Des noyaux sans neutrons

Aperçus sur les modèles en physique nucléaire avant 1932

Joël Pouthas

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

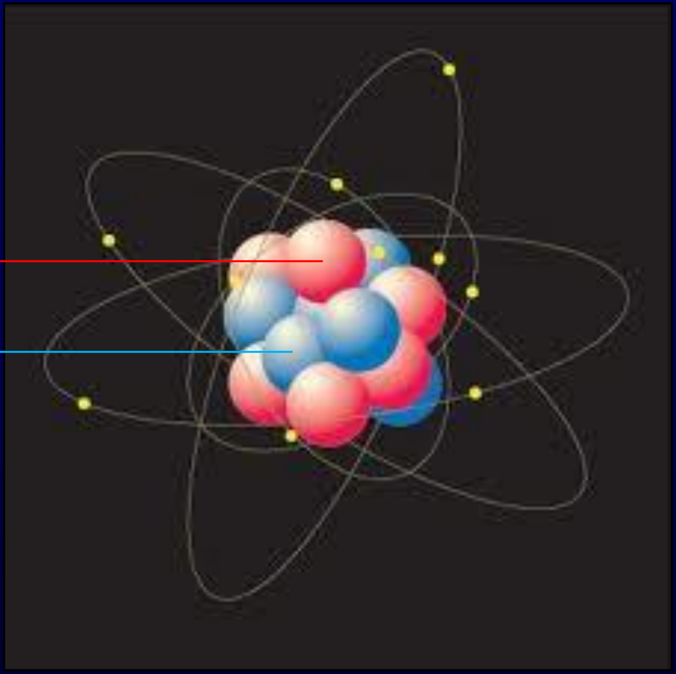
Atome

Noyau

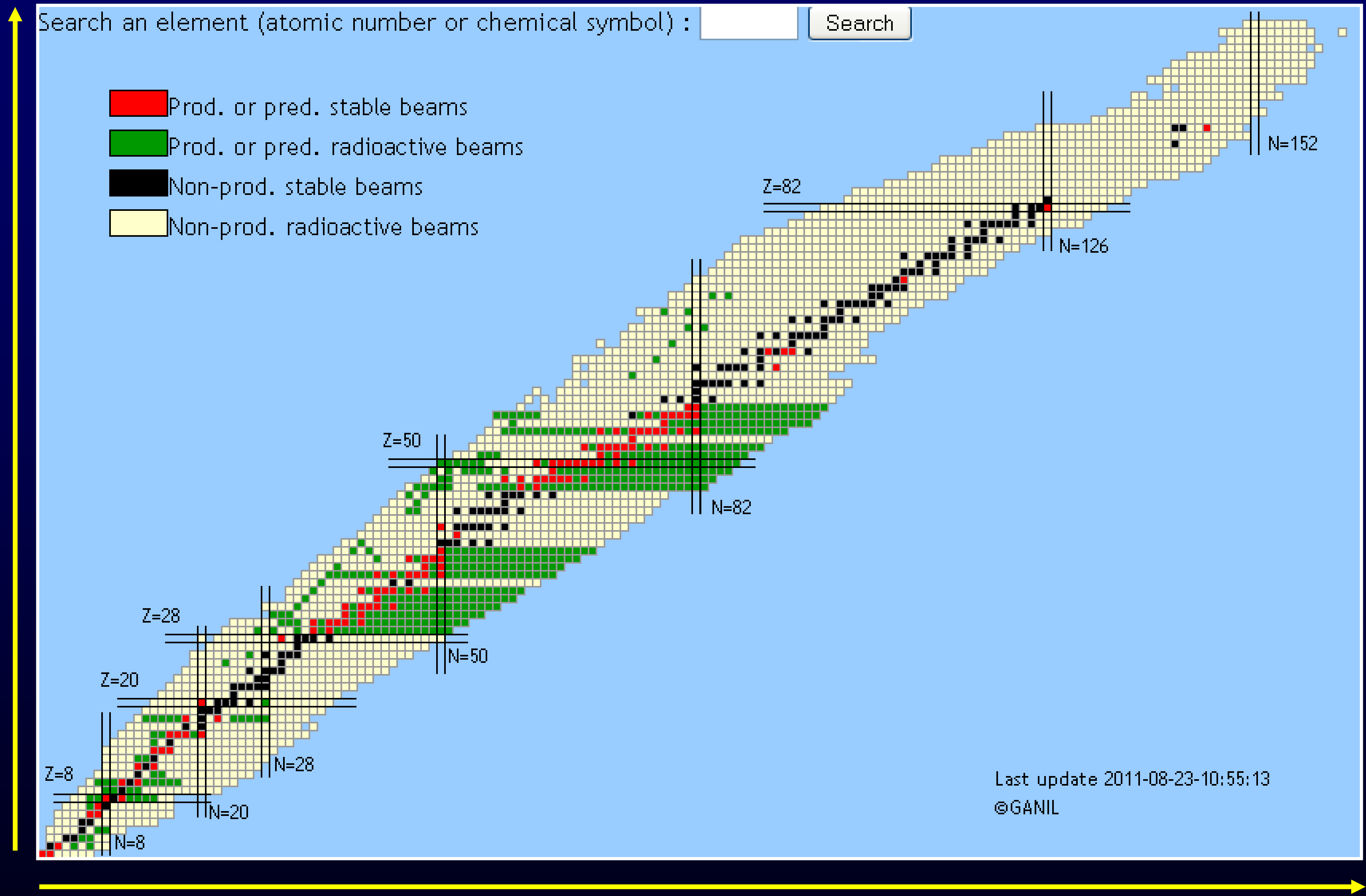
Electrons

Protons

Neutrons



Noyau … avant 1932



Z ~~nombre de protons~~

~~N nombre de neutrons~~

Noyau … avant 1932

Z ~~nombre de protons~~

Z

Numéro atomique de l'élément
Charge du noyau

Composants du noyau

Protons Electrons Autres ?

