Introdução à Física de Partículas

Introduction to particle Physics

(2/3)

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1564-1896

1564-1642
Galileo

O pai da Física moderna

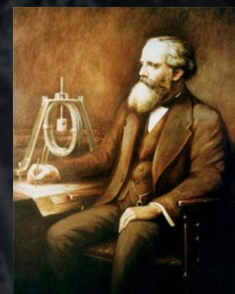
1642 - 1727
Newton

Mecânica Clássica

1773 - 1829
Young

Teoria ondulatóra da luz

1873
Maxwell

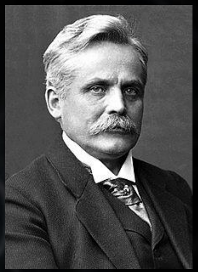


Electromagnetismo e propagação da luz

1887
Michelson-Morley

Não à Teoria do Éter

1896
Wien



Lei de Wien

1571-1630
Kepler

Movimento planetário

1791 - 1867
Faraday

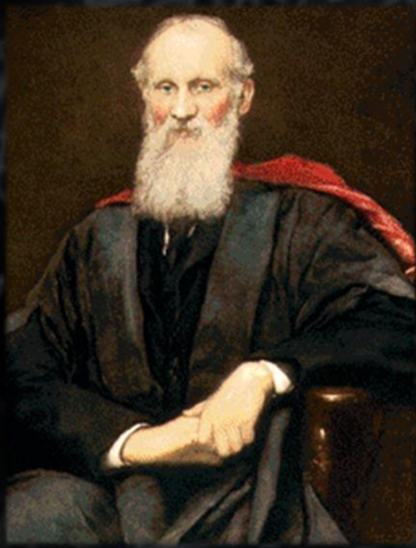
1799 - 1878
Henry

Indução

1904,1905
Rayleigh Jeans

Rayleigh - Jeans

"Nineteenth-Century Clouds over the Dynamical Theory of Heat and Light"



Lord Kelvin, 27 de Abril 1900

"The beauty and clearness of the dynamical theory, which asserts heat and light to be modes of motion, is at present obscured by two clouds."

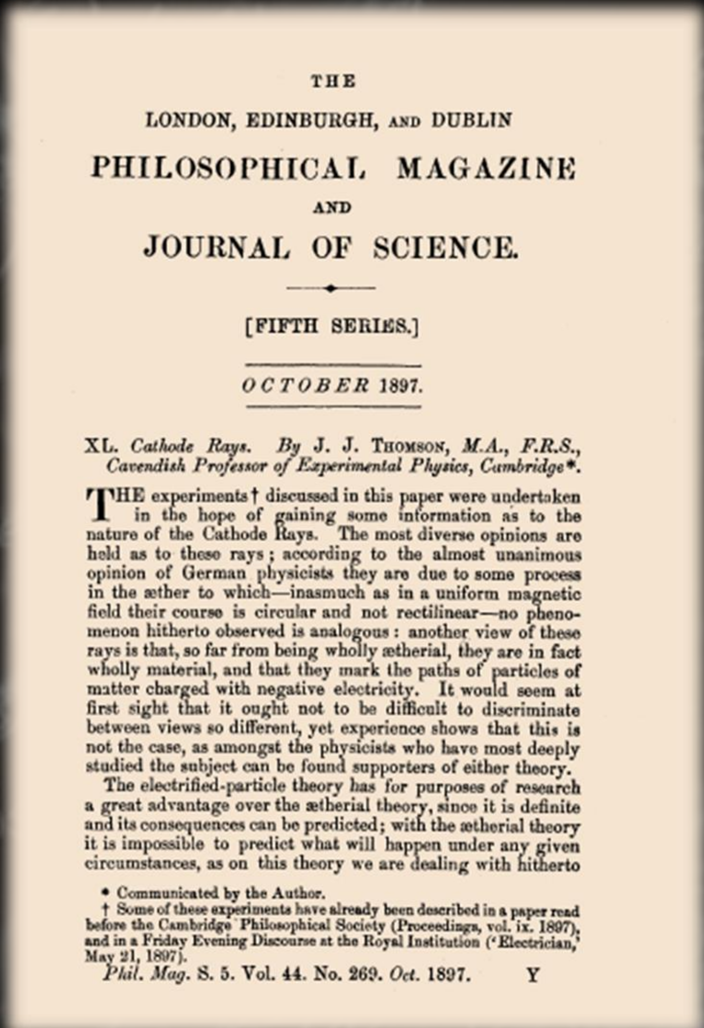
Que núvens eram essas?

Incapacidade de detectar o Éter e a "Catástrofe ultra-violeta"

A Física estaria limitada à medição de quantidades conhecidas com grande precisão...

Kelvin não podia estar mais enganado...

1897
1894-1896



THE

LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[FIFTH SERIES.]

OCTOBER 1897.

XL. *Cathode Rays.* *By* J. J. THOMSON, *M.A., F.R.S., Cavendish Professor of Experimental Physics, Cambridge**.

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 æther 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 ætherial, 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.

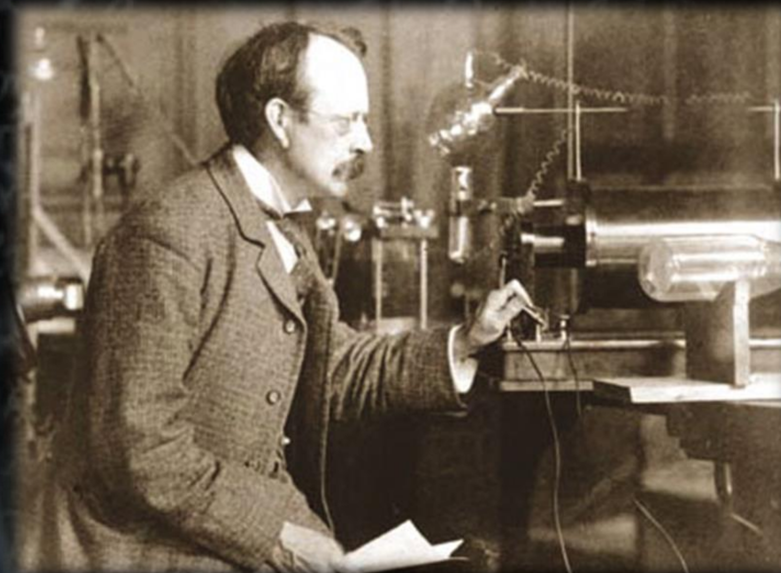
The electrified-particle theory has for purposes of research a great advantage over the ætherial theory, since it is definite and its consequences can be predicted; with the ætherial theory it is impossible to predict what will happen under any given circumstances, as on this theory we are dealing with hitherto

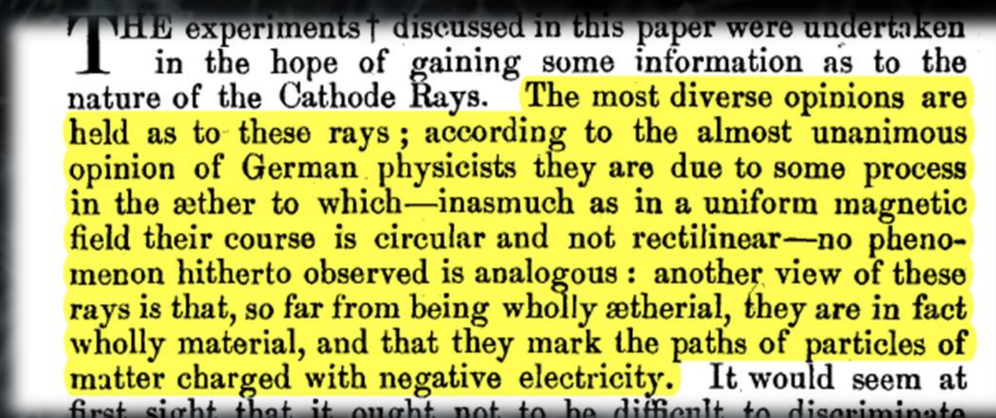
* Communicated by the Author.

† Some of these experiments have already been described in a paper read before the Cambridge Philosophical Society (Proceedings, vol. ix. 1897), and in a Friday Evening Discourse at the Royal Institution ('Electrician,' May 21, 1897).

Phil. Mag. S. 5. Vol. 44. No. 269. *Oct.* 1897. Y

J.J. Thomson





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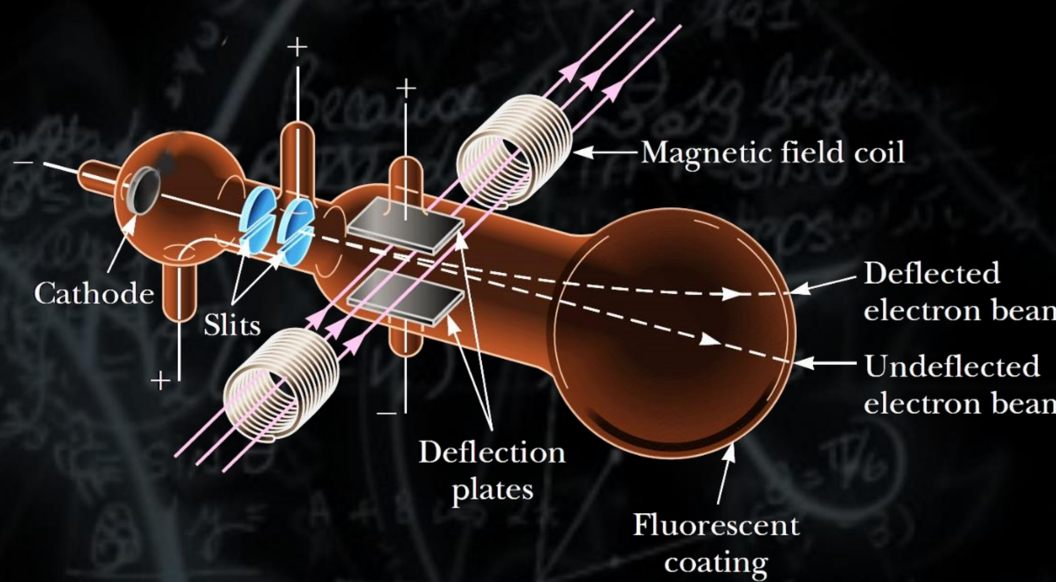
1897

1564-1896

Os raios catódicos são constituídos por "partículas" carregadas

$$\frac{q}{m} = 1.758820088 \pm 39 \times 10^{11}\ \mathrm{C/Kg}$$



Gas.	θ.	H.	F.	l.	m/e.	v.
Air	8/110	5·5	$1·5\times10^{10}$	5	$1·3\times10^{-7}$	$2·8\times10^{9}$
Air	9·5/110	5·4	$1·5\times10^{10}$	5	$1·1\times10^{-7}$	$2·8\times10^{9}$
Air	13/110	6·6	$1·5\times10^{10}$	5	$1·2\times10^{-7}$	$2·3\times10^{9}$
Hydrogen	9/110	6·3	$1·5\times10^{10}$	5	$1·5\times10^{-7}$	$2·5\times10^{9}$
Carbonic acid...	11/110	6·9	$1·5\times10^{10}$	5	$1·5\times10^{-7}$	$2·2\times10^{9}$
Air	6/110	5	$1·8\times10^{10}$	5	$1·3\times10^{-7}$	$3·6\times10^{9}$
Air	7/110	3·6	1×10^{10}	5	$1·1\times10^{-7}$	$2·8\times10^{9}$

O prémio Nobel da Física foi atríbuido a J.J. Thomson em 1906.

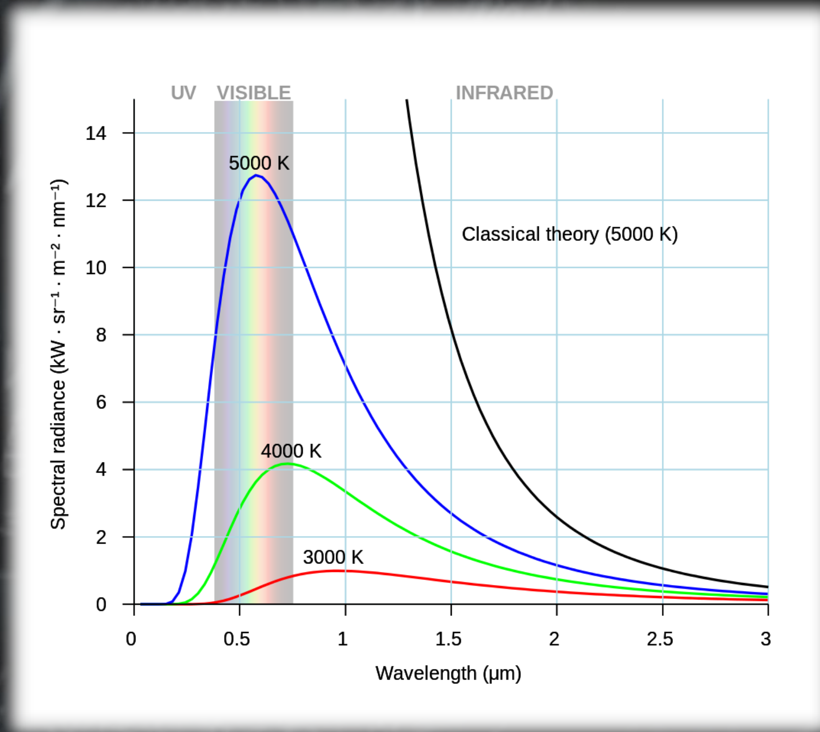
"in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases".

