# Topic 19 – Thermal Properties of Matter

**Content**

- Internal energy
- Specific heat capacity
- Melting, boiling and evaporation
- Specific latent heat

**Learning Outcomes**

Candidates should be able to:

(a) describe a rise in temperature of a body in terms of an increase in its internal energy (random thermal energy)

(b) define the terms *heat capacity* and *specific heat capacity*

(c) recall and apply the relationship *thermal energy = mass x specific heat capacity x change in temperature* to new situations or to solve related problems

(d) describe melting/solidification and boiling/condensation as processes of energy transfer without a change in temperature

(e) explain the difference between boiling and evaporation

(f) define the terms *latent heat* and *specific latent heat*

(g) recall and apply the relationship *thermal energy = mass x specific latent heat* to new situations or to solve related problems

(h) explain latent heat in terms of molecular behaviour

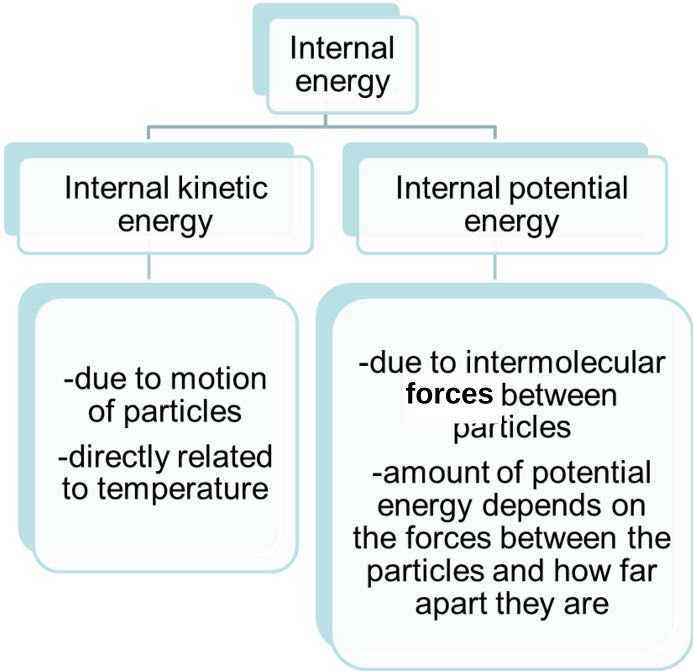
(i) sketch and interpret a cooling curve

**Note that the following Learning outcomes of Transfer of Thermal Energy had been completed in IP2 Green Science (refer to Physics Matters reference book Chapter 10)**

1. show understanding that thermal energy is transferred from a region of higher temperature to a region of lower temperature
2. explain what is meant by conduction, convection and radiation
3. describe, in molecular terms, how energy transfer occurs in solids
4. describe, in terms of density changes, convection in fluids
5. explain that energy transfer of a body by radiation does not require a material medium and the rate of energy transfer is affected by:
   - colour and texture of the surface
   - surface temperature
   - surface area
6. infer from experiments that different materials have different rates of heat flow
7. apply the concept of thermal energy transfer to everyday applications

## 19.1 Internal energy *LO (a)*

All particles in matter vibrate about fixed positions (kinetic energy) and are held together by strong intermolecular forces (potential energy). The total energy for the particles is called the ***internal energy.***




The internal energy in molecules consists of:

- kinetic energy that directly depends on temperature
- potential energy that depends on the force between the molecules and their distance apart
- when the temperature of a substance rises, internal energy increases
- when the temperature of a substance falls, energy is released and internal energy decreases

## 19.2 Thermal Energy in relation to change in temperature *LO (b) & (c)*

**Heat Capacity *C* of an object**

The quantity/amount of thermal energy or heat absorbed / emitted, *Q*, by the body per unit temperature change (1K or 1°C).

$$C = \frac{Q}{\Delta T}$$

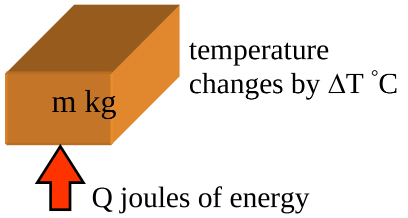
Where Q - thermal energy absorbed
$\Delta$T - change in temperature

- SI unit is J $K^{-1}$ or J °$C^{-1}$
- different substances have different heat capacities

**Specific heat capacity *c* of an object**

The quantity/amount of thermal energy or heat absorbed / emitted, *Q*, per unit mass (1 kg) of the material per unit temperature change (1K or 1°C).

$$c = \frac{Q}{m\Delta T}$$




- SI unit is J $kg^{-1}$ $K^{-1}$ or J $kg^{-1}$ °$C^{-1}$
- substances with a high specific heat capacity warm up (or cool) more slowly than substances with a lower heat capacity because they must absorb (or lose) more heat to raise (or lower) the temperature
- Examples: specific heat capacity for – water : 4200 J $kg^{-1}$°$C^{-1}$
  - copper : 400 J $kg^{-1}$°$C^{-1}$

**Effects and applications of the high specific heat capacity of water**

Water has a high specific heat capacity compared to other substances.

