Physics 200 Problem Set 6

Due at the end of class, Wed Oct 27$^{\text{th}}$

Practice problems: do not hand in. Textbook pg 1182, problems 75, 72, 74, 76

1. Two bullets collide head on. The first bullet is going with speed 0.1c and weights 5g. The second bullet is going with speed 0.2c and weights 3g. Assume that after the collision, the two bullets form one stuck-together mass.

(a) What is the mass and the velocity of the resulting object?

(b) Assume that before they collided, the bullets were at a temperature of 200C. The heat capacity of lead is 130 J/(g C). If the increase in rest mass energy is due to heat, how hot is the resulting object? (assume that heat capacity per atom is constant at all temperatures, and make other simplifying assumptions: ignore that lead will melt, ignore that atoms will form plasma, etc...)

2. An accelerator experiment produces a new unstable particle X at rest. X quickly decays to a tau (mass $1777 MeV/c^2$) and a tau anti-neutrino (which we will take to be massless). Neutrinos are very difficult to observe, so its energy cannot be measured. The tau is measured to have energy of $4000MeV$. What was the mass of the mystery X particle?

3. The Sun's total luminosity is $3.8 \times 10^{26} W$.

(a) Assuming the luminosity is a constant, by how much will the Sun's mass decrease in the next 2 billion years?

(b) Assuming that the dominating source of the Sun's energy is conversion of four protons and two electrons into one helium-4 nucleus and two neutrinos, and that all of this energy is lost via radiation, how many moles of hydrogen does the Sun convert to helium in one second? Masses: $m(p^+) = 938.272MeV$, $m(^4He^{+2}) = 3727.379MeV$, $m(e^-) = 0.510MeV$, $m(\nu) \approx 0MeV$.

4. In this question, we will consider another Sci-Fi concept, a ship driven by an Earth-based laser. This works as follows: a really powerful and well collimated laser beam is sent from Earth in the direction the ship is supposed to go in. The spaceship is equipped with a large mirror and the laser beam is reflected back to the Earth. Since light carries momentum, this propels the ship forward.

Let's consider a time after the initial boost-off, when the laser is off and ship is moving with a large velocity v away from the Earth. To give the ship's velocity a final adjustment, a single short laser burst is emitted towards the ship, with total energy E in the Earth's frame of reference. How much momentum, in the Earth's frame of reference, does this burst give to the ship once it's been reflected off its mirror?

Hint I: You may assume that the spaceship is very massive and therefore, in the *ship's frame of reference* the momentum of the reflected pulse has the same magnitude as the momentum of the incident pulse. Equivalently, in the ship's frame of reference, the reflected light has the same wavelength as the incident light.

Hint II: There are two ways to do this problem. You can either use Lorentz transformations for p and E or the Doppler shift formula you derived in Tutorial 6.

Challenge problem (not for credit): what about the motion of the ship if the laser beam is continuously turned on? Prove that

$$\frac{dv}{dt} = 2(P/Mc)(1 + v/c)^{1/2}(1 - v/c)^{5/2}$$

where P is the total power of the laser beam, M is the mass of the ship and t is time in the Earth's frame of reference. Try to integrate to get the velocity as a function of time.