Introdução à Física de Partículas...

Introduction to particle Physics and the Universe

... e ao Universo

(1/3)

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A Física de partículas é um ramo da Física que estuda os constituintes elementares da matéria e da radiação, e a interação entre eles e suas aplicações. É também chamada de Física de altas energias, porque muitas partículas elementares só podem ser criadas a energias elevadas, logo a detecção destas também é possível apenas a altas energias de aceleração. O elétron e o próton foram as únicas partículas aceleradas até os dias de hoje, outras nunca foram detectadas (como o gráviton) e as restantes foram detectadas através da radiação cósmica (como o méson pi e o méson mu).

A Física de partículas, estudada pela Mecânica Quântica (parte da Física Moderna), busca o fundamental, o nível mais básico da matéria e da Natureza. Todo o nosso mundo visível se fundamenta nesse nível invisível das partículas elementares.

"Todo o nosso mundo visível se fundamenta nesse nível invisível das partículas elementares."

- Partículas e interacções
- As revoluções da Física no sec. XX
- A teoria do "quase-tudo"...
- Porquê "quase-tudo" ?

IMPOSSÍVEL SER RIGOROSO E PROFUNDO

MAIS DE 100 ANOS DE IDEIAS, TEORIAS, DESCOBERTAS …

Standard Model of

FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	–1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	–1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	–1

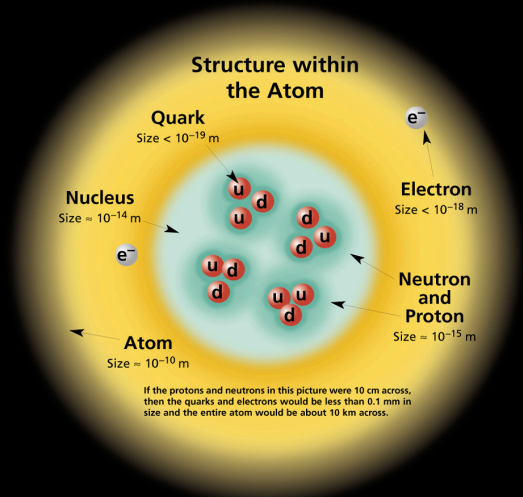
Quarks spin = 1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	175	2/3
b bottom	4.3	–1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of $\hbar$, which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s = 1.05×10^{-34} J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The **energy** unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c^2 (remember $E = mc^2$), where 1 GeV = 10^9 eV = 1.60×10^{-10} joule. The mass of the proton is 0.938 GeV/c^2 = 1.67×10^{-27} kg.



BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	–1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Color Charge
Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically-charged particles interact by exchanging photons, in strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and ***W*** and ***Z*** bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons
One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge. Two types of hadrons have been observed in nature: **mesons** $q\bar{q}$ and **baryons** qqq.

Residual Strong Interaction
The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
Strength relative to electromag for two u quarks at: 3×10^{-17} m	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$
Baryons are fermionic hadrons.
There are about 120 types of baryons.

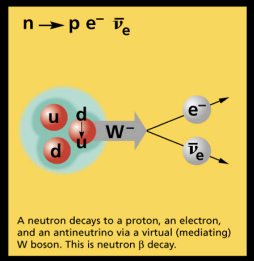
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	–1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	–1	1.672	3/2

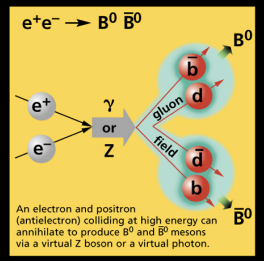
Mesons $q\bar{q}$
Mesons are bosonic hadrons.
There are about 140 types of mesons.

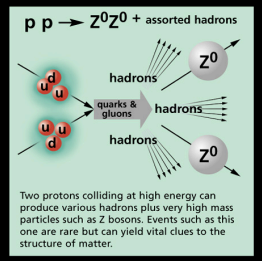
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	–1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2.980	0

Matter and Antimatter
For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or – charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ, and $\eta_c = c\bar{c}$, but not $K^0 = d\bar{s}$) are their own antiparticles.

Figures
These diagrams are an artist's conception of physical processes. They are ***not*** exact and have ***no*** meaningful scale. Green shaded areas represent the cloud of gluons or the gluon field, and red lines the quark paths.







The Particle Adventure
Visit the award-winning web feature *The Particle Adventure* at
http://ParticleAdventure.org

This chart has been made possible by the generous support of:
U.S. Department of Energy
U.S. National Science Foundation
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Stanford Linear Accelerator Center
American Physical Society, Division of Particles and Fields
BURLE INDUSTRIES, INC.

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Strong (color) spin = 1

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g gluon	0	0

Spin = 0

h^0 Higgs	~126	0

HADRÕES

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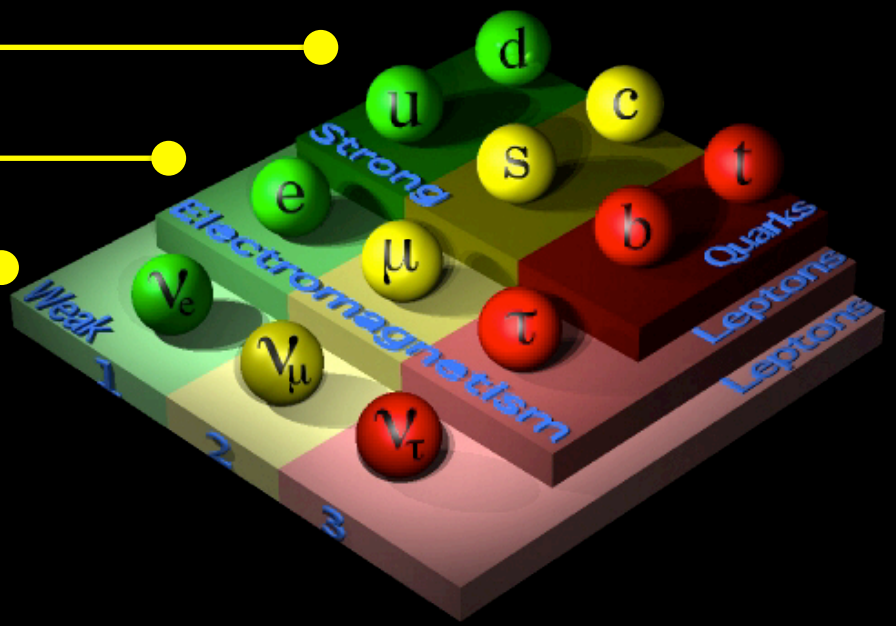
Força Forte (g)

