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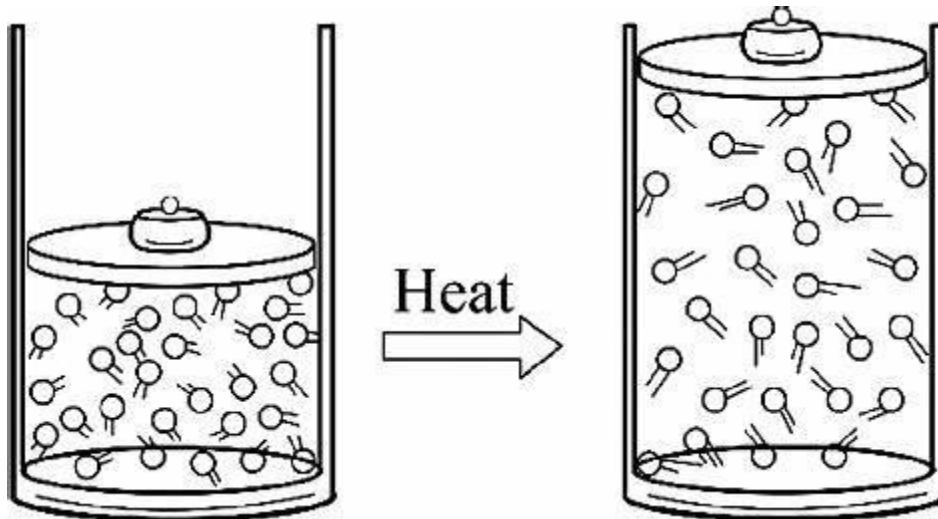


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S3 New Curriculum Physics

Theme: Heat

Chapter 6 – Heat quantities and vapours



Temperature change and heat capacity

When a body is heated its temperature increases and when a body is cooled its temperature decreases. The amount of temperature required to increase or decrease the temperature of the body by 1K or 1⁰C is its **heat capacity, C**.

Specific heat capacity

The word Specific refers to a unit quantity of physical property,

Specific heat capacity is the amount of heat required to raise the temperature of **1kg** mass of a substance by **1K or 1⁰C**.

The S.I. unit is $\text{Jkg}^{-1}\text{K}^{-1}$

$$\text{Specific heat capacity} = \frac{\text{Heat capacity}}{\text{mass}}$$

Hence, Heat = Mass x Specific heat x Temperature rise (K)

$$\text{Heat} = mc\theta$$

where θ is the temperature rise from initial temperature θ_1 to final temperature θ_2 K

$\theta = \theta_2 - \theta_1$, m = mass of substance, c = Specific heat capacity.

\therefore Heat capacity $C = c\theta$

Example 1

If the temperature of substance changes from 20°C to 40°C , find the temperature change

$$\begin{aligned}\text{Temperature rise} &= \theta_2 - \theta_1 \\ &= 40 - 20 \\ &= 20^\circ\text{C}\end{aligned}$$

Example 2

Determine the specific heat capacity of metal if 3000J of heat is used to raise the temperature of 10kg of the metal from 25°C to 45°C .

$m = 10\text{kg}$, amount heat $Q = 190,000\text{J}$, temperature change, $\theta = 45 - 25 = 20^\circ\text{C}$

Heat = $mc\theta$

$$c = \frac{190,000}{10 \times 20} = 950 \text{Jkg}^{-1}\text{K}^{-1}$$

Trial 1

- (a) What is meant by specific heat capacity of a substance?
(b) When a block of iron of mass 2 kg absorbs 19 kJ of heat, its temperature rises by 10°C . Find the specific heat capacity of the iron. [$950 \text{Jkg}^{-1}\text{K}^{-1}$]
- The amount of heat required to raise the temperature of 0.5kg of iron from 25°C to 50°C is (specific heat capacity of iron is $460 \text{joules kg}^{-1} \text{K}^{-1}$) [5,750J]
- How much heat is required to raise the temperature of 20g of water from 30°C to 60°C ? [2520J]
- How much heat is needed to raise the temperature from 30°C to 40°C for an iron of 5kg. Specific heat capacity of iron is $440 \text{Jkg}^{-1}\text{K}^{-1}$. [22.000J]

