Chapter 21
Special Relativity
21.1 Time Dilation/Length Contraction — Homework # 167

Time Dilation

I

01. A pion particle has a lifetime of 2.60×10^{-8} s when measured at rest. What is its average measured lifetime when it is traveling at 2.75×10^{8} m/s?

02. A muon particle has a lifetime of 2.2×10^{-6} s when measured at rest. What is the speed of a beam of muons if their average lifetime when is measured to be 3.4×10^{-6} s?

03. The average measured lifetime of a kaon particle is 2.15×10^{-8} s when moving at 2.45×10^{8} m/s. What is the particle's lifetime at rest?

Length Contraction

I

04. A 260-m long spaceship passes an observer at 0.85*c*. What is the length of the spacecraft as measured by the observer?

05. Two spacecraft, A and B, pass each other moving at 0.43*c* relative to each other. Spacecraft A measures the length of its own ship to be 220 m and that of spacecraft B to be 167 m. What will be the length of Spacecraft _____ as measured by spacecraft B?
    a.) A b.) B

06. Alpha Centauri is a star system that is approximately 4.3 ly away [Proxima Centauri (or Alpha Centauri C) is the closest of this system while Alpha Centauri A and Alpha Centauri B are close binary stars]. How fast must a spaceship travel to reduce the distance to this star system to 3.2 ly?

07. Betelgeuse (Alpha Orionis), the second brightest star of the constellation Orion, is 520 ly away from earth. To an observer on a spaceship traveling at 2.45×10^{8} m/s from earth toward the Betelgeuse, what would be the measured distance of the trip?

08. A spacecraft is traveling from the earth to Beta Cass, a star that is approximately 100 ly away, at 0.925*c*.
    a.) How long would it take this spacecraft to make this trip as measured by observers on earth?
    b.) How long would it take this spacecraft to make this trip as measured by observers on the spacecraft?
    c.) What is the distance traveled by this spacecraft as measured by observers on earth?
    d.) What is the distance traveled by this spacecraft as measured by observers on the spacecraft?
    e.) Use the answers to parts b.) and c.) above to measure the speed of the spacecraft as measured by its occupants.

09. A spacecraft travels by the earth at 073*c*. On this ship is a lab table that is 2.10 m long and 0.92 m tall as measured by a scientist on the earth. What is the measurement of its _____ by someone on the ship?
    a.) length b.) height

ANSWERS: **01.** 6.5×10^{-8} s **02.** 2.3×10^{8} m/s **03.** 1.24×10^{-8} s **04.** 137 m **05.** a.) 199 m b.) 185 m **06.** 2.0×10^{8} m/s **07.** 300 ly **08.** a.) 108 yr b.) 41 yr c.) 100 ly d.) 38 ly e.) 0.925*c* **09.** a.) 0.48 m b.) 0.92 m

Chapter 21
Special Relativity
21.2 Relativistic Momentum/Velocity Transformations — Homework # 168

Useful Information: The rest mass of an electron is 9.11 x 10^{-31} kg, the rest mass of a proton is 1.67 x 10^{-27} kg.

Relativistic Momentum (Mass Increase)

I

01. What is the mass of a proton traveling at 0.95c?

02. What is the mass of an electron at the following speeds? (The rest mass of an electron is 9.11 x 10^{-31} kg)
a.) 0.9000c b.) 0.9900c c.) 0.9990c d.) 0.9999c

03. What is the momentum of an electron at the following speeds? (The rest mass of an electron is 9.11 x 10^{-31} kg)
a.) 0.9000c b.) 0.9900c c.) 0.9990c d.) 0.9999c

II

04. At what speed will the mass of an object be _____ times its rest mass?
a.) two b.) ten c.) one hundred d.) one thousand

05. In the Stanford Linear Accelerator at the Stanford Linear Accelerator Center (SLAC), electrons can attain a mass 10,000 times its rest mass. What is the speed of such electrons? (The rest mass of an electron is 9.11 x 10^{-31} kg)

III

06. What is the percent increase in mass for an object moving at the escape velocity of the earth? [Hint: To determine the escape velocity, an object must have a kinetic energy equal to the gravitational potential energy of an object at the surface of the earth $\left(\text{GPE} = G\frac{M_E m_o}{r}, \text{ where GPE } = 0 \text{ at } r = \infty \right)$]

Velocity Transformations

I

07. A person in a rocket traveling at 0.600c with respect to the earth observes a meteor approach and pass the rocket. This person measures the speed of the meteor to be 0.600c with respect to the rocket. What will astronomers on earth record as the speed of the meteor if it passes the rocket in the _____ direction as the rocket?
a.) same b.) opposite

II

08. Two spaceships leave the earth in opposite directions. The speed of each spaceship is identical and measured to be 0.750c 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?