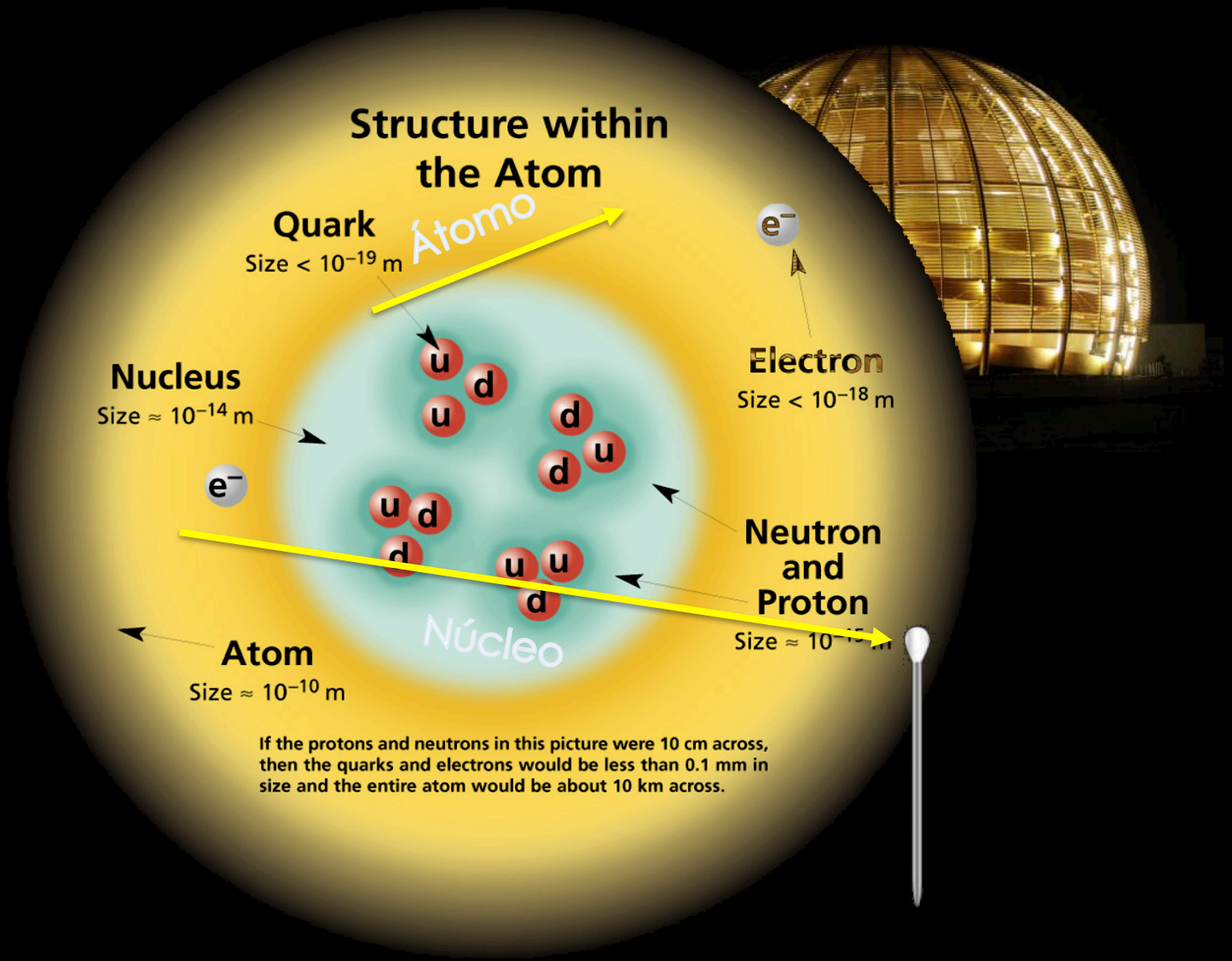
Força Electromagnética (γ)

Força fraca (W^+, W^-, Z^0)



W^+, W^- - Correntes carregadas

γ, Z^0 - Correntes neutras


Structure within the Atom
Quark
Size < 10^{-19} m
Átomo
e⁻
Electron
Size < 10^{-18} m
Nucleus
Size ≈ 10^{-14} m
u
d
u
d
d
u
e⁻
u
d
d
Neutron and Proton
Size ≈ 10^{-15} m
u
u
d
Núcleo
Atom
Size ≈ 10^{-10} m
If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

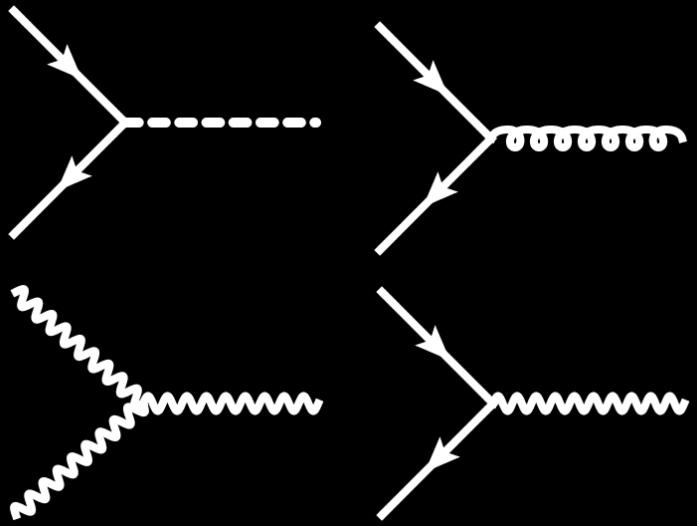

Fermiões e anti-fermiões (leptões e quarks)


Bosões de gauge ($W^{\pm}$, Z^0, γ)

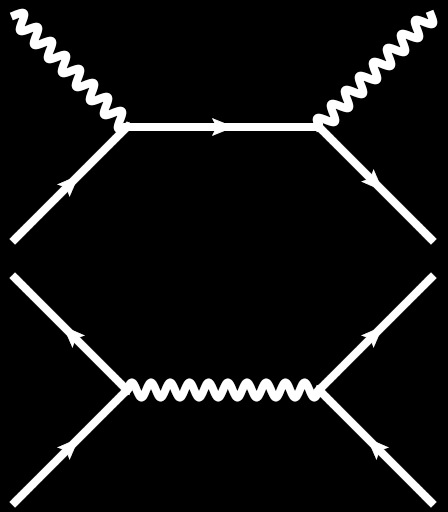

Partículas escalares (h^0)


Gluões (g)

