Science One Physics Problem Set 7

Problem 1

The energy produced by the Sun comes from *nuclear fusion reactions*, in which lighter elements fuse together into heavier elements (in contrast to the fission reactions on which nuclear reactors operate). Much research has gone into developing nuclear fusion power, since the potential for accidents and runaway reactions is much less. The simplest fusion reaction involves two isotopes of Hydrogen (deuterium, with 1 proton and 1 electron, and tritium, with one proton and two neutrons).

$$^2H + ^3H \rightarrow ^4He + n \ .$$

The masses here are:

$$^2H : 2.0141amu, \;\; ^3H : 3.0161amu, \;\; ^4He : 4.0026amu, \;\; n : 1.0087amu$$

where $1amu = 1.661 \times 10^{-27}kg$. The total yearly energy consumption from electrical power in Canada is around $2 \times 10^{18}J$. If we want to produce this amount of energy using fusion power, what mass of deuterium would we need?

Problem 2

After a successful career as a particle physicist, Abigail moves to a small town in the country and opens up a cafe / particle accelerator called Abby's Particles 'n More. One foggy morning, after fixing several cappuccinos and a double espresso, Abby collides an electron and a positron at relativistic speeds. In the collision, a new unstable particle is created with a mass of $500MeV/c^2$. The particle is initially at rest and decays into two other particles, each with mass $200MeV/c^2$. 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 $MeV = 10^6eV$). For example, the mass energy of an electron is $m_ec^2 = 0.511MeV$.

Problem 3

A proton (mass M) from space with speed $v = 4/5c$ collides with a stationary proton in the upper atmosphere. As a result of the collision, the protons annihilate, leaving a stationary Q^{++} particle (mass $4/9M$) and a meson (an unstable particle with mass m) which travels directly towards the Earth's surface. If the collision happens $100km$ above the Earth's surface and the half-life of the meson is $\tau = 8.8910^{-5}s$, what are the chances that the meson will reach the surface of the Earth before decaying? What is the mass of the meson?

(Note: the half life τ is defined so that for a particle at rest, the chance of that the particle hasn't decayed is 1/2 after time τ, 1/4 after time 2 τ?, 1/8 after time 3τ?, etc)