On the Question of the Spin and Parity of the τ–Meson

I. S. SHAPIRO, E. I. DOLINSKII AND
A. P. MISHAKOVA
Moscow State University,
Academy of Sciences, USSR
(Submitted to JETP editor October 5, 1956)
J. Exptl. Theoret. Phys. (U.S.S.R.) 32, 173–175
(January, 1957)

A COMPARISON* of the experimental data on the energy spectrum and angular distribution of the π–mesons formed in $\tau^{\pm}$- decay with the theoretical curves of Dalitz[1] leads to the conclusion that the most probable spin and parity values for the τ–meson are 0^-. Dalitz' curves were obtained on the assumption that in the τ–decay the π–mesons are produced in states with the smallest possible orbital angular momenta. Since the correctness of this assumption is not obvious, Marshak[2] pointed out the possibility of securing agreement of the experimental and theoretical data on the energy spectrum of the π–mesons by assuming that the spin and parity of the τ–meson have the values 2^+ and that the mesons are emitted with orbital angular momenta (2,1) and (2,3) (in each of the parentheses, the first number is the relative orbital angular momentum of the two π^+–mesons and the second is the orbital angular momentum of the π^-–meson relative to the center of mass of the two π^+–mesons). In the present paper, we use ideas not previously taken into consideration to show that the experimental data exclude the possibility considered by Marshak. The basis on which we proceed is as follows.

1. We assume that the isotopic spin $I_{3\pi}$ of the system of three π–mesons produced in the τ–decay is equal to 1. This hypothesis, already put forward by several writers (Gell–Mann,[3] Wentzel[4]) follows directly from the Gell–Mann scheme,[5] according to which the τ–meson has isotopic spin

$$I_\tau = 1/2$$

and the slowness of the decay

$$\tau^+ \rightarrow \pi^+ + \pi^+ + \pi^-$$

is explained by nonconservation of isotopic spin. It is natural to suppose that the smallest possible change of isotopic spin takes place.

2. We regard the K–mesons that undergo the τ'–decay.

$$\tau'^{\pm} \rightarrow \pi^{\pm} + 2\pi^0,$$

as identical with τ–mesons.

3. According to the experimental data*[6–8] the ratio of the probabilities of τ and τ' disintegration is close to 4:

$$W_\tau / W_{\tau'} \approx 4.$$

As has been shown independently by Dalitz[9] and by Berestetskii[10], if the assumptions 1) and 2) are valid the ratio of these probabilities satisfies the equation:

$$W_\tau / W_{\tau'} = (4F + \Phi) / (F + \Phi),$$

where F is a quantity obtained by integrating with respect to the energies of the π–mesons the squares of the absolute values of matrix elements symmetric in the momenta of all π–mesons, and Φ is an analogous quantity obtained from matrix elements symmetric only with respect to the momenta of identical π–mesons. Thus we come to the conclusion that $\Phi \approx 0$, or in other words that the π–mesons are produced in states symmetric in the momenta of all three particles. We note that if this is the case the spectrum of the π^+–mesons from τ' decay must be identical with the spectrum of π^- mesons from τ–decay.** The lower orbital angular momenta corresponding to such states are shown in Table 1, where there are also shown for comparison the orbital angular momenta and types of matrix elements used by Dalitz.

The diagram shows curves for the energy spectrum of the π–mesons calculated from matrix elements of symmetric states with the orbital angular momenta indicated in Table I (for the formulas by which the calculation was done, cf. Ref. 11). The experimental data are shown in the diagram in the form of a histogram representing the total of 492 cases of τ^+–decay* published in the literature.[12–20] As can be seen from the diagram, the curves corresponding to spins and parities 1^+, 1^-, and 2^+ differ markedly from the experimental spectrum. The curve for the case 2^-, although indeed closer in shape to the experimental distribution, agrees with it considerably less well than the curve corresponding to spin and parity 0^-. These conclusions are confirmed by calculations of the quantity χ^2 and the Pearson probability P_{χ^2} which are shown in Table 2.

Summarizing what has been said above, we come to the following conclusions: a) the most probable values of the spin and parity of the τ–meson are the combination 0^-; b) the combinations 1^+, 1^-, and 2^+ must be regarded as practically excluded.

Thus the most probable values of the spin and parity of the τ–mesons turn out to be just the values that lead to the appearance of the so–called "τ– ϑ problem."

In conclusion we express our sincere gratitude to Prof. I. I. Gurevich for an interesting discussion of the results.

TABLE I

Spin and parity of the τ-meson	0^-	1^+	1^-	2^+	2^-
Minimal pairs of values (l, l') for symmetric states	(0,0) F	(2,1) F	(4,4) F	(2,3) F	(0,2) (2,0) F
Minimal pairs of values (l, l') and types of matrix elements used by Dalitz[1]	(0,0) F	(0,1) Φ	(2,2) Φ	(2,1) Φ	(0,2) (2,0) F

TABLE II*

Spin and parity of the τ-meson	0^-	2^-	1^-	1^+	2^+
χ^2	7.53	25.92	68.49	112.32	135.55
P_{χ^2}	0.188	$\sim 10^{-4}$	$< 2 \cdot 10^{-16}$	$\ll 10^{-16}$	$\ll 10^{-16}$

*The experimental data are not very exact. In Refs. 6 and 7 the error is not indicated; in Ref. 8, the result

$$W_{\tau'} / W_{\tau} = 0.25 \pm 0.12.$$

is obtained. The analysis of the stability of the results of the present paper with respect to small additions Φ is complicated by interference effects.

**At present there are 34 cases of τ' decay for which the energy of the π^+ meson is known. These data are insufficient, however, for comparison with the theoretical curves because of the small statistical precision.

*After the conclusion of the present work, the writers learned of a paper[21] in which 481 cases of τ^+ decays are collected. The comparison of these experimental data is made, however, with theoretical curves found without taking into account the considerations 1)–3) that are the basis of the present paper.

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Translated by W. H. Furry
39