Energy Matters – Heat

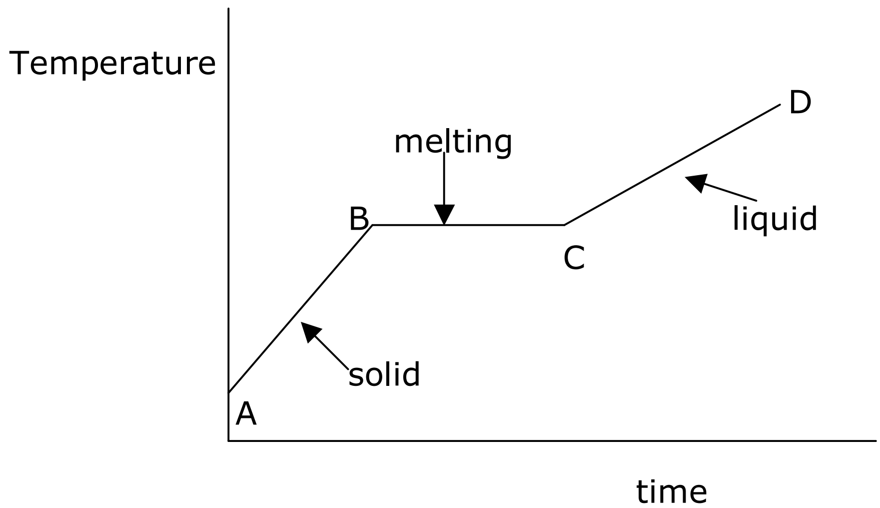
Changes of State

Fusion

If we supply heat to a solid, such as a piece of copper, the energy supplied is given to the molecules. These start to vibrate more rapidly and with larger vibrations – the molecules gain Kinetic Energy E_k. The heat supplied has been converted to molecular kinetic energy.

If the solid is cooled, the reverse happens (the molecules vibrate more slowly and these vibrations become smaller). The molecules have lost kinetic energy and this lost E_k is converted back into heat energy that is lost to the surroundings.

If we heat the solid to a high enough temperature it will eventually melt to form a liquid. If we monitor the temperature of the material during heating, we would see that it varies with time during heating as shown in the graph below.



What is happening in this graph?

- Between A & B, the material is a solid. The heat supplied to the material is used to increase the E_k of the molecules and the temperature rises.

- Between B & C, the solid is melting. Heat is still being supplied to the material but the temperature does not change. Heat energy is not being changed into kinetic energy. Instead, the heat is used to change the arrangement of the molecules.

PTO

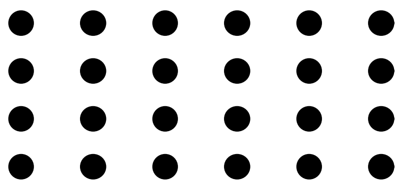
What is happening in this graph? (continued)

- At point C, all of the material has been changed to liquid.

- Between C & D, the heat supplied is again used to increase E_k of the molecules and the temperature of the liquid starts to rise.

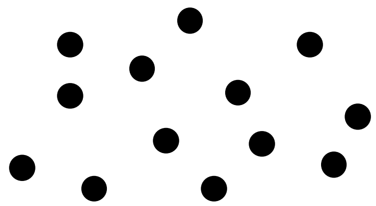
Compare the arrangement of molecules in solids and liquids.

Solid



Molecules vibrate but are held in fixed positions by very strong forces.

Liquid



Molecules vibrate but can also move short distances. The molecules are slightly farther apart than those in a solid.

The heat supplied during melting is used to set the solid molecules free so that a liquid can be formed. The heat supplied is known as **latent heat of fusion** (melting) and is stored in the liquid as a kind of potential energy.

If the liquid cools as resolidifies (freezes), the stored potential energy is given back out as heat energy.

A lot of heat energy is required to free the solid molecules, so the latent heat of fusion is usually large. This also means that when a liquid freezes, it must give out a lot of heat energy.

