Introdução à Física de Partículas...

Introduction to particle Physics and the Universe

... e ao Universo

(2/3)

FILIPE JOAQUIM

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Escola de Professores no CERN em Língua Portuguesa 2013

CERN Portuguese Language Teachers Programme 2013

1-6 Setembro, CERN, Genebra

1924

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

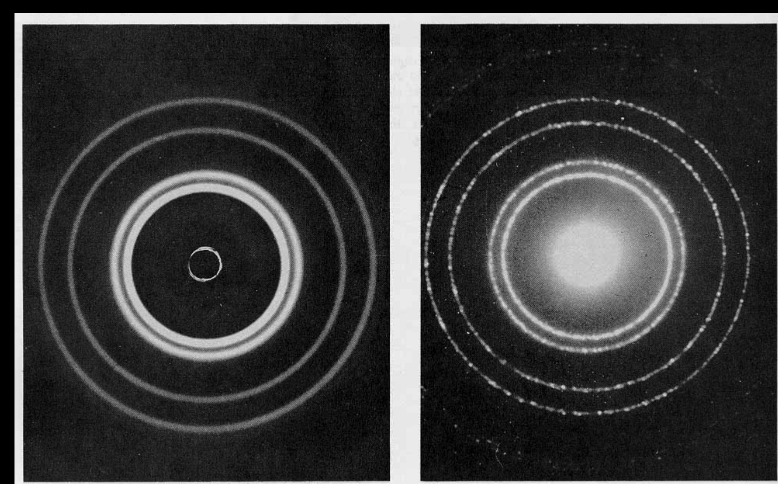
When I conceived the first basic ideas of wave mechanics in 1923–24,[(1)] I was guided by the aim to perform a real physical synthesis, valid for all particles, of the coexistence of the wave and of the corpuscular aspects that Einstein had introduced for photons in his theory of light quanta in 1905. 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".

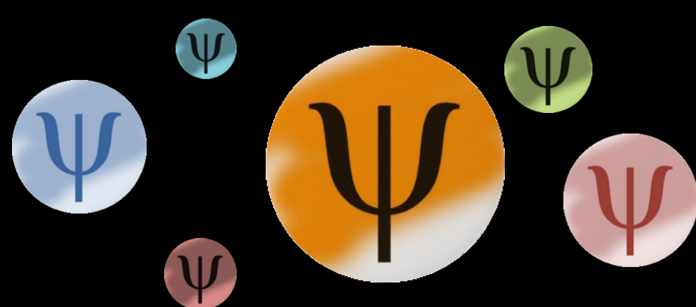


1920-1925

Apesar dos sucessos do modelo de Bohr, o mesmo falhava na explicação de várias observações.

ERA NECESSÁRIA UMA TEORIA QUE FOSSE BASEADA EM PRIMEIROS PRINCÍPIOS

A NOVA TEORIA QUÂNTICA



1920-1925

Abandono do determinismo da Física clássica

)

EQUAÇÃO DE SCHRöDINGER

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

Numa versão mais moderna:

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).

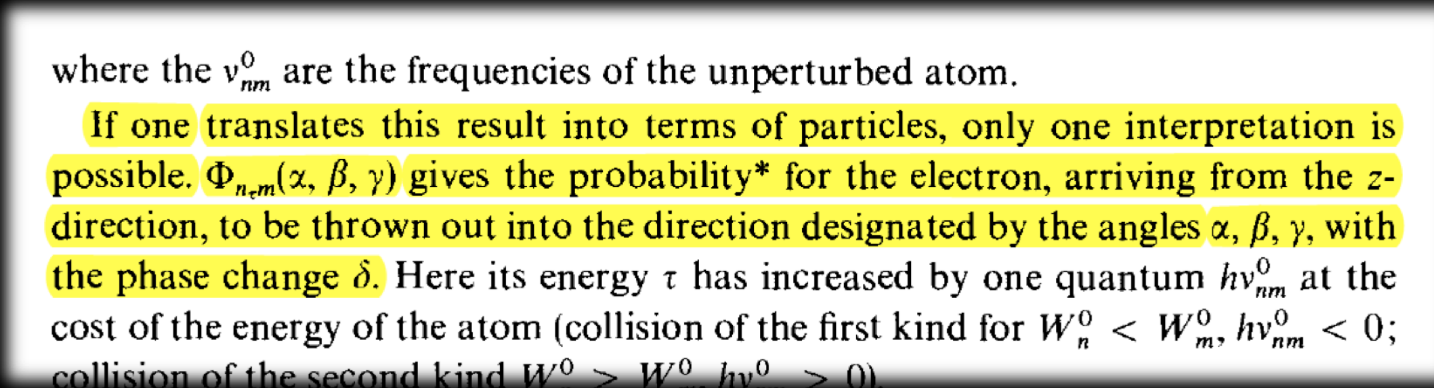
1049

1920-1925

1926

Qual o significado de ψ ?

Max Born



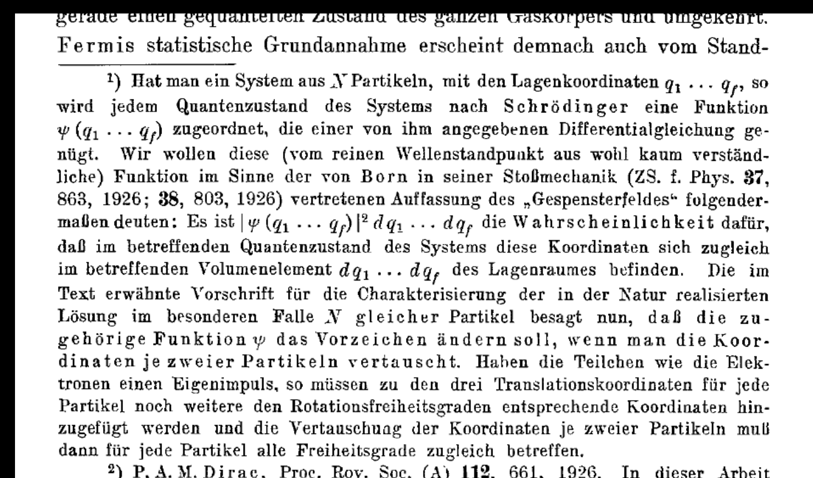
where the ν^0_{nm} are the frequencies of the unperturbed atom.