Importance of the high specific heat capacity of water

- The high specific heat capacity of water makes the temperature rise and fall to be slower for water. This is one of the major reasons why water is used in the cooling system of engines and radiators of central heating systems. It also, used to maintain the body temperature to more or less constant.
- Living organisms—especially humans—are mostly made of water. That means our bodies can resist sudden temperature changes, keeping internal conditions stable for enzymes and cells to function properly.
- The specific heat capacity of water is $4200 \text{J kg}^{-1}\text{K}^{-1}$ and that of soil is about $800 \text{J kg}^{-1}\text{K}^{-1}$. This results in the temperature of the sea to rise and fall more slowly than that of land.
- Islands are surrounded by water so they experience much smaller change of temperatures from summer to winter because the specific heat capacity of water is high so the temperature rises and falls more slowly.

- (e) The amount of heat required to raise the temperature of equal masses of metals X and Y through the same temperature is 3600J and 4800J respectively. Calculate the specific heat capacity of Y, given that the specific heat capacity of X is $300\text{Jkg}^{-1}\text{K}^{-1}$ [400Jkg⁻¹K⁻¹]

Relationship between power, time and heat

$$\text{Power} = \frac{\text{Heat energy}}{\text{time taken}}$$

Example 3

A tank holding 60kg is heated by 3KW electric immersion. If specific heat capacity is $4200\text{Jkg}^{-1}\text{K}^{-1}$. Calculate the time taken for temperature to rise from 10°C to 60°C.

$$\text{Power} = \frac{\text{heat energy}}{\text{time taken}} = \frac{MC\theta_2 - \theta_1}{t}$$

$$3000 = \frac{60 \times 4200 \times (60 - 10)}{t}$$

$$t = \frac{60 \times 4200 \times 50}{3000}$$

$$t = 4200\text{S or } 70 \text{ minutes}$$

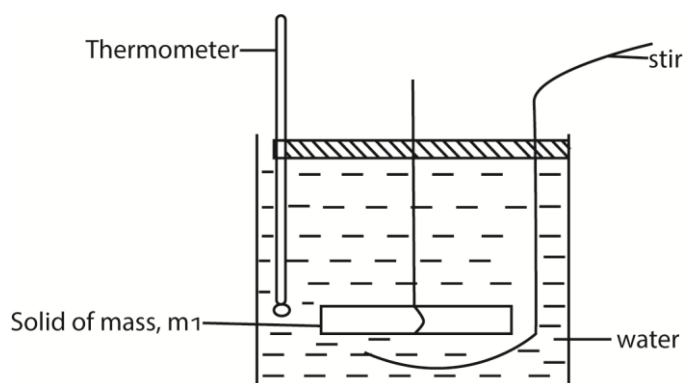
Trial 2

An immersion heater rated 1000W, 250 V supplies heat to 80kg of liquid in a tank. If the temperature of the liquid rises by 40°C in 48 minutes, what is the specific heat capacity of the liquid? [$900\text{Jkg}^{-1}\text{K}^{-1}$]

Experiment to measure specific heat capacity,

Specific heat capacity can be measured by using a container called a calorimeter which is usually made of copper or Aluminium.

Determining the specific heat capacity of solid by mixture



Procedure

A solid of mass, m_1 is heated in water to 100°C and transferred to water of mass, m_w of specific heat capacity c_w at $\theta_1^\circ\text{C}$ in a calorimeter of negligible heat capacity, the final temperature $\theta_2^\circ\text{C}$ is noted.

Calculations

Let specific heat capacity of the solid be c_s .

Heat lost by solid = heat gained by water

$$m_1 c_s (100 - \theta_2) = m_w c_w (\theta_2 - \theta_1)$$

$$c_s = \frac{m_w c_w (\theta_2 - \theta_1)}{m_1 (100 - \theta_2)}$$

Example 4

A piece of metal of mass 0.5kg is heated to 100°C and then placed in 0.4kg of water at 10°C . If the final temperature of the mixture is 30°C . Calculate the specific heat capacity of the metal.

$$\text{Heat} = mc\theta$$

Heat lost by the solid = Heat gained by water

$$0.5 \times C_m (100 - 30) = 0.4 \times 4200 (30 - 10)$$

$$0.5 \times C_m \times 70 = 0.4 \times 4200 \times 20$$

$$C_m = \frac{0.4 \times 4200 \times 20}{0.5 \times 70}$$

$$C_m = 960 \text{Jkg}^{-1}\text{K}^{-1}$$

Example 5

A 100g quantity of water at 24°C is added to 50g of water at 36°C . The temperature of the mixture is

