4.14 GAS LAWS: WHY GASES BEHAVE THE WAY THEY DO

PRACTICE

(Page 335)

Understanding Concepts

1. One property of a gas is that a gas assumes the shape and volume of the container. A second property is that a gas is highly compressible; since there are large spaces between gas particles, the volume of a gas can be easily reduced. The third main property of a gas is that it flows readily because there are little or no forces between the particles.
2. Atmospheric pressure is the force per unit area exerted on all objects in the atmosphere by air particles. This pressure is created when moving air particles collide with the surface of Earth, objects on the surface, and with each other.
3. The pressure within a container of gas results from the gas particles colliding with the walls of the container and with each other.
4. $v_1 = 0.650$ L
   $p_1 = 100$ kPa (at SATP)
   $v_2 = 0.250$ L
   $p_2 = ?$

   $$p_1v_1 = p_2v_2$$
   $$p_2 = \frac{p_1v_1}{v_2}$$
   $$= \frac{100\ \text{kPa} \times 0.650\ \text{L}}{0.250\ \text{L}}$$
   $$p_2 = 260\ \text{kPa}$$

   The pressure required to change the volume of the bicycle pump is 260 kPa.
5. $v_1 = 110$ mL = 0.110 L
   $p_1 = 300$ kPa
   $p_2 = 200$ kPa
   $v_2 = ?$

   $$p_1v_1 = p_2v_2$$
   $$v_2 = \frac{p_1v_1}{p_2}$$
   $$= \frac{300\ \text{kPa} \times 0.110\ \text{L}}{200\ \text{kPa}}$$
   $$v_2 = 0.165\ \text{L}$$

   The final volume of the balloon is 0.16 L, or 16 mL.

PRACTICE

(Page 338)

Understanding Concepts

6. $v_1 = 1.0$ L
   $T_1 = 20°\text{C} + 273 = 293$ K
   $T_2 = 80°\text{C} + 273 = 353$ K
   $v_2 = ?$

$$\frac{v_1}{T_1} = \frac{v_2}{T_2}$$

$$v_2 = \frac{v_1T_2}{T_1}$$

$$= \frac{1.0\ \text{L} \times 353\ \text{K}}{293\ \text{K}}$$

$$v_2 = 1.2\ \text{L}$$

Every initial 1.0 L of air at 20°C increases to 1.2 L when heated to 80°C.

7. (a) $v_1 = 2.0$ L
   $T_1 = 5°\text{C} + 273 = 278$ K
   $T_2 = 21°\text{C} + 273 = 294$ K
   $v_2 = ?$

   $$\frac{v_1}{T_1} = \frac{v_2}{T_2}$$

   $$v_2 = \frac{v_1T_2}{T_1}$$

   $$= \frac{2.0\ \text{L} \times 294\ \text{K}}{278\ \text{K}}$$

   $$v_2 = 2.1\ \text{L}$$

   The volume of air in the bottle will expand to 2.1 L.

   (b) 2.12 L – 2.00 L = 0.12 L
   The volume of air that will escape from the bottle is 0.12 L.

8. (a) Given that the boiling point of butane is –0.5°C, the butane in a lighter will be in liquid form at –11°C. Therefore, very little, if any, butane gas will be released at temperatures colder than –0.5°C.
   (b) Butane lighters do not work well at very cold temperatures because very little or no butane gas is present inside the container. Almost all of the butane will be in liquid form at temperatures below –0.5°C.

9. $v_1 = 1.5\ \text{L} - 1.0\ \text{L} = 0.5$ L
   $T_1 = 22°\text{C} + 273 = 295$ K
   $T_2 = 100°\text{C} + 273 = 373$ K
   $v_2 = ?$

   $$\frac{v_1}{T_1} = \frac{v_2}{T_2}$$

   $$v_2 = \frac{v_1T_2}{T_1}$$

   $$= \frac{0.5\ \text{L} \times 373\ \text{K}}{295\ \text{K}}$$

   $$v_2 = 0.6\ \text{L}$$

   The volume of gas in the pot will increase from 0.5 L to 0.6 L when heated from 22°C to 100°C. Thus, 0.1 L of gas will escape during heating.

PRACTICE

(Page 339)

Understanding Concepts

10. From the kinetic molecular theory, gases consist of many particles that are constantly moving, and colliding with each other and with the walls of the container. The force of the collisions of gas particles with the walls of the container is the pressure exerted by a gas.

