

3. Thermodynamics

3.1 Heat and Temperature

Heat is a measure of **energy** associated with a material body, it has units the units joules (J). It is the quantity transferred from one body to another because of a **temperature difference** between the two bodies.

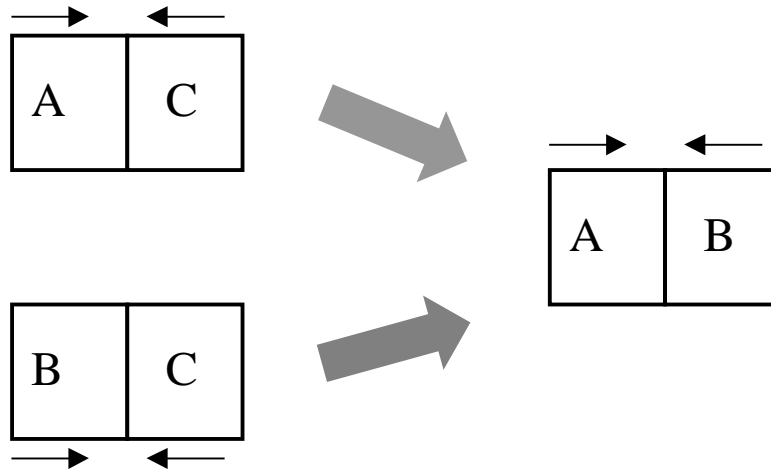
Heat is transferred from one body to another until **thermal equilibrium** is established, the two bodies are then said to be at the **same temperature**.

We can measure quantity of heat – the number of joules - transferred from one body to another because of their difference in temperature. We can also measure the temperature - **in kelvin (K)** - of the bodies involved by setting up a **temperature scale**.

3.2 Zeroth law of thermodynamics

This tells us formally what thermal equilibrium (and temperature) mean.

If two bodies A and B are each (individually) in thermal equilibrium with a third body C then A and B are in thermal equilibrium with each other - and are said to be at the same temperature.



3.3 Temperature Scales and Measurement

We choose some property of a material ('thermometric substance') that varies in a suitable way with change in temperature – this provides the basis for a **thermometer**.

We then establish fixed points and make a calibration to set up a **temperature scale**.

Some examples of thermometric substances and their useful temperature dependent property include:

Substance	Property	Thermometer	Application or use
Ideal gas (H, He etc.)	Variation of P with T	Constant volume gas thermometer	Temperature standard
Mercury, alcohol	Thermal expansion of liquids	Mercury in glass	Household, clinical (medical)
Pair electrically conducting wires	Thermally generated voltage	Thermocouple	Low and high temperatures
Two different metal strips joined	Differing thermal expansion of metals	Bi-metallic strip	Oven thermostat or thermometer
Semi-conductor crystal or diode	Variation of electrical resistance with T .	Semiconductor thermometer	Scientific work, robots??

3.4 Constant volume gas thermometer (CVGT)

This is a **primary** thermometer: it is used as a reference or standard for establishing temperature scales.

Gas enclosed in a glass bulb maintained at fixed volume is immersed in a temperature controlled bath.

1. We assume

$$T = cP$$

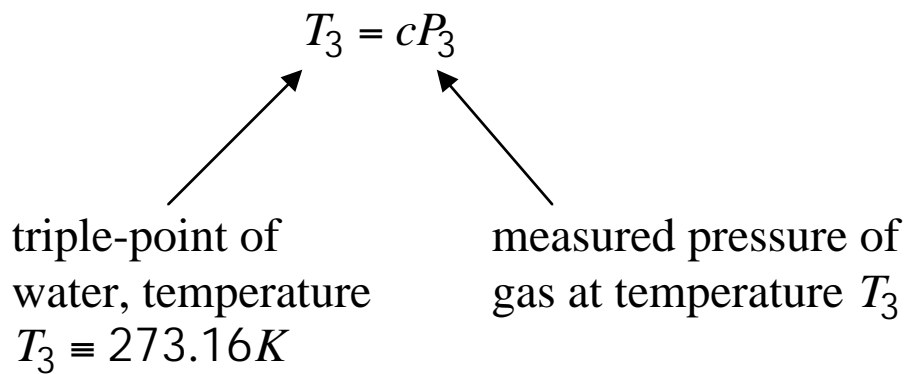
temperature of liquid bath pressure of gas in bulb

where c is a constant. We measure pressure P using a Hg column (manometer).

