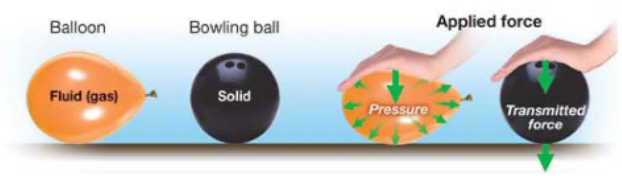
10.3 Properties of Fluids

A **fluid** is defined as any matter that flows when force is applied. Liquids, such as water, are one kind of fluid. Gases, such as air, are also fluids. You might notice cool air flowing into a room when a window is open, or the smell of someone's perfume drifting your way. These examples provide evidence that gases flow. What are some other properties of fluids?

Pressure

Forces in fluids When you push down on a bowling ball, what happens? Because the bowling ball is a solid, the force is transmitted down in the same direction as the applied force. Now, what happens when you push down on an inflated balloon? The downward force you apply creates forces that act sideways as well as down. The balloon is filled with air, a fluid. Because fluids change shape, forces in fluids are more complicated than forces in solids.



Pressure A force applied to a fluid creates **pressure**. Pressure acts in all directions, not just the direction of the applied force. When you inflate a car tire, you are increasing the pressure in the tire. This force acts up, down, and sideways in all directions inside the tire.

Units of pressure The units of pressure are force divided by area (Figure 10.13). If your car tires are inflated to 35 pounds per square inch (35 psi), then a force of 35 pounds acts on every square inch of area inside the tire. The pressure on the bottom of the tire is what holds up the car! The SI unit of pressure is the **pascal** (Pa). One pascal is one newton of force per square meter of area (N/m^2).

VOCABULARY

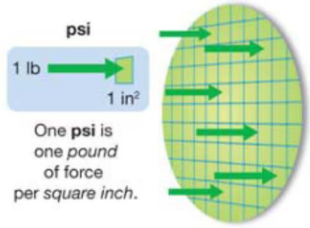
fluid - any matter that flows when force is applied.

pressure - the amount of force exerted per unit of area.

pascal - the SI unit of pressure equal to one newton of force per square meter of area.

Units of Pressure

Pressure is force per unit of area.



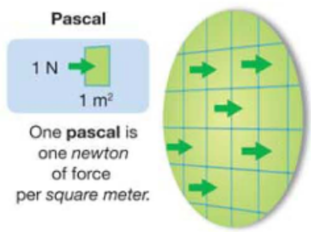


Figure 10.13: *Comparing units of pressure.*

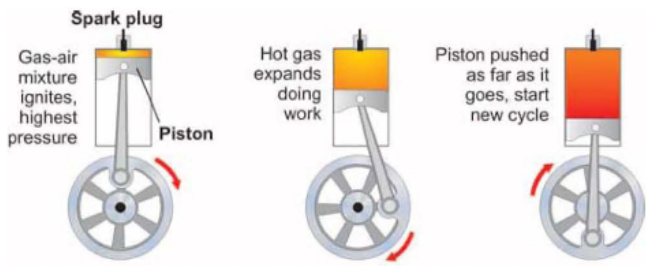
Pressure, energy, and force

The atomic level explanation

What causes pressure? On the atomic level, pressure comes from collisions between atoms and molecules. Look at Figure 10.14. Molecules move around and bounce off each other and off the walls of the pitcher. It takes force to make a molecule reverse its direction and bounce the other way. The bouncing force is applied *to* the molecule *by* the inside surface of the pitcher. According to Newton's third law, an equal and opposite reaction force is exerted *by* the molecule *on* the pitcher. The reaction force is what creates the pressure acting on the inside surface of the pitcher. Trillions of molecules per second are constantly bouncing against every square millimeter of the inner surface of the pitcher. Pressure comes from the collisions of those many, many molecules.

Pressure is potential energy

Differences in pressure create potential energy in fluids just like differences in height create potential energy from gravity. A pressure difference of one newton per m^2 is equivalent to a potential energy of one joule per m^3. We get useful work when we allow a fluid under pressure to expand. In a car engine, high pressure is created by an exploding gasoline–air mixture. This pressure pushes the cylinders of the engine down, doing work that moves the car.



An engine uses pressure in an expanding gas to do work.

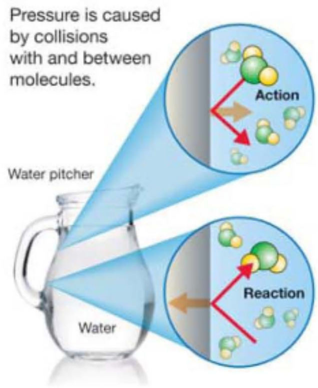


Figure 10.14: *Pressure comes from constant collisions of trillions of molecules.*

CHALLENGE

Car tires are usually inflated to a pressure of 32–40 pounds per square inch (psi). Racing bicycle tires are inflated to a much higher pressure, 100–110 psi. A bicycle and rider are much lighter than a car. Why is the pressure in a bicycle tire higher than the pressure in a car tire?