- water needs a lot of energy to warm it up; once warm, it holds a good store of energy
- loss of a large amount of energy causes a small drop in temperature
- sea temperature rises and falls very slowly

The high specific heat capacity of water (as well as its relative cheapness and availability) accounts for its use

- as the circulating liquid in central heating systems
- as a cooling liquid in car engines
- as hot water bottles to keep people or things warm

**Worked Example 1**

An electric heater of power 800 W raises the temperature of 4.0 kg of a liquid from 30°C to 50°C in 100 s. Calculate

(a) the heat capacity of the 4.0 kg liquid,

(b) the specific heat capacity of the liquid.

(a) Assuming that heat loss to surrounding/ environment is **neglected**,
by conservation of energy,
Heat supplied by electric heater = Heat absorbed by container + Heat absorbed by water
$P\,t = C\,\Delta T$
(800 W) (100 s) = C (50 – 30)
C = 4000 J°$C^{-1}$

(b) C = mc → 4000 J°$C^{-1}$ = (4.0 kg) c → c = 1000 J$kg^{-1}$ °$C^{-1}$

**Worked Example 2**

A copper container of mass 350 g and specific heat capacity 0.4 $Jg^{-1}°C^{-1}$ contains 500g of water (specific heat capacity 4.2 $Jg^{-1}°C^{-1}$). The water and container are heated from 30 °C to 100 °C by an electrical coil.

(a) How much heat is absorbed by the container?

(b) How much heat is absorbed by the water?

(c) If the heating takes 3 minutes, how many joules of heat does the coil supply per second? (Neglect heat loss)

(a) Heat absorbed by container = $mc\Delta T$ = (350 g) (0.4 $Jg^{-1}°C^{-1}$) (100 – 30) = 9800 J

(b) Heat absorbed by water = $mc\Delta T$ = (500 g) (4.2 $Jg^{-1}°C^{-1}$) (100 – 30) = 147000 J

(c) Assuming that heat loss to surrounding/ environment is neglected ,

by conservation of energy,

Heat supplied by electrical coil = Heat absorbed by container + Heat absorbed by water

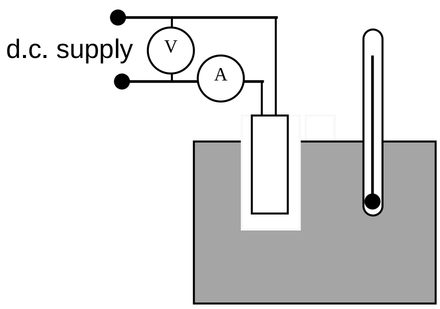
$Pt$ = 9800 + 147000

$P$ (3 x 60 s) = 156800 J

$P$ = 871 W

**Practice Question 1**

An experiment is carried out to determine the specific heat capacity of an unknown metal, using a 1 kg block of the metal as shown in Fig. 1. The heater is switched on for 500 s. The following readings are obtained:




Change in thermometer reading: 50°C

Ammeter reading: 5.0 A

Voltmeter reading: 8.0 V

(a) Calculate the specific heat capacity of the unknown metal.

(b) State why it is not advisable to take the thermometer reading immediately after switching off the current.

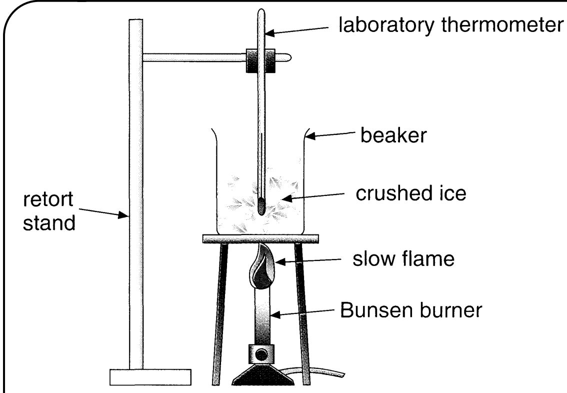
**19.3 Thermal Energy in relation to change in state (phase change)** ***LO (d) to (i)***

**Latent heat** is the heat absorbed or emitted by a substance in order to change a substance from one phase to another phase without a temperature change.

