PHYSICS 357S - Problem Set #1 - January 2003

Distributed **8th January**. Due to be handed in by **22nd January** at class. After this date it should be handed to Stan Lai. Please be careful handing work in. Try to give it to Stan personally. Lost work cannot be given credit.

This problem set counts for 10% of the grade. For the numerical values of constants, such as masses, (that I may have forgotten to give you!) , you should use the Appendix A at end of the text book starting on page 377. If you don't understand a question ask me about it. If you think there is a bug (error, typo, etc) in a question..tell me. You might be right!

1) At modern accelerators we can produced beams of various kinds of particles. Two of the most common particles are called *pions* and *kaons*. Assume that we produce beams of these particles with energies of $200\,\mathrm{GeV}$. The proper mass of the charged *pion* is $0.14\,\mathrm{GeV}/c^2$, and the proper lifetime is $2.6\times10^{-8}\,\mathrm{s}$. The proper mass of the charged *kaon* is $0.494\,\mathrm{GeV}/c^2$, and the proper lifetime is $1.2\times10^{-8}\,\mathrm{s}$. Calculate the observed lifetimes in the laboratory frame of these two particles.

2) a) The energy flux reaching the earth from the sun is $2\,\mathrm{cal\,cm^{-2}\,min^{-1}}$.
How much mass does the sun lose each second? Would you expect there to be an affect on planetary orbits? (The mass of the sun is $2\times10^{33}\,\mathrm{gm}$, and it is about 93 million miles from the earth)

b) The mass of the hydrogen atom is $1.6735\times10^{-24}\,\mathrm{gm}$, and the mass of the helium atom is $6.6456\times10^{-24}\,\mathrm{gm}$. The sun is a main sequence star which, as you know, means that it is powered by the conversion of hydrogen to helium. How many tonnes of helium does the sun produce per second?

3) In class we discussed how some of the kinetic energy of a *beam* particle colliding with a *target* particle can be transformed into the masses of new particles in the final state. Assume that a beam particle *A* of total energy *E* collides with a target particle *B,* which is at rest *(remember the LAB is defined as the frame where the target is at rest.)* New particles C_1, C_2 ... are produced in the final state. We write this according to the notation:

$$A + B \to C_1 + C_2 + ... + C_n$$

a) Show that the minimum energy *E* for *A* is

$$E = \frac{M^2 - m_A^2 - m_B^2}{2m_B} c^2 \text{, where } M \equiv m_1 + m_2 + ... + m_n$$

This minimum energy is know as the *Threshold Energy* for producing the final state $C_1 + C_2 + ... + C_n$.

b) Imagine an experiment to produce a particle called the *Upsilon (*Υ*)*. This particle is a bound state made of a *b*-quark and its anti-particle (the $\overline{b}$ -quark ... we will discuss all these concepts later). The Υ has a mass of $9.46\,\mathrm{GeV/c^2}$. Our experiment consists of firing a beam of positrons at a target containing stationary electrons. What energy does the positron beam have to have? *(Assume that the final state consists of a single* Υ *.)* Say we made a machine which collided electron and positron beams head on, with equal and opposite momentum. What would have to be the momentum of each beam?

c) Calculate the minimum π^- momentum in the laboratory necessary for the reaction

$$\pi^- p \to \Lambda^0 K^0$$

to occur. This experiment consists of firing a *pion* beam in to a liquid hydrogen target. ($m_p = 0.981\,\mathrm{GeV/c^2}$, $m_{\pi^-} = 0.140\,\mathrm{GeV/c^2}$, $m_K = 0.498\,\mathrm{GeV/c^2}$, $m_{\Lambda^0} = 1.115\,\mathrm{GeV/c^2}$)

4) Here are some questions about Feynman diagrams. When you draw them, use the ones I did as examples. Remember to put in little arrows showing the direction of particles and antiparticles, also label each line. Also remember that electric charge is conserved at each vertex of a Feynman diagram. Make sure that you understand what is a virtual particle line, and what is a freely propagating particle line. Virtual lines do not have arrows on them .... why is that?

a) Compton scattering is the scattering of photons off of electrons. Draw all the 4th order diagrams (ones with four vertices) for this process. There are 17 of them! These represent very small corrections to the leading order process. *Remember that all the lines have to be connected; except the ends of the incoming and outgoing particles.*

b) Elastic scattering between electrons and positrons, $e^-e^+ \to e^-e^+$, is known as *Bhabha* scattering after the Indian physicist of that name. Determine the mass of the virtual photon in Bhabha scattering, assuming that the electron and positron are at rest. What is the velocity of the virtual photon? Is that possible for *real* photons?

c) In the introductory lecture I mentioned that the Z^0 was a mediator of the weak interaction. So, it couples weakly to both e^+, e^- and to the charged mediators of the weak interaction, W^+, W^-. I also said that the weak and electromagnetic interactions were really the *same interaction*. That means that a process taking place via virtual photon exchange, can equally well take place through virtual Z^0 exchange. Now, draw all the lowest order diagrams contributing to the process $e^+e^- \to W^+W^-$; assuming that the weak and electromagnetic interactions have equal strength. The Large Electron Positron collider (LEP) at CERN studied this process, as a precission test of the electroweak model.

d) Draw leading order Feynman diagrams (in terms of quark transitions if hadrons are involved) for the following weak decays (??? How do I know thatthey are weak decays??). Notice how I leave the "+" out between the different final state particles.

$$\pi^+ \to \mu^+\nu_\mu$$
$$\Lambda \to pe^-\nu_e$$
$$K^0 \to \pi^+\pi^-$$
$$\pi^+ \to \pi^0 e^+\nu_e$$

question continues on next page!!!!!

and also Draw Feynman diagrams for the following strong decays (again, how do I know that they are strong decays?)

$$\omega^0 \to \pi^+\pi^-\pi^0$$
$$\rho^0 \to \pi^+\pi^-$$
$$\Delta^{++} \to p\pi^+$$