1900

Rayleigh-Jeans:

$$B_T(\lambda) = \frac{2ck_BT}{\lambda^4}$$

$\lambda \to 0$: Catástrofe UV



Falha da teoria clássica:

$$P(E) \propto \exp\left(-\frac{E}{k_BT}\right) \to \langle\, E \,\rangle = k_BT$$

A "energia electromagnética" pode apenas ser emitida em múltiplos de uma "energia fundamental" igual a $h\nu$.

$$P(E) \propto \exp\left(-\frac{nh\nu}{k_BT}\right) \to \langle\, E \,\rangle = \frac{h\nu}{e^{h\nu/k_BT} - 1}$$

1900

Distribuição de Planck para a radiação do corpo negro:

$$u = \frac{8 \pi h \nu^3}{c^3} \cdot \frac{1}{e^{\frac{h\nu}{k\vartheta}} - 1}$$

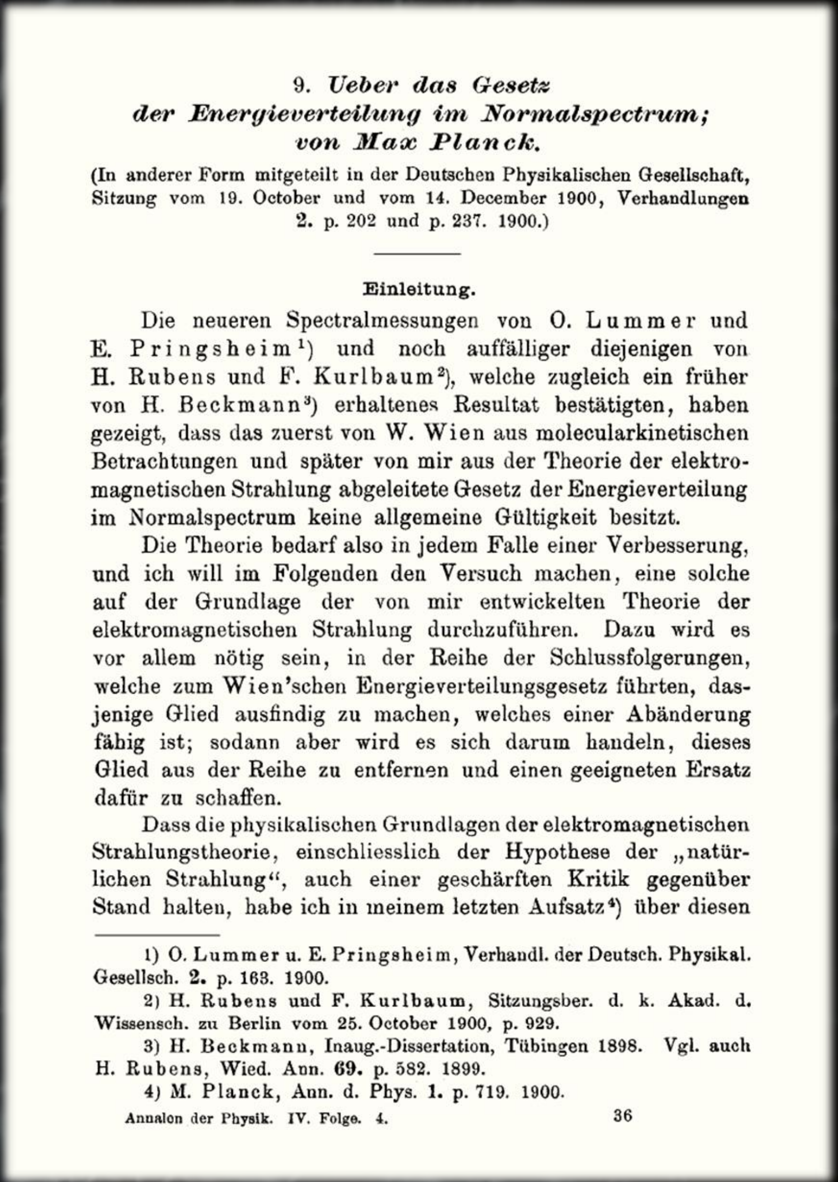
onde:

$$h = 6{,}55 \, . \, 10^{-27} \, \mathrm{erg} \, . \, \mathrm{sec}$$

ERA O ÍNICIO DA “TEORIA QUÂNTICA”

O prémio Nobel da Física foi atríbuido a Max Planck em 1918

"in recognition of the services he rendered to the advancement of Physics by his discovery of energy quanta".



9. *Ueber das Gesetz der Energieverteilung im Normalspectrum;* *von Max Planck.*

(In anderer Form mitgeteilt in der Deutschen Physikalischen Gesellschaft, Sitzung vom 19. October und vom 14. December 1900, Verhandlungen 2. p. 202 und p. 237. 1900.)

Einleitung.

Die neueren Spectralmessungen von O. Lummer und E. Pringsheim[1]) und noch auffälliger diejenigen von H. Rubens und F. Kurlbaum[2]), welche zugleich ein früher von H. Beckmann[3]) erhaltenes Resultat bestätigten, haben gezeigt, dass das zuerst von W. Wien aus molecularkinetischen Betrachtungen und später von mir aus der Theorie der elektromagnetischen Strahlung abgeleitete Gesetz der Energieverteilung im Normalspectrum keine allgemeine Gültigkeit besitzt.

Die Theorie bedarf also in jedem Falle einer Verbesserung, und ich will im Folgenden den Versuch machen, eine solche auf der Grundlage der von mir entwickelten Theorie der elektromagnetischen Strahlung durchzuführen. Dazu wird es vor allem nötig sein, in der Reihe der Schlussfolgerungen, welche zum Wien'schen Energieverteilungsgesetz führten, dasjenige Glied ausfindig zu machen, welches einer Abänderung fähig ist; sodann aber wird es sich darum handeln, dieses Glied aus der Reihe zu entfernen und einen geeigneten Ersatz dafür zu schaffen.

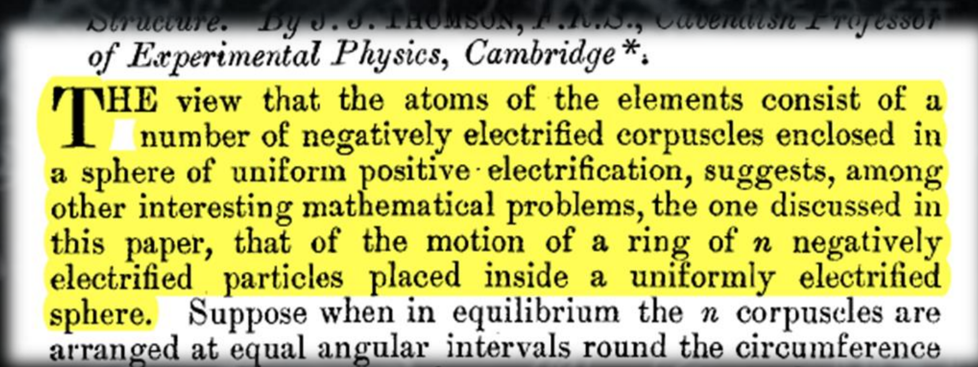
Dass die physikalischen Grundlagen der elektromagnetischen Strahlungstheorie, einschliesslich der Hypothese der „natürlichen Strahlung“, auch einer geschärften Kritik gegenüber Stand halten, habe ich in meinem letzten Aufsatz[4]) über diesen

1) O. Lummer u. E. Pringsheim, Verhandl. der Deutsch. Physikal. Gesellsch. 2. p. 163. 1900.
2) H. Rubens und F. Kurlbaum, Sitzungsber. d. k. Akad. d. Wissensch. zu Berlin vom 25. October 1900, p. 929.
3) H. Beckmann, Inaug.-Dissertation, Tübingen 1898. Vgl. auch H. Rubens, Wied. Ann. 69. p. 582. 1899.
4) M. Planck, Ann. d. Phys. 1. p. 719. 1900.

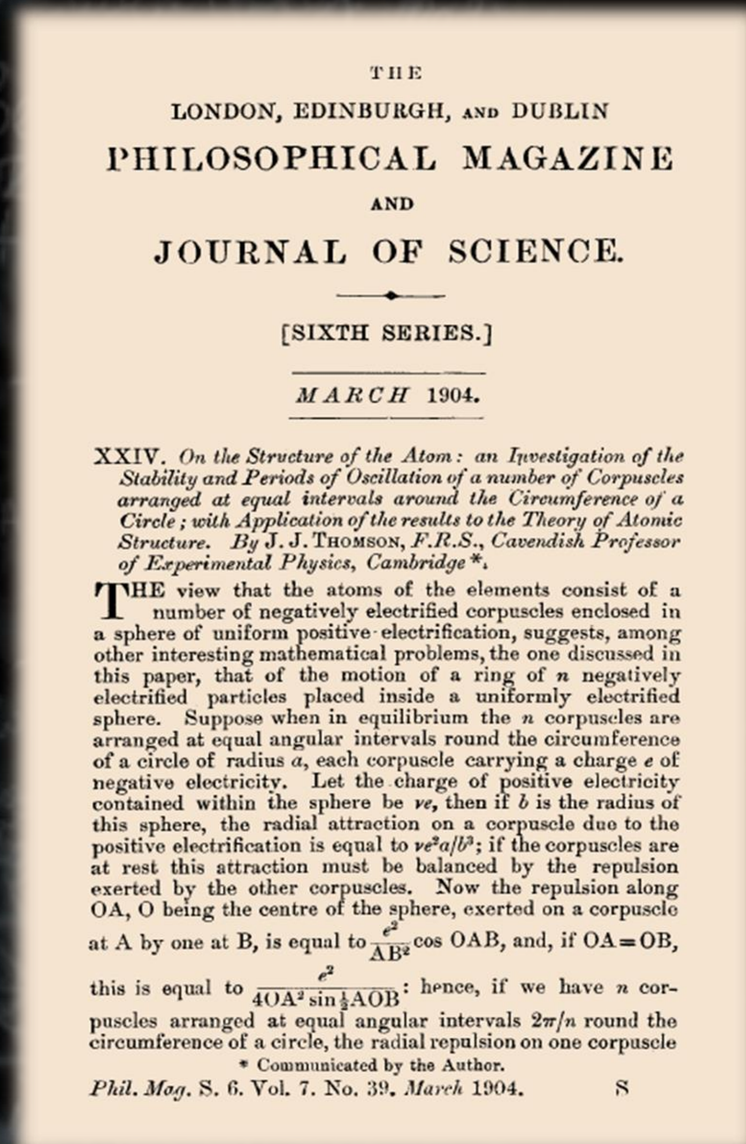
Annalen der Physik. IV. Folge. 4. 36

1904

O modelo “Bolo de passas”


Structure. By J. J. Thomson, F.R.S., Cavendish Professor of Experimental Physics, Cambridge *.

THE view that the atoms of the elements 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


THE

LONDON, EDINBURGH, AND DUBLIN

PHILOSOPHICAL MAGAZINE

AND

JOURNAL OF SCIENCE.

[SIXTH SERIES.]

MARCH 1904.

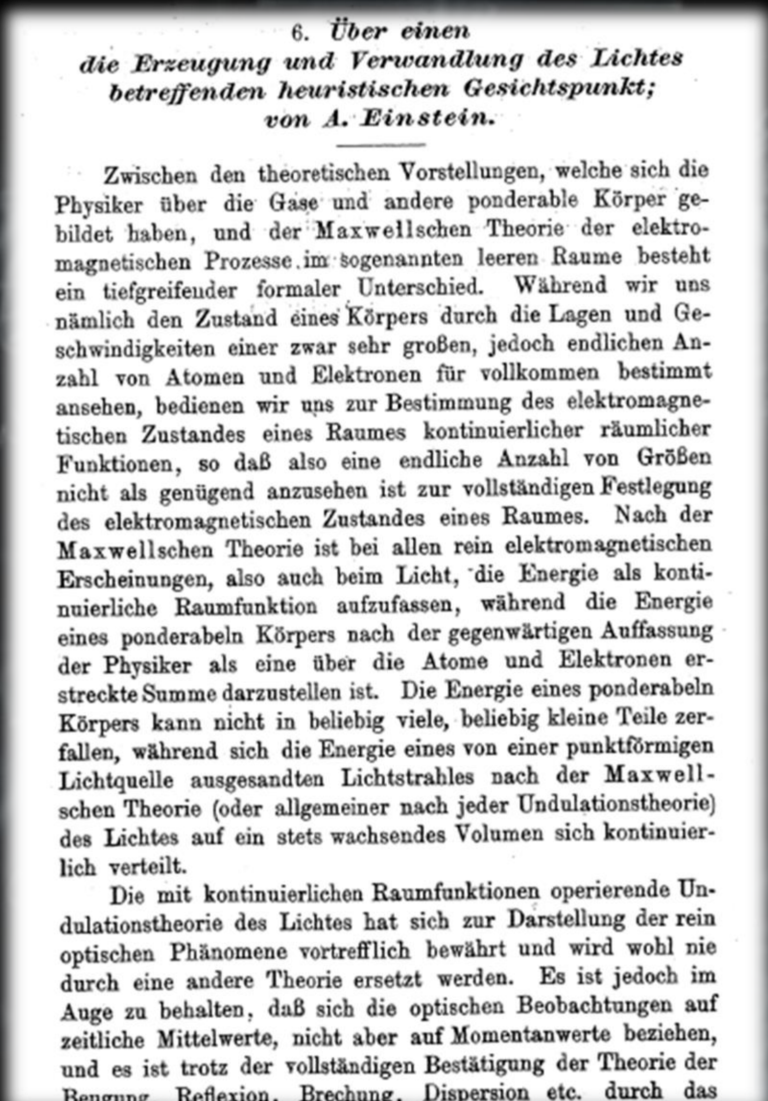
XXIV. *On the Structure of the Atom: an Investigation of the Stability and Periods of Oscillation of a number of Corpuscles arranged at equal intervals around the Circumference of a Circle; with Application of the results to the Theory of Atomic Structure.* By J. J. Thomson, *F.R.S., Cavendish Professor of Experimental Physics, Cambridge* *.

THE view that the atoms of the elements 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 $\frac{e^2}{4OA^2\sin\frac{1}{2}AOB}$: 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.

Phil. Mag. S. 6. Vol. 7. No. 39. *March* 1904. S

1905



6. *Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt;* *von A. Einstein.*

Zwischen den theoretischen Vorstellungen, welche sich die Physiker über die Gase und andere ponderable Körper gebildet haben, und der Maxwellschen Theorie der elektromagnetischen Prozesse im sogenannten leeren Raume besteht ein tiefgreifender formaler Unterschied. Während wir uns nämlich den Zustand eines Körpers durch die Lagen und Geschwindigkeiten einer zwar sehr großen, jedoch endlichen Anzahl von Atomen und Elektronen für vollkommen bestimmt ansehen, bedienen wir uns zur Bestimmung des elektromagnetischen Zustandes eines Raumes kontinuierlicher räumlicher Funktionen, so daß also eine endliche Anzahl von Größen nicht als genügend anzusehen ist zur vollständigen Festlegung des elektromagnetischen Zustandes eines Raumes. Nach der Maxwellschen Theorie ist bei allen rein elektromagnetischen Erscheinungen, also auch beim Licht, die Energie als kontinuierliche Raumfunktion aufzufassen, während die Energie eines ponderabeln Körpers nach der gegenwärtigen Auffassung der Physiker als eine über die Atome und Elektronen erstreckte Summe darzustellen ist. Die Energie eines ponderabeln Körpers kann nicht in beliebig viele, beliebig kleine Teile zerfallen, während sich die Energie eines von einer punktförmigen Lichtquelle ausgesandten Lichtstrahles nach der Maxwellschen Theorie (oder allgemeiner nach jeder Undulationstheorie) des Lichtes auf ein stets wachsendes Volumen sich kontinuierlich verteilt.

