# **47.0** Acceleration

Lesson Objectives

- Define acceleration.
- Explain how to calculate acceleration.
- Describe velocity-time graphs.

### Introduction

Imagine the thrill of riding on a roller coaster like the one in **Figure** below. The coaster crawls to the top of the track and then flies down the other side. It also zooms around twists and turns at breakneck speeds. These changes in speed and direction are what make a roller coaster ride so exciting. Changes in speed or direction are called **acceleration**.

Did you ever ride on a roller coaster like this one? It’s called the "Blue Streak" for a reason. As it speeds around the track, it looks like a streak of blue.

### Defining Acceleration

Acceleration is a measure of the change in velocity of a moving object. It shows how quickly velocity changes. Acceleration may reflect a change in speed, a change in direction, or both. Because acceleration includes both a size (speed) and direction, it is a vector.

People commonly think of acceleration as an increase in speed, but a decrease in speed is also acceleration. In this case, acceleration is negative. Negative acceleration may be called deceleration. A change in direction without a change in speed is acceleration as well. You can see several examples of acceleration in **Figure**.


How is velocity changing in each of these pictures?

If you are accelerating, you may be able to feel the change in velocity. This is true whether you change your speed or your direction. Think about what it feels like to ride in a car. As the car speeds up, you feel as though you are being pressed against the seat. The opposite occurs when the car slows down, especially if the change in speed is sudden. You feel yourself thrust forward. If the car turns right, you feel as though you are being pushed to the left. With a left turn, you feel a push to the right. The next time you ride in a car, notice how it feels as the car accelerates in each of these ways. For an interactive simulation about acceleration, go to this URL: http://phet.colorado.edu/en/simulation/moving-man.

### Calculating Acceleration

Calculating acceleration is complicated if both speed and direction are changing. It's easier to calculate acceleration when only speed is changing. To calculate acceleration without a change in direction, you just divide the change in velocity (represented by Δv) by the change in time (represented by Δt). The formula for acceleration in this case is:

$$\text{Acceleration} = \frac{\Delta \text{v}}{\Delta \text{t}}$$

Consider this example. The cyclist in **Figure** below speeds up as he goes downhill on this straight trail. His velocity changes from 1 meter per second at the top of the hill to 6 meters per second at the bottom. If it takes 5 seconds for him to reach the bottom, what is his acceleration, on average, as he flies down the hill?

$$\text{Acceleration} = \frac{\Delta \text{v}}{\Delta \text{t}} = \frac{6\ \text{m/s} - 1\ \text{m/s}}{5\ \text{s}} = \frac{5\ \text{m/s}}{5\ \text{s}} = \frac{1\ \text{m/s}}{1\ \text{m}} = 1\ \text{m/s}^2$$

In words, this means that for each second the cyclist travels downhill, his velocity increases by 1 meter per second (on average). The answer to this problem is expressed in the SI unit for acceleration: $\text{m/s}^2$ ("meters per second squared").

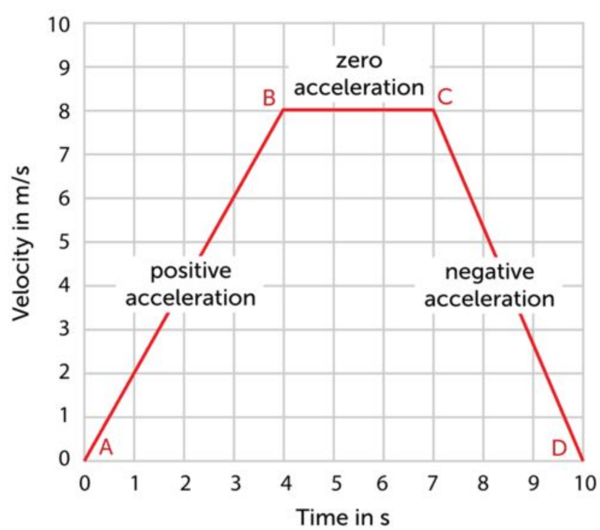
Gravity helps this cyclist increase his downhill velocity.