Latent Heat of Fusion has the symbol $\mathbf{L_f}$.
The units of Latent Heat of Fusion are J/kg (Joules per kilogram)

$\mathbf{L_f}$ is the heat energy required to change

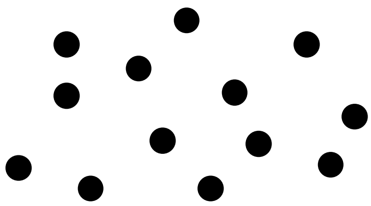
1kg of a solid (at melting point)
into
1kg of liquid (at freezing point).

Vaporisation

If a liquid is heated to a sufficiently high temperature it **vaporises** (boils). During boiling, there is no change in temperature. The heat supplied to the material is used to change the arrangement of the molecules inside the liquid.

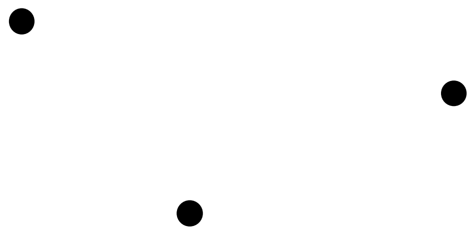
Compare the arrangement of molecules in liquids and gases.

Liquid



Molecules are close together, they have limited movement.

Gas



Molecules are very far apart, they have complete freedom of movement.

The heat applied during boiling is used to set the molecules free to form a gas. The heat energy is stored in the gas as a form of potential energy and is known as the **latent heat of vaporisation**.

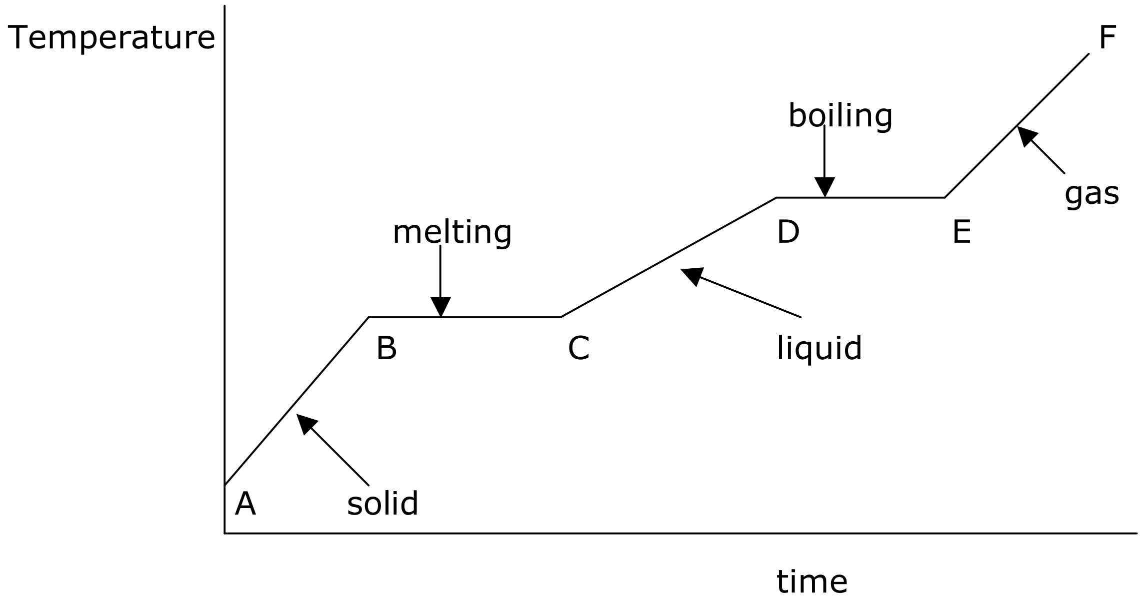
When the gas cools and condenses, the stored energy is given out as heat energy. A lot of heat is required to vaporise a liquid, so the latent heat of vaporisation is large. When a gas cools and condenses into a liquid, a lot of heat energy is given out.

