10.2: The Gas Laws

The behavior of gases in the atmosphere is governed by several fundamental **gas laws** which are covered briefly here. In using these laws, it should be kept in mind that the quantity of gas is most usefully expressed in numbers of moles. There are many units of pressure, but the most meaningful conceptually is the **atmosphere** (atm) where 1 atmosphere is the average pressure of air in the atmosphere at sea level. (Air has pressure because of the mass of all the molecules of air pressing down from the atmosphere above; as altitude increases, this pressure becomes less.) For calculations involving temperature, the **absolute** temperature scale is used in which each degree is the same size as a degree Celsius (or Centigrade, the temperature scale used for scientific measurements and for temperature readings in most of the world), but zero is 273 degrees below the freezing point of water, which is taken as zero on the Celsius scale. Three important gas laws are the following:

> **Avogadro's law:** At constant temperature and pressure the volume of a gas is directly proportional to the number of moles; doubling the number of moles at a constant temperature and pressure doubles the volume.
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> **Charles' law:** At constant pressure the volume of a fixed number of moles of gas is directly proportional to the absolute temperature (degrees Celsius +273) of the gas; doubling the absolute temperature at constant pressure doubles the volume.**Boyle's law:**
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> At constant temperature the volume of a fixed number of moles of gas is inversely proportional to the pressure; doubling the pressure halves the volume.

These three laws are summarized in the **general gas law** relating volume (V), pressure (P), number of moles (n), and absolute temperature (T) expressed as

$$\mathrm{PV{=}nRT} \tag{10.2.1}$$

where R is a constant.

Mathematical calculations involving the gas laws are simple. One of the most common such calculations is that of changes in volume resulting from changes in pressure, temperature, or moles of gas. The parameter that does not change is the constant R. Using subscripts to represent conditions before and after a change yields the following relationship:

$$R = \frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2} \tag{10.2.2}$$

This equation can be arranged in a form that can be solved for a new volume resulting from changes in P, n, or T

$$V_2 = V_1 \times \frac{n_2T_2P_1}{n_1T_1P_2} \tag{10.2.3}$$

As an example, calculate the volume of a fixed number of moles of gas initially occupying 12.0 liters when the temperature is changed from 10°C to 90°C at constant pressure. In order to use these temperatures, they must be changed to absolute temperature by adding 273°. Therefore, T_1=10° + 273° = 283° , and T_2= 90° + 273° = 363°. Since n and P remain constant, they cancel out of the equation yielding

$$V_2 = V_1 \times \frac{T_2}{T_1} = 12.0L \times \frac{363^\circ}{283^\circ} = 15.4L \tag{10.2.4}$$

As another example consider the effects of a change of pressure, holding both the temperature and number of moles constant. Calculate the new volume of a quantity of gas occupying initially 16.0 L at a pressure of 0.900 atm when the pressure is changed to 1.20 atm. In this case, both n and T remain the same and cancel out of the equation giving the following relationship:

$$V_2 = V_1 \times \frac{P_1}{P_2} = 16.0L \times \frac{0.900\text{ atm}}{1.20\text{ atm}} = 12.0L \tag{10.2.5}$$

Note that an increase in temperature *increases* the volume and an increase in pressure *decreases* the volume.