Physics

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1958

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Abstract

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Physics

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ON THE POSSIBLE EXISTENCE OF A SECOND NEUTRAL π-MESON

(Presented by Academician D. V. Skobeltsyn, 5 VI 1958)

An analysis of the data ([1]) on the photoproduction of π^-- and π^+-mesons on free nucleons showed that the ratio of the cross sections of these processes near threshold is constant and is approximately 1.4 (accuracy $\sim$ 10%)—this is in good agreement with the results of field theory using the renormalized coupling constant $f^2 = 0.08$. If this result is combined with the latest data on the phases of S-scattering of π-mesons on nucleons ([2]), one can obtain the following value for the Panofsky ratio:

$$P = \frac{\sigma(\pi^- + p \to n + \pi^0)}{\sigma(\pi^- + p \to n + \gamma)} = 2.4 \pm 0.4.$$

The error includes the errors in measuring the cross section $\sigma(\gamma + n \to p + \pi^-)$, in measuring the scattering phases, and in the mass difference of the π^-- and π^0-mesons. The weighted mean of the measured values of this quantity ([3]) is 1.66 ± 0.10. Thus, the difference between the calculated and measured values of P is about two standard deviations, which makes it possible to speak of a contradiction in the experimental data. As a possible way out of this difficulty, in ([1]) the hypothesis of a two-component π^0-meson was proposed. It was assumed that, in the absorption of π^--mesons in hydrogen, what is emitted is mainly not the neutral meson with isotopic spin $T = 1$ (whose existence follows from the hypothesis of isotopic invariance), but a neutral meson with isotopic spin $T = 0$. From this assumption there automatically follow the properties of this second neutral meson: its spin, parity, mass, and strength of interaction with nucleons. In ([1]) it was asserted that at present, apparently, there are no experimental facts in direct contradiction with the proposed hypothesis. In the present note we discuss this point and other consequences of the hypothesis.*

According to ([1]) we assume that the mass of the neutral meson $m_{\pi^0} = 264.3\, m_e$, measured by Panofsky et al. ([4]) and by Chinowsky and Steinberger ([5]), should be assigned to the π^0_0-meson (an isotopically scalar π-meson), which, with the exception of isotopic spin, inherits almost all the properties of the ordinary π^0-meson; the ordinary π^0-meson we shall denote by π^0_1 and shall assume that its mass is close to the mass of the $\pi^{\pm}$-mesons. We shall use the old notation for the neutral meson π^0 when we do not distinguish between these two types of mesons.

The π_0^0-meson must interact with the nucleon approximately as strongly as—

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* After a considerable part of the work had been completed, we received the manuscript of an article by J. Yamaguchi, in which it is also pointed out that there are no direct experimental indications against the hypothesis of the existence of an isotopically scalar π-meson.

strongly, as do ordinary π-mesons. Just as the ordinary π_1^0-meson, the π_0^0-meson is unstable with respect to decay into two photons:

$$\pi^0 \to 2\gamma.$$

For lifetimes comparable with the lifetime of the π_1^0-meson, the technique for detecting γ-quanta has not yet reached the level required to distinguish the γ-quanta from the decays of π_0^0 and π_1^0. We note that the decay

$$\pi_1^0 \to \pi_0^0 + \gamma$$

is strongly forbidden.

If our hypothesis is accepted, then the simple connection between the cross section for photoproduction of π^--mesons, the Panofsky ratio, and the S-phases of scattering ceases to exist, since, according to our hypothesis, the main contribution to the Panofsky ratio is made by the π_0^0-meson. Thus the contradiction noted above is removed.

Let us write the cross section of the process

$$\pi^- + p \to \begin{cases} \pi_0^0 + n, \\ \pi_1^0 + n \end{cases} \qquad (1^0, 1^1)$$

in the region of positive energies of the π^--meson.

It is easy to show that at small π^--meson energies the concepts of scattering amplitudes in the state with isotopic spin $\frac{1}{2}$, a_1, and isotopic spin $\frac{3}{2}$, a_3, retain their previous meaning, and the cross section of the process (1^1) is written in the form

$$\sigma(\pi^- \to \pi^0) = 4\pi \left\{ \frac{v_1^0}{v} \frac{2}{3} |a_3 - a_1|^2 + \frac{v_0^0}{v} \frac{1}{6} |a_0|^2 \right\}, \qquad (2)$$

where v, v_1^0, and v_0^0 are the velocities, respectively, of the π^--, π_1^0-, and π_0^0-mesons.