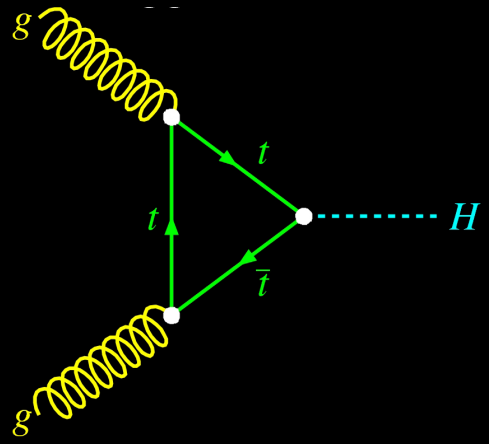
Exemplos de acoplamentos

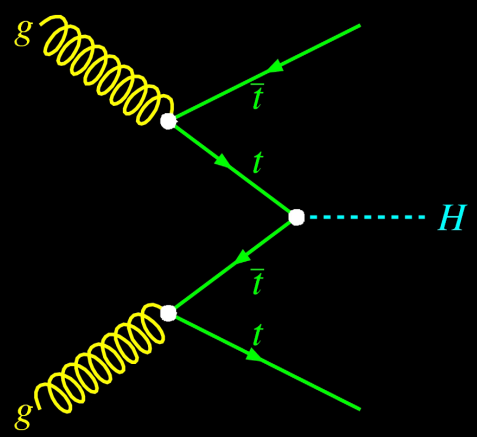


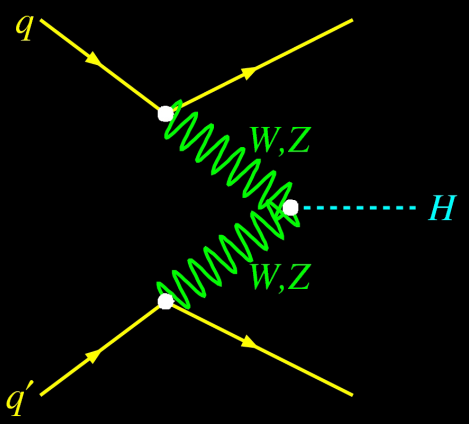
Exemplos de processos

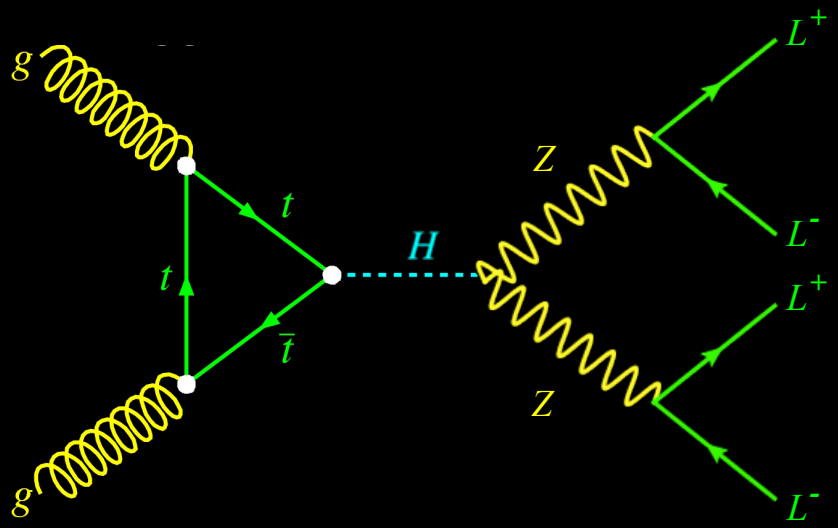


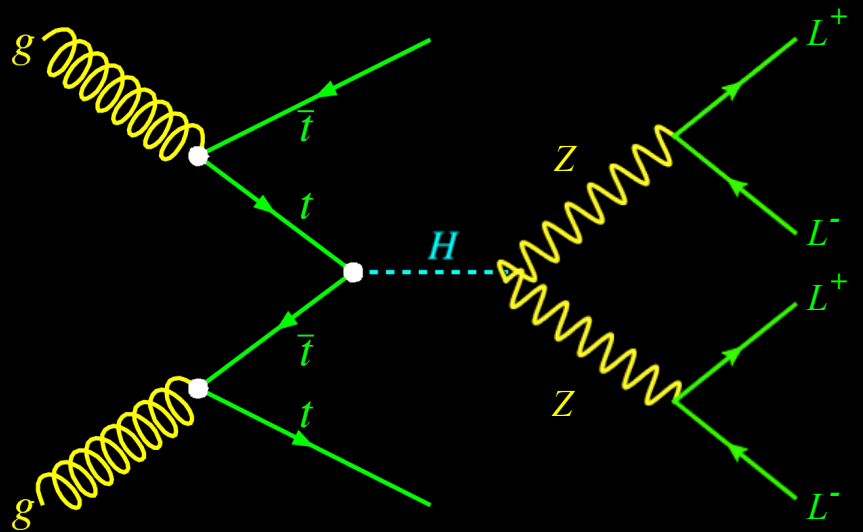
Mais exemplos...