Let the final temperature be θ

$$\text{Heat} = mc\theta$$

Heat lost = heat gained

$$\frac{50}{4200} \times 4200 \times (36 - \theta) = \frac{100}{1000} \times 4200 \times (\theta - 24)$$

$$36 - \theta = 2\theta - 48$$

$$3\theta = 84$$

$$\theta = 28^\circ\text{C}$$

Trial 3

450g of water at 60°C is to be cooled to 35°C by addition of cold water at 20°C . How much cold is to be added? [0.75kg]

Latent heat

This is the quantity of heat absorbed or released when a substance changes physical state at constant temperature. E.g. during melting, evaporation, sublimation, condensing, solidification

Specific latent heat (L)

Specific latent heat is the heat required to change one kilogram of substance from one state of matter to another without changing its temperature. The SI unit is J/kg.

Specific Latent heat of fusion (L_f)

Fusion is a change of state from solid to liquid or liquid to solid.

Specific Latent heat of fusion is the heat required to change 1kg of substance from solid to liquid without temperature change. The SI unit is J/kg.

E.g. specific latent heat of fusion of water is $3.36 \times 10^5 \text{ Jkg}^{-1}$

$$\begin{aligned}\text{Heat for change of state} &= \text{Mass (kg)} \times \text{Specific latent heat (I)} \\ &= ML\end{aligned}$$

Note that:

Same amount of heat is required to change 1kg of substance from solid to liquid or given out when 1kg of substance is changed from liquid to solid at constant temperature.

Example 6

How much heat is required to melt 10g of ice at 0°C given specific latent heat of fusion is $3.36 \times 10^5 \text{ Jkg}^{-1}$

$$\text{Heat} = ML_f$$

$$M=10\text{g} = \frac{10}{1000} = 0.01\text{Kg}$$

$$\text{Heat} = 0.01 \times 336000$$

$$= 3,360\text{J}$$

Trial 4

How much energy is required to melt 2kg of ice at 0°C ? (specific latent heat = $3.34 \times 10^5 \text{ kg}^{-1}$) [668 kJ]

Specific Latent heat of vaporization (L_v)

Vaporization is a change of state from liquid to vapour or vapour to liquid at constant temperature.

Specific Latent heat of vaporization is the heat required to change 1kg of substance from liquid to vapour without temperature change. The SI unit is Jkg^{-1} .

E.g. .Specific latent heat of vaporization of water = $2.26 \times 10^6 \text{ Jkg}^{-1}$.

$$\begin{aligned}\text{Heat for change of state} &= \text{Mass (kg)} \times \text{Specific latent heat (I)} \\ &= ML\end{aligned}$$

Note that:

Same amount of heat is required to change 1kg of substance from liquid to vapour or given out when 1kg of substance is changed from vapour to liquid at constant temperature.

Example 7

Calculate the amount of heat required to change 100g of water at 100°C to steam at 100°C .(specific latent heat of steam = $2.26 \times 10^6 \text{ Jkg}^{-1}$)

$$\begin{aligned}\text{Heat} &= M \times L \\ &= 0.1 \times 2.26 \times 10^6 \text{ J} \\ &= 2.26 \times 10^5 \text{ J}\end{aligned}$$

Trial 5

Heat is supplied at constant rate to 20kg water whose initial temperature is 25°C until half of water has turned into steam. Given that the specific heat capacity of water is $4200 \text{ kg}^{-1}\text{K}^{-1}$ and specific latent heat of steam is $2.26 \times 10^6 \text{ Jkg}^{-1}$, determine the total amount of heat used. [$2.89 \times 10^7 \text{ J}$]

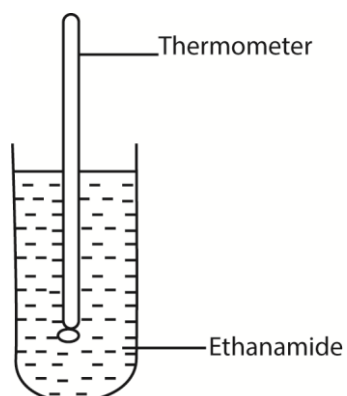
Latent heat fusion and kinetic theory:

Supply of heat to a melting solid reduces the forces of attraction between the molecules and increases the separation between them. This increases the potential energy (P.E) between the molecules while keeping kinetic energy (K.E) of the molecules the same. Further increase in separation between the molecules causes the regular pattern to collapse as the solid changes to liquid. Until this process is complete, the temperature does not change.

