Test 1 Name _____
September 18, 2020

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

Part I: Multiple Choice [20 points]
For each question, choose the best answer (2 points each). Your test will have had these questions in a random order.

2. In relativity, vectors should have four components. What is the fourth component of the momentum vector?
   A) Space B) Time C) Energy D) Mass E) Proper time

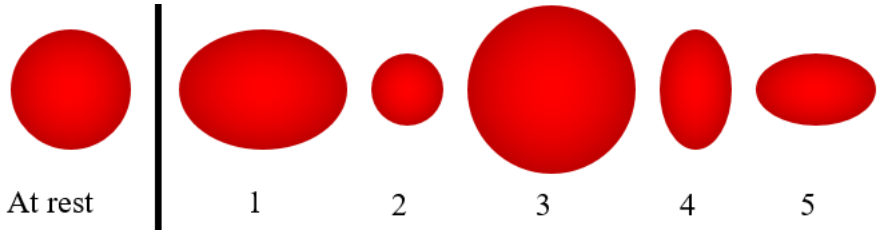
3. Below is a four step proof that $\vec{F} = m\vec{a}$. Which step, if any, is wrong?
   A) $\vec{F} = \frac{d\vec{p}}{dt}$
   B) $\frac{d\vec{p}}{dt} = \frac{d}{dt}\left(m\vec{v}\right)$
   C) $\frac{d}{dt}\left(m\vec{v}\right) = m\frac{d\vec{v}}{dt}$
   D) $m\frac{d\vec{v}}{dt} = m\vec{a}$
   E) None of these are wrong

4. Suppose we took an uncompressed spring of mass m and then compressed it. What effect would this have on the mass?
   A) It would decrease a lot
   B) It would decrease a little
   C) It would stay the same
   D) It would increase a little
   E) It would increase a lot

5. As a particle of mass m approaches the speed of light, the momentum approaches _____ and the kinetic energy approaches _____ .
   A) $mc, \frac{1}{2}mc^2$ B) mc, mc^2 C) mc, ∞ D) ∞, mc^2 E) ∞, ∞

6. Which of the following is **not** a prediction of special relativity?
   A) The speed of light will look different to different observers.
   B) There are no rigid objects
   C) Which of two events occurs first may be disagreed on by two observers
   D) Putting internal energy into an object increases its mass
   E) Moving clocks, according to a stationary observer, run more slowly.

7. Suppose the image below left represents an object at rest. Which of the other images could represent the same objects moving to the right at high velocity?
   A) 1 B) 2 C) 3 D) 4 E) 5



8. In a particle collider, the particles are kept in a circular track by placing _____ fields on them that are _____ to the direction of motion.
   A) Magnetic, parallel
   B) Magnetic, perpendicular
   C) Electric, parallel
   D) Electric, perpendicular
   E) Gravitational, parallel

9. The speed of light in vacuum as measured by a moving observer depends on which of the following?
   A) The speed of the source towards or away from you (only)
   B) The speed of the source lateral to you (only)
   C) The speed of the observer (only)
   D) All three of the above
   E) None of the above

10. Suppose two observers both start at event *A* and end at event *B*. Observer 1 moved at constant velocity, while observer 2 accelerated. Which one will have experienced more proper time?
   A) Observer 1
   B) Observer 2
   C) They will experience the same amount of time
   D) Insufficient information
   E) I have no idea; please mark this one wrong

11. According to relativity, if an object moving very close to the speed of light is emitting light, which direction does most of that light go, as viewed in a frame not moving with the object?
   A) About equal in all directions
   B) Backwards (only)
   C) Forwards (only)
   D) Perpendicular to the direction of motion
   E) Forwards and backwards, but not sideways

Part II: Short essay [20 points]

Choose two of the following three questions, and write a short essay (2-3 sentences). You may type both answers into the answer box at the end, or you may upload your answers as an image into the box. Each question is worth 10 points.

12A. Suppose two identical spaceships fly past each other. You can tell which one is actually moving by seeing which of their clocks is running slower. Comment on this statement.

12B. Since which of two events happens first is ambiguous in relativity, is it possible that according to some observers, you finished this test even before you started it? Explain your reasoning.

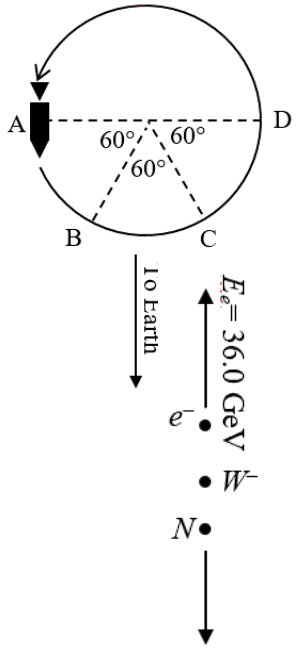
12C. If you have a container filled with gas and you heat it, the mass of each molecule does not change, they just move (on the average) faster. How, then, can the mass of the total change when you heat it? Or does it change?

Part III: Calculation: [60 points]

Choose three of the following four questions. Each question is worth 20 points. Type only your answers to each part into the essay box provided.

13. A group of 48,000 ^{216}Po atoms are accelerated to high speed and sent in a circular path circling the Earth (radius = 6370 km), such that they circle it in 0.230 s.
    a) What is the velocity of these atoms? What is the Lorentz factor γ?
    b) It is found that only 19,600 of them remain after circling the Earth once. This is because they radioactively decay, with the probability of survival given by $P = e^{-\lambda\tau}$, where τ is the proper time and λ is the decay constant. What is λ in units of s^{-1}?

14. A cylindrical spaceship of length 260. m and diameter 22.0 m is moving in a circular orbit at $v = 0.800c$.
    a) What is the Lorentz factor γ? What would be the apparent dimensions of the spaceship as viewed by a non-moving observer?
    b) The spaceship sends a signal to Earth every one-sixth of a cycle around its orbit at a frequency of 225 MHz. What is the frequency of the received signal coming from points *A*, *B*, *C*, and *D*?



16. A W^- particle at rest ($m_W = 80.4$ GeV/c^2) decays to a nearly massless electron moving up with energy 36.0 GeV ($m_e \approx 0$), and a massive neutrino *N* moving down.
    a) Find the energy (in GeV) and momentum (in GeV/c) of the *N*.
    b) Find the mass (in GeV/c^2) and speed (as a fraction of *c*) of the *N*.

17. A nanobot is launched from rest to explore the stars! It has a mass of $m = 1.62\times10^{-9}$ kg, and is intended to travel to the stars at a speed of $v = 2.10\times10^{8}$ m/s. It will be accelerated electromagnetically with a force *F* = 13.75 N.
    a) What are the initial and final momentum of the nanobot? What are the initial and final energy of the nanobot?
    b) How long will it take to accelerate the nanobot to this speed?