Physics 322 Problem Set #2
(Kinematics in Special Relativity)

Due Friday, January 30 at 4:00 pm

ASSUMED READING: Before starting this homework, you should read Chapter 1 and Chapter 2.6 through 2.10 (you can skim the sections on General Relativity) of Harris' *Modern Physics*.

HINT: Most of these problems involve extended algebra. If you are doing a page of algebra, you may be on the wrong track. Problems 5 and 8b may require a bit more algebra.

SCORING: There are 60 points possible on this Problem Set. Scoring per problem is indicated.

1. **[Harris 2.10] (5 points)** A relativity enthusiast says, "If $E=mc^2$ and energy is conserved, then mass is conserved." How do you answer?

2. **[Harris 2.12 tweaked] (5 points)** Can two moving objects of mass 2 and 3 (in arbitrary units) stick together and form a single object of mass less than 5 (in the same arbitrary units)? Explain your reasoning.

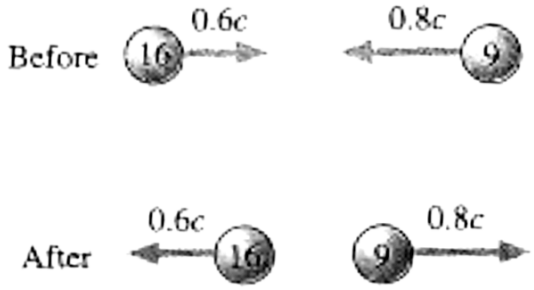
3. **[Harris 2.69] (5 points)** What is the ratio of the relativistically correct expression for momentum to the classical expression? Under what conditions does the deviation become significant?

4. **[Harris 2.62] (5 points)** In a particle collider experiment, particle 1 is moving to the right at 0.99*c* and particle 2 is moving to the left at 0.99*c*, both relative to the laboratory. What is the relative velocity of the two particles according to (an observing moving with) particle 2?

5. **[Harris 2.64 tweaked] (10 points)** A light beam moves at an angle θ with the *x*-axis as seen from frame *S*. Using the relativistic velocity transformation, find the components of its velocity when viewed from frame *S'* (which is moving in the direction of the *x*-axis relative to the *S* frame). From these, verify explicitly that its speed is *c*. **HINT:** The solution to this involves a bit more algebra than the other problems and could exploit the trigonometric identity $\cos^2\theta + \sin^2\theta = 1$.

6. **[Harris 2.79 tweaked] (10 points)** At Earth's location, the intensity of Sunlight is 1.5 kW/m^2. Assuming Earth is spherical with a radius of 6370 km and no energy escaped Earth, by how much would Earth's mass increase in 1 day?

7. **[Harris 2.76] (10 points)** In the collision shown, energy is conserved, because both objects have the same speed and mass after as before the collision (since this copy of the image may be unclear, the particle on the left has a mass of 16 before and after the collision, the particle on the right has a mass of 9 before and after the collision). Since the collision merely reverses the velocities, the final (total) momentum is opposite the initial. Thus, momentum can be conserved only if it is zero.



   a. Using the relativistically correct expression for momentum, show that the total momentum is zero – that momentum is conserved. (Masses are in arbitrary units).
   b. Using the relativistic velocity transformation, find the four velocities in a frame moving to the right at 0.6*c*.
   c. Verify that momentum is conserved in the new frame.

8. **[Harris 2.94] (10 points)** A kaon (denoted K^0) is an unstable particle of mass 8.87×10^{-28} kg. One of the means by which it decays is by spontaneous creation of two pions, a π^+ and a π^-. The decay process may be represented as

   $K^0 \rightarrow \pi^+ + \pi^-$.

   Both the π^+ and a π^- have mass 2.49×10^{-28} kg. Suppose that a kaon moving in the $+x$ direction decays by this process, with the π^+ moving off at speed 0.9*c* and the π^- at 0.8*c*.
   a. What was the speed of the kaon before the decay?
   b. In what directions do the pions move after the decay? **HINT:** Use momentum conservation and remember momentum is a vector. **HINT #2:** Unless you are very, very good at keeping track of all the variables, I would suggest insert all the known values into your momentum equations and reduce everything to just numbers.
      [You will get full credit if you outline how you would arrive at the solution to part (b). Successful completion of part (b) will result in +6 extra credit points, that's 10% of the homework total.]