On the Nature of the Meson Decay

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(Received February 8, 1941)

Theoretical values for the intensity of the soft component due to meson decay are compared with the experimental data.

THE lifetime of the meson has been determined by the Duke University group[1] to be

$$\tau=\gamma\times 10^{-6}(\mu c^2/10^8\text{ ev})\text{ sec};\quad \gamma=1.25\pm 0.3.$$

We believe this value to be the most reliable one obtained so far. The considerably smaller value compared to those reported previously[2] necessitates a reconsideration of the role of the decay part of the soft component. It will be seen that, with the data available at present, a rather critical situation is reached which might possibly lead to important consequences as to the nature of the meson decay.

The intensity of the soft component produced by the meson decay depends essentially on the lifetime of the meson and the fraction α of the total mesonic energy given to electrons and quanta. The counting rate in one of the usual arrangements will depend sensitively on the energy distribution of the electron component in equilibrium with the mesons. The corresponding problem of the theory of showers, i.e., the determination of the electron track length in showers in their dependence on energy has been solved in reasonable approximation by Tamm and Belenky.[3] Their result can be expressed as follows:

A single electron of energy E_0 produces a total track length with energy larger than E

$$l(E)=\frac{E_0}{\beta}\varphi(E_0,E). \tag{1}$$

Here β is the specific energy loss and

$$\varphi(E_0,E)=\int_\epsilon^{\epsilon_0}\frac{\epsilon e^{\epsilon-x}}{x^2}dx;\quad \epsilon=\frac{2.4E}{E_j}, \tag{2}$$

where E_j is the energy at which ionization and radiation losses for electrons are equal. For $E_0\gg E$ the upper limit of the integral (2) can be taken as infinite and φ can then be expressed by an exponential integral function. For air ($E_j=10^8$ ev) the function $\varphi(\infty, E)$ has the following values:

E ev	0	4×10^6	10×10^6	25×10^6	100×10^6
φ	1	0.8	0.67	0.5	0.25

The limiting value $\varphi(0)=1$ expresses the fact that all energy will finally be dissipated by ionization, whatever multiplication processes may have taken place before.

The probability of decay of a meson of energy E_μ per unit path is[4]

$$w=\frac{1}{c\tau}\frac{\mu c^2}{pc}\sim\frac{1}{c\tau}\frac{\mu c^2}{E_\mu}.$$

If we assume that every meson gives the fraction α of its energy to electrons or photons of comparable energy and that $f(E_\mu)dE_\mu$ is the distribution function of the mesons, then the total energy given to the electrons per unit length is

$$\Delta E_0=\alpha\frac{\mu c^2}{c\tau}\int\frac{E_\mu f(E_\mu)}{E_\mu}dE_\mu=\alpha\frac{\mu c^2}{c\tau}N, \tag{3}$$

where N is the total number of mesons. Inserting this for E_0 into (1) and dividing by N, we obtain the ratio of electrons with energy larger than E to

[1] See the preceding paper by W. M. Nielsen *et al.*, Phys. Rev. **59**, 547 (1941).

[2] The only other measurements comparable to ours, by B. Rossi, Norman Hilberry and J. Barton Hoag, Phys. Rev. **57**, 461 (1940), also led to a rather short lifetime. Our value for the ratio τ/μ is still only one-half of theirs.

[3] Ig. Tamm and S. Belenky, J. Phys. U.S.S.R. **1**, 177 (1939).

[4] The number of mesons of kinetic energy $\sim\mu c^2$ and less is rather small. In the following we neglect corrections due to the difference between pc and E and also those due to the continuous energy distribution of the decay electrons produced by mesons of definite energy.

the total number of mesons

$$r=\frac{N_{el}}{N_{\text{mes}}}=\alpha\frac{\mu c^2}{\beta c\tau}\varphi(E) \tag{4}$$

and with our value for $\mu c^2/c\tau$

$$r=1.3\frac{\alpha}{\gamma}\varphi(E). \tag{5}$$

The value for E to be inserted into (5) depends on the characteristics of the counter telescope. For the usual arrangements a lower limit between 4 and 10×10^6 ev might be assumed which would give $\varphi\sim0.7$ to 0.8.

