Section 14.2

The Combined Gas Law and Avogadro's Principle

Objectives

- **State** the relationship among temperature, volume, and pressure as the combined gas law.
- **Apply** the combined gas law to problems involving the pressure, temperature, and volume of a gas.
- **Relate** numbers of particles and volumes by using Avogadro's principle.

Vocabulary

combined gas law
Avogadro's principle
molar volume

In the previous section, you applied the three gas laws covered so far to problems in which either pressure, volume, or temperature of a gas sample was held constant as the other two changed. As illustrated in **Figure 14-6**, in a number of applications involving gases, all three variables change. If all three variables change, can you calculate what their new values will be? In this section you will see that Boyle's, Charles's, and Gay-Lussac's laws can be combined into a single equation that can be used for just that purpose.

The Combined Gas Law

Boyle's, Charles's, and Gay-Lussac's laws can be combined into a single law. This **combined gas law** states the relationship among pressure, volume, and temperature of a fixed amount of gas. All three variables have the same relationship to each other as they have in the other gas laws: Pressure is inversely proportional to volume and directly proportional to temperature, and volume is directly proportional to temperature. The equation for the combined gas law can be expressed as

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

As with the other gas laws, this equation allows you to use known values for the variables under one set of conditions to find a value for a missing variable under another set of conditions. Whenever five of the six values from the two sets of conditions are known, the sixth can be calculated using this expression for the combined gas law.

This combined law lets you work out problems involving more variables that change, and it also provides a way for you to remember the other three laws without memorizing each equation. If you can write out the combined gas law equation, equations for the other laws can be derived from it by remembering which variable is held constant in each case.

For example, if temperature remains constant as pressure and volume vary, then $T_1 = T_2$. After simplifying the combined gas law under these conditions, you are left with

$$P_1V_1 = P_2V_2$$

You should recognize this equation as the equation for Boyle's law. See whether you can derive Charles's and Gay-Lussac's laws from the combined gas law.

Figure 14-6

Constructing an apparatus that uses gases must take into account the changes in gas variables such as pressure, volume, and temperature that can take place. As a hot-air balloonist ascends in the sky, pressure and temperature both decrease, and the volume of the gas in the balloon is affected by those changes.

EXAMPLE PROBLEM 14-4

The Combined Gas Law

A gas at 110 kPa and 30.0°C fills a flexible container with an initial volume of 2.00 L. If the temperature is raised to 80.0°C and the pressure increased to 440 kPa, what is the new volume?

1. Analyze the Problem

You are given the initial pressure, temperature, and volume of a gas sample as well as the final pressure and temperature. The volume of a gas is directly proportional to kelvin temperature, so volume increases as temperature increases. Therefore the volume should be multiplied by a temperature factor greater than one. Volume is inversely proportional to pressure, so as pressure increases, volume decreases. Therefore the volume should be multiplied by a pressure factor that is less than one.

Known	Unknown
P_1 = 110 kPa	V_2 = ? L
T_1 = 30.0°C	
V_1 = 2.00 L	
T_2 = 80.0°C	
P_2 = 440 kPa	

2. Solve for the Unknown

Add 273 to the Celsius temperature to obtain the kelvin temperature.

$T_K = 273 + T_C$

Substitute the known Celsius temperatures for T_1 and T_2 to convert them to kelvin units.

$T_1 = 273 + 30.0°C = 303\ K$

$T_2 = 273 + 80.0°C = 353\ K$

Multiply both sides of the equation for the combined gas law by T_2 and divide it by P_2 to solve for V_2.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$V_2 = V_1\left(\frac{P_1}{P_2}\right)\left(\frac{T_2}{T_1}\right)$$

Substitute the known values into the rearranged equation.

$$V_2 = 2.00\ L\left(\frac{110\ kPa}{440\ kPa}\right)\left(\frac{353\ K}{303\ K}\right)$$

Multiply and divide numbers and units to solve for V_2.

$$V_2 = 2.00\ L\left(\frac{110\ \cancel{kPa}}{440\ \cancel{kPa}}\right)\left(\frac{353\ \cancel{K}}{303\ \cancel{K}}\right) = 0.58\ L$$

3. Evaluate the Answer

Increasing the temperature causes the volume to increase, but increasing the pressure causes the volume to decrease. Because the pressure change is much greater than the temperature change, the volume undergoes a net decrease. The calculated answer agrees with this. The unit is L, a volume unit.

Math Handbook

Review rearranging algebraic equations in the **Math Handbook** on page 897 of this textbook.