Latent heat of vaporization and kinetic theory

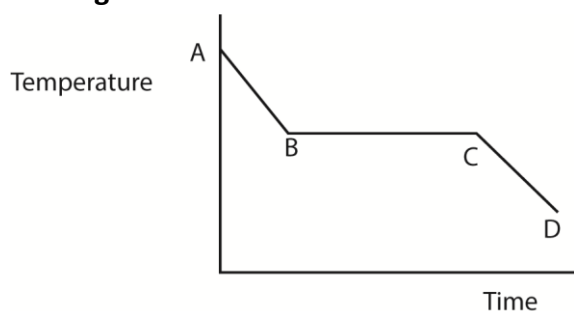
Supply of heat to a boiling reduces the forces of attraction between the molecules and increases the separation between them to a freer and independent motion in the gaseous state. This increases the potential energy (P.E) between the molecules while keeping kinetic energy (K.E) of the molecules the same. Further increase in separation between the molecules causes the regular pattern to collapse as the liquid changes to gas. Until this process is complete, the temperature does not change.

Experiment for the cooling curve



The ethanamide is heated until it melts. Then the temperature is recorded every minute until it has fallen to 70°C.

Cooling curve



AB – liquid is cooling

BC – change of state from liquid to solid

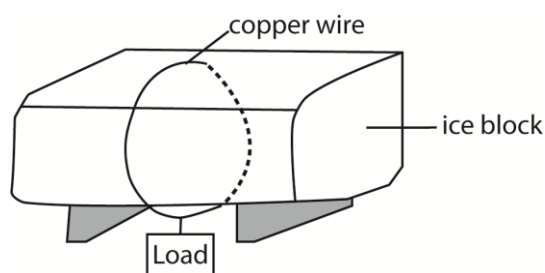
CD – solid is cooling

Melting and boiling points

The **melting point** is temperature at which the solid and liquid forms of a pure substance can exist in equilibrium.

The **boiling point** of a substance is the temperature at which the vapor pressure of a liquid equals the pressure surrounding the liquid and the liquid changes into a vapor.

Effect of pressure on melting point of ice.



When pressure is increased by the weighted copper wire.

Observation

The weighed copper wire passes through the block of ice without cutting it into two pieces.

Explanation

This is because increasing pressure by the weighted copper wire lowers the melting point of ice, so the copper wire sinks through water and water which is no longer under pressure refreezes and gives out latent heat to the copper wire to enable melting of ice below.

Effect of impurities on the melting point

Impurities like salt lower the melting point of solid, e.g. temperature of a well stirred ice water mixture is normally 0°C but when an impurity such as salt is added it may fall to -20°C .

Evaporation

Evaporation is the process by which a liquid turns into a gas **at temperatures below its boiling point**. It happens when molecules at the surface of a liquid gain enough energy to break free and become vapour.

Explanation of cooling during evaporation according to kinetic theory

At a particular temperature, molecules of a liquid have an average speed but some molecules are moving faster than others. During evaporation, the average kinetic energy of the molecules remaining in the liquid decreases because faster moving molecules on reaching the surface of the liquid escape leaving behind slower molecules. The fall in average kinetic energy of molecules results in temperature fall shown by cooling.

Factors affecting evaporation

- (i) Temperature; the higher the temperature the higher the rate of evaporation due to increase in kinetic energy of molecules
- (ii) surface area; the bigger the surface area, the higher the rate of evaporation due to increased chance of escape of molecules
- (iii) Draught or wind blowing over surface of liquid; wind blows away saturated air increasing the rate of evaporation

- (iv) Nature of liquid; liquids with lower latent heat of evaporation evaporate more easily than those with higher latent heat of evaporation

Application of evaporation

- (i) **Sweating:** Your body cools down as sweat evaporates from your skin.
(ii) **Drying clothes:** Water evaporates from fabric into the air.
(iii) **Puddles disappearing:** Even without boiling, water slowly vanishes on a warm day.

