MESONIUM AND ANTIMESONIUM[x)]

B. Pontecorvo

Gell-Mann and Pais[1)] first pointed out the interesting consequence of the fact that K^0 and $\tilde{K}^0$ particles are not identical[2)]. The possibility of $K^0 \to \tilde{K}^0$ transitions induced by weak interactions makes it necessary to consider neutral K mesons as a mixture of particles of different (combined)[3)] parity (K_1^0 and K_2^0).

We discuss here the problem as to whether there exist other "mixed" neutral particles (not necessarily "elementary" ones) which are not identical to the corresponding antiparticles and for which particle ⇄ antiparticle transitions are not strictly forbidden.

The number of possible mixed neutral systems are strongly limited by conservation laws for the number of baryons and light fermions (conservation of nuclear[4)] and neutrino[5)] charges). According to the first law mixed particles cannot exist among baryons (for instance, neutron, hydrogen atom) and due to the second law such particles cannot exist among systems of light particles with only one fermion (e.g., neutrino, π^+e^- and π^-e^+ systems...).

From this it apparently follows that mesonium defined as the bound system (μ^+e^-) is the only mixed particle of interest existing (in addition to the K^0 meson) among already well-known systems. Antimesonium, that is the system (μ^-e^+), obviously differs from mesonium; in addition mesonium → antimesonium transitions not only are not forbidden by any known law but, what is more, they must take place due to known interactions.

Indeed, transitions

$$(\mu^+e^-) \to (\nu+\tilde{\nu}) \to (\mu^-e^+) \qquad (1)$$

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x) JETP, 33, 549 (1957).

are induced by the same interaction which is responsible for the μ-meson decay. Incidentally the probability $1/\theta$ of real decay processes

$$(\mu^+e^-) \rightarrow \nu + \tilde{\nu} + 106{,}1\,\mathrm{MeV} \tag{2}$$

which can be easily estimated taking into account the dimensions of mesonium, turns out to be equal to 10^{-4} sec^{-1}, that is about 10^{10} times less than the decay probability $1/\tau$ of the μ meson. For this reason it is practically impossible to observe the (non trivial) absence of an electron track at the point where a μ^+-meson comes to rest, which would be connected with the process (2).

As for the mesonium → antimesonium transition, its characteristic time $\frac{\hbar}{c^2\Delta m}$ is determined by the mass difference Δm between the symmetrical (ψ mesonium + ψ antimesonium) and the antisymmetrical (ψ mesonium − ψ antimesonium) systems. The value Δm is proportional to the first power of the matrix element responsible for the mesonium → antimesonium transformation and that is why Δm is proportional to the square of the coupling constant when such transformation is due to two successive transitions as in (1).

Thus, the time characterizing the transformation (1) is of the same order of magnitude as θ, that is about 10^{10} times larger than the life-time of μ-meson (τ = 2×10^{-6} sec), which in fact determines also the rate of the mesonium decay. If we assume, however, that the mesonium → antimesonium transformation is due to the direct interaction (μ^+e^-) (μ^-e^+), the time T characterizing this transformation turns out to be considerably smaller than θ. Indeed, in this case the mass difference $\Delta m'$ between the symmetrical and antisymmetrical systems ($\Delta m' = \frac{2M}{c^2}$, where M is the matrix element) is proportional to the first power7) of the coupling constant g.

Consequently, we have

$$T \sim \frac{\hbar}{c^2\Delta m'} \sim \frac{\hbar}{2g/\pi r^3}$$

where r is the mesonium radius. If we suppose that the direct interaction (μ^+e^-) (μ^-e^+) has an intensity comparable with the intensity of all the other known weak interactions, g is about 3.10^{-49} erg.cm^3, and T is found to be $\sim 5.10^{-4}$ sec, that is only ~ 300 times larger than τ. Under such circumstances it seems at first glance that the process of mesonium → antimesonium transformation can be easily observed, for instance, by detecting a "fast" negative electron from a μ^+-meson coming to rest

$$(\mu^+e^-) \rightarrow (\mu^-e^+) \rightarrow e^-_{fast} + \nu + \tilde{\nu} + e^+ .$$

Unfortunately, however, the mesonium → antimesonium transformation in presence of matter is impossible: on account of the electrical asymmetry of nucleons the masses of mesonium and antimesonium are no more equal under such conditions. Besides, it is necessary to note that the probability of fast negative electron emission from mesonium (in vacuum) is proportional to $\left(\frac{\tau}{T}\right)^2$ and not to $\frac{\tau}{T}$. Indeed, if $\mathcal{E}_{\mu^+}(t)$ and $\mathcal{E}_{\mu^-}(t)$ are the probabilities that (in vaouum) mesonium or antimesonium are found at the time t when at $t = 0$ there is one "atom" of mesonium, then

$$\mathcal{E}_{\mu^+}(t) \sim \frac{1}{2} e^{-t/\tau}\left(1+\cos\frac{t}{T}\right)$$
$$\mathcal{E}_{\mu^-}(t) \sim \frac{1}{2} e^{-t/\tau}\left(1-\cos\frac{t}{T}\right)$$

where the life-times of the symmetrical and antisymmetrical systems are assumed to be identical and equal to the μ-meson life-time. Under such initial conditions the probability of emission of a fast positive or negative electron in the decay process is found to be

$$P(e^+) \sim \int_0^\infty \frac{\mathcal{E}_{\mu^+}(t)}{\tau}\,dt \sim \frac{1}{2}\left(1+\frac{T^2}{T^2+\tau^2}\right) \sim 1$$
$$P(e^-) \sim \int_0^\infty \frac{\mathcal{E}_{\mu^-}(t)}{\tau}\,dt \sim \frac{1}{2}\left(1-\frac{T^2}{T^2+\tau^2}\right) \sim \frac{1}{2}\left(\frac{\tau}{T}\right)^2$$

respectively.

If in nature there existed other weakly interacting charged particles with a very long life-time it is possible that effects analogous to those discussed here might be observed. The life-time of the particles with mass about 500 m_e recently discovered by Alikhanyan and others (JETP, 31, 955, (1956)), has not yet been determined; only its lower limit (5×10^{-9} sec) is known.

Above it was supposed that neutrino charge is conserved. This means that scattering cannot convert a neutrino into an antineutrino in any approximation. The law of conservation of neutrino charge is not yet definitely established: it is only established experimentally that neutrino and antineutrino are not identical particles[8].

If the theory of two component neutrino[9] was not valid (which is hardly probable at present) and if the conservation law for neutrino charge took no place, neutrino → antineutrino transitions in vacuum would be in principle possible. Even in this case, just as in the case where it is supposed that to every would correspond an antiworld, the number of neutrino and antineutrino in the universe would be the same.

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