Bernoulli's principle

Bernoulli's principle Everything obeys the law of energy conservation. But this energy conservation is more challenging to explain in a flowing fluid such as water coming out of a hole in a container. In addition to potential and kinetic energy, the fluid also has *pressure energy*. If friction is ignored, the total energy stays constant for any particular sample of fluid. This relationship is known as **Bernoulli's principle**.

Streamlines *Streamlines* are imaginary lines drawn to show the flow of fluid. We draw streamlines so that they are always parallel to the direction of flow. If water is coming out of a hole in a container, the streamlines look like the one shown in Figure 10.15. Bernoulli's principle tells us that the energy of any sample of fluid moving along a streamline is constant.

Bernoulli's principle

Form of energy	Potential energy	Kinetic energy	Pressure energy	=	Constant along any streamline in a fluid
Variable	height	speed	pressure		

The three variables Bernoulli's principle says the three variables of height, pressure, and speed are related by energy conservation. Height is associated with potential energy, speed with kinetic energy, and pressure with pressure energy. If one variable increases along a streamline, *at least one of the other two must decrease*. For example, if speed goes up, pressure goes down.

The airfoil An important application of Bernoulli's principle is the airfoil shape of wings on a plane (Figure 10.16). The shape of an airfoil causes air flowing along the top (A) to move faster than air flowing along the bottom (B). According to Bernoulli's principle, if the speed goes up, the pressure goes down. When a plane is moving, the pressure on the top surface of the wings is lower than the pressure beneath the wings. The difference in pressure is what creates the lift force that supports the plane in the air.

VOCABULARY

Bernoulli's principle - a relationship that describes energy conservation in a fluid.

Figure 10.15: *Streamlines are imaginary lines drawn to show the flow of a fluid.*

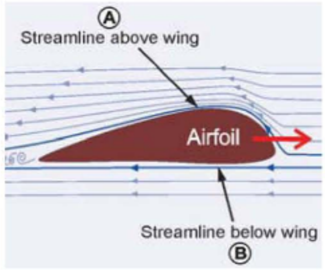


Figure 10.16: *Streamlines showing air moving from right to left around an airfoil (wing).*

Pressure, volume and density of gases

How gases are different from liquids Gases are fluids but they are different from liquids because the molecules in a gas are completely separated from each other. Because gas molecules act independently, gases are free to expand or contract. Unlike liquids, a gas will expand to completely fill its container.

Pressure and volume When you squeeze a fixed quantity of gas into a smaller volume, the pressure goes up (Figure 10.17). This rule is known as **Boyle's law**. The pressure increases because the same number of molecules are now squeezed into a smaller space. The molecules hit the walls more often because there are more of them per unit of area. The formula for Boyle's law relates the pressure and volume of gas. If the mass and temperature are kept constant, the product of the pressure multiplied by the volume stays the same.

BOYLE'S LAW

$$P_1 V_1 = P_2 V_2$$

Initial pressure (P_1), Initial volume (V_1), New pressure (P_2), New volume (V_2)

Mass and temperature remain constant

Pressure and density The density of a gas *usually* increases when the pressure increases. (We say "usually" because density and pressure are also affected by temperature.) By increasing the pressure you are doing one of two things: squeezing the same amount of mass into a smaller volume, or squeezing more mass into the same volume. Either way, the density goes up. For example, air has a density of 0.0009 g/cm^3 at atmospheric pressure. When compressed in a diving tank to 150 times higher pressure, the density is about 0.135 g/cm^3. The density of a gas can vary from near zero (in outer space) to greater than the density of some solids. This is very different from the behavior of liquids or solids.

VOCABULARY

Boyle's law - in a fixed quantity of a gas, the pressure and volume are inversely related if the mass and temperature are held constant.

Figure 10.17: *Compressing the volume of air to increase the pressure.*

Boyle's law graph The inverse relationship between pressure and volume for a gas, when temperature remains constant, is evident in the graph in Figure 10.18. The example below shows you how to solve problems using Boyle's law.

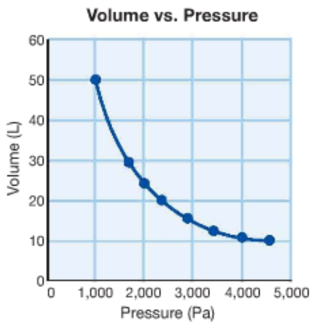


Figure 10.18: *This graph shows the relationship between the pressure and volume of a gas when the temperature does not change.*

Solving Problems: Boyle's Law

Another unit of pressure is the atmosphere (atm). One atm = 101,325 pa. A kit used to fix flat tires consists of an aerosol can containing compressed air and a patch to seal the hole in the tire. Suppose 5 liters of air at 1 atm is compressed into a 0.5 liter aerosol can. What is the pressure, in atm, of the compressed air in the can? Assume no change in temperature or mass.