The same ratio (5) with $\varphi=1$ (i.e., all electronic energy used up in ionization) will also hold for the total ionization[5] produced by the decay electrons and the hard component.

The empirical situation regarding the ratio of soft to hard component seems still to be rather ambiguous. Counter telescopes operated at sea level in open air give a ratio $\sim4:3$ for counts without any absorber and with 10 to 15 cm Pb.[6] This means a ratio $r\cong0.33$ for the *total* soft component and the most absorbable part of the mesons to the mesons which can penetrate the lead absorber. The chief uncertainty of this method consists in the possible neglect of coherence between rays of the soft component which might lead to an underestimate of the soft intensity. Measurements with thin-walled ionization chambers without and with lead shielding give a considerably higher ratio[7] $r\sim0.5$ to 0.6. None of these measurements have, however, been made under ideal conditions for the present purpose. The chief uncertainties in such measurements lie in the effects of the walls and of the radioactivity of the surroundings which may depend on the shielding and probably tend to increase r. The values for r are, of course, for the total of the soft component including knock-on and primary electrons. Attempts to resolve this total ratio into the various contributions seem still to be rather uncertain. An estimate by Euler[8] seems to show that the effect of primary electrons is at sea level only a few percent of the total. The percentage of knock-on electrons is about 10 percent of the hard component according to the best estimate given by Tamm and Belenky.[3]

The principal hypotheses regarding the meson decay and their consequences are as follows:

I. The meson has the spin $\frac{1}{2}$ and decays into an electron and a photon. In this case $\alpha=1$. With $\gamma=1.25$, r would be ~0.8 for counters and ~1 for the total ionization. These values seem to be quite incompatible with the empirical data, and this hypothesis can be definitely ruled out.

II. The meson has the spin 1 and decays into an electron and a neutrino. In this case $\alpha=\frac{1}{2}$ and $r\sim0.4$ for counters and ~0.5 for total ionization. These figures give about twice the amount of $r\sim0.2$ to 0.25 which follows from the counter experiments, and which has been assumed for the decay component by previous investigators.[5,6] The only way to remove this discrepancy would be to assume a rather high degree of coherence between the rays of the soft component and possibly of the soft and the hard rays.[9]

On the face of the present evidence it does not seem assured that even $\alpha=\frac{1}{2}$ can be admitted. Smaller values of α would mean, of course, that more complex modes of disintegration would have to be assumed with simultaneous creation of a number of neutrinos. One possibility would be the disintegration of a meson with spin $\frac{1}{2}$ into an electron and two neutrinos ($\alpha=\frac{1}{3}$). Or else the meson disintegration would have to be considered as a kind of explosion and not as a simple β-decay process. In this case, of course, no information regarding the spin of the meson could be obtained. It seems highly important in any case that this situation should be clarified by further experiments.

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[5] B. Rossi, Phys. Rev. **57**, 469 (1940) has used this argument already with slight refinements which, however, give rise only to insignificant corrections. The values used by him correspond to $\gamma=2.5$.

[6] Compare for instance the Durham curve of the preceding paper which has been taken under the best possible conditions. See also G. Bernardini *et al.*, Phys. Rev. **58**, 1017 (1940).

[7] H. Schindler, Zeits. f. Physik **72**, 625 (1931); H. Hoerlin, Zeits. f. Physik **102**, 652 (1936); J. C. Street and R. T. Young, Phys. Rev. **46**, 832 (1934); **52**, 552 (1937).

[8] H. Euler, Zeits. f. Physik **116**, 73 (1940).

[9] An indication for such a coherence effect might be found in the fact that a comparison of counter and ionization-chamber measurements tends to give higher values for the specific ionization of cosmic rays than direct countings of droplets; compare the summary by Thomas H. Johnson, Rev. Mod. Phys. **10**, 209 (1938).