AN EXPERIMENTAL INVESTIGATION OF SOME CONSEQUENCES OF CP INVARIANCE IN K_2^0-MESON DECAYS

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In the analysis of 597 K_2^0 decays recorded in a cloud chamber no events corresponding to the decay into two charged pions were found. This result favors the hypothesis that the decay interaction of neutral K mesons is CP-invariant, and the equality (within experimental errors) of the probabilities of leptonic K_2^0 decays with the emission of a π^+ or π^- does not contradict this assumption. Previously obtained data, indicating a large probability for the decays $K_2^0 \to 3\pi$, are also in agreement with this conclusion. Among the 597 K_2^0 decays no decays into two charged leptons were found.

NEARLY simultaneously with the first experiments that established parity nonconservation in β decay, Landau[1] and Lee and Yang[2] proposed the hypothesis of CP invariance, according to which weak interactions are not invariant under space parity (P) and charge conjugation (C) separately, but are invariant under the product of these operations (CP). Up to the present little work has been done to verify this hypothesis and the bulk of experimental data in its favor comes from decay interactions not involving strange particles. For this reason additional experimental studies testing the consequences of CP invariance are of great importance for the theory of weak interactions.

The application of CP invariance to the decays of neutral K mesons leads to a number of consequences that are relatively easy to investigate experimentally: 1) the decay of the long-lived K^0 meson into two pions is forbidden; 2) for the three-body leptonic decays the ratio of the probabilities of emission of positive and negative pions (referred to by us in the following as the "charge ratio")

$$R = w(K_2^0 \to \pi^- + e^+(\mu^+) + \nu)/w(K_2^0 \to \pi^+ + e^-(\mu^-) + \nu)$$

is equal to unity; 3) the decay into $3\pi^0$ mesons is allowed only for the K_2^0 meson, and the decay $K_2^0 \to \pi^+ + \pi^- + \pi^0$ is at least a hundred times more probable than the analogous decay of the short-lived K^0 meson.*

The first experimental data on the consequence 1) were obtained by Bardon et al,[4] who did not find a single decay into two charged pions among 150 K_2^0 decays. At the 1957 Rochester Conference Lederman[5] reported on 54 identified events of K_2^0 decays, 16 of which occurred with the emission of π^-, and 38 with the emission of π^+ mesons.* However the author of the report did not consider it possible to draw conclusions on whether these data were in agreement or not with CP invariance.

The present work was carried out using a cloud chamber in a magnetic field at the proton synchrotron of the Joint Institute for Nuclear Research. Consequences 1), 2), and 3) were investigated on the basis of an analysis of 649 decays of the long-lived K^0 meson. The details of the experimental setup were described in our previous paper.[6]

1. The first step in the search for two-body decays consisted in visual scanning of all K_2^0 mesons registered. In this selection it was considered that a K_2^0 meson did not undergo a two-body decay if both tracks of the charged products of the decay were off to the same side of the direction of motion of the K^0 mesons, or if both tracks were directed upward or downward relative to the horizontal plane (which coincided with the plane of the photographs). By visual means 339 events of three-body decays were selected. For the remaining K_2^0 decays we measured the momenta (p) of the decay particles, the angle of

*Strictly speaking, consequences 1) and 2) are not independent since, as was shown by Weinberg,[3] forbidding the decay $K_2^0 \to 2\pi$ restricts the size of the possible "charge asymmetry."

*The indicated number of identified events, besides the data of Bardon et al,[4] includes eight K_3^0 decays identified by the Berkeley group.

emission (θ), the azimuth angle φ and the angle γ between the tracks. In the measurements we excluded from consideration K_2^0 decays for which one or both tracks were less than 40 mm in length, or whose azimuth angle was more than 60°. We also excluded from consideration those K_2^0 decays for which the angles of emission of the produced particles were close to 90°, as well as those that were found in photographs with so high a background "contamination" that reliable measurements were impossible.

For these reasons 52 K_2^0 decays were excluded from further considerations. Thereafter each of the measured events was analyzed using the following criteria for two-body decay:

a) coplanarity of the tracks of the secondary particles with the direction of motion of the decayed K_2^0 meson:

$$\varphi_+ = \varphi_- + 180°$$

(the indices + or − indicate that the measured quantity refers to a positive or negative secondary particle);

b) balance of the transverse momenta of the produced particles:

$$p_+ \sin\theta_+ = p_- \sin\theta_-;$$

c) consistency of the measured momenta of the secondary particles and the angle between them:

$$E_+E_- - p_+p_- \cos\gamma = (m^2_{K^0} - m^2_+ - m^2_-)/2,$$

where $E_\pm$ are the total energies, and $m_\pm$ and m_{K^0} are the masses of the corresponding particles.

As a measure of the deviation of the event being analyzed from the decay into two pions we took the ratio of the difference of the quantities being compared—azimuth angle, transverse momentum and the angle between tracks (measured and calculated)—to the value of the mean square error in the determination of this difference. The mean square errors in the measurements were as follows: not more than 15% for the momentum, 4 to 5° for the azimuth angle, 3 to 4° for the angle between tracks. The direction of the incident K_2^0-meson beam was given by the geometric parameters of the experiment accurate to within ± 1°. In practice it was determined by hanging an elastic stretched string from the internal target of the proton synchrotron through the collimator into the middle of the working volume of the cloud chamber. The indicated direction was in addition confirmed by measuring the angular distribution of electron-positron pairs, produced in the gas of the chamber by "beam" photons.

