IPC
Chapter 2
Motion
IPC Chapter 2 Vocabulary

• acceleration
• average speed
• centripetal acceleration
• displacement
• distance
• instantaneous speed
• momentum
• motion
• speed
• velocity
1 Describing Motion

Before You Read
Have you ever been on a roller coaster? You can feel the steep drops and quick turns in your body. Write how it feels to travel up a steep hill slowly and then to go down the other side quickly.

Read to Learn

Motion and Position

Distance and time are important in describing a race. The winner covers the distance in the shortest amount of time. It takes more time to run a 10-km race than to run a 5-km race because 10-km is a longer distance.

How are motion and position related?
You don’t need to see something move to know that it has moved. Suppose you see a mail truck stopped next to a mailbox. When you look again later, the truck is farther down the street by a tree. You didn’t see the truck move, but you know that motion has taken place because of the truck’s new position.

What is a reference point?
A reference point is needed to determine the position of an object. Motion occurs when an object goes from one reference point to another. In the example above, the mailbox was the first reference point for the mail truck. The tree was the second reference point.

After a reference point is chosen, a frame of reference can be created. A frame of reference is a coordinate system in which the position of the objects is measured. A coordinate system is like a map. The reference point is at the origin and each object’s position can be described with its coordinates.
**Change in Position**

**Distance** is how far something has moved. It is important in describing motion. In the 50-m dash, a runner travels 50 m between the start line and the finish line. The distance is 50 m.

The SI unit of length or distance is the meter (m). Long distances are measured in kilometers (km). One kilometer is equal to 1,000 meters. Short distances are measured in centimeters (cm). One meter is equal to 100 centimeters.

Not all motion is in a straight line. In the figure, the runner jogged 50 m to the east. Then she turned around and jogged 30 m to the west. The total distance she jogged is 80 m. She is 20 m from the starting point. **Displacement** is the distance and direction of an object’s position relative to the starting point. The runner’s displacement is 20 m east.

**Speed**

So far, motion has been described by the distance something has moved and by displacement from the starting point. You might also want to tell how fast something is moving. To do this, you need to know how far it travels in a certain amount of time. **Speed** is the distance an object travels per unit of time.

**How is speed calculated?**

The SI unit of distance is the meter (m). The SI unit of time is the second (s). So, in SI, speed is measured in meters per second (m/s). Sometimes it is easier to express speed in other units so that the numbers will not be very large or very small. Something that moves very quickly, such as a rocket, can be measured in kilometers per second (km/s). Very low speeds, such as geological plate movements, can be measured in centimeters per year (cm/y).

To calculate the speed of an object, divide the distance it traveled by the time it took to travel the distance. Here is a formula for calculating speed.

\[ \text{speed (in meters/second)} = \frac{\text{distance (in meters)}}{\text{time (in seconds)}} \]

\[ s = \frac{d}{t} \]

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**Take a Look**

1. Describe another way a runner could have a displacement of 20 m east.

**Apply Math**

2. Calculate A train traveling at a constant speed covers a distance of 960 meters in 30 s. What is the train’s speed? Show your work.

\[ s = \frac{d}{t} \]

\[ s = \frac{960 \text{ m}}{30 \text{ s}} = 32 \text{ m/s} \]
What is motion with constant speed?

A speedometer measures the speed of a car. Suppose you look at the speedometer when you are riding on a freeway. The car’s speed hardly changes. If the car is not speeding up or slowing down, it is moving at a constant speed. If you are traveling at a constant speed, you can measure your speed over any distance from millimeters to light years.

What is changing speed?

Usually, speed is not constant. The graph below shows how the speed of a cyclist changes during a 5-km ride. Follow the graph as the ride is described. As the cyclist starts off, his speed increases from 0 km/h to 20 km/h. Then he comes to a steep hill. He slows down to 10 km/h as he pedals up the hill. He speeds up to 30 km/h going down the other side of the hill. At the bottom, he stops for a red light. He speeds up when the light turns green. At the end of the ride, he slows down and then stops. The ride took 15 min.

