WEAK η-MESON DECAYS

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A measurement of the probabilities of weak $\eta \to \pi e\nu$ and $\eta \to 2\pi e\nu$ decays can be used to verify the accuracy with which the vector current is conserved and possesses a definite G-parity. Unfortunately the expected relative probability for weak η-meson decays is very small ($\sim 10^{-10}$ for the $\eta \to 2\pi e\nu$ decay and $\sim 10^{-13}$ for the $\eta \to \pi e\nu$ decay).

IN connection with investigations of the properties of new mesons, it is of interest to discuss the possible weak decays of these particles. For ρ and K* mesons, the widths Γ of which are of the order of 30—100 MeV, estimates of the probabilities of two-particle lepton decays yield

$$\Gamma(\mu+\nu) \sim \Gamma(e+\nu) \sim (10^{-13} - 10^{-14})\Gamma.$$

Thus, observation of weak decays of ρ and K* mesons is far beyond the limits of present-day experimental techniques. One could hope for the situation to improve greatly in the case of the η meson, the total width Γ_η of which is theoretically estimated to be only several hundred electron volts, corresponding to a lifetime $\sim 2\times 10^{-18}$ sec. Unfortunately, as will be shown below, the widths of the η-meson weak decays are exceedingly small.

The following lepton decays, due to the interaction between the charged lepton and hadron currents, are possible for the η meson:

$$\eta \to e^\pm \pm \nu + \pi^\mp, \qquad (1)$$

$$\eta \to \mu^\pm \pm \nu + \pi^\mp, \qquad (2)$$

$$\eta \to e^\pm \pm \nu + K^\mp. \qquad (3)$$

The amplitudes of these decays take the form (see, for example [1])

$$2^{-1/2}G[f_+(k_1+k_2)+f_-(k_1-k_2)],$$

where $G = 10^{-5}/M_p^2$—weak-interaction constant, k_1 and k_2—4-momenta of the decaying (η) and produced (π or K) mesons. The probabilities of the decays (1)—(3), calculated under the assumption that f_+ and f_- are constant, are

$$\Gamma_1 = 2.54 f_+^2 \cdot 10^8\ \mathrm{sec}^{-1},$$

$$\Gamma_2 = (1.78 f_+^2 + 0.28 f_+ f_- + 0.045 f_-^2)\cdot 10^8\ \mathrm{sec}^{-1},$$

$$\Gamma_3 = 0.62 f_+^2 \cdot 10^5\ \mathrm{sec}^{-1}.$$

The smallness of Γ_3 is due to the small amount of energy released in the decay (3). Taking $f_+ = 0.24$ from the experimental probability of K_{e3} decay, we obtain $\Gamma_3 \approx 5.4\times 10^3\ \mathrm{sec}^{-1}$.

If f_1 were to be of the order of unity for the decays (1) and (2), then we would obtain values $\sim 10^{-9}$ for the ratios Γ_1/Γ_η and Γ_2/Γ_η. (We recall that for the decay $\pi_{e3}(\pi^+ \to \pi^0 + e + \nu)$ we have $f_+ \approx 1$, $f_- = 0$, $\Gamma(\pi_{e3}) \approx 1\ \mathrm{sec}^{-1}$, and $\Gamma(\pi_{e3})/\Gamma(\pi) \sim 10^{-8}$.) Unfortunately, if the vector nucleon current has positive G-parity, as is the case, for example, in the Sakata model (see, for example, [1]), then $f_+ \ll 1$, since decays (1) and (2) are forbidden by G-parity. The latter can be readily verified by recognizing that the G-parity of the η meson is positive while that of the pion is negative. According to crude estimates, f_+ should be of the order of 10^{-2} (due to virtual electromagnetic processes), and consequently $\Gamma_1 \approx \Gamma_2 \sim 10^5\ \mathrm{sec}^{-1}$ and $\Gamma_{1,2}/\Gamma_\eta \sim 10^{-13}$.

We emphasize that the probabilities of the decays (1) and (2) are very sensitive to the magnitude of the G-odd interaction; in particular, a small admixture of scalar interaction in the nucleon current can greatly increase the probabilities of these decays. Therefore the decays (1) and (2) can serve in principle as checks on the extent to which G-parity of the vector nucleon current is a good quantum number.

