

The Special Theory of Relativity Problem Sets

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CHAPTER

1

The Special Theory of Relativity Problem Sets

1. What are the two postulates of special relativity?
2. What do Einstein's postulates say about relative and absolute motion?
3. Define the Lorentz factor mathematically.
4. You are sitting a spaceship traveling at $0.99c$ relative to the Earth while an exact copy of you is sitting in a classroom on planet Earth. Would there be a difference in your pulse rate compared to your copy on Earth and if so, which would be slower?
5. If two people are moving at the speed of light will each persons' measurement of time be the same or different?
6. If you are traveling at half the speed of light, will your measurement of time be larger or smaller than someone who measures time standing still?
7. A spaceship located 300 km from Earth emits a signal every 10 minutes. How many flashes will be received by a station located on Earth in an hour?
8. While walking through a completely dark room you let out a *meep* every 2 seconds as you approach your sleeping brother. As you get closer to your brother, does the spacing between the noise you make change?
9. A 1 m by 2 m board is being held up by a pedestrian as you drive by. At what speed would you have to be traveling for the board to appear to be of equal dimensions?
10. While at the airport you walk on the moving walkway at 3 m/s. If the walkway is moving at 5 m/s, what is your speed with respect to the ground?
11. While riding an elevator from the 1st to the 4th floor, you walk from one side of the elevator to the other at a speed of 0.5 m/s. What is your horizontal speed with respect to the ground?
12. What did the Michelson-Morley experiment disprove?
13. Three coordinate axes are used to describe 3-dimensional space. What is measured in the fourth dimension?
14. When time is dilated does that imply an event is longer or short?
15. Calculate the Lorentz factor for an object that is traveling at half the speed of light.
16. Determine the speed an object is moving at if its Lorentz factor is 1.33.
17. A person carrying a strobe light approaches you at $0.5c$, does the speed of light or the frequency of light change and how so?
18. Determine what the maximum value of the following expression: $\frac{v_1 v_2}{c^2}$.
19. You are traveling on the earth at 99.9% the speed of light.
 1. How long would a meter stick appear to be to someone at rest with respect to the earth?
 2. How long do you measure the meter stick to be?
20. What is the momentum of an object that is moving at the speed of light.
21. If you were in a sealed container traveling at a constant velocity, how could you tell the whether you were moving or sitting still?
22. While chasing a criminal across the top of a speeding train, you throw a bola at him to try and trip him. If you throw the bola towards the front of the train, is the bola moving faster or slower relative to the ground?
23. Two children play catch in the isle of an airplane. If the ball is thrown in the opposite direction that the plane is traveling, does the ball have a faster or slower velocity when viewed from the ground?
24. One twin leaves the earth and travels at a speed near the speed of light.
 1. When the twin returns, would his twin that stayed behind be younger or older? Explain.
 2. If one twin leaves the earth, is it possible for him to return to Earth before the twin that was left behind is born? Explain.
25. If you are traveling at a relativistic speed, what reference frames will detect a change in your rate of breathing? Explain.

