

CHAPTER FIVE

THERMAL PROPERTIES OF MATTER

LEARNING OBJECTIVES

By the end of this chapter, you should be able to:

1. Differentiate between heat and temperature
 2. (a) State:
 - (i) Any two thermometric liquid.
 - (ii) The properties of thermometric liquid.
 - (iii) Advantages of mercury over alcohol as used a thermometer.
 - (b) Define: The lower and upper fixed points.
 - (c) Solve problems involving
 - (i) Conversion of temperature from one scale to another.
 - (ii) Calculation of temperature for unmarked thermometer.
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5.1 HEAT AND TEMPERATURE

Heat and measurement of temperature

Heat - is a form of energy which when absorbed by an object makes it hotter and when lost by an object leaves it colder.

Temperature - is the degree of hotness or coldness of a body.

Words such as warm, hot, tepid, cool and cold tell u about the temperature of an object. The words are not very precise, so if we need to be more accurate about the temperature of an object, we use a thermometer graduated with some scales called temperature scales.

NB: Temperature is the measure of how hot or cold a body is and should **not** be confused with the amount of heat the body contains.

(a) Thermometers

Definition: A thermometer is an instrument used to measure temperature.

A number of different types of thermometer are available. Each type of thermometer makes use of a particular thermometric property i.e. a property that changes with temperature. Examples of such properties are:

- (i) Change in length of liquid column
- (ii) Increase in electrical resistance

The most common type of thermometer is the liquid-in-glass thermometer. Thermometric liquids used in liquid-in-glass are **mercury** and alcohol.

(b) Properties of thermometric liquids

A thermometric liquid should have the following properties:

- (i) Should be opaque for easy reading.
- (ii) Good conductor of heat.
- (iii) High and uniform expansivity.
- (iv) High boiling point.
- (v) Low freezing point and
- (vi) Should not wet glass.

Mercury and alcohol compared

Mercury	Alcohol
(i) Opaque and therefore can easily be read	- Not opaque but can be coloured.
(ii) Good conductor of heat therefore sensitive to small temperature changes.	- Poor conductor of heat therefore not so sensitive to small temperature changes
(iii) Has uniform expansivity	- Expansion not so regular
(iv) Has high boiling point (357 °C) and therefore can measure high temperatures	- Low boiling point (78 °C) and therefore not suitable for measuring high temperatures
(v) Not very low freezing point (-39 °C) therefore can not measure temperatures below its freezing point.	- Low freezing point (-115 °C)
(vi) Does not wet glass	- Wets glass

(c) Advantages of alcohol over mercury as thermometric liquid

1. It has higher expansivity (about six times) that of mercury.
2. It has lower freezing point than mercury. Alcohol freezes at -115°C while mercury freezes at -39°C. The high freezing point of mercury makes the measurement of temperatures lower than -39°C to be impossible.

Apart from the disadvantage, mercury is preferred to alcohol for the following reasons.

- (i) It is a better conductor of heat than alcohol and therefore responds more readily to changes in temperature.
- (ii) It is opaque and makes reading easy.
- (iii) It has a high boiling point, 357°C and where as alcohol has low boiling point, 78°C, can easily vaporize to fill the upper part with vapour.

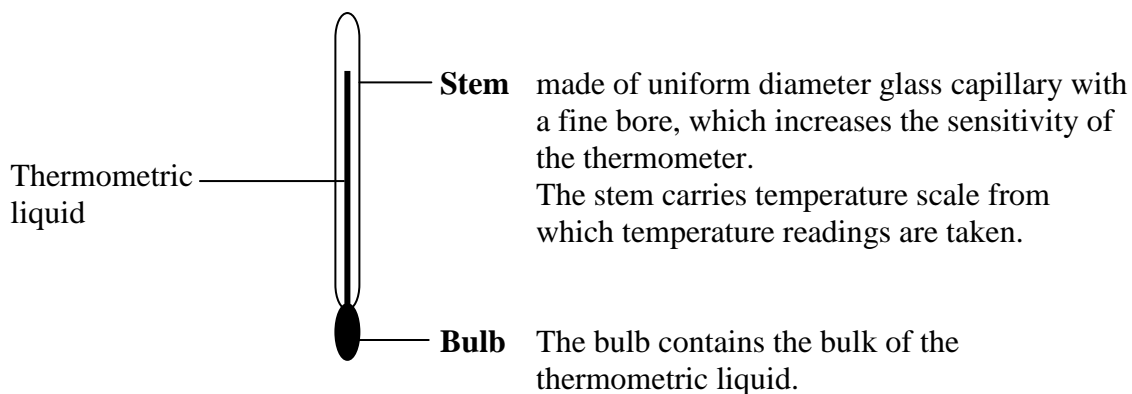
(d) Reasons why water is not used as a thermometric liquid

Water is unsuitable for use in thermometers because of the following reasons.