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

Probabilidade de encontrar a partícula num volume infinitesimal



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

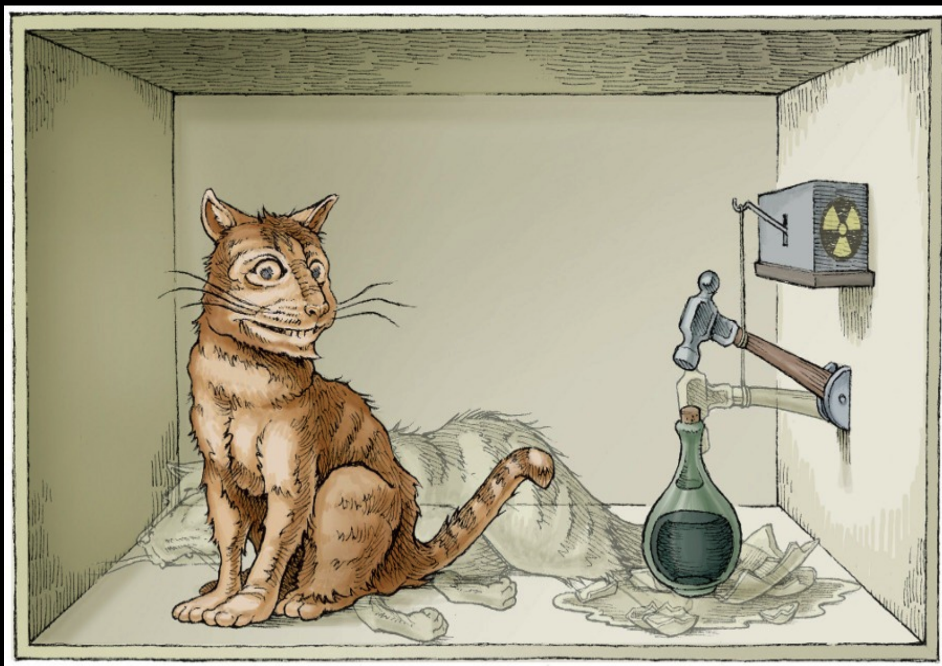
[1]) Hat man ein System aus N Partikeln, mit den Lagenkoordinaten $q_1 \dots q_f$, so wird jedem Quantenzustand des Systems nach Schrödinger eine Funktion $\psi(q_1 \dots q_f)$ zugeordnet, die einer von ihm angegebenen Differentialgleichung genügt. Wir wollen diese (vom reinen Wellenstandpunkt aus wohl 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 $|\psi(q_1 \dots q_f)|^2 \, dq_1 \dots dq_f$ die Wahrscheinlichkeit dafür, daß im betreffenden Quantenzustand des Systems diese Koordinaten sich zugleich im betreffenden Volumenelement $dq_1 \dots dq_f$ 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

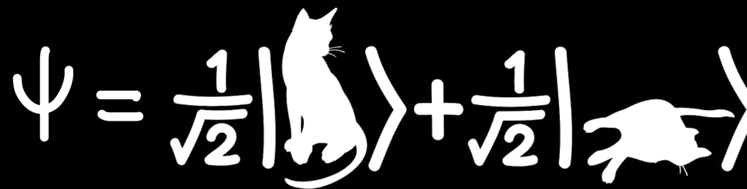
W. Pauli, Z. für Physik 41, 81-102 (1927)

1926

1920-1925



Qual a função de onda do gato de Schrödinger?



Depois de abrirmos a caixa:

OU

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

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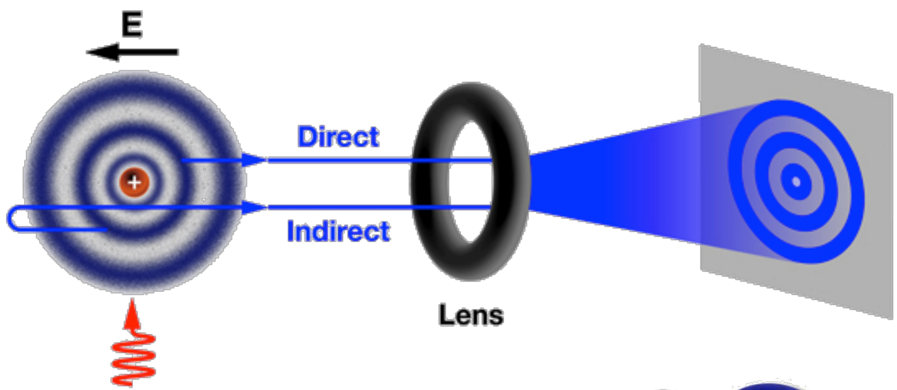
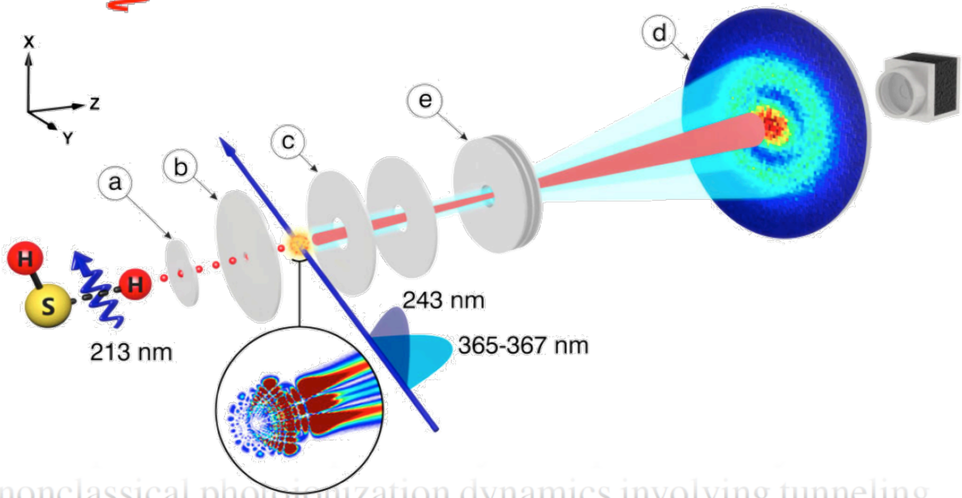
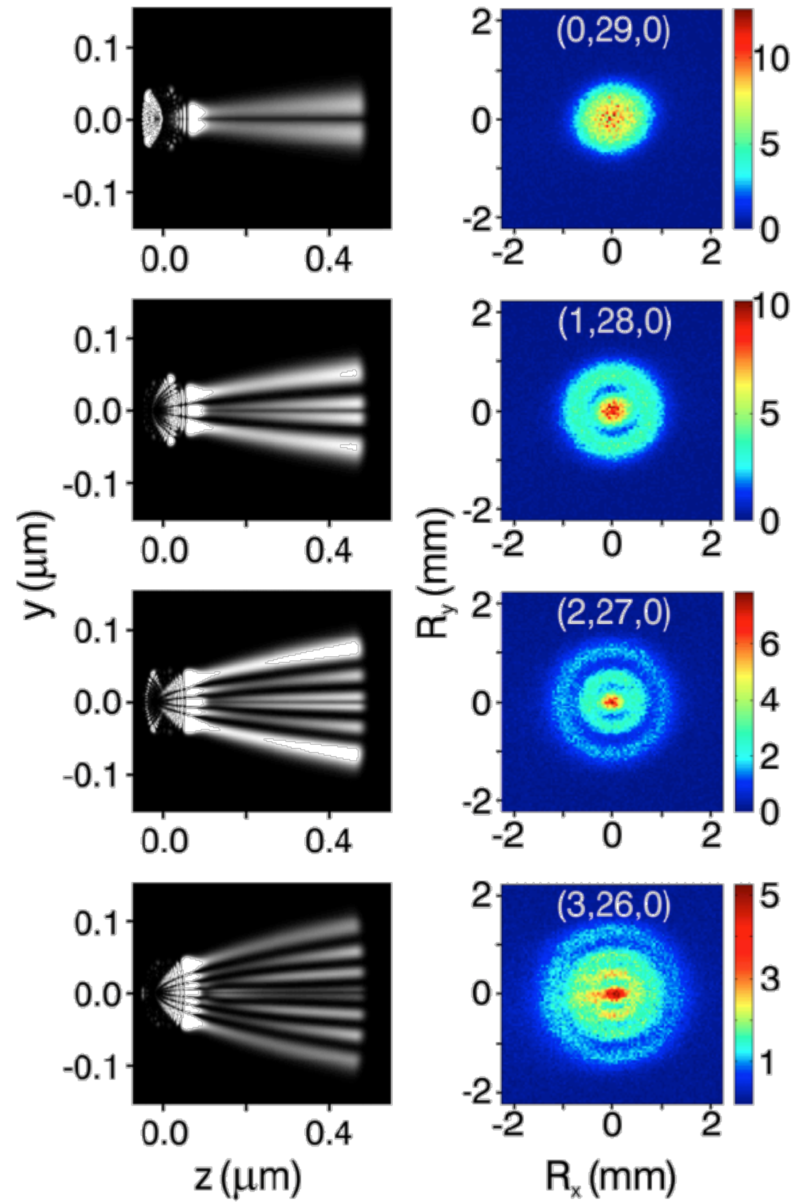
To describe the microscopic properties of matter, quantum mechanics uses wave functions, whose structure and time dependence is governed by the Schrödinger equation. In atoms the charge distributions described by the wave function are rarely observed. The hydrogen atom is unique, since it only has one 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?