**You Try It!**

*Problem:* Tranh slowed his skateboard as he approached the street. He went from 8 m/s to 2 m/s in a period of 3 seconds. What was his acceleration?

### Velocity-Time Graphs

The acceleration of an object can be represented by a velocity–time graph like the one in **Figure**. A velocity-time graph shows how velocity changes over time. It is similar to a distance-time graph except the y−axis represents velocity instead of distance. The graph in **Figure** represents the velocity of a sprinter on a straight track. The runner speeds up for the first 4 seconds of the race, then runs at a constant velocity for the next 3 seconds, and finally slows to a stop during the last 3 seconds of the race.




This graph shows how the velocity of a runner changes during a 10-second sprint.

In a velocity-time graph, acceleration is represented by the slope of the graph line. If the line slopes upward, like the line between A and B in **Figure** above, velocity is increasing, so acceleration is positive. If the line is horizontal, as it is between B and C, velocity is not changing, so acceleration is zero. If the line slopes downward, like the line between C and D, velocity is decreasing, so acceleration is negative.

**Lesson Summary**

- Acceleration is a measure of the change in velocity of a moving object. It shows how quickly velocity changes and whether the change is positive or negative. It may reflect a change in speed, a change in direction, or both.
- To calculate acceleration without a change in direction, divide the change in velocity by the change in time.
- The slope of a velocity-time graph represents acceleration.

**Lesson Review Questions**

**Recall**

1. What is acceleration?
2. How is acceleration calculated?
3. What does the slope of a velocity-time graph represent?

**Apply Concepts**

4. The velocity of a car on a straight road changes from 0 m/s to 6 m/s in 3 seconds. What is its acceleration?

**Think Critically**

5. Because of the pull of gravity, a falling object accelerates at 9.8 $m/s^2$. Create a velocity-time graph to represent this motion.

# **48.0** Pressure of Fluids

### Lesson Objectives

- Describe pressure and how to calculate it.
- Relate fluid depth and density to pressure.State Pascal's and Bernoulli's laws.

### Introduction

Did you ever use a bicycle pump like the one in **Figure** below? The pump forces air into a tire through a small hole. Like other fluids (both liquids and gases), air can flow and take the shape of its container. The air that enters the tire from the pump quickly spreads out to fill the entire tire evenly. As the tire fills with air, it feels firmer. That's because the air exerts pressure against the inside surface of the tire.

You can use a bicycle pump to force air into a tire.

### What Is Pressure?

All fluids exert pressure like the air inside a tire. The particles of fluids are constantly moving in all directions at random. As the particles move, they keep bumping into each other and into anything else in their path. These collisions cause pressure, and the pressure is exerted equally in all directions. When particles are crowded together in one part of their container, they quickly spread out to fill their container. They always move from an area of higher pressure to an area of lower pressure. That's why air entering a tire quickly spreads throughout the tire.

### Pressure, Force, and Area

Pressure is the result of force acting on a given area. It can be represented by the equation:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

Pressure shows how concentrated the force is on a given area. The smaller the area to which force is applied, the greater the pressure is. Think about pressing a pushpin, like the one in **Figure** below, into a bulletin board. You apply force with your thumb to the broad head of the pushpin. However, the force that the pushpin applies to the bulletin board acts only over the tiny point of the pin. This is a much smaller area, so the pressure the point applies to the bulletin board is much greater than the pressure you apply with your thumb. As a result, the pin penetrates the bulletin board with ease.

A pushpin concentrates the force you apply to it. Can you explain how?

### SI Unit for Pressure

In the equation for pressure, force is expressed in newtons (N) and area is expressed in square meters ($m^2$). Therefore, pressure is expressed in $N/m^2$, which is the SI unit for pressure. This unit is also called the **pascal (Pa)**. It is named for the scientist Blaise Pascal, whose discovery about pressure in fluids is described later in this lesson. Pressure may also be expressed in the kilopascal (kPa), which equals 1000 pascals. For example, the correct air pressure inside a mountain bike tire is usually about 200 kPa.

