SOME CONSEQUENCES OF THE LONG LIFETIME OF η AND ω MESONS

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The possibility of an experimental verification of isospin conservation in strong interactions by the study of the decays of η and ω mesons is considered. The estimates show that isospin invariance is fulfilled to an accuracy of $\sim 10^{-4}$. The absence of certain hypothetical mesons is deduced from the long lifetime of the η and ω mesons.

1. DECAY OF THE η- AND ω-MESONS AND EXPERIMENTAL EXAMINATION OF THE PRINCIPLE OF ISOSPIN INVARIANCE

THE isospin invariance of the strong interactions leads to definite reaction branching ratios and to additional selection rules. The investigation of reactions which are related by isospin considerations has shown that the predicted and observed branching ratios agree within the experimental errors which have a magnitude of several per cent.[1] Much better agreement cannot be expected also from theoretical considerations. In fact, the processes to be considered can take place also in second order of the electromagnetic interaction which perturbs the isospin invariance. The interference between the strong and the electromagnetic interaction leads in these conditions to corrections in the isospin ratios of first order in α ($\alpha = 1/137$).

It is therefore of particular interest to investigate forbidden reactions which can be used for an examination of the isospin invariance with a much higher accuracy. For example, a study of the reaction[2]

$$d + d \rightarrow \mathrm{He}^4 + \pi^0, \tag{1}$$

which is electromagnetically allowed in second order can show whether the selection rule forbidding this reaction is fulfilled or not to an accuracy of $\alpha^2\sigma_{\mathrm{all}}$ (σ_{all} is the cross section this reaction would have in case of nonexistence of isospin conservation). The experimental investigation of reaction (1) at $E_d = 400$ MeV has shown that the violation of the selection rule does not exceed a few percent.[1] A further improvement of the accuracy meets considerable difficulties in this method.

In this connection we want to point out that the η-meson decays

$$\eta \rightarrow 3\pi^0, \qquad \eta \rightarrow \pi^+\pi^-\pi^0,$$

are forbidden according to isospin conservation and therefore their investigation also permits us to determine the degree to which this rule is obeyed with an accuracy of $\alpha^2 W_{\mathrm{all}}$, where W_{all} is the probability of an allowed decay.[1)]

From the available experimental data we can at present obtain rough estimates. From [3] it is known that

$$W(\eta \rightarrow 3\pi)/W(\eta \rightarrow 2\gamma) \approx 1. \tag{2}$$

Using the simplest possible form of the matrix element[4] we find

$$W(\eta \rightarrow 2\gamma) \approx 10^{-4}\,\mathrm{MeV}. \tag{3}$$

Hence

$$W(\eta \rightarrow 3\pi) \approx 10^{-4}\,\mathrm{MeV}. \tag{4}$$

It should be mentioned in connection with (3) that an analogous estimate for the π^0 lifetime gives a satisfactory agreement with the experimental results.

On the other hand, the well investigated resonances (K^*, ρ, Y_1^*, N^*) which decay through strong interactions have widths of the order of tens of MeV. The ω meson is an exception and its small width can be explained as due to kinematic factors.[4] If we take for concreteness the characteristics of the ρ meson and take into account the difference of the phase space of the $\eta \rightarrow 3\pi$ and $\rho \rightarrow 2\pi$ decays; then we find for the expected probability of the $\eta \rightarrow 3\pi$ decay in the absence of the selection rule forbidding this decay

$$W_{\mathrm{all}}(\eta \rightarrow 3\pi) \approx 1\,\mathrm{MeV}.$$

From this we have

$$W(\eta \rightarrow 3\pi)/W_{\mathrm{all}}(\eta \rightarrow 3\pi) \approx 10^{-4}.$$

[1)]Our starting point is that the η meson has the quantum numbers $J^{PG} = 0^{-+}$ and $I = 0$. Here J^{PG} and I represent spin, parity, G-parity, and isospin respectively.

Thus the experimental data on the $\eta \rightarrow 3\pi$ and $\eta \rightarrow 2\gamma$ decays give grounds for assuming that the isospin invariance is fulfilled to an accuracy of the magnitude of second order electromagnetic processes.

