# PHYS 124 Final Exam Question 1

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

**(i) $\boldsymbol{\tau^+ + \tau^- \to \mu^+ + e^-}$**

On the left side,

$$\begin{aligned} L_\tau &= -1 + 1 = 0 \\ L_\mu &= 0 \\ L_\mathrm{e} &= 0. \end{aligned}$$

On the right side,

$$\begin{aligned} L_\tau &= 0 \\ L_\mu &= -1 \\ L_\mathrm{e} &= 1. \end{aligned}$$

The conservation of $L_\mu$ and $L_\mathrm{e}$ are violated, so this is forbidden.

**(ii) $\mathbf{p} + \bar{\mathbf{n}} \to \mathbf{p} + \mathbf{n}$**

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) $\mathbf{u} + \bar{\mathbf{u}} \to \bar{\mathbf{s}} + \mathbf{s}$**

On the left side,

$$\begin{aligned} Q/e &= \frac{2}{3} - \frac{2}{3} = 0 \\ B &= \frac{1}{3} - \frac{1}{3} = 0 \\ S &= 0. \end{aligned}$$

On the right side,

$$\begin{aligned} Q/e &= \frac{1}{3} - \frac{1}{3} = 0 \\ B &= -\frac{1}{3} + \frac{1}{3} = 0 \\ S &= 1 - 1 = 0. \end{aligned}$$

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

**(iv) $\boldsymbol{\gamma + \gamma \to \mu^+ + \mu^-}$**

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

**(v) $\mathrm{n} + \pi^- \to \bar{\mathrm{p}} + \Lambda$**

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.

**(vi) $\mathrm{p} + \bar{\mathrm{p}} \to \gamma + \gamma + \gamma$**

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

$$E_{\mathrm{a}}^2 = 2mc^2(E_m + mc^2)$$

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

$$\begin{aligned}
E_{\mathrm{a}}^2 &= 2mc^2(E_m + mc^2) \\
E_m + mc^2 &= \frac{E_{\mathrm{a}}^2}{2mc^2} \\
E_m &= \frac{E_{\mathrm{a}}^2}{2mc^2} - mc^2 \\
&= \frac{(8.010\,88 \times 10^{-6}\ \mathrm{J})^2}{2(1.672\,62 \times 10^{-27}\ \mathrm{kg})(2.997\,92 \times 10^8\ \mathrm{m\,s^{-1}})^2} - (1.672\,62 \times 10^{-27}\ \mathrm{kg})(2.997\,92 \times 10^8\ \mathrm{m\,s^{-1}})^2 \\
&= 0.213\,448\ \mathrm{J}
\end{aligned}$$

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

$$\mathrm{p} + \mathrm{p} \to K^+ + K^+ + X.$$

**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,

$$\begin{aligned} Q/e &= 1 + 1 + Q_X/e \\ B &= 0 + B_X \\ S &= S_X. \end{aligned}$$

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