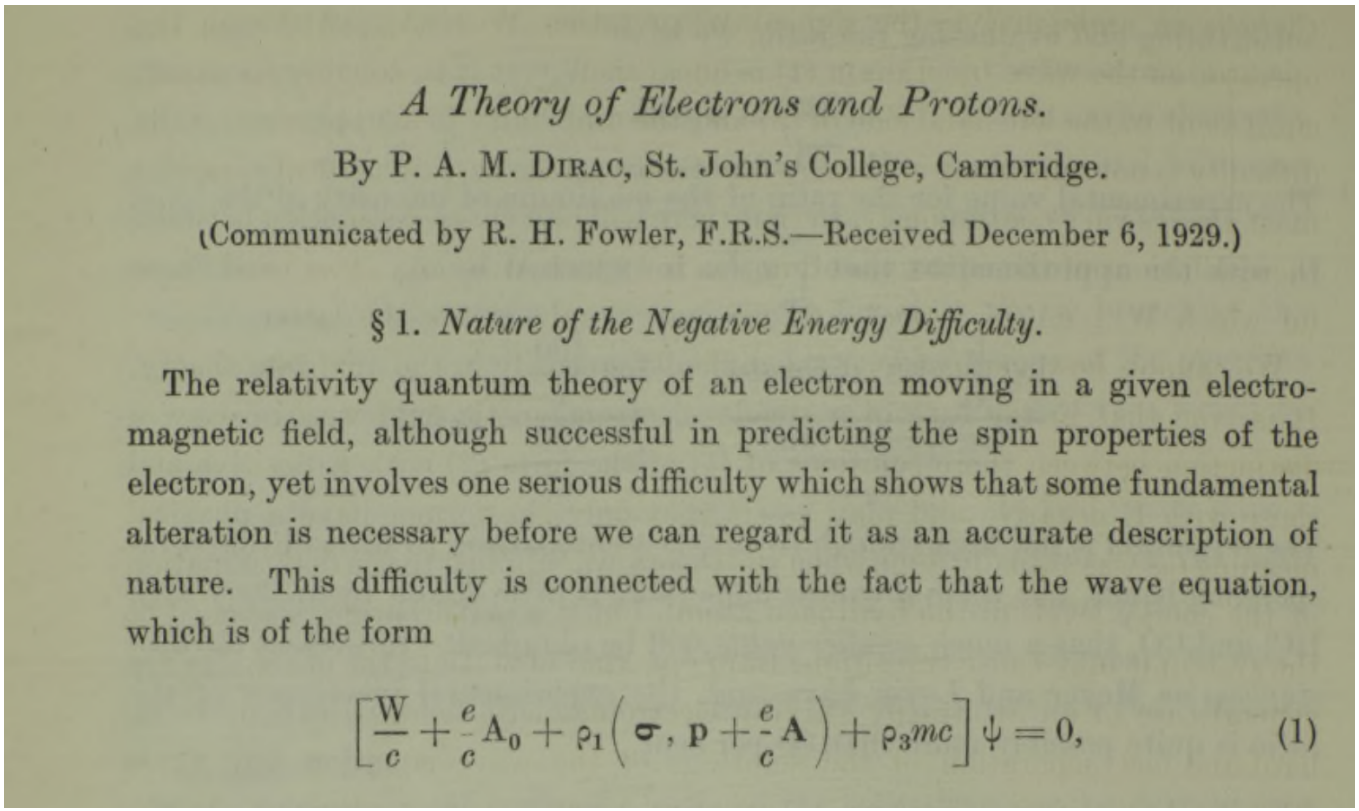
Can one ever prove that neutrinos are Dirac particles?

Rahul Srivastava
Work Done in Collaboration with
Martin Hirsch and José W. F. Valle
arXiv: 1711.06181 [hep-ph]

Journal Club, IFIC, Valencia
22nd Nov 2017

Piece of History: Dirac Fermions

- 1929-34: In a series of papers Dirac points out the need of anti-particles in order to have a consistent relativistic version of quantum mechanics



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

$$\left[\frac{\mathrm{W}}{c}+\frac{e}{c}\mathrm{A}_0+\rho_1\left(\boldsymbol{\sigma},\ \mathbf{p}+\frac{e}{c}\mathbf{A}\right)+\rho_3 mc\right]\psi=0, \qquad (1)$$

Piece of History: Majorana Fermions

- 1937-38: Majorana showed that Dirac's theory also includes the possibility of particle being its own anti-particle

TEORIA SIMMETRICA DELL'ELETTRONE E DEL POSITRONE

Nota di ETTORE MAJORANA

Sunto. - *Si dimostra la possibilità di pervenire a una piena simmetrizzazione formale della teoria quantistica dell'elettrone e del positrone facendo uso di un nuovo processo di quantizzazione. Il significato delle equazioni di* DIRAC *ne risulta alquanto modificato e non vi è più luogo a parlare di stati di energia negativa; nè a presumere per ogni altro tipo di particelle, particolarmente neutre, l'esistenza di « antiparticelle » corrispondenti ai « vuoti » di energia negativa.*

Piece of History: Beta Decay

- 1934: Fermi introduces neutrinos (a electrically neutral particle with very tiny or zero mass) in context of β Decays

Versuch einer Theorie der β-Strahlen. I[1]).

Von **E. Fermi** in Rom.

Mit 3 Abbildungen. (Eingegangen am 16. Januar 1934.)