### Calculating Pressure or Force

When you know how much force is acting on a given area, you can calculate the pressure that is being applied to the area using the equation for pressure given above. For example, assume that a big rock weighs 500 newtons and is resting on the ground on an area of 0.5 $m^2$. The pressure exerted on the ground by the rock is:

$$\text{Pressure} = \frac{500\ \text{N}}{0.5\ \text{m}^2} = 1000\ \text{N}/\text{m}^2 = 1000\ \text{Pa, or } 1\ \text{kPa}$$

Sometimes pressure but not force is known. To calculate force, the equation for pressure can be rewritten as:

$$\text{Force} = \text{Pressure} \times \text{Area}$$

For example, suppose another rock exerts 2 kPa of pressure over an area of 0.3 $m^2$. How much does the rock weigh? Change 2 kPa to 2000 $N/m^2$ and substitute it for pressure in the force equation:

$$\text{Force (Weight)} = 2000\ \text{N}/\text{m}^2 \times 0.3\ \text{m}^2 = 600\ \text{N}$$

### Problem Solving

*Problem:* A break dancer has a weight of 450 N. She is balancing on the ground on one hand. The palm of her hand has an area of 0.02 $m^2$. How much pressure does her hand exert on the ground?

*Solution:* Use the equation $\text{Pressure} = \frac{\text{Force}}{\text{Area}}$.

$$\text{Pressure} = \frac{450\ \text{N}}{0.02\ \text{m}^2} = 22500\ \text{Pa, or } 22.5\ \text{kPa}$$

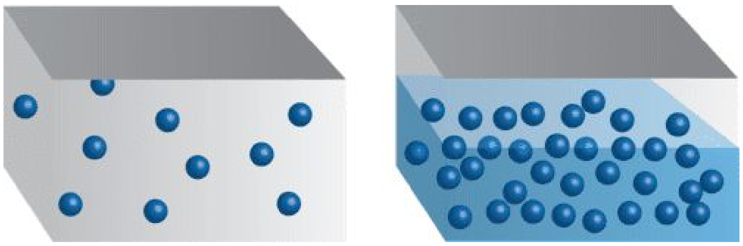
**You Try It!**

*Problem:* If the break dancer lies down on the ground on her back, her weight is spread over an area of 0.75 $m^2$. How much pressure does she exert on the ground in this position?

## Pressure in the Ocean and the Atmosphere

Both the water in the ocean and the air in the atmosphere exert pressure because of their moving particles. The ocean and atmosphere also illustrate two factors that affect pressure in fluids: depth and density.

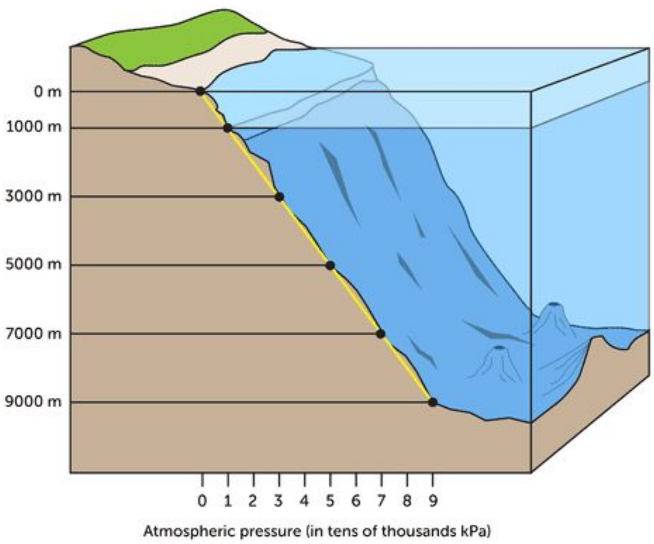
- A fluid exerts more pressure at greater depths. Deeper in a fluid, all of the fluid above results in more weight pressing down. This causes greater pressure.
- Denser fluids such as water exert more pressure than less dense fluids such as air. The particles of denser fluids are closer together, so there are more collisions in a given area. This is illustrated in **Figure** below for water and air.



