1.8.7: Ideal Gas Law

There are a number of chemical reactions that require ammonia. In order to carry out a reaction efficiently, we need to know how much ammonia we have for stoichiometric purposes. Using gas laws, we can determine the number of moles present in the tank if we know the volume, temperature, and pressure of the system.

Ideal Gas Law

The combined gas law shows that the pressure of a gas is inversely proportional to volume and directly proportional to temperature. Avogadro's Law shows that volume or pressure is directly proportional to the number of moles of gas. Putting these laws together gives us the following equation:

$$\frac{P_1 \times V_1}{T_1 \times n_1} = \frac{P_2 \times V_2}{T_2 \times n_2}$$

As with the other gas laws, we can also say that $\frac{(P \times V)}{(T \times n)}$ is equal to a constant. The constant can be evaluated provided that the gas being described is considered to be ideal.

The **ideal gas law** is a single equation which relates the pressure, volume, temperature, and number of moles of an ideal gas. If we substitute in the variable R for the constant, the equation becomes:

$$\frac{P \times V}{T \times n} = R$$

The ideal gas law is conveniently rearranged to look this way, with the multiplication signs omitted:

$$PV = nRT$$

The variable R in the equation is called the **ideal gas constant**.

Evaluating the Ideal Gas Constant

The value of R, the ideal gas constant, depends on the units chosen for pressure, temperature, and volume in the ideal gas equation. It is necessary to use Kelvin for the temperature and it is conventional to use the SI unit of liters for the volume. However, pressure is commonly measured in one of three units: kPa, atm, or mm Hg. Therefore, R can have three different values.

We will demonstrate how R is calculated when the pressure is measured in kPa. Recall that the volume of 1.00 mol of any gas at STP is measured to be 22.414 L We can substitute 101.325 kPa for pressure, 22.414 L for volume, and 273.15 K for temperature into the ideal gas equation and solve for R.

$$R = \frac{PV}{nT} = \frac{101.325 \text{ kPa} \times 22.414 \text{ L}}{1.000 \text{ mol} \times 273.15 \text{ K}} = 8.314 \text{ kPa} \cdot \text{L/K} \cdot \text{mol}$$

This is the value of R that is to be used in the ideal gas equation when the pressure is given in kPa. The table below shows a summary of this and the other possible values of R. It is important to choose the correct value of R to use for a given problem.

Table 1.8.7.1: Values of the Ideal Gas Constant

Unit of P	Unit of V	Unit of n	Unit of T	Value and Unit of R
kPa	L	mol	K	$8.314 \text{ J/K} \cdot \text{mol}$
atm	L	mol	K	$0.08206 \text{ L} \cdot \text{atm/K} \cdot \text{mol}$
mm Hg	L	mol	K	$62.36 \text{ L} \cdot \text{mm Hg/K} \cdot \text{mol}$

Notice that the unit for R when the pressure is in kPa has been changed to $\text{J/K} \cdot \text{mol}$. A kilopascal multiplied by a liter is equal to the SI unit for energy, a joule (J).

Example 1.8.7.1

What volume is occupied by 3.760 g of oxygen gas at a pressure of 88.4 kPa and a temperature of 19^oC? Assume the oxygen is an ideal gas.

Solution

Step 1: List the known quantities and plan the problem.

Known

- $P = 88.4 \text{ kPa}$
- $T = 19^\text{o} \text{C} = 292 \text{ K}$
- $\text{Mass O}_2 = 3.760 \text{ g}$
- $\text{O}_2 = 32.00 \text{ g/mol}$
- $R = 8.314 \text{ J/K} \cdot \text{mol}$

Unknown

In order to use the ideal gas law, the number of moles of O_2 (n) must be found from the given mass and the molar mass. Then, use $PV = nRT$ to solve for the volume of oxygen.

Step 2: Solve.

$$3.760 \text{ g} \times \frac{1 \text{ mol O}_2}{32.00 \text{ g O}_2} = 0.1175 \text{ mol O}_2$$

Rearrange the ideal gas law and solve for V.

$$V = \frac{nRT}{P} = \frac{0.1175 \text{ mol} \times 8.314 \text{ J/K} \cdot \text{mol} \times 292 \text{ K}}{88.4 \text{ kPa}} = 3.23 \text{ L O}_2$$

Step 3: Think about your result.

The number of moles of oxygen is far less than one mole, so the volume should be fairly small compared to molar volume (22.4 L/mol) since the pressure and temperature are reasonably close to standard. The result has three significant figures because of the values for T and P. Since a joule $(\text{J}) = \text{kPa} \cdot \text{L}$, the units cancel out correctly, leaving a volume in liters.

Summary

- The ideal gas constant is calculated.
- An example of calculations using the ideal gas law is shown.