

Thermal Properties of matter

Sensible Heat

- Heat that causes a change in temperature of a substance.
- Heat absorbed or released before/after state change.

Temp → KE of molecules
inc. inc.

- * Heat Capacity
- * Specific Heat Capacity

Latent Heat

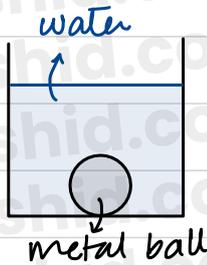
- Heat that does not bring a change in temperature of a substance.
- Heat absorbed or released during state change.

Temp → KE of molecules
const. constant

- * Specific Latent Heat
 - fusion (melting)
 - vaporization (boiling)

Example #1

A hot metal ball of mass 200g at a temp of 200°C is placed under water. The mass of water is 0.5 kg and its initial temperature is 25°C. Heat transfer between bodies occur and both bodies reach thermal equilibrium. Determine their final temperature if no net heat transfer, $T_{\text{metal}} = T_{\text{water}}$



- No heat is lost to surrounding
- if 20% heat is lost to surrounding.

($C_{\text{metal ball}} = 800 \text{ J/kg} \cdot \text{C}$)
($C_{\text{water}} = 4200 \text{ J/kg} \cdot \text{C}$)

a) heat lost metal = heat gained by ball water

$$mc\Delta T = mc\Delta T$$

$$(T_{\text{high}} - T_{\text{low}}) = (T_{\text{high}} - T_{\text{low}})$$

$$(0.2)(800)(200 - T) = (0.5)(4200)(T - 25)$$

$$T = 37.4^\circ\text{C}$$

b) 80% heat lost = heat gained by by metal ball water

$$0.8 \times mc\Delta T = mc\Delta T$$

$$0.8(0.2 \times 800)(200 - T) = (0.5 \times 4200)(T - 25)$$

$$T = 35.1^\circ\text{C}$$

Heat Capacity

Amount of heat needed to bring a unit change in temperature of a substance.

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

C: heat capacity
Q: heat energy
 ΔT : change in temp.

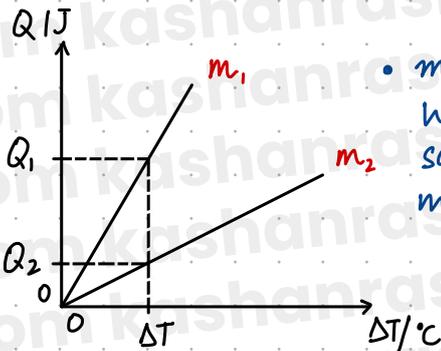
e.g. $Q = 10,000 \text{ J}$ $T_i = 25^\circ\text{C}$ $T_f = 30^\circ\text{C}$

$$C = \frac{10,000}{30-25} = \frac{2000 \text{ J/}^\circ\text{C}}{2000 \text{ J/K}}$$

• SI Unit of C: J/K

→ It is not a material property because it depends upon the mass of substance.

more mass → more heat needed → more heat capacity



• m_1 needed more heat to bring the same ΔT than m_2 , hence $m_1 > m_2$

Specific Heat Capacity

Amount of heat needed to bring a unit change in temperature in a unit mass of substance.

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

$$Q = mc \Delta T$$

specific heat capacity

Make sure units of Q and m are consistent with the units of c.

e.g. water $c = 4200 \text{ J/kg}\cdot\text{K}$

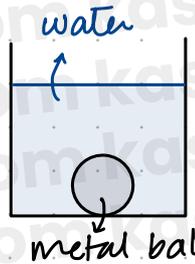
1 kg water needs 4200J of heat to change its Temperature by 1K or 1°C .

if power rating of heat and time of operation is given, then

$$Q = mc \Delta T \Rightarrow P \times t = mc \Delta T$$

Example #1

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no net heat transfer, $T_{\text{metal}} = T_{\text{water}}$

- No heat is lost to surrounding
- if 20% heat is lost to surrounding.

($C_{\text{metal ball}} = 800 \text{ J/kg}\cdot^\circ\text{C}$)
($C_{\text{water}} = 4200 \text{ J/kg}\cdot^\circ\text{C}$)

a) heat lost by metal = heat gained by water

$$-mc \Delta T = mc \Delta T$$

$$-(0.2)(800)(T-200) = (0.5)(4200)(T-25)$$

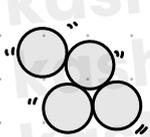
$$T = 37.4^\circ\text{C}$$

b) 80% heat lost by metal = heat gained by water

$$80\% \times -mc \Delta T = mc \Delta T$$

$$0.8(-0.2 \times 800 \times (T-200)) = 0.5 \times 4200 \times (T-25)$$

$$T = 35.1^\circ\text{C}$$



HEAT →



✓ K.E./vibration increase

✓ Gap/Seperation between molecules inc.