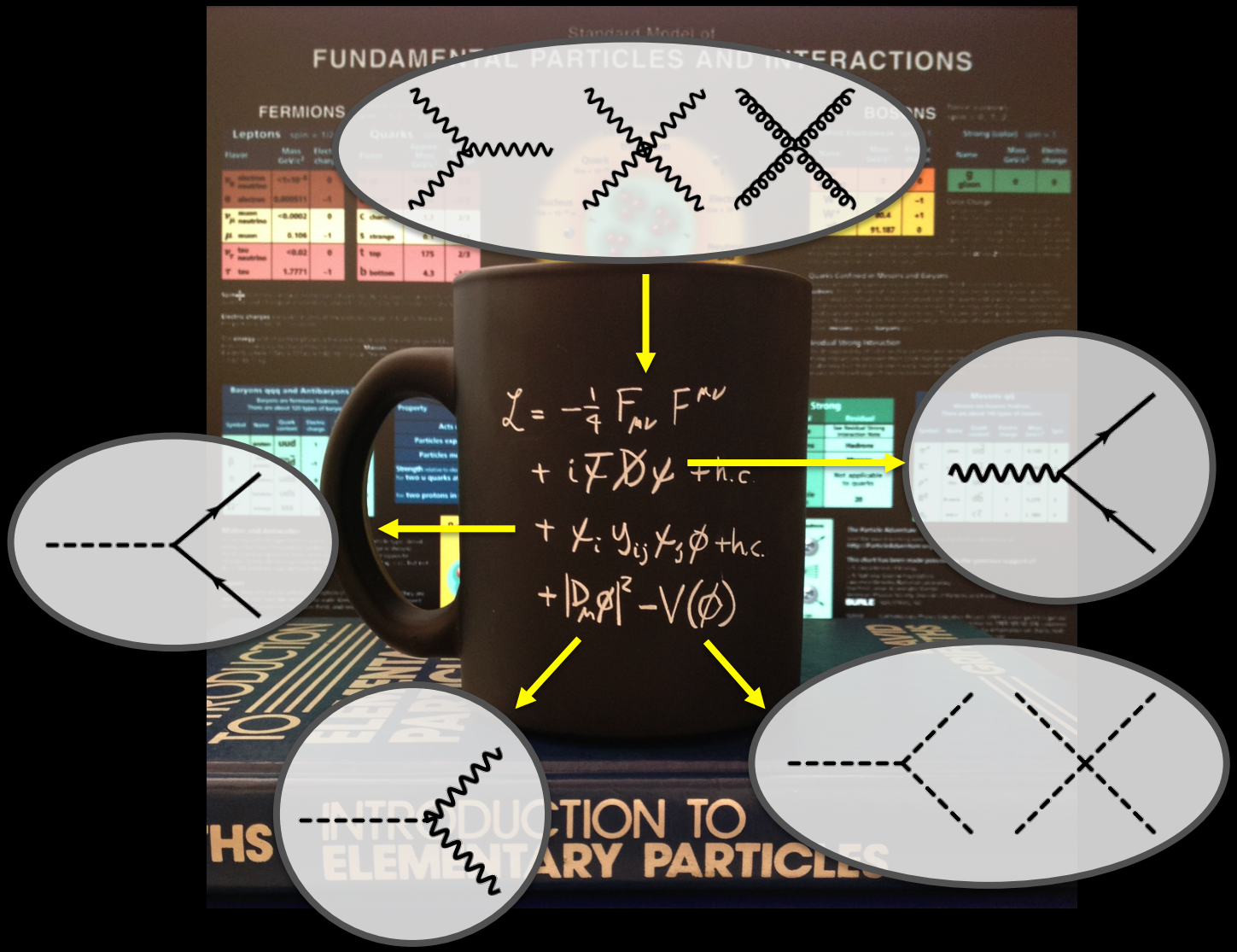


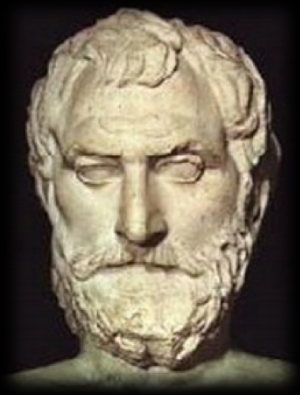









FERMIONS
Leptons
$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$
$+ i \not{D} \psi + h.c.$
$+ \chi_i y_{ij} \chi_j \phi + h.c.$
$+ |D_\mu \phi|^2 - V(\phi)$
INTRODUCTION TO
ELEMENTARY PARTICLES



Tales de Mileto (624-547 A.C.)

Tales de Mileto foi pioneiro no que respeita à procura da origem das substâncias e suas transformações sem recorrer a entidades divinas (mitologia).

ἄτομος Átomo

Indivisível

A matéria é composta por algumas espécies de átomos fundamentais, que diferem na sua forma e tamanho, e por espaço vazio.

Leucipo e Demócrito (500-400 A.C.)

A complexidade da Natureza é o resultado das inúmeras combinações destes átomos e das suas posições no espaço vazio.

Atomismo baseado no raciocínio abstrato e filosófico. Mas...

A ideia de que a matéria é constituida por unidades discretas está na base da Física moderna.

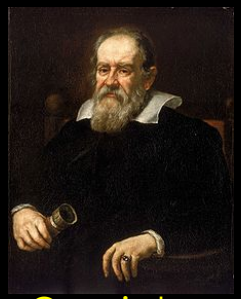
1-2 Matter is made of atoms

If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words? I believe it is the *atomic hypothesis* (or the atomic *fact*, or whatever you wish to call it) that *all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another*. In that one sentence, you will see, there is an *enormous* amount of information about the world, if just a little imagination and thinking are applied.

In "Feynman lectures on Physics", R. Feynman, 1964.

1564-1896

1564-1642 Galileo

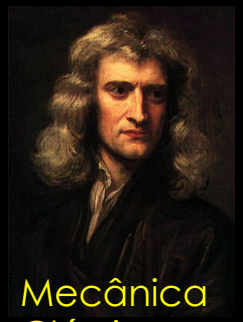


O pai da Física moderna

1571-1630 Kepler

Movimento planetário

1642 - 1727 Newton



Mecânica Clássica

1773 - 1829 Young

Teoria ondulatóra da luz

1791 - 1867 Faraday

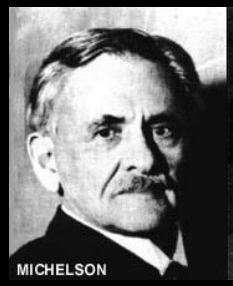
1799 - 1878 Henry

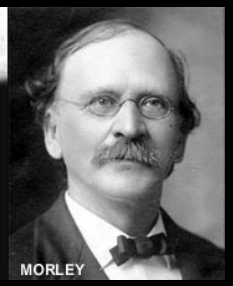
Indução

1873 Maxwell

Electromagnetismo e propagação da luz

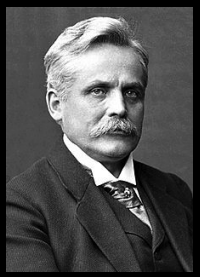
1887 Michelson-Morley





Não à Teoria do Éter

1896 Wien



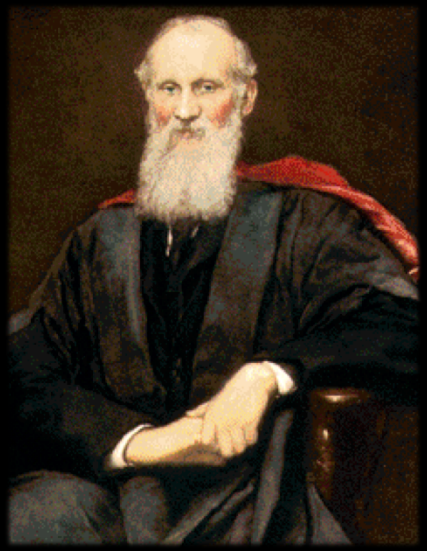
Lei de Wien

1904,1905 Rayleigh Jeans

Rayleigh - Jeans

AS NÚVENS DE KELVIN

"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?

