CHAPTER 17 Review

REFLECTING ON CHAPTER 17

- The Michelson-Morley experiment indicated that the speed of light was the same for observers in any inertial frame of reference.
- The special theory of relativity is based on two postulates.
  1. All physical laws hold true in any inertial frame of reference.
  2. The speed of light is the same for observers in any inertial frame of reference.
- The special theory of relativity predicts that events that are simultaneous for observers in one inertial frame of reference are not necessarily simultaneous for observers in a different inertial frame of reference.
- The special theory of relativity predicts that if you are observing events in an inertial frame of reference that is moving rapidly relative to you, times in that observed frame of reference will appear to slow down. This is known as "time dilation." The effect is expressed in the formula
$$\Delta t = \frac{\Delta t_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$
- The special theory of relativity predicts that if you are observing objects in an inertial frame of reference that is moving rapidly relative to you, lengths in that observed frame of reference in the direction of the motion will appear to be shorter. This is known as "length contraction." The effect is expressed in the formula
$$L = L_o\sqrt{1 - \frac{v^2}{c^2}}$$
- The special theory of relativity predicts that objects moving at a high rate of speed relative to a given inertial frame of reference will have greater mass than when they are at rest in that frame of reference. This is known as "mass increase." The effect is expressed in the formula
$$m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$
- The previous equations are shortened by the use of the quantity called "gamma."
$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$
Using gamma, the equations become
$$\Delta t = \gamma \Delta t_o$$
$$L = \frac{L_o}{\gamma}$$
$$m = m_o\gamma$$
- Relativistic kinetic energy is given by
$$E_k = mc^2 - m_oc^2$$
or $E_k = (\Delta m)c^2$
- The speed of light through a vacuum is the fastest speed possible. Objects with mass must travel slower than this speed. Massless objects such as photons must travel at this speed.
- mc^2 represents the total energy of the particle.

Knowledge/Understanding

1. Briefly describe the Michelson-Morley experiment.
   (a) What were the predicted results?
   (b) What did Michelson and Morley actually observe?
   (c) Why did the observed results cause a complete rethinking of their basic postulates?
2. (a) In the Michelson-Morley experiment, what was the purpose of rotating the apparatus 90°?
   (b) What were the results and implications of this procedural step?
3. While riding in a streetcar in Bern, Switzerland, Einstein realized that moving clocks might not run at the same rate as

stationary clocks. He looked at a clock on a tower and realized that if the streetcar moved away from the clock at the speed of light, it would appear to him as if the clock had stopped. Describe a thought experiment to illustrate his thinking.

4. Explain, using examples, why seemingly simultaneous events might occur at different times and different places, depending on your frame of reference.
5. The speed of light in water is 2.25×10^8 m/s. Using Einstein's thinking, explain whether it is possible for a particle to travel through water at a speed greater than 2.25×10^8 m/s.
6. Explain how the behaviour of muons is used as evidence for the concepts of time dilation and length contraction.
7. Why is it postulated that electrons, protons, and other forms of matter can never travel at the speed of light?
8. A photon can be considered as a particle with a specific energy that travels at the speed of light.
   (a) According to the special theory of relativity, what is the rest mass of the photon?
   (b) If a photon has energy, does that mean it also has momentum?
9. Explain how the equation $E = mc^2$ is consistent with the law of conservation of energy.

Inquiry

10. Examine the question of when relativistic effects become important by plotting graphs of $1/\gamma$ versus velocity and γ versus velocity for speeds of 0 to 1.0c.
    (a) At what speed would an observer experience a 1.0% time dilation effect or a 1.0% length contraction effect?
    (b) Repeat part (a) for 10%, 50%, 90%, and 99.99%.
11. Explain the first postulate of the theory of special relativity by describing how the laws of classical physics hold in an inertial frame of reference, but do not hold in a non-inertial frame of reference.
12. Describe a thought experiment to consider the effect on your everyday life if the speed of light was 3.0×10^2 m/s, rather than 3.0×10^8 m/s. Assume appropriate rates of speed and consider how much younger you would be if you flew from Halifax to Winnipeg and back than if you stayed home. If the distance from Halifax to Winnipeg is 3.7×10^3 km, measured at a walking pace, what distance will you have covered from the airplane's frame of reference? Assume that the airplane is flying at approximately 800 km/h.
13. Estimate the number of lights in the city of Toronto or Calgery. Make reasonable assumptions. Suppose all of the light energy used in the city in 1 h in the evening could be captured and put into a box. Approximately how much heavier would the box become?

