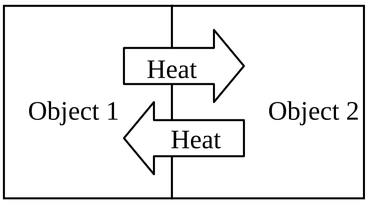
CHAPTER 4: HEAT

4.1 Thermal Equilibrium



Thermal equilibrium is reached between two objects in contact when:
- The net transfer of heat is zero (rate of exchange of heat are equal)
- The two objects have the same temperature

4.1.1 Calibration of a thermometer

To calibrate a thermometer, two extreme points must be chosen to mark its scale. These points must be able to be reproduced accurately.

In the Celsius scale, the two fixed points of temperature are:

(i) **ice point (0°C)** – temperature of pure ice melting under standard atmospheric pressure

(ii) **steam point (100°C)** – temperature of pure water boiling under standard atmospheric pressure

To calculate the scale of a thermometer, given the two fixed points:

$$\theta_x - \theta_0 = \frac{l_x - l_0}{l_{100} - l_0} \times (\theta_{100} - \theta_0)$$

where l_1 = length on scale based on lower fixed point (typically 0°C)
l_2 = length on scale based on higher fixed point (typically 100°C)
lx = length on scale based on temperature of object to be measured
θ_1 = temperature of lower fixed point (typically 0°C)
θ_2 = temperature of higher fixed point (typically 100°C)
θ_x = temperature to be calculated

4.2 Heat Capacity and Specific Heat Capacity

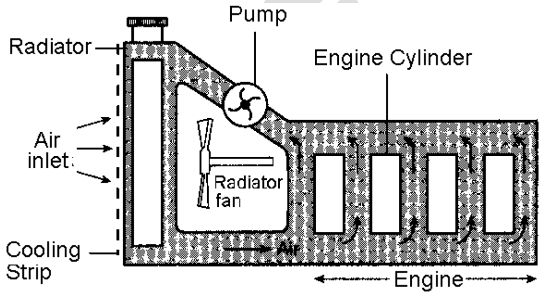
Heat capacity: An object that has a large heat capacity requires a bigger quantity of heat to raise the temperature to 1°C

Specific heat capacity: The amount of heat energy needed to raise the temperature of 1 kg of a material by 1°C

$$Q = mc\theta$$

where Q = heat energy [J]
m = mass [kg]
c = specific heat capacity of the material [J kg^{-1} °C^{-1}]
θ = change in temperature [°C]

4.2.1 Applications



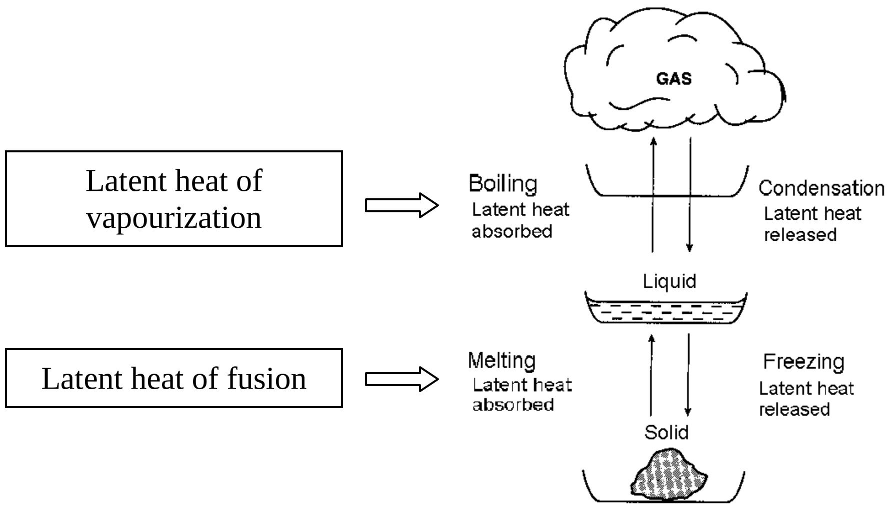
- Water is used as a coolant in car engines because
  - Specific heat capacity is large,
  - Easily obtained and cheap,
  - Does not chemically react with the materials in the engine.

- Cooking utensils (woks, pots) are usually made of material with low specific heat capacity to ensure temperature increases quickly when heated.
- Handles are made of material with high specific heat capacity and are poor conductors.
- Clay pots are made of clay with high specific heat capacity and are poor conductors. When removed from heat, the soup inside the pot will continue to boil as heat is still being received from the pot.

4.3 Latent Heat and Specific Latent Heat

Latent heat: Heat that is absorbed during the change of state of the material (solid ↔ liquid ↔ gas)

Specific latent heat: The amount of heat needed to change the state of 1 kg of a material



$$Q = mL$$

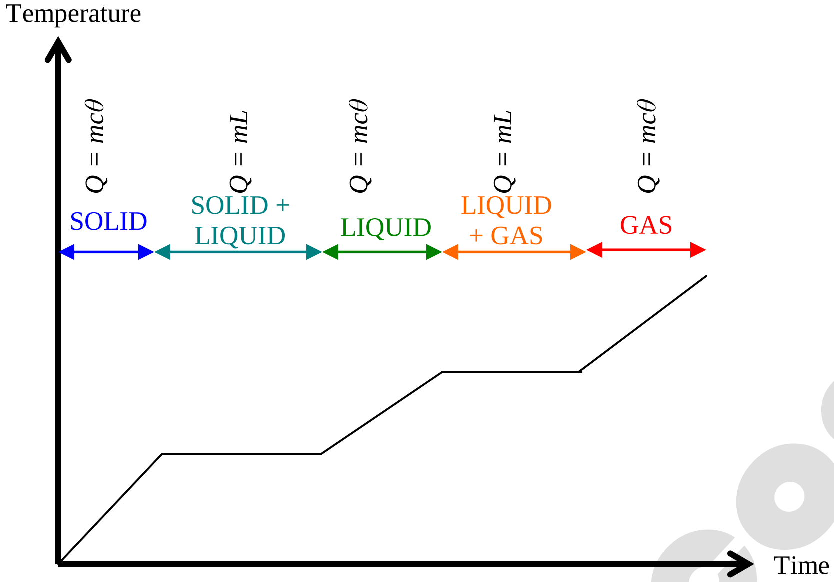
where Q = heat energy [J]
m = mass [kg]
L = specific latent heat of the material [J kg^{-1}]*

