PROBLEMS

SECTIONS 26–5 AND 26–6

1. (I) A beam of a certain type of elementary particle travels at a speed of 2.80×10^8 m/s. At this speed, the average lifetime is measured to be 1.80×10^{-6} s. What is the particle's lifetime at rest?

2. (I) What is the speed of a beam of pions if their average lifetime is measured to be 3.5×10^{-8} s? At rest, their lifetime is 2.6×10^{-8} s.

3. (I) A spaceship passes you at a speed of $0.90c$. You measure its length to be 80 m. How long would it be when at rest?

4. (I) You are sitting in your car when a very fast sports car passes you at a speed of $0.28c$. A person in that car says his car is 6.00 m long and yours is 6.15 m long. What do you measure for these two lengths?

5. (I) Suppose you decide to travel to a star 75 light-years away. How fast would you have to travel so the distance would be only 20 light-years?

6. (I) If you were to travel to a star 60 light-years from earth at a speed of 2.3×10^8 m/s, what would you measure this distance to be?

7. (II) A certain star is 45.0 light-years away. How long would it take a spacecraft traveling $0.970c$ to reach that star from earth, as measured by observers: (*a*) on earth: (*b*) on the spacecraft? (*c*) What is the distance traveled according to observers on the spacecraft? (*d*) What will the spacecraft occupants compute their speed to be from the results of (*b*) and (*c*)?

8. (II) A friend of yours travels by you in her fast sports vehicle at a speed of $0.660c$. It appears to be 5.80 m long and 1.20 m high. (*a*) What will be its length and height at rest? (*b*) How many seconds did you see elapse on your friend's watch when 20.0 s passed on yours? (*c*) How fast did you appear to be traveling to your friend? (*d*) How many seconds did she see elapse on your watch when she saw 20.0 s pass on hers?

9. (III) How fast must a pion be moving to travel 15 m before it decays? The average lifetime, at rest, is 2.6×10^{-8} s.

SECTION 26–8

10. (I) What is the mass of a proton traveling at $v = 0.90\,c$?

11. (I) At what speed will an object's mass be twice its rest mass?

12. (II) At what speed v will the mass of an object be 1 percent greater than its rest mass?

13. (II) Escape velocity from the earth is 40,000 km/h. What would be the percent increase in mass of a 5.5×10^5-kg spacecraft traveling at that speed?

14. (II) (*a*) What is the speed of an electron whose mass is 10,000 times its rest mass? Such speeds are reached in the Stanford Linear Accelerator, SLAC. (*b*) If the electrons travel in the lab through a tube 3.0 km long (as at SLAC), how long is this tube in the electrons' reference frame?

SECTION 26–10

15. (I) How much energy can be obtained from conversion of 1.0 mg of mass? How much mass could this energy raise to a height of 100 m?

16. (I) What is the kinetic energy of an electron whose mass is 3.0 times its rest mass?

17. (I) A certain chemical reaction requires 5.86×10^4 J of energy input for it to go. What is the increase in mass of the products over the reactants?

18. (II) Calculate the rest energy of an electron in joules and in MeV (1 MeV $= 1.60 \times 10^{-13}$ J).

19. (II) Calculate the rest energy of a proton in MeV.

20. (II) (*a*) By how much does the mass of the earth increase each year as a result solely of the sunlight reaching it? (*b*) How much mass does the sun lose per year? (Radiation from the sun reaches the earth at a rate of about 1400 W/m^2 of area perpendicular to the energy flow.)

21. (II) Calculate the kinetic energy and momentum of a proton traveling 9.2×10^7 m/s.

22. (II) What is the momentum of a 500-MeV proton (that is, one with KE = 500 MeV)?

23. (II) What is the speed of a proton accelerated by a potential difference of 250 MV?

24. (II) What is the speed of an electron whose KE is 1.00 MeV?

25. (II) What is the mass and speed of an electron that has been accelerated by a voltage of 200 kV?

26. (II) Calculate the mass of a proton ($m_0 = 1.67 \times 10^{-27}$ kg) whose kinetic energy is half its total energy. How fast is it traveling?

27. (II) Suppose a spacecraft of rest mass 30,000 kg is accelerated to $0.18c$. (*a*) How much kinetic energy would it have? (*b*) If you used the classical formula for KE, by what percentage would you be in error?

28. (II) Calculate the kinetic energy and momentum of a proton ($m_0 = 1.67 \times 10^{-27}$ kg) traveling 9.5×10^7 m/s. By what percentages would your calculations have been in error if you had used classical formulas?