The amplitude of the process (1^0) can be found from the magnitude of the Panofsky ratio ($P = 1.66$), assuming that this effect is completely due to the π_0^0-meson*:

$$a_0 = 0.27.$$

Thus, in the region of positive π^--meson energies the charge-exchange scattering cross section may turn out to be too large. This difficulty can be avoided in two ways. The first, simplest variant is that, using a certain freedom in the choice of the mass of the π_1^0-meson and of the magnitude a_0, one can make the cross section $\sigma(\pi^- \to \pi^0)$ agree, within errors, with that measured experimentally and not come into contradiction with the data on the Panofsky effect. In this case, obviously, both mesons will contribute to the Panofsky effect.

The second variant consists in assuming

$$a_1 \approx a_3. \tag{3}$$

We consider that the value $a_3 = -0.11$ is well determined from experiments on the scattering of π^+-mesons on hydrogen; therefore our assumption (3) means a change in the value of a_1. At first sight it may seem that such a change in the value of a_1 would be in contradiction with the experimental data on the scattering of low-energy π^--mesons on hydrogen, which gave for a_1 the value $+0.17$.

We have found, however, that these experimental data also admit another solution, which precisely corresponds to our suppo–

* $\hbar = c = \mu = 1$.

position (3). For a more accurate determination of a_1, the same kind of analysis is needed as was carried out in finding the value 0.17, but it will not change relation (3). If our solution proves correct, it will answer one of the most intensively discussed questions of π-meson physics—the question of the dependence of the S-phases on isotopic spin.

In the region of 40 MeV the new solution leads to a considerably larger value of the cross section for the interaction of π^--mesons with protons than the old solution, owing to the diminished role of the interference of Coulomb and nuclear scattering in the region of high energies. (This interference is positive for the old solution and negative for the new solution.) This result is not in contradiction with the experimental data [6].

In the region of π-meson energies ~ 60 MeV and above, P-waves begin to play an essential role in scattering; in addition, in this region the dependence of the phases on the energy may differ substantially from ak^{2l+1}, where k is the meson momentum.

Therefore an analysis of the data in which the possible existence of π_0^0 must also be taken into account is rather complicated and ambiguous. Manifestations of the existence of the π_0^0-meson should in general be expected outside the range of π-meson energies 60–300 MeV, since in this region the main regularities of meson phenomena are determined by the resonance in the state $(3/2, 3/2)$, whereas π_0^0 and the nucleon cannot be in this state.

The change in the sign of a_1, and consequently also in the sign of the $\pi^- - p$ scattering length, can in principle be checked by determining the sign of the shift of the π-mesoatomic level in hydrogen; however, such an experiment has not been carried out. For other atoms the magnitude of the π-mesoatomic shift, with the new choice of phases, turns out to have the same sign as before, but is approximately 5 times larger than that observed experimentally, if one assumes that the theory of Deser et al. ([7]) is valid. However, the theory of the interaction of mesons with complex nuclei is still far from satisfactory, and we are not inclined to regard this difficulty as completely ruling out the second alternative.

One may think that the equality of the angular distributions and the ratio of the cross sections $2:1$, found ([8]) for the reactions

$$\begin{aligned} p + p &\to d' + \pi^+, \\ p + n &\to d + \pi^0 \end{aligned} \tag{4}$$

contradict the existence of π_0^0. This is not so, since the indicated result means only that the amplitudes for reactions (4) in the state with $T = 0$ are small compared with the amplitudes in the state with $T = 1$. If one takes into account the resonant interaction of mesons with one of the nucleons in the state $(3/2, 3/2)$, then this ratio of amplitudes is not incompatible with the existence of π_0^0. It seems to us that there are no experimental data that strictly exclude the hypothesis. Therefore the question of its direct experimental verification is highly desirable. Fortunately, such a verification can be carried out rather easily. Direct proof of the existence of π_0^0 would be the registration of the formation of single π^0-mesons in reactions in which only particles with isotopic spin equal to zero participate. The most convenient reaction for this experiment is

$$d + d \to \mathrm{He}^4 + \pi^0, \tag{5}$$

proposed in work ([1]).*

If observation of reaction (5) proves the existence of π_0^0, then it will become necessary to re-examine a fairly large range of phenomena, for exam-

* This reaction is also mentioned in a manuscript by Y. Yamaguchi, although he asserts that it is forbidden for a pseudoscalar π^0-meson. We do not agree with this assertion.

examples include the problem of the electromagnetic structure of the nucleon, the second maximum in the interaction of π^- mesons with protons, the formation and decays of strange particles, and many others.

We express our gratitude to Prof. R. E. Peierls for his constant interest in the work and valuable discussions, to Dr. L. Castillejo for criticism, and to other members of the Department of Mathematical Physics of the University of Birmingham for interesting discussions.

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Received
5 VI 1958

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Note: Figure translations are in progress. See original paper for figures.