We now consider 4-particle decays of the η meson:

$$\eta \to e^\pm \pm \nu + \pi^\mp + \pi^0, \qquad (4)$$

$$\eta \to \mu^\pm \pm \nu + \pi^\mp + \pi^0. \qquad (5)$$

These decays could, generally speaking, be the result of either vector or axial currents. However, the axial current makes no contribution, since the G-parity of the η meson and of the two pions is positive, while that of the axial current is negative. The decay due to the vector currents satisfies G-parity conservation; its amplitude is of the form

$$2^{-1/2} G f \varepsilon_{\alpha\beta\gamma\delta} p_\alpha^{\ +} p_\beta^{\ 0} k_\gamma l_\delta,$$

where f—form factor connected with the virtual strong interaction (we shall henceforth assume that f is constant), p^+ and p^0—4-momenta of the pions, k—total 4-momentum of the leptons, $l_\delta = \bar{u}_\nu \gamma_\delta (1+\gamma_5) u_l$.

By virtue of the analogy between the weak vector current and the electromagnetic current [2], the same form factor f is contained also in the amplitude of the electromagnetic decay

$$\eta \to \pi^+ + \pi^- + \gamma \tag{6}$$

(it is easy to see that an isovector photon is emitted in this case). Indeed, the decay (6) is described by the amplitude [3]

$$\sqrt{\alpha} f \varepsilon_{\alpha\beta\gamma\delta} p_\alpha^+ p_\beta^- k_\gamma e_\delta,$$

where $\alpha = 1/137$ and e_δ—photon wave function.

The calculations lead to the following probabilities of the decays (4), (5), and (6):

$$\Gamma_{4,5} = \frac{f^2 G^2 M_\eta^{11}}{2^{15}\cdot 45\pi^5} \frac{431}{70} h_{4,5}, \quad \Gamma_6 = \frac{f^2 \alpha M_\eta^7}{2^{13}\cdot 15\pi^3} h_6,$$

where the coefficients h take into account the masses of the produced particles. In the approximation $m/M_\eta = \mu/M_\eta = 0$ (m and μ—masses of the pion and of the muon), $h_{4,5} = h_6 = 1$; the numerical integration leads to the following values:

$$h_4 = 0.457, \quad h_5 = 5.9\cdot 10^{-6}, \quad h_6 = 0.146.$$

We then obtain for the relative probabilities

$$\Gamma_4/\Gamma_6 = 2.6\cdot 10^{-10}, \quad \Gamma_5/\Gamma_6 = 3.4\cdot 10^{-16}.$$

An experimental measurement of these ratios would make it possible to check on the hypothesis that the weak and electromagnetic currents are similar. If we are interested in the dependence of the function f on the invariants, we must compare the decays (4) and (5) with the electromagnetic decay

$$\eta \to \pi^+ + \pi^- + e^+ + e^-, \tag{7}$$

in which the photon is virtual. Unfortunately, the low probability of decays (1)—(5) gives no hope of their experimental investigation in the nearest future.

Let us ascertain now the possibility of observing η-meson decays due to hypothetical neutral weak currents. If the neutral currents exist and their interaction has, for example, the form

$$2^{-1/2} G (\bar{p} O_\alpha p + \bar{n} O_\alpha n)(\bar{\mu} O_\alpha \mu + \bar{e} O_\alpha e + \bar{\nu} O_\alpha \nu),$$

where $O_\alpha = \gamma_\alpha(1+\gamma_5)$, then the following two-particle decays of the η meson are possible:

$$\eta \to \mu^+ + \mu^-, \quad \eta \to e^+ + e^-, \quad \eta \to \bar{\nu} + \nu.$$

Only the axial part of the isoscalar nucleon current makes a contribution to these decays.

It is easy to see that the probabilities of these decays are related approximately like the squares of the masses of the corresponding leptons. Consequently, the greatest probability is possessed by the decay (4). If the amplitude of this decay is of the form $2^{-1/2} G K_\alpha$, then we obtain for the width a value $\Gamma_8 = 3.2 (f/M_p)^2 \times 10^{10}$ sec^{-1}. Using for the estimate $f \sim m$ from the $\pi \to \mu + \nu$ decay, we obtain $\Gamma_8 \approx 0.7 \times 10^9$ sec^{-1}. Unfortunately, this probability is small compared with the probability of the $\eta \to \mu^+ + \mu^-$ decay due to the virtual electromagnetic interaction via two photons ($\eta \to 2\gamma \to \mu^+ + \mu^-$). Using the estimate of Berman and Geffen [4], who considered an analogous diagram for the process $\pi^0 \to e^+ + e^-$, we obtain $\Gamma_{e.m.}(\eta \to \mu^+ + \mu^-)/\Gamma(\eta \to 2\gamma) \approx 10^{-5}$, which is several orders of magnitude larger than the possible contribution of the neutral weak currents.

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