Die mit kontinuierlichen Raumfunktionen operierende Undulationstheorie des Lichtes hat sich zur Darstellung der rein optischen Phänomene vortrefflich bewährt und wird wohl nie durch eine andere Theorie ersetzt werden. Es ist jedoch im Auge zu behalten, daß sich die optischen Beobachtungen auf zeitliche Mittelwerte, nicht aber auf Momentanwerte beziehen, und es ist trotz der vollständigen Bestätigung der Theorie der Beugung, Reflexion, Brechung, Dispersion etc. durch das

On a heuristic point of view about the creation and conversion of light

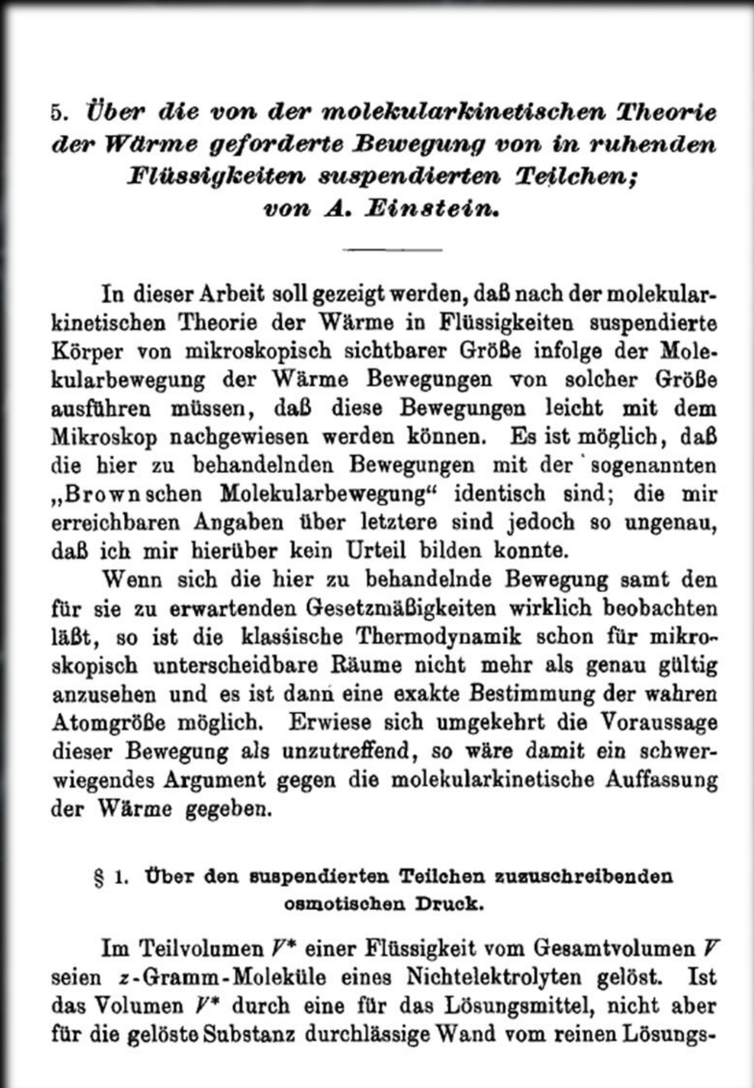
Annalen der Physik **17** (6): 132–148 (1905)

$$K_{MAX} = h\nu - W$$

O prémio Nobel da Física foi atríbuido a Albert Einstein em 1921;

"for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect".

1904 — 1905


5. *Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen;*
von A. Einstein.

In dieser Arbeit soll gezeigt werden, daß nach der molekularkinetischen Theorie der Wärme in Flüssigkeiten suspendierte Körper von mikroskopisch sichtbarer Größe infolge der Molekularbewegung der Wärme Bewegungen von solcher Größe ausführen müssen, daß diese Bewegungen leicht mit dem Mikroskop nachgewiesen werden können. Es ist möglich, daß die hier zu behandelnden Bewegungen mit der sogenannten „Brownschen Molekularbewegung" identisch sind; die mir erreichbaren Angaben über letztere sind jedoch so ungenau, daß ich mir hierüber kein Urteil bilden konnte.

Wenn sich die hier zu behandelnde Bewegung samt den für sie zu erwartenden Gesetzmäßigkeiten wirklich beobachten läßt, so ist die klassische Thermodynamik schon für mikroskopisch unterscheidbare Räume nicht mehr als genau gültig anzusehen und es ist dann eine exakte Bestimmung der wahren Atomgröße möglich. Erwiese sich umgekehrt die Voraussage dieser Bewegung als unzutreffend, so wäre damit ein schwerwiegendes Argument gegen die molekularkinetische Auffassung der Wärme gegeben.

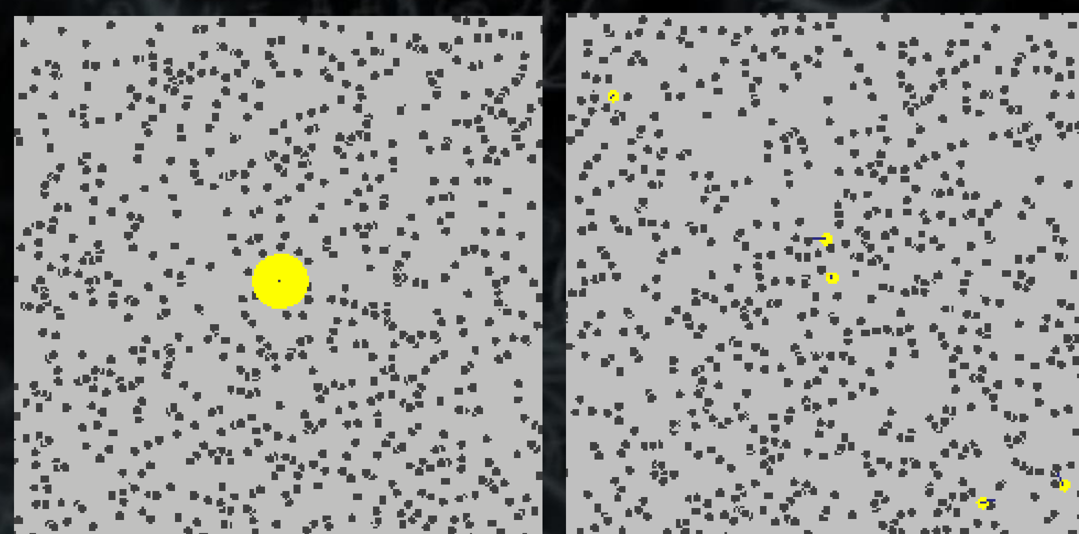
§ 1. Über den suspendierten Teilchen zuzuschreibenden osmotischen Druck.

Im Teilvolumen V^* einer Flüssigkeit vom Gesamtvolumen V seien z-Gramm-Moleküle eines Nichtelektrolyten gelöst. Ist das Volumen V^* durch eine für das Lösungsmittel, nicht aber für die gelöste Substanz durchlässige Wand vom reinen Lösungs-

"On the Motion of Small Particles Suspended in a Stationary Liquid, as Required by the Molecular Kinetic Theory of Heat"

Annalen der Physik **17** (8): 549–560 (1905)

Movimento de partículas suspensas num líquido ou gás



Movimento Browniano

1904

1905

Deslocamento médio:

$$\lambda_x = \sqrt{t} \cdot \sqrt{\frac{RT}{N} \frac{1}{3 \pi k P}}.$$

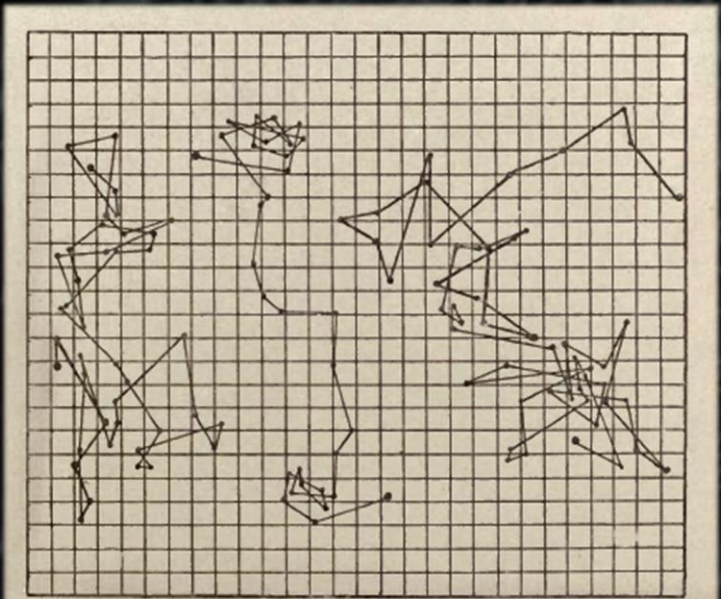


FIG. 8.

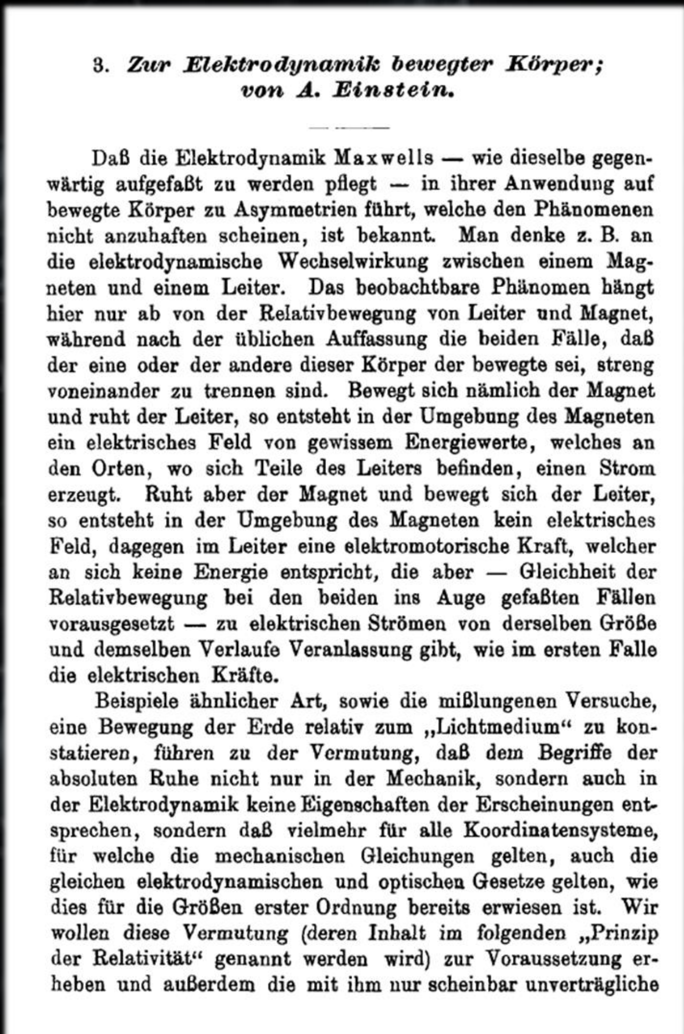
Jean Perrin verificou experimentalmente a teoria de Einstein e determinou o número de Avogadro:

$$N = 62.10^{22};$$

O prémio Nobel da Física foi atríbuido a Jean Baptiste Perrin em 1926;

"for his work on the discontinuous structure of matter, and especially for his discovery of sedimentation equilibrium"

1904 — 1905


3. *Zur Elektrodynamik bewegter Körper;*
von A. Einstein.

Daß die Elektrodynamik Maxwells — wie dieselbe gegenwärtig aufgefaßt zu werden pflegt — in ihrer Anwendung auf bewegte Körper zu Asymmetrien führt, welche den Phänomenen nicht anzuhaften scheinen, ist bekannt. Man denke z. B. an die elektrodynamische Wechselwirkung zwischen einem Magneten und einem Leiter. Das beobachtbare Phänomen hängt hier nur ab von der Relativbewegung von Leiter und Magnet, während nach der üblichen Auffassung die beiden Fälle, daß der eine oder der andere dieser Körper der bewegte sei, streng voneinander zu trennen sind. Bewegt sich nämlich der Magnet und ruht der Leiter, so entsteht in der Umgebung des Magneten ein elektrisches Feld von gewissem Energiewerte, welches an den Orten, wo sich Teile des Leiters befinden, einen Strom erzeugt. Ruht aber der Magnet und bewegt sich der Leiter, so entsteht in der Umgebung des Magneten kein elektrisches Feld, dagegen im Leiter eine elektromotorische Kraft, welcher an sich keine Energie entspricht, die aber — Gleichheit der Relativbewegung bei den beiden ins Auge gefaßten Fällen vorausgesetzt — zu elektrischen Strömen von derselben Größe und demselben Verlaufe Veranlassung gibt, wie im ersten Falle die elektrischen Kräfte.

Beispiele ähnlicher Art, sowie die mißlungenen Versuche, eine Bewegung der Erde relativ zum „Lichtmedium" zu konstatieren, führen zu der Vermutung, daß dem Begriffe der absoluten Ruhe nicht nur in der Mechanik, sondern auch in der Elektrodynamik keine Eigenschaften der Erscheinungen entsprechen, sondern daß vielmehr für alle Koordinatensysteme, für welche die mechanischen Gleichungen gelten, auch die gleichen elektrodynamischen und optischen Gesetze gelten, wie dies für die Größen erster Ordnung bereits erwiesen ist. Wir wollen diese Vermutung (deren Inhalt im folgenden „Prinzip der Relativität" genannt werden wird) zur Voraussetzung erheben und außerdem die mit ihm nur scheinbar unverträgliche

On the electrodynamics of moving bodies

Annalen der Physik **17** (10): 891-921 (1905)

Postulados da RR:

- As leis da Física são válidas em todos os referenciais inerciais.
- A velocidade da luz é constante e o seu valor não depende do estado de movimento do observador (nem da fonte).

Espaço – tempo: $x^\mu = (ct, x, y, z)$

Consequências: Contracção do espaço, dilatação do tempo, equivalência massa-energia.

1904 — 1905

Does the inertia of a body depend on its energy content?

Annalen der Physik **18** (13): 639-641 (1905)

13. ***Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig?***
von A. Einstein.

Die Resultate einer jüngst in diesen Annalen von mir publizierten elektrodynamischen Untersuchung[1]) führen zu einer sehr interessanten Folgerung, die hier abgeleitet werden soll.

Ich legte dort die Maxwell-Hertzschen Gleichungen für den leeren Raum nebst dem Maxwellschen Ausdruck für die elektromagnetische Energie des Raumes zugrunde und außerdem das Prinzip:

Die Gesetze, nach denen sich die Zustände der physikalischen Systeme ändern, sind unabhängig davon, auf welches von zwei relativ zueinander in gleichförmiger Parallel-Translationsbewegung befindlichen Koordinatensystemen diese Zustandsänderungen bezogen werden (Relativitätsprinzip).