Bertrand Russel, *Analysis of Matter*, 1927

Radioactivité

Rayons uraniques de Becquerel en 1896

Isolation d'éléments Polonium et Radium (P. et M. Curie)
(« Radio-activité », 1898)

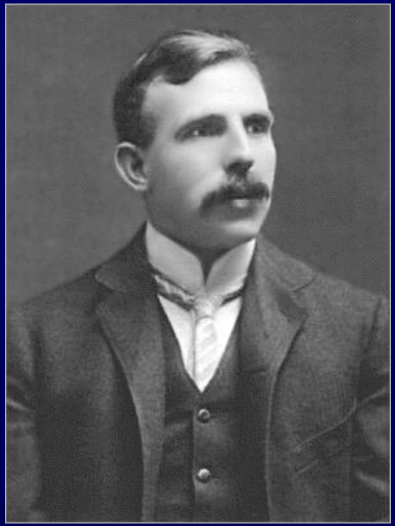
Analyse des rayons

Séparation α β γ (Pénétration, déviation dans des champs)

β -> électrons

α -> atome d'hélium projeté

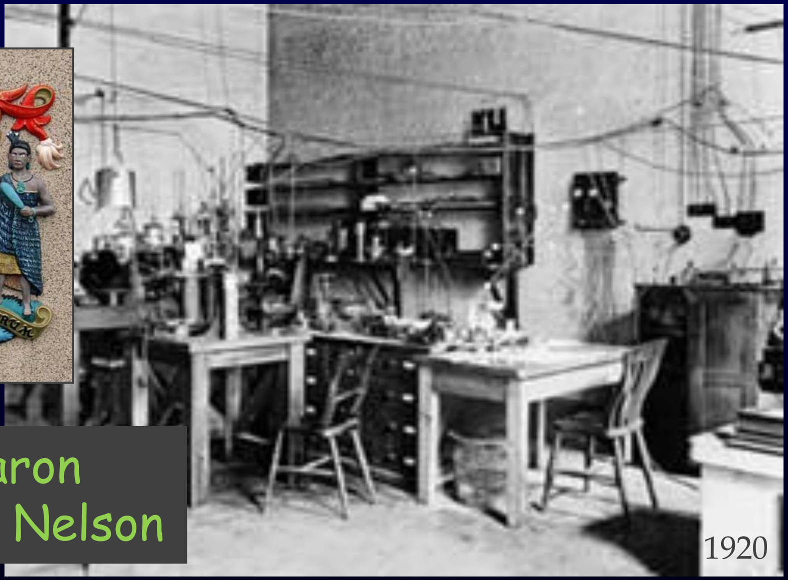
Ernest Rutherford



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

1919 Cavendish Laboratory



1931 Baron Rutherford of Nelson

1937 Décès à Cambridge

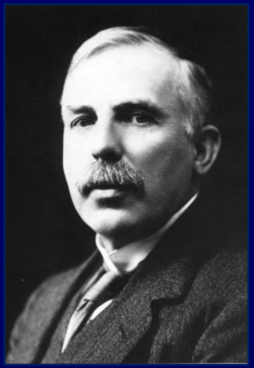
Rutherford 1920

BAKERIAN LECTURE : *Nuclear Constitution of Atoms*

By Sir E. Rutherford, F.R.S., Cavendish Professor of Experimental Physics, University of Cambridge

(Received June 3, - Lecture delivered June 3, 1920.)

Rutherford 1920



BAKERIAN LECTURE : *Nuclear Constitution of Atoms*

Introduction

The conception of the nuclear constitution of atoms arose initially from attempts to account for the scattering of α-particles through large angles in traversing thin sheets of matter.* Taking into account the large mass and velocity of the α-particles, these large deflexions were very remarkable, and indicated that very intense electric or magnetic fields exist within the atom. To account for these results, it was found necessary to assume+ that the atom consists of a charged massive nucleus of dimensions very small compared with the ordinarily accepted magnitude of the diameter of the atom. This positively charged nucleus contains most of the mass of the atom, and is surrounded at a distance by a distribution of negative electrons equal in number to the resultant positive charge of the nucleus.

