Chapter 4
Motion

How long can you stand perfectly still? Ten seconds? A minute? Even if you stand still, things inside your body, such as your heart and lungs, are moving. Even when you are fast asleep your body is not really at rest.

The 24-hour rotation of Earth is carrying you around at several hundred miles per hour. Every 365 days, Earth completes a 584-million-mile orbit around the Sun. To make this trip, Earth (with you on its surface) is rushing through space at the astounding speed of 67,000 miles per hour! In order to understand nature, we need to think about motion. How do we describe going from here to there? The ideas in this chapter apply to all motion, whether it is a toy car rolling along a track or Earth rushing through space. Position, speed, and acceleration are basic concepts of motion we need to understand in order to understand the physical world. We will explore these concepts, and more, in this chapter.

Key Questions

- ✔ *How do we accurately describe our position?*
- ✔ *How do we show motion on a graph?*
- ✔ *What is special about the motion of falling objects?*

Photo courtesy of NASA

Chapter 4 MOTION

4.1 Speed and Velocity

The term **speed** describes how quickly something moves. In this section, you will learn about speed and speed with direction, called velocity.

Speed

Calculating speed To calculate the speed of a moving object, you divide the distance the object moves by the time it takes to move. For example, if you drive 120 miles (the distance) and it takes you 2 hours (the time), your speed is 60 miles per hour (60 mph = 120 miles ÷ 2 hours). The lowercase letter *v* is used to represent speed, as shown in the formula below.

SPEED

$$\text{Speed (cm/s)}\ v = \frac{d\ \text{Distance (cm)}}{t\ \text{Time (s)}}$$

Units for speed The units for speed are distance units over time units. If distance is in kilometers and time is in hours, then speed is in kilometers per hour (km/h). Other SI units for speed are cm per second (cm/s) and meters per second (m/s). Your family's car probably shows speed in miles per hour (mph).

Average speed and instantaneous speed When you divide the total distance of a trip by the time taken, you get the **average speed**. Figure 4.1 shows an average speed of 100 km/h. But think about what happens when you are riding in a car. On a real trip, your car will slow down and speed up. Sometimes your speed will be higher than 100 km/h, and sometimes lower (even 0 km/h). The speedometer shows you the car's **instantaneous speed**. The instantaneous speed is the *actual* speed an object has at any moment.

VOCABULARY

speed - describes how quickly an object moves, calculated by dividing the distance traveled by the time it takes.

average speed - the total distance divided by the total time for a trip.

instantaneous speed - the actual speed of a moving object at any moment.

$$\frac{150\ \text{kilometers}}{1.5\ \text{hours}} = 100\ \text{kilometers (km/h)}$$

Figure 4.1: *A driving trip with an average speed of 100 km/h.*

Solving Problems: Speed

How far will you go if you drive for 2 hours at a speed of 100 km/h?

1. Looking for: You are asked for a distance.

2. Given: You are given the speed and the time.

3. Relationships: speed = distance ÷ time

distance = speed × time

4. Solution: distance = (100 km/h) × (2 h) = 200 km

Your turn...

a. You travel at an average speed of 20 km/h in a straight line to get to your grandmother's house. It takes you 3 hours to get to her house. How far away is her house from where you started?

b. What is the speed of a snake that moves 20 meters in 5 seconds?

c. A train is moving at a speed of 50 km/h. How many hours will it take the train to travel 600 kilometers?

SCIENCE FACT

The Speed Limit of the Universe

The fastest speed in the universe is the speed of light. Light moves at approximately 300 million meters per second (3×10^8 m/s). If you could make light travel in a circle, it would go around the Earth 7.5 times in one second! Scientists believe the speed of light is the ultimate speed limit in the universe.

SOLVE FIRST LOOK LATER

a. Your grandmother's house is 60 km away from where you started.

b. The snake's speed is 4 m/s.

c. It will take the train 12 hours to travel 600 kilometers.

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Velocity

What is velocity?

Recall that *position* is an example of a kind of variable called a *vector*. We use the term **velocity** to mean speed with direction. Velocity (Figure 4.2) is usually defined as positive when moving forward (to the right from an outside observer), and negative when moving backward (to the left to an outside observer).

The difference between velocity and speed

Velocity is a vector, speed is not. In regular conversation, you might use the two words to mean the same thing. In science, they are related but different. Speed can have only a positive value (or zero) that tells you how far you move per unit of time (like meters per second). Velocity is speed *and* direction. If the motion is in a straight line, the direction can be shown with a positive or negative sign. The sign tells the direction and the quantity (speed) tells you how quickly you are moving.

Use two variables to find the third one

Any formula that involves speed can also be used for velocity. For example, you move 2 meters if your *speed* is 0.2 m/s and you keep going for 10 seconds. But did you move forward or backward? You move –2 meters (backward) if you move with a *velocity* of –0.2 m/s for 10 seconds. Using the formula with velocity gives you the change of *position* instead of *distance*.

