107 Answer Key HW #11- Chapter 18 assignment

Conceptual: 6, 10, 12
Problems: 2, 4

December 14, 2005

1 Conceptual Exercises

6.) "Of the 10 electroweak particles (Table 18.1), which ones travel at (or near) lightspeed?"

To travel at or near lightspeed, the mass needs to be zero, or extremely close to zero. The $\boxed{\text{photon,}}$ with zero mass, will certainly travel at lightspeed. The $\boxed{\text{neutrinos,}}$ with a very small mass (much smaller than the electron's), will travel close to lightspeed (this includes the electron-, muon-, and tau-neutrinos). The electron, even though it has a small mass, does not typically travel at lightspeed. In fact, an electron in an atom is to a large degree *nonrelativistic*, i.e. its speed is much less than the speed of light.

10.) "According to the standard model, which of the following are elementary: neutrino, neutron, quark, muon, photon, antiproton?"

An elementary particle is something that is not made of anything else. According to the standard model, the $\boxed{\text{neutrinos, quarks, muon, and photon}}$ are all elementary, since they are not "made of anything else." The neutron and antiproton are not elementary because they are made of quarks; the neutron is two down quarks and an up quark, while the antiproton is two antiup quarks and an antidown quark.

12.) "In what ways are quarks similar to electrons? In what ways are they different?"

Similarities: Both are <u>fermions</u>, which means both have half-integer spins, obey the Pauli exclusion principle, and pairs of identical particles are antisymmetric. Both feel the <u>gravitational</u>, <u>weak</u>, and <u>electromagnetic</u> forces - which means both electrons and quarks have electric charges (as well as weak charges). Quarks and electrons make up the "stuff" we are used to thinking of: atoms.

Differences: Quarks have <u>fractional</u> electric charges (i.e. -1/3, +2/3), while electrons have whole electric charges (-1). Quarks feel the <u>strong force</u>, while electrons do not. Electrons can exist on their own as a single particle, but quarks must be <u>confined</u>, appearing only with other quarks.

2 Problems

2.) "A proton-antiproton pair, at rest, annihilate and create two photons. Using the information in the preceding problem, and the fact that a proton is 1,800 times more massive than an electron, find the frequency of each photon."

The information from the preceding problem states that the frequency of photons emitted when an electron-positron pair annihilate is 10^{20} Hz. The process for this to happen is $e^- + e^+ \rightarrow 2\gamma$, where γ stands for a photon.

We will use energy conservation, setting the initial energy equal to the final energy. The initial energy comes just from rest mass: $E_i = 2 * m_e c^2$, where m_e is the mass of an electron/positron (they have the same mass), and the factor of 2 comes from the fact that the electron and position have the same mass.

The final energy is the energy of the two photons: $E_f = 2hf_e$, where $f_e = 10^{20}$ Hz is the frequency we are told from problem 1.). Energy conservation says $E_i = E_f \rightarrow 2m_e c^2 = 2hf_e$. Simplifying this expression by dividing out the common factor of 2: $m_e c^2 = hf_e$.

How do we figure out the frequency for a proton and antiproton? The only thing different is the mass: the mass of the proton/antiproton is 1800 times the mass of the electron/position. Thus, we can increase the mass by a factor of 1800, and see what happens to the frequency: $(1800 * m_e)c^2 = h * (1800 * f_e)$. Thus, the frequency increases by 1800 as well! The new frequency is $\boxed{1800 * 10^{20}\ Hz = 1.8 * 10^{23}\ Hz}$.

4.) "Making estimates. A large electric power plant generates 1000 MW of electricity. If the energy came from matter-antimatter annihilation, about what total mass of matter and of antimatter would be required each year, assuming that the electricity is generated at an energy efficiency of 50%?"

The main idea we need is this: (Energy needed for 1 year) = (energy from matter-antimatter annihilation). Let's work on the left-hand side first: to get the energy needed for 1 year, we will multiply the power by 1 year, in seconds (this works because power is energy divided by time - we need 1 year in seconds because a Watt = 1 Joule/1 sec, and multiplying by seconds cancels those units, leaving us with Joules).

$$\begin{aligned} Energy\ needed\ for\ 1\ year\ &= (Power) * (1\ year\ in\ sec) = 1000MW * (3.1 * 10^7 sec) \\ &= 1000 * 10^6 W * (3.1 * 10^7 sec) = 3.1 * 10^{16} J. \end{aligned} \tag{1}$$

Now lets work on the right-hand side: the energy from matter-antimatter annihilation comes mainly from the (unknown amount of) rest mass of the matter and antimatter (see prob (2) above): $2mc^2$. However, the plant operates at 50% efficiency, so we only get half of this energy to use to generate electricity: $1/2 * (2mc^2)$. Putting both sides of the equation together, we have:

$$3.1 * 10^{16} J = 1/2(2mc^2) = mc^2. \tag{2}$$

Solving for the amount of matter/antimatter we would need to run the plant for a year, we have $\boxed{m = .35kg.}$ Altogether, the total amount of matter and antimatter we would need is $2 * .35kg = .70kg$! Compare this to the tons of coal, oil, and natural gas that are burned every year to generate electricity! Clearly, matter-antimatter annihilation is a powerful source of energy.