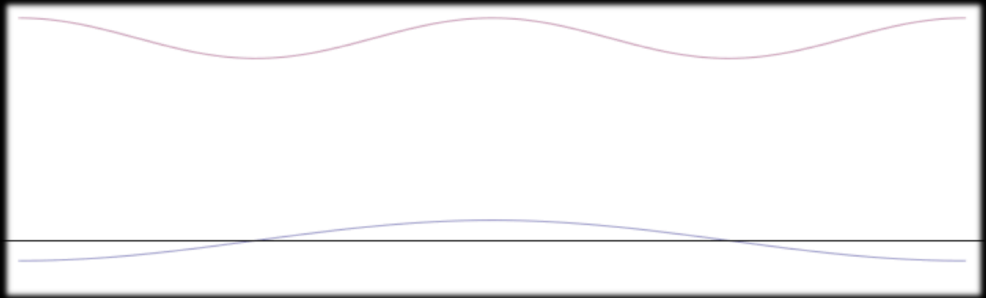


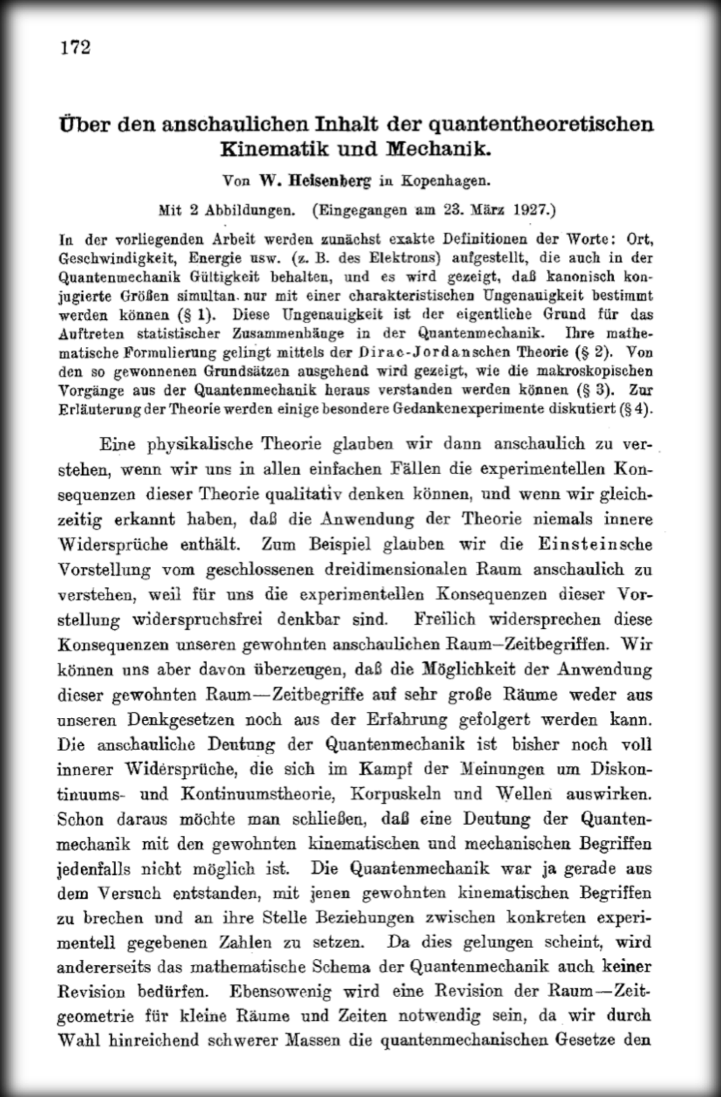
nonclassical photoionization dynamics involving tunneling through the $V(\eta)$ potential barrier, can be experimentally realized, providing both a beautiful demonstration of the intricacies of quantum mechanics and a fruitful playground, where the fundamental implications of this theory can be further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

1927

1926

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





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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

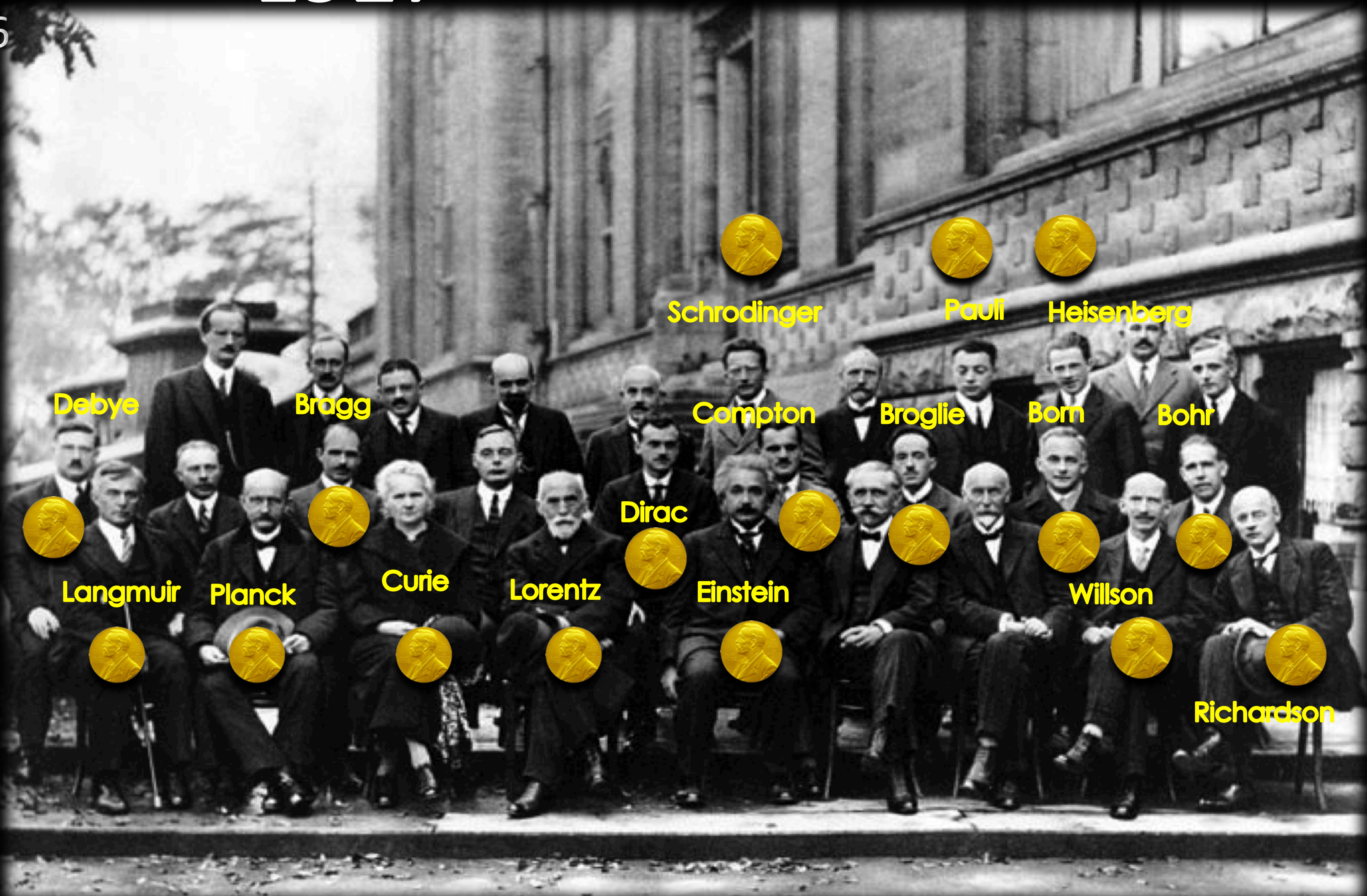
O prémio Nobel da Física foi atríbuido a Werner Heisenberg em 1932;

"for the creation of quantum mechanics".