Gestützt auf diese Grundlagen[2]) leitete ich unter anderem das nachfolgende Resultat ab (l. c. § 8):

Ein System von ebenen Lichtwellen besitze, auf das Koordinatensystem (x, y, z) bezogen, die Energie l; die Strahlrichtung (Wellennormale) bilde den Winkel φ mit der x-Achse des Systems. Führt man ein neues, gegen das System (x, y, z) in gleichförmiger Paralleltranslation begriffenes Koordinatensystem (ξ, η, ζ) ein, dessen Ursprung sich mit der Geschwindigkeit v längs der x-Achse bewegt, so besitzt die genannte Lichtmenge — im System (ξ, η, ζ) gemessen — die Energie:

$$l^* = l \frac{1 - \frac{v}{V} \cos \varphi}{\sqrt{1 - \left(\frac{v}{V}\right)^2}},$$

wobei V die Lichtgeschwindigkeit bedeutet. Von diesem Resultat machen wir im folgenden Gebrauch.

1) A. Einstein, Ann. d. Phys. 17. p. 891. 1905.
2) Das dort benutzte Prinzip der Konstanz der Lichtgeschwindigkeit ist natürlich in den Maxwellschen Gleichungen enthalten.

42*

allgemeineren Folgerung geführt werden:

Die Masse eines Körpers ist ein Maß für dessen Energieinhalt; ändert sich die Energie um L, so ändert sich die Masse in demselben Sinne um $L/9.10^{20}$, wenn die Energie in Erg und die Masse in Grammen gemessen wird.

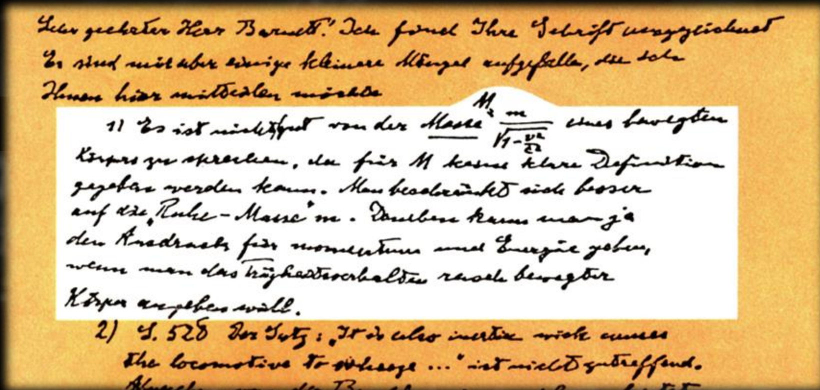
Es ist nicht ausgeschlossen, daß bei Körpern, deren

Se um corpo emitir uma energia L na forma de radiação, então a sua massa diminui de L/c^2.

Ou, em linguagem moderna:

$$E = mc^2$$

1904 — **1905**



$$m^2c^4 = E^2 - p^2c^2$$

THE mass m is a lorentz invariant quantity.
No need for other mass definitions.

THE CONCEPT OF MASS

In the modern language of relativity theory there is only one mass, the Newtonian mass m, which does not vary with velocity; hence the famous formula $E = mc^2$ has to be taken with a large grain of salt.

Lev B. Okun

Letter from Albert Einstein to Lincoln Barnett, 19 June 1948.

"It is not good to introduce the concept of mass

$$M = \frac{m}{\sqrt{1 - v^2/c^2}}$$

of a moving body for which no clear definition can be given. It is better to introduce no other mass concept than the 'rest mass' m. Instead of introducing M, it is better to mention the expression for the momentum and energy of a body in motion".

opinion poll related to it.

The famous Einstein relation between mass and energy is a symbol of our century. Here you have four equations:

$$E_0 = mc^2 \quad (1)$$

$$E = mc^2 \quad (2)$$

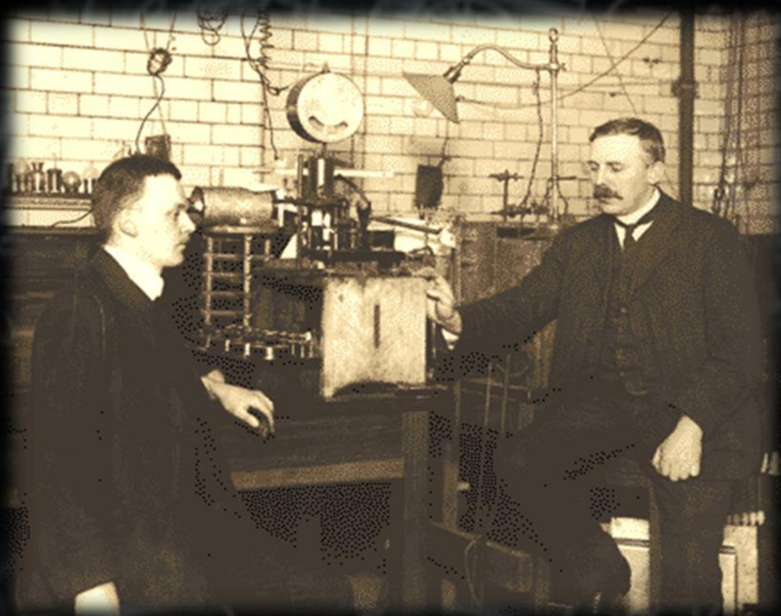
$$E_0 = m_0c^2 \quad (3)$$

$$E = m_0c^2 \quad (4)$$

In these equations c is the velocity of light, E the total energy of a free body, E_0 its rest energy, m_0 its rest mass and m its mass.

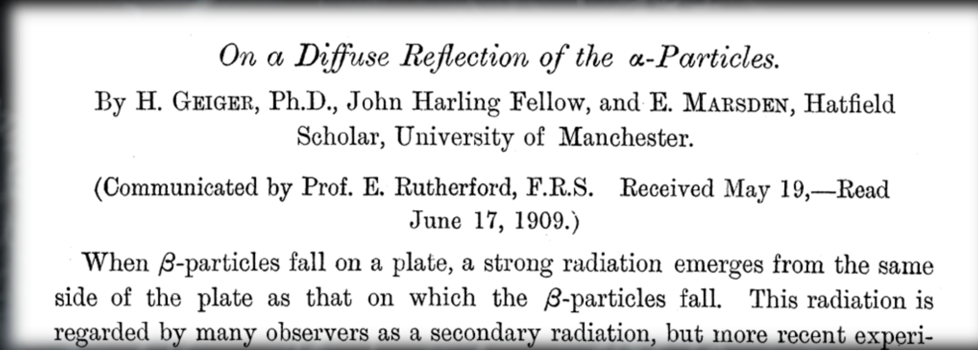
1905 / 1911

Rutherford & Geiger



“It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fire a 15-inch shell at a piece of tissue paper and it came back and hit you.”

E. Rutherford

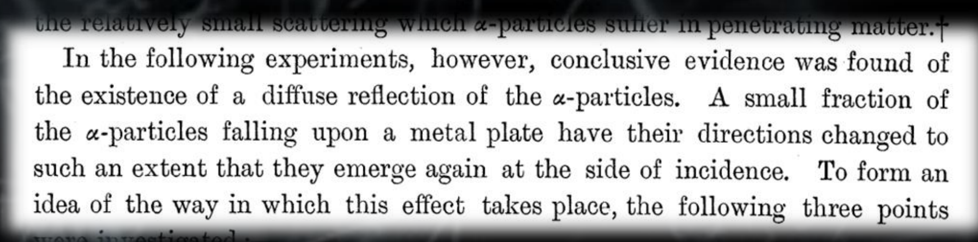


On a Diffuse Reflection of the α-Particles.

By H. Geiger, Ph.D., John Harling Fellow, and E. Marsden, Hatfield Scholar, University of Manchester.

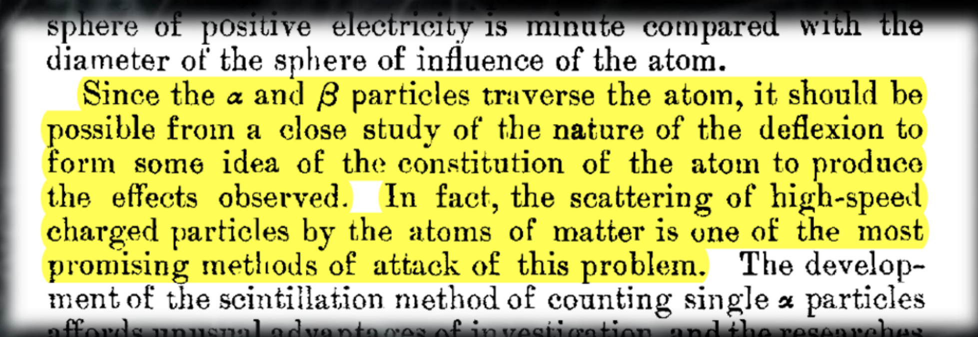
(Communicated by Prof. E. Rutherford, F.R.S. Received May 19,—Read June 17, 1909.)

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 experi-



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

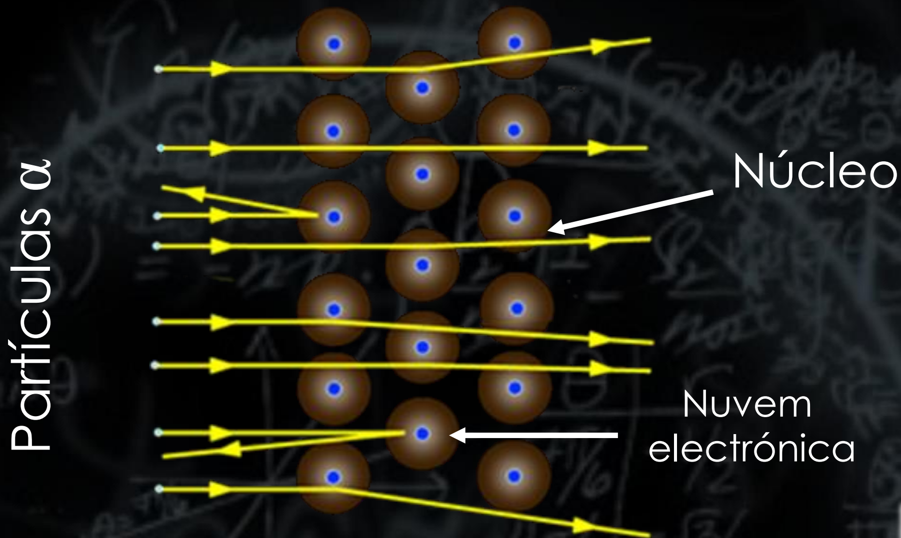


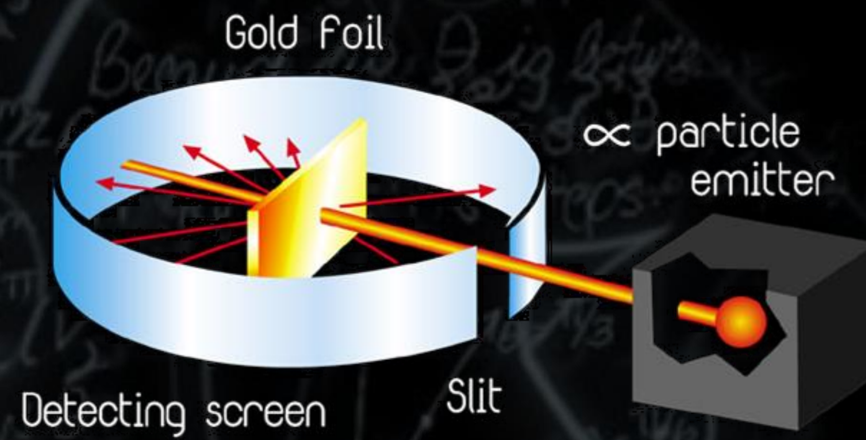
sphere of positive electricity is minute compared with the diameter of the sphere of influence of the atom.

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

“The scattering of a and β particles by matter and the structure of the atom”, E. Rutherford, 1911.

1905 — **1911**





Secção eficaz de Rutherford (clássica).

$$\frac{d\sigma}{d\theta} = \left(\frac{Zze^2}{8\pi\varepsilon_0 m v^2}\right)^2 \frac{1}{\sin^4(\theta/2)}$$

Variation of scattering with angle.

I	II	III	IV	V	VI
		Silver		Gold	
Angle of deflection, ϕ	$\mathrm{cosec}^4 \frac{1}{2}\phi$	Number of scintillations, N	$\frac{N}{\mathrm{cosec}^4 \frac{1}{2}\phi}$	Number of scintillations, N	$\frac{N}{\mathrm{cosec}^4 \frac{1}{2}\phi}$
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

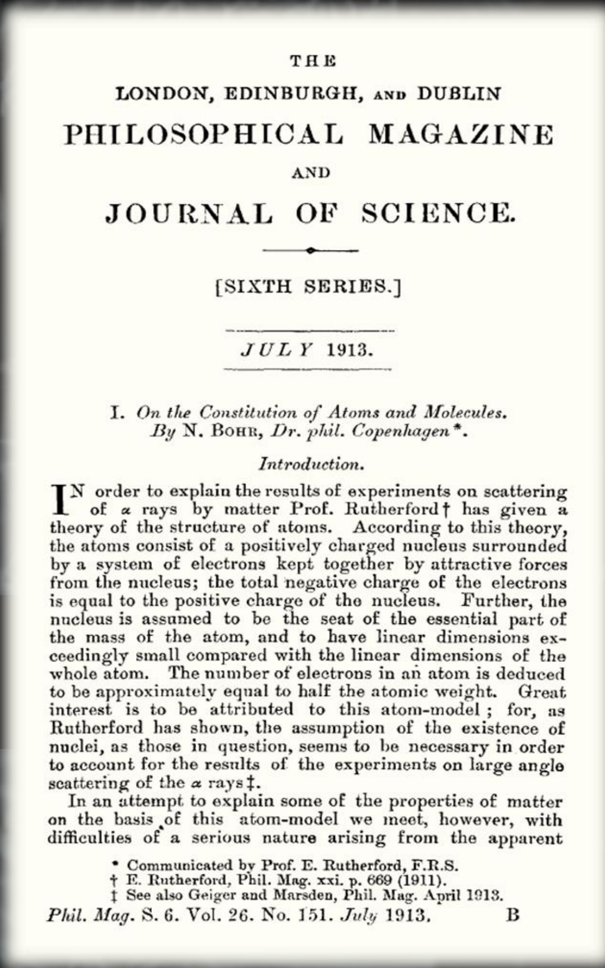
1913

Modelo “Planetário” de Rutherford → Átomo instável

MODELO DE BOHR – O electrão orbita em volta do núcleo em órbitas bem definidas.

