

erbium. The weighted mean of the last column gives (170–168): (168–166):(166–164) = 1:0.92±0.05:0.88±0.07, where the disturbance of the Er¹⁶⁷-components is roughly taken into account in considering the limits of error.

Classification of the erbium lines into arc and spark lines was also tried, and it was found that λ5173 belongs to the Er I spectrum. It seems probable that the isotope shift in λ5173 represents approximately the contribution of one 6s electron to the isotope shift in the neutral erbium atom, because it fits reasonably well in the diagram referred to at the beginning of this letter.

The present work was started in the Department of Physics of the University of Wisconsin by Mr. J. S. Ross and one of us (K.M.), and resumed in Tokyo by us. One of us (K.M.) would like to express his appreciation for the kind cooperation of Mr. Ross in the work.

¹ K. Murakawa and J. S. Ross, *Phys. Rev.* **83**, 1272 (1951).

² L. Wilets and L. C. Bradley, *Phys. Rev.* **84**, 1055 (1951). We thank Mr. Wilets for showing us their manuscript before publication.

³ For example, H. A. Bethe, *Elementary Nuclear Theory* (J. Wiley and Sons, Inc., New York, 1947).

⁴ B. Bleaney and H. E. D. Scovil, *Proc. Phys. Soc. (London)* **64**, 204 (1951).

Is There a Neutral μ -Meson?

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THE recent experiments of Sagane, Gardner, and Hubbard¹ on the continuous beta-spectrum in the μ^- decay seem to indicate that the spectrum goes to zero at the upper limit. The same authors put the value of the upper limit at 53±2 Mev, which is in agreement with the accepted view that the μ^- meson decays into an electron and two neutrinos. However, it seems to us that such a conclusion is perhaps premature, and that one should consider again the possibility of a neutral μ -meson of finite mass.

The reason is the following. If the μ^- decay is similar to the ordinary beta-decay as is suggested by the value of the lifetime of the μ -meson, then one would expect that the shape of the spectrum would not differ in a qualitative way from the so-called statistical factor which arises from the available phase space. Now, it is well known² that for the decay into electron and two neutrinos the statistical factor gives a finite value at the upper limit, which is $\frac{1}{2}\mu c^2$. This is because of the fact that at the upper limit the electron and the neutrinos go off in opposite directions, and since the momentum of the electron can be balanced by the momenta of the two neutrinos in an infinite number of ways, there is still phase space available at the upper limit. The simplest way to obtain a zero value at the upper limit is, therefore, to assume that the μ^- meson decays into a neutral meson of finite mass μ_0 and an electron and a neutrino. The statistical factor then goes to zero, since the μ_0 momentum will then balance the electron momentum at the upper limit. The value of the upper limit will be reduced by $(\mu_0/2\mu)\mu_0 c^2$, so that an experimental uncertainty of 2 Mev would still allow a mass μ_0 of the order of 40m.

These simple considerations were, of course, well recognized in the theoretical discussions of the μ -decay by Tommo and Wheeler³ and by Michel.⁴ However, since at that time only the Wilson chamber data of Leighton, Anderson, and Seriff⁵ on the μ -decay spectrum were available, which were more compatible with a finite value at the upper limit, the reaction $\mu^\pm \rightarrow e^\pm + 2\nu$ seemed to be the most natural assumption to make. It is, of course, not impossible to obtain a zero value at the upper limit with the same assumption, but it requires a special form of the beta-interaction between the four spinor fields. This possibility has recently been investigated in an interesting report by MacCallum and Wight-

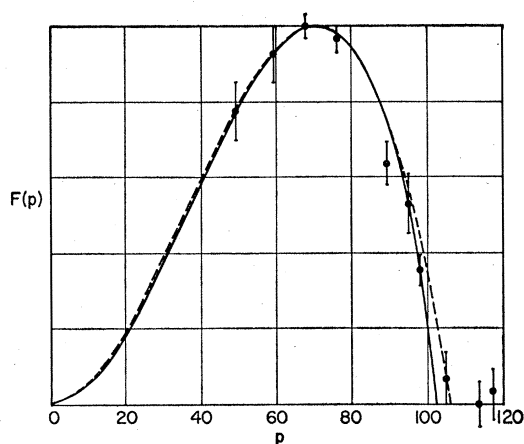


FIG. 1. Comparison of μ -decay spectrum with theory.

man⁶ especially in connection with the question whether there is a universal beta-interaction, which would account both for the μ -decay and for all the known facts of beta-radioactivity. It may well be that this is the correct point of view and there is no doubt that the data of Sagane and co-workers can be represented in this fashion. However, we think that one should not forget the possibility of a finite mass for the μ_0 meson. The choice of the beta-interaction becomes then much more flexible and much less can be concluded from the μ -decay spectrum.

The situation is perhaps best summarized by Fig. 1, where the experimental data are compared with two theoretical curves. The dotted curve represents the equation⁷

$$F(p)d\mu \sim (\mu - 2p)p^2 d\mu,$$

and results from the scalar interaction with so-called charge retention (which means that the spinors of μ -meson and electron, and the spinors of the two neutral particles are paired together) and with zero mass for the μ_0 meson. This is one of the few interactions which fit the data. The full curve represents the equation

$$F(p) \sim p^3 \left\{ 5\mu(\mu - 2p) \left(\mu - \frac{28}{15}p \right) + \mu_0^2 \left(\mu - \frac{2}{3}p \right) \right\} \frac{(\mu^2 - \mu_0^2 - 2\mu p)^2}{(\mu - 2p)^3}$$

and results from the tensor interaction with the usual pairing (μ^-, μ_0) (e^-, ν) of the spinor fields and with the mass 40m for the μ_0 meson. We have not investigated whether this is the best choice; there are no doubt many other possibilities.

In conclusion we may perhaps point out, that if there is a triad of μ -mesons, one would expect that they are connected with the triad of π -mesons in a similar way. This means that the reaction $\pi_0 \rightarrow \mu_0 + \nu$ should occur with the same coupling constant as the reactions $\pi^\pm \rightarrow \mu^\pm + \nu$. It could presumably, therefore, not compete with the decay of the π_0 meson into two γ -rays, but it would have as a consequence that the μ_0 meson could decay into a neutrino and two photons. The lifetime would be of the order of 10^{-9} sec, and the photons would be rather soft, so that the detection will be difficult. However, it would make the μ_0 meson much less elusive than the neutrino.

¹ Sagane, Gardner, and Hubbard, *Phys. Rev.* **82**, 557 (1951).

² E. Fermi, *Elementary Particles* (Vale University Press, New Haven, 1951), p. 44.

³ J. Tommo and J. Wheeler, *Revs. Modern Phys.* **21**, 144 (1949).

⁴ L. Michel, *Proc. Phys. Soc. (London)* **A63**, 514 (1950).

⁵ Leighton, Anderson, and Seriff, *Phys. Rev.* **75**, 1432 (1949); see also A. Lagarrigue and C. Peyrou, *J. phys. et radium* **12**, 848 (1951).

⁶ C. J. MacCallum and A. S. Wightman, Technical Report No. 7, Princeton University Cosmic-Ray Group, June 15, 1951. See also E. R. Caianiello, *Nuovo cimento* **8**, 749 (1951).

⁷ Rational units are used: $m=c=\hbar=1$; rest-mass of the electron is neglected.