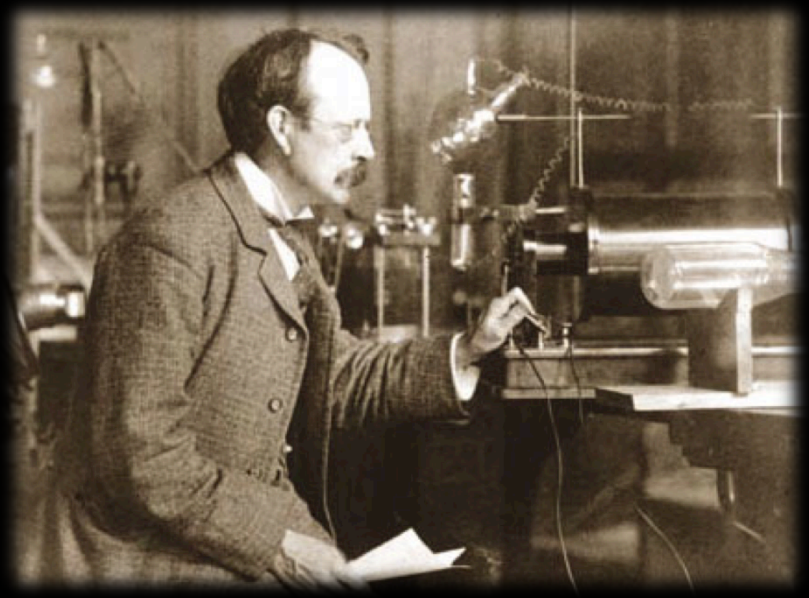
Incapacidade de detector o Éter e a "Catástrofe ultra-violeta"

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

Kelvin não podia estar mais enganado...

1897-1896

J.J. Thomson



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

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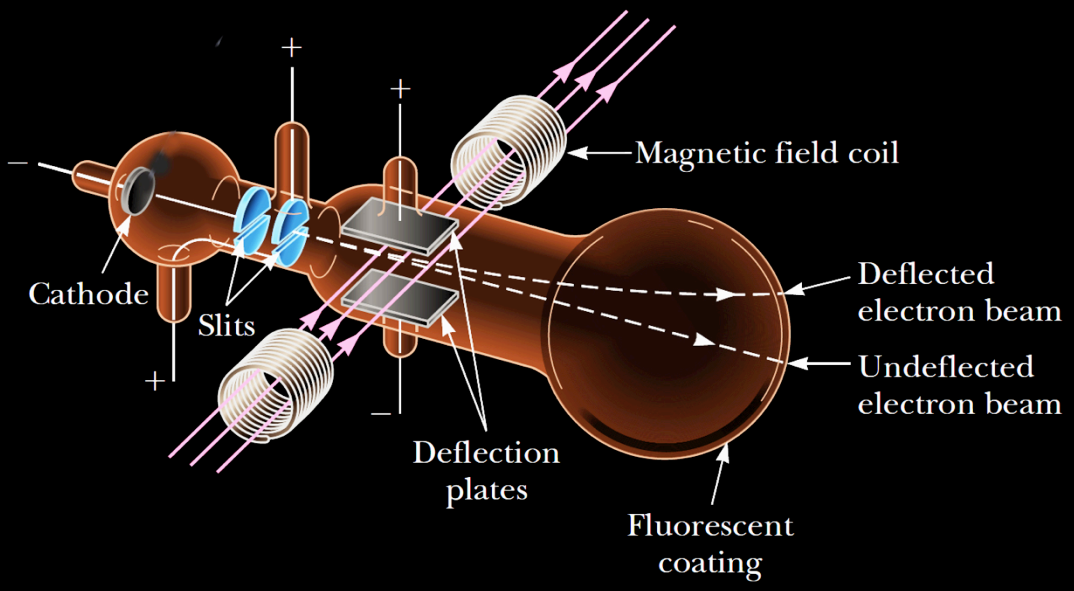
1564-1896 — 1897

Os raios catódicos são constituídos por "partículas" carregadas



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

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

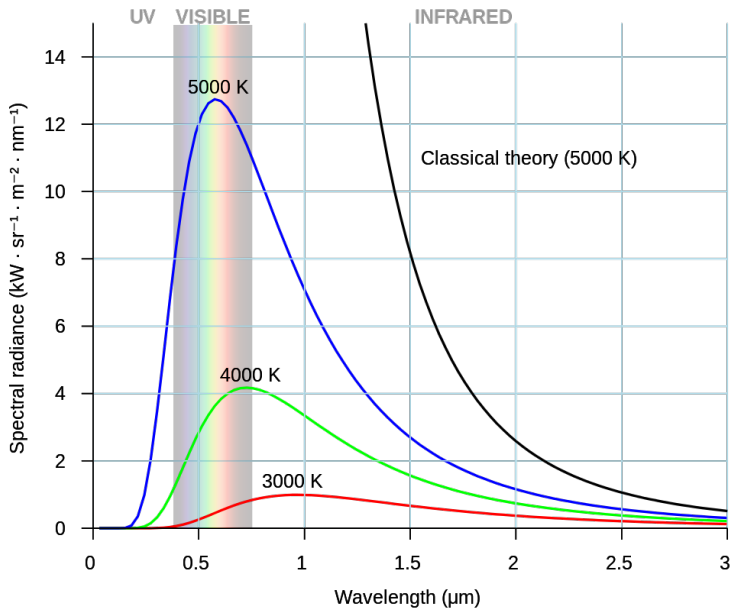
"in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases".

1900

Rayleigh-Jeans:

Catástrofe UV

Falha da teoria clássica:



A "energia electromagnética" pode apenas ser emitida em múltiplos de uma "energia fundamental" igual a

1900

Distribuição de Planck para a radiação do corpo negro:

