Physics 200 Problem Set 4

Problem 1

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 mass $200 MeV/c^2$. At what speed (relative to c) do the lighter particles travel away?

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 plain donut of mass M is traveling in the $+\hat{x}$ direction at speed $\frac{3}{5}c$ while a chocolate donut of mass M is traveling in the $-\hat{x}$ direction with speed $\frac{4}{5}c$. If the two donuts collide inelastically and stick together, what is the mass and velocity of the resulting dessert?

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.*

Problem 4

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.

Problem 5

a) Hubble's Law in astronomy states that due to the expansion of the universe, objects at a distance D from our galaxy appear on average to be moving away from us at a velocity

$$v = H_0 D$$

where $H_0 = c/(1.38 \times 10^{10} lyr)$ is Hubble's constant. Astronomers spot a distant cluster of galaxies of a type that emits light with a peak wavelength of 500nm. For these galaxies, the peak wavelength that they observe is actually 1000nm. How far away is this cluster of galaxies (assuming they are moving directly away from us)?

b) By approximately how much does the peak wavelength of light we observe from the Sun differ from the actual peak wavelength of the emitted sunlight due to the relative motion of the Sun and the Earth?