What is average speed?

Look at the graph of speed for the bicycle trip. Sometimes the bicycle was moving fast, sometimes it was moving slowly, and sometimes it was stopped. How could you describe the speed of the whole ride? Would you use the fastest speed or the slowest?

Average speed describes the speed of motion when speed is changing. Average speed is the total distance traveled divided by the total time of travel. It is calculated using the relationships among speed, distance, and time.

The total distance the cyclist traveled was 5 km. The total time was 15 minutes, or \(\frac{1}{4}\) h. You can write \(\frac{1}{4}\) h as 0.25 h. The average speed for the bicycle trip can be found using a mathematical equation.

\[
\text{average speed} = \frac{\text{total distance}}{\text{total time}} = \frac{5 \text{ km}}{0.25 \text{ h}} = 20 \text{ km/h}
\]
What is instantaneous speed?
The speed shown on a car’s speedometer is the speed at one point in time, or one instant. **Instantaneous speed** is the speed at one point in time. If an object is moving with constant speed, the instantaneous speed doesn’t change. The speed is the same at every point in time. However, when a car speeds up or slows down, its instantaneous speed is changing. The speed is different at every point in time.

**Graphing Motion**
A distance-time graph shows the motion of an object over time. The graph below shows the motion of three toy cars moving across a lab floor. Time is plotted along the horizontal axis of the graph. The distance traveled is plotted along the vertical axis of the graph.

If an object moves with constant speed, the increase in distance over equal time intervals is the same. This results in a straight line on a distance-time graph. Look at the graph below. The straight red line represents the motion of the red car. The red car traveled at a constant speed of 1 m/s.

The blue line is also straight. This means that the blue car was also moving at a constant speed. The red and blue lines are different because the red and blue cars were moving at different speeds. The blue car had a slower speed than the red car. It moved at 0.75 m/s. The steepness of a line on a graph is the line’s slope. The slope of a line on a distance-time graph equals the object’s speed. The steeper the line, the faster the speed.

**Apply Math**
6. **Explain** why the slopes are different for each car.
How is changing speed graphed?
Look back at the graph of the three cars. Unlike the other lines, the line for the green car is not straight. The green car traveled at a constant speed of 0.5 m/s for 4 seconds. Then, the green car stopped for 4 seconds. After that, the green car moved at a constant speed of 1 m/s for 4 seconds.
When the green car was stopped, its line is horizontal. A horizontal line on a distance-time graph has a zero slope. A zero slope means the object has a speed of 0 m/s.

How do you draw a distance-time graph?
A distance-time graph plots data for distance and time. The distance traveled is plotted on the vertical axis. Time is plotted on the horizontal axis. Each axis has a scale, or a series of numbers, that covers the range of the data.
The data for the toy cars’ movements were recorded for 12 seconds. The time scale for the graph must range from 0 to 12 s. The red car traveled the farthest. Since the red car traveled 12 meters, the distance scale must range from 0 to 12 m. Both the \(x\)-axis and the \(y\)-axis must be divided into equal intervals. Then, the data points are plotted on the graph. Finally, lines are drawn to connect the points.

What is a coordinate system?
When you use a map to locate a small town in a different state, you may not know where to look at first unless you have some additional information. Maps are set up with coordinate systems and an index of the towns on the map. Suppose you look up the town and next to it is the notation L6. You look on the map and see that along the top of the map are the letters of the alphabet. Along the side of the map are numbers. Using the L6 information you follow the imaginary line that passes through L down the map until it crosses the imaginary line running across the map from 6. Close to the point where they cross you should see the town.

How can you use coordinates and displacement?
Suppose you want to travel by bus from city A to city B on the map. City A is your starting point and City B is where you want to end up. In other words, City B is the displacement of the bus. The coordinate system of the map tells you what direction and how great the displacement of the bus needs to be to reach city B.
2 Velocity and Momentum

Before You Read
If an object is moving at 2 m/s towards a porcelain vase, do you think it will have enough momentum to break the vase? Explain.