Quantização do momento angular:

$$m_e v\, r = n\hbar \rightarrow E_n = -\frac{13.6}{n^2}\ \text{eV}$$



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.

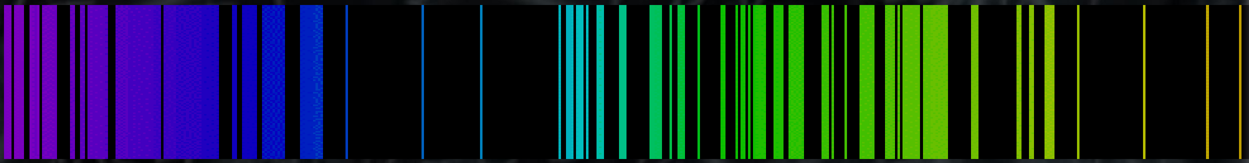
IN order to explain the results of experiments on scattering of α rays by matter Prof. Rutherford† has given a theory of the structure of atoms. According to this theory, the atoms consist of a positively charged nucleus surrounded by a system of electrons kept together by attractive forces from the 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

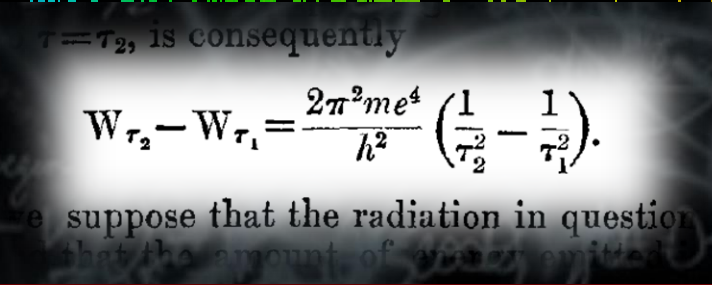
* Communicated by Prof. E. Rutherford, F.R.S.
† E. Rutherford, Phil. Mag. xxi. p. 669 (1911).
‡ See also Geiger and Marsden, Phil. Mag. April 1913.

Phil. Mag. S. 6. Vol. 26. No. 151. *July* 1913. B

Explicação para as linhas de emissão atómicas:



Fórmula de Rydberg:



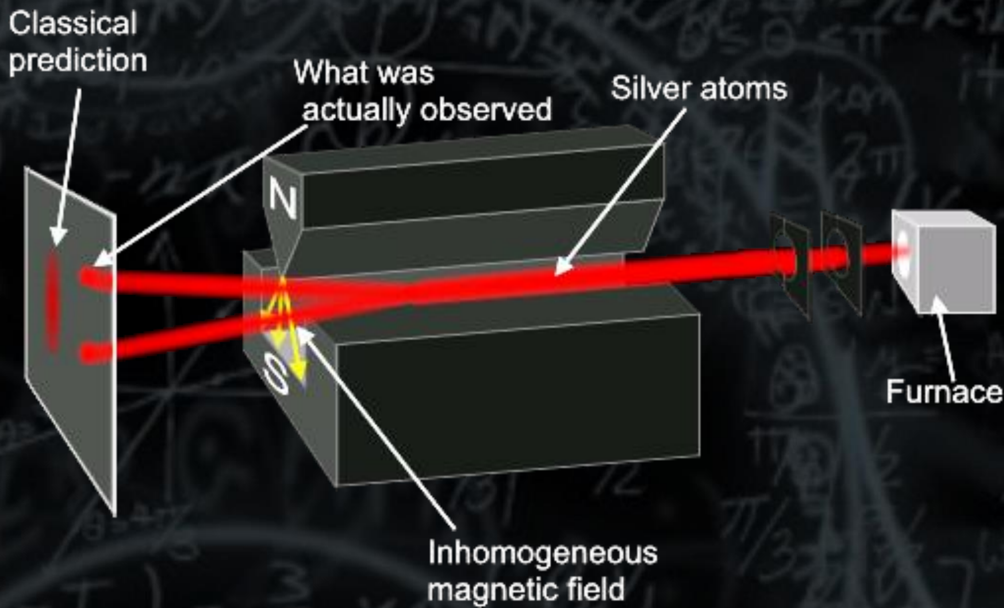
$\tau = \tau_2$, is consequently

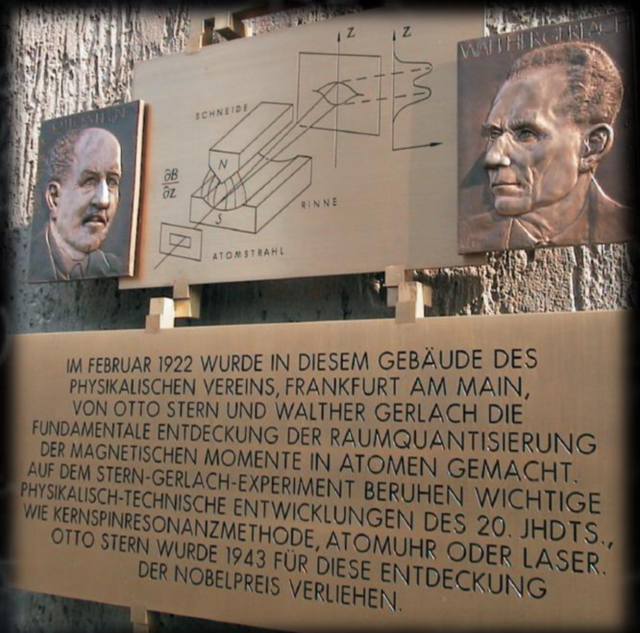
$$W_{\tau_2} - W_{\tau_1} = \frac{2\pi^2 m e^4}{h^2}\left(\frac{1}{\tau_2^2} - \frac{1}{\tau_1^2}\right).$$

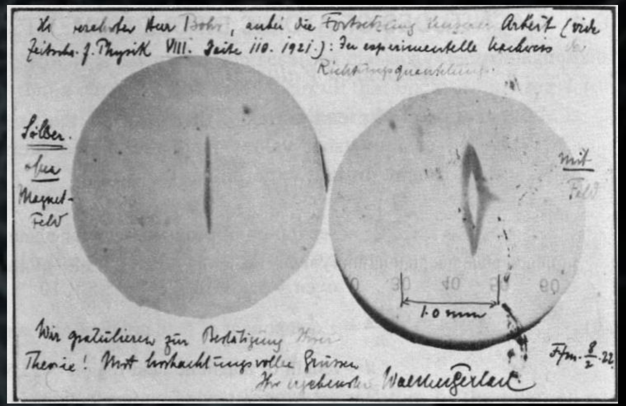
suppose that the radiation in question

1922

EXPERIÊNCIA DE STERN-GERLACH







Os electrões têm um momento angular intrínseco.

SPIN: $S_z = \pm \frac{\hbar}{2}$ Quantização !!!

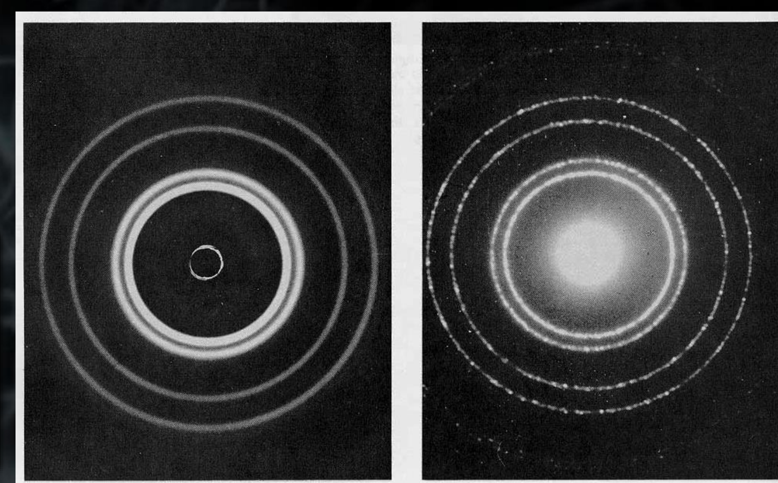
1924

NATUREZA ONDULATÓRIA DA MATÉRIA: $\lambda = h/p$

When I conceived the first basic ideas of wave mechanics in 1923–24,[1] I was guided by the aim to perform a real physical synthesis, valid for all particles, of the coexistence of the wave and of the corpuscular aspects that Einstein had introduced for photons in his theory of light quanta in 1905. I did not have any doubts at that time about the physical reality of the wave and the localization of the particle in the wave.

At that time, one remark made a deep impression on me. The phase of the plane monochromatic wave, written as

Verificada experimentalmente por Davisson e Germer em 1927



O prémio Nobel da Física foi atríbuido a Louis De Broglie em 1929;

"for his discovery of the wave nature of electrons".

1920-1925

Apesar dos sucessos do modelo de Bohr, o mesmo tinha várias limitações.

- Intensidade relativa das riscas de emissão;
- Não permitia descrever átomos com mais eletrões;
- Separação das linhas espetrais devido a campos magnéticos externos (efeito de Zeeman);
- Estrutuna fina e hiperfina dos átomos;

1920-1925

ERA NECESSÁRIA UMA TEORIA QUE FOSSE BASEADA EM PRIMEIROS PRINCÍPIOS

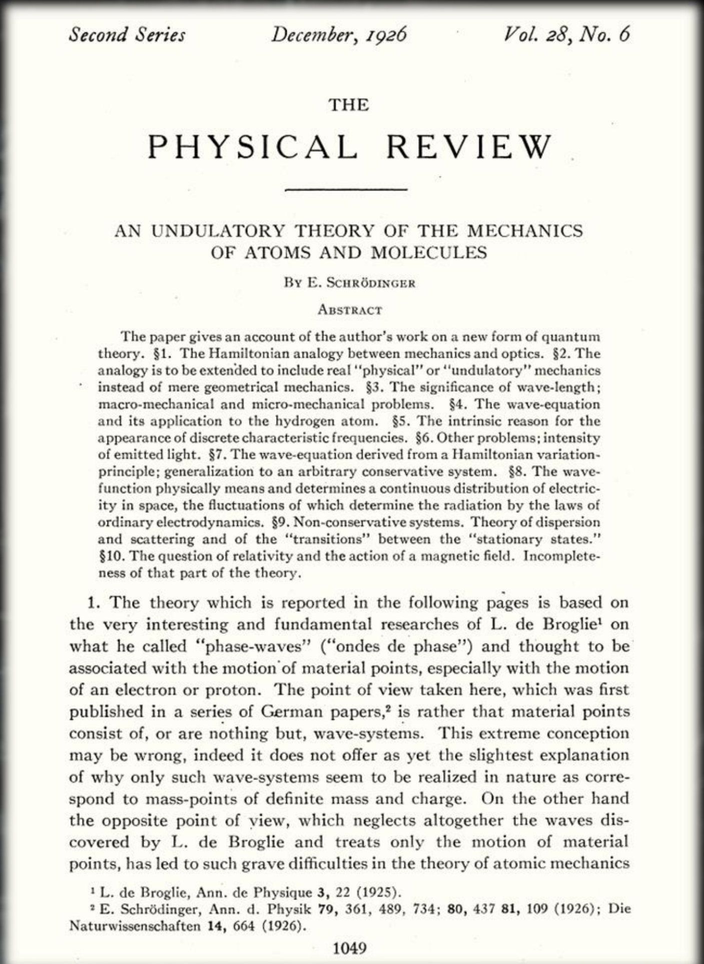
1920-1925

Abandono do determinismo da Física clássica

$$\vec{r}, t \quad \rightarrow \quad \psi(\vec{r}, t)$$

EQUAÇÃO DE SCHRöDINGER

$$\Delta\psi + 8\pi^2 m(E - V)\psi / h^2 = 0$$



Second Series *December, 1926* *Vol. 28, No. 6*

THE

PHYSICAL REVIEW

AN UNDULATORY THEORY OF THE MECHANICS OF ATOMS AND MOLECULES

By E. Schrödinger

Abstract

The paper gives an account of the author's work on a new form of quantum theory. §1. The Hamiltonian analogy between mechanics and optics. §2. The analogy is to be extended to include real "physical" or "undulatory" mechanics instead of mere geometrical mechanics. §3. The significance of wave-length; macro-mechanical and micro-mechanical problems. §4. The wave-equation and its application to the hydrogen atom. §5. The intrinsic reason for the appearance of discrete characteristic frequencies. §6. Other problems; intensity of emitted light. §7. The wave-equation derived from a Hamiltonian variation-principle; generalization to an arbitrary conservative system. §8. The wave-function physically means and determines a continuous distribution of electricity in space, the fluctuations of which determine the radiation by the laws of ordinary electrodynamics. §9. Non-conservative systems. Theory of dispersion and scattering and of the "transitions" between the "stationary states." §10. The question of relativity and the action of a magnetic field. Incompleteness of that part of the theory.

1. The theory which is reported in the following pages is based on the very interesting and fundamental researches of L. de Broglie[1] on what he called "phase-waves" ("ondes de phase") and thought to be associated with the motion of material points, especially with the motion of an electron or proton. The point of view taken here, which was first published in a series of German papers,[2] is rather that material points consist of, or are nothing but, wave-systems. This extreme conception may be wrong, indeed it does not offer as yet the slightest explanation of why only such wave-systems seem to be realized in nature as correspond to mass-points of definite mass and charge. On the other hand the opposite point of view, which neglects altogether the waves discovered by L. de Broglie and treats only the motion of material points, has led to such grave difficulties in the theory of atomic mechanics

[1] L. de Broglie, Ann. de Physique **3**, 22 (1925).
[2] E. Schrödinger, Ann. d. Physik **79**, 361, 489, 734; **80**, 437 **81**, 109 (1926); Die Naturwissenschaften **14**, 664 (1926).

1049

Numa versão mais moderna:

$$i\hbar \frac{d\psi(\vec{r}, t)}{dt} = \left[-\frac{\hbar^2}{2m} \nabla^2 + V(\vec{r}, t) \right] \psi(\vec{r}, t)$$

1920-1925

1926

Qual o significado de ψ?

Max Born

where the ν^0_{nm} are the frequencies of the unperturbed atom.

If one translates this result into terms of particles, only one interpretation is possible. $\Phi_{n_\tau m}(\alpha, \beta, \gamma)$ gives the probability* for the electron, arriving from the z-direction, to be thrown out into the direction designated by the angles α, β, γ, with the phase change δ. Here its energy τ has increased by one quantum $h\nu^0_{nm}$ at the cost of the energy of the atom (collision of the first kind for $W^0_n < W^0_m$, $h\nu^0_{nm} < 0$; collision of the second kind $W^0_n > W^0_m$, $h\nu^0_{nm} > 0$).