* Geiger and Marsden, 'Roy. Soc. Proc.,' A, vol. 82, p. 495 (1909)

\+ Rutherford, 'Phil. Mag.,' vol. 21, p. 669 (1911) ; vol. 27, p. 488 (1914)

Radioactivité

Utilisation des particules α comme sonde

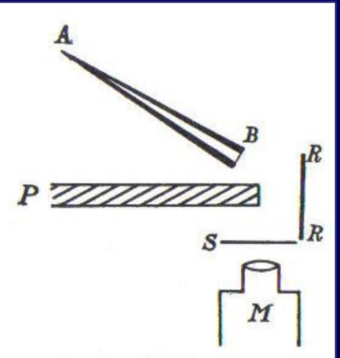


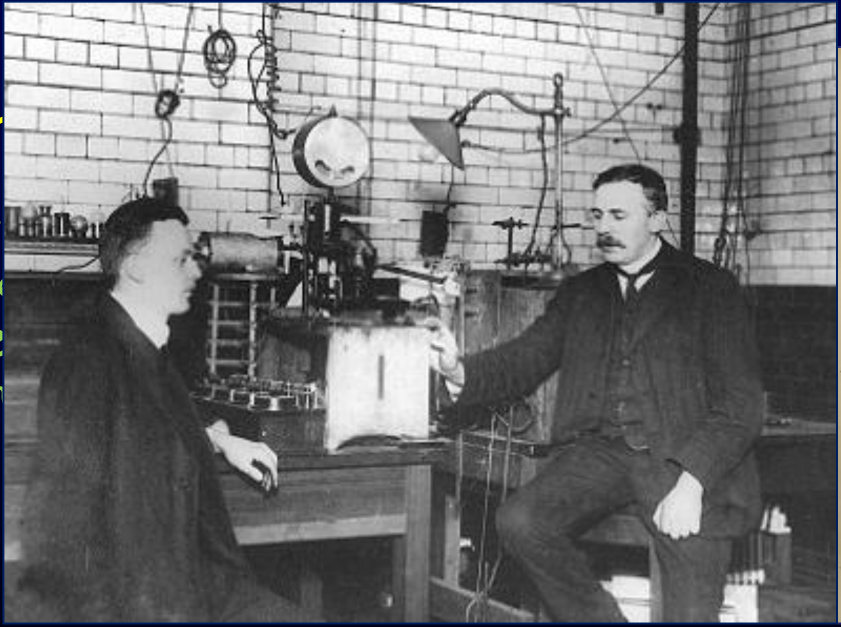
Fig. 1.

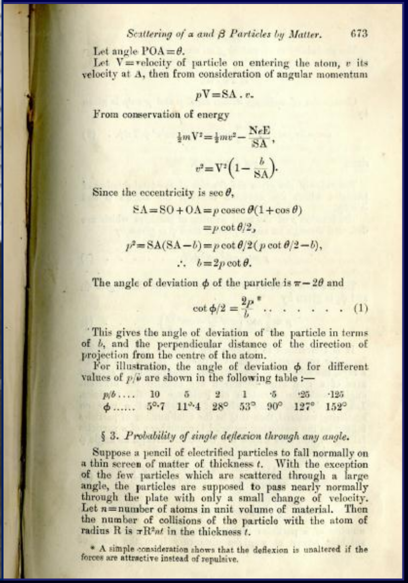
Geiger et Marsden, 1909

On a Diffuse Reflexion of the α-Particles

Rutherfor

The Scat
of th
α and β Particle
and th
Structure of





Scattering of α and β Particles by Matter. 673

Let angle POA $=\theta$.

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

$$\tfrac{1}{2}mV^2 = \tfrac{1}{2}mv^2 - \frac{NeE}{SA},$$

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

Since the eccentricity is $\sec\theta$,

$$SA = SO + OA = p\,\mathrm{cosec}\,\theta(1+\cos\theta)$$
$$= p\cot\theta/2,$$
$$p^2 = SA(SA-b) = p\cot\theta/2(p\cot\theta/2 - b),$$
$$\therefore\quad b = 2p\cot\theta.$$

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 :—

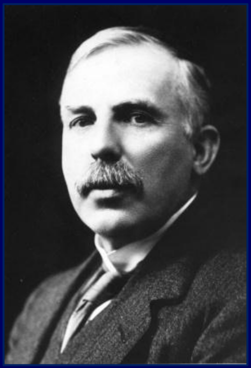
p/b	10	5	2	1	·5	·25	·125
ϕ	5°·7	11°·4	28°	53°	90°	127°	152°

§ 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 $\pi R^2 nt$ in the thickness t.

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

Rutherford 1920

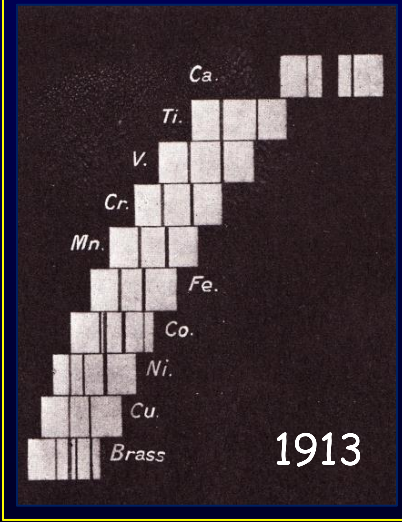


Bakerian lecture : *Nuclear Constitution of Atoms*

Introduction

This relation received an interpretation by supposing that the nuclear charge varied by unity in passing from atom to atom, and was given numerically by the atomic number.