Read to Learn
Velocity
Suppose you hear that there is a storm nearby. The storm is traveling at a speed of 20 km/h and is 100 km east of your location. Do you have enough information to know whether the storm will reach you?

Knowing only the speed of the storm is not enough to find the answer. The speed tells you how fast the storm is moving. To find the answer, you also need to know the direction the storm is moving. In other words, you need to know the velocity of the storm. **Velocity** is the speed of an object and the direction it is moving.

**How do speed and direction affect velocity?**
To help you understand velocity, think about two escalators. Some escalators go up and others go down. One escalator is moving upward at the same speed that another escalator is moving downward. The two escalators are going the same speed, but they are going in different directions. They each have a different velocity. If the second escalator were moving upward, both elevators would have the same velocity.
Velocity depends on both speed and direction. Because of this, an object moving at a constant speed will have a changing velocity if it changes direction. A race car on an oval track has a constant speed. But, as the race car goes around the track, the direction in which the car is moving changes. This means that the velocity of the car is changing. An object has constant velocity if neither the speed nor direction it is moving changes. The light from a laser beam travels at a constant velocity.

**Motion of Earth’s Crust**

Some motion is so slow that it is hard to see. The surface of Earth doesn’t seem to change from year to year. But if you look at geological evidence of Earth over 250 million years, you will see that large changes have occurred.

According to the theory of plate tectonics, the continents are moving constantly over Earth’s surface. The movement is shown in the figure below. The changes are so slow that we do not notice them.

![250 million years ago](image1) ![66 million years ago](image2)

**How do continents move?**

Earth is made of layers. The top layer is the crust. The layer below the crust is the upper mantle. Together, the crust and the top part of the upper mantle are the lithosphere. The lithosphere is broken into huge sections, called plates.

Below the lithosphere, the layers are like putty. The plates slide slowly on these soft layers. The moving plates cause geological changes on Earth. These changes include the formation of mountain ranges, earthquakes, and volcanic eruptions.

The plates move very slowly. The speed of the plates is measured in centimeters per year. In California, two plates are sliding past each other along the San Andreas Fault. The average relative speed of the two plates is about 1 cm per year.

**Take a Look**

2. **Describe** the movement of the continents over the past 250 million years.

**Think it Over**

3. **Explain** Why is the speed of the movement of Earth’s plates measured in centimeters per year instead of in meters per second?
Relative motion

Have you ever watched cars pass you on the highway? Cars traveling in the same direction seem to pass you slowly. Cars traveling in the opposite direction seem to be moving very quickly. This apparent difference in speeds is because the reference point—your vehicle—is also moving. When you are sitting still in a desk, you appear not to be moving. However, you are moving. You are not moving in relation to your desk or school building. You are moving in relation to the Sun because you are sitting on Earth.

Relative motion means that one thing moves in relation to another thing. Earth is moving in space in relation to the Sun. The Sun is the reference point for Earth’s motion. Depending on your point of reference, objects can appear to be moving at different speeds and even in different directions.

Momentum

A moving object has a property called momentum. Momentum is related to how much force is needed to change an object’s motion. The momentum of an object is the product of its mass and its velocity. Momentum can be found using the following equation. The symbol \( p \) represents momentum. The unit for momentum is kg\( \cdot \)m/s.

\[
\text{momentum} = \text{mass} \times \text{velocity}
\]

Suppose a sprinter with a mass of 80 kg has a speed of 10 m/s. What is the sprinter’s momentum? Substitute the known values into the momentum equation.

\[
p = mv
\]

\[
= (80 \text{ kg})(10 \text{ m/s})
\]

\[
= 800 \text{ kg} \cdot \text{m/s}
\]

The sprinter’s momentum is 800 kg\( \cdot \)m/s.

How do momentums compare?

Picture a small car and a large truck moving at the same speed on the highway. They have the same velocity. But the truck has more momentum, because it has more mass. Now, picture two identical cars on the highway traveling at different speeds. The car with the higher velocity will have a greater momentum.

