

State Examination Commission – Physics Higher Level, 2006

Question 10

During a nuclear interaction an antiproton collides with a proton. Pair annihilation takes place and two gamma ray photons of the same frequency are produced.

What is a photon? Calculate the frequency of a photon produced during the interaction. (12)

Why are two photons produced? Describe the motion of the photons after the interaction. (9)

How is charge conserved during this interaction? (6)

After the annihilation, pairs of negative and positive pions are produced. Explain why. (6)

Pions are mesons that consist of up and down quarks and their antiquarks. Give the quark composition of (i) a positive pion, (ii) a negative pion. (9)

List the fundamental forces of nature that pions experience. (6)

A neutral pion is unstable with a decay constant of $2.5 \times 10^{12} \text{ s}^{-1}$. What is the half-life of a neutral pion? (8)

(mass of proton = $1.673 \times 10^{-27} \text{ kg}$; Planck constant = $6.626 \times 10^{-34} \text{ J s}$; speed of light = $2.998 \times 10^8 \text{ m s}^{-1}$)

During a nuclear interaction an antiproton collides with a proton. Pair annihilation takes place and two gamma ray photons of the same frequency are produced.

What is a photon? Calculate the frequency of a photon produced during the interaction. (12)

A photon is an elementary particle, a packet of electromagnetic radiation which is a form of energy.

$$\begin{aligned} \Rightarrow \text{Mass of particles annihilated, } m &= 2 \times 1.673 \times 10^{-27} \text{ kg} = 3.346 \times 10^{-27} \text{ kg} \\ \text{energy created, } E &= mc^2 \\ &= (3.346 \times 10^{-27})(2.998 \times 10^8)^2 \\ &= 3.0074 \times 10^{-10} \text{ J} \end{aligned}$$

This energy is divided among both photons, \Rightarrow each photon has energy $E = 1.5037 \times 10^{-10} \text{ J}$

$$\begin{aligned} \text{Now, for a photon } E &= hf \\ f &= E/h \\ &= 1.5037 \times 10^{-10} / 6.626 \times 10^{-34} \\ &= 2.2694 \times 10^{23} \text{ Hz} \end{aligned}$$

Why are two photons produced? Describe the motion of the photons after the interaction. (9)

Two photons need to be produced to prevent violation of the principle of conservation of momentum. The photons thus move in opposite directions

How is charge conserved during this interaction? (6)

The total charge is zero both before and after the interaction (the proton and anti-proton have equal but opposite charges, and the photons are uncharged)

After the annihilation, pairs of negative and positive pions are produced. Explain why. (6)

The electromagnetic energy initially produced (photons) changes to mass, which is merely another form that energy can take. There is equal amount of negative & positive charge produced for conservation reasons.

Pions are mesons that consist of up and down quarks and their antiquarks. Give the quark composition of (i) a positive pion, $u\bar{d}$ (ii) a negative pion. $\bar{u}d$ (9)

List the fundamental forces of nature that pions experience. (6)
Gravitational, electromagnetic, strong and weak forces.

A neutral pion is unstable with a decay constant of $2.5 \times 10^{12} \text{ s}^{-1}$. What is the half-life of a neutral pion? (8)

$$\begin{aligned} \lambda T_{1/2} &= \ln 2 \\ \Rightarrow T_{1/2} &= \ln 2 / \lambda = 0.693 / 2.5 \times 10^{12} = 2.8 \times 10^{-13} \text{ s} \end{aligned}$$