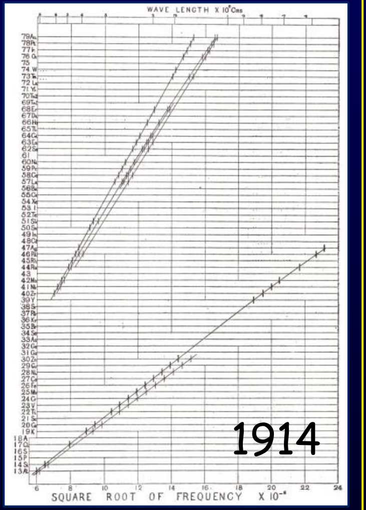
Henry Moseley



Every … gold is charac… rmines its X-ray …

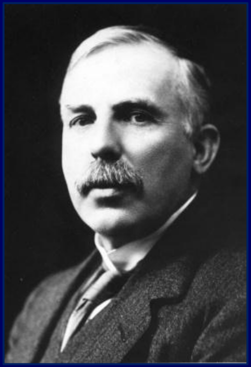
This i… element, is ide… units of electri… .

The or… ne as that of the … he latter disagre… es



Regarding the periodic classification of the elements, the atomic number, or its equivalent the nuclear charge, is of more fundamental importance than its atomic weight.

Rutherford 1920



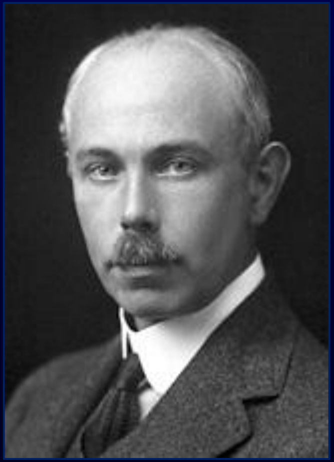
BAKERIAN LECTURE : *Nuclear Constitution of Atoms*

Introduction

The dependence of the properties of an atom on its nuclear charge and not on its mass thus offers a rational explanation of the existence of isotopes in which the chemical and physical properties may be almost indistinguishable, but the mass of the isotopes may vary within certain limits.

Isotopes

Francis W. ASTON

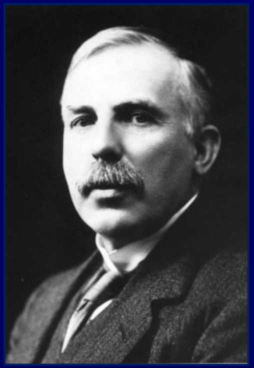


Prix Nobel de chimie 1922 “pour sa découverte à l’aide de son spectrographe de masse d’isotopes pour un grand nombre d’éléments non radioactifs et pour l’énonciation de la règle des nombres entiers.

La découverte des isotopes

Extrait de son livre "Isotopes" de 1922

Rutherford 1920



BAKERIAN LECTURE : *Nuclear Constitution of Atoms*

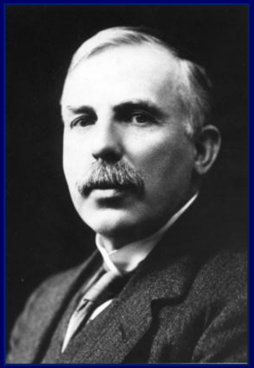
The general problem of the structure of the atom thus naturally divides itself into two parts :

1. Constitution of the nucleus itself.
2. The arrangement and modes of vibration of the external electrons.

Dimensions of Nuclei

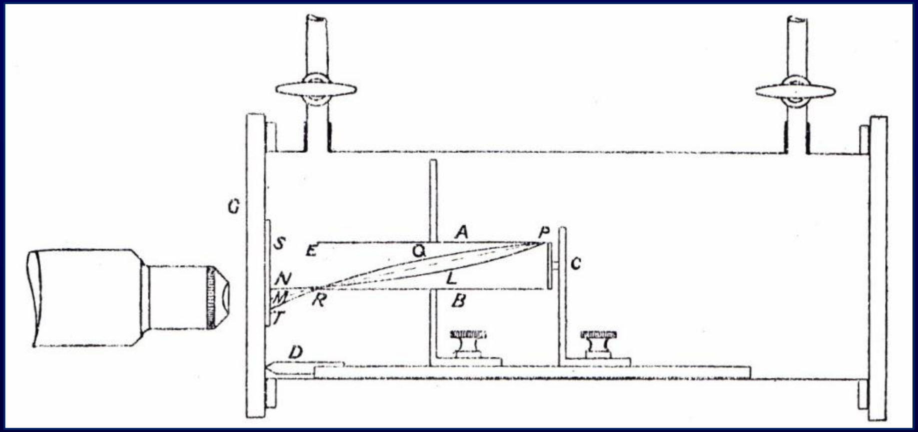
The diameter of the nuclei of the light atoms except hydrogen are probably of the order of magnitude 5×10^{-13} cm. and in a close collision the nuclei come nearly in contact and may possibly penetrate each other's structure. Under such conditions, only very stable nuclei would be expected to survive the collision and it is thus of great interest to examine whether evidence can be obtained of their disintegration.

Rutherford 1920



BAKERIAN LECTURE : *Nuclear Constitution of Atoms*

Long Range Particles from Nitrogen



The passage of α-particles through dry nitrogen gives rise to swift particles which closely resembled in brilliancy of the scintillations and distance of penetration hydrogen atoms set in motion by close collision with α-particles.