09. A spaceship leaves the earth traveling at 0.800c. It fires a very small missile measured to have a velocity of 0.920c with respect to the spaceship. Since the mass of the missile is very small compared to the spaceship, assume the recoil effect of the spaceship is negligible such that it maintains its 0.800c velocity with respect to the earth. What is the velocity of the missile with respect to the earth if it is fired in _____ the spaceship?
a.) the same direction as b.) the opposite direction as c.) a direction perpendicular to that of

ANSWERS: **01.** 5.35 x 10^{-27} kg **02.** a.) 2.09 x 10^{-30} kg b.) 6.46 x 10^{-30} kg c.) 2.04 x 10^{-29} kg
02. d.) 6.44 x 10^{-29} kg **03.** a.) 5.64 x 10^{-22} kg·m/s b.) 1.92 x 10^{-21} kg·m/s c.) 6.11 x 10^{-21} kg·m/s
03. d.) 1.93 x 10^{-20} kg·m/s **04.** a.) 0.866c b.) 0.995c c.) 0.99995c d.) 0.9999995$c \approx 1$ **05.** 0.925c
06. 6.87 x 10^{-8}% **07.** a.) 0.882c b.) 0 **08.** a.) 0.960c opposite 2 b.) 0.960c opposite 1
09. a.) 0.991c b.) -0.445c c.) $u_x = 0.800c$, $u_y = 0.883c$

Chapter 21
Special Relativity
21.3 Relativistic Energy — Homework # 169

Useful Information: The rest mass of an electron is 9.11 x 10^{-31} kg, the rest mass of a proton is 1.67 x 10^{-27} kg.

I

01. An electron is moving at 0.750*c*. What is its _____?
    a.) rest energy? b.) total energy? c.) kinetic energy? d.) momentum

02. A 1000.0-kg sample of water is heated from 0.00°C to 100.00°C? The specific heat of water, c = 4.18 x 10^{3} kJ/kg.
    a.) How much energy must be added to the water to produce this temperature change? [Remember, $Q = mc\Delta T$]
    b.) What is the increase in mass of the water during this temperature change?

03. Assume exactly one gram of a material could be converted into energy.
    a.) How much energy would be "released"?
    b.) If this energy could be harnessed to lift an object 100 m (about the length of a football field) off the ground, what is the maximum mass that could be lifted to this height?

II

04. Calculate the rest energy of _____ in J and MeV. [1 MeV = 1.60 x 10^{-13} J]
    a.) an electron b.) a proton

05. An electron has a mass is 5 times its rest mass.
    a.) What is the kinetic energy of this electron? b.) How fast is the electron traveling?

06. A proton is accelerated by a 750-MeV potential difference. What is the _____ of this proton?
    a.) kinetic energy b.) total energy c.) momentum d.) speed

07. An electron has a kinetic energy that is half its total energy.
    a.) What is the mass of the electron? b.) How fast is the electron traveling?

08. Assume a 45,000-kg spacecraft could be accelerated to 0.2250*c*.
    a.) Calculate its kinetic energy using classical physics.
    b.) Calculate its kinetic energy using relativistic physics.
    c.) What is the percent difference of the classical result from the relativistic result for kinetic energy?
    d.) Calculate its momentum using classical physics.
    e.) Calculate its momentum using relativistic physics.
    f.) What is the percent difference of the classical result from the relativistic result for momentum?

III

09. How much mass does the earth gain from the sun each year? [The radius of the earth is 6.38 x 10^{6} m, the area of a sphere is πr^2, radiation form the sun reaches the earth at the rate of 1400 W/m^2. The area of a circle is used rather than the surface area of a sphere because the maximum 1400-W/m^2 rate of radiation striking the earth occurs when the sunlight is at right angles to the surface of the earth. The "horizontal" component of a sphere is a circle.]

ANSWERS: **01.** a.) 8.20 x 10^{-14} J b.) 1.24 x 10^{-13} J c.) 4.20 x 10^{-13} J d.) 3.10 x 10^{-22} kg
02. a.) 4.18 x 10^{9} J b.) 6.64 x 10^{-8} kg **03.** a.) 9.00 x 10^{-13} J b.) 9.18 x 10^{10} kg
04. a.) 8.20 x 10^{-14} J (0.512 MeV) b.) 1.50 x 10^{-10} J (939.375 MeV) **05.** a.) 3.28 x 10^{-13} J b.) 0.980*c*
06. a.) 1.20 x 10^{-10} J b.) 2.70 x 10^{-10} J c.) 7.49 x 10^{-19} kg d.) 0.882*c* **07.** a.) 1.82 x 10^{-30} kg b.) 0.882*c*
08. a.) 1.025 x 10^{20} J b.) 1.066 x 10^{20} J c.) 3.813% d.) 3.038 x 10^{12} kg·m/s e.) 3.117 x 10^{12} kg·m/s
08. f.) 2.564% **09.** 6.27 x 10^{7} kg