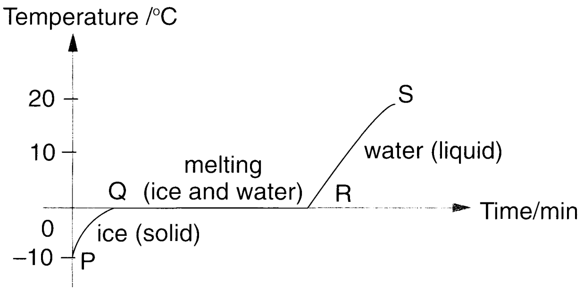
**19.3.1 Melting and Freezing (solidification)** ***LO (d) & (i)***

| **Melting** | **Freezing** |
|---|---|
| A process in which a substance changes its **state** from **solid to liquid <u>without a change in temperature.</u>** | A process in which a substance changes its **state** from **liquid to solid <u>without a change in temperature</u>** |
| For a pure substance, melting occurs at a **definite (constant)** temperature called the **melting point** | For a pure substance, freezing occurs at a **definite (constant)** temperature called the **freezing point** |

**Melting**




Experiment: To determine the melting point of ice




Graph of temperature recorded in the experiment

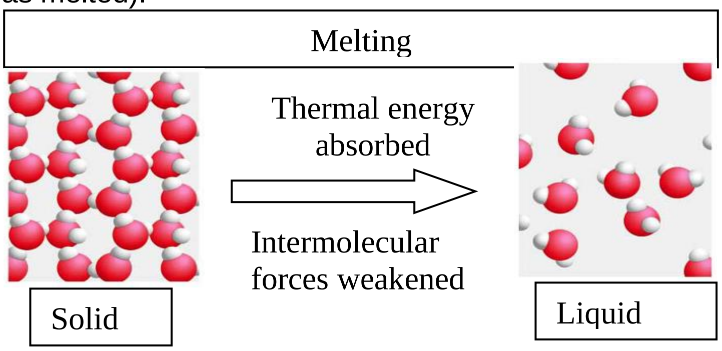
During the <u>change of state</u> from ice to water, there is <u>no change in temperature</u> even though heat is being absorbed.

*Where has the heat gone to?*

This can be explained by making **<u>use of the *kinetic molecular model of matter.*</u>**

Thermal energy or heat is <u>absorbed</u> by the solid to do work to <u>overcome the intermolecular forces of attraction</u> between the molecules of the solid. Once the intermolecular forces are weakened, the molecules can now move out of their former fixed positions. Only the total internal potential energy of the molecules is increased as molecules move further apart. Since none of the thermal energy is converted to internal kinetic energy, there is no change in temperature.

⇨ Molecules can move more freely and exhibit greater disorder that characterize the liquid state. Thus, the solid has melted, that is, the change of state from solid to liquid has occurred. This explains why there is no change in temperature during melting (that is until all the solid has melted).



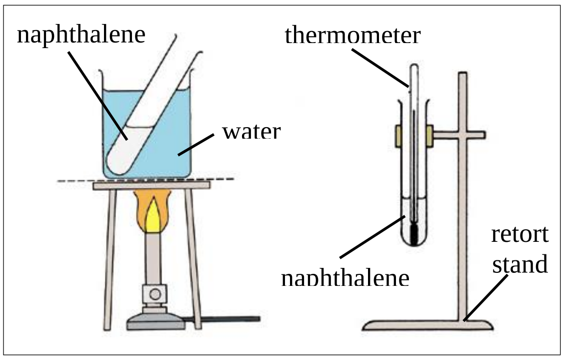
**Latent Heat of Fusion** ***LO (f)***

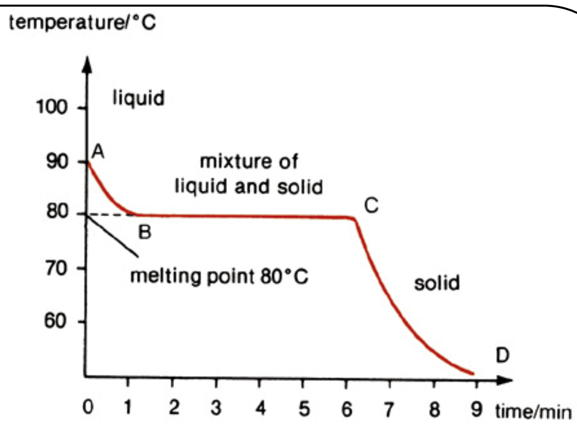
The heat that is absorbed to change an object from its solid state to liquid state without a change in temperature is termed latent heat of fusion (melting) of the substance.

