NOTAS DE FÍSICA
VOLUME XIX
Nº 3

ON THE MASS DIFFERENCE OF THE ELECTRON AND THE MUON

by

Mario Novello and Miguel Armony

CENTRO BRASILEIRO DE PESQUISAS FÍSICAS
Av. Wenceslau Braz, 71 - Botafogo - ZC-82
RIO DE JANEIRO, BRAZIL
1972

Notas de Física - Volume XIX - Nº 3

ON THE MASS DIFFERENCE OF THE ELECTRON AND THE MUON

Mario Novello
Centro Brasileiro de Pesquisas Físicas
Rio de Janeiro, Brazil

Miguel Armony
Pontifícia Universidade Católica do Rio de Janeiro
Rio de Janeiro, Brazil

(Received October 30th, 1972)

The idea that Cosmology plays an important role in the properties of the elementary particles has been considered many times in the literature (Einstein, Dirac, Klein, etc.). Recently, Hoyle and Narlikar [1] have claimed to be able to explain the mass difference of the electron (e) and the muon (μ) by making an appeal to Cosmology by means of what they called a Machian theory of inertia. However, it seems to us that there is a crucial drawback in this model because there is no way to predict the value of the mass difference $m_\ell - m_{\ell'}$ by an actual measurement. This is due to the fact that their proposal relates the value of $m_\ell - m_{\ell'}$ to the relative abundance of electron and muon in the

Universe, what is not an easy number to obtain. However, we do believe that it is fashionable to look for the explanation of this mass difference in the actual structure of the Universe. To realize such program we will make an appeal to a recent suggestion of Novello and Rotelli [2] in which the weak interaction process depends on the cosmological time. These authors have proposed that the weak interaction current, in a Friedmann-type Universe assumes the form

$$J_\alpha(x) = \frac{1+\varepsilon(t)}{2} \, \bar{\psi}_\ell(x)\gamma_\alpha(\mathbb{1}+\gamma_5)\,\psi_{\ell'}(x) + \frac{1-\varepsilon(t)}{2}\,\bar{\psi}_\ell(x)\,\gamma_\alpha(\mathbb{1}-\gamma_5)\,\psi_{\ell'}(x)$$

where $\varepsilon^2(t)$ is the norm of $\gamma_5(x)$. In the above expression of the current, γ_α and γ_5 are the constant Dirac matrices.

Let us consider now what could be the origin of the muon and the electron mass. Recently, Higgs [3] has suggested a very useful mechanism in which this mass could appear by an interaction of the leptons with a scalar field. To realize such program we start by considering a modification of a unified model of weak and electromagnetic interaction by means of a Yang-Mills type theory of leptons as has been proposed by Weinberg, Salam [4] etc.. From the fundamental spinors e, ν_e, μ, ν_μ we construct two left and right-handed doublets defined by

$$L_\ell = \frac{1+\varepsilon}{2}\,(1+\gamma_5)\begin{pmatrix}\nu_\ell\\ \ell\end{pmatrix} \text{ and } R_\ell = \frac{1-\varepsilon}{2}\,(1-\gamma_5)\begin{pmatrix}\nu_\ell\\ \ell\end{pmatrix}$$

for $\ell = e, \mu$. Then, we construct a theory in which the minimal Yang-Mills group is $SU(2) \otimes U(1)$. The mass appears as a consequence of an interaction between L, R and a doublet of real scalar fields. We remark here that due to the fact of the time-dependence of $\gamma_5(x)$ there is now two possibilities of parity violating interaction between the leptons and the scalar fields. Let us consider the two singlets $S_\ell^{(-)} = (1 - \gamma_5)\ell$ and $S_\ell^{(+)} = (1 + \gamma_5)\ell$. Then we construct the interacting Lagrangian

$$\mathcal{L} = f \{\bar{S}_\ell^{(-)} \varphi^* (1 + \gamma_5) L_\ell + \bar{S}_{\ell'}^{(+)} \varphi^* (1 - \gamma_5) R_{\ell'} + h.c.\}$$

Due to the gauge invariance of the theory we can choose $\varphi = \binom{0}{p+\phi}$ where p is a constant and ϕ is a real scalar field. With this choice we guarantee the null mass of the neutrinos and the corresponding mass for the leptons:

$$m_\ell = f\, p\, (1 + \varepsilon)$$

$$m_{\ell'} = f\, p\, (1 - \varepsilon)$$

We remark that the coupling constant of the two massive leptons with the φ-field is the same (f). Then the mass factor Δm defined by $m_\ell / m_{\ell'}$ will be equal to $\Delta m = \frac{1+\varepsilon}{1-\varepsilon}$. This relationship shows the dependence of the mass factor on the actual structure of the Universe.

For actual measurements on the earth we can put $\varepsilon = 1-\delta$, with a very small quantity δ. The limits that actual theoretical and experimental arguments can put on δ have been analysed [2] by an investigation on the behaviour of the Michel parameter on μ-decay, for instance and for β-decay. These results suggest the value $\delta \sim 0.01$ as a representative one. This value will imply a mass factor $\Delta m \sim 200$. However, the above simple model gives a relationship between Δm and δ in which any change on δ

gives origin to a very sensitive change on the value of Δm.

Now we could use the other way round argument. That is we assume the experimental value of Δm and deduce by the above expression the value of δ. Then, this value of δ can be used, for instance to evaluate second-order radiative corrections to the μ-decay and checked by experiment. For $\Delta m \sim 206$ the value of δ is 9×10^{-3}. The above value is compatible with the analysis of the Michel parameter on μ-decay in which $\delta < 0.05$.

So, we claim here that an accurate measurement of δ can predict the value of Δm. One of the most interesting features of the theory we are presenting here is that it gives a relationship between the masses of the leptons and the dependence of the value of these masses on the structure of the Universe.

To study this dependence more carefully we have to know the function $\varepsilon(t)$. This function will be available when cosmic neutrinos have been detected, as explained earlier [2].

ACKNOWLEDGEMENTS

One of us (MN) is thankful to Professors C. G. Bollini and J. J. Giambiagi for attracting attention to Higgs' paper.

REFERENCES

1. F. Hoyle, J. V. Narlikar, Nature, vol. 238, July 14 (1972).

2. M. Novello, P. Rotelli, preprint IC/71/148.

3. P. W. Higgs, Phys. Rev. 145 (1966) 1156.

4. See the review paper of B. Zumino and references therein, Cargèse lectures, July, 1972.