Word Formulas		Equation
speed = distance ÷ time	velocity = distance ÷ time	$v = \frac{d}{t}$
distance = speed × time	distance = velocity × time	$d = vt$
time = distance ÷ speed	time = distance ÷ velocity	$t = \frac{d}{v}$

Direction of movement

Suppose an object moves forward at 0.2 m/s for 10 seconds. Its velocity is +0.2 m/s. In 10 seconds, its position changes by +2 meters.

Now, suppose the object goes backward at 0.2 m/s for 4 seconds. This time the velocity is –0.2 m/s. The change in position is –0.8 meters. *A change in position is velocity × time* (Figure 4.3).

VOCABULARY

velocity - a variable that tells you both speed and direction.

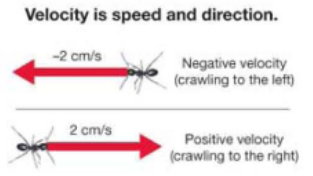


Figure 4.2: *Velocity can be a positive or a negative value.*

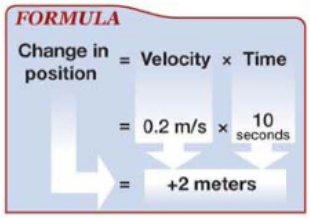


Figure 4.3: *The change in position or distance is the velocity multiplied by the time.*

Solving Problems: Velocity

A train travels at 100 km/h heading east to reach a town in 4 hours. The train then reverses and heads west at 50 km/h for 4 hours. What is the train's position now?

1. Looking for: You are asked for position.

2. Given: You are given two velocity vectors and the times for each.

3. Relationships: change in position = velocity × time

4. Solution: The first change in position is (+100 km/h) × (4 h) = +400 km
The second change in position is (−50 km/h) × (4 h) = −200 km
The final position is (+400 km) + (−200 km) = +200 km. The train is 200 km east of where it started.

Your turn...

a. A car travels south on a highway for 2 h at 90 km/h. The car reverses direction and heads north for 0.5 h at 80 km/h. What is the car's position relative to where it started?

b. A ship needs to sail to an island that is 1,000 km south of where the ship starts. If the captain sails south at a steady velocity of 30 km/h for 30 h, will the ship make it?

SCIENCE FACT

Fast Trains!

The bullet train of Japan was the world's first high-speed train. When it came into use in 1964, it went 210 km/h.

Research today's high-speed trains of the world. How fast can they go?

Research to find out why the United States lags behind in having high-speed trains. Find out the advantages and disadvantages of having high-speed trains in the U.S.

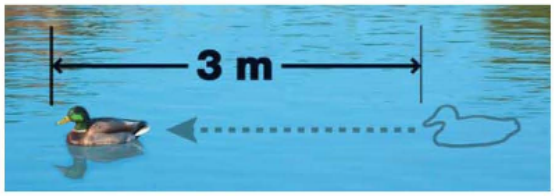
SOLVE FIRST LOOK LATER

a. The car is 140 km south of where it started.

b. No, because 30 km/h × 30 h = 900 km. The island is still 100 km away.

Section 4.1 Review

1. What is your average speed if you walk 2 kilometers in 20 minutes?
2. Give an example where instantaneous speed is different from average speed.
3. A weather report says winds blow at 5 km/h from the northeast. Is this description of the wind a speed or velocity? Explain your answer.
4. What velocity vector will move you 200 miles east in 4 hours traveling at a constant speed?
5. Explain how a bicycle can be fast compared to walking and slow compared to driving. How can two opposite words (*fast* and *slow*) describe the same speed?
6. What is the speed of the duck in the picture below if it takes 15 seconds to move the distance shown?

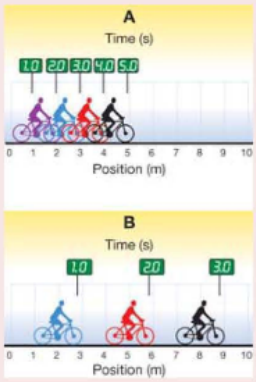


7. Can you go 500 kilometers in 8 hours without driving faster than 55 mph? Explain your answer.
8. A boat sails an average speed of 20 km/h for 2 days. How far does the boat travel?
9. What is the difference between speed and velocity?
10. A bird flies west for 1 hour at a velocity of 15 km/hr. The bird switches direction and flies east for 1 hour at a velocity of 10 km/hr. What is the bird's position relative to where it started?

CHALLENGE

Look at the graphic below and answer the following questions.

1. How fast is each cyclist going in units of meters per second*?
2. Which cyclist is going faster? How much faster is this cyclist going compared to the other one?



*The word *per* means "for every" or "for each." Saying "5 kilometers per hour" is the same as saying "5 kilometers for each hour." You can also think of *per* as meaning "divided by." The quantity before the word *per* is divided by the quantity after it.