Differences in density between water and air lead to differences in pressure.

## Water Pressure

As you go deeper in the ocean, the pressure exerted by the water increases steadily. The diagram in **Figure** below shows how pressure changes with depth. For every additional meter below the surface, pressure increases by 10 kPa. At 30 meters below the surface, the pressure is double the pressure at the surface. At a depth greater than 500 meters, the pressure is too great for humans to withstand without special equipment to protect them. Around 9000 meters below the surface, in the deepest part of the ocean, the pressure is tremendous. You can see a video demonstration of changes in water pressure with depth at this URL: http://www.youtube.com/watch?v=dL08xX4lBQg (0:42).

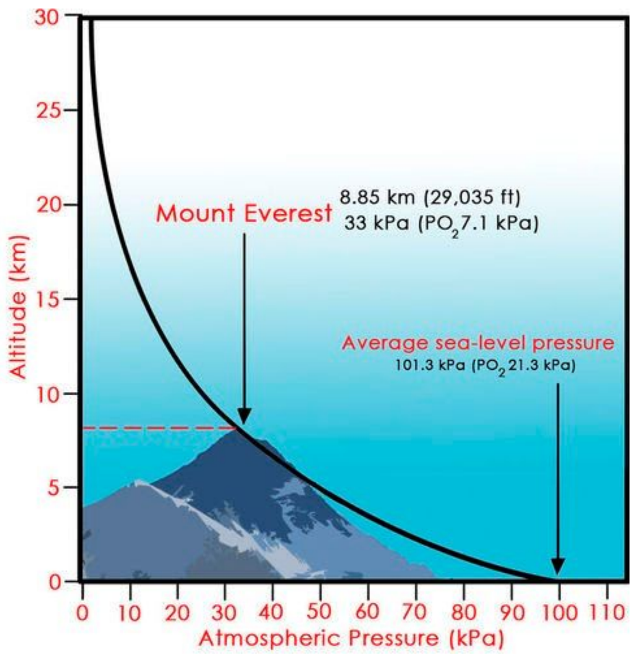



The pressure of ocean water increases rapidly as the water gets deeper.

Because of the pressure of the water, divers who go deeper than about 40 meters below the surface must return to the surface slowly and stop for several minutes at one or more points in their ascent. That's what the divers in **Figure** below are doing. The stops are needed to let the pressure inside their body adjust to the decreasing pressure of the water as they swim closer to the surface. If they were to rise to the surface too quickly, the gases dissolved in their blood would form bubbles and cause serious health problems.

**Air Pressure**

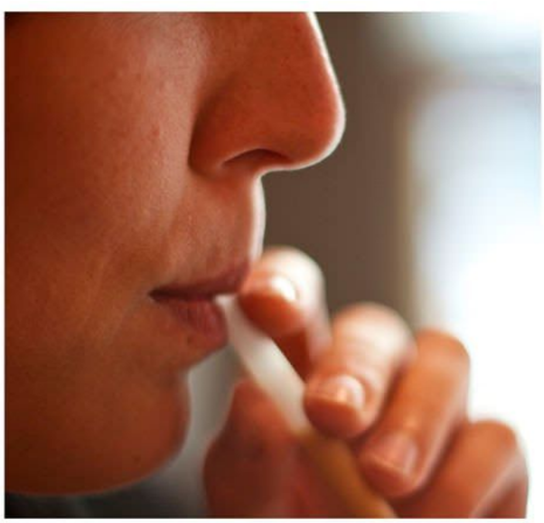
Like water in the ocean, air in the atmosphere exerts pressure that increases with depth. Most gas molecules in the atmosphere are pulled close to Earth's surface by gravity. As a result, air pressure decreases quickly at lower altitudes and then more slowly at higher altitudes. This is illustrated in **Figure** below. Air pressure is greatest at sea level, where the depth of the atmosphere is greatest. At higher altitudes, the pressure is less because the depth of the atmosphere is less. For example, on top of Mount Everest, the tallest mountain on Earth, air pressure is only about one-third of the pressure at sea level. At such high altitudes, low air pressure makes it hard to breathe and is dangerous to human health.