"On the quantum mechanics of collisions", 1926

INTERPRETAÇÃO PROBABILISTICA

$$|\psi(\vec{r},t)|^2 d^3\vec{r}$$

Probabilidade de encontrar a partícula num volume infinitesimal $d^3\vec{r}$

$$\int |\psi(\vec{r},t)|^2 \, d^3\vec{r} = 1$$

gerade einen gequantelten Zustand des ganzen Gaskörpers und umgekehrt. Fermis statistische Grundannahme erscheint demnach auch vom Stand-

1) Hat man ein System aus N Partikeln, mit den Lagenkoordinaten $q_1 \ldots q_f$, so wird jedem Quantenzustand des Systems nach Schrödinger eine Funktion $\psi(q_1 \ldots q_f)$ zugeordnet, die einer von ihm angegebenen Differentialgleichung genügt. Wir wollen diese (vom reinen Wellenstandpunkt aus wohl kaum verständliche) Funktion im Sinne der von Born in seiner Stoßmechanik (ZS. f. Phys. **37**, 863, 1926; **38**, 803, 1926) vertretenen Auffassung des „Gespensterfeldes" folgendermaßen deuten: Es ist $|\psi(q_1 \ldots q_f)|^2 dq_1 \ldots dq_f$ die Wahrscheinlichkeit dafür, daß im betreffenden Quantenzustand des Systems diese Koordinaten sich zugleich im betreffenden Volumenelement $dq_1 \ldots dq_f$ des Lagenraumes befinden. Die im Text erwähnte Vorschrift für die Charakterisierung der in der Natur realisierten Lösung im besonderen Falle N gleicher Partikel besagt nun, daß die zugehörige Funktion ψ das Vorzeichen ändern soll, wenn man die Koordinaten je zweier Partikeln vertauscht. Haben die Teilchen wie die Elektronen einen Eigenimpuls, so müssen zu den drei Translationskoordinaten für jede Partikel noch weitere den Rotationsfreiheitsgraden entsprechende Koordinaten hinzugefügt werden und die Vertauschung der Koordinaten je zweier Partikeln muß dann für jede Partikel alle Freiheitsgrade zugleich betreffen.

2) P. A. M. Dirac, Proc. Roy. Soc. (A) **112**, 661, 1926. In dieser Arbeit

W. Pauli, Z. für Physik 41, 81-102 (1927)

1926

1920-1925

Qual a função de onda do gato de Schrödinger?

Depois de abrirmos a caixa:

COLAPSO DA FUNÇÃO DE ONDA DEVIDO À INTERAÇÃO COM O OBSERVADOR

Ψ : realidade ou matemática?

Selected for a Viewpoint in *Physics*

PRL **110,** 213001 (2013) PHYSICAL REVIEW LETTERS week ending 24 MAY 2013

Hydrogen Atoms under Magnification: Direct Observation of the Nodal Structure of Stark States

A. S. Stodolna,[1,*] A. Rouzée,[1,2] F. Lépine,[3] S. Cohen,[4] F. Robicheaux,[5]
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[1]*FOM Institute AMOLF, Science Park 104, 1098 XG Amsterdam, Netherlands*
[2]*Max-Born-Institut, Max Born Straße 2A, D-12489 Berlin, Germany*
[3]*Institut Lumière Matière, Université Lyon 1, CNRS, UMR 5306, 10 Rue Ada Byron, 69622 Villeurbanne Cedex, France*
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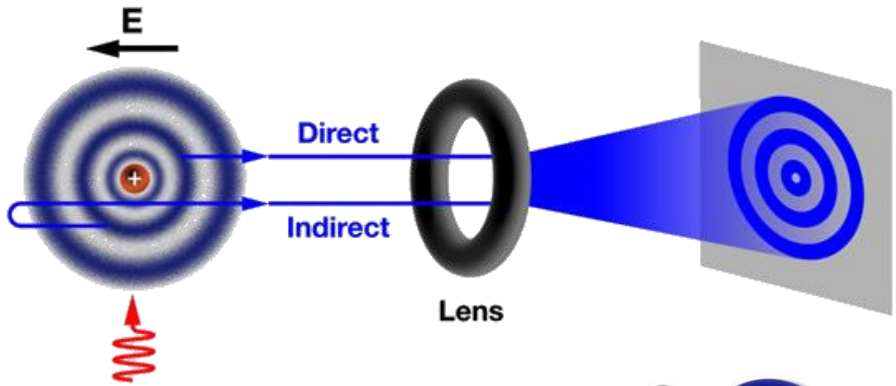
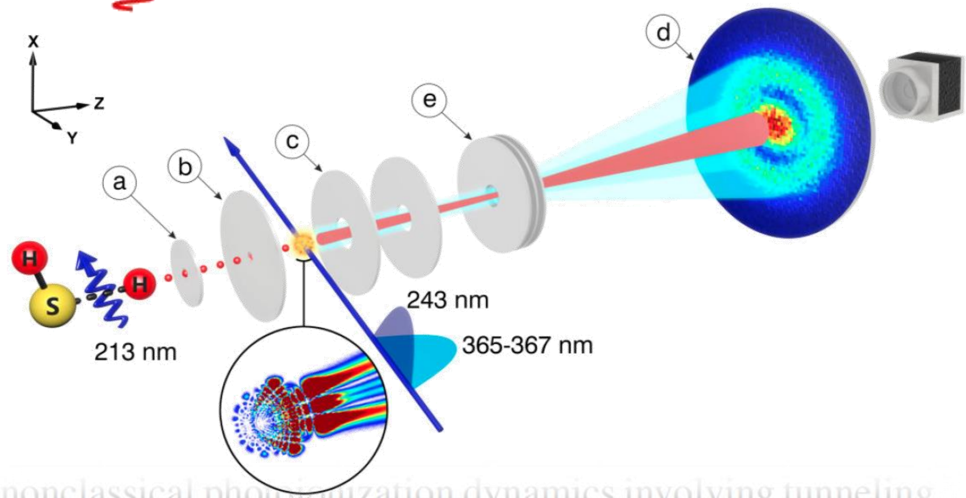
(Received 18 January 2013; revised manuscript received 13 March 2013; published 20 May 2013)

To describe the microscopic properties of matter, quantum mechanics uses wave functions, whose structure and time dependence is governed by the Schrödinger equation. In atoms the charge distributions described by the wave function are rarely observed. The hydrogen atom is unique, since it only has one electron and, in a dc electric field, the Stark Hamiltonian is exactly separable in terms of parabolic coordinates (η, ξ, φ). As a result, the microscopic wave function along the ξ coordinate that exists in the vicinity of the atom, and the projection of the continuum wave function measured at a macroscopic distance, share the same nodal structure. In this Letter, we report photoionization microscopy experiments where this nodal structure is directly observed. The experiments provide a validation of theoretical predictions that have been made over the last three decades.

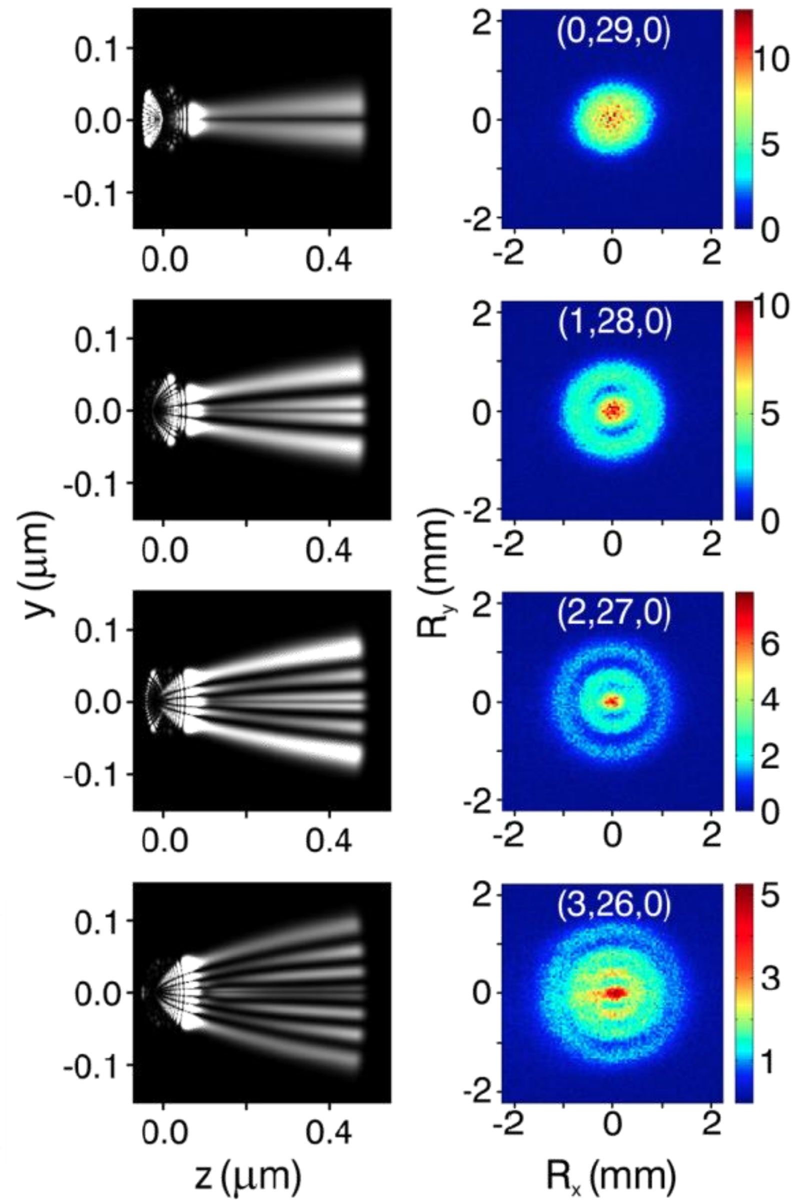
DOI: 10.1103/PhysRevLett.110.213001 PACS numbers: 32.80.Fb, 32.60.+i

Ψ : realidade ou matemática?





nonclassical photoionization dynamics involving tunneling through the $V(\eta)$ potential barrier, can be experimentally realized, providing both a beautiful demonstration of the intricacies of quantum mechanics and a fruitful playground, where the fundamental implications of this theory can be further explored. For example, predictions have already been made for the case where both electric and magnetic fields are present [32]. The experimental

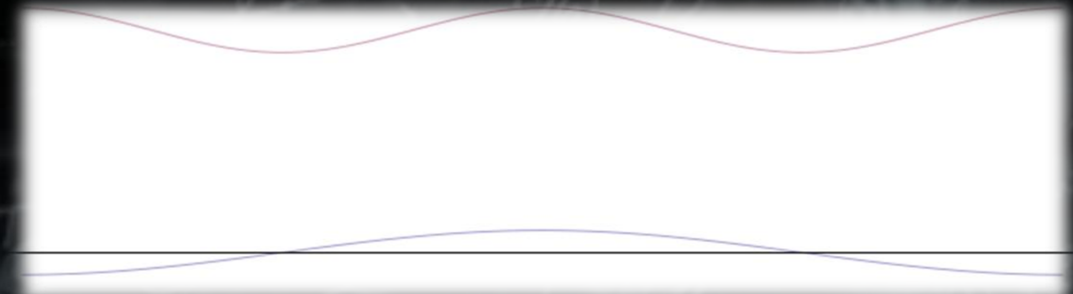


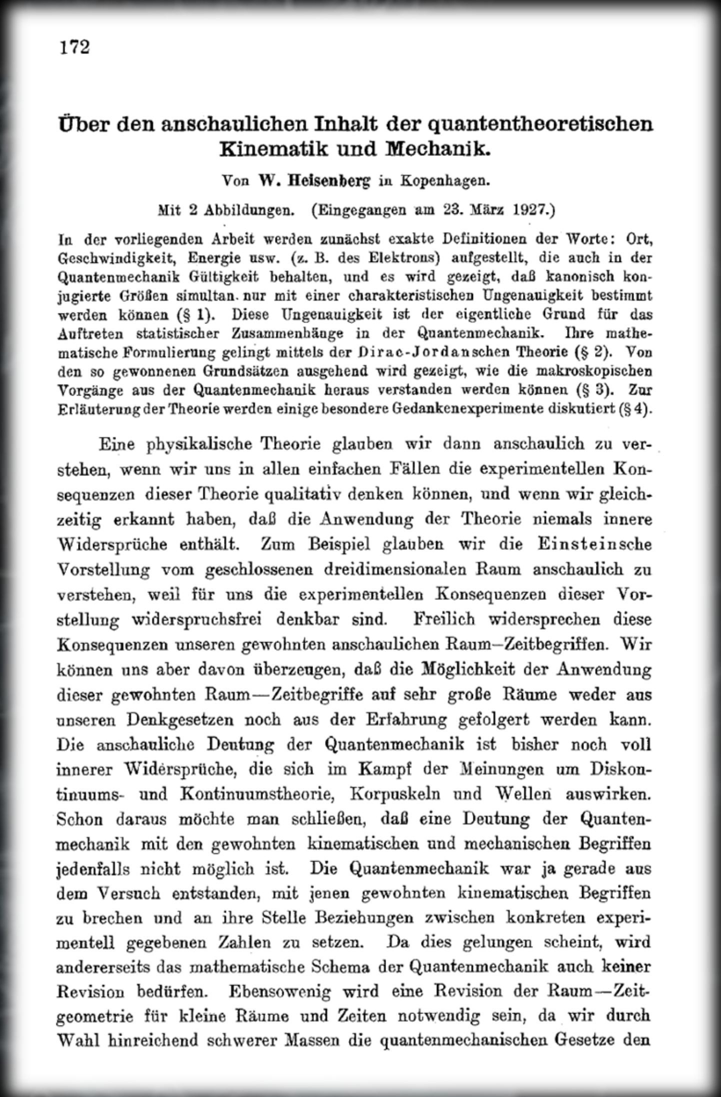
1926

1927

Não é possível medir **simultâneamente** a posição e o momento de uma partícula

$$\Delta p \Delta x \geq \hbar/2$$





172

Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik.

Von **W. Heisenberg** in Kopenhagen.

Mit 2 Abbildungen. (Eingegangen am 23. März 1927.)

In der vorliegenden Arbeit werden zunächst exakte Definitionen der Worte: Ort, Geschwindigkeit, Energie usw. (z. B. des Elektrons) aufgestellt, die auch in der Quantenmechanik Gültigkeit behalten, und es wird gezeigt, daß kanonisch konjugierte Größen simultan nur mit einer charakteristischen Ungenauigkeit bestimmt werden können (§ 1). Diese Ungenauigkeit ist der eigentliche Grund für das Auftreten statistischer Zusammenhänge in der Quantenmechanik. Ihre mathematische Formulierung gelingt mittels der Dirac-Jordanschen Theorie (§ 2). Von den so gewonnenen Grundsätzen ausgehend wird gezeigt, wie die makroskopischen Vorgänge aus der Quantenmechanik heraus verstanden werden können (§ 3). Zur Erläuterung der Theorie werden einige besondere Gedankenexperimente diskutiert (§ 4).