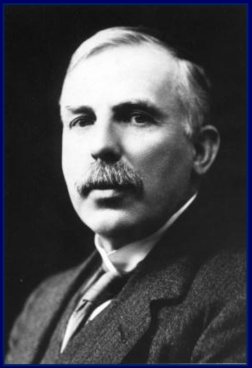
E. RUTHERFORD (1919)

Collisions of α Particles with Light Atoms

IV. An Anomalous Effect in Nitrogen

We must conclude that the nitrogen 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

Rutherford 1920

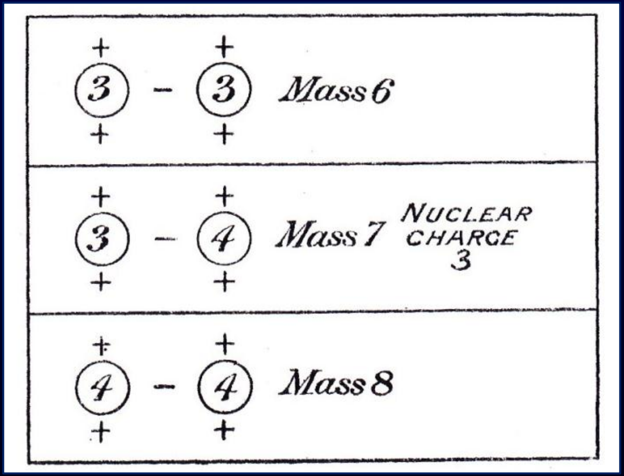


BAKERIAN LECTURE : *Nuclear Constitution of Atoms*

Constitution of Nuclei and Isotopes

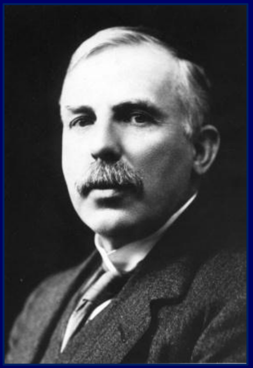
In considering the possible constitution of the elements, it is natural to suppose that they are built up ultimately of hydrogen nuclei and electrons. On this view the helium nucleus is composed of four hydrogen nuclei and two negative electrons with a resultant charge of two.

It seems premature at this stage to attempt to discuss with any detail the possible structure of even the lighter and presumably less complex atoms.



Lithium

Rutherford 1920



BAKERIAN LECTURE : *Nuclear Constitution of Atoms*

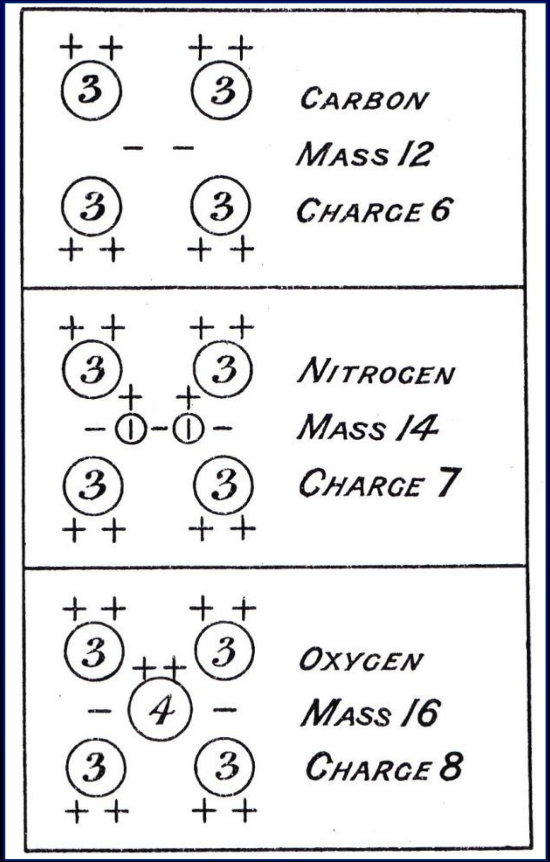
Structure of Carbon, Oxygen, and Nitrogen Nuclei

In the light of the present experiments, it may be of interest to give some idea, however crude, of the possible formation of the above atoms to account for experimental facts.

It will be remembered that nitrogen alone gives rise to H atoms while carbon and oxygen do not

Both nitrogen and oxygen give rise to atoms of mass 3, while carbon has not yet been investigated from this point of view.

The carbon nucleus is taken to consist of four atoms of mass 3 and charge 2, and two binding electrons. The change to nitrogen is represented by the addition of two H atoms with a binding electron and an oxygen nucleus by the substitution of a helium nucleus in place of the two H atoms.



Rutherford 1930

RADIATIONS
FROM
RADIOACTIVE SUBSTANCES

by

SIR ERNEST RUTHERFORD, O.M., D.Sc., Ph.D., LL.D., F.R.S.
NOBEL LAUREATE
Cavendish Professor of Experimental Physics in the University of Cambridge

JAMES CHADWICK, Ph.D., F.R.S.
Fellow of Gonville and Caius College, Cambridge

and

C. D. ELLIS, Ph.D., F.R.S.
Fellow of Trinity College, Cambridge

1904 Radioactivity
Enlarged edition 1905

1912 Radioactive Substances and their Radiations

University Press, Cambridge
1930 (Reprinted 1951)

Since 1912… the literature has rapidly expanded

Many thousands of new papers has been published

Allemagne Stefan Meyer and Egon v Schweidler, Radioaktivität (1916 , 1927)
K. W. F. Kohlrausch Radioaktivität (1928, Handbuch der Experimental Physik)

Etats Unis A. F. Kovarik and L. W. McKeehan, Radioactivity (1925)