1. Looking for: You are looking for the pressure inside an aerosol can.

2. Given: You are given initial volume (in liters), initial pressure (in atmospheres), and final volume.

3. Relationships: Use Boyle's law, $P_1V_1 = P_2V_2$; rearrange variables to solve for P_2:

$$P_2 = \frac{P_1 \times V_1}{V_2}$$

4. Solution: Plug in the numbers and solve:

$$P_2 = \frac{1\ \text{atm} \times 5.0\ \text{L}}{0.5\ \text{L}} = 10\ \text{atm}$$

Your turn...

a. 0.50 L of O_2 is collected at a pressure of 0.50 atm. What volume will this gas occupy at sea level (1 atm) at constant temperature and mass?

b. 1.0 L of helium is stored at sea level (1 atm). If the gas is carried to the top of Mt. Washington (pressure = 0.80 atm), what volume will it occupy at constant temperature and mass?

SOLVE FIRST LOOK LATER

a. 0.25 L

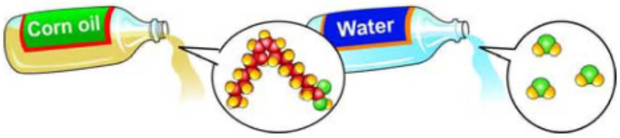
b. 1.2 L

Viscosity

What is viscosity? **Viscosity** is the measure of a fluid's resistance to flow. High-viscosity fluids take longer to pour from their containers than low-viscosity fluids. Ketchup, for example, has a high viscosity and water has a low viscosity.

Viscosity and motor oils Viscosity is an important property of motor oils. If an oil is too thick, it might not flow quickly enough to parts of an engine. However, if an oil is too thin, it might not provide enough "cushion" to protect the engine from the effects of friction. A motor oil must function properly when the engine is started on a bitterly cold day, and when the engine is operating at high temperatures (see Science Fact on the next page).

Viscosity and particles Viscosity is determined in large part by the shape and size of the particles in a liquid. If the particles are large and have bumpy surfaces, a great deal of friction will be created as they slide past each other. For instance, corn oil is made of large, chain-like molecules. Water is made of much smaller molecules. As a result, corn oil has greater viscosity than water. This is especially interesting when you consider that corn oil is less dense than water.



As a liquid gets warmer, its viscosity decreases As the temperature of a liquid is raised, the viscosity of the liquid decreases. In other words, warm liquids have less viscosity than cold liquids. Fudge topping, for example, is much easier to pour when it's warm than when it's chilled. Also, if you heat corn oil on the stove you would notice that the viscosity decreases. Why is this? When temperature rises, the vibration of molecules increases. This allows molecules to slide past each other with greater ease. As a result, the viscosity decreases (Figure 10.19).

VOCABULARY

viscosity - a measure of a fluid's resistance to flow.

Figure 10.19: *Heating fudge topping decreases viscosity so it is much easier to pour.*

Section 10.3 Review

1. Explain why liquid silver is less dense than solid silver.
2. The pressure at the bottom of Earth's atmosphere is about 100,000 N/m^2. This means there is a force of 100,000 N acting on every square meter of area! Your body has about 1.5 square meters of surface. Why aren't you crushed by the atmosphere?
3. The pressure at the bottom of the ocean is great enough to crush submarines with solid steel walls that are ten centimeters thick. At a depth of 1,000 meters, the weight of water pushing on each square meter of the submarine is 9,800,000 newtons.

PRESSURE

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

   a. What is the pressure exerted on the submarine at 1,000 m?
   b. How does this pressure compare with the air pressure we experience every day on Earth's surface (100,000 N/m^2)?
4. What does pressure have to do with how a car engine works?
5. Bernoulli's principle relates the speed, height, and pressure in a fluid. Suppose streamline speed goes up and height stays the same. What happens to the pressure?
6. Boyle's law states that if you squeeze a fixed amount of a gas into a smaller volume, the pressure will increase. Explain why in your own words.
7. At the atomic level, what causes fudge topping to pour faster when it is heated?

SCIENCE FACT

Motor Oil Numbers

Numbers on the label of a quart of motor oil are based on a scale established by the Society of Automotive Engineers (SAE). The first number indicates the lowest temperature at which the oil will work well (–10°F in this case). The *W* means the oil works well in cold weather. The second number is a grade for the oil: 50 is best for hot-weather driving, 30 for cold-weather driving, and 40 for mild weather temperatures.