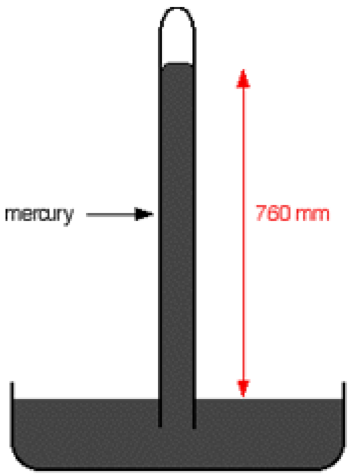
Gases

C020

Measurement of Gases

Gas Pressure: traditionally measured as the height to which it will raise a column of Hg in an evacuated tube



$$\boxed{\text{1 atmosphere (atm) = 760 mm Hg = 760 Torr}}$$

In SI units 1 atm = 101.3 kPa and 1 bar = 100 kPa

$\therefore$ 1 atm = 1.013 bar

The Ideal Gas Law

For a given quantity of gas, the volume, V, varies inversely with pressure, P, at constant temperature, T

≡ **Boyle's Law**

that is, $V \propto 1/P$ $\therefore$ PV = constant (1)

Who was Boyle?

• Robert Boyle was an Irishman born in 1627 and died in 1691.

• Viewed himself as an alchemist: (believed in the transmutation of metals)

• Despite his accomplishments in Physics: (the enunciation of Boyle's law, the discovery of the part taken by air in the propagation of sound, and investigations on the expansive force of freezing water, on specific gravities and refractive powers, on crystals, on electricity, on colour, on hydrostatics), History notes that he loved Chemistry the most!

Next, at constant P, V varies linearly with T

$\equiv$ **Charles' Law**

that is, $V \propto T$ $\therefore$ $V = cT$ (where c = constant) (2)

when T is measured in degrees Kelvin (K) where $K = {}^{o}C + 273.15$

Next, at constant T and P, the volume of gas varies directly with the number of moles of gas, n

that is, $V \propto n$ $\therefore$ $V = Rn$ (where R = gas constant) (3)

Combining all three expressions leads to the **Ideal Gas Equation**:

$$\boxed{PV = nRT}$$

Who was Charles?

•Jacques Alexandre Cesar Charles was a Frenchman born in 1746 and died in 1823.

•Charles never published Charles' Law. It was communicated and credited to him by Joseph Louis Gay-Lussac.

• Charles confirmed Benjamin Franklin's electricity experiments.

The **value** of the gas constant **R** depends on the units of P

- If P is in Pascal units, and V is m^3 (all proper SI units)

use R =8.314 J K^{-1} mol^{-1}

Note 1 L = 10^{-3} m^3

- If P is in atmospheres, and V is L

use R =0.0821 L-atm K^{-1} mol^{-1}

- If P is in bar, and V is L

use R =0.0831 L-bar K^{-1} mol^{-1}

T is **always** in Kelvin

Example question:

A quantity of O_2 has a volume of 100.0 L at 25^{o}C and 70.0 kPa.
What will be the volume of this O_2 gas at 0^{o}C and 1.00 bar?

For questions of this type **where the quantity of gas remains unchanged** (that is, n = constant) we recognize that for initial conditions:

$$\frac{P_1V_1}{T_1R} = n$$

and for the final conditions

$$\frac{P_2V_2}{T_2R} = n$$

Since n = n,

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

$$\boxed{\therefore \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \quad \text{for constant n}}$$

We can now solve the question above.

P_1 = 70 kPa = 0.7 bar
T_1 = 298 K
V_1 = 100.0 L

P_2 = 1.00 bar
T_2 = 273 K
V_2 = ?

$$\therefore \frac{(0.70)(100.0)}{(298)} = \frac{(1.0)(V_2)}{(273)}$$

= 64.1 L

Molar Mass and Density Calculations

The number of moles of a substance is:

$$\frac{w}{M} = \frac{(\text{mass})}{(\text{Molar mass})}$$

We can substitute this expression into the Ideal Gas Equation

$$\therefore \quad \boxed{PV = \left(\frac{w}{M}\right)RT}$$

By measuring the **mass** in g, of a gas at a known P, V, and T, we can calculate its molar mass, M

≡ one of the best experimental means of **determining M for a gas**

This equation can be rearranged to yield:

$$PM = \left(\frac{w}{V}\right)RT$$

But w/V = d = density of the gas in g L^{-1}

$$\therefore \quad \boxed{PM = dRT} \quad \text{or} \quad \boxed{\frac{PM}{RT} = d}$$

This leads to some well-known properties:

- Increasing pressure increases density (compressed He cylinders are very heavy)
- Increasing the temperature decreases density (hot air balloons rise)
- Decreasing M decreases the density

Example question:

What is the density of NO_2 at 0^oC and 740 Torr?

$$PM = dRT$$

Molar mass of NO_2 = 14.0 + 2x(16.0) = 46.0 g mol^{-1}

$$\therefore \quad \left(\frac{740}{760}\right)(46.0) = d(0.0821)(273)$$

d = 2.00 g L^{-1}

Example question:

1.40 L of a gas at 27^oC and 1.17 bar weighs 2.273g.
What is its molar mass?

$$PV = \left(\frac{w}{M}\right)RT = \left(\frac{1.17}{1.013}\text{atm}\right)(1.40\text{L}) = \frac{2.27\text{g}}{M}\left(0.0821\text{L - atm K}^{-1}\text{mol}^{-1}\right)(300\text{K})$$

$\therefore$ M = 34.5 g mol^{-1}