Trial 6

Which of the following statements about boiling and evaporation is correct?

- A. Boiling takes place at all temperatures while evaporation does not
B. Evaporation takes place throughout the liquid while boiling takes place at the bottom of the container
C. Boiling takes place throughout the liquid while evaporation takes place at the surface
D. Evaporation takes place at lower temperature than boiling does [C]

Vapour Pressure

Vapour pressure is the pressure exerted by a vapour when it's in **equilibrium with its liquid** at a given temperature. When a liquid is exposed to air it evaporates and as the molecules collide with container walls and liquid surface, they exert pressure called vapour pressure

Note

- **Higher vapor pressure** means a liquid evaporates more easily (it's more volatile).
- **Lower vapor pressure** means it evaporates slowly.
- **It increases with temperature**—as molecules gain energy, more escape into the vapor phase.

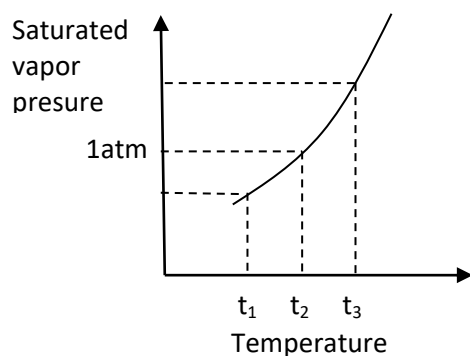
Saturated vapour pressure

This is the maximum vapour pressure that can be developed by a liquid at a given temperature when the **rate of evaporation equals the rate of condensation**.

Note:

- It **depends only on temperature**, not on the amount of liquid or vapor present.
- As temperature increases, more molecules have enough energy to escape the liquid, so **saturated vapor pressure increases**.
- A liquid boils at a temperature at which its saturated vapor pressure is equal to atmospheric pressure or pressure above the liquid. Hence, a liquid boils at lower temperature at lower pressure such as at the top of the mountain than at high pressure such as at sea level or inside a pressure cooker

A plot of the saturated vapour pressure against temperature is shown below



t_1 = boiling point at reduced pressure
 t_2 = boiling point at 1 atmosphere
 t_3 = boiling point at external pressure above 1 atmosphere

Unsaturated Vapor Pressure

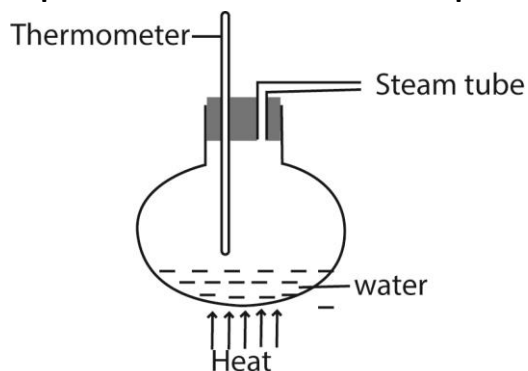
This occurs when the vapor pressure is **below the saturated level** at a given temperature. In this case:

- The **rate of evaporation is greater than condensation**.
- More liquid can still evaporate until saturation is reached.

Trial 7

1. Saturated vapour pressure is the pressure exerted by a
 - A. vapor which is in dynamic equilibrium with its liquid
 - B. liquid which is in dynamic equilibrium with its vapour
 - C. solid which is in dynamic equilibrium with its vapour
 - D. liquid which is in dynamic equilibrium with its solid [A]
2. When saturated vapour is compressed
 - A. more liquid evaporates
 - B. more vapour condenses
 - C. the amount of vapour remains the same
 - D. the vapour becomes saturated. [B]

Experiment to show the effect of pressure on boiling point



When heating is stopped the tube is closed and the flask is cooled by cold water.

Observation

Water starts to boil again though there is no heating.

Explanation

This is because when the flask is cooled the water vapour or steam above the water condenses resulting in the pressure above to decrease. The decreases in pressure decreases the boiling point of water. This explains why the boiling point of water is less than 100°C at Kampala and on the top mountains because of low atmospheric pressure.

Effect of impurities on boiling point

Impurities such as salt when added to a liquid e.g. water the boiling point of the liquid rises.

