

Test 1 Name _____
September 15, 2021

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:

$x' = \gamma(x - vt)$	$E' = \gamma(E - vp_x)$	$u'_x = \frac{u_x - v}{1 - vu_x/c^2}$	$f = \frac{f_0}{\gamma(1 - v \cos \theta/c)}$
$t' = \gamma(t - vx/c^2)$	$p'_x = \gamma(p_x - vE/c^2)$	$u'_y = \frac{u_y}{\gamma(1 - vu_x/c^2)}$	$e = 1.602 \times 10^{-19} \text{ C}$ $eV = 1.602 \times 10^{-19} \text{ J}$ $y = 3.156 \times 10^7 \text{ s}$ $ly = 9.461 \times 10^{15} \text{ m}$
$y' = y, \quad z' = z$	$p'_y = p_y, \quad p'_z = p_z$	$u'_z = \frac{u_z}{\gamma(1 - vu_x/c^2)}$	
$\vec{F} = q\vec{E} + q\vec{u} \times \vec{B}$	$\frac{\vec{u}}{c} = \frac{\vec{p}c}{E}$		
$p = qRB$			

Part I: Multiple Choice [20 points]

For each question, choose the best answer (2 points each)

1. If two meter sticks are moving past each other in the direction of length, which one will be shorter?
 - A) The one that is actually moving is shorter
 - B) The one that is actually stationary is shorter
 - C) Each will claim that the other meter stick is shorter
 - D) Each will claim that the other meter stick is longer
 - E) Since both are meter sticks, they will be the same

2. If one person travels at high velocity to a distant star and returns, and another stays on Earth the whole time, when they are reunited which one will apparently be older?
 - A) They will be the same age
 - B) The one who travels is older
 - C) The one on Earth is older
 - D) It depends on whether the person who traveled went in a straight line or not
 - E) I have no idea; please mark this one wrong

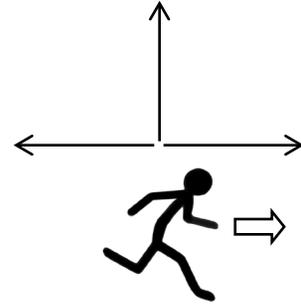
3. At some point you received a letter indicating you were admitted to Wake Forest, and now you are here. How does the receipt of that letter compare to here and now?
 - A) It was in the absolute past
 - B) It was on the past light cone
 - C) It is in the past according to us, but another observer might say it was in the future
 - D) It was in the absolute future
 - E) Insufficient information

4. If a particle had a negative mass squared (a tachyon), what property would it also have?
- It would always have negative energy
 - It would always travel faster than light
 - It would have zero size
 - It would exist only at one moment in time
 - It would have an imaginary velocity
5. A mass spectrometer has causes particles to move in a circle. How is this managed?
- Constant magnetic fields
 - Constant electric fields
 - Oscillating magnetic fields
 - Oscillating electric fields
 - Circular wave guides
6. In the limit that the velocity of a massive object approaches the speed of light, the energy will approach _____ and the momentum will approach _____ .
- mc^2, mc
 - $\frac{1}{2}mc^2, mc$
 - mc^2, ∞
 - ∞, mc
 - ∞, ∞
7. Which type(s) of energy, when added to an object, will increase its mass?
- Nuclear energy (only)
 - Chemical energy (only)
 - Heat energy (only)
 - All of the above
 - None of the above
8. Since space-time is four dimensional, momentum should have a fourth component. What is the fourth component of momentum?
- Mass
 - Time
 - Distance
 - Velocity
 - Energy
9. There were four transformations that we described as “good” in class: space translation, time translation, rotation, and Lorentz boost. What distinguishes these transformations from “bad” ones like the Galilean boost or the rescaling transformation?
- They were experimentally observed to be correct before Einstein
 - They preserve the four-dimensional distance formula
 - Objects moving at constant velocity will still be at constant velocity
 - They lead to the correct formulas for momentum in relativity
 - They take into account that moving objects have more energy
10. Which of the following formulas is still valid in special relativity, without modification?
- $E_{kin} = \frac{1}{2}mv^2$
 - $F = ma$
 - $p = mv$
 - $W = Fd$
 - $F = \frac{d}{dt}(mv)$

Part II: Short answer [20 points]

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

11. Three light beams are moving to the right, up, and to the left, each with velocity c . According to an observer moving to the right at $0.5c$, which, if any, of the three light beams will appear to move faster than c , and which slower than c ?