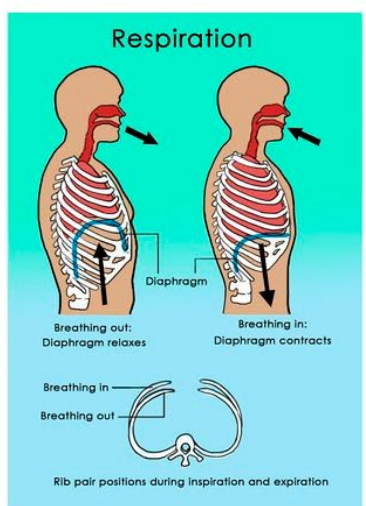



This graph shows how air pressure decreases with increasing altitude.

The pressure of air in the atmosphere allows you to do many things, from sipping through a straw to simply breathing (see **Figure** below).

- When you first suck on a straw, you remove air from the straw, so the air pressure in the straw is lower than the air pressure on the surface of the drink. Because fluid flows from an area of high to low pressure, the drink moves up the straw and into your mouth.
- When you breathe, a muscle called the diaphragm causes the rib cage and lungs to expand or contract. When they expand, the air in the lungs is under less pressure than the air outside the body, so air flows into the lungs. When the ribs and lungs contract, air in the lungs is under greater pressure than air outside the body, so air flows out of the lungs.






Both drinking through a straw and moving air into and out of the lungs is possible because of differences in air pressure. Can you think of other ways that differences in air pressure are useful?

## Laws of Fluid Pressure

Some of the earliest scientific research on fluids was conducted by a French mathematician and physicist named Blaise Pascal (1623–1662). Pascal was a brilliant thinker. While still a teen, he derived an important theorem in mathematics and also invented a mechanical calculator. One of Pascal's contributions to our understanding of fluids is known as Pascal's law.