26. A spaceship has a velocity of $0.85c$. If the ship sends out a probe that has half of that speed with respect to the spaceship, determine the probe's speed with respect to an outside observer.
27. While on a space freighter, you decide to take a 10-minute nap while the ship is traveling at $0.5c$. To an outside observer, how long is your nap?
28. An interplanetary transport ship is 500 m long.
 1. If it transports cargo at a speed of $0.7c$, what length does the ship have from a fixed point outside of it?
 2. What if the speed of the ship is $0.35c$?
29. Determine how many times bigger a 100 m object appears to an outside observer when it is traveling at 50% of the speed of light as opposed to 99%.
30. Explain the classical velocity addition formula.
31. 600 nm light originating from a distance galaxy is measured on Earth to be 1500 nm. At what speed is the galaxy moving from the Earth?
32. A beam of light is emitted in a reference frame that is moving with a speed c . What is the speed of the light in a reference frame that is not moving?
33. Determine the total energy of an electron that has a velocity of $0.7c$. (Hint: The rest mass is approximately 0.5 MeV)
34. Determine the magnitude of the momentum of an electron that has a velocity $0.85c$.
35. A proton has a total energy equal to 1000 MeV
 1. Calculate its velocity.
 2. Find its momentum.
36. Determine the initial momentum of a system that has two particles; one with a rest mass of $1 \text{ MeV}/c^2$ and a kinetic energy of 2 MeV and another particle with a rest mass of $3 \text{ MeV}/c^2$ that is stationary.
37. After a collision, a two particle system has an energy of 8 MeV and a momentum of $4.4 \text{ MeV}/c$. Determine the rest mass of the two particle system.
38. If your heart beat on Earth is 59 beats/min,
 1. what would your heart beat measure (by someone on the same craft) if you were traveling at $0.9c$?
 2. what would someone on earth measure your heart rate at?
39. Two particles that are moving towards one another have their speeds measured in the reference frame of the Earth. The velocity for particle A is $0.6c$ and the velocity for particle B is $-0.8c$. Determine the velocity of B with respect to A.
40. Compare the relativistic momentum and the classical momentum of an electron that has a velocity of $0.70c$.
41. Is the rest energy of a particle dependent or independent on the mass and momentum?
42. Calculate the rest energy of an electron in electron volts.
43. The total energy of a specific electron is twice its rest energy.
 1. How fast is the electron moving?
 2. Calculate its kinetic energy.
44. If Billy and Jimmy are both traveling at relativistic speeds, what two speed measurements will they both agree on?
45. A particle suddenly increases its speed by a factor of 4. What is the particle's momentum in terms of the original velocity?
46. Why is it considered not possible to accelerate a particle to the speed of light c ?
47. Do masses particles exists? If so, what are they?
48. At what speed does a clock move at half its rate in a rest frame?
49. If a meter stick is moving at 90% the speed of light, what length does it measure to an outside observer?
50.
 1. A physicist on Earth observes an alien ship approaching the Earth at a speed of $0.5c$. How long will it be before the ship reaches Earth if it is 15 light years away?
 2. How long will a 15 light year trip take for an observer on a spaceship traveling at $0.5c$?
51. A particle with a velocity of $0.9c$ decays into two smaller particles of equal and opposite charge after traveling 5000 m. Calculate the time that elapses in the particle's frame before it decays.

52. Determine the momentum of an electron that has a speed of $0.01\ c$.
53. How much energy is needed to accelerate an electron from rest to 85% the speed of light?
54. Give an example of the first postulate Einstein used to derive Special Relativity?
55. Under what conditions will you and a friend have the same frame of reference? When will you have different frames of reference?
56. If you were riding in a car that had perfect shocks, so there was no bouncing on the road, and the windows were dark so you couldn't see out of them, is there a way for you to know the difference between being at rest and being in motion at a constant speed? What about being at rest and being in an accelerated motion?
57. Jeanette is riding in a car and shoots a paintball gun forwards. Relative to an outside observer, does the paintball she fired have a faster or slower velocity than if she had fired while standing still outside of the car? What about the perspective of someone inside the car with her — do they perceive the paintball as flying faster, slower, or the same as if they were standing still with Jeanette outside of the car?
58. If 2 events, such as fireworks going off, occur in exactly the same place and time in a frame of reference, is there any way to have observers in other frames of reference see the fireworks going off in different places or at different times?
59. You learned in this chapter about the "Twin Paradox." Since you learned that a twin returning from a long trip will be younger than their earthbound counterpart, why is it not possible for the traveling twin to return before the earthbound twin was born?
60. When traveling close to the speed of light, objects and people along your direction of motion appear "shrunk", so that their length is less. How do you appear to the people you are watching? Explain.
61. Nuclear reactions produce a tremendous amount of energy. However, even after nuclear fission, there are still byproducts made of matter. In a matter-antimatter reaction, both the matter and antimatter are annihilated, leaving only energy. According to $E=mc^2$, how much energy does reaction between a kilogram of Uranium and a kilogram of anti-Uranium produce?
62. A starship is passing by Earth at 85% of the speed of light. The ship sends a shuttlecraft forward at 85% the speed of light relative to the starship. What is the shuttlecraft's speed relative to Earth?
63. A traveler on a long space trip hibernates for part of the journey while the ship carrying her is moving at 95% of the speed of light. If the traveler hibernates for one year in her time frame, how long does the sleep cycle last according to someone on a planet watching the ship travel?
64. Muons are particles produced when high energy radiation strikes the upper atmosphere. The muons decay in 2.2×10^{-6} seconds as measured from the muon's frame of reference.
 1. If the muon is moving at $0.995\ c$ relative to you standing still on Earth, what will you measure the lifetime of the muon to be?
 2. You are at rest and an second observer is traveling with a muon. Since there is a difference in times depending on the reference frame chosen, does the particle travel different distances? Explain.
65. A bobsled with children on it goes past you on very flat land at $0.80\ c$ (It's a very fast sled!). You measure the sled to be 2 meters long. What length does a child on the sled say it is?
66. Ted is standing by a freeway watching cars go by very quickly. Inside one of the cars, Pam turns on the car's overhead light, and then turns it off.
 1. Who can measure the proper interval between the turning on and turning off of the light?
 2. Who can measure the proper length of the car?
 3. Who can measure the proper length of a sign next to the highway?
67. When light of a single wavelength is coming from a source that moves toward an observer, such as a laser, the wavelength of light appears to become shorter than it would be otherwise. Does this contradict Einstein's postulate that the speed of light is the same for all observers? Why or why not?
68. An airplane flies overhead at $0.01\ c$. The pilot turns on a big sign on its side to advertise for 2 seconds, according to the spectators below. How long is the sign on according to the ship's pilot?
69. A pilot turns a big sign on his airplane on and off to advertise. Do the spectators or the pilot measure the proper time the sign is on?
70. Mary is measuring the length of a battle class cruiser as it flies past. She measures it to be 110 meters and