* Specific latent heat of fusion – for melting/freezing
Specific latent heat of vapourization – for boiling/condensation

4.3.1 Applications

- Cooling drinks with ice
- Ice packages to keep cooled food cold
- Cooking by steaming
- Heating drinks using steam

4.3.2 Specific Heat Capacity and Specific Latent Heat



Heating graph of a material from solid to gas

When calculating the amount of heat needed to change the state *and* temperature of an object, remember to take into account the different stages of heating as shown in the graph above.

Example:
To calculate the amount of heat needed to heat ice at 0 ºC to water at 25 ºC:

$$\text{Amount of heat needed} = \underbrace{mL}_{\text{Heat needed to change ice at 0 ºC to water at 0 ºC}} + \underbrace{mc\theta}_{\text{Heat needed to change water at 0 ºC to water at 25 ºC}}$$

When calculating the exchange of heat, remember to take into account the different stages of heating for *each side of the equation.*

Example:
Ice 0 ºC is added to hot water 90 ºC. To calculate the final temperature, *x* ºC:

Amount of heat absorbed by ice = Amount of heat released by hot water

$$\underbrace{mL}_{\text{Heat needed to change ice at 0 ºC to water at 0 ºC}} + \underbrace{mc\theta}_{\text{Heat needed to change water at 0 ºC to water at } x \text{ ºC}} = \underbrace{mc\theta}_{\text{Heat needed to change hot water at 90 ºC to water at } x \text{ ºC}}$$

ASSUMPTION: No heat lost to surrounding.

4.4 Gas Laws

- A closed container containing gas has:
  - Fixed number of molecules
  - Constant mass
- The gas behaviour is dependant on three variables:
  - Pressure
  - Volume
  - Temperature

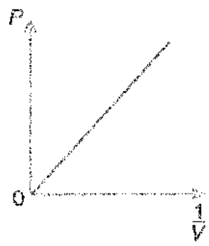
Note: For all gas law equations, the temperature involved must be absolute, i.e. in **Kelvin**

$$T = \theta + 273$$

where T = temperature [Kelvin]
θ = temperature [°C]

4.4.1 Boyle's Law

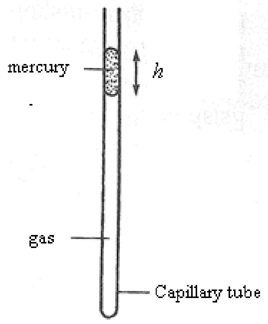
For a gas of fixed mass, the **pressure** is inversely proportional to its **volume** if the temperature is constant.



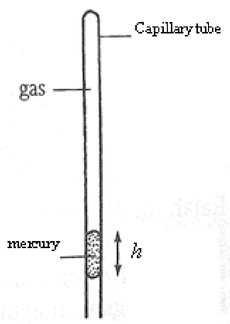
$$PV = k$$
$$P_1V_1 = P_2V_2$$

where P = pressure of the gas [Pa]
V = volume of the gas [m^3]

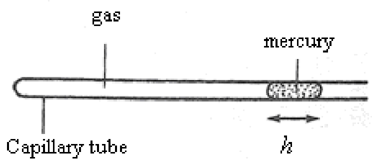
Examples of typical Boyle's Law questions: Capillary tube with a mercury column trapping some air in it. Given that the atmospheric pressure is 76 cm Hg, to calculate the pressure of the air in the tube:



Pressure of the gas = $(76+h)$ cm Hg



Pressure of the gas = $(76-h)$ cm Hg



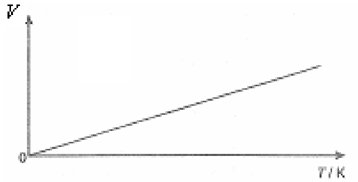
Pressure of the gas = 76 cm Hg

4.4.2 Charles' Law

For a gas of fixed mass, the **volume** is directly proportional to its **absolute temperature** if the pressure is constant.

$$\frac{V}{T} = k$$

$$\boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2}}$$



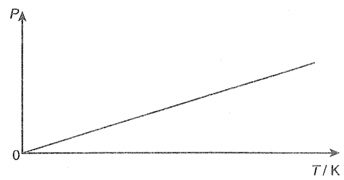
where V = volume of the gas [m^3]
T = absolute temperature of the gas [K]

4.4.3 Pressure Law

For a gas of fixed mass, the **pressure** is directly proportional to its **absolute temperature** if the volume is constant.

$$\frac{P}{T} = k$$

$$\boxed{\frac{P_1}{T_1} = \frac{P_2}{T_2}}$$



where V = volume of the gas [m^3]
T = absolute temperature of the gas [K]

4.4.4 Universal Gas Law

Combining all three gas laws:

$$\frac{PV}{T} = k$$

$$\boxed{\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}}$$

END OF CHAPTER