2. Put gas bulb into a triple-point cell – a ‘bath’ containing ice, water and water vapour at known temperature, the triple point of water,

$$T_{triple} = T_3 = 273.16K \quad \text{triple point of water}$$

Now



Thus we have

$$T = T_3 \left(\frac{P}{P_3} \right)$$
$$= 273.16K \left(\frac{P}{P_3} \right) \quad (*)$$

However, caution! Using equation (*) is found to give unsatisfactory results. Measured temperatures are inconsistent when using

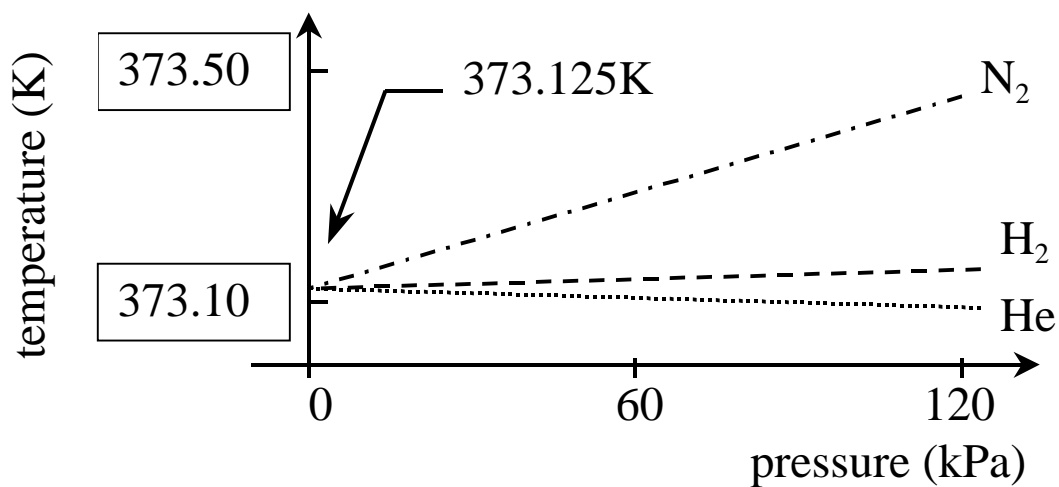
1. different initial pressures (i.e. different amounts) of gas,
2. different gases.

This happens because

1. different gases approach 'ideal' gas behaviour at different rates,

2. All gases converge to ideal behaviour as $P \rightarrow 0$.

Graphically : if we use the CVGT to measure the temperature of boiling pure water:



This shows that we need to use

$$T = (273.16K) \left(\lim_{P \rightarrow 0} \frac{P}{P_3} \right)$$

This establishes the **ideal gas temperature scale**.

Practically the measurement of $\left(\lim_{P \rightarrow 0} \frac{P}{P_3} \right)$ is achieved by a process of iteration, working with successively smaller initial quantities of a given gas and then extrapolating the data for $\frac{P}{P_3}$ to zero pressure.

3.5 Kelvin, Celsius and Fahrenheit temperature scales

The kelvin scale is the internationally agreed temperature scale for scientific work. The unit kelvin, K is part of the SI system.

Celsius (or centigrade) and Fahrenheit (mainly US) scales are in common use. The scale are related thus:

	Kelvin	Celsius	Fahrenheit
Triple point of water	273.16K	0.01°C	32.02°F
Absolute zero	0K	-273.15°C	-459.67°F

Note that:

- The Kelvin and Celsius scales start at different points (separated by 273.15K) but a 1-degree interval is the same on either scale.

Thus we convert from K to °C or °C to K by subtracting or adding 273.15. That is

$$T_C = T - 273.15^\circ$$

- The Celsius (or Kelvin) and Fahrenheit scales start at different points and 1-degree intervals are different.

1- degree Fahrenheit is 5/9 of 1-degree Celsius,

[Celsius: 0° - $100^\circ = 100$ intervals

Fahrenheit: 32° - $212^\circ = 180$ intervals

this ratio $100/180 = 5/9$]

so to convert,

$$T_F = \frac{9}{5}T_C + 32^\circ$$