Summary

THE BIG IDEA **You can describe the motion of an object by its position, speed, direction, and acceleration.**

4.1 Motion Is Relative

An object is moving if its position relative to a fixed point is changing.

- When we describe the motion of one object with respect to another, we say that the object is moving **relative** to the other object.
- Unless stated otherwise, when we discuss the speeds of things in our environment, we mean speed with respect to the surface of Earth.

4.2 Speed

You can calculate the speed of an object by dividing the distance covered by time.

- Galileo is credited as being the first to measure *speed* by considering the distance covered and the time it takes.
- **Speed** is how fast an object is moving.
- Any combination of units for distance and time that are useful and convenient are legitimate for describing speed.
- Some units that describe speed are miles per hour (mi/h) and kilometers per hour. The slash symbol (/) is read as "per."
- The speed of an object at any instant is called the **instantaneous speed.**
- The **average speed** of an object is the total distance covered divided by the time.
- Average speed does not indicate variations in the speed that may take place during the trip.
- A simple rearrangement of the definition of average speed gives the total distance covered:

$$\text{total distance covered} = \text{average speed} \times \text{travel time}$$

4.3 Velocity

Speed is a description of how fast an object moves; velocity is how fast and in what direction it moves.

- **Velocity** is speed in a given direction.
- A quantity such as velocity, which specifies direction as well as magnitude, is called a vector quantity.
- Quantities that require only magnitude for a description are scalar quantities.
- Constant speed means steady speed.
- Constant velocity means both constant speed *and* constant direction, which is in a straight line.
- If *either* an object's speed *or* its direction (or both) is changing, then the object's velocity is changing.

4.4 Acceleration

You can calculate the acceleration of an object by dividing the change in its velocity by time.

- **Acceleration** is the rate at which the velocity is changing.
- In physics, the term *acceleration* applies to decreases as well as increases in speed.
- Acceleration also applies to changes in *direction.*
- Acceleration is defined as the rate of change in *velocity,* rather than *speed.*
- Acceleration, like velocity, is a vector quantity because it is directional.
- If an object's speed, direction, or both, changes, the object changes velocity and accelerates.
- When the direction is not changing, acceleration may be expressed as the rate at which *speed* changes.
- Since acceleration is the change in velocity or speed per time interval, its units are those of speed per time.

4.5 Free Fall: How Fast

The acceleration of an object in free fall is about 10 meters per second squared (10 m/s^2).

- Gravity causes objects to accelerate downward once they begin to fall.
- In real life, air resistance affects the acceleration of a falling object.
- An object moving under the influence of the gravitational force only is said to be in **free fall.** Freely falling objects are affected only by gravity.
- The **elapsed time** is the time that has elapsed, or passed, since the beginning of any motion.
- For free fall, it is customary to use the letter g to represent the acceleration because the acceleration is due to gravity.
- Although g varies slightly in different parts of the world, its average value is nearly 10 m/s^2.
- The instantaneous speed of an object falling from rest is equal to the acceleration multiplied by the amount of time it falls (the elapsed time).
- The instantaneous speed v of an object falling from rest after an elapsed time t can be expressed in equation form as $v = gt$. Note that the letter v symbolizes both speed and velocity.
- At the highest point of a rising object, when the object is changing its direction of motion from upward to downward, its instantaneous speed is zero.
- As an object rises, its speed decreases at the same rate it increases when moving downward—at 10 meters per second each second.
- The instantaneous speed at points of equal elevation in a moving object's path is the same whether the object is moving upward or downward.

4.6 Free Fall: How Far

For each second of free fall, an object falls a greater distance than it did in the previous second.

- The initial speed of fall is zero and takes a full second to get to 10 m/s.
- Whenever an object's initial speed is zero and the acceleration a is constant, that is, steady and "non-jerky," the equations for the velocity and distance traveled are:

$$v = at \text{ and } d = \frac{1}{2}at^2$$

4.7 Graphs of Motion

On a speed-versus-time graph the slope represents speed per time, or acceleration.

- On a speed-versus-time graph, if the line forms a straight line, time and speed are directly proportional to each other.
- The *slope* of the line is the vertical change divided by the horizontal change for any part of the line.
- On a distance-versus-time graph for a falling object, the relationship is *quadratic* and the curve is *parabolic.*

4.8 Air Resistance and Falling Objects

Air resistance noticeably slows the motion of things with large surface areas like falling feathers or pieces of paper. But air resistance less noticeably affects the motion of more compact objects like stones and baseballs.

- Air resistance can affect the acceleration of objects outside a vacuum.
- In many cases, however, the effect of air resistance is small enough to be neglected.
- With negligible air resistance, falling objects can be considered to be falling freely.

4.9 How Fast, How Far, How Quickly How Fast Changes

Acceleration is the rate at which velocity itself changes.

- When we wish to specify how fast something freely falls from rest after a certain elapsed time, we are talking about speed or velocity. The appropriate equation in these cases is $v = gt$.
- When we wish to specify how far an object has fallen, we are talking about distance. The appropriate equation in these cases is $d = \frac{1}{2}gt^2$.