A nova teoria quântica - Heisenberg

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

Eq. de Schrödinger relativista

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

ESTA EQUAÇÃO PARECE TER ALGUNS PROBLEMAS...

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

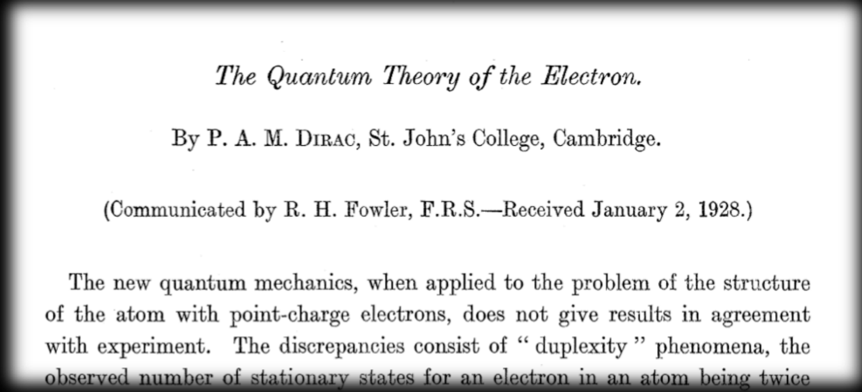
1927

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



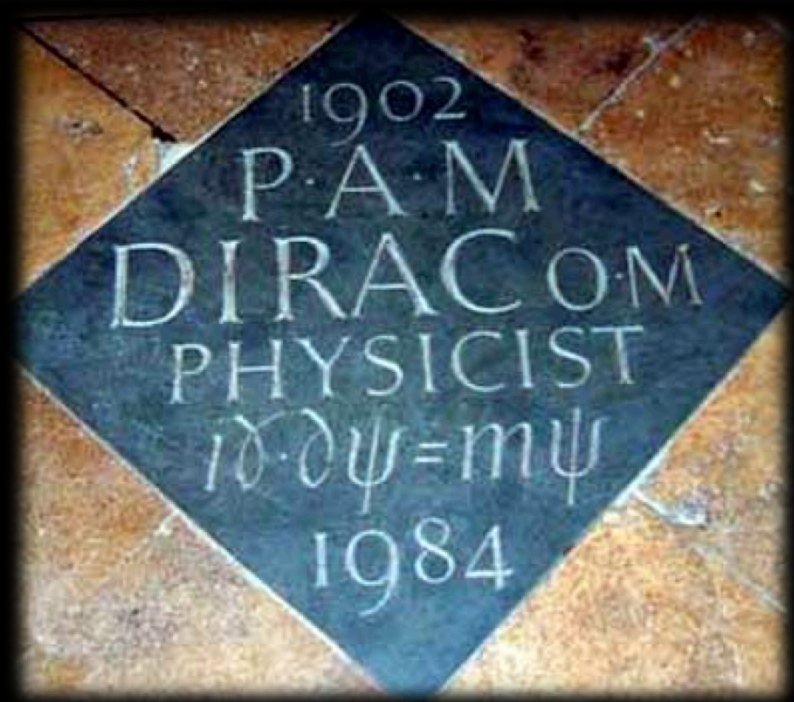
The Quantum Theory of the Electron.

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

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

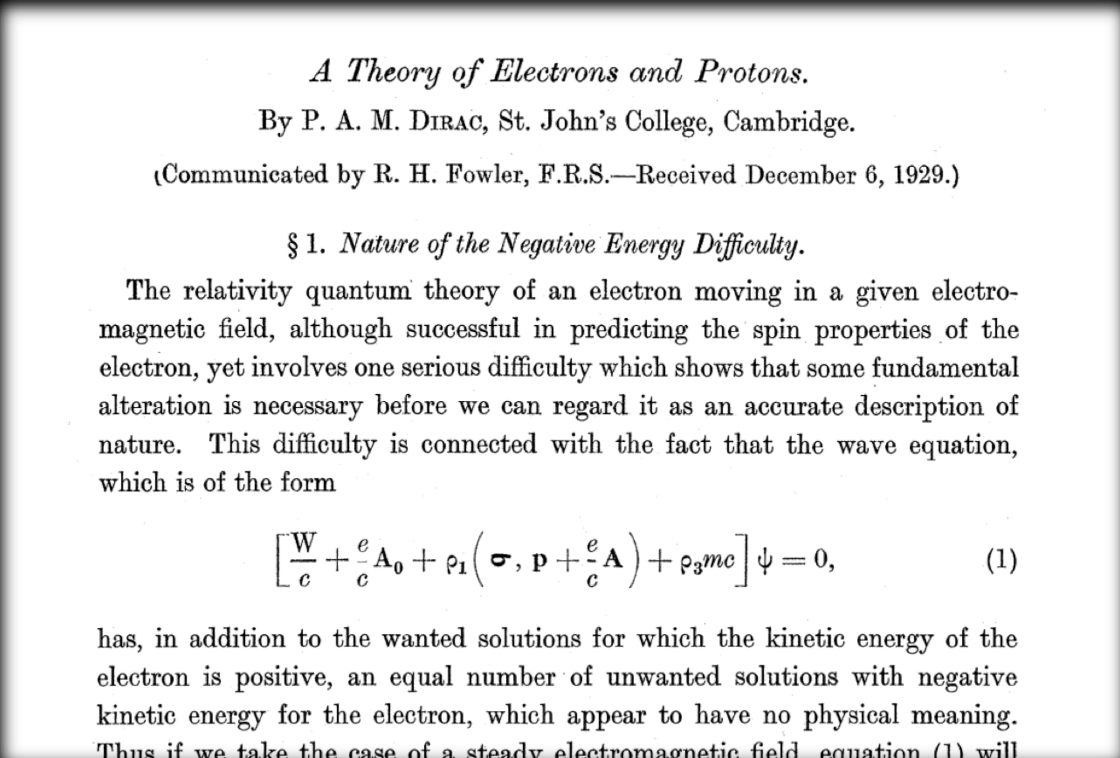


A eq. De Dirac parece permitir soluções de energia NEGATIVA !!!