Rutherford 1930

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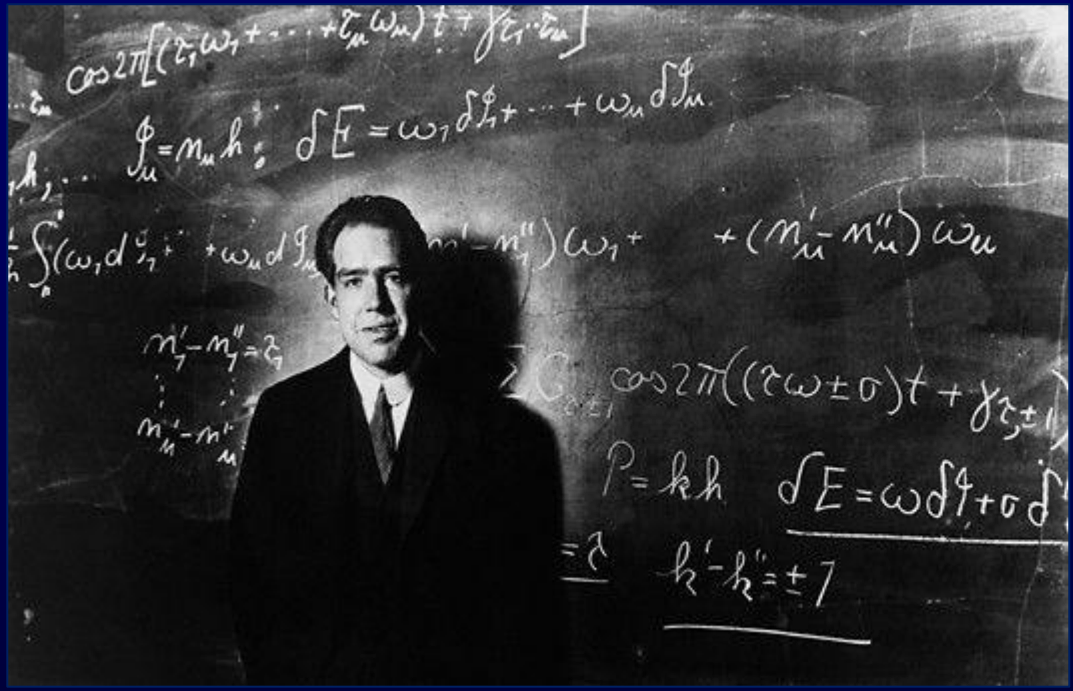
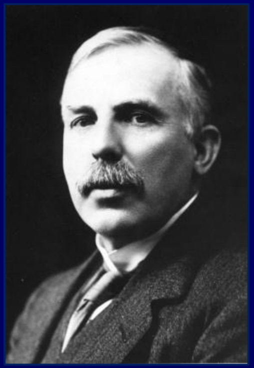
Niels Bohr 1931



Chemistry and the Quantum Theory of Atomic Constitution

Faraday Lecture, Chemical Society , London

Rutherford 1920



BAKERIAN LECTURE : *Nuclear Constitution of Atoms*

Constitution of Nuclei and Isotopes

The idea of the possible existence of an atom of mass 1 which has zero nucleus charge.

Such an atomic structure seems by no means impossible. On present views, the neutral hydrogen atom is regarded as a nucleus of unit charge with an electron attached at a distance, and the spectrum of hydrogen is ascribed to the movements of this distant electron. Under some conditions, however, it may be possible for an electron to combine much more closely with the H nucleus, forming a kind of neutral doublet. Such an atom will have very novel properties. Its external field would be practically zero, except very close to the nucleus, and in consequence it should be able to move freely through matter. Its presence would probably be difficult to detect…

If the existence of such atoms be possible, it is to be expected that they may be produced, but probably only in very small numbers, in the electric discharge through hydrogen, where both electrons and H nuclei are present in considerable numbers. It is the intention of the writer to make experiments to test whether any indication of the production of such atoms can be obtained under these conditions.

James Chadwick

1891 Naissance à Bollington (Angleterre)
1907 – 1913 Université de Manchester
(2 ans Laboratoire de Rutherford)
1913 Charlottenburg (TU Berlin, H. Geiger)

1914 - 1918 Camp de Ruhleben

1919 Cambridge, Gonville and Caius College
Gonville and Caius College 1923
1923 Cambridge au Cavendish
Directeur assistant de la recherche

1935 Professeur à l'Université de Liverpool

1935 Prix Nobel de chimie
pour la découverte du neutron

1974 Décès à Cambridge

James Chadwick

1962

Some personal notes
on the
Search for the Neutron

Actes du X^{ème} Congrès International d'histoire des Sciences, Ithaca 1962
Réédition (revue par l'auteur) dans Adventures in experimental ,physics, 1972

Découverte du neutron

Allemagne (Berlin) 1930 W. Bothe et H. Becker

Bombardement du B et Be par les α du polonium
Mise en évidence d'un rayonnement très pénétrant… de type γ

France (Paris) 1931 (décembre) I. Curie et F. Joliot

Etude de l'absorption de ce « rayonnement γ nucléaire »

1932 (18 janvier)

Ce rayonnement arrache des protons à des substances hydrogénées

Angleterre (Cambridge) 1932 (17 février) J. Chadwick

Reprise et surtout interprétation des expériences par :
L'existence possible d'un neutron

Possible Existence of a Neutron

Letters to the Editor

[The Editor does not hold himself responsible for opinions expressed by his correspondents. Neither can he undertake to return, nor to correspond with the writers of, rejected manuscripts intended for this or any other part of NATURE. *No notice is taken of anonymous communications.]*

