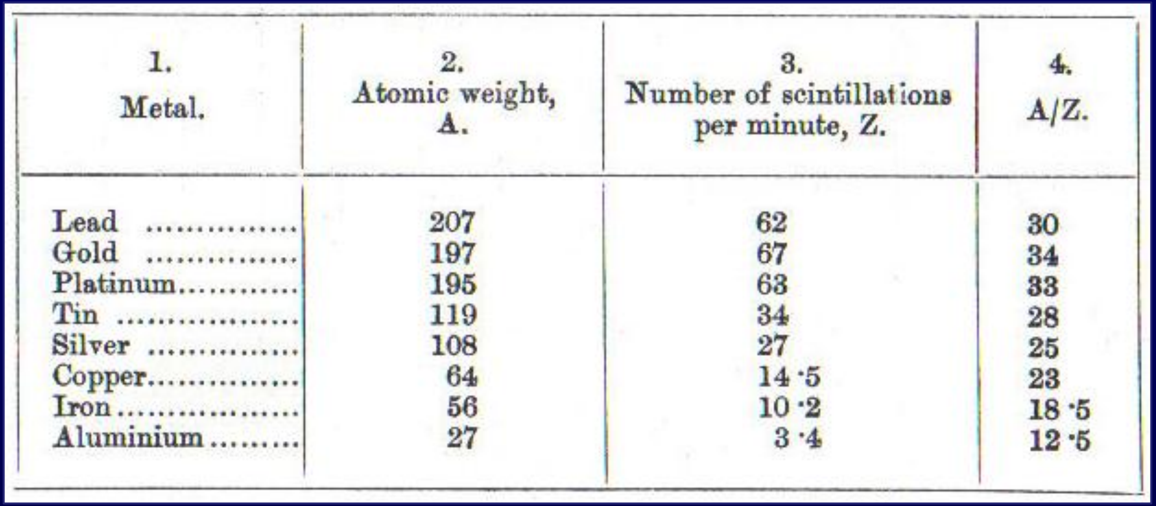
* Manch. Lit. & Phil. Soc. 1910.

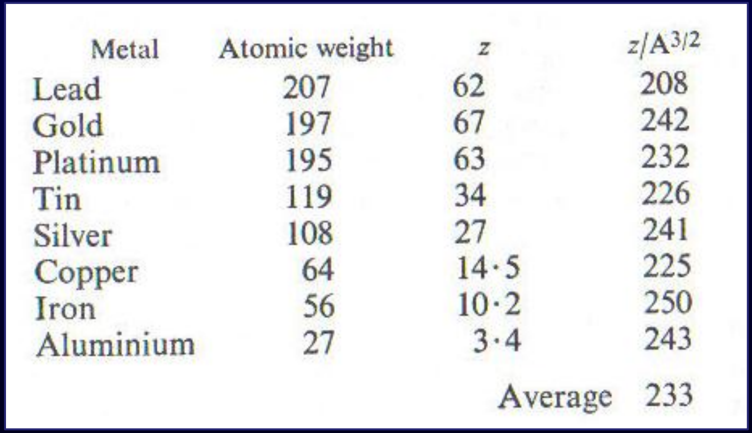
1911

Le modèle de Rutherford



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

Résultats de Geiger et Marsden en 1909



Metal	Atomic weight	z	$z/A^{3/2}$
Lead	207	62	208
Gold	197	67	242
Platinum	195	63	232
Tin	119	34	226
Silver	108	27	241
Copper	64	14·5	225
Iron	56	10·2	250
Aluminium	27	3·4	243
		Average	233

Repris par Rutherford en 1911

Conseil de Physique

Institut International de Physique Solvay

(27 -31 octobre 1913)

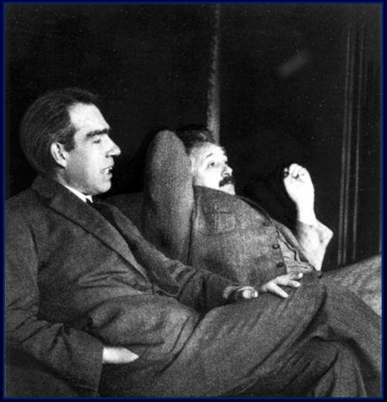
Niels Bohr

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

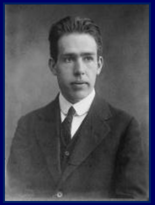
1922
Prix Nobel
de physique

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   Mariage au Danemark

En juillet 1913, Professeur à Copenhague (Etudiants en médecine)

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

1913

L'atome de Bohr

On the Constitution of Atoms and Molecules

Publication en 3 parties dans
Philosophical Magazine

Partie 1

Envoyée par Rutherford le 5 avril 1913
Publiée en juillet 1913

1914

1918

Thomson

Rutherford

Bohr

Bohr
1913


1923

Rutherford
1911

L'activité rationaliste de la physique contemporaine
(Gaston Bachelard)