An archer’s arrow can have a large momentum because of its high velocity, even though its mass is small. A walking elephant may have a low velocity, but because of its large mass, it has a large momentum.

Apply Math

4. Apply What is the momentum of a bicycle with a mass of 18 kg traveling at 20 m/s?

Think it Over

5. Compare Which has more momentum, a car traveling at 12 km/h or a bicycle traveling at the same speed? Explain why.
Before You Read
Describe what happens to the speed of a bicycle as it goes uphill and downhill.

Read to Learn

Velocity and Acceleration
A car sitting at a stoplight is not moving. When the light turns green, the driver presses the gas pedal and the car starts moving. The car moves faster and faster. Speed is the rate of change of position. Acceleration is the rate of change of velocity. When the velocity of an object changes, the object is accelerating.

Remember that velocity is a measure that includes both speed and direction. Because of this, a change in velocity can be either a change in how fast something is moving or a change in the direction it is moving. Acceleration means that an object changes its speed, its direction, or both.

How are speeding up and slowing down described?
When you think of something accelerating, you probably think of it as speeding up. But an object that is slowing down is also accelerating. Remember that acceleration is a change in speed. A car that is slowing down is decreasing its speed. It is also accelerating, because its speed is changing.

Imagine a car being driven down a road. If the speed is increasing, the car has positive acceleration. When the car slows down, the speed decreases. The decreasing speed is called negative acceleration. In both cases, the car is accelerating, but one acceleration is positive and one is negative.

When a car changes direction, it is also accelerating. In the figure to the right, compare the direction of the acceleration to the direction of the velocity.

What You’ll Learn
- how acceleration, time, and velocity are related
- the different ways an object can accelerate
- how to calculate acceleration
- the similarities and differences between straight line motion, projectile motion, and circular motion

Focus
As you read the section, make an outline of the important information in each paragraph.

GET IT?
1. Identify three ways that an object can accelerate.
Acceleration has direction, just like velocity. In the figure below, both cars are accelerating because their speeds are changing. When a car’s acceleration and velocity are in the same direction, the speed increases and the acceleration is positive. Car A has positive acceleration. When a car is slowing down, the acceleration and velocity are in opposite directions. The acceleration is negative. Car B has negative acceleration.

**Car A**

**Car B**

**How do you graph acceleration?**

When an object travels in a straight line, it does not change direction. You can graph its speed over time to learn about its acceleration. Below is a speed-time graph. The graph shows Tamara’s car as she drives to the store. Recall that slope on a distance-time graph is an object’s speed. On a speed-time graph, the slope is the object’s acceleration. When Tamara pulls out of her driveway, the car’s acceleration is 0.33 km/min², which is equal to the slope of the line from \( t = 0 \) to \( t = 0.5 \) min.

Compare the slope of that line to the slope of the line from \( t = 3 \) to \( t = 3.75 \) min. In both cases the slope is positive. In both cases, she is increasing her speed. Positive acceleration has a positive slope. Negative acceleration has a negative slope. Horizontal lines indicate zero acceleration, but they do not necessarily mean zero speed.

**Take a Look**

2. **Describe** the acceleration of the cars in each figure.
How do you calculate acceleration?

Acceleration is the rate of change in velocity. To calculate acceleration, you first find the change in velocity. To find change in velocity subtract the beginning velocity of an object from the velocity at the end of its movement. Beginning velocity is called the initial velocity, or \( v_i \). Velocity at the end is called the final velocity, or \( v_f \).

\[
\text{change in velocity} = \text{final velocity} - \text{initial velocity} = v_f - v_i
\]

If motion is in a straight line, the change in speed can be used to calculate the change in velocity. The change in speed is the final speed minus the initial speed.

To find acceleration, divide the change in velocity by the length of time during which the velocity changed.

\[
\text{acceleration (m/s}^2\text{)} = \frac{\text{change in velocity (m/s)}}{\text{time (s)}}
\]

\[
a = \frac{(v_f - v_i)}{t}
\]

The SI unit for velocity is meters per second (m/s). To find acceleration, velocity is divided by the time in seconds (s). So, the unit for acceleration is m/s^2.

