

Chapter 41

Elementary Particles and the Beginning of the Universe

Conceptual Problems

3 • How can you tell whether a decay proceeds by the strong interaction or the weak interaction?

Determine the Concept A decay process involving the strong interaction has a very short lifetime ($\sim 10^{-23}$ s), whereas decay processes that proceed by the weak interaction have lifetimes of order 10^{-10} s.

The Conservation Laws

19 •• Using Figure 41-2 and the laws of conservation of charge number, baryon number, strangeness, and spin, identify the unknown particle, symbolized by (?), in each of the following reactions: (a) $p + \pi^- \rightarrow \Sigma^0 + (?)$, (b) $p + p \rightarrow \pi^+ + n + K^+ + (?)$, and (c) $p + K^- \rightarrow \Xi^- + (?)$

Picture the Problem We can systematically determine Q , B , S , and s for each reaction and then use these values to identify the unknown particles.

(a) For the strong reaction:

$$p + \pi^- \rightarrow \Sigma^0 + (?)$$

Charge number: $+1 - 1 = 0 + Q \Rightarrow Q = 0$

Baryon number: $+1 + 0 = +1 + B \Rightarrow B = 0$

Strangeness: $0 + 0 = -1 + S \Rightarrow S = +1$

Spin: $+\frac{1}{2} + 0 = +\frac{1}{2} + s \Rightarrow s = 0$

These properties indicate that the particle is the kaon $\boxed{K^0}$.

(b) For the strong reaction:

$$p + p \rightarrow \pi^+ + n + K^+ + (?)$$

Charge number: $+1 + 1 = +1 + 0 + 1 + Q \Rightarrow Q = 0$

Baryon number: $+1 + 1 = 0 + 1 + 0 + B \Rightarrow B = +1$

Strangeness: $0 + 0 = 0 + 0 + 1 + S \Rightarrow S = -1$

Spin: $+\frac{1}{2} + \frac{1}{2} = 0 + \frac{1}{2} + 0 + s \Rightarrow s = +\frac{1}{2}$

These properties indicate that the particle is either the Σ^0 or the Λ^0 baryon.

(c) For the strong reaction: $p + \bar{K}^- \rightarrow \Xi^- + (?)$

Charge number: $+1 - 1 = -1 + Q \Rightarrow Q = +1$

Baryon number: $+1 + 0 = +1 + B \Rightarrow B = 0$

Strangeness: $0 - 1 = -2 + S \Rightarrow S = +1$

Spin: $+\frac{1}{2} + 0 = +\frac{1}{2} + s \Rightarrow s = 0$

These properties indicate that the particle is the kaon K^+ .

Quarks

27 •• Find a possible quark combination for the following particles: (a) Λ^0 , (b) p^- , and (c) Σ^- .

Picture the Problem Because Λ^0 , p^- , and Σ^- are baryons, they are made up of three quarks. We can use Tables 41-1 and 41-2 to find combinations of quarks with the correct values for electric charge, baryon number, and strangeness for these particles.

(a) For Λ^0 we need:

$$Q = 0$$

$$B = +1$$

$$S = -1$$

The quark combination that satisfies these conditions is uds .

(b) For p^- we need:

$$Q = -1$$

$$B = +1$$

$$S = 0$$

The quark combination that satisfies these conditions is $\bar{u}\bar{u}\bar{d}$.

(c) For Σ^- we need:

$$Q = -1$$

$$B = +1$$

$$S = -1$$

The quark combination that satisfies these condition is \boxed{dds} .

The Evolution of the Universe

31 • A galaxy is receding from Earth at 2.5 percent the speed of light. Estimate the distance from Earth to this galaxy.

Picture the Problem We can use Hubble's law to find the distance from Earth to this galaxy.

The recessional velocity of galaxy is related to its distance by Hubble's law:

$$v = Hr \Rightarrow r = \frac{v}{H}$$

Substitute numerical values and evaluate r :

$$\begin{aligned} r &= \frac{(0.025)c}{23 \text{ km/s}} = \frac{(0.025)(2.998 \times 10^5 \text{ km/s})}{23 \text{ km/s}} \\ &= \boxed{3.3 \times 10^8 c \cdot y} \end{aligned}$$

General Problems

37 •• (a) In terms of the quark model, show that the reaction $\pi^0 \rightarrow \gamma + \gamma$ does not violate any conservation laws. (b) Which conservation law is violated by the reaction $\pi^0 \rightarrow \gamma$?

Picture the Problem The π^0 particle is composed of two quarks, $u\bar{u}$. Hence, the reaction $\pi^0 \rightarrow \gamma + \gamma$ is equivalent to $u\bar{u} \rightarrow \gamma + \gamma$.

(a) The u and \bar{u} annihilate – resulting in the photons.

(b) Two or more photons are required to conserve linear momentum.