1928

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

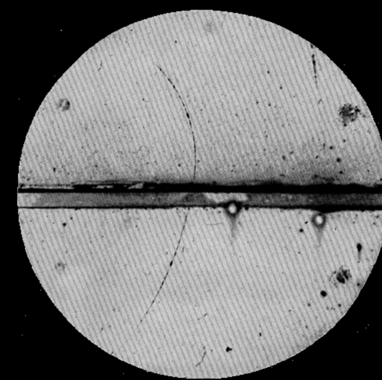
1929
1931

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,

O POSITRÃO

Carl Anderson, 1932



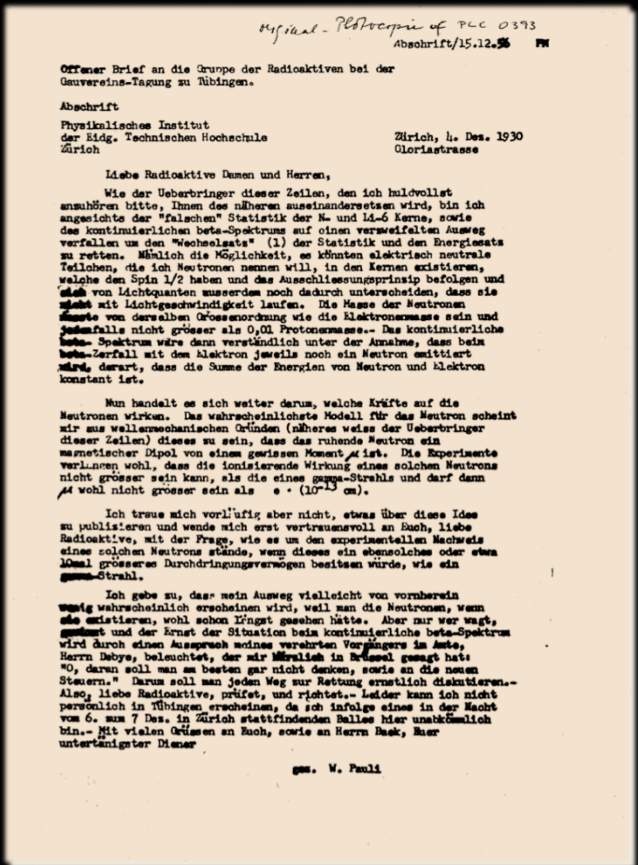
Como construir uma câmara de Wilson

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

"for the discovery of the positron".

ESTAVA DESCOBERTA A **ANTIMATÉRIA!**

1930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Offener Brief an die Gruppe der Radioaktiven bei der Gauvereins-Tagung zu Tübingen.

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Des. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

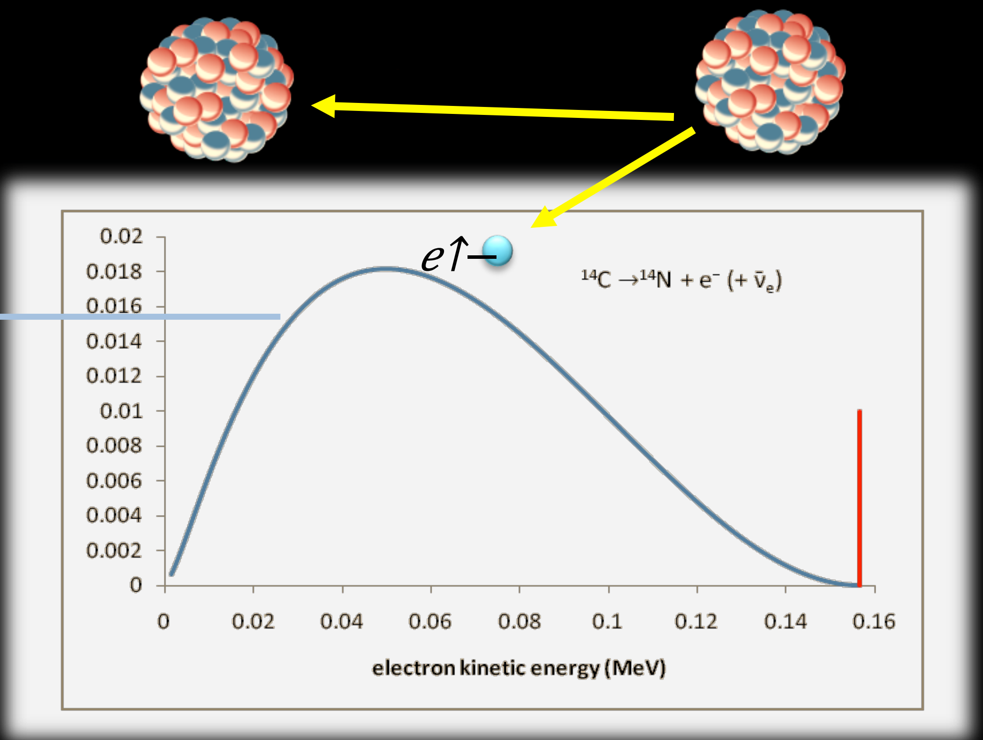
Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik 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 Des. in Zürich stattfindenden Balles hier unabkömmlich bin.- Mit vielen Grüssen an Euch, sowie an Herrn Back, Euer untertänigster Diener

gez. W. Pauli



CONSERVAÇÃO DA ENERGIA?

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


W. Pauli

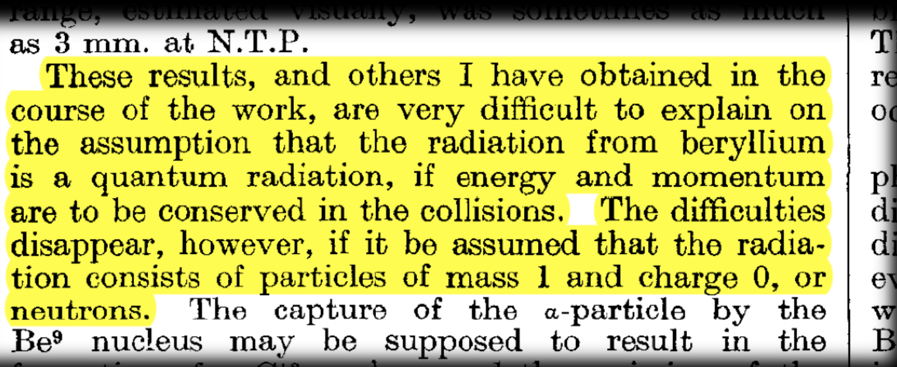
O espectro beta contínuo faria sentido se, além do electrão, um neutrão for emitido de tal modo que a soma da energia do electrão e do neutrão é constante.

1932

Modelo do átomo durante os anos 20:

Protões + electrões

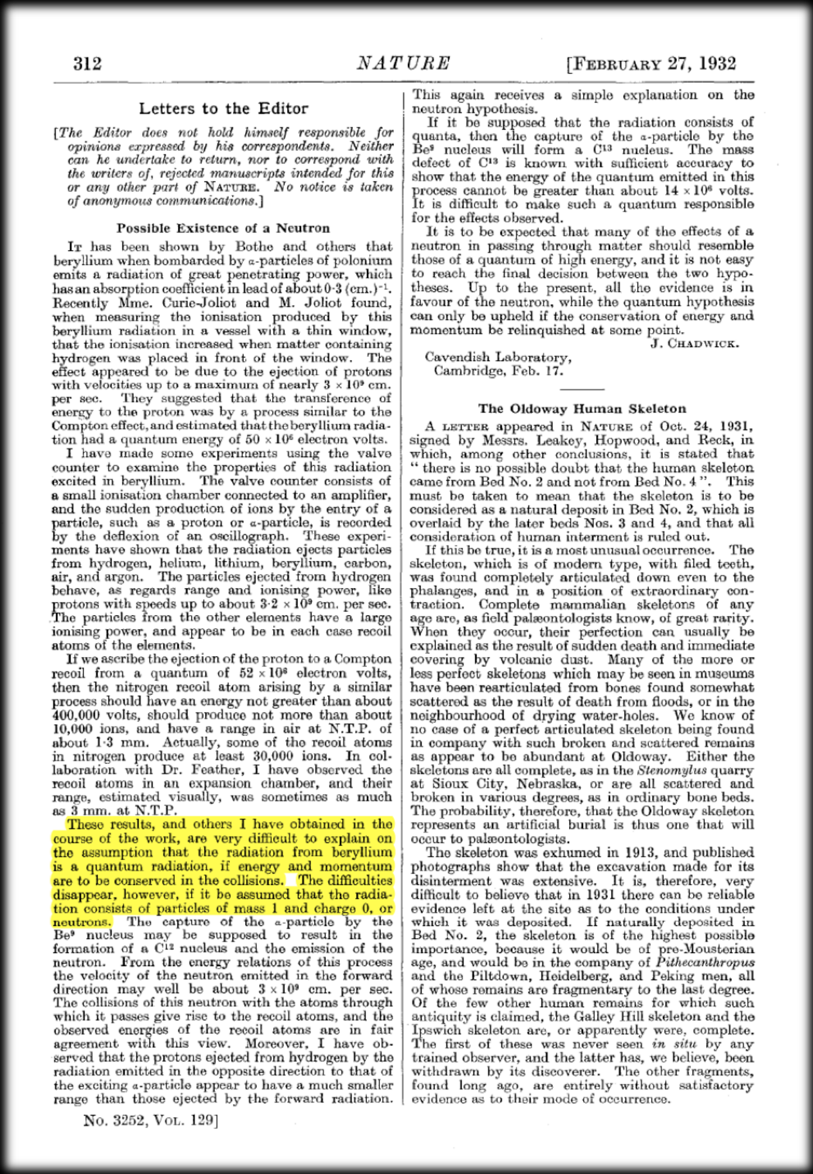
Inconsistente com a "nova" MQ.