How is positive acceleration calculated?

How is the acceleration of an object that is speeding up different from that of an object that is slowing down? The acceleration of an object that is speeding up is always positive. The acceleration of an object that is slowing down is always negative.

Suppose an airplane is sitting at the end of a runway. The plane takes off and moves down the runway. It takes 20 s for the plane to travel from one end of the runway to the other. When the airplane reaches the end of the runway, it is traveling 80 m/s. The airplane is traveling in a straight line. The initial velocity of the plane is 0 m/s and the final velocity of the plane is 80 m/s. The time is 20 seconds. The acceleration for the plane can be calculated as follows:

\[
a = \frac{(v_f - v_i)}{t} = \frac{(80 \text{ m/s} - 0 \text{ m/s})}{20 \text{ s}} = 4 \text{ m/s}^2
\]

The airplane is speeding up as it goes down the runway. The final speed is greater than the initial speed. The acceleration is positive.
How is negative acceleration calculated?

Now imagine a skateboarder moving in a straight line. The skateboarder is moving at a speed of 3 m/s. It takes the person 2 s to come to a stop. The initial velocity is 3 m/s and the final velocity is 0 m/s. The total time is 2 seconds. The calculation for the skateboarder’s acceleration is as follows:

\[
a = \frac{(v_f - v_i)}{t} = \frac{(0 \text{ m/s} - 3 \text{ m/s})}{2 \text{ s}} = -1.5 \text{ m/s}^2
\]

The skateboarder is slowing down. The final speed is less than the initial speed. The acceleration has a negative value.

**Motion in Two Dimensions**

So far, we have only discussed motion in a straight line. But most objects are not restricted to moving in a straight line. Recall that we can only add measurements in that are the same or opposite directions. So, to talk about motion in two dimensions, we will discuss each direction separately.

When an object changes direction, it is accelerating. Its acceleration is not in the same or opposite direction as its velocity. This means we cannot use the acceleration equation. Accelerations that are not in the same or opposite directions cannot be directly combined.

**How is acceleration measured in circular motion?**

Think about a horse on a carousel as shown below. The horse moves in a circular path. Its speed remains constant. The direction of each horse’s motion is indicated by a red arrow. Because its direction is changing, it is accelerating. The direction of the acceleration is toward the center of the carousel. The blue arrows show the acceleration for each horse. Acceleration toward the center of a curved or circular path is called **centripetal acceleration**. In the same way, Earth experiences centripetal acceleration as it orbits the Sun.

**Think it Over**

6. **Think Critically** A car that is slowing down is still moving forward. Why is this considered negative acceleration?

7. **Define** the term centripetal acceleration.

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**GET IT?**

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What is projectile motion?

What happens when you toss a ball to someone? Thrown objects do not travel in straight lines. They curve downward. That is why archers, dart players, and quarterbacks aim above their targets. Anything that is thrown or shot through the air is called a projectile. Earth’s gravity causes projectiles to follow a curved path.

Horizontal and Vertical Motion

Picture shooting a rubber band. The object has a horizontal velocity that is constant. The rubber band does not accelerate horizontally. Gravity causes it to accelerate downward. The rubber band has an increasing vertical velocity. The path the rubber band might take is shown below.

Throwing and Dropping

Consider what would happen if you threw a ball in a perfectly horizontal direction. Would it take longer to reach the ground than if you dropped it from the same height? Surprisingly, it would not. The diagram above shows that both balls travel the same vertical distance. The horizontal motion of the thrown ball is independent of its vertical motion.

What acceleration happens at an amusement park?

Roller coasters are exciting rides. Roller coasters and other rides at amusement parks feel dangerous, but they are designed to be safe. Ride engineers use the laws of physics. The steep drops and loops of steel roller coasters give the rider large accelerations. When riders move down a steep hill, gravity will cause them to accelerate toward the ground. When riders go around sharp turns, they are also accelerated. This acceleration makes them feel as if a force is pushing them toward the side of the car.