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

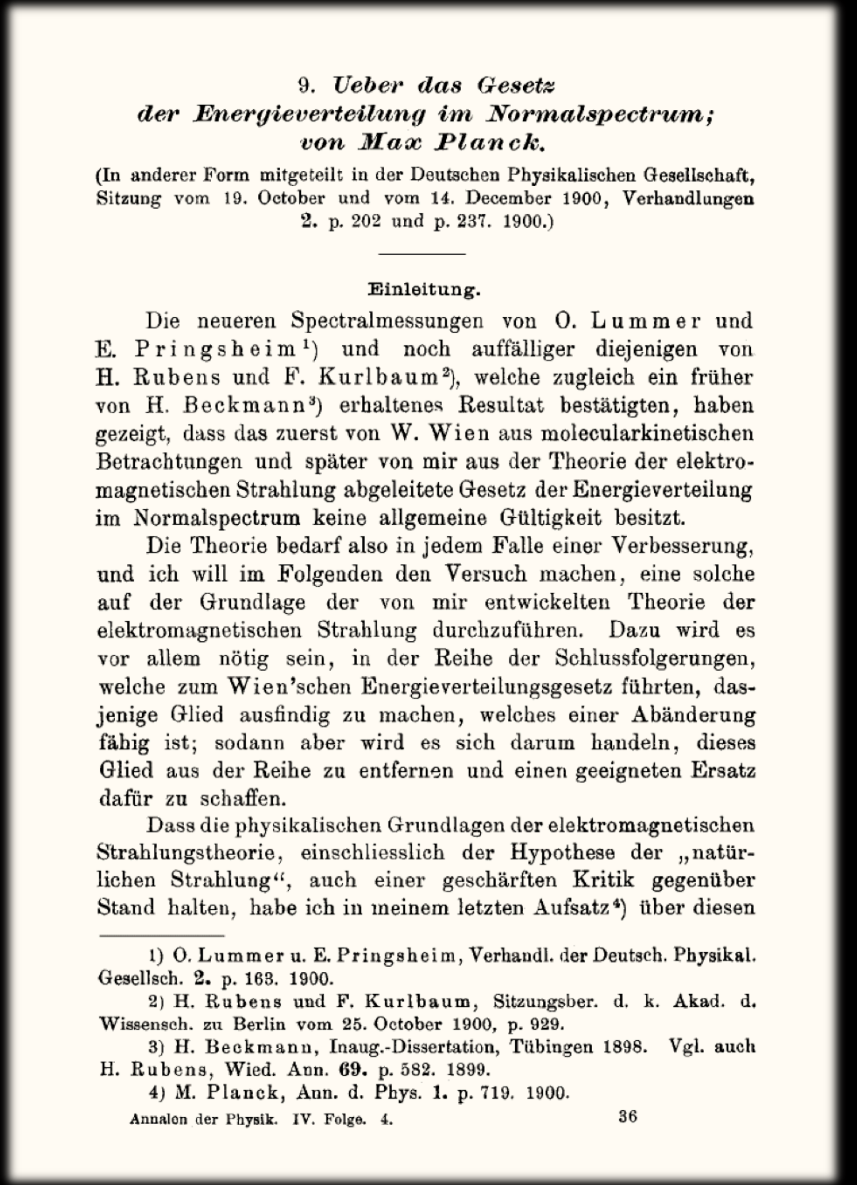
onde:

$$h = 6{,}55 \cdot 10^{-27}\ \text{erg} \cdot \text{sec}$$

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.

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

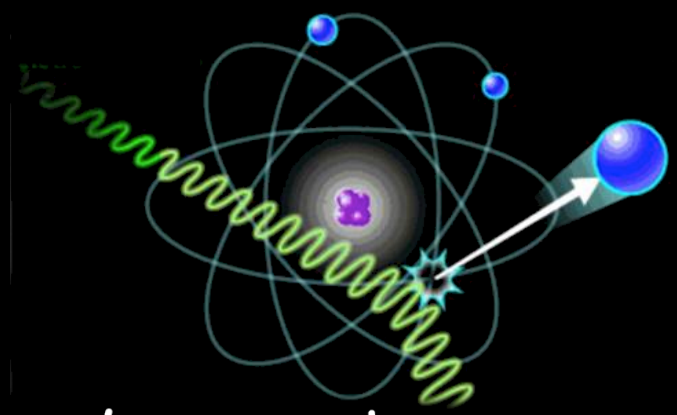
6. *Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt; von A. Einstein.*

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.

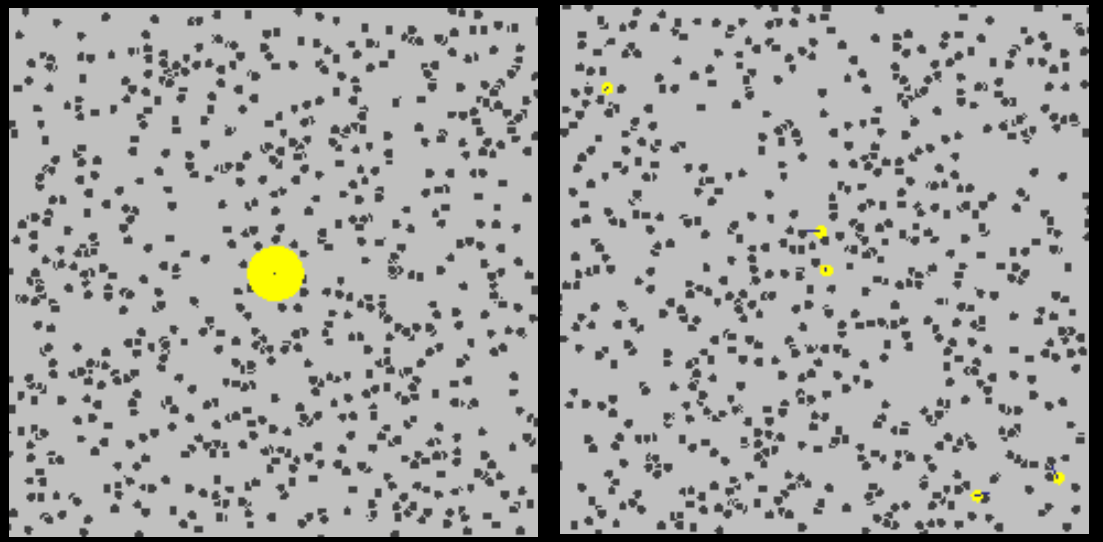
§ 1. Über den suspendierten Teilchen zuzuschreibenden osmotischen Druck.

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:

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

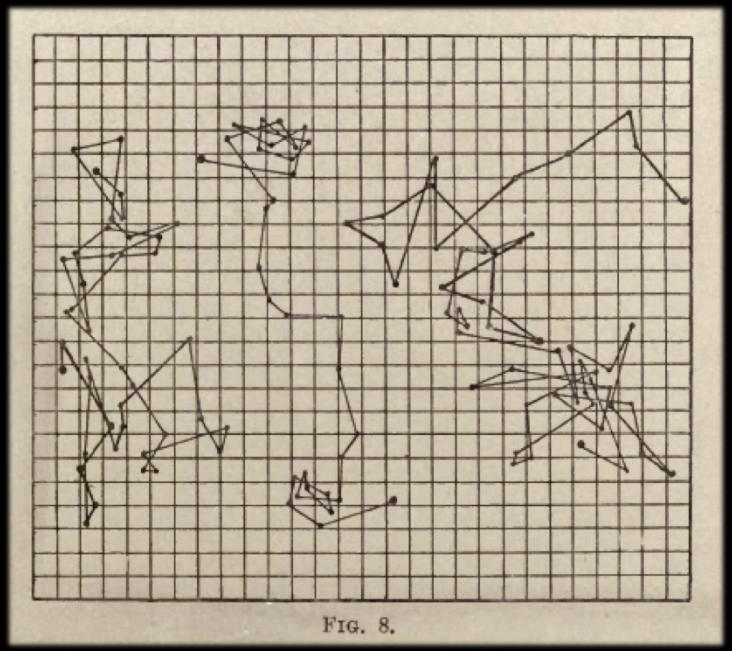
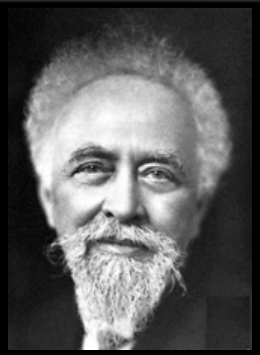


FIG. 8.