11. (a) If the number of oxygen molecules in a container is increased by a factor of 2 (100 molecules + 100 molecules), while the temperature and volume of the container remain constant, the pressure in the container will also increase two-fold. Twice as many molecules means that there are twice as many collisions with the walls of the container.
    (b) If 100 nitrogen molecules are added to 100 oxygen molecules in a container, while the temperature and volume of the container remain constant, the number of gas molecules will increase two-fold, causing a two-fold increase in pressure. Twice as many molecules means that there are twice as many collisions with the walls of the container.
    (c) Nitrogen gas and oxygen gas are nonreactive gases. Thus, the pressure will increase by a factor of two. This increase confirms Dalton's law of partial pressures, which states that the total pressure of a mixture of nonreacting gases is equal to the sum of the partial pressures of the individual gases.
12. Since the temperature and the volume remain constant, the pressure exerted by the carbon dioxide gas would still be 2 kPa.

SECTION 4.14 QUESTIONS

(Pages 341–342)

Understanding Concepts

1. (a) One common property of solids and liquids is that both have a defined volume. The strong or relatively strong intermolecular forces in solids and liquids keep the particles close together, thus giving a constant volume.
   (b) One property that differs between solids and liquids is shape. Solids have a defined shape, whereas the shape of a liquid is defined by its container. The forces between the liquid particles, although relatively strong, are weak enough to allow the particles to move past one another.
2. (a) There is little or no force between gas molecules at room temperature.
   (b) Gas particles move independently of one another in a straight-line motion.
3. (a) As the partially inflated balloon rises through the atmosphere, the atmospheric pressure exerted on the outside of the balloon decreases. Assuming constant temperature, the force exerted by the gas particles (the pressure) in the balloon will be higher than the pressure outside the balloon at increased altitude, causing the balloon to increase in size.
   (b) A carbonated drink is bottled under pressure so that more carbon dioxide will dissolve in solution. At sea level, when the drink is opened, the pressure drops back to atmospheric pressure and the carbon dioxide fizzes out and produces bubbles. Since atmospheric pressure decreases as altitude increases, at a high elevation, the atmospheric pressure is lower than at sea level and, thus, more bubbles will be produced as more carbon dioxide comes out of solution.
4. (a) 25°C = 298 K
   (b) 30°C = 303 K
   (c) –35°C = 238 K
   (d) 312K = 39°C
   (e) 208K = –65°C
5. (a) $v_1 = 27$ L
   $p_1 = 225$ kPa
   $p_2 = 98$ kPa
   $v_2 = ?$

$$p_1v_1 = p_2v_2$$

$$v_2 = \frac{p_1v_1}{p_2}$$

$$= \frac{225\ \text{kPa} \times 27\ \text{L}}{98\ \text{kPa}}$$

$$v_2 = 62\ \text{L}$$

   The final volume of air inside the tire would be 62 L if it escaped into the atmosphere.

(b) Compare the ratio of the new volume, v_2 with the old volume, v_1.

$$\frac{v_2}{v_1} = \frac{62\ \text{L}}{27\ \text{L}}$$
$$= 2.3$$

The new volume of the escaped gas is 2.3 times the old volume.
The ratio of pressure, p_2 compared with pressure, p_1:

$$\frac{p_1}{p_2} = \frac{225\ \text{kPa}}{98\ \text{kPa}}$$
$$= 2.3$$

The ratio of the volume change $\left(\frac{v_2}{v_1}\right)$ equals the inverse of the ratio of change in pressure $\left(\frac{p_1}{p_2}\right)$. Therefore, the pressure is inversely related to volume of a gas.

$$\frac{v_2}{v_1} = \frac{p_1}{p_2}$$

6. $v_1 = x$ L
$p_1 = 100$ kPa
$p_2 = 25$ kPa
$v_2 = ?$

$$p_1v_1 = p_2v_2$$
$$\frac{p_1}{p_2} = \frac{v_2}{v_1}$$
$$\frac{100\ \text{kPa}}{25\ \text{kPa}} = \frac{v_2}{x\ \text{L}}$$
$$v_2 = 4x\ \text{L}$$

Therefore, as the pressure decreases by a factor of 4 (100 kPa to 25 kPa), the volume of the balloon would increase by a factor of 4. The two assumptions that must be made are that the temperature and the amount of gas in the balloon remain constant.

7. $v_1 = 50$ mL = 0.050 L
$p_1 = 100$ kPa
$v_2 = 10$ mL = 0.010 L
$p_2 = ?$

$$p_1v_1 = p_2v_2$$
$$p_2 = \frac{p_1v_1}{v_2}$$
$$= \frac{100\ \text{kPa} \times 0.050\ \text{L}}{0.010\ \text{L}}$$
$$p_2 = 500\ \text{kPa}$$

The final pressure of the gas would be 500 kPa, or five times the original pressure.