- (i) It freezes at 0°C.
- (ii) It has irregular expansion.

5.12 Structure of a liquid in glass thermometer

A *liquid-in-glass* thermometer consists of the following features.



(f) How to use a thermometer

The bulb is inserted or placed in contact with the object /substance whose temperature is to be measured.

The liquid in the bulb will either:

- (i) Acquire heat energy from the substance and expand making its level rise or
- (ii) Loses heat energy to the substance making its level to fall.

The temperature value is then read at the liquid level which directly corresponds on the temperature scale.

5.13 Graduation or Calibration of a thermometer

In order to establish a temperature scale, we choose two *fixed points*. A fixed point is a definite temperature at which a change of state occurs.

The two fixed points chosen are called *lower fixed point* and *upper fixed point*.

- (a) Lower fixed point** - *is the temperature of pure melting ice at standard atmospheric pressure (i.e. at pressure 760mmHg).*
- (b) Upper fixed point** - *is the temperature of steam from pure water boiling under standard atmospheric pressure.*

NB: *The ice and the water must be pure because the presence of impurities lowers melting point of ice and elevate the boiling point of water.*

Finding the fixed points of a thermometer

(a) Lower fixed point

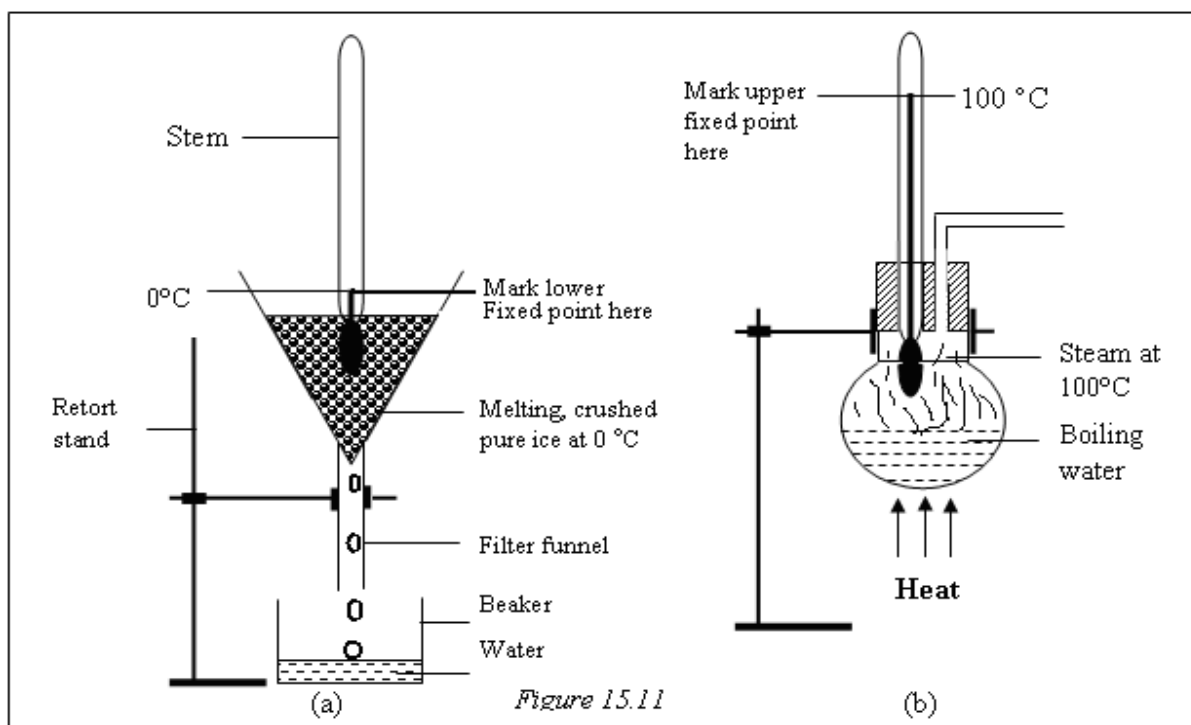
- Freeze some pure (distilled) water.
- Crush the ice into small pieces and fill a filter funnel with the pieces and wait for the ice to begin melting.
- When the ice begins to melt (i.e. at 0°C) insert the bulb of the thermometer so that it is covered with ice, figure 15.11 (a). The melting ice cools the mercury to 0°C.
- When the mercury stops shrinking (i.e. when the level becomes constant), mark the stem of the thermometer at the mercury level.
- This point is the lower fixed point, or the ice point on Celsius scale.

