Physics 200 Problem Set 4

Problem 1

a) A ball of gold with a temperature of close to absolute zero is found to have a mass of 1kg. If the ball of gold is heated to 1000K, by how much does its mass increase?

For this problem, we need to use the fact that temperature is proportional to the average kinetic energy of the individual atoms. Thermodynamics tells us that the quantitative relationship is

$$\frac{1}{2}mv^2 = \frac{3}{2}kT$$

where m is the mass of the atom, T is the temperature in Kelvin, and k is the Boltzmann constant, $k = 1.38 \times 10^{-23} J/K$.

b) Suppose that scientists discover a new kind of engine that can directly convert the mass energy from butter into the kinetic energy of a vehicle. If one of these engines were placed on the space shuttle, how much butter (in grams) would it take to bring the shuttle to the velocity required to escape the gravitational pull of the Earth (ignore momentum conservation here)?

Problem 2

One rainy afternoon down at Dave's New Particle World, Dave collides an electron and a positron and creates a new unstable particle with a mass of 500 MeV/c^2. The particle is initially at rest and decays into two other particles, each with speed $0.5c$. What are the masses of the two particles that are created (express your answer in units of MeV/c^2)?

Note: an electron volt is the amount of energy it takes to move an electron through a potential difference of 1 Volt = 1 Joule/Coulomb. This means $1eV = 1.6 \times 10^{-19} J$. *The electron volt is the standard unit used to describe energies in atomic and particle physics. Masses of subatomic particles are also described by giving their mass energy in electron volts (or* $MeV = 10^6 eV$ *). For example, the mass energy of an electron is* $m_e c^2 = 0.511 MeV$.

Problem 3

A 2kg ball traveling at 0.6c collides with a 3kg ball that is initially at rest and bounces directly backwards. The collision is elastic, so that the masses are not changed in the collision. In this question, we would like to determine the final velocity of each ball. We could analyze everything in the original frame of reference using energy and momentum conservation, but the simplest way to do the problem is to go to a frame where momentum is zero, analyze the collision, and then transform back:

a) Determine the total momentum and total energy in the original frame of reference.

b) Using the Lorentz transformation for momentum, determine the velocity of a reference frame S' in which the total momentum p'_{TOT} is zero.

c) Calculate the velocities of the two objects in this frame before the collision.

d) Determine the velocities of the two objects in this frame after the collision

hint: for this part, no calculation is required; you should be able to guess what happens after the collision using the fact that it is an elastic collision and that the total momentum is zero before and after. If it's not obvious, draw a picture of the momentum vectors for the two object before the collision.

e) Determine the velocities of the two objects in the original frame after the collision.

see next page
Problem 4

One day, Stéphane Dion is sitting at a sidewalk cafe eating some crepes covered liberally with maple syrup. Glancing down the road to his right, he notices Stephen Harper driving conservatively towards him at speed 3/5 c in his SUV, which has mass M. Glancing to his left, he sees Jack Layton coming down the road at speed 4/5 c from the other direction in a hydrogen-powered Volkswagen minibus, which also has a mass M. Jack, socially chatting on his i-Phone to Elizabeth May about the upcoming election, fails to notice Stephen Harper's vehicle coming towards him, and the two vehicles collide head on and stick together. What is the mass and velocity of the resulting wreckage?

For this problem, you may find it useful to use the result that

$$E^2 - p^2c^2 = m^2c^4$$

This is easy to check based on the formulae for E *and* $\vec{p}$*. This gives the energy of an object in terms of its mass and momentum, or alternatively, its mass in terms of energy and momentum.*