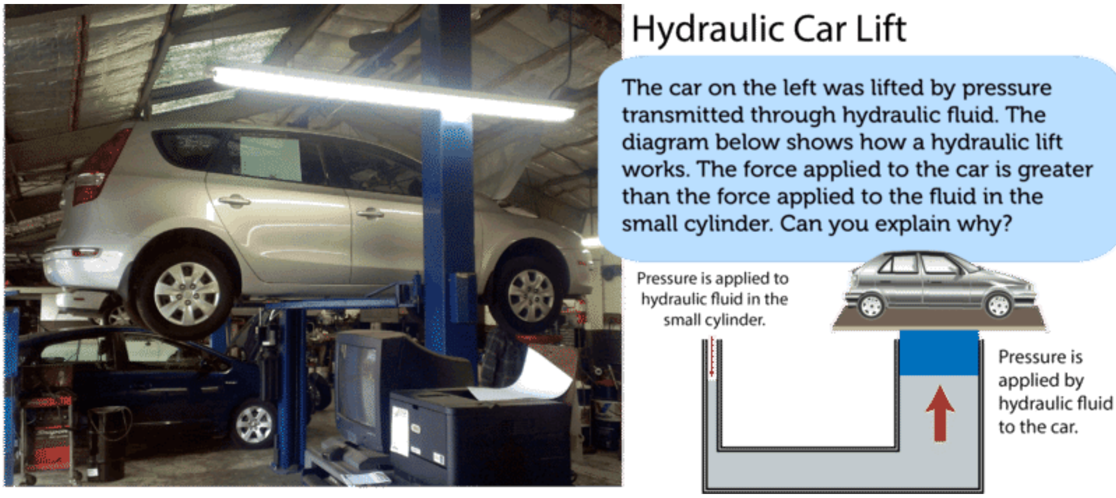
### Pascal's Law

**Pascal's law** states that a change in pressure at any point in an enclosed fluid is transmitted equally throughout the fluid. A simple example may help you understand Pascal's law. Assume you have a small packet of ketchup, like the one in **Figure** below. If you open one end of the packet and then apply pressure to the other end, what will happen? Ketchup will squirt out the open end. The pressure you exert on the packet is transmitted throughout the ketchup. When the pressure reaches the open end, it forces ketchup out of the packet. To see a video about Pascal's law, go to this URL: http://www.youtube.com/watch?v=4uRnPTQxZtw (2:59).

Ketchup is a fluid, so it transmits pressure from one end of the packet to the other.

The ability of fluids to transmit pressure in this way can be very useful — besides providing ketchup for your French fries! For example, the hydraulic car lift in **Figure** below contains fluid that transmits pressure and raises a car so a mechanic can work on it from below. The fluid used, usually a type of oil, can't be compressed. Force is placed on the fluid in a narrow cylinder, and the fluid transmits the pressure throughout the hydraulic system. When the pressure reaches the fluid in the wide cylinder, it forces the cylinder upward, along with the car. The force applied to the car is much greater than the force applied to the fluid in the narrow cylinder. Why? When pressure acts over a wider area, it creates a larger force. That's because force equals pressure multiplied by the area over which it acts, as you saw above in the equation

$$\text{Force} = \text{Pressure} \times \text{Area}.$$




Pascal's law explains why fluid can be used to transmit pressure in a car lift.

Besides hydraulic car lifts, other equipment that uses hydraulic fluid to increase force ranges from brakes to bulldozers. Even the controls in airplanes use hydraulics. Because of the force-multiplying effect, a flick of a switch can raise or lower heavy wing flaps or landing gear. You can see animations of hydraulic systems at this URL:

- http://science.howstuffworks.com/transport/engines-equipment/hydraulic1.htm

**Bernoulli's Law**

Another important law about pressure in fluids was described by Daniel Bernoulli, a Swiss mathematician who lived during the 1700s. Bernoulli used mathematics to arrive at his law. **Bernoulli's law** states that pressure in a moving fluid is less when the fluid is moving faster. For an animation of this law, go to the URL below.

http://mitchellscience.com/bernoulli_law_animation

Bernoulli's law explains how the wings of both airplanes and birds create lift that allows flight (see **Figure** below). The shape of the wings causes air to flow more quickly — and air pressure to be lower — above the wings than below them. This allows the wings to lift the plane or bird above the ground against the pull of gravity. A spoiler on a race car, like the one in **Figure** below, works in the opposite way. Its shape causes air to flow more slowly — and air pressure to be greater — above the spoiler than below it. As a result, air pressure pushes the car downward, giving its wheels better traction on the track.

The wings of airplanes and birds give them left. This allows the plane to take off the ground and the hawk to soar high in the air without flapping its wings.

The spoiler across the back of this car acts like an inverted wing. It causes air pressure to push the car towards the groud. How does this increase friction between the wheels and the road?

## Lesson Review Questions

### Recall

1. Define pressure.
2. What is the SI unit for pressure?
3. Identify two factors that affect the pressure of fluids.
4. Describe how pressure changes with depth in fluids.

### Apply Concepts

5. Apply Pascal's law to explain why squeezing one end of a toothpaste tube causes toothpaste to squirt out the other end.
6. A box weighing 200 N is resting on the ground on an area of 1 $m^2$. How much pressure is the box exerting on the ground?

### Think Critically

7. Explain why fluids exert pressure.
8. Relate Bernoulli's law to lift in an airplane.