SH/IM Particle Physics - Introductory Quiz, with Answers!

1. What are the allowed spin states of an electron?

   Spin up ($m_s = +\frac{1}{2}\hbar$) and spin down ($m_s = -\frac{1}{2}\hbar$).

2. List the quarks and leptons in the Standard Model. Give the electric charge, Q, and spin, S, of each one.

down quark, **d**	$Q = -\frac{1}{3}$	$S = \frac{1}{2}$	All charges in units in the electron charge, $\lvert e \rvert$
up quark, **u**	$Q = +\frac{2}{3}$	$S = \frac{1}{2}$	
strange quark, **s**	$Q = -\frac{1}{3}$	$S = \frac{1}{2}$	
charm quark, **c**	$Q = +\frac{2}{3}$	$S = \frac{1}{2}$	
bottom quark, **b**	$Q = -\frac{1}{3}$	$S = \frac{1}{2}$	
top quark, **t**	$Q = +\frac{2}{3}$	$S = \frac{1}{2}$	
electron, e^-	$Q = -1$	$S = \frac{1}{2}$	
muon, μ^-	$Q = -1$	$S = \frac{1}{2}$	
tau, τ^-	$Q = -1$	$S = \frac{1}{2}$	
electron neutrino, ν_e	$Q = 0$	$S = \frac{1}{2}$	
muon neutrino, ν_μ	$Q = 0$	$S = \frac{1}{2}$	
tau neutrino, ν_τ	$Q = 0$	$S = \frac{1}{2}$	

3. List the forces present in the Standard Model, with the associated boson(s). Give the electric charge, Q, and spin, S, of each boson.

Force	Boson	Charge	Spin
Strong	Gluon, g	$Q = 0$	$S = 1$
Electromagnetic	Photon, γ	$Q = 0$	$S = 1$
Weak	*W*-boson, $W^\pm$	$Q = \pm 1$	$S = 1$
“	*Z*-boson, Z^0	$Q = 0$	$S = 1$

Gravity isn't part of the Standard Model. But for this question it's not unreasonable to list it too.

Gravity	graviton	$Q = 0$	$S = 2$

4. Write down the components of the four momentum of a particle, p^μ.

   $p^\mu = (E/c, p_x, p_y, p_z) = (E/c, \underline{p})$ or in natural units: $p^\mu = (E, p_x, p_y, p_z) = (E, \underline{p})$

   Where $\underline{p}$ is the three vector.

   The $^\mu$ is used to refer to the element of the four vector: $p^0 = E, p^1 = p_x, p^2 = p_y, p^3 = p_z$

5. What is the relativistic relationship between mass, m, energy, E and three-momentum, p?

$E^2=p^2c^2+m^2c^4$ or in natural units: $E^2=p^2+m^2$

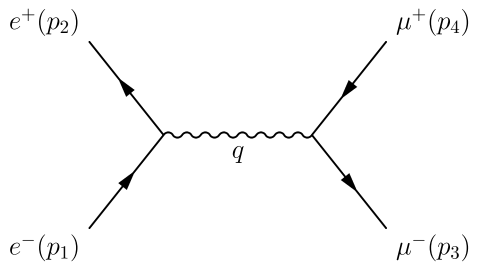
6. Write down the definition of the scalar product of two four momenta, p_a and p_b.

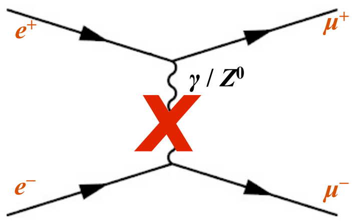
$$
\begin{aligned}
p_a \cdot p_b &= p_a^0 p_b^0 - (p_a^1 p_b^1 + p_a^2 p_b^2 + p_a^3 p_b^3) \\
&= E_a E_b / c^2 - (p_{x,a} p_{x,b} + p_{y,a} p_{y,b} + p_{z,a} p_{z,b}) \\
&= E_a E_b / c^2 - \underline{p_a} \cdot \underline{p_b}
\end{aligned}
$$

Where $\underline{p}$ are the three vectors.

In natural units: $p_a \cdot p_b = E_a E_b - \underline{p_a} \cdot \underline{p_b}$

7. Draw a Feynman diagram illustrating $e^+e^- \to \mu^+\mu^-$ scattering.





These diagrams are drawn with the time axis going from left to right. This process can be either electromagnetic or weak. The boson, represented by the wavy line, is a photon or a *Z*-boson.

Note that the electron/positron line is continuos and the muon/anti-muon line is continuous. This reflects the conservation of electron number and the conservation of muon number

A common, illustrated, mistake was to draw the electron line turning into a muon with $e^- \to \mu^- \gamma$ and $\gamma e^+ \to \mu^+$. This would violate electron and muon number conservation.

8. What is the *cross section* of a process?

The *cross section,* usually written as σ, is a measure of how often a **scattering** process occurs. It is measured in units of area. (See chapter 8 of Dynamics and Relativity.)

9. What is the *branching ratio* of a process?

The branching ratio, often written as **BR**, is the fraction of decays of a given particle to a given final state. It is often expressed as a percentage.

As an example:

$$
\mathrm{BR}(Z \to e^+e^-) = \frac{\Gamma(Z \to e^+e^-)}{\Gamma_Z} = \frac{\text{Number of } Z\text{-boson decays into } e^+e^-}{\text{Total number of } Z\text{-boson decays}}
$$