Eine quantitative Theorie des β-Zerfalls wird vorgeschlagen, in welcher man die Existenz des Neutrinos annimmt, und die Emission der Elektronen und Neutrinos aus einem Kern beim β-Zerfall mit einer ähnlichen Methode behandelt, wie die Emission eines Lichtquants aus einem angeregten Atom in der Strahlungstheorie. Formeln für die Lebensdauer und für die Form des emittierten kontinuierlichen β-Strahlenspektrums werden abgeleitet und mit der Erfahrung verglichen.

Piece of History: Double Beta Decay

- 1935: Shortly after Fermi's paper, Goeppert-Mayer discussed the possibility of double-beta decay ($2\nu2\beta$)

SEPTEMBER 15, 1935 PHYSICAL REVIEW VOLUME 48

Double Beta-Disintegration

M. GOEPPERT-MAYER, *The Johns Hopkins University*

(Received May 20, 1935)

From the Fermi theory of β-disintegration the probability of simultaneous emission of two electrons (and two neutrinos) has been calculated. The result is that this process occurs sufficiently rarely to allow a half-life of over 10^{17} years for a nucleus, even if its isobar of atomic number different by 2 were more stable by 20 times the electron mass.

Piece of History: Neutrinoless Double Beta Decay

- 1939: Shortly after Majorana's paper, Furry showed that for case of Majorana neutrinos, one also has the possibility of neutrinoless double-beta decay ($0\nu2\beta$)

DECEMBER 15, 1939 PHYSICAL REVIEW VOLUME 56

On Transition Probabilities in Double Beta-Disintegration

W. H. Furry
Physics Research Laboratory, Harvard University, Cambridge, Massachusetts
(Received October 16, 1939)

The phenomenon of double β-disintegration is one for which there is a marked difference between the results of Majorana's symmetrical theory of the neutrino and those of the original Dirac-Fermi theory. In the older theory double β-disintegration involves the emission of four particles, two electrons (or positrons) and two antineutrinos (or neutrinos), and the probability of disintegration is extremely small. In the Majorana theory only two particles—the electrons or positrons—have to be emitted, and the transition probability is much larger. Approximate values of this probability are calculated on the Majorana theory for the various Fermi and Konopinski-Uhlenbeck expressions for the interaction energy. The selection rules are derived, and are found in all cases to allow transitions with $\Delta i = \pm 1,0$. The results obtained with the Majorana theory indicate that it is not at all certain that double β-disintegration can never be observed. Indeed, if in this theory the interaction expression were of Konopinski-Uhlenbeck type this process would be quite likely to have a bearing on the abundances of isotopes and on the occurrence of observed long-lived radioactivities. If it is of Fermi type this could be so only if the mass difference were fairly large ($\epsilon \gtrsim 20$, $\Delta M \gtrsim 0.01$ unit).

Piece of History: Black Box Theorem

- 1981-82: Schechter-Valle showed that if you observe neutrinoless double beta decay ($0\nu2\beta$) then at least one neutrino has to be a Majorana fermion via the "Black Box" theorem

PHYSICAL REVIEW D VOLUME 25, NUMBER 11 1 JUNE 1982

Neutrinoless double-β decay in SU(2)×U(1) theories

J. Schechter and J. W. F. Valle
Department of Physics, Syracuse University, Syracuse, New York 13210
(Received 14 December 1981)

It is shown that gauge theories give contributions to neutrinoless double-β decay [$(\beta\beta)_{0\nu}$] which are not covered by the standard parametrizations. While probably small, their existence raises the question of whether the observation of $(\beta\beta)_{0\nu}$ implies the existence of a Majorana mass term for the neutrino. For a "natural" gauge theory we argue that this is indeed the case.

Piece of History: Black Box Theorem

- 1981-82: "Black Box" theorem

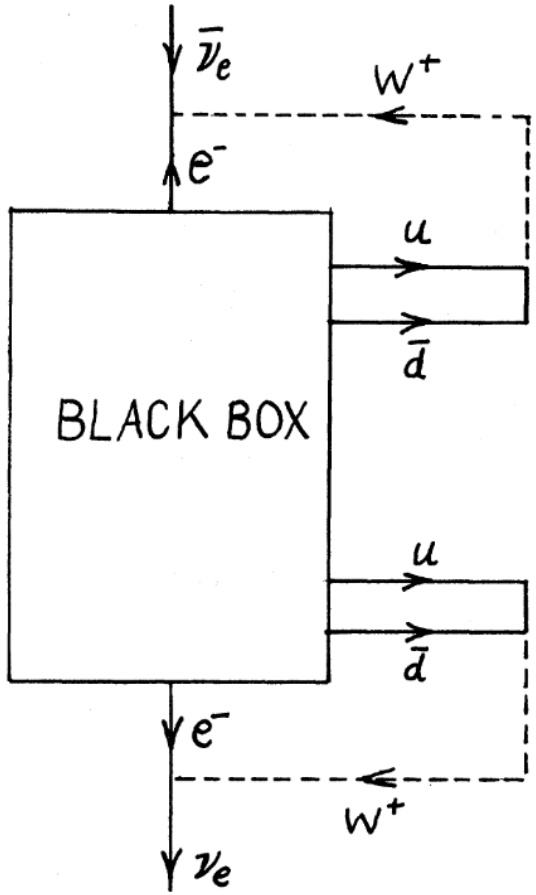


FIG. 2. Diagram showing how any neutrinoless double-β decay process induces a $\bar{\nu}_e$-to-ν_e transition, that is, an effective Majorana mass term.

Gracias