

## MiniChem 7: Gases

### Definition of Pressure:

$$p = \frac{F}{A}$$

The pressure is the force exerted per unit area. The SI unit of pressure is the pascal (Pa). See Minichem2 for conversion factors between Pa and other more common units of pressure.

### Ideal Gas Law: a first equation of state

$$p = n \frac{RT}{V}$$

where  $p$  is the pressure,  $V$  the volume occupied by the gas and  $T$  the temperature of the gas.  $R$  is the gas law constant, see Minichem 1 for values of  $R$  expressed in different units.

The ideal gas law is an equation of state. It describes how the values of the pressure, the volume, and the temperature for a given quantity of gas are constrained with respect to each other. This is better seen by rearranging the

equation as follows:  $\frac{pV}{T} = nR$ , which states that for a given amount of gas

' $n$ ' the ratio  $pV/T$  is constant.

The ideal gas law does not contain any information about the nature of the gas, i.e. it pretends to be valid for all gases independently of their molecular structure. In fact the theoretical derivation of the ideal gas law is based on two main assumptions: (1) gas particles have no interactions with one another and (2) gas particles do not occupy any volume in space.

A better approximation of the behavior of the variables  $p$ ,  $V$ , and  $T$  that characterize the state of a gas was first given by van der Waals:

$$p = \frac{RT}{\left(\frac{V}{n} - b\right)} - \frac{a}{\left(\frac{V}{n}\right)^2}$$

In the van der Waals equation of state the parameters ' $a$ ' and ' $b$ ' are specific to the gas under investigation.

### Mixtures of Ideal Gases and Definition of Partial Pressure

Using the ideal gas law it is straightforward to verify that when dealing with a mixture of  $N$  ideal gases, where the total number of moles of gas particles is

$n_{total} = \sum_{i=1}^N n_i$ , the pressure exerted by all the gas particles inside a container of volume 'V' maintained at temperature 'T' can be written as the sum of the partial pressures of the individual gases, where partial pressure is defined as the pressure of gas would exert on the container if it were alone:

$$P_{total} = n_{total} \frac{RT}{V} = \left( \sum_{i=1}^N n_i \right) \frac{RT}{V} = \sum_{i=1}^N n_i \frac{RT}{V} = \sum_{i=1}^N P_i$$

Note that:

$$P_i = n_i \frac{RT}{V} = n_i \frac{n_{total} RT}{n_{total} V} = \frac{n_i}{n_{total}} n_{total} \frac{RT}{V} = \frac{n_i}{n_{total}} P = x_i P_{total}$$

This derivation shows that the partial pressure of an ideal gas in a mixture of gases is the product of the molar fraction  $x_i$  of the gas and the total pressure.

### Kinetic Theory of Ideal Gases

The equation below is an important finding that describes how the temperature of an ideal gas is related to the kinetic energy of the gas particles. In the form below it states that the kinetic energy of 1 mole of ideal gas (M represents the molar mass of the gas) is proportional to the temperature T of the gas:

$$\frac{1}{2} M \overline{u^2} = \frac{3}{2} RT$$

This equation also shows how the mean square velocity of a gas is inversely proportional to its molar mass:

$$\overline{u^2} = 3 \frac{RT}{M}$$