12. In a variation of the barn-pole paradox, a runner runs completely through the barn (in the front, out the back). The runner claims both ends of the pole simultaneously sticks out of the barn, while the farmer claims both ends of the pole are simultaneously inside the barn. Explain how special relativity helps resolve this apparent paradox.
13. Neutral hydrogen atoms are detected by their radiation from the hyperfine splitting with a natural frequency of $f = 1420.4$ MHz; however, the frequency detected is often lower or higher than this frequency. Explain how the frequency shifts if the hydrogen cloud is moving (i) towards us, (ii) away from us, or (iii) perpendicular to our line of sight. If two of them are affected the same way, make clear which of them is the larger effect (for fixed speed).

Part III: Calculation: [60 points]

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

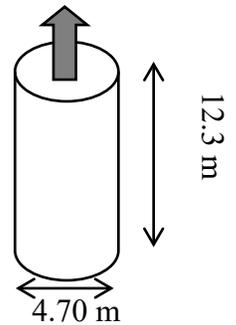
14. Consider three events in space-time with coordinates (x, y, z, ct) given by

$$A = (0, 0, 0, 0) \text{ m}; \quad B = (2, 2, 0, 3) \text{ m}; \quad C = (3, 4, 0, 5) \text{ m}.$$

For each of the pairs listed below, determine whether the separation is timelike, spacelike, or lightlike, and when appropriate, determine which is in the past/future of the other (absolute past/future, or past/future light cone). If the separation is not lightlike, also find either the proper distance s or the proper time $c\tau$ in meters.

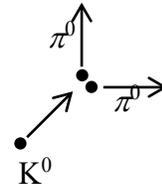
- (a) A with B (b) A with C (c) B with C

15. Travelers board a cylindrical spacecraft which is 12.3 m long in the direction it is moving and 4.70 m in diameter in the perpendicular direction. The spacecraft is traveling to the star Sirius which is 8.61 ly ($= 8.61 c \cdot y$) away. They will travel at $v = 2.18 \times 10^8$ m/s



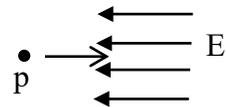
- (a) What are the dimensions of the spacecraft as viewed by us?
 (b) How long in years will it take to get there according to us?
 (c) How long in years will it take to get there according to the occupants?
 (d) If the total spacecraft has a mass of 5430 kg, what is the kinetic energy of the spacecraft in J?

16. A K^0 meson decays to two pions with mass $m_\pi = 135.0 \text{ MeV}/c^2$, one of which goes to the right and one of which goes straight up, both at a speed of $u = 0.9078c$.



- (a) What is the energy of each of the pions (in MeV)?
 (b) What is the momentum of each of the pions (in MeV/c)?
 (c) What is the energy and momentum of the K^0 before it decays?
 (d) What is the mass of the K^0 (in MeV/c^2)?

17. A proton of mass $m = 938 \text{ MeV}/c^2$ and charge $+e = 1.602 \times 10^{-19} \text{ C}$ is moving to the right at a speed of $u = 0.468c$. It is being pushed to the left by a constant electric field of $E = 1.602 \times 10^6 \text{ V/m}$,



- (a) What is its initial momentum, in MeV/c ?
 (b) How long will it take to come to a stop, in s?
 (c) After the proton stops it will turn around and go the opposite direction. When it has returned to its starting point, what will be its velocity (direction and sign) be? (Hint: use the work formula). How long will it take to return to this point?