Latent Heat of Vaporisation has the symbol $\mathbf{L_v}$.
The units of Latent Heat of Vaporisation are J/kg.

$\mathbf{L_v}$ is the heat energy required to change

1kg of a liquid (at boiling point)
into
1kg of gas (at condensing point).

The complete heating curve for a material is shown below.



What is happening in this graph?
(see earlier explanation for points A-D)

- Between C & D, the liquid is heated until it starts to boil.

- Between D & E, the liquid is still being heated but the extra heat energy does not change the temperature (kinetic energy) of the molecules. The heat energy is used to change the arrangement of the molecules to form a gas.

- At point E all of the liquid has been changed into gas.

- Between E & F, the gas is heated and the heat energy increases the E_k of molecules once more, so the temperature of the gas increases.

For **General level**, you need to be able to explain changes of state as described in these notes.

At **Credit level**, as for General Level **and** you also have to be able to perform energy calculations – see attached examples.

Sample Questions on Latent Heat of Fusion/Vaporisation

Use these examples to help you see how to deal with problems involving changes of state (freezing/melting/boiling).

Example:
How much energy is required to change 2.6kg of **ice at 0˚C** into **water** at the same temperature?

Solution:
Use

$$\mathbf{E_h = mL_f}$$

$$= 2.6 \times (3.34 \times 10^5)$$

where E_h = heat energy (J)
m = mass = 2.6kg
L_f = 3.34×10^5J/kg

so

E_h = $\underline{8.7 \times 10^5 \text{ J}}$

this is the value of L_f for water, the value will change for different materials

Example:
How much energy is required to change 2.6kg of **water** at **100˚C** into **steam** at the same temperature?

Solution:
Use

$$\mathbf{E_h = mL_v}$$

$$= 2.6 \times (2.26 \times 10^6 \text{J})$$

where E_h = heat energy (J)
m = mass = 2.6kg
L_v = 2.26×10^6J/kg

so

E_h = $\underline{5.9 \times 10^6 \text{ J}}$

this is the value of L_v for water, the value will change for different materials

Example:
How much energy is required in total to change 1.9kg of ice at -10°C to steam at 100°C?

Solution:
Split the problem into parts.

We need to calculate the energy required to
1. Heat the ice from -10°C to 0°C
2. melt all of the ice
3. heat the liquid water up to 100°C
4. change the boiling water into steam.

then add all 4 answers together to get the total energy required.

1. Energy to heat ice up to melting point:

Use

$$\mathbf{E_h = cm\Delta T}$$

$$= 2100 \times 1.9 \times 10$$

so <u>$E_h = 39{,}900$ J</u>

E_h = heat energy (J)
m = mass = 1.9kg
ΔT = 10
c = specific heat capacity of **ice** (= 2100J/kg/°C)

2. Energy to melt the ice:

Use

$$\mathbf{E_h = mL_f}$$

$$= 1.9 \times (3.34 \times 10^5)$$

so

<u>$E_h = 634{,}600$ J</u>

where E_h = heat energy (J)
m = mass = 1.9kg
L_f = 3.34×10^5J/kg

3. Energy to heat the water up to boiling point:

Use

$$\mathbf{E_h = cm\Delta T}$$

$$= 4200 \times 1.9 \times 100$$

so <u>$E_h = 798{,}000$ J</u>

E_h = heat energy (J)
m = mass = 1.9kg
ΔT = 100
c = specific heat capacity of **water** (= 4200J/kg/°C)

PTO

Solution (continued)

4. Energy to convert the boiling water into steam;

Use

$$\mathbf{E_h = mL_v}$$

where E_h = heat energy (J)
m = mass = 1.9kg
L_v = 2.26×10^6J/kg

$= 1.9 \times (2.26 \times 10^6)$

so

$\underline{E_h = 4,294,000 \text{ J}}$

Now add all 4 answers together to get the total energy required.

Energy required = 39,900J + 634,600J + 798,000J + 4,294,000J

= **5,766,500 Joules**