

# PHYS 124 Final Exam Question 1

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1. (a) Which processes below are physically forbidden? Why?

(i)  $\tau^+ + \tau^- \rightarrow \mu^+ + e^-$

On the left side,

$$L_\tau = -1 + 1 = 0$$

$$L_\mu = 0$$

$$L_e = 0.$$

On the right side,

$$L_\tau = 0$$

$$L_\mu = -1$$

$$L_e = 1.$$

The conservation of  $L_\mu$  and  $L_e$  are violated, so this is forbidden.

(ii)  $p + \bar{n} \rightarrow p + n$

On the left side,  $B = 1 - 1 = 0$ . On the right side,  $B = 1 + 1 = 2$ . The conservation of baryon number is violated, so this is forbidden.

(iii)  $u + \bar{u} \rightarrow \bar{s} + s$

On the left side,

$$Q/e = \frac{2}{3} - \frac{2}{3} = 0$$

$$B = \frac{1}{3} - \frac{1}{3} = 0$$

$$S = 0.$$

On the right side,

$$Q/e = \frac{1}{3} - \frac{1}{3} = 0$$

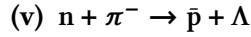
$$B = -\frac{1}{3} + \frac{1}{3} = 0$$

$$S = 1 - 1 = 0.$$

Charge, baryon number, and strangeness are all conserved, so this is allowed.

(iv)  $\gamma + \gamma \rightarrow \mu^+ + \mu^-$

On the left side,  $L_\mu = 0$ . On the right side,  $L_\mu = -1 + 1 = 0$ .  $L_\mu$  is conserved, so this is allowed.



On the left side,

$$Q/e = 0 - 1 = -1$$

$$B = 1$$

$$S = 0.$$

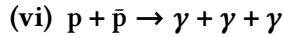
On the right side,

$$Q/e = -1 + 0 = -1$$

$$B = -1 + 1 = 0$$

$$S = -1.$$

Charge, baryon number, and strangeness are all violated, so this is forbidden.



On the left side,  $B = 1 - 1 = 0$ . On the right side,  $B = 0$ . Baryon number is conserved, so this is allowed.

- (b) **The Future Circular Collider (FCC), if built, will collide two beams of protons, each beam having an average energy of 50 TeV. How much energy would a beam in a fixed-target experiment have to have to get the same average total amount of useable energy per collision?**

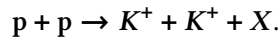
The useable energy from the collision of a particle into a stationary particle with similar mass is given by

$$E_a^2 = 2mc^2(E_m + mc^2)$$

where  $m$  is the mass of each particle and  $E_m$  is the total energy of the moving particle. Solving this for  $E_m$ :

$$\begin{aligned} E_a^2 &= 2mc^2(E_m + mc^2) \\ E_m + mc^2 &= \frac{E_a^2}{2mc^2} \\ E_m &= \frac{E_a^2}{2mc^2} - mc^2 \\ &= \frac{(8.01088 \times 10^{-6} \text{ J})^2}{2(1.67262 \times 10^{-27} \text{ kg})(2.99792 \times 10^8 \text{ m s}^{-1})^2} - (1.67262 \times 10^{-27} \text{ kg})(2.99792 \times 10^8 \text{ m s}^{-1})^2 \\ &= 0.213448 \text{ J} \end{aligned}$$

- (c) **An experiment is performed at Fermilab to find a new particle  $X$  from the scattering process**



**What are the values of the electric charge, strangeness, and baryon number of the  $X$  particle? What quarks must it be made of?**

On the left side,

$$Q/e = 0$$

$$B = 1 + 1 = 2$$

$$S = 0.$$

On the right side,

$$Q/e = 1 + 1 + Q_X/e$$

$$B = 0 + B_X$$

$$S = S_X.$$

To abide by the conservation laws,  $Q_X/e$  must be -2,  $B_X$  must be 2, and  $S_X$  must be 0.