✓ Temperature depends upon the kinetic energy of molecules

HEAT → K.E of molecules due to vibrations and motion + P.E of molecules due to intermolecular forces & separation

The sum of microscopic kinetic and Potential energy of molecules is called Internal Energy.

Why temperature stays constant during state change process?

- Temperature depends on the mean kinetic energy of molecules
- Heat supplied during state change is EITHER used to do work against intermolecular forces OR used to increase the potential energy of molecules by separating them.
- There is no change in kinetic energy hence no change in temperature

This is the reason why the heat supplied during state change is called Latent Heat i.e. Hidden Heat.

Latent Heat

Amount of heat needed to change the state of a substance at constant temperature.

Specific Latent Heat

Amount of heat needed to change the state of a unit mass of substance at constant temperature.

Specific Latent Heat of Fusion

Amount of heat needed to change a unit mass of solid to liquid, at its melting point.

$$Q = l_f \times m$$

Q → Latent heat
 l_f → spec. latent heat of fusion
 m → mass that melts.

Specific Latent Heat of Vaporization

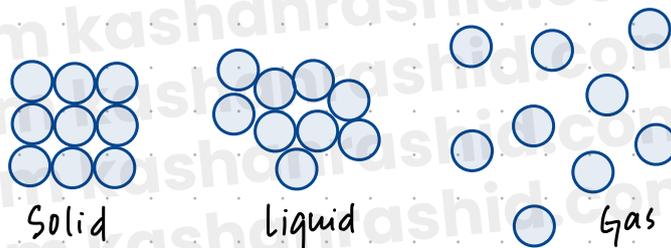
Amount of heat needed to change a unit mass of liquid to gas at its boiling point.

$$Q = l_v \times m$$

Q → Latent heat
 l_v → spec. latent heat of vap.
 m → mass that boils

- What is larger l_v or l_f ?? (What needs more energy, melting or boiling)

Boiling needs more energy than melting i.e. $l_v > l_f$

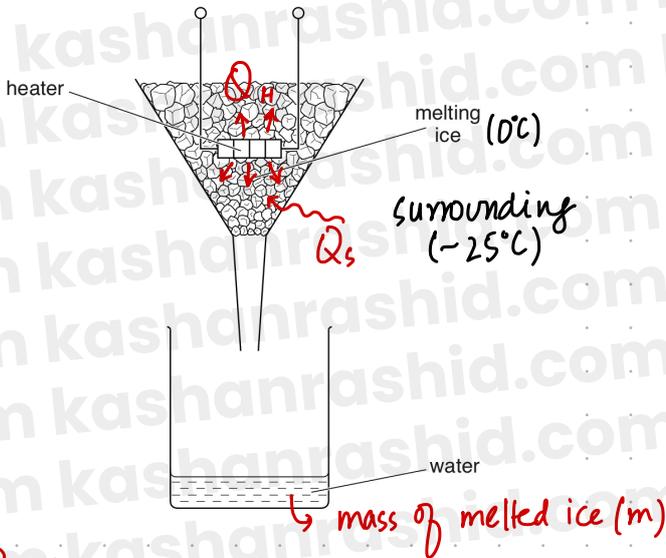


Reason #1: More work done against intermolecular forces during boiling due to greater increase in separation between molecules.

Reason #2: Work is also done against atmospheric pressure when gas expands.

Determining the value of l_f using electric heater

(Heat exchange with surrounding **NOT** ignored)



$$Q = l_f \times m$$

↓
heat gained by ice

Q_H : heater's heat
 Q_S : heat from surrounding

$$Q_H + Q_S = l_f \times m$$

$$(P \times t) + Q_S = l_f \times m$$

$$\frac{P \times t}{t} + \frac{Q_S}{t} = \frac{l_f \times m}{t}$$

$$P + \dot{Q}_S = l_f \times \dot{m}$$

$\dot{Q}_S = \frac{Q_S}{t} \rightarrow$ unit (W)
rate of heat gained from surrounding

$\frac{m}{t} = \dot{m} \rightarrow$ unit (kg s^{-1})
rate of melting

• \dot{Q}_S i.e. rate of heat gained from the surrounding depends of temp diff between ice and surrounding

• Ice melts at 0°C and surrounding is 25°C always so ΔT and hence \dot{Q}_S will always be the same even if the experiment was repeated with a heater of different power rating.