Possible Existence of a Neutron

IT has been shown by Bothe and others that beryllium when bombarded by α-particles of polonium emits a radiation of great penetrating power, which has an absorption coefficient in lead of about 0·3 (cm.)$^{-1}$. Recently Mme. Curie-Joliot and M. Joliot found, when measuring the ionisation produced by this beryllium radiation in a vessel with a thin window, that the ionisation increased when matter containing hydrogen was placed in front of the window. The effect appeared to be due to the ejection of protons with velocities up to a maximum of nearly 3×10^9 cm. per sec. They suggested that the transference of energy to the proton was by a process similar to the Compton effect, and estimated that the beryllium radiation had a quantum energy of 50×10^6 electron volts.

I have made some experiments using the valve counter to examine the properties of this radiation excited in beryllium. The valve counter consists of a small ionisation chamber connected to an amplifier, and the sudden production of ions by the entry of a particle, such as a proton or α-particle, is recorded by the deflexion of an oscillograph. These experiments have shown that the radiation ejects particles from hydrogen, helium, lithium, beryllium, carbon, air, and argon. The particles ejected from hydrogen behave, as regards range and ionising power, like protons with speeds up to about $3{\cdot}2 \times 10^9$ cm. per sec. The particles from the other elements have a large ionising power, and appear to be in each case recoil atoms of the elements.

If we ascribe the ejection of the proton to a Compton recoil from a quantum of 52×10^6 electron volts, then the nitrogen recoil atom arising by a similar process should have an energy not greater than about 400,000 volts, should produce not more than about 10,000 ions, and have a range in air at N.T.P. of about 1·3 mm. Actually, some of the recoil atoms in nitrogen produce at least 30,000 ions. In collaboration with Dr. Feather, I have observed the recoil atoms in an expansion chamber, and their range, estimated visually, was sometimes as much as 3 mm. at N.T.P.

These results, and others I have obtained in the course of the work, are very difficult to explain on the assumption that the radiation from beryllium is a quantum radiation, if energy and momentum are to be conserved in the collisions. The difficulties disappear, however, if it be assumed that the radiation consists of particles of mass 1 and charge 0, or neutrons. The capture of the α-particle by the Be^9 nucleus may be supposed to result in the formation of a C^{12} nucleus and the emission of the neutron. From the energy relations of this process the velocity of the neutron emitted in the forward direction may well be about 3×10^9 cm. per sec. The collisions of this neutron with the atoms through which it passes give rise to the recoil atoms, and the observed energies of the recoil atoms are in fair agreement with this view. Moreover, I have observed that the protons ejected from hydrogen by the radiation emitted in the opposite direction to that of the exciting α-particle appear to have a much smaller range than those ejected by the forward radiation. This again receives a simple explanation on the neutron hypothesis.

If it be supposed that the radiation consists of quanta, then the capture of the α-particle by the Be^9 nucleus will form a C^{13} nucleus. The mass defect of C^{13} is known with sufficient accuracy to show that the energy of the quantum emitted in this process cannot be greater than about 14×10^6 volts. It is difficult to make such a quantum responsible for the effects observed.

It is to be expected that many of the effects of a neutron in passing through matter should resemble those of a quantum of high energy, and it is not easy to reach the final decision between the two hypotheses. Up to the present, all the evidence is in favour of the neutron, while the quantum hypothesis can only be upheld if the conservation of energy and momentum be relinquished at some point.

J. CHADWICK.

Cavendish Laboratory,
Cambridge, Feb. 17.