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

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

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Possible Existence of a Neutron

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

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

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

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

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

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

J. CHADWICK.

Cavendish Laboratory,
Cambridge, Feb. 17.

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.

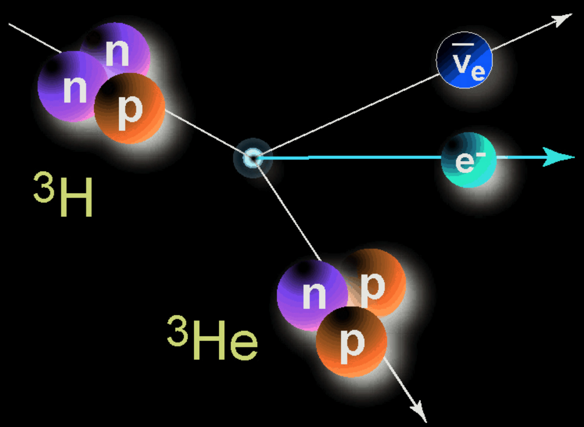
If this be true, it is a most unusual occurrence. The skeleton, which is of modern type, with filed teeth, was found completely articulated down even to the phalanges, and in a position of extraordinary contraction. Complete mammalian skeletons of any age are, as field palæontologists know, of great 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.

No. 3252, VOL. 129]

1934

Em 1934, Fermi propõe a primeira teoria para explicar o decaimento β dos núcleos.



Esta descrição não é válida para toda a gama de energias...

Tempo de vida do muão:

TENTATIVO DI UNA TEORIA DEI RAGGI β

Nota (1) di Enrico Fermi

Sunto. - *Si propone una teoria quantitativa dell'emissione dei raggi β in cui si ammette l'esistenza del « neutrino » e si tratta l'emissione degli elettroni e dei neutrini da un nucleo all'atto della disintegrazione β con un procedimento simile a quello seguito nella teoria dell'irradiazione per descrivere l'emissione di un quanto di luce da un atomo eccitato. Vengono dedotte delle formule per la vita media e per la forma dello spettro continuo dei raggi β, e le si confrontano coi dati sperimentali.*

Ipotesi fondamentali della teoria.

§ 1. Nel tentativo di costruire una teoria degli elettroni nucleari e dell'emissione dei raggi β, si incontrano, come è noto, due difficoltà principali. La prima dipende dal fatto che i raggi β primari vengono emessi dai nuclei con una distribuzione continua di velocità. Se non si vuole abbandonare il principio della conservazione dell'energia, si deve ammettere perciò che una frazione dell'energia che si libera nel processo di disintegrazione β sfugga alle nostre attuali possibilità di osservazione. Secondo la proposta di Pauli si può p. es. ammettere l'esistenza di una nuova particella, il così detto « neutrino », avente carica elettrica nulla e massa dell'ordine di grandezza di quella dell'elettrone o minore. Si ammette poi che in ogni processo β vengano emessi simultaneamente un elettrone, che si osserva come

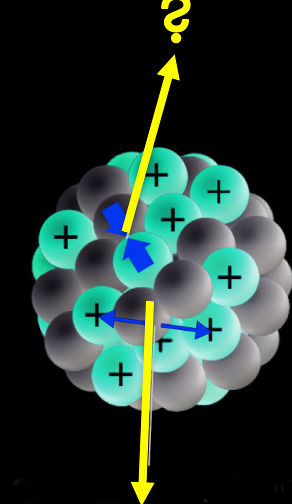
Constante de Fermi:

1934

O núcleo é constituido por protões e neutrões...

Mas qual a força que os mantém ligado no núcleo?

To remove this defect, it seems natural to modify the theory of Heisenberg and Fermi in the following way. The transition of a heavy particle from neutron state to proton state is not always accompanied by the emission of light particles, i. e., a neutrino and an electron, but the energy liberated by the transition is taken up sometimes by another heavy particle, which in turn will be transformed from proton state into neutron state. If the probability of occurrence of the latter process is much larger than that of the former, the interaction between



Repulsão electrostática

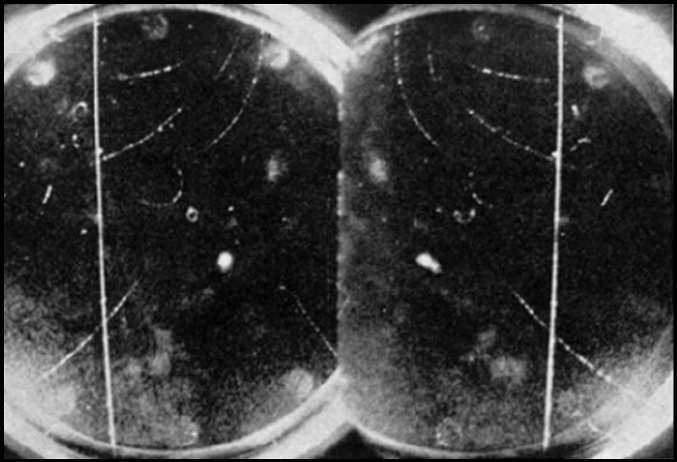
Potencial de Yukawa:

MeV

O prémio Nobel da Física foi atríbuido a Hideki Yukawa em 1949;

"for his prediction of the existence of mesons on the basis of theoretical work on nuclear forces".

1936



Em 1936 Anderson observam novos rastos numa câmara de Wilson com massa "intermédia".

Seria esta partícula de Yukawa?

Não. Esta nova partícula não tinha afinidade para se ligar ao núcleo.

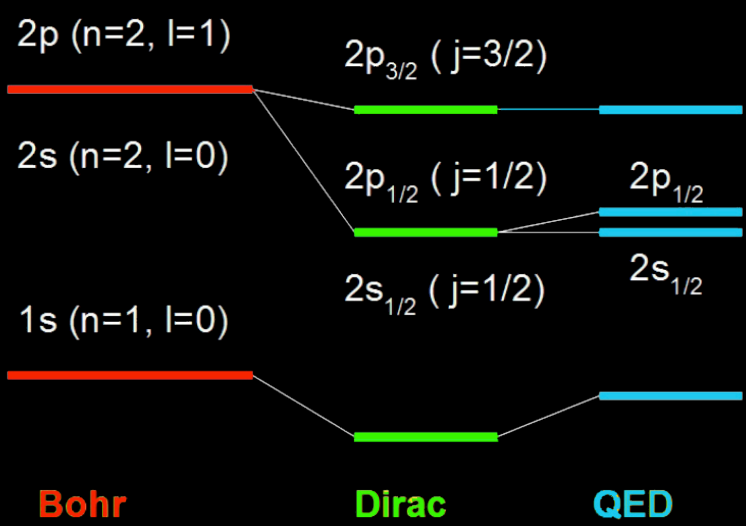
Anderson chamou a esta partícula o "mesotrão" (hoje conhecida como muão μ). O pião viria a ser descoberto em 1946.