Differences between evaporation and boiling

Evaporation	Boiling
i) Occurs at any temperature	(i) Occurs at a fixed temperature called boiling point
ii) Occurs at the surface of the liquid. No bubbles	(ii) Occurs within the liquid Bubbles appear
iii) Depends on the surface area	iii) Does not depend on surface area
iv) Can occur even when atmospheric pressure is not equal to saturated vapour pressure	iv) Occurs only when atmospheric pressure is equal to saturated vapour pressure

However evaporation and boiling are similar in that:

- (i) Both evaporation and boiling need latent heat of vaporization
- (ii) Both evaporation and boiling involve change of state from liquid to gas.

Application of latent

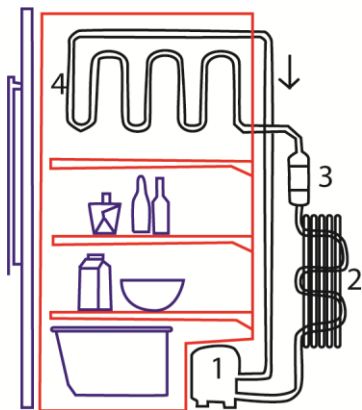
- (a) Steam scalds because it contains a lot of heat of vaporization.
- (b) Considerable amount of latent heat is lost during freezing and this heat is lost through the fins making them feel very hot.

The role that oceans play in global temperature regulation

Oceans act like a heat sink and temperature regulator through;

- (i) Absorption of heat when atmospheric temperature rises and releasing heat when the temperature falls due to water's high specific latent heat and heat capacities.
- (ii) absorption of carbon dioxide by its biological pump of phytoplankton, thereby reducing global warming
- (iii) influencing weather patterns, rainfall and storm formation

A refrigerator



1. Compressor

The compressor is essentially an engine. Its job is to kick start the entire cooling process. The compressor pumps the vapour refrigerant (the cooling agent) through the fridge by increasing the pressure and temperature of the coolant as it makes its way through the refrigeration cycle.

2. Condenser coils/cooling fins

The condenser coils, located on the back or bottom of your fridge, are the pipes where the vapour refrigerant condenses into liquid form as the compressor continues to increase pressure.

Cooling fins is where heat is lost to the surrounding.

3. Expansion device

The expansion device causes a rapid pressure reduction in the refrigerant, transforming it back to a vapour state. Located between the condenser and evaporator coils, its function is to control the release of pressure as the change of state from liquid to vapour occurs.

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The expansion device causes a rapid pressure reduction in the refrigerant, transforming it back to a vapour state. Located between the condenser and evaporator coils, its function is to control the release of pressure as the change of state from liquid to vapour occurs.

Trial 8

A domestic refrigerator uses a volatile liquid. Which of the following represents the order of the process the liquid undergoes?

- A. Evaporation compression condensation evaporation.
- B. Cooling condensation evaporation compression evaporation.
- C. Compression evaporation condensation cooling evaporation.
- D. Condensation cooling evaporation compression evaporation. [C]

Contraction

Is reduction in the size of a substance on cooling

Expansion

This is the increase in length or volume when a substance is heated

Linear expansivity

Linear expansivity is the fraction of its original length by which a rod of a substance expands per kelvin rise in temperature.

$$\begin{aligned}\text{Linear expansivity} &= \frac{\text{Expansion}}{\text{original length} \times \text{temperature rise}} \\ &= \frac{L_2 - L_0}{L_0 \times (\theta_2 - \theta_1)}\end{aligned}$$

where L_0 = original length of rod

L_2 = New length

θ_1 = Initial temperature

θ_2 = Final temperature

The unit of linear expansivity is K^{-1}

Example 8

In an experiment to measure linear expansivity of a metal, a rod of this metal is 800mm long is found to expand 1.36mm when the temperature rise from 15°C to 100°C.