NATURE [FEBRUARY 27, 1932

J. CHADWICK

Cavendish Laboratory
Cambridge, Feb. 17

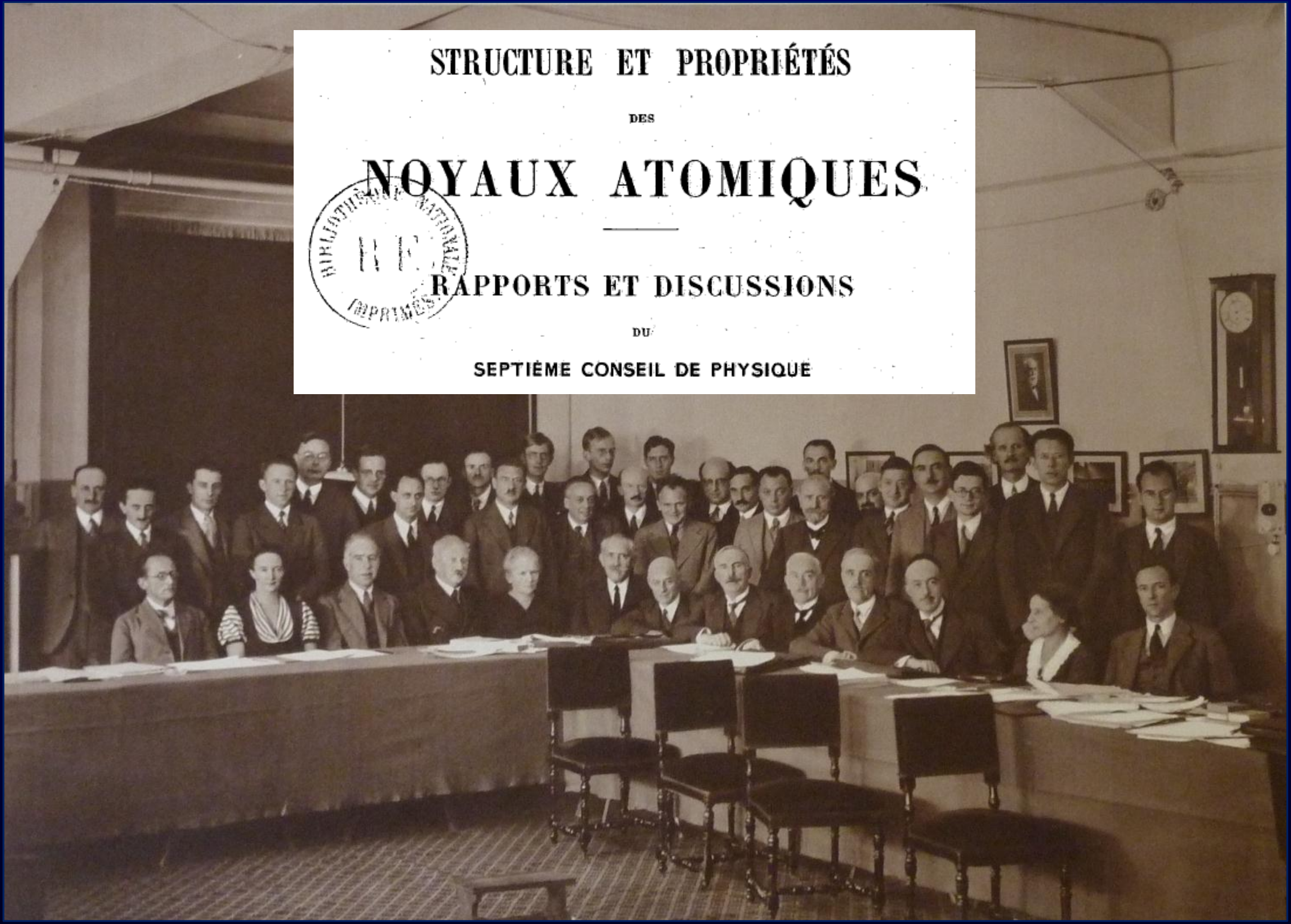
The Existence of a Neutron

By J. Chadwick, F.R.S.

(Received May 10, 1932.)

Proc. Roy. Soc., 1932, A, 136, 692-708

Institut International de Physique Solvay



Bruxelles du 22 au 29 octobre 1933

Institut International de Physique Solvay

J. D. Cockcroft	La désintégration des éléments par des protons accélérés
J. Chadwick	Diffusion anormale des particules α Transmutation des éléments par des particules α Le neutron
M et Mme Joliot	Rayonnement pénétrant des atomes sous l'action des rayons α

Bruxelles du 22 au 29 octobre 1933

Institut International de Physique Solvay

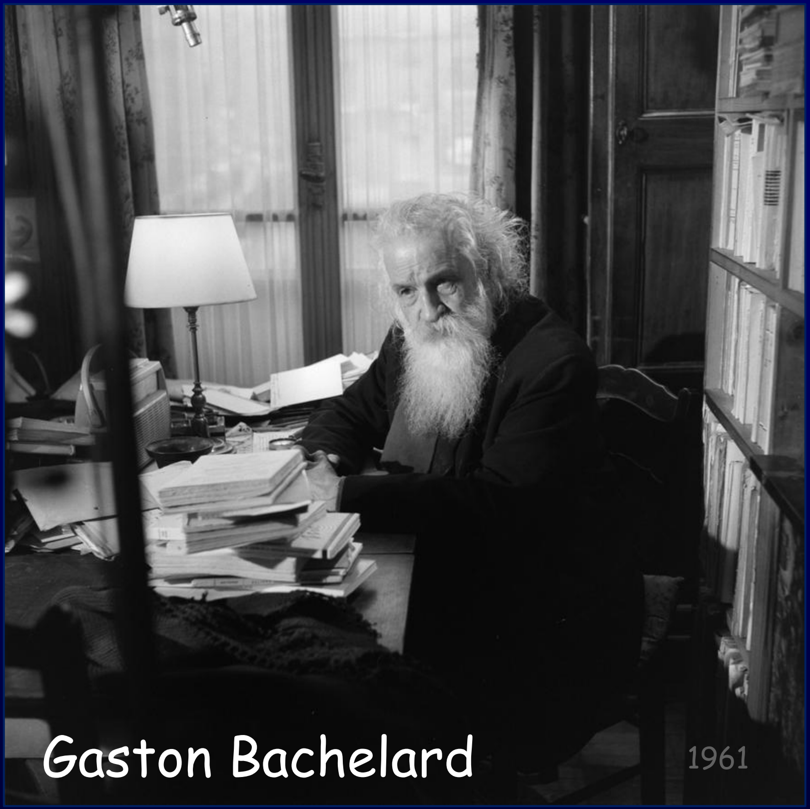
P.A.M. Dirac	Théorie du positron
G. Gamov	L'origine des rayons γ
W. Heisenberg	Considérations théoriques générales sur la structure du noyau

Bruxelles du 22 au 29 octobre 1933

Institut International de Physique Solvay

W. Heisenberg Considérations théoriques générales sur la structure du noyau

Bruxelles du 22 au 29 octobre 1933



Le nouvel esprit scientifique 1934