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:

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

1904 — 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*

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

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

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 $L/9 \cdot 10^{20}$, wenn die Energie in Erg und die Masse in Grammen gemessen wird.

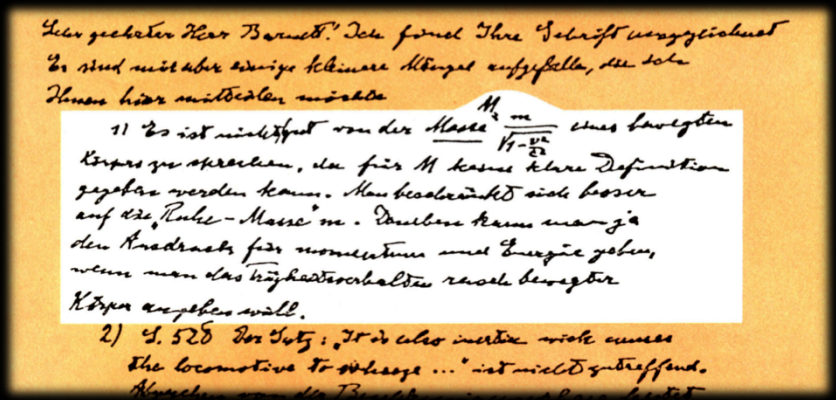
Es ist nicht ausgeschlossen, daß bei Körpern, deren

Se um corpo emitir uma energia na forma de radiação, então a sua massa dimunui de .

Ou, em linguagem moderna:

$$E = mc^2$$

1904 — 1905



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".

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

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

opinion poll related to it.

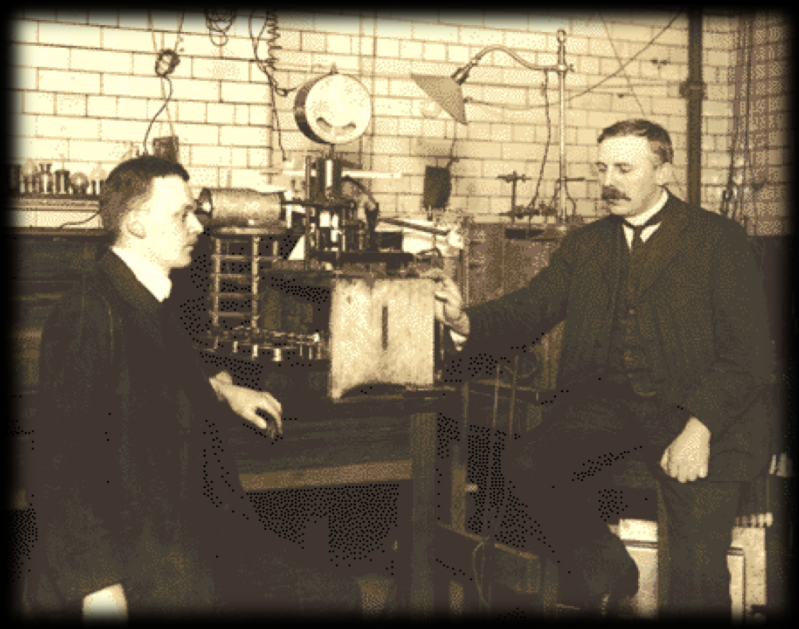
The famous Einstein relation between mass and energy is a symbol of our century. Here you have four equations:

$$E_0 = mc^2 \quad (1)$$
$$E = mc^2 \quad (2)$$
$$E_0 = m_0c^2 \quad (3)$$
$$E = m_0c^2 \quad (4)$$

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

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.†

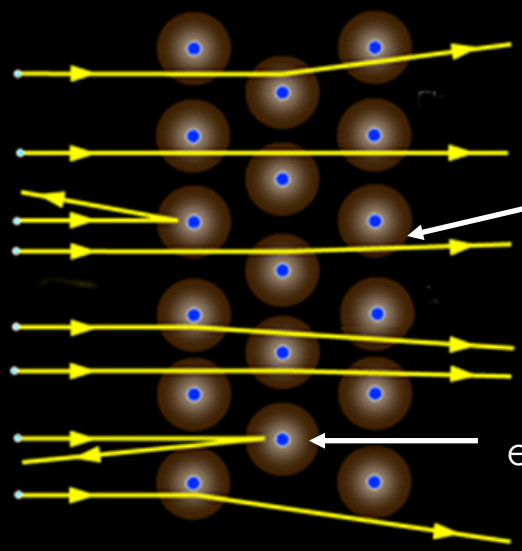
In the following experiments, however, conclusive evidence was found of the existence of a diffuse reflection of the α-particles. A small fraction of the α-particles falling upon a metal plate have their directions changed to such an extent that they emerge again at the side of incidence. To form an idea of the way in which this effect takes place, the following three points were investigated :—

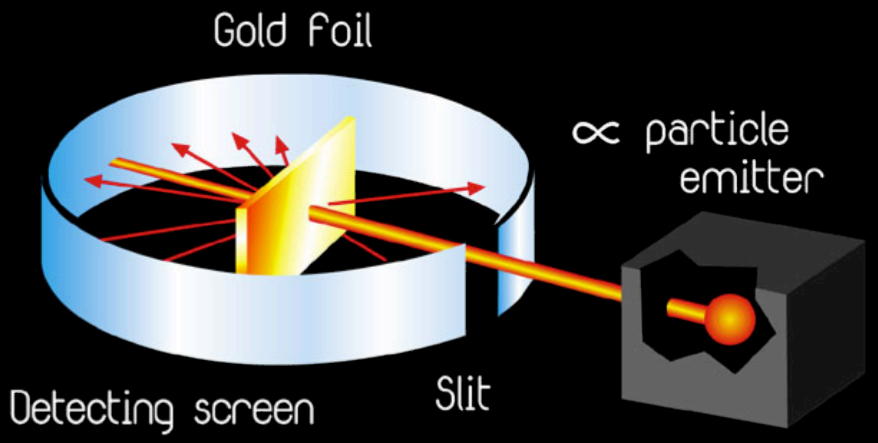
sphere of positive electricity is minute compared with the diameter of the sphere of influence of the atom.