O prémio Nobel da Física foi atríbuido a Cecil Powell em 1950;

"for his development of the photographic method of studying nuclear processes and his discoveries regarding mesons made with this method".

1947

Segundo as previsões de Dirac, os estados $2S_{1/2}$ e $2P_{1/2}$ são degenerados



Em 1947 Willis Lamb e Robert Retherford mediram uma diferença de energia entre estes dois níveis.

O prémio Nobel da Física foi atríbuido a Willis Lamb em 1955;

"for his discoveries concerning the fine structure of the Hydrogen spectrum".

1947

1936

Bethe calculou pela primeira vez o desvio de Lamb obtendo o valor de:

1040 MHz

Conferência em Shelter Island (1947)

figure and $K = mc^2$, the logarithm has the value 7.63, and we find

$$W_{ns}' = 136 \ln[K/(E_n - E_m)]$$
$$= 1040 \text{ megacycles.} \quad (12)$$

[7] I am indebted to Dr. Stehn and Miss Steward for the numerical calculations.

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The Electromagnetic Shift of Energy Levels

H. A. BETHE
Cornell University, Ithaca, New York
(Received June 27, 1947)

BY very beautiful experiments, Lamb and Retherford[1] have shown that the fine structure of the second quantum state of hydrogen does not agree with the prediction of the Dirac theory. The $2s$ level, which according to Dirac's theory should coincide with the $2p_{\frac{1}{2}}$ level, is actually higher than the latter by an amount of about 0.033 cm^{-1} or 1000 megacycles. This discrepancy had long been suspected from spectroscopic measurements.[2,3] However, so far no satisfactory theoretical explanation has been given. Kemble and Present, and Pasternack[4] have shown that the shift of the $2s$ level cannot be explained by a nuclear interaction of reasonable magnitude, and Uehling[5] has investigated the effect of the "polarization of the vacuum" in the Dirac hole theory, and has found that this effect also is much too small and has, in addition, the wrong sign.

Schwinger and Weisskopf, and Oppenheimer have suggested that a possible explanation might be the shift of energy levels by the interaction of the electron with the radiation field. This shift comes out infinite in all existing theories, and has therefore always been ignored. However, it is possible to identify the most strongly (linearly) divergent term in the level shift with an electromagnetic *mass* effect which must exist for a bound as well as for a free electron. This effect should

[1] Phys. Rev. **72**, 241 (1947).
[2] W. V. Houston, Phys. Rev. **51**, 446 (1937).
[3] R. C. Williams, Phys. Rev. **54**, 558 (1938).
[4] E. C. Kemble and R. D. Present, Phys. Rev. **44**, 1031 (1932); S. Pasternack, Phys. Rev. **54**, 1113 (1938).
[5] E. A. Uehling, Phys. Rev. **48**, 55 (1935).

Bethe foi o primeiro a determinar as correcções relevantes para o desvio de Lamb.

Mais problemas...

Apesar de resolver algumas questões em aberto, a MQR ainda não era uma teoria satisfatória.

$$E_c \sim mc^2 \rightarrow p \sim mc \rightarrow \lambda \sim \frac{h}{mc} = \lambda_c$$

- Comprimento de onda de Compton

PRINCIPIO DA INCERTEZA: $\Delta p \geq \frac{\hbar}{\Delta x} = mc$

Conclusão: Se tentarmos localizar uma partícula de massa m numa região do espaço de dimensões menores que , então as flutuações na energia são suficientes para criar um par partícula-antíparticula.

UMA TEORIA COMPLETAMENTE RELATIVISTA NÃO SE PODE BASEAR NA IDEIA DE QUE UM SISTEMA PODE SER DESCRITO PELA FUNÇÃO DE ONDA A 1 PARTÍCULA.

MECÂNICA QUÂNTICA: Posição e momento são tratados como operadores:

E O TEMPO t ?

Numa teoria relativista espaço deveriam estar em pé de igualdade. Mas em MQ o tempo é um parâmetro.

$$T\ \psi = t\ \psi$$

EM TQC, A POSIÇÃO E O ESPAÇO SÃO DESPROMOVIDOS A PARÂMETROS QUE SÃO ARGUMENTOS DE UM CAMPO

SEGUNDA QUANTIFICAÇÃO

- operadores de criação e aniquilação

Estados em TQC: $|p\rangle = a^{\dagger}(p)\,|0\rangle$

Estados com várias partículas:

Estados com vária partículas:

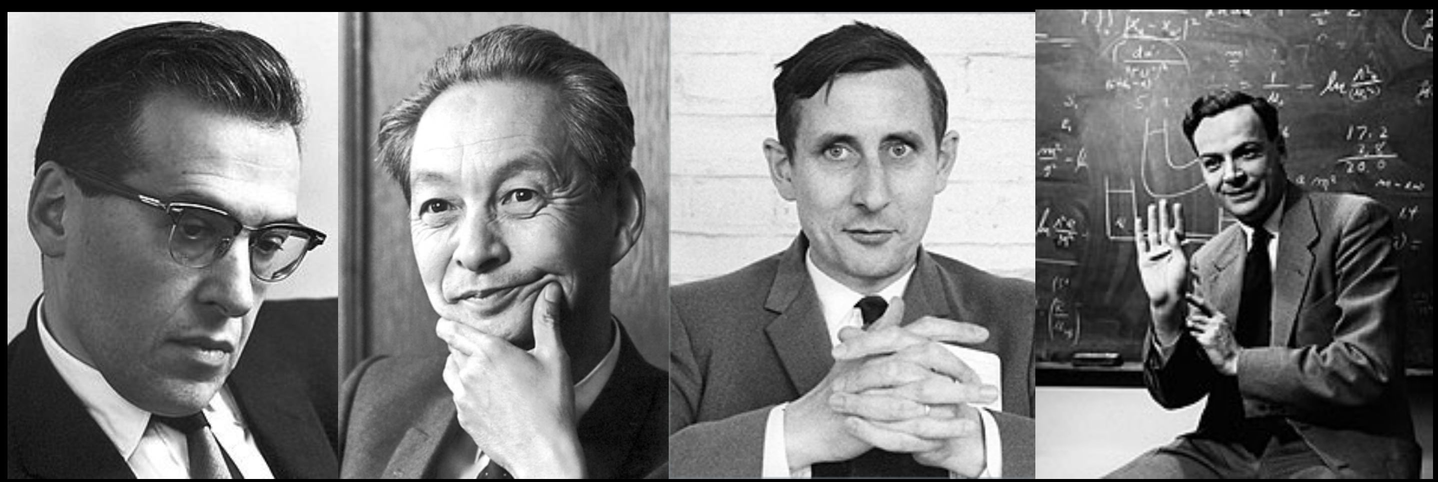
Aniquilação:

O operador campo actua em estados de tal modo que se podem criar ou aniquilar partículas!