SI unit: joule (J)

When a liquid freezes, latent heat is released without any change in its temperature.

**Solidification**

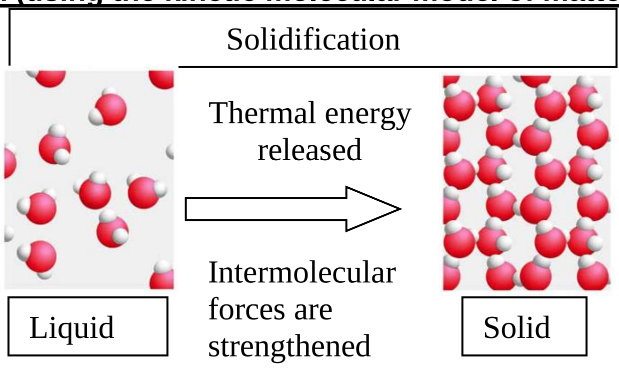



Cooling curve of naphthalene

During the change of state from liquid to solid, there is no change in temperature even though heat is lost to the surroundings as the naphthalene cools. ***Where does the energy come from?***

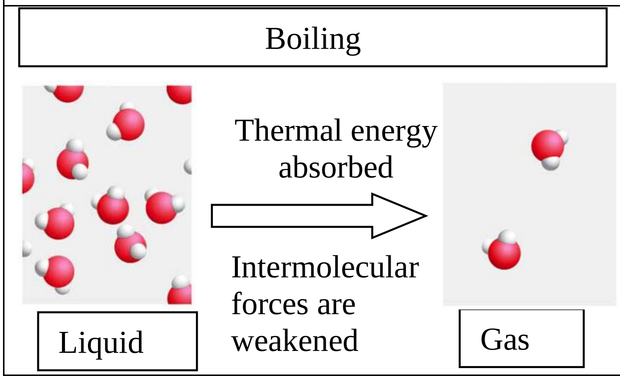
**Latent Heat of Fusion (using the kinetic molecular model of matter)** ***LO (h)***

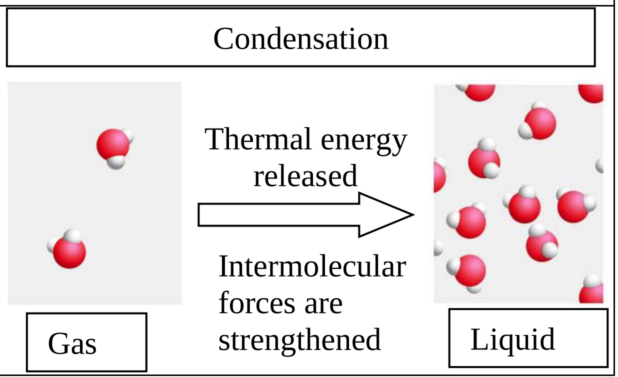



Heat is released as intermolecular forces are strengthened when the liquid atoms or molecules come together to form a solid. The atoms or molecules now take on a more ordered structure as compared to the less ordered structure of the moving liquid atoms or molecules. This explains why there is no change in temperature during solidification.

### 19.3.2 Boiling and Condensation *LO (d) & (i)*

| Boiling | Condensation |
|---|---|
| A process in which a substance changes its **state** from the **liquid state to the gaseous state** <u>without a change in temperature</u> | A process in which a substance changes its **state** from **gaseous to liquid state** <u>without a change in temperature</u> |
| For a pure substance, **boiling** occurs at a **definite (constant)** temperature called the **boiling point**<br>*No change in temperature until all liquid has vaporised.* | For a pure substance, **condensation** occurs at a **definite (constant)** temperature called the **condensation point** |




**Latent Heat of Vaporisation** ***LO (f)***

The heat that is <u>gained or released</u> to change object from <u>liquid state to vapour state or vice versa without any rise in temperature</u> is called the latent heat of vaporisation.
SI unit: joule (J)

**<u>Latent Heat of Vaporisation (using the kinetic molecular model of matter)</u>** ***LO (h)***

The <u>heat supplied</u> to the liquid is used to <u>do work in separating the molecules</u> as well as in <u>pushing back the surrounding atmosphere</u>. The molecules are now far apart (i.e. large increase in volume) with negligible intermolecular forces of attraction between them.
=> A change of state (boiling) from liquid to gas has taken place.
The heat that is absorbed without a change in temperature is called latent heat of vaporisation of the substance.

