The Ideal Gas Law

The ideal gas combines all the three laws discussed earlier into one single law due to the following reason. If you examine all the three laws, the following relationship is evident.

Boyle's law: $V \alpha \frac{1}{P}$ (at constant temperature)

Charles's law: $V \alpha T$ (at constant pressure)

Avogadro's law: $V \alpha n$ (at constant pressure and volume)

That means that volume is inversely proportional to pressure, directly proportional to temperature, and directly proportional to number of moles. Due to this, these three expressions can be combined into one expression as

$$V \alpha \frac{nT}{P}$$

The proportionality sign can be replaced with an equal sign by incorporating a constant R, known as the **gas constant**. Thus,

$$V = \frac{RnT}{P}$$

Rearranging this yields a simple equation like

$$PV = nRT$$

This is known as the **ideal gas law**.

There are two kinds of gases; (a) ideal gas, and (b) real gas. The **ideal gas** is the gas where there are no attractions or repulsions between gaseous molecules and the volume of the gas molecules is negligible compared to the volume of the container. The **real gas is the gas the way it exists in nature.** In reality, there is no such thing as an ideal gas. But the difference between the behaviors of ideal gas and real gas is not that significant over reasonable temperature and pressure ranges, and hence the ideal gas equation can be used for calculations. Thus, the ideal gas is a hypothetical gas whose pressure-volume-temperature relations are completely described by the ideal gas law.

In order to understand how the value of R is derived, it is necessary to understand (a) standard temperature and pressure (STP), and (b) molar volume.

The condition of 0^0C (or 273 K) and 1 atm are called ***standard temperature and pressure and abbreviated as STP.***

It has been proved experimentally that one mole of any gas occupies the same volume as any other gas at STP condition. The volume at this condition is known as a **molar volume,** which has the value of 22.4 L. Therefore, 22.4 L is the volume of one mole of any gas at STP condition:

Molar volume = volume of one mole of gas at STP = 22.4 L

The value of the gas constant R is the same for all the gases since they occupy the same volume at STP, which is,

$$R = 0.082 \frac{L \text{ x atm}}{\text{mol x K}}$$

The ideal gas contains four variables, P, V, n, and T. Therefore, any one of them can be calculated by knowing the other three. But, there is one stringent requirement that must be satisfied before the above value of R can be used in calculations.

Requirement

- The pressure must in atm, the volume must be in L, and the temperature must be in Kelvin.

Calculation of Volume using the Ideal gas law

Example

Determine the volume in ml occupied by 0.567 moles of oxygen gas at a pressure of 77.5 cm Hg and a temperature of 30.5^0C?

Answer

Given : n = 0.567 mol
pressure = 77.5 cm Hg
temperature = 30.5^0C

The pressure and the temperature have to be converted into atm and K respectively:

atm = 77.5 cm Hg / 76.0 cm Hg/atm = 1.02 atm
K = 30.5 + 273.15 = 303.65 K

Now substitute these values and evaluate for volume.

$$V = \frac{nRT}{P} = \frac{(0.567\,\text{mol})(0.082\,\frac{\text{L x atm}}{\text{mol x K}})(303.65\,\text{K})}{1.02\,\text{atm}} = 13.84\,\text{L}$$

ml of volume = 13.84 L x (1000 ml /L) = 1.384 x 10^4 ml

Calculation of Pressure using the Ideal gas law

Example

A bicycle tire of 5.45 L volume is filled with 0.255 moles of gas at a temperature of 310 K. What is the pressure of the tire in atm and psi?

Answer

$$P = \frac{nRT}{V} = \frac{(0.225\,\text{mol})(0.082\,\frac{\text{L x atm}}{\text{mol x K}})(310\,\text{K})}{5.45\,\text{L}} = 1.05\,\text{atm}$$

Pressure in psi = 1.05 atm x (14.7 psi/atm) = 15.43 psi
