Physics 390: Homework 10

This homework is due in class on **Monday, April 20**, which is the last day of this class.

For full credit, show all your working.

1. **Fundamental forces:** Which of the four fundamental forces is responsible for each of the following processes?

   (a) $n \to p + e^- + \overline{\nu}_e$

   (b) $\pi_0 \to \gamma + \gamma$

   (c) $\Delta^+ \to \pi^0 + p$

   (d) $\pi^+ \to \mu^+ + \nu_\mu$

2. **Conservation laws:** Which of the follow processes is allowed and which is forbidden? For the forbidden ones, state which conservation law or laws is broken in each case:

   (a) $p \to n + e^+ + \nu_e$

   (b) $e^+ + e^- \to \gamma$

   (c) $p + \overline{p} \to \gamma + \gamma$

   (d) $n \to p + \pi^-$

   (e) $\nu_e + p \to n + e^+$

3. **Proton mass:** The masses of the up and down quarks are 2.4 MeV and 4.8 MeV.

   (a) What is the combined mass of the three quarks in a proton? How does this compare to the observed mass of the proton?

   (b) The quarks in a proton have kinetic energy on account of the uncertainty principle—we know their location very accurately, so their momentum cannot be zero. Use the uncertainty principle to make a rough estimate of the momentum of a quark trapped in a volume of radius about 1 fm (the radius of a proton). Show that the quark is traveling close to the speed of light. Taking this into account, estimate the kinetic energy of the quark.

   (c) Adding the mass energy and the kinetic energy together, how much total mass should the proton have? How does this compare with the observed mass of the proton?

Turn page →

4. **Strange matter:** The stable baryons are made of up and down quarks. Particles containing the next heaviest quark, the strange quark, are normally unstable because the strange can decay to an up. It's possible, however, that there might be exceptions.

   (a) The neutron is unstable on its own (it decays to a proton), but neutrons inside nuclei can be stable. The neutrons in a helium nucleus, for example, will last forever without decaying. Why are these neutrons inside nuclei stable?

   (b) It has been proposed that the same type of stability could occur for strange baryons inside nuclei, giving rise to a new kind of "strange matter" composed of heavy elements with stable strange baryons in their nuclei. What is the lightest strange baryon? Give the quark composition, mass, charge, and spin of this particle.

   (c) Consider a nucleus that contains protons and neutrons and consider adding to it (1) another neutron or (2) the strange baryon from part (b). According to the exclusion principle the strange baryon can go into the lowest-lying nucleon state, whereas the neutron has to go into an excited state, the lower states being already full. How big would the difference in energies have to be between the lowest-lying state and the first unoccupied neutron state for the "strange matter" nucleus to be energetically favored over the normal nucleus, thereby producing stable strange matter?

5. **Expansion of the universe:** Hubble's law tells us that objects in the sky that are farther away from the Earth are moving away from us faster. Let us assume that everything we see was once very close to us (at the big bang) and then expanded away from us, each individual object moving away at its own constant velocity. Let T be the age of the universe.

   (a) In order for us to see an object that's moving away from us, it must have moved away starting at the big bang, then at some point emitted some light that traveled back to us and is just now arriving at the Earth. For an object moving at constant velocity v away from us calculate the distance r it was from us when it emitted that light in terms of v and T.

   (b) Hence show that the *current* distance R to an object that *appears* to be at distance r satisfies

$$\frac{1}{R} = \frac{1}{r} - \frac{1}{cT}$$

   where c is the speed of light.

   (c) Given that the current age of the universe is about 13.7 billion years, what is the current distance to an object that appears to be 10 billion light years away? What is the velocity v of such an object?