$$\text{Heater \#1: } P_1 + \dot{Q}_S = l_f \times \dot{m}_1$$

$$\text{Heater \#2: } P_2 + \dot{Q}_S = l_f \times \dot{m}_2$$

$$P_1 - P_2 = l_f \dot{m}_1 - l_f \dot{m}_2$$

$$P_1 - P_2 = l_f (\dot{m}_1 - \dot{m}_2)$$

$$P_1 - P_2 = l_f \left(\frac{m_1 - m_2}{t} \right)$$

$$\Delta P \times t = l_f \times \Delta m$$

similarly for boiling...

$$\Delta P \times t = l_v \times \Delta m$$

$$\rightarrow Q_H - Q_S = l_v \times m$$

↓
heat lost to surrounding

3 (a) Define *specific latent heat*.

Amount of heat need to change the state of a unit mass of substance, at constant Temperature.

[2]

(b) An electrical heater is immersed in some melting ice that is contained in a funnel, as shown in Fig. 3.1.

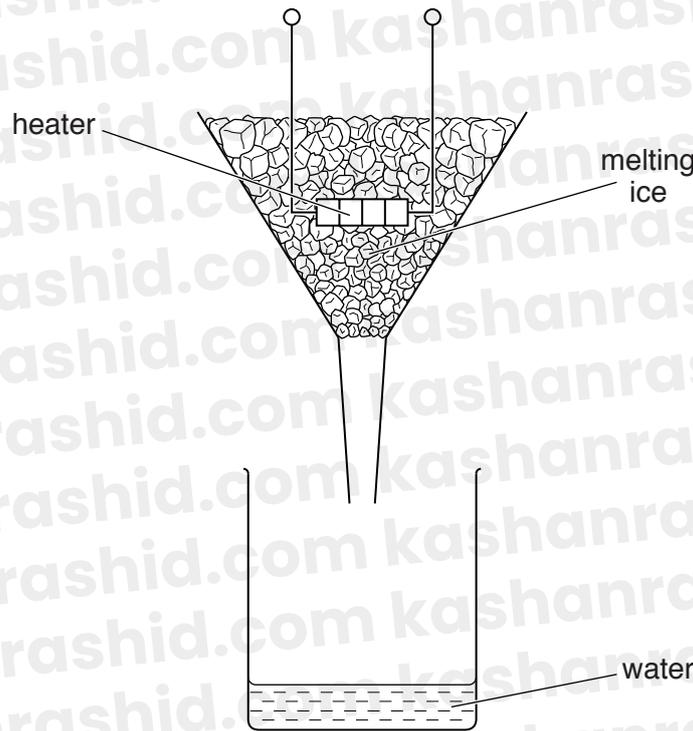


Fig. 3.1

The heater is switched on and, when the ice is melting at a constant rate, the mass m of ice melted in 5.0 minutes is noted, together with the power P of the heater. The power P of the heater is then increased. A new reading for the mass m of ice melted in 5.0 minutes is recorded when the ice is melting at a constant rate.

Data for the power P and the mass m are shown in Fig. 3.2.

power of heater P/W	mass m melted in 5.0 minutes/g	mass m melted per second/ gs^{-1}
70	78	$\frac{78}{300} = 0.26$
110	114	$\frac{114}{300} = 0.38$

Fig. 3.2

- (i) Complete Fig. 3.2 to determine the mass melted per second for each power of the heater. [2]
- (ii) Use the data in the completed Fig. 3.2 to determine

1. a value for the specific latent heat of fusion L of ice,

$$\Delta P \times t = L_f \times \Delta m \quad \left\{ \begin{array}{l} \Delta P = L_f \times \Delta m \\ (110 - 70) \times 300 = L_f (114 - 78) \\ L_f = 333 \text{ J/g} \end{array} \right. \quad \left\{ \begin{array}{l} \Delta P = L_f \times \Delta m \\ (110 - 70) = L_f \times (0.38 - 0.26) \\ L_f = 333 \text{ J/g} \end{array} \right.$$

$$L = \dots\dots\dots 330 \dots\dots\dots \text{ Jg}^{-1} \quad [3]$$

2. the rate h of thermal energy gained by the ice from the surroundings.

$$\begin{aligned} Q &= L_f \times m \\ Q_H + Q_S &= L_f \times m \\ P_H + \dot{Q}_S &= \frac{L_f \times m}{t} \\ 70 + \dot{Q}_S &= \frac{333.333 \times 78}{300} \\ \dot{Q}_S &= 16.7 \approx 17 \text{ W.} \end{aligned}$$

$$h = \dots\dots\dots 17 \dots\dots\dots \text{ W} \quad [2]$$

3 (a) Define *specific latent heat*.