29. (II) What is the speed and momentum of an electron ($m_0 = 9.11 \times 10^{-31}$ kg) whose kinetic energy is half its rest energy?

30. (II) An electron ($m_0 = 9.11 \times 10^{-31}$ kg) is accelerated from rest to speed v by a conservative force. In this process, its potential energy decreases by 5.60×10^{-14} J. Determine the electron's speed, v.

31. (II) Make a graph of the kinetic energy versus momentum for (*a*) a particle of nonzero rest mass, and (*b*) a particle with zero rest mass.

32. (II) What magnetic field intensity is needed to keep 400-GeV protons revolving in a circle of radius 1.0 km (at, say, the Fermilab synchrotron)? Use the relativistic mass. The proton's rest mass is 0.938 GeV/c^2. (1 GeV $= 10^9$ eV.)

33. (II) Show that the energy of a particle of charge e revolving in a circle of radius r in a magnetic field B is given by E (in eV) $= Brc$ in the relativistic limit ($v \approx c$).

34. (III) Show that the kinetic energy (KE) of a particle of rest mass m_0 is related to its momentum p by the equation $p = \sqrt{(\text{KE})^2 + 2(\text{KE})(m_0c^2)}/c$.

SECTION 26–11

35. (I) A person on a rocket traveling at $0.50c$ (with respect to the earth) observes a meteor come from behind and pass her at a speed she measures as $0.50c$. How fast is the meteor moving with respect to the earth?

36. (II) Two spaceships leave the earth in opposite directions, each with a speed of $0.50c$ with respect to the earth. (*a*) What is the velocity of spaceship 1 relative to spaceship 2? (*b*) What is the velocity of spaceship 2 relative to spaceship 1?

37. (II) A spaceship leaves earth traveling $0.75c$. A second spaceship leaves the first at a speed of $0.86c$ with respect to the first. Calculate the speed of the second ship with respect to earth if it is fired (*a*) in the same direction the first spaceship is already moving, (*b*) directly backward toward earth.

*SECTION 26–12

*38. (I) Suppose in Fig. 26–14 that the origins of S and S' overlap at $t = t' = 0$ and that S' moves at speed $v = 50$ m/s with respect to S. In S', a person is resting at a point whose coordinates are $x' = 15$ m, $y' = 10$ m, and $z' = 0$. Calculate this person's coordinates in $S(x, y, z)$ at (*a*) $t = 5.0$ s, and (*b*) $t = 10.0$ s. Use the Galilean transformation.

*39. (I) Repeat Problem 38 using the Lorentz transformation and a relative speed $v = 2.0 \times 10^8$ m/s, but calculate at time t' equals (*a*) 5.0 μs and (*b*) 10.0 μs.

*40. (II) In Problem 38, suppose that the person moves with a velocity whose components are $u'_x = u'_y = 30$ m/s. What will be his velocity with respect to S? (Give magnitude and direction.)

*41. (II) In Problem 39, suppose that the person moves with a velocity (in a rocket) whose components are $u'_x = u'_y = 1.8 \times 10^8$ m/s. What will be the person's velocity (magnitude and direction) with respect to S?

CHAPTER 26

1. 6.46×10^{-7} s

3. 184 m

5. $0.96c$

7. (*a*) 46.4 yr; (*b*) 11.3 yr; (*c*) 10.9 ly; (*d*) $0.970c$

9. $0.89c$

11. $0.866c$

13. 7×10^{-8} %

15. 9.0×10^{13} J; 9.2×10^{10} kg

17. 6.51×10^{-13} kg

19. 939 MeV

21. 7.6×10^{-12} J; 1.6×10^{-19} kg·m/s

23. $0.61c$

25. $1.39m_0$; $0.70c$

27. (*a*) 4.5×10^{19} J; (*b*) 2.4%

29. $0.745c$; 3.06×10^{-22} kg·m/s

35. $0.80c$

37. (*a*) $0.979c$; (*b*) $-0.31c$

39. (*a*) $x = 1.36 \times 10^3$ m, $y = 10$ m, $z = 0$; (*b*) $x = 2.70 \times 10^3$ m, $y = 10$ m, $z = 0$

41. 2.88×10^8 m/s at 19.4°

43. (*a*) A; (*b*) 2.8×10^{-14} s; (*c*) B

45. (*a*) 2.68 s; (*b*) 2.00 s

47. 0.85 mm

49. 3.5×10^{-5} g

51. (*a*) 4×10^9 kg/s; (*b*) 4×10^7 yr; (*c*) 1×10^{13} yr

53. 4.54×10^{-12} J = 28.3 MeV