Electrodinâmica quântica

TQC DOS FOTÕES, ELECTRÕES, POSITRÕES E SUAS INTERAÇÕES

ElectroDinâmica Quântica - EDQ (QED)

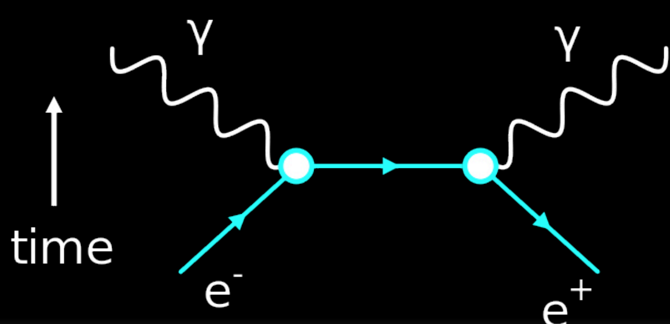


Schwinger Tomonaga Dyson Feynman

The Nobel Prize in Physics 1965 was awarded jointly to Sin-Itiro Tomonaga, Julian Schwinger and Richard P. Feynman "for their fundamental work in quantum electrodynamics, with deep-ploughing consequences for the physics of elementary particles".

1948

Em 1948 Feynman desenvolveu um método "gráfico" que permite calcular processos que envolvem interacções entre particulas elementares.



A furgoneta Feynman

Para o diagram acima: $\mathcal{M} = \varepsilon^*_\mu(p_1,\lambda_1)\varepsilon^*_\nu(p_2,\lambda_2)\bar{v}(e^+)(ie\gamma^\nu)\frac{i}{\not{q} - m}(ie\gamma^\mu)u(e^-)$

A TÉCNICA DOS DIAGRAMAS DE FEYNMAN É USADA PARA CALCULAR AS "PROBABILIDADES" DE OCORRÊNCIA DE PROCESSOS ENVOLVENDO PARTÍCULAS ELEMENTARES.

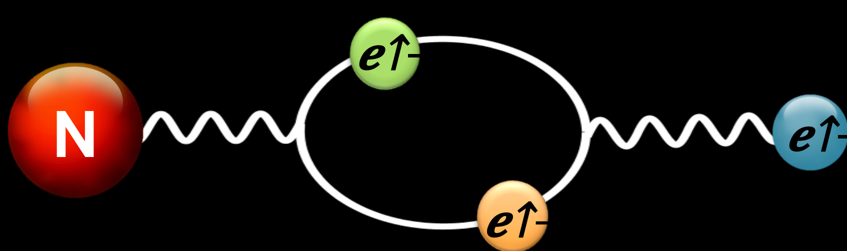
O VÁCUO QUÂNTICO

vácuo
(latim *vacuus, -a, -um*)
adj.
1. Que não contém nada; que não se acha ocupado por coisa alguma. = OCO, VAZIO
2. [Jurídico, Jurisprudência] Que se possui mas que não se desfruta ou não se goza.
s. m.
3. Espaço circunscrito que não contém ar ou que se supõe vazio.
4. O espaço entre os corpos celestes que se supõe vazio.

EM FÍSICA QUÂNTICA O VÁCUO ESTÁ LONGE DE SER ESPAÇO VAZIO...

PIH Energia-tempo

2ª Quantização: O campo E.M. Pode ser interpretado como um conjunto infinito de osciladores harmónicos cujo estado fundamental tem energia não nula.

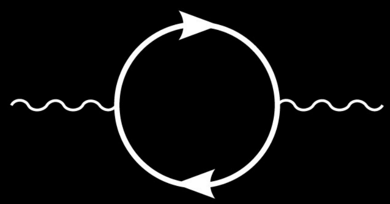


Polarização do vácuo

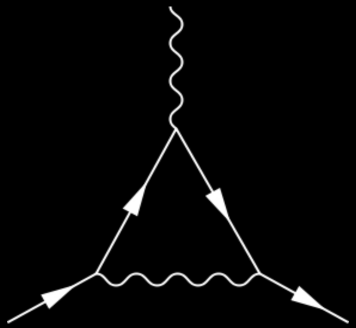
À semelhança da polarização de um dieléctrico.

O VÁCUO EM QED

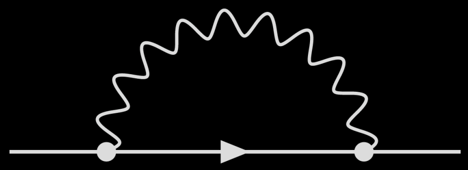
Polarização do vácuo

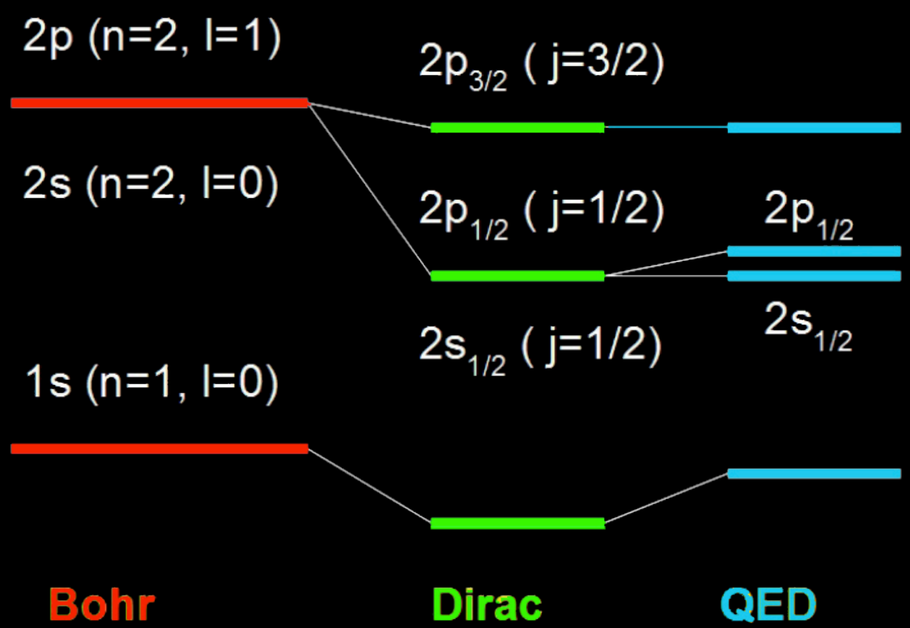


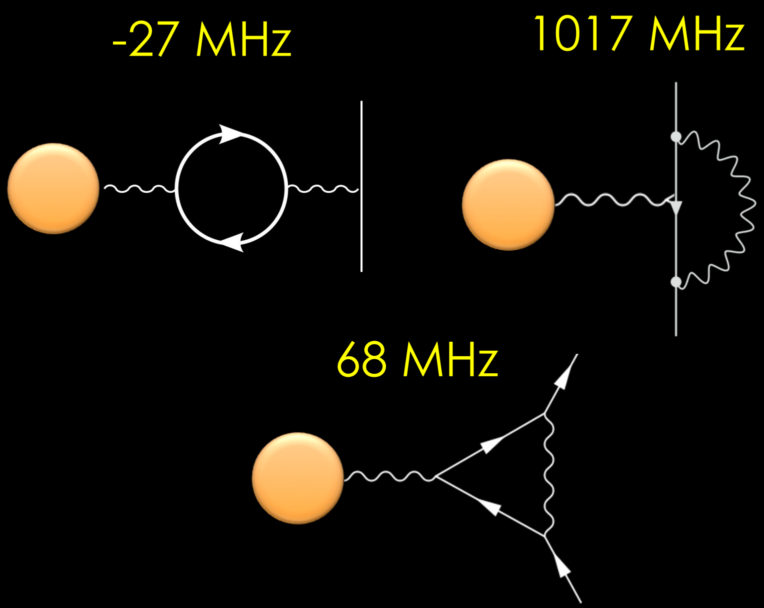
Correcção ao vértice



Correcção à energia própria







Teoria: 1058 MHz , Exp: 1057.9