Amount of heat needed to change the state of a unit mass of substance at constant temperature.

[2]

(b) A beaker containing a liquid is placed on a balance, as shown in Fig. 3.1.

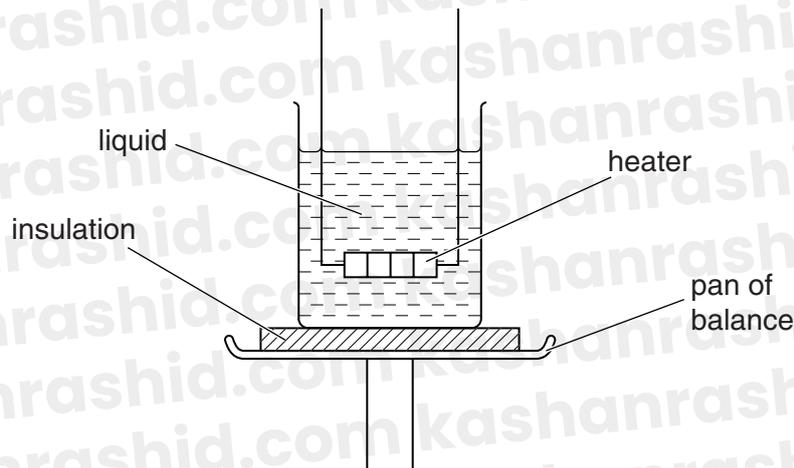


Fig. 3.1

A heater of power 110W is immersed in the liquid. The heater is switched on and, when the liquid is boiling, balance readings m are taken at corresponding times t .

A graph of the variation with time t of the balance reading m is shown in Fig. 3.2.

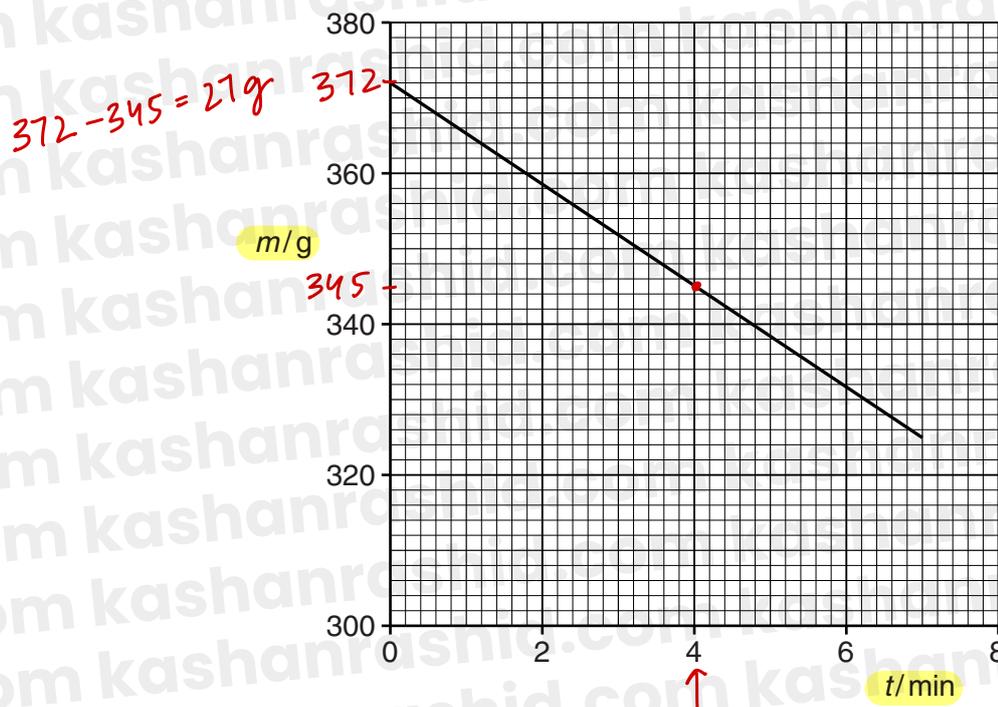


Fig. 3.2

- (i) State the feature of Fig. 3.2 which suggests that the liquid is boiling at a steady rate.

The gradient of the graph is constant

[1]

- (ii) Use data from Fig. 3.2 to determine a value for the specific latent heat L of vaporisation of the liquid.

$$Q = l_v \times m$$

$$P \times t = l_v \times m$$

$$110 \times (4 \times 60) = l_v \times \frac{27}{1000}$$

$$l_v = 9.78 \times 10^5$$

$$L = 9.8 \times 10^5 \text{ J kg}^{-1} \text{ [3]}$$

- (iii) State, with a reason, whether the value determined in (ii) is likely to be an overestimate or an underestimate of the normally accepted value for the specific latent heat of vaporisation of the liquid.

