54. An electron $(m = 9.11 \times 10^{-31}\,\text{kg})$ enters a uniform magnetic field $B = 1.8\,\text{T}$, and moves perpendicular to the field lines with a speed $v = 0.92c$. What is the radius of curvature of its path? See hint for Problem 42.

55. A negative muon traveling at 33% the speed of light collides head on with a positive muon traveling at 50% the speed of light. The two muons (each of rest mass $105.7\,\text{MeV}/c^2$) annihilate, and produce how much electromagnetic energy?

56. A free neutron can decay into a proton, an electron, and a neutrino. Assume the neutrino's rest mass is zero, and the other masses can be found in the Table inside the front cover. Determine the total kinetic energy shared among the three particles when a neutron decays at rest.

57. The Sun radiates energy at a rate of about $4 \times 10^{26}\,\text{W}$. (*a*) At what rate is the Sun's mass decreasing? (*b*) How long does it take for the Sun to lose a mass equal to that of Earth? (*c*) Estimate how long the Sun could last if it radiated constantly at this rate.

58. An unknown particle is measured to have a negative charge and a speed of $2.24 \times 10^8\,\text{m/s}$. Its momentum is determined to be $3.07 \times 10^{-22}\,\text{kg}\cdot\text{m/s}$. Identify the particle by finding its rest mass.

59. How much energy would be required to break a helium nucleus into its constituents, two protons and two neutrons? The rest masses of a proton (including an electron), a neutron, and helium are, respectively, 1.00783 u, 1.00867 u, and 4.00260 u. (This energy difference is called the *total binding energy* of the ^4_2He nucleus.)

60. What is the percentage increase in the (relativistic) mass of a car traveling 110 km/h as compared to at rest? [*Hint*: use the binomial expansion.]

61. Two protons, each having a speed of $0.935c$ in the laboratory, are moving toward each other. Determine (*a*) the momentum of each proton in the laboratory, (*b*) the total momentum of the two protons in the laboratory, and (*c*) the momentum of one proton as seen by the other proton.

62. Show analytically that a particle with momentum p and energy E has a speed given by

$$v = \frac{pc^2}{E} = \frac{pc}{\sqrt{m_0^2c^2 + p^2}}.$$

63. The fictional starship *Enterprise* obtains its power by combining matter and antimatter, achieving complete conversion of mass into energy. If the mass of the *Enterprise* is approximately $5 \times 10^9\,\text{kg}$, how much mass must be converted into kinetic energy to accelerate it from rest to one-tenth the speed of light?

64. An electron is accelerated so that its kinetic energy is greater than its rest energy m_0c^2 by a factor of (*a*) 5.00, (*b*) 999. What is the speed of the electron in each case?

65. A farm boy studying physics believes that he can fit a 15.0-m-long pole into a 12.0-m-long barn if he runs fast enough (carrying the pole). Can he do it? Explain in detail. How does this fit with the idea that when he is running the barn looks even shorter to him than 12.0 m?

66. When two moles of hydrogen and one mole of oxygen react to form two moles of water, the energy released is 484 kJ. How much does the mass of the elements decrease in this reaction? What % of the total original mass of the system does this mass change represent?

67. In a nuclear reaction two identical particles are created, traveling in opposite directions. If the speed of each particle is $0.75c$, relative to the laboratory frame of reference, what is one particle's speed relative to the other particle?

68. An astronaut on a spaceship traveling at $0.75c$ relative to Earth measures his ship to be 25 m long. On the ship, he eats his lunch in 23 min. (*a*) What length is the spaceship according to observers on Earth? (*b*) How long does the astronaut's lunch take to eat according to observers on Earth?

69. You are traveling in a spaceship at a speed of $0.85c$ away from Earth. You send a laser beam toward the Earth traveling at velocity c relative to you. What do observers on the Earth measure for the speed of the laser beam?

70. A spaceship and its occupants have a total mass of 150,000 kg. The occupants would like to travel to a star that is 25 light-years away at a speed of $0.60c$. To accelerate, the engine of the spaceship changes mass directly to energy. How much mass will be converted to energy to accelerate the spaceship to this speed? Assume the acceleration is rapid, so the speed for the entire trip can be taken to be $0.60c$, and ignore decrease in total mass for the calculation. How long will the trip take according to the astronauts on board?

71. Suppose a 12,500-kg spaceship left Earth at a speed of $0.99c$. What is the spaceship's kinetic energy? Compare with the total U.S. annual energy consumption (about $10^{20}\,\text{J}$).

72. A 42,000-kg spaceship is to travel to the vicinity of a star 6.0 light-years from Earth. Passengers on the ship want the (one-way) trip to take no more than 1.0 year. How much work must be done on the spaceship to bring it to the speed necessary for this trip?

73. A 1.68-kg mass oscillates on the end of a spring whose spring stiffness constant is $k = 48.7\,\text{N/m}$. If this system is in a spaceship moving past Earth at $0.900c$, what is its period of oscillation according to (*a*) observers on the ship, and (*b*) observers on Earth?

74. A pi meson of rest mass m_π decays at rest into a muon (rest mass m_μ) and a neutrino of negligible or zero rest mass. Show that the kinetic energy of the muon is $\text{KE}_\mu = (m_\pi - m_\mu)^2c^2/2m_\pi$.

Answers to Exercises

A: Yes.

B: (*a*) 2.21 μs; (*b*) 5.0 μs.

C: (*a*) No; (*b*) yes.

D: $0.36c$.

E: No.

F: $0.030c$, same as classical, to an accuracy of better than 0.1%.