

# Physics 216: Problem Set 4

*Due Thursday, Feb 26, 2004*

1. A particle of mass  $m$  is moving in the  $x$  direction. It is acted on by a 4-force  $\vec{F}$  whose  $y$  and  $z$  components are zero, and whose  $x$  component is a constant,  $F_x$ . The particle starts at  $t = 0$  with  $x = 0$  and  $dx/dt = 0$ . Compute the subsequent motion of the particle. Does the speed of the particle ever exceed the speed of light?
2. (K & K problem 13.1) Cosmic rays consist of protons that have been accelerated to very high velocities. The highest energies such protons can have are of order  $10^{13}$  MeV, almost  $10^8$  times larger than the highest energies that can be achieved with particle accelerators used in particle physics experiments. Our Galaxy has a diameter of about  $10^5$  light years. How long does it take such a cosmic ray proton to traverse the Galaxy, as measured in its own rest frame? [1 eV =  $1.6 \times 10^{-19}$  J, and the mass of a proton is  $m_p = 1.67 \times 10^{-27}$  kg.]
3. A star in a distant galaxy emits a photon of light of energy 1 eV as measured in the rest frame of that galaxy. The galaxy is moving away from our Galaxy at 10 percent of the speed of light. Using a Lorentz transformation, compute the energy and momentum of the photon as detected by observers on the Earth.
4. (K & K problem 13.5) A particle of rest mass  $m$  and speed  $v$  collides and sticks to a stationary particle of mass  $M$ . What is the final speed of the composite particle?
5. A moving particle is seen to decay into two  $\pi$  mesons, which are short lived particles that have a rest mass of  $135 \text{ GeV}/c^2$ . One  $\pi$  meson has a momentum of  $656 \text{ MeV}/c$  and makes an angle of 18.32 degrees with the direction of travel of the decaying particle. The other has a momentum of  $940 \text{ MeV}/c$  and makes an angle of 12.36 degrees. Calculate the mass of the particle that decayed.
6. A  $\pi^0$  meson (whose rest mass is  $135 \text{ MeV}/c^2$ ) decays into two photons.
  - a. Find the energies of the two photons if the  $\pi^0$  is at rest when it decays.
  - b. Suppose that the  $\pi^0$  has an energy of 1 GeV in the lab frame at the time when it decays. Find the energies of the two photons in the lab frame, if one of the photons emerges in the direction in which the  $\pi^0$  was travelling.
  - c. Suppose that the  $\pi^0$  has energy of 1 GeV in the lab frame, and that the photons emerge at equal angles with respect to the  $\pi^0$  direction. Find the photon energies.