Eine physikalische Theorie glauben wir dann anschaulich zu verstehen, wenn wir uns in allen einfachen Fällen die experimentellen Konsequenzen dieser Theorie qualitativ denken können, und wenn wir gleichzeitig erkannt haben, daß die Anwendung der Theorie niemals innere Widersprüche enthält. Zum Beispiel glauben wir die Einsteinsche Vorstellung vom geschlossenen dreidimensionalen Raum anschaulich zu verstehen, weil für uns die experimentellen Konsequenzen dieser Vorstellung widerspruchsfrei denkbar sind. Freilich widersprechen diese Konsequenzen unseren gewohnten anschaulichen Raum–Zeitbegriffen. Wir können uns aber davon überzeugen, daß die Möglichkeit der Anwendung dieser gewohnten Raum—Zeitbegriffe auf sehr große Räume weder aus unseren Denkgesetzen noch aus der Erfahrung gefolgert werden kann. Die anschauliche Deutung der Quantenmechanik ist bisher noch voll innerer Widersprüche, die sich im Kampf der Meinungen um Diskontinuums- und Kontinuumstheorie, Korpuskeln und Wellen auswirken. Schon daraus möchte man schließen, daß eine Deutung der Quantenmechanik mit den gewohnten kinematischen und mechanischen Begriffen jedenfalls nicht möglich ist. Die Quantenmechanik war ja gerade aus dem Versuch entstanden, mit jenen gewohnten kinematischen Begriffen zu brechen und an ihre Stelle Beziehungen zwischen konkreten experimentell gegebenen Zahlen zu setzen. Da dies gelungen scheint, wird andererseits das mathematische Schema der Quantenmechanik auch keiner Revision bedürfen. Ebensowenig wird eine Revision der Raum—Zeitgeometrie für kleine Räume und Zeiten notwendig sein, da wir durch Wahl hinreichend schwerer Massen die quantenmechanischen Gesetze den

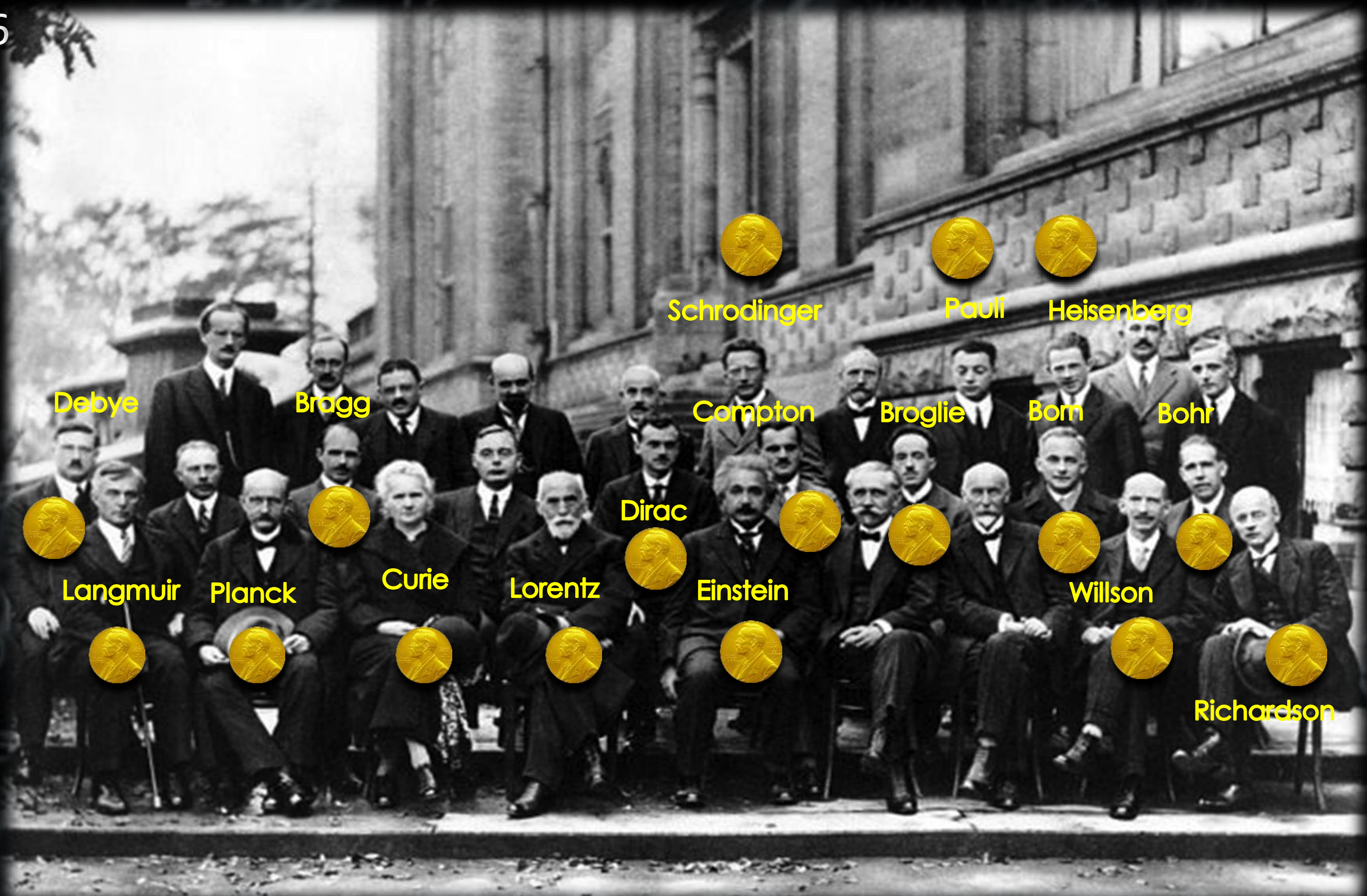
O prémio Nobel da Física foi atríbuido a Werner Heisenberg em 1932;

"for the creation of quantum mechanics".

1927

1926

1927



Fifth conference participants, 1927. Institut International de Physique Solvay in Leopold Park.

1928

Apesar dos inúmeros sucessos, a MQ não fornecia resposta para vários fenómenos.

$$\Delta p \Delta x \geq \frac{\hbar}{2}$$

$$p = -i\hbar\vec{\nabla}$$

$$E^2 = p^2c^2 + m^2c^4$$

$$E = i\hbar\frac{\partial}{\partial t}$$

MQ + RR

$$E_0 = mc^2$$

$$i\hbar\frac{\partial\psi}{\partial t} = -\frac{\hbar^2}{2m}\psi + V\psi$$

$$x^\mu = (ct, x, y, z)$$

COMO COMPATIBILIZAR ESTAS DUAS TEORIAS?

MQ + RR = Mecânica Quântica Relativista (MQR)

1927 — 1928

$$E^2 = p^2c^2 + m^2c^4$$

Energia: $E = i\hbar\frac{\partial}{\partial t}$ $p = -i\hbar\vec{\nabla}$: Momento

Eq. de Schrödinger relativista

$$i\hbar\frac{\partial\psi}{\partial t} = \sqrt{-\hbar^2c^2\nabla^2 + m^2c^4}\,\psi$$

ESTA EQUAÇÃO PARECE TER ALGUNS PROBLEMAS...

Não trata espaço e tempo da mesma forma, não é invariante de Lorentz, operador não local....

1927

1928

Dirac foi o primeiro a obter uma equação quântica relativista que estava de acordo com a experiência. Além disso tinha em conta o

SPIN

de uma forma natural

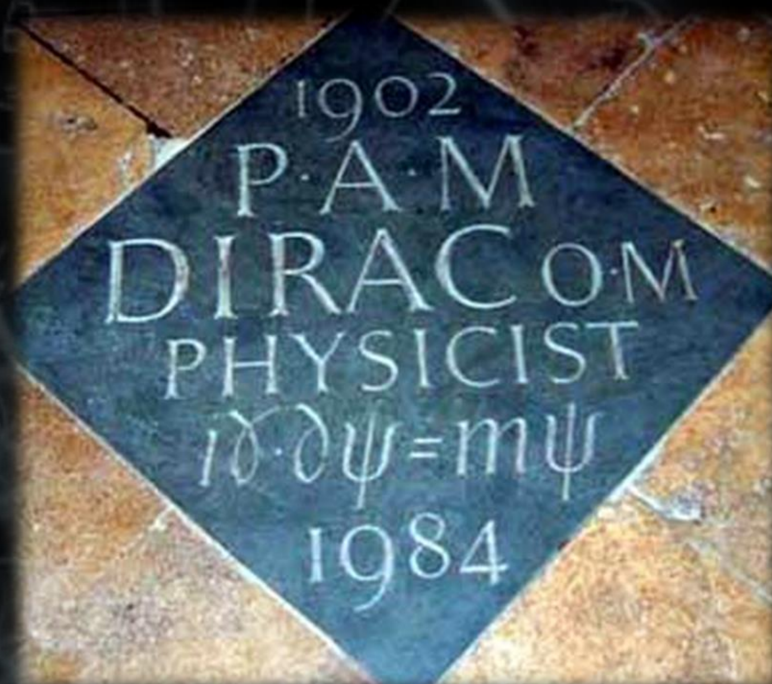
The Quantum Theory of the Electron.

By P. A. M. Dirac, St. John's College, Cambridge.

(Communicated by R. H. Fowler, F.R.S.—Received January 2, 1928.)

The new quantum mechanics, when applied to the problem of the structure of the atom with point-charge electrons, does not give results in agreement with experiment. The discrepancies consist of "duplexity" phenomena, the observed number of stationary states for an electron in an atom being twice

$$[i\Sigma\gamma_\mu p_\mu + mc]\,\psi = 0, \qquad \mu = 1, 2, 3, 4.$$



$$E = \pm\sqrt{p^2c^2 + m^2c^4}$$

A eq. De Dirac parece permitir soluções de energia NEGATIVA !!!

1928

$$\psi \rightarrow \begin{pmatrix} \psi_1 \\ \psi_2 \\ \psi_3 \\ \psi_4 \end{pmatrix}$$

Soluções de energia positiva, dois estados de spin

Soluções de energia negativa, dois estados de spin

A Theory of Electrons and Protons.

By P. A. M. Dirac, St. John's College, Cambridge.

(Communicated by R. H. Fowler, F.R.S.—Received December 6, 1929.)

§ 1. *Nature of the Negative Energy Difficulty.*

The relativity quantum theory of an electron moving in a given electromagnetic field, although successful in predicting the spin properties of the electron, yet involves one serious difficulty which shows that some fundamental alteration is necessary before we can regard it as an accurate description of nature. This difficulty is connected with the fact that the wave equation, which is of the form

$$\left[\frac{W}{c} + \frac{e}{c}A_0 + \rho_1\left(\boldsymbol{\sigma}, \mathbf{p} + \frac{e}{c}\mathbf{A}\right) + \rho_3 mc\right]\psi = 0, \qquad (1)$$

has, in addition to the wanted solutions for which the kinetic energy of the electron is positive, an equal number of unwanted solutions with negative kinetic energy for the electron, which appear to have no physical meaning. Thus if we take the case of a steady electromagnetic field, equation (1) will

Dirac interpretou as soluções de energia negativa como correspondendo aos dois estados de spin de uma partícula com carga oposta.

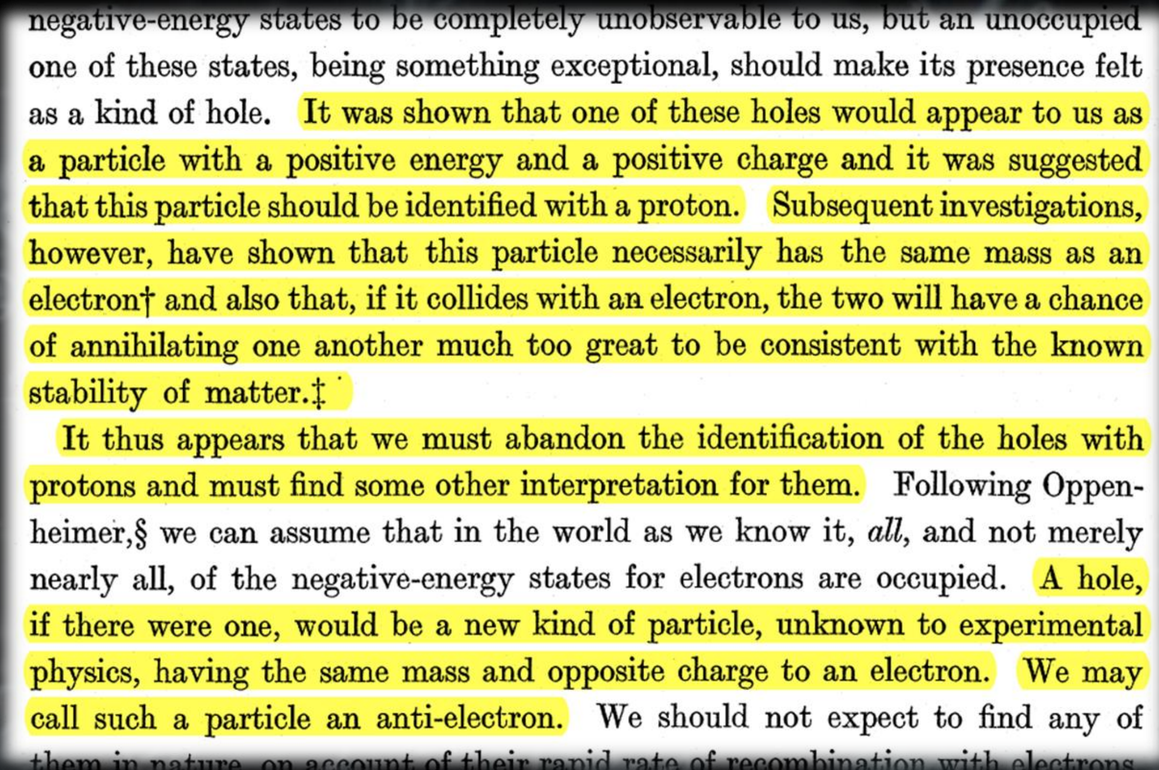
A ANTI-PARTÍCULA

1932

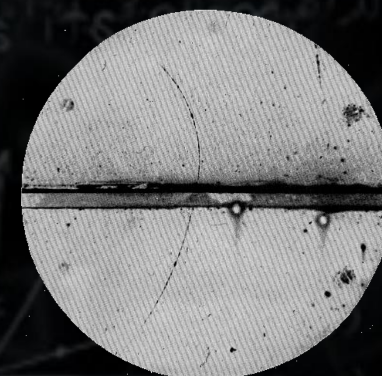
O POSITRÃO

Carl Anderson, 1932

e^+


negative-energy states to be completely unobservable to us, but an unoccupied one of these states, being something exceptional, should make its presence felt as a kind of hole. It was shown that one of these holes would appear to us as a particle with a positive energy and a positive charge and it was suggested that this particle should be identified with a proton. Subsequent investigations, however, have shown that this particle necessarily has the same mass as an electron† and also that, if it collides with an electron, the two will have a chance of annihilating one another much too great to be consistent with the known stability of matter.‡

