Name ________________

Test 1
September 19, 2005

This test consists of three parts. Please note that in parts II and III, you can skip one question of those offered.

Possibly useful formulas:

$$f = \frac{f_0}{\gamma\left(1 - v\cos\theta/c\right)}$$

$$p'_x = \gamma\left(p_x - vE/c^2\right)$$
$$E' = \gamma\left(E - vp_x\right)$$
$$p'_y = p_y$$
$$p'_z = p_z$$

$$u'_x = \frac{u_x - v}{1 - vu_x/c^2}$$
$$u'_y = \frac{u_y}{\gamma\left(1 - vu_x/c^2\right)}$$
$$u'_z = \frac{u_z}{\gamma\left(1 - vu_x/c^2\right)}$$

$$p = qRB$$

$$\left(1+\varepsilon\right)^n = 1 + n\varepsilon + \tfrac{1}{2}n\left(n-1\right)\varepsilon^2 + \cdots$$

Part I:
Multiple Choice [20 points]
For each question, choose the best answer (2 points each)

1. Which of the following would be the best description of Lorentz contraction; that is, why a moving rod has a different length than a stationary one?
   A) The tremendous force of acceleration causes the rod to be compressed and shrink in space
   B) The mass of the rod decreases, and since it has less mass, it is smaller
   C) Some of the length of the rod was "consumed" by the acceleration process
   D) The rod is filled with particles of light, which slow down at high velocities, making the rod shorter
   E) Motion is like a tilting in space-time, and when you tilt a rod, its apparent length changes

2. In conventional physics, if here and now is $t = 0$, the "past" is any point in space-time with $t < 0$. In special relativity, it is useful to define the "past" (or "absolute past") as:
   A) Any point with $t > 0$
   B) Any point with $t = 0$
   C) Any point with $t < 0$ and spacelike separated from you
   D) Any point with $t < 0$ and timelike separated from you
   E) There is no sensible definition of "past" in special relativity

3. Momentum is a vector with three components in three-dimensional space. In special relativity, vectors have four components, and the fourth component of momentum is
   A) Energy B) Time C) Mass D) Force E) Work

4. Many of the equations of Newtonian mechanics are wrong, but the discrepancies weren't noticed until (relatively) modern times because
   A) Most experiments involve velocities much slower than the speed of light
   B) The equations are almost exactly identical, no matter what the speed of the objects
   C) Energy comes in so many forms that they didn't understand it could be in the form of mass
   D) Equipment used for measurements in the 19th century was so poor that even large discrepancies could not be detected
   E) The Bible implicitly assumes the equations of Newtonian mechanics, and people hesitated to challenge its authority

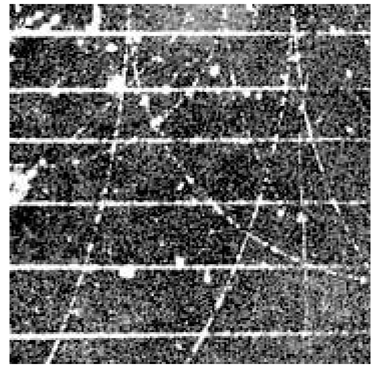
5. Which of the following is true about the momentum and energy of a particle of mass m?
   A) The momentum and energy can never exceed mc and mc^2 respectively
   B) The momentum can exceed mc, but the energy can never exceed mc^2.
   C) The energy can exceed mc^2, but the momentum can never exceed mc
   D) The momentum and energy can exceed mc and mc^2 respectively
   E) The energy is always exactly equal to mc^2

6. Suppose I take some object, and add some energy to it. Which types of energy will cause a change in the object's mass m (also known as rest-mass)
   A) Any type of energy, including potential or kinetic energy
   B) Potential energy, like nuclear, chemical or mechanical energy, but not kinetic energy
   C) Nuclear or chemical energy, but not mechanical energy
   D) Nuclear energy, but not chemical or mechanical energy
   E) No type of energy changes an object's rest-mass

7. Below are five equations from introductory physics. Which one is correct, according to special relativity?
   A) $E_{\text{kin}} = \frac{1}{2} mv^2$
   B) $p = mv$
   C) $W = Fd$
   D) $F = ma$
   E) All of them are incorrect

8. According to special relativity, when is energy conserved in an interaction?
   A) Energy is never, or almost never, conserved
   B) Energy is only conserved in elastic collisions, not inelastic ones
   C) Energy is only conserved when no matter is created/destroyed, in accordance with the formula $E = mc^2$
   D) Energy is always conserved in one reference frame; in other reference frames, it will generally not be conserved
   E) Energy is always conserved

9. At right is a picture of a bubble chamber. The curved white lines represent the circular paths of particles through the bubble chamber. (I don't know what the straight white lines are). What is a likely explanation for why the particle tracks are curved?
   A) There's probably an electric field present
   B) There's probably a magnetic field present
   C) The particles are probably scattering off molecules in the bubble chamber, changing their direction
   D) Relativity is making straight lines look curved
   E) They are probably in giant atoms, orbiting their nucleus

