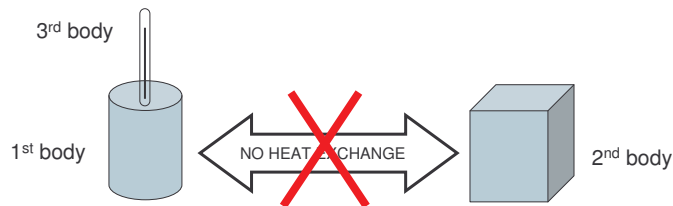


## The Zeroth Law of Thermodynamics

The Zeroth Law states that if any two bodies are in thermal equilibrium with a third body they are in thermal equilibrium with each other.

To put it more simply: - if we measure the temperature of one body (with a thermometer) and (using the same thermometer) find it to be the same as a second body, the two bodies will **not** exchange heat with each other. i.e. they are in **thermal equilibrium** with each other.



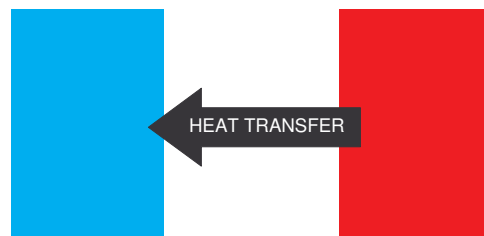
The Zeroth Law is thus an **affirmation of temperature** - which can best be thought of as a 'level' of hotness (or coldness).

If temperature is a measure of hotness or coldness, what is heat?

Heat (transfer) is what occurs when two bodies at different temperatures are brought into thermal contact with each other.

Heat is therefore a form of energy transferring across a boundary **in** to or **out** of a system. A finite temperature difference is required to achieve a finite heat transfer rate.

If the temperature difference is infinitesimal, the heat transfer is said to be '**reversible**', (and the heat transfer rate is also infinitesimal!)



*The rate at which energy transfers by heat transfer is generally comparatively slow!*

Heat transfer between two bodies can be slowed down by the interposition of an **insulating** material between them.

Heat is transferred by three main processes:

**Conduction**;

**Convection**; and

**Radiation**.

Generally, metals are good **conductors** of heat – whereas most other materials are relatively poor. Materials which are particularly poor conductors are called 'insulators'.

Good conductors of heat are normally also good conductors of electricity.

Heat transfer between a solid surface and a fluid is called **convective heat transfer**. The rate of heat transfer depends on a number of different parameters but is particularly influenced by the relative velocity between the fluid and the surface and by the thermal conductivity of the fluid as well as the temperature difference between them..

Generally, heat transfer '**gas**>< surface' is slower than '**liquid** ><surface'.

The flow of heat is similar to the flow of electrons (electrical current) in that it is 'driven' by a potential difference (temperature) and the rate at which it flows depends upon the resistance that it encounters.

$$E = IR \qquad \Delta T = \dot{Q} \theta \qquad \theta \text{ is the thermal resistance}$$

## Perfect Gases

The air that we breathe is a mixture of approximately 78% Nitrogen, 21% Oxygen and 1% Argon by volume.

There are many gases - but with all real gases, if they are compressed and cooled sufficiently, they will become liquid.

At atmospheric pressure Nitrogen liquefies at  $-196^{\circ}\text{C}$   
and Oxygen liquefies at  $-183^{\circ}\text{C}$ .

Gases like Hydrogen and Helium have to be cooled to close to the absolute zero of temperature before they will liquefy.

The air we breathe is therefore a vaporised liquid at a temperature well above its boiling temperature - it is, in fact, a superheated vapour.

It is possible to imagine a gas that would never liquefy no matter how much it is cooled or compressed - such a gas is called a perfect, or ideal, gas. It is found that a real gas (or mixture of gases) behaves reasonably closely to such an ideal gas provided its temperature stays well above its boiling point for its pressure.

Avogadro discovered that if the quantity of gas is measured by counting the number of molecules (rather than using its mass) then all gases behave in the same way... in particular that certain properties are related to one another as expressed by the UNIVERSAL GAS LAW.

$$pV = n\bar{R}T$$

$p$  is pressure in kPa

$V$  is volume in  $\text{m}^3$

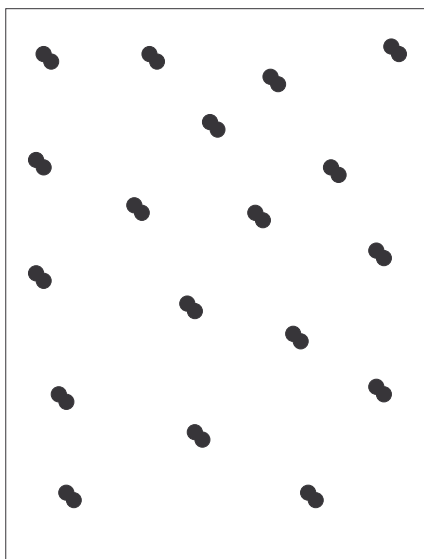
$n$  is the number of molecules measured in kmol\*

$\bar{R}$  is the Universal Gas Constant (8.3145 kJ/kmol K)

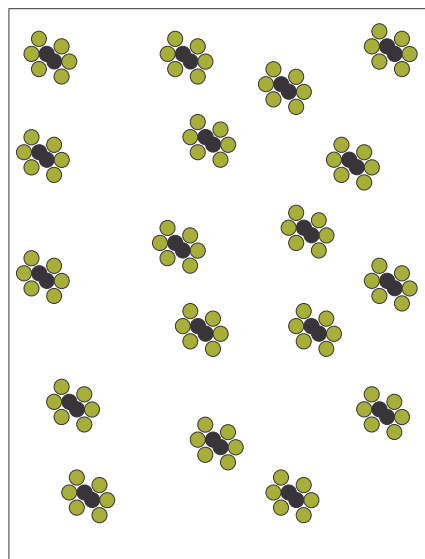
$T$  is the temperature in Kelvin

A 'mol' is defined as the number of atoms in 12g of  $\text{C}_{12}$  ~ about  $6.023 \times 10^{23}$   
\*A 'kmol' is therefore the number of atoms in 12kg of  $\text{C}_{12}$  ~ about  $6.023 \times 10^{26}$

This behaviour arises because compared with liquids and solids the distance between gas molecules is relatively large compared to their size



oxygen molecules  $\text{O}_2$



ethane molecules  $\text{C}_2\text{H}_6$

Different gas molecules have different masses.  
 We can find this information by looking up their molar mass ( $M$ ).  
 (Haywood tables page 2).  
 e.g. oxygen ( $O_2$ ) has a molar mass of 32 kg/kmol;  
 carbon dioxide ( $CO_2$ ) has a molar mass of 44 kg/kmol.

If we know how much of a gas we have in **kg** we can find the quantity in kmol by dividing by its **molar mass**:  $n = \frac{m}{M}$

The Universal gas equation then becomes:  $pV = \frac{m}{M} \bar{R}T$

$\frac{\bar{R}}{M}$  is called the specific gas constant ( $R$ ) for any gas or gas mixture:

so we obtain:  $pV = mRT$  the Perfect Gas equation

$m$  is the mass of gas in kg  
 $R$  is the Specific Gas Constant (in kJ/kg K)