It thus appears that we must abandon the identification of the holes with protons and must find some other interpretation for them. Following Oppenheimer,§ we can assume that in the world as we know it, *all*, and not merely nearly all, of the negative-energy states for electrons are occupied. A hole, if there were one, would be a new kind of particle, unknown to experimental physics, having the same mass and opposite charge to an electron. We may call such a particle an anti-electron. We should not expect to find any of them in nature, on account of their rapid rate of recombination with electrons



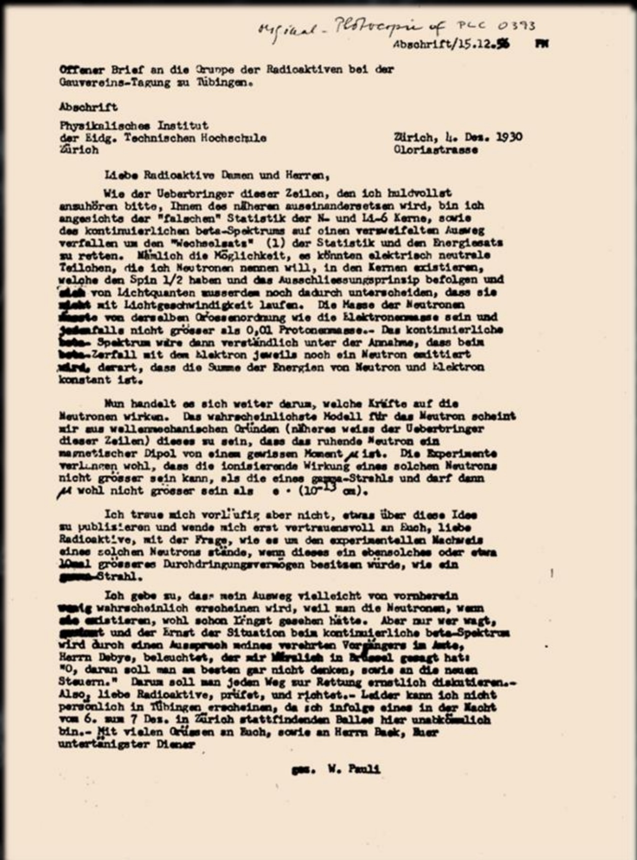
Como construir uma câmara de Wilson

ESTAVA DESCOBERTA A ANTIMATÉRIA!

O prémio Nobel da Física foi atríbuido a Carl Anderson em 1936;

"for the discovery of the positron".

1930



Physical - Photocopie of PLC 0393
Abschrift/15.12.56 PM

Offener Brief an die Gruppe der Radioaktiven bei der Gauvereins-Tagung zu Tübingen.

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

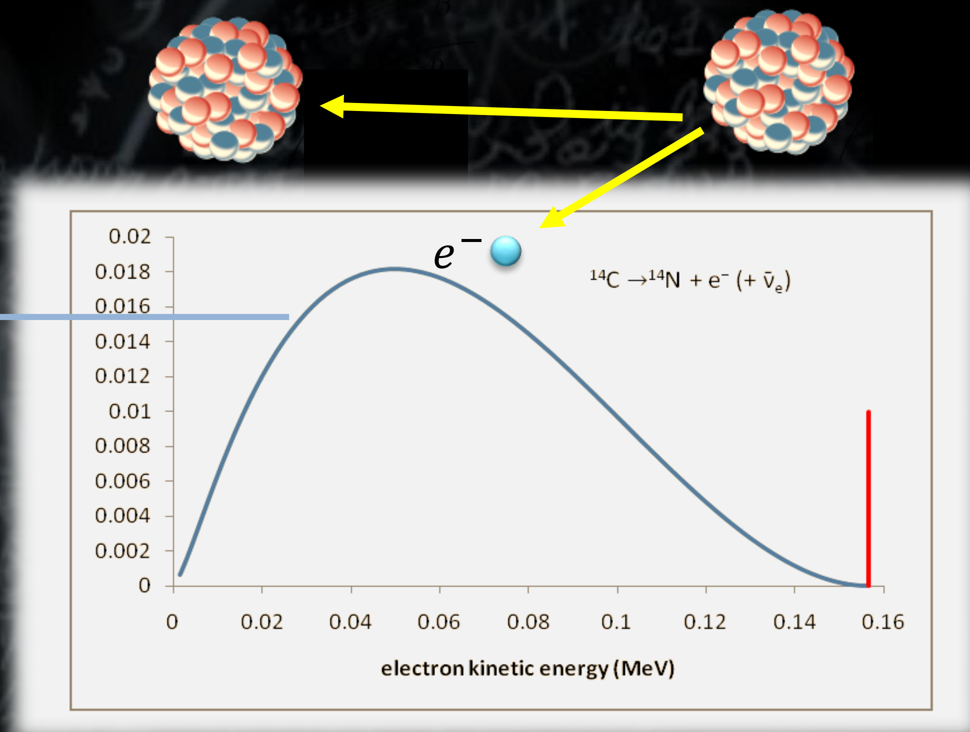
Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Grossenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta- Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

Nun handelt es sich weiter darum, welche Kräfte auf die Neutronen wirken. Das wahrscheinlichste Modell für das Neutron scheint mir aus wellenmechanischen Gründen (näheres weiss der Ueberbringer dieser Zeilen) dieses zu sein, dass das ruhende Neutron ein magnetischer Dipol von einem gewissen Moment μ ist. Die Experimente verlangen wohl, dass die ionisierende Wirkung eines solchen Neutrons nicht grösser sein kann, als die eines gamma-Strahls und darf dann μ wohl nicht grösser sein als $e \cdot (10^{-13}$ cm).

Ich traue mich vorläufig aber nicht, etwas über diese Idee zu publizieren und wende mich erst vertrauensvoll an Euch, liebe Radioaktive, mit der Frage, wie es um den experimentellen Nachweis eines solchen Neutrons stände, wenn dieses ein ebensolches oder etwa 10mal grösseres Durchdringungsvermögen besitzen würde, wie ein gamma-Strahl.

Ich gebe zu, dass mein Ausweg vielleicht von vornherein wenig wahrscheinlich erscheinen wird, weil man die Neutronen, wenn sie existieren, wohl schon längst gesehen hätte. Aber nur wer wagt, gewinnt und der Ernst der Situation beim kontinuierliche beta-Spektrum wird durch einen Ausspruch meines verehrten Vorgängers im Amte, Herrn Debye, beleuchtet, der mir kürzlich in Brüssel gesagt hat: "O, daran soll man am besten gar nicht denken, sowie an die neuen Steuern." Darum soll man jeden Weg zur Rettung ernstlich diskutieren.- Also, liebe Radioaktive, prüfet, und richtet.- Leider kann ich nicht persönlich in Tübingen erscheinen, da ich infolge eines in der Nacht vom 6. zum 7 Dez. in Zürich stattfindenden Balles hier unabkömmlich bin.- Mit vielen Grüssen an Euch, sowie an Herrn Back, Euer untertänigster Diener

ges. W. Pauli



CONSERVAÇÃO DA ENERGIA?

PRIMEIRA VEZ EM QUE SE PROPÔS A EXISTÊNCIA DE UMA NOVA PARTÍCULA PARA EXPLICAR UM DADO EXPERIMENTAL.

W. Pauli

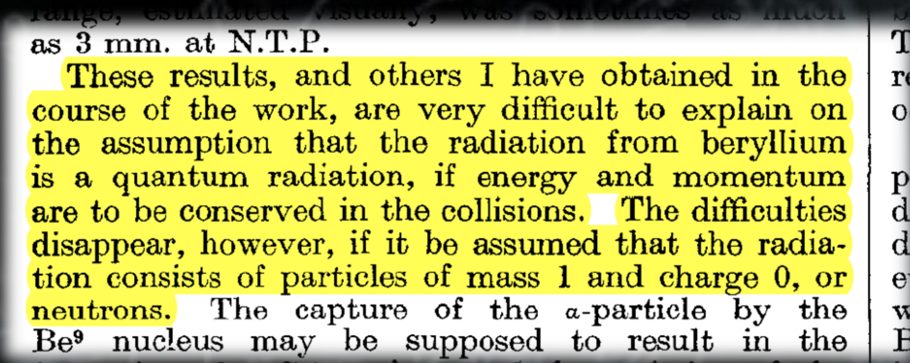
O espectro beta contínuo faria sentido se, além do electrão, um neutrão for emitido de tal modo que a soma da energia do electrão e do neutrão é constante.

1932

Modelo do átomo durante os anos 20:

Protões + electrões

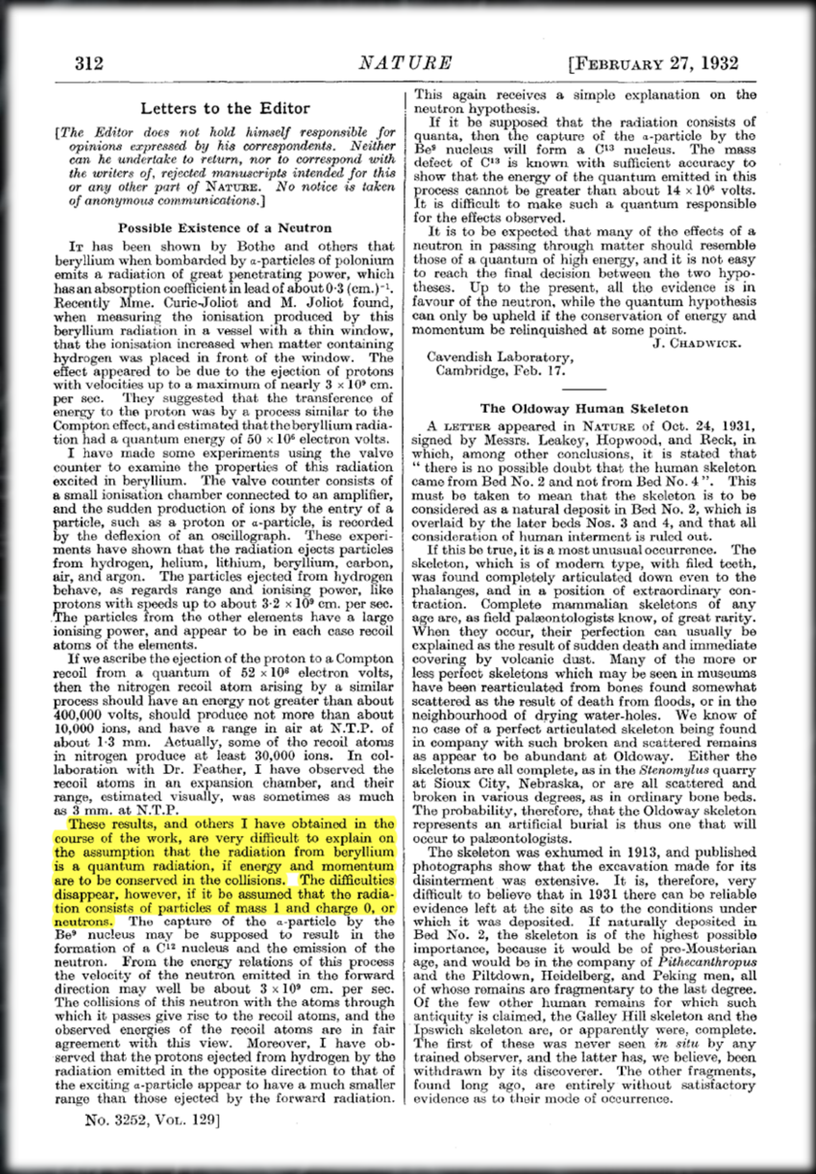
Inconsistente com a "nova" MQ.


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

O prémio Nobel da Física foi atríbuido a James Chadwick em 1935;

"for the discovery of the neutron".


312 *NATURE* [FEBRUARY 27, 1932

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 $3·2 \times 10^9$ 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.

The Oldoway Human Skeleton

A LETTER appeared in NATURE of Oct. 24, 1931, signed by Messrs. Leakey, Hopwood, and Reck, in which, among other conclusions, it is stated that "there is no possible doubt that the human skeleton came from Bed No. 2 and not from Bed No. 4". This must be taken to mean that the skeleton is to be considered as a natural deposit in Bed No. 2, which is overlaid by the later beds Nos. 3 and 4, and that all consideration of human interment is ruled out.

If this be true, it is a most unusual occurrence. The skeleton, which is of modern type, with filed teeth, was found completely articulated down even to the phalanges, and in a position of extraordinary contraction. Complete mammalian skeletons of any age are, as field palæontologists know, of great rarity. When they occur, their perfection can usually be explained as the result of sudden death and immediate covering by volcanic dust. Many of the more or less perfect skeletons which may be seen in museums have been rearticulated from bones found somewhat scattered as the result of death from floods, or in the neighbourhood of drying water-holes. We know of no case of a perfect articulated skeleton being found in company with such broken and scattered remains as appear to be abundant at Oldoway. Either the skeletons are all complete, as in the *Stenomylus* quarry at Sioux City, Nebraska, or are all scattered and broken in various degrees, as in ordinary bone beds. The probability, therefore, that the Oldoway skeleton represents an artificial burial is thus one that will occur to palæontologists.

The skeleton was exhumed in 1913, and published photographs show that the excavation made for its disinterment was extensive. It is, therefore, very difficult to believe that in 1931 there can be reliable evidence left at the site as to the conditions under which it was deposited. If naturally deposited in Bed No. 2, the skeleton is of the highest possible importance, because it would be of pre-Mousterian age, and would be in the company of *Pithecanthropus* and the Piltdown, Heidelberg, and Peking men, all of whose remains are fragmentary to the last degree. Of the few other human remains for which such antiquity is claimed, the Galley Hill skeleton and the Ipswich skeleton are, or apparently were, complete. The first of these was never seen *in situ* by any trained observer, and the latter has, we believe, been withdrawn by its discoverer. The other fragments, found long ago, are entirely without satisfactory evidence as to their mode of occurrence.

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