Analogous considerations can be made for the forbidden decay of the ω meson[4] $\omega \rightarrow \pi^+\pi^-$. Investigations of this decay have shown[5] that

$$W(\omega \rightarrow \pi^+\pi^-)/W(\omega \rightarrow \pi^0\gamma) \lesssim 0.2, \tag{5}$$

$$W(\omega \rightarrow \pi^+\pi^-)/W(\omega \rightarrow \pi^+\pi^-\pi^0) \lesssim 2\%. \tag{6}$$

From (5) one can deduce that the violation of the isospin selection rule does not exceed 1%. Using (6) and taking into account the difference of phase space for the decays $\omega \rightarrow \pi^+\pi^-$ and $\omega \rightarrow \pi^+\pi^-\pi^0$, we find

$$W(\omega \rightarrow \pi^+\pi^-)/W_{\text{all}}(\omega \rightarrow \pi^+\pi^-) \lesssim 10^{-3}, \tag{7}$$

which indicates an even better fulfillment of the selection rules. Thus the existing experimental data on the decays of the η and ω mesons confirm well the existence of isospin invariance of the strong interactions.

To conclude this section we indicate a possibility which in principle could allow the experimental determination of the lifetime of the η meson. Starting with the estimate (3), we have $\tau_\eta \sim 0.1\,\tau_{\pi^0}$. We recall that the π^0 lifetime was determined in the investigation in photoemulsions of the following type of K^+-meson decays:

$$K^+ \rightarrow \pi^0 + \pi^+ \rightarrow \pi^+ + e^+ + e^- + \gamma, \tag{8}$$

in which the distance d between the place where the K^+ meson stopped and the place where the π^0 meson decayed was measured ($d \sim 0.1\,\mu$).

To measure the lifetime of the η meson one could do an analogous experiment in which one would measure the distance between the point of creation and the point of decay of the η meson into the channel $\eta \rightarrow \pi^+\pi^-\pi^0$. In order for these distances to be about $0.1\,\mu$ (the resolving power of nuclear emulsions) one needs η-mesons with energies of the order of several GeV.

The η-meson production cross section is not large ($\sigma \approx 1$ mb). Nevertheless the problem of accumulating sufficient statistics in this case does not pose special difficulties since the decay of interest, $\eta \rightarrow \pi^+\pi^-\pi^0$ has $1/3$ of the total decay probability of the η meson (in contrast the decay $\pi^0 \rightarrow e^+e^-\gamma$ in reaction (8) has only a frequency ~ 0.01 relative to the usual mode $\pi^0 \rightarrow \gamma\gamma$).

2. THE LIFETIME OF THE η AND ω PARTICLES AND THE NEW MESONS

From the fact that the lifetime of the η- and ω-particles is long compared to the lifetime of the other resonances (K^*, ρ, N^*, Y_1^*) one can obtain some conclusions concerning the nonexistence of certain types of new mesons. To illustrate this statement we consider two examples.

We consider a σ meson with the quantum numbers $J^{PG} = 0^{-+}$ and $I = 0$ and which is supposed to interact strongly with nucleons.[4,6] Then the decay $\eta \rightarrow \pi^+\pi^-\sigma$ is allowed if the relative angular momenta of the π and σ mesons equal zero. In this case the decay goes via the strong interactions and there are no kinematic factors to substantially decrease the probability. Therefore the width of the η meson would be ~ 1 MeV (see Sec. 1 of this paper and [4]). Since according to experiment the decay probability of the η meson is considerably smaller, we can deduce that a σ meson with $M \lesssim 250$ MeV does not exist.

One can perform analogous considerations using the experimental data on the ratio of the probabilities of the decay of the ω meson[3,5]:

$$W(\omega \rightarrow \text{neutrals})/W(\omega \rightarrow \pi^+\pi^-\pi^0) \lesssim 10\%. \tag{9}$$

The relation (6) shows that the decay of the ω meson into neutral particles is strongly forbidden. One can find such hypothetical particles which would soften this selection rule. An example is the χ-meson with the quantum numbers $J^{PG} = 0^{-+}$ and $I = 1$. Then the decay $\omega \rightarrow \chi^0\pi^0$ would take place. Considering the difference in phase space of that decay and of $\omega \rightarrow \pi^+\pi^-\pi^0$ one can conclude that no χ meson with $M \lesssim 500$ MeV can exist.

Similar considerations can be also performed for the vector mesons.

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