8. $v_1 = 0.5$ L
$T_1 = 25°\text{C} + 273 = 298$ K
$T_2 = 200°\text{C} + 273 = 473$ K
$v_2 = ?$

$$\frac{v_1}{T_1} = \frac{v_2}{T_2}$$

$$v_2 = \frac{v_1 T_2}{T_1}$$

$$= \frac{0.5\ \text{L} \times 473\ \text{K}}{298\ \text{K}}$$

$$v_2 = 0.8\ \text{L}$$

The final volume of carbon dioxide in the loaf of bread will be 0.8 L.

Applying Inquiry Skills

9. **Prediction**

(a) As the temperature of a gas increases, the pressure would also increase. As the temperature of a gas increases, the molecules move faster and there are more collisions with the sides of the cylinder.

Analysis

(b) **Figure 1** is a graph of the data in **Table 2**. Using the graph, we can see that gas pressure is directly proportional to temperature.

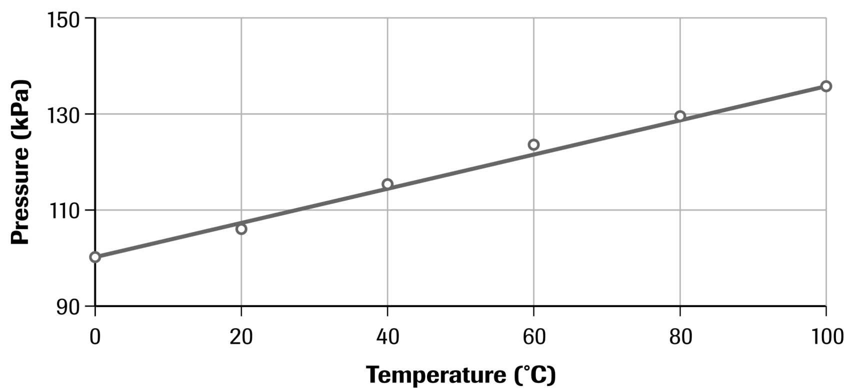


Figure 1: Pressure–temperature graph

Evaluation

(c) Analysis of the data supports the prediction that temperature and gas pressure are directly related.

10. Students' reports will vary. A sample report is provided.

Question

What effect does air pressure have on the size and shape of a marshmallow?

Prediction

The volume of a marshmallow will increase as the surrounding air pressure is reduced. The overall shape of the marshmallow will remain the same.

Procedure

1. Obtain a large marshmallow. Carefully measure the length and width of the marshmallow.
   (a) Record your observations in **Table 1**.
2. Place the marshmallow next to two rulers inside a pressure chamber. Seal the pressure chamber tightly.
   (b) Record the initial air pressure in the chamber in **Table 1**.
3. Using a pump or other vacuum source, slowly remove air from the chamber.
4. At regular intervals, record the air pressure in the chamber. Measure the length and width of the marshmallow using the rulers inside the chamber. Observe any changes to the shape of the marshmallow.

Table 1 Dimensions of Marshmallow Relative to Air Pressure

Air pressure	Marshmallow		
	length (cm)	**width (cm)**	**shape (description)**
100 kPa			

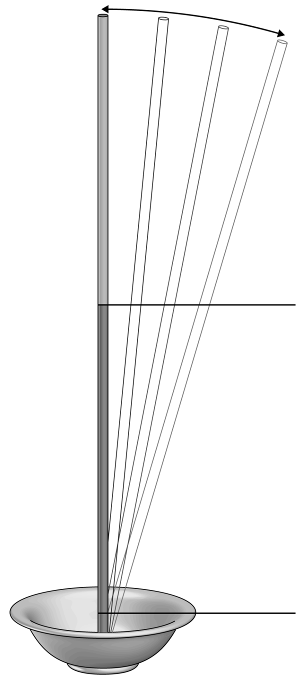
11. By reducing the volume of a container to one quarter of its original volume, the gas pressure in the container would increase by a factor of four, assuming that temperature and amount of gas in the container remain constant.