$$L_2 - L_0 = 1.36\text{mm}$$

$$L_0 = 800\text{mm}$$

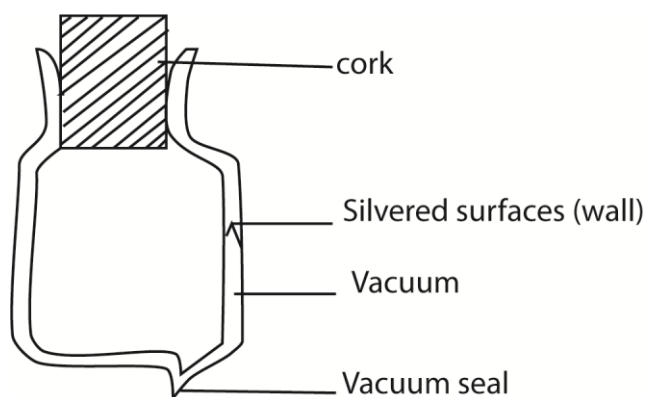
$$\theta_1 = 15 + 273 = 288\text{K} \quad \theta_2 = 100 + 273 = 373\text{K}$$

$$\text{Linear expansivity} = \frac{1.36}{800(373-288)} = \frac{1.36}{800 \times 85} = \frac{1.36}{6800} = 0.00002\text{K}^{-1}$$

Revision Exercise

- What is meant by specific heat capacity of a substance?
 - When a block of iron of mass 2 kg absorbs 19 kJ of heat, its temperature rises by 10°C. Find the specific heat capacity of the iron.
- What is meant by **boiling point of a liquid**?
 - Why is cooking faster with a pressure cooker?
 - State **two** differences between boiling and evaporation.
 - What is meant by specific latent heat of vaporization?
- State two factors which affect boiling points of water.
 - Calculate the heat required to convert 0.8 kg of water at 100°C to steam. (Specific latent heat of vaporization of water = $2.26 \times 10^6 \text{ Jkg}^{-1}$) [$1.808 \times 10^6 \text{ J}$]
 - Define the terms
 - Convection
 - Radiation
- State one difference between boiling and evaporation of liquids
 - Explain each of the following observations
 - There is no change in temperature at boiling point even though heat is being supplied
 - A change in pressure alters the boiling point of a liquid
- Equal volumes of water at the same temperature are poured in a basin and in a jug. State, giving a reason, which water will evaporate faster?
 - What are the functions of the following in a refrigerator?
 - Compressor
 - Coiling fins

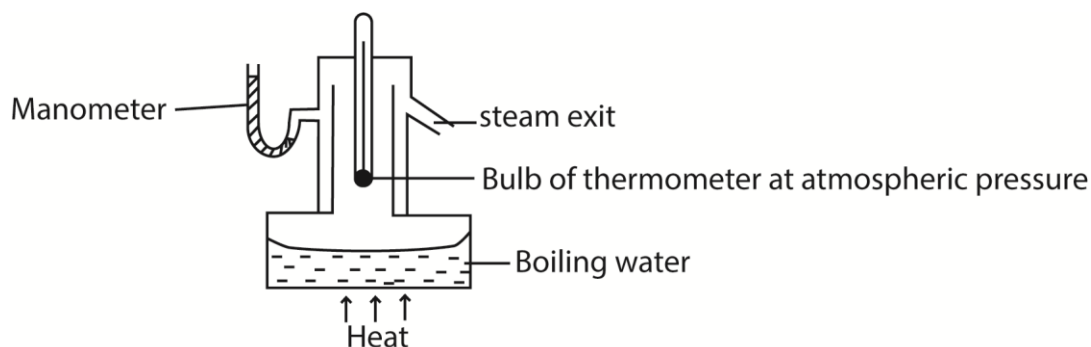
6. (a) Define specific heat capacity.
- (b) An immersion heater rated 1000W, 250 V supplies heat to 80kg of liquid in a tank. If the temperature of the liquid rises by 40°C in 48 minutes, what is the specific heat capacity of the liquid? [900Jkg⁻¹K⁻¹]
7. (a) With the aid of a labelled diagram, describe a vacuum flask is able to keep a liquid cold for a long time



When a cold liquid is put inside the flask

- The vacuum minimizes heat gain by convection and conduction
- Silvered surfaces minimizes heat gain by radiation
- The cork minimizes heat gain by conduction

- (b) How would you determine the upper fixed point of an uncalibrated thermometer



Boil water , the upper fixed point is the highest constant reading of the thermometer thread

- (c) Explain the following
- (i) A bare cement floor feels colder than a carpeted one
Bare cement is a conductor that conducts heat away from the feet (body) while a carpet is an insulator and does not conduct heat
- (ii) A beam with a notch that is used for constructing a bridge, lasts longer when the notch is on its top surface than when the notch is on its lower surface.

The upper notch is under compression while the lower notch is under tension. Concrete is stronger under compression than under tension.

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Thanks

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