Deviation, in mean square errors	Number of events	
	I	II
0—1	0	0
1—2	2	1
2—3	15	7
3—4	37	23
4—5	51	38
>5	96	83
Total	201	152

The results of the analysis are given in the table, in which in column I we list the distribution of all analyzed events, and in column II we list only those to which we could apply no less than two of the kinematic selection criteria simultaneously.

To test the reliability of the visual selection we measured the tracks for 60 K_2^0 decays that were previously rejected visually. For these events the measure of deviation from the two-body decay scheme turned out to be in excess of five mean square errors.

In this manner we found that not one of the 597 analyzed K_2^0 decays would fit, within the limits of one mean square error, into the decay scheme $K_2^0 \to \pi^- + \pi^+$.

There are two circumstances that could interfere with the determination of the true number of decays of the long-lived K^0 meson into two pions. First, the regeneration of K_1^0 mesons in the chamber walls and in the lead plates, followed by the decay of the K_1^0 meson into two charged pions, and, second, three-body decays masquerading as two-body decays. To estimate the number of regenerated K_1^0 mesons in the unscattered beam of K_2^0 particles we made use of the data of Muller et al, [7] who has studied in a bubble chamber the regeneration of 670 MeV/c K_2^0 particles on iron nuclei. According to these data we could have seen approximately one K_1^0 decay. Consequently decays of regenerated K_2^0 mesons could not in our case make a noticeable contribution to the possible decays according to the scheme $K_2^0 \to \pi^- + \pi^+$.*

The only three-body decays that can masquerade as two-body decays are those in which the neutrino is emitted forward with little energy. If it is assumed that the energy spectra of the electron and neutrino are the same, then it is possible to make an estimate on the basis of the measured

*It should also be taken into account that the mean range of regenerated K_1^0 mesons amounts to ~2.5 cm, while the probability of detecting a V^0 event near the front wall of the chamber and the lead plate is less, because of background conditions, than in the remaining volume of the chamber.

momenta of the decay products the number of such false two-body decays to be expected.

Among all the decay electrons there is only one with energy less than 20 MeV, and in the interval of angles of emission between 0 and 30° there was found only one electron with energy of 21 MeV, all other decay electrons in this interval of emission angles having an energy in excess of 100 MeV. According to these data we could have identified within the measurements errors approximately two three-body decays, whose kinematic characteristics would be close to the two-body decay $K_2^0 \to \pi^- + \pi^+$, which is not in disagreement with the results of the analysis given above (see the table).

Consequently, within the framework of the statistical material obtained in the present experiment, neither of the above mentioned circumstances presents an obstacle to the determination of the relative probability of the two-body decay

$$K_2^0 \to \pi^- + \pi^+.$$

2. For the determination of the "charge ratio" R we utilized the data on the identification of K_{e3} decays obtained by us in the investigation of the transmission of the decay products through a lead plate* and in the measurement of the ionization of the decay products with momentum less than 120 MeV/c. In the second method of identification secondary particles with minimum ionization were selected. Such particles were identified as electrons if their measured momenta did not exceed 100 MeV/c, or it was assumed that the secondary particles were not pions if their momenta were between 100 and 120 MeV/c.

As a result of this analysis the charge ratio was determined to be

$$R = 46/51 = 0{,}90 \pm 0{,}18.$$

As can be seen, the obtained ratio does not differ from unity within the experimental errors.†

Consequently the absence of the decays $K_2^0 \to \pi^- + \pi^+$ testifies in favor of CP invariance in the decay interaction of K^0 and the magnitude of the charge ratio (within the limits of the experimental errors) is not in contradiction with this hypothesis.

Previously obtained [6,9] experimental data on the decays of the long-lived K_2^0 meson into three pions are also qualitatively in agreement with the CP-invariance hypothesis. Indeed, the observed by us event of $K_2^0 \to \pi^- + \pi^+ + \pi^0$, followed by the decay of the π^0 through a Dalitz pair, indicates that this type of decay amounts to a considerable fraction of all K_2^0 decays. On the other hand, as our previous analysis [6] has shown, the detection of four Dalitz pairs should be taken as direct experimental indication that the decay $K_2^0 \to \pi^0 + \pi^0 + \pi^0$ exists.

At the same time for the K_1^0 meson there has not as yet been seen a single reliable case of decay according to the scheme $K_1^0 \to \pi^- + \pi^+ + \pi^0$. As regards the forbidden decay $K_1^0 \to 3\pi^0$, the situation is much more difficult to verify experimentally. However on the basis of isotopic invariance and the selection rule ($\Delta I = 1/2$) one can assert that this decay is forbidden at least to the same extent as the decay $K_1^0 \to \pi^- + \pi^+ + \pi^0$. This totality of experimental data fits well into the framework of CP invariance.

In conclusion we note that among the 597 K_2^0 decays analyzed by us not one event could be identified as a two-lepton decay of the type:*

1) $K_2^0 \to e^- + e^+$, 2) $K_2^0 \to \mu^- + \mu^+$, 3) $K_2^0 \to \mu^\pm + e^\mp$.

This experimental fact shows that neutral lepton "currents" are absent in the decay interaction of K_2^0 mesons. This circumstance makes it harder to introduce neutral intermediate bosons into the theory of weak interactions. [10]

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*The method was described in detail in our previous paper.[6]

†This result, published by us in a preliminary communication,[8] is now made more precise.

*It should be emphasized that the decays of type 1) and 2) (in contrast to the corresponding decays of the K_1^0 meson) are allowed as far as CP invariance is concerned.

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