SECTION 2.1

Displacement and Velocity

Motion

Motion happens all around us. You will explore ways to describe and analyze motion in this chapter.

KEY TERMS

frame of reference
displacement
average velocity
instantaneous velocity

One-dimensional motion is a simple form of motion.

One way to simplify the study of motion is to limit it to one dimension. An example is movement forward and backward along a line. The trains in the photo have this type of movement.

This chapter deals only with one-dimensional motion. Objects might move forward and back or up and down.

A train traveling along a straight route is an example of one-dimensional motion. Each train can move only forward and backward along the tracks.

Motion takes place over time and depends on the frame of reference.

Picture yourself on a forward-moving train. You walk toward the back of the car. The car is 20 m long and you walk at 1 m/s. How long will it take to walk the length of one car?

You walk toward the back of the train. The train rolls forward along the tracks. Earth beneath the tracks rotates as the planet revolves around the sun. The sun moves through our galaxy. But you want to know how long it will take to walk the length of one train car. The motion of Earth relative to the sun can be ignored. So can the motion of the train relative to the tracks.

Physicists call a **frame of reference** the frame against which changes in position are measured. The train car was the frame of reference in the example above. Your position and speed were measured relative to a point on the inside of the car. So the motion of the car relative to things outside the car did not matter. Any frame of reference can be chosen for a motion problem. Usually you choose a frame of reference that will make any calculations as simple as possible.

TIP

Motion is measured relative to something that is stationary in the frame of reference. An example would be the door of the train car or a seat.

READING CHECK

1. What is the frame of reference for the speed of a train?

Displacement

The length of a straight line drawn from an object's initial position to its final position is the object's **displacement.**

Displacement is a change in position.

The Greek letter delta (Δ) before a variable indicates a change in that variable.

$$\Delta x = x_f - x_i$$

The change in x is equal to the final value of x minus the initial value of x.

Displacement is not always equal to the distance traveled.

The path doesn't matter when you measure displacement. Only the starting and ending points matter.

Displacement can be positive or negative.

Movement can be both forward and backward. The displacement therefore includes a sign. So "3 meters back" might be written $\Delta x = -3$ m.

Critical Thinking

2. **Apply Concepts** Suppose movement to the right is positive. Movement to the left is negative. A pen is 22 cm from the left edge of the desk. You move it to be 15 cm from the left edge of the desk. What is the pen's displacement? Is the value positive or negative?

Velocity

Velocity combines speed and direction. Velocity can be positive or negative to indicate the direction of motion.

Conceptual Challenge

Spacecraft A spacecraft took off from Florida and circled Earth several times. It then landed in California. A photographer took pictures of the astronauts boarding the spacecraft in Florida. The photographer then flew to California and took pictures as they stepped off the spacecraft. Did the photographer or the astronauts undergo a greater displacement?

Round Trip The astronauts take a plane from California back to Florida. How does their displacement compare with the displacement of the photographer flying from Florida to California?

Did YOU Know?

The branch of physics that includes the study of motion is mechanics. The area of mechanics that describes motion without regard to mass or force is kinematics.

Average velocity is displacement divided by the time interval.

The **average velocity** of an object is its displacement divided by the time interval.

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

The average velocity of an object is its change in position divided by the change in time. Average velocity does not tell you the velocity at any one point in a trip. A trip with $v_{avg} = 25$ km/h might include moments when the speed is 30 km/h or 0 km/h.

TIP

The values for v_{avg} and Δx will have the same positive or negative sign. The value of Δt will always be positive.

SAMPLE PROBLEM

Andrea is running a race on level ground. She runs with an average velocity of 6.02 m/s to the east. What is her displacement after 137 s?

SOLUTION

1 ANALYZE *Determine what information is given and unknown.*

Given: $v_{avg} = 6.02$ m/s (treat east as positive)

$\Delta t = 137$ s

Unknown: $\Delta x = ?$

2 SOLVE *Use the equation for average velocity. Solve for Δx.*

$$v_{avg} = \frac{\Delta x}{\Delta t}$$

$$\Delta x = v_{avg}\Delta t = (6.02 \text{ m/s})(137 \text{ s}) = \boxed{825 \text{ m to the east}}$$

PRACTICE

A. Heather and Matthew walk with an average velocity of 0.98 m/s eastward. It takes them 34 min to walk to the store. What is their displacement?

Given:

Unknown:

SAMPLE PROBLEM (continued)

B. Sam drives with an average velocity of 48.0 km/h east. How long will it take him to drive 144 km on a straight highway?

C. How much time would Sam save by increasing his average velocity to 56.0 km/h east?

Velocity is not the same as speed.

Velocity and *speed* mean the same thing in everyday language. Physics uses the terms in different ways. Velocity describes motion with a number and a direction. The number is called magnitude. Speed has no direction. It has only magnitude.

Velocity can be interpreted graphically.

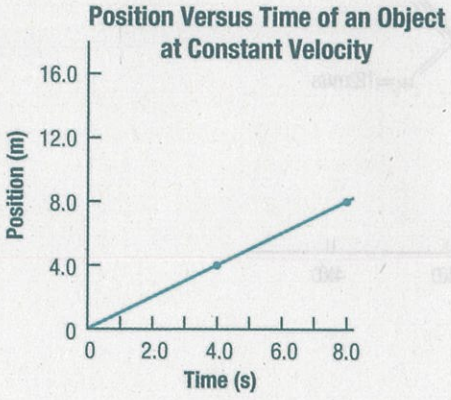
A graph can help you recognize patterns in motion problems. Time is plotted along the horizontal axis and position along the vertical axis in a position-time graph. An example is shown below.

The object is at 0 m at $t = 0$. The object is at 4 m after 4 s. It is at 8 m after 8 s. The average velocity is shown below.

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{4\text{ m}}{4\text{ s}} = 1\text{ m/s}$$

Note the formula for slope.

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{\Delta x}{\Delta t}$$



Conceptual Challenge

Book on a Table A book is moved once around the edge of a tapletop 1.75 m high and 2.25 m wide. The book ends up at its initial position. What is its displacement? Suppose the book moves around the table in 23 s. What is its average velocity? What is its average speed?

Travel Car A travels from New York to Miami at a speed of 25 m/s. Car B travels from New York to Chicago. Car B also has a speed of 25 m/s. Are the velocities of the cars equal? Explain.