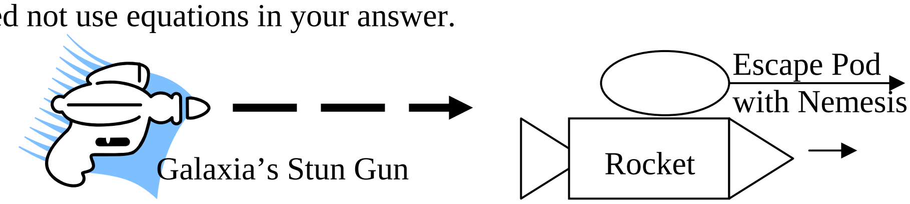


10. Which of the following is <u>not</u> a prediction of special relativity?
   A) No perfectly rigid objects can actually exist
   B) Light in vacuum always moves at the speed *c* according to all observers, even if those observers are moving
   C) An object moving at very high velocities will seem, to us, to have time slow down
   D) Two observers will disagree on whether two events were simultaneous or not
   E) Actually, all of these <u>are</u> predictions of special relativity

Part II: Short answer [20 points]

Choose **two** of the following questions and give a short answer (1-3 sentences) (10 points each).

11. The evil villain Nemesis is being chased by the brave Galaxia. Nemesis is traveling in his space ship at $v = 2\times10^8$ m/s, when he turns and sees Galaxia, behind him, about to fire a stun beam, which travels at *c*, the speed of light. Nemesis climbs aboard his escape pod, which is fired from his ship at $v = 1.5\times10^8$ m/s. Nemesis reasons that since the ship speed plus escape pod speed is 3.5×10^8 m/s, he can outrun Galaxia's stun beam. Is he correct? Explain explicitly where he went wrong, if anywhere. You need not use equations in your answer.



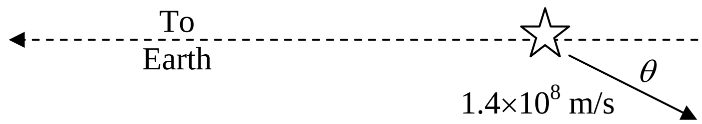
12. Explain how massive particles, massless particles, and tachyons behave (particularly their velocity), and explain which of these particles are observed in nature, giving at least one example (if they exist).

13. At right is the official logo of the 2005 Year of Physics. What is that funny thing that looks like an hourglass? Explain in some detail what information it is intended to convey.

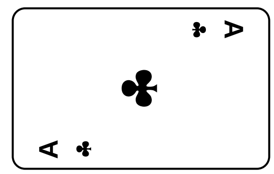
Part III: Calculation: [60 points]

Choose **three** of the following four questions and perform the indicated calculations (20 points each)

14. A distant star is moving at a speed of 1.4×10^8 m/s at an unknown angle compared to the Earth. There is a spectral line of the star, which normally has a frequency of 2.468×10^{15} Hz, but it is observed at Earth to have a frequency of 3.218×10^{15} Hz. What is the angle θ compared to the line of sight at which the distant star is moving?



15. A standard playing card is about 8.9 cm × 5.7 cm (3½ in × 2¼ in) in size. A card thrower attempts to throw the card in such a way that to a stationary observer, it appears square.



   (a) How fast would the card have to be moving to look square?
   (b) Which direction would it have to be thrown?
   (c) According to an observer moving along with the card, what would the dimensions of the card be?
   (d) The card contains a timed explosive, designed to go off one second after it explodes (1 s in the card's frame of reference). How long, according to a stationary observer, after it is thrown does the card explode?

16. Some people say that exercise can keep you young. Maybe it's true! A runner starts at birth and sprints consistently at v = 10 m/s (no bathroom breaks) for 70 years (1 year = 3.155×10^7 s).
   (a) Ignoring physiological effects, after 70 years as measured by a stationery observer, will the runner seem younger, older, or exactly the same (assume the effects are noticeable, no matter how small they are).
   (b) After precisely 70 years, how much older or younger is the runner than a stationary observer?
   (c) If the runner is carrying a (very accurate) watch while he is running, after 70 years on the watch, will the runner be older, younger, or exactly 70 years old?

17. A stationary charged pion decays into a muon (mass m_μ = 105.7 MeV/c^2) with velocity v = 0.271c and a massless neutrino (mass m_ν = 0).

$$\pi^+ \rightarrow \mu^+ + \nu$$

   (a) What is the momentum and energy of the muon?
   (b) Using conservation of momentum, what is the momentum of the neutrino? What is its energy?
   (c) What is the energy, momentum, and mass of the original pion? Hint: At least one of these is trivial.