Communication

14. Sketch the appearance of a baseball as it flies past an observer at low speeds and at speeds that approach the speed of light.
15. A friend states that, according to Einstein, "Everything is relative." Disprove this popular statement by making a list of quantities that according to special relativity are **(a)** relative, that is, their value depends on the frame of reference, and **(b)** invariant, that is, their value is the same for all inertial observers.
16. Your lab partner is trying to convince you that a spaceship, which can travel at 0.9 c, can fit into a garage shorter than the spaceship's actual length. He suggests that if the spaceship is backed into the garage at full speed, it will undergo length contraction and thus fit into the garage. Explain to him the flaws in his thinking.

Making Connections

17. Until recently, the neutrino was thought to be massless and, therefore, to travel at the speed of light. Evidence from the Sudbury Neutrino Observatory (see the Physics Magazine in Chapter 20, Radioactivity), published in

June 2001, suggests that the neutrino has a tiny mass. Research the latest developments.

(a) What is the neutrino's mass now considered to be?

(b) Why has it been so difficult to measure?

(c) If the premise that neutrinos have mass is accepted, what are the implications in relation to setting an upper limit on their speed?

Problems for Understanding

18. How fast must a spaceship be moving for you to measure its length to be half its rest length?

19. You are speeding along in your sports car when your friend passes you on a relativistic motorcycle at 0.60c. You see your own car as being 4.0 m long and your friend's motorcycle as being 1.5 m long. You also notice that your friend's watch indicates that 8.5×10^{-8} s elapsed as she passed you. (It is a very large watch!)

(a) How long is your car as seen by your friend?

(b) How long is the motorcycle as seen by your friend?

(c) How much time passed on your watch while 8.5×10^{-8} s passed on your friend's watch?

20. A proton has a rest mass in a laboratory of 1.67×10^{-27} kg.

(a) What would its mass be relative to the laboratory if it was accelerated up to a speed of 0.75c?

(b) While the experimenter was determining the proton's mass in (a), what would be the proton's mass in its own frame of reference?

21. Create a graph showing the observed mass of an object that has a 1.0 kg rest mass as its speed goes from rest to 0.99c.

22. If a clock in an airplane is found to slow down by 5 parts in 10^{13}, (i.e., $\Delta t/\Delta t_o = 1.0 + 5.0 \times 10^{-13}$), at what speed is the airplane travelling? (**Hint:** You might need to use an expansion for γ.)

23. A spaceship travelling at 0.9 c fires a beam of light straight ahead.

(a) How fast would the crew on the spaceship measure the light beam's speed to be?

(b) How fast would a stationary observer on a spacewalk measure the light beam's speed to be?

(c) How fast would the crew on another spaceship travelling parallel to the first at the same speed of 0.9c measure the light beam's speed to be?

24. A pion is an unstable elementary particle that has a lifetime of 1.8×10^{-8} s. Assume that a beam of pions produced in a lab has a velocity of 0.95c.

(a) By what factor is the pions' lifetime increased?

(b) What will be their measured lifetimes?

(c) How far will they travel in this time?

25. What is the mass of an electron travelling at two thirds of the speed of light? Compare this to its rest mass.

26. What is the kinetic energy of an electron with the following speeds?

(a) 0.0010c; **(b)** 0.10c; **(c)** 0.50c; **(d)** 0.99c

(e) For which, if any, of these speeds, can you use the non-relativistic expression $\frac{1}{2}mv^2$ and have an error of less than 10%?

27. If an object has a mass that is 1.0% larger than its rest mass, how fast must it be moving?

28. How many 100 W light bulbs could be powered for one year by the direct conversion of 1 g of matter into energy?

29. An electron is accelerated from rest through a potential difference of 2.2 MV, so that it acquires an energy of 2.2 MeV. Calculate its mass, the ratio of its mass to its rest mass, and its speed.

30. An object at rest explodes into two fragments, each of which has a rest mass of 0.50 g.

(a) If the fragments move apart at speeds of 0.70c relative to the original object, what is the rest mass of the original object?

(b) How much of the object's original mass became kinetic energy of the fragments in the explosion?