

University of Minnesota
School of Physics and Astronomy

2025 Fall Physics 8901
Elementary Particle Physics I
Assignment Solution

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Problem Set 2 due 9:30 AM, Monday, September 29th

Question 1

The $\tau - \theta$ Puzzle

In the 1950's, two particles τ , θ were discovered with the same mass and lifetime that decayed differently. At the time, physicists believed that parity was conserved in all interactions.

- (a) Consider the decay $\theta \rightarrow \pi^+\pi^0$. Assuming parity invariance and zero for the spin of θ , find the parity of θ .
- (b) Now consider the decay process $\tau \rightarrow \pi^+\pi^+\pi^-$. (This is an old symbol for the K meson.) Let l be the orbital angular momentum of $\pi^+\pi^+$ and l' the orbital angular momentum of π^- relative to the center-of-mass of $\pi^+\pi^+$. Assuming parity invariance and the spin of τ equal to zero, find its parity.
- (c) What resolved the $\tau - \theta$ puzzle?

Answer

(a)

First, we note that the intrinsic parity of a pion is -1 . The parity of a two-particle system is given by

$$P_\theta = P_1 P_2 (-1)^l, \quad (1)$$

where P_1 and P_2 are the intrinsic parities of the two particles, and l is their relative orbital angular momentum. Since the θ and pions have spin 0, the system of two pions must have total angular momentum $j = s + l = 0$, in order to satisfy the conservation of total angular momentum. This means that l must be 0, too. Therefore, we have $P_\theta = 1$. It is even parity.

(b)

The parity of a three-particle system is given by

$$P_\tau = P_1 P_2 P_3 (-1)^{l+l'}, \quad (2)$$

where P_1 , P_2 , and P_3 are the intrinsic parities of the three particles, and l and l' are their relative orbital angular momenta. Since the τ and pions have spin 0, the system of three pions must have total angular momentum $j = s + l + l' = 0$, in order to satisfy the conservation of total angular momentum. This means that $l + l'$ must be 0, too. Therefore, we have $P_\tau = -1$. It is odd parity.

(c)

Since the τ and θ have the same mass and lifetime, they are actually the same particle, now known as the K meson. The resolution of the $\tau - \theta$ puzzle was the discovery that parity is not conserved in weak interactions, which is how the K meson decays. \square

Question 2

List all applicable conservation laws that are or would be violated in the following decays:

1. $\rho^0 \rightarrow \pi^0 \pi^0$
2. $\rho \rightarrow \gamma \gamma$
3. $K^+ \rightarrow \pi^+ \pi^0$
4. $\pi^0 \rightarrow 5\gamma$

(Look up the corresponding parities from the Particle Data Group at <http://pdg.lbl.gov>.)

Answer

1. The decay $\rho^0 \rightarrow \pi^0 \pi^0$ violates Bose-Einstein statistics. The ρ^0 has quantum numbers $J^{PC} = 1^{--}$, while the two π^0 system has quantum numbers $J^{PC} = 0^{++}, 2^{++}, 4^{++}, \dots$. Therefore, the decay is forbidden.

Question 3

List all states (J^{PC}) with total spin $J = 0, 1, 2$ and P, C parities that cannot be realized as a fermion-antifermion system (i.e., as e^+e^- or quark-antiquark). (Hypothetical particles with such combinations of quantum numbers are called exotic, and are being sought for in experiments, so far unsuccessfully.)

Answer

Question 4

State which of the following combinations can or cannot exist in a state of isospin $I = 1$, and give the reasons:

1. $\pi^0\pi^0$
2. $\pi^+\pi^-$
3. $\Sigma^0\pi^0$
4. $\Lambda\pi^0$

Answer