Since the α and β particles traverse the atom, it should be possible from a close study of the nature of the deflexion to form some idea of the constitution of the atom to produce the effects observed. In fact, the scattering of high-speed charged particles by the atoms of matter is one of the most promising methods of attack of this problem. The development of the scintillation method of counting single α particles affords unusual advantages of investigation, and the researches

"The scattering of α and β particles by matter and the structure of the atom", E. Rutherford, 1911.

1905 — 1911





Secção eficaz de Rutherford (clássica).

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

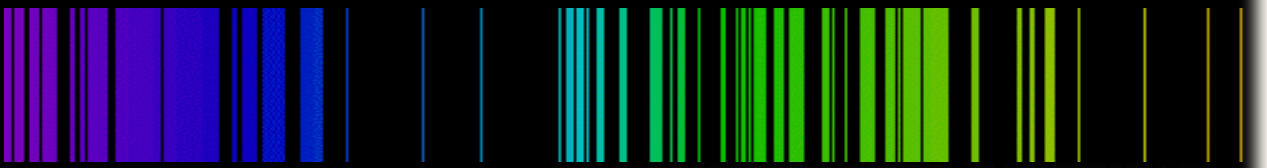
1913

Modelo "Planetário" de Rutherford → Átomo instável

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

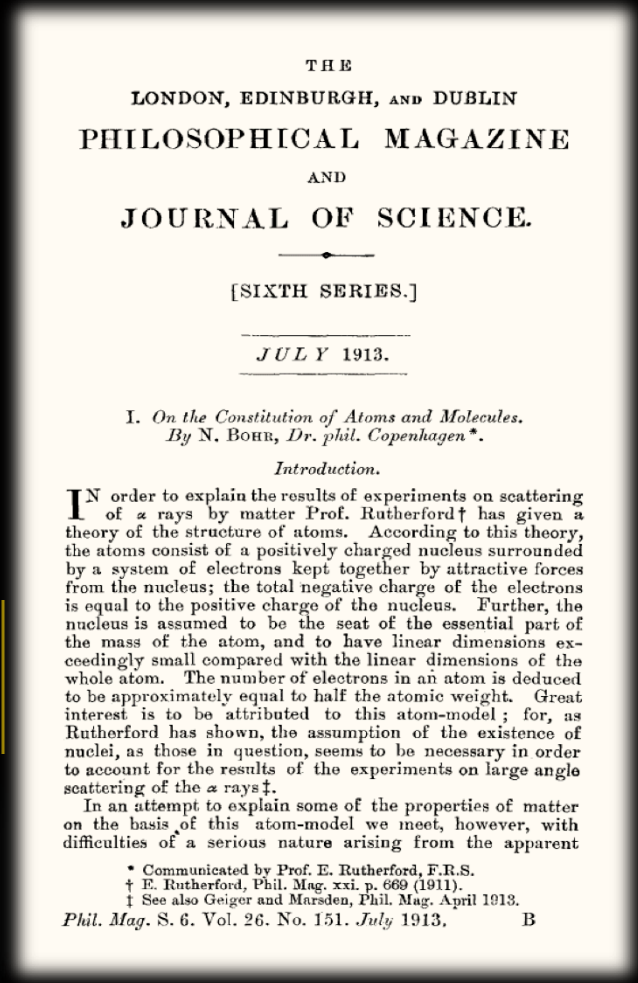
Quantização do momento angular:

Explicação para as linhas de emissão atómicas:



Fórmula de Rydberg:

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



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‡.

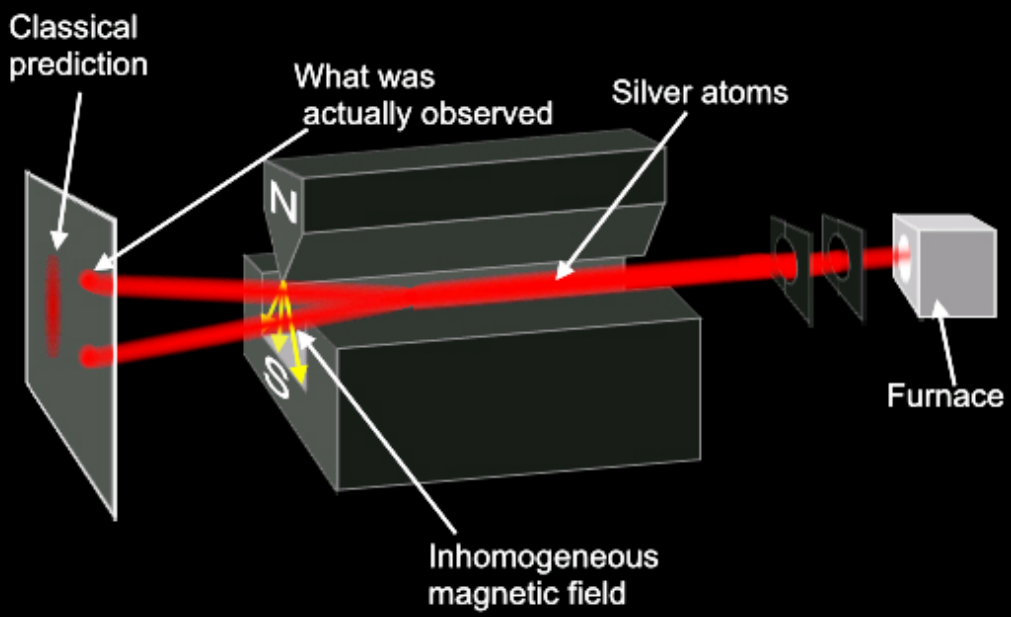
In an attempt to explain some of the properties of matter on the basis of this atom-model we meet, however, with difficulties of a serious nature arising from the apparent

* 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

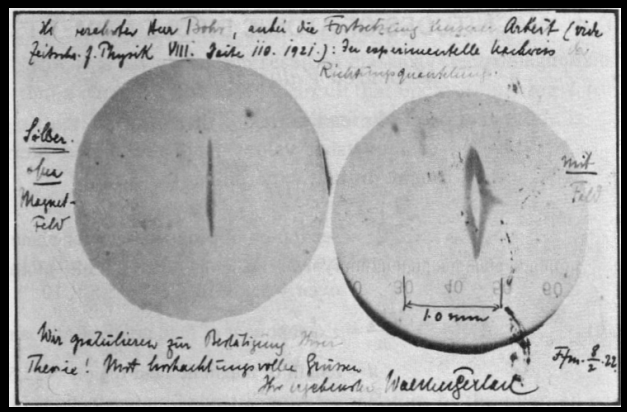
1922

EXPERIÊNCIA DE STERN-GERLACH



Os electrões têm um momento angular intrínseco.

SPIN: 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".