**<u>Worked Example 3</u>**
**Why is specific latent heat of vaporisation larger than specific latent heat of fusion for the same substance?**

In both vaporization (liquid to gas) and melting (solid to liquid), forces of attraction binding the molecules are overcome and the molecular separations are increased.
However, the increase in intermolecular separation during vaporisation is larger than melting. Hence, the increase in internal potential energy is larger.
Also, some of the latent heat is used as work done to overcome the atmospheric pressure as the vapour expands.
Therefore, for the same given mass of a substance, the specific latent heat of vaporisation is larger than the specific latent heat of fusion.

## 19.3.3 Differences between Evaporation and Boiling *LO (e)*

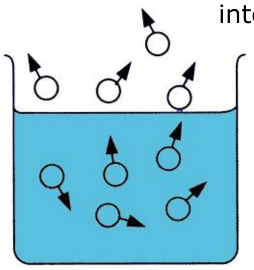
| Boiling | Evaporation |
|---|---|
| Occurs at a **definite/ fixed temperature** (boiling point) and **temperature remains constant** | Occurs at **any temperatures** and **temperature may change** |
| Occurs **throughout the liquid** | Takes place **only at the exposed surface** of the liquid |
| **External thermal energy source** required | **External thermal energy source is not required** (typically, energy is supplied by surroundings) |
| Relatively fast | Relatively slow |
| Bubbles are formed in the liquid | No bubbles formed in the liquid |

| Factors Affecting Rate of Evaporation | |
|---|---|
| **Temperature** | Higher temperature ⇒ faster rate of evaporation |
| **Area of exposed surface** | Greater exposed surface area ⇒ faster rate of evaporation |
| **Humidity of surrounding air** | Higher humidity ⇒ slower rate of evaporation |
| **Motion of air** | Greater motion of the air ⇒ faster rate of evaporation |
| **Pressure** | Lower external pressure ⇒ faster rate of evaporation |
| **Nature of liquid** | Lower boiling point ⇒ faster rate of evaporation |

**Explanation of cooling by evaporation**
Cooling by evaporation can be explained by using kinetic theory.

The particles of a liquid are in continuous motion at different speeds.

- The average kinetic energy of particles is proportional to the temperature of the liquid
- Evaporation occurs when faster-moving particles escape from the surface of the liquid, leaving behind liquid particles having slower speeds
- The average speed (kinetic energy) of the particles remaining in the liquid decreases and temperature falls




> Temperature is a measure of the **average kinetic energy per molecule** in a body.

**Specific latent heat of fusion and vaporization** ***LO (f)***

| **Specific Latent Heat of Fusion ($l_f$)** | **Specific Latent Heat of Vaporisation ($l_v$)** |
|---|---|
| The quantity of thermal energy or heat required to change a unit mass of the substance from **solid phase to liquid phase** without a change in temperature | The quantity of thermal energy or heat required to change a unit mass of the substance from **liquid phase to gaseous phase** without a change in temperature |
| SI unit is J kg$^{-1}$ | SI unit is J kg$^{-1}$ |
| $l_f = \frac{Q}{m}$ | $l_v = \frac{Q}{m}$ |

where $Q$ : thermal energy released or absorbed
(latent heat of fusion or latent heat of vaporisation)
$m$ : mass in kg
$l_f$ : specific latent heat of fusion of ice = 3.36 x $10^5$ J kg$^{-1}$
$l_v$ : specific latent heat of vaporisation of water = 2.26 x $10^6$ J kg$^{-1}$

**Worked Example 4**

An ice cream has a mass of 150 g. If the specific latent heat of fusion of ice is 340 kJ kg$^{-1}$, find the energy required to melt the ice cream.

Energy required to melt the ice cream = latent heat of fusion =m $l_f$ = (150 x $10^{-3}$) (340 kJ kg$^{-1}$
= 51000 J

**Worked Example 5**

What is the amount of energy required to change 10 g of ice at 0 °C to water at 20 °C? Given that the specific latent heat of fusion of ice = 336 J g$^{-1}$; specific heat capacity of water = 4.2 J g$^{-1}$ °C$^{-1}$.

Assuming that heat loss to surrounding/ environment is **neglected**,

by conservation of energy,

Amount of energy required= Heat gained by ice in melting (0 °C) + Heat absorbed by water in raising temp from 0 to 20 °C

P t = m$l_f$ + mc$\Delta$T
Energy required = (10g )(336 J g$^{-1}$) + (10g)( 4.2 J g$^{-1}$ °C$^{-1}$) (20 -0) = 3360 + 840 = 4200 J