traveling at $0.75c$. She measures the length again later when the cruiser is docked in the hangar bay. What length does she measure it to be?

71. A meter stick is flying past you at close to the speed of light. You measure its length to be 40 centimeters. How fast is the meter stick moving relative to you?
72. As measured by someone on the deck of an aircraft carrier, the runway has a length of 7000 feet. A pilot overhead is flying a jet at Mach 2000 (343 meters per second times 2000).
 1. What length does the pilot measure the deck to be?
 2. An observer on the deck measures the time from when the jet passes the start of the runway to when the jet passes the end. How long does the observer say the trip took?
 3. How long does the pilot claim the trip took?
73. An observer in frame S' is moving to the right at a speed of $0.75c$ away from a stationary observer in frame S . The observer in S' measures the speed v' of a particle moving to the right away from her. What speed does the observer in S measure for the particle if $v' = 0.8c$?
74. Emily flies past Brian at $0.55c$. Both Emily and Brian start timers when the front of Emily's ship is above Brian. When Emily reads 7 seconds on her stopwatch, she flashes a bright light on the front of her spaceship. What is the time interval between the front of the spaceship passing overhead and the light coming on as measured by Brian?
75. Two particles at the Fermilab particle accelerator in Batavia, Illinois are about to collide head-on. Each particle has a speed of $0.96c$. Both particles travel at the same speed when measured in the frame of reference of the laboratory. What is the speed of the velocity of one particle relative to the other?
76. A box that had sides each with a length of 10 meters is moving at $0.8c$. What is the difference in the volume of the box as measured in the frame of the box and the frame of someone outside the frame of the box, watching it fly past?
77. A colony ship is sent to the planet Pandora, which is 50 light years from Earth. The soldiers on board the ship are 18 when they begin the journey at $0.925c$. What is the biological age of the soldiers when they reach Pandora?
78. A person traveling in a high speed car could reach speeds of 90 m/s (over 200 mph). How much is the relativistic momentum differ from the classical momentum? (Hint: Determine $(\text{rel-pclas})/mv$)
79. Scott throws a javelin at $0.7c$. The javelin, when at rest, is 2 meters long. How long does the javelin appear to be to a spectator in the crowd?
80. Two travelers leave to colonize a new planet moving at different speeds. Mirella moves at $0.9c$, and Sam moves at $0.75c$. If the planet is 15 light years away, how much difference is there in the age of the travelers when Sam arrives on the planet, assuming they were the same age when they left?