Overestimated value as some of heat produced by heater is lost to the surrounding and water boiled using less heat.

[2]

- 3 (a) During melting, a solid becomes liquid with little or no change in volume.

Use kinetic theory to explain why, during the melting process, thermal energy is required although there is no change in temperature.

Temperature depends on the average kinetic energy of molecules. During melting, heat supplied is used to do work against intermolecular forces. No heat is converted to kinetic energy hence no change in Temp occurs.

[3]

- (b) An aluminium can of mass 160 g contains a mass of 330 g of warm water at a temperature of 38°C, as illustrated in Fig. 3.1.

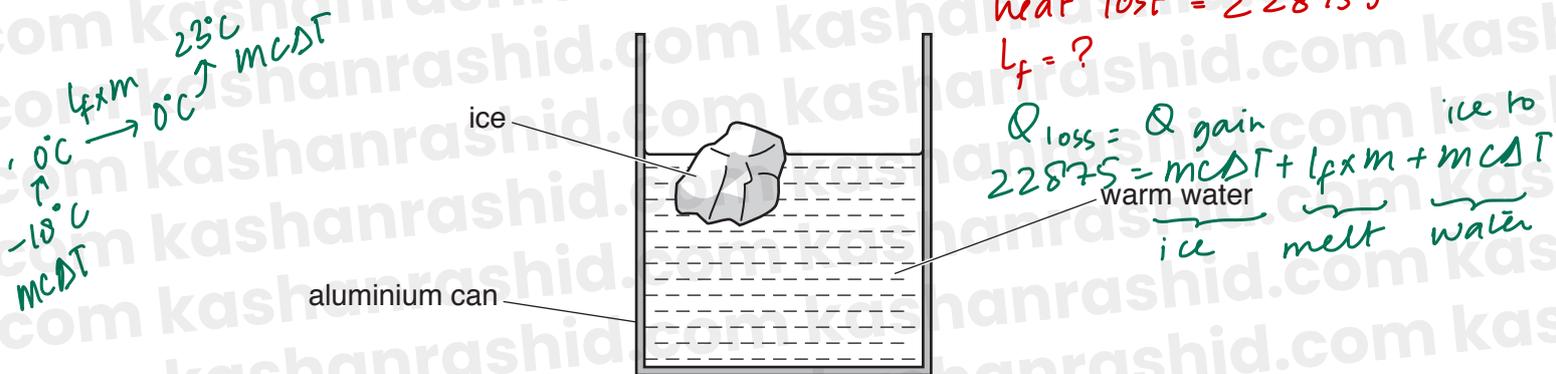


Fig. 3.1

A mass of 48 g of ice at -18°C is taken from a freezer and put in to the water. The ice melts and the final temperature of the can and its contents is 23°C .

Data for the specific heat capacity c of aluminium, ice and water are given in Fig. 3.2.

	$c/\text{Jg}^{-1}\text{K}^{-1}$
aluminium	0.910 ✓
ice	2.10 ✓
water	4.18

Fig. 3.2

Assuming no exchange of thermal energy with the surroundings,

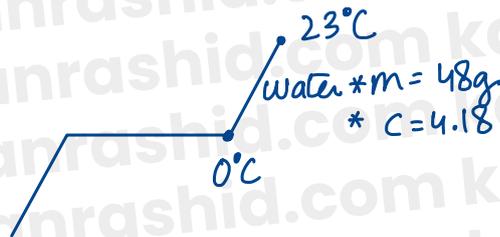
- (i) show that the loss in thermal energy of the can and the warm water is 2.3×10^4 J,

$$\begin{aligned} & \text{heat loss by can} + \text{heat loss by water} \\ & mc\Delta T + mc\Delta T \\ & (160)(0.910)(23-38) + (330)(4.18)(23-38) \\ & -22875 \approx -2.3 \times 10^4 \text{ J} \end{aligned}$$

[2]

- (ii) use the information in (i) to calculate a value L for the specific latent heat of fusion of ice.

$$\begin{aligned} & \text{heat lost} = \text{heat gained by ice} \\ & -(-2.3 \times 10^4) = mc\Delta T + l_f \times m + mc\Delta T \\ & 22875 = (48)(2.10)(0 - (-18)) + l_f \times 48 + (48)(4.18)(23 - 0) \\ & l_f = 342.6 \text{ J/g} \end{aligned}$$



$$L = \dots 340 \dots \text{ Jg}^{-1} \text{ [2]}$$

[Total: 7]