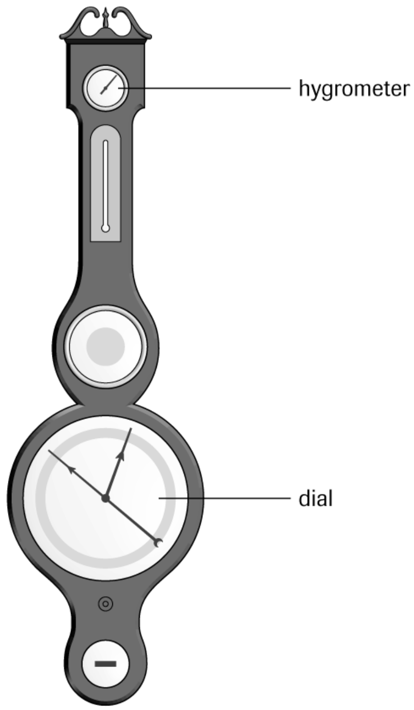
Making Connections

12. As the rubber bulb of the meat baster is squeezed, most of the air in the bulb is expelled. When the tip of the baster is placed into the meat juice and the bulb is released, an area of low air pressure is formed in the bulb. This low pressure is caused by increasing the volume of the bulb with a fixed amount of air molecules inside. The pressure on the juice on the outside of the baster is now greater than the pressure inside the baster. The greater air pressure outside pushes the liquid up the baster.
13. Student answers may vary. A barometer, an instrument used in the science of meteorology, measures atmospheric pressure. Evangelista Torricelli is credited with the invention of the barometer in 1643. However, Gasparo Berti actually built the first barometer while trying to produce a vacuum a few years earlier.

Table 2 Invention and Refinement of the Barometer

Date	Person	Description
1630	Galileo Galilei	Galileo was asked to explain why water did not rise and travel over a hill 21 m high through a siphon. It was believed that a suction pump worked because, as the pump created a vacuum, the water would rise to fill the space. It was also believed that there was no limit to the height to which water could be raised. Galileo investigated and found that a suction pump could only raise a column of water 11 m. Galileo asked his student Torricelli to solve the problem.
1631	René Descartes	Descartes described the design of an experiment on atmospheric pressure determination, but there is no evidence that he built a working barometer at that time.
c. 1640	Gasparo Berti	Gasparo Berti performed similar experiments to Torricelli's while working on Galileo's problem. Berti constructed a long lead tube and attached it to his house. After filling the tube with water and sealing the top, when he put the opened end of the tub into a pail of water, the water level in the tube dropped and then maintained a level. Berti realized that he had produced a vacuum in the tube above the water line, but did not realize he had also just built the first barometer.

Date	Person	Description
1643	Evangelista Torricelli & Vincenzo Viviani	Torricelli devised an experiment, conducted by his student Vincenzo Viviani, in which they constructed the prototype mercury barometer (**Figure 2**). The tube was filled with mercury and inverted into a basin filled with mercury. The height of the mercury column fell to a level of 76 cm and then remained fairly steady. Torricelli believed that the pressure the air exerted on the mercury in the basin kept the mercury column at 76 cm. He also believed that the space above the mercury in the tube was a true and stable vacuum.  **Figure 2:** Torricelli's barometer
1648	Blaise Pascal	Pascal hypothesized that air pressure decreased with altitude above sea level. He and his brother-in-law, Florin Perier, carried a barometer up to the peak of a mountain in France. As Pascal predicted, the height of the mercury column had decreased by 8.6 cm at the 1490-m summit.

Date	Person	Description
1665	Robert Hooke	Hooke created the wheel barometer, which had a circular scale and dial assembly to the mercury barometer (**Figure 3**).  **Figure 3**: Hooke's wheel barometer
1669	Robert Boyle	Boyle described the pressure-measuring instrument as a barometer in his plans for a portable barometer.
c. 1700	Gottfried Wilhelm Leibniz	Leibniz described, but never built, an *aneroid* (without liquid) barometer. Pressure changes were detected using a sealed bellows.
1843	Lucien Vidie	Vidie built the first working version of the aneroid barometer. The aneroid barometer was very portable, and become a common meteorological instrument.
Present		Today, barometers contain sensitive electronic sensors instead of metal aneroid cells.

4.15 EXPLORE AN ISSUE: CANADA AND THE KYOTO PROTOCOL

Understanding the Issue

(Page 349)

1. Earth's atmosphere is sometimes referred to as a "sink" because it acts as a reservoir for airborne wastes, such as those from industrial activities.
2. (a) Ozone is formed in the stratosphere. UV radiation reacts with oxygen gas to produce oxygen atoms, which are very reactive. The oxygen atoms react with oxygen molecules to form ozone.
   $O_{2(g)} + \text{UV energy} \rightarrow O_{(g)} + O_{(g)}$
   $O_{(g)} + O_{2(g)} \rightarrow O_{3(g)}$
   (b) The ozone in the stratosphere absorbs UV radiation and decomposes back into oxygen molecules and oxygen atoms.
   $O_{3(g)} + \text{UV energy} \rightarrow O_{2(g)} + O_{(g)}$
   (c) Chlorofluorocarbons (CFCs) are relatively inert. Thus, the molecules remain unchanged until they reach the stratosphere. UV radiation causes single chlorine atoms to split off from the CFC molecule. These chlorine