(b) Upper fixed point

- Remove the thermometer and insert it through a two holed cork.
- Fill a flask with pure water and cork it with the cork carrying the thermometer and a delivery tube such that the bulb is just above the water surface, figure 15.11 (b).
- Heat the water in the flask to a boiling point.
- When the mercury stops expanding (i.e. when the level becomes constant) mark its level on the thermometer stem.

This point is the upper fixed point, or steam point (100°C) on the Celsius. Then divide the difference between the two points into 100 equal points. Mark the points as a scale along the stem either in Celsius scale or Kelvin or both.

Finding the fixed points of a thermometer



5.2 Temperature Scales

There are two common scales of temperature, namely:

- (i) Celsius Scale and
- (ii) Kelvin Scale

(a) Celsius scale (Centigrade)

The centigrade or Celsius scale assigns a value of $0\text{ }^{\circ}\text{C}$ to the freezing point and $100\text{ }^{\circ}\text{C}$ to the boiling point of pure water. It is defined by dividing the fundamental difference (the difference between the upper and lower fixed points) into $100\text{ }^{\circ}\text{C}$ equal degrees. The temperatures on this scale are called “Degree Celsius”.

(b) Kelvin scale (Thermodynamic Scale)

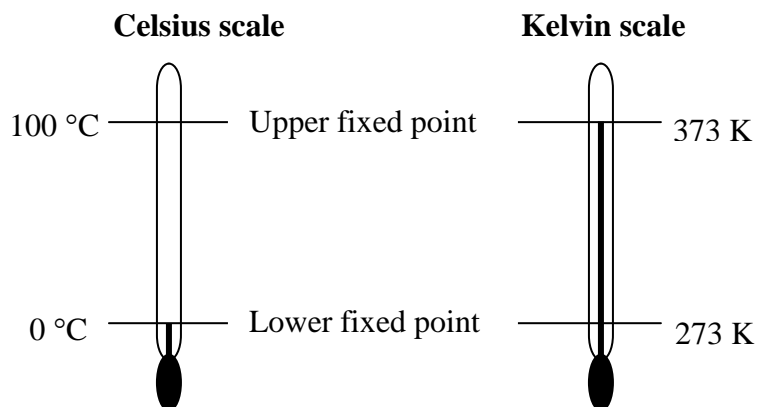
In the Kelvin or absolute scale, the lower fixed point is 273.15 K and the upper fixed point is 373.15 K . The *Kelvin* (K) is the S.I unit of temperature.

- Note:**
- (i) *The degree intervals are identical to those measured on the Celsius scale.*
 - (ii) *Absolute zero is approximately $-273.15\text{ }^{\circ}\text{C}$ or zero (0 K) degree on the Kelvin scale.*
 - (iii) *Absolute zero is the lowest possible temperature. It is characterized by complete absence of heat energy.*
 - (iv) *Temperatures on Kelvin do **not** have degree symbol ($^{\circ}$).*
 - (v) *One Kelvin is the same as one Celsius. i.e. $1\text{ K} = 1\text{ }^{\circ}\text{C}$*

5.21 (a) Relationship between Celsius scale and Kelvin scale

The two temperature scales are related to each other as shown below.

Fixed point	Celsius scale	Kelvin scale
Lower fixed point	0	273
Upper fixed point	100	373



(b) Conversion of temperature from one scale to another

The temperature value, θ , on Celsius scale is related to the temperature value, T on Kelvin scale by the formula:

$$\theta = T - 273$$

Or $T = \theta + 273$

Worked Examples

1. Convert the following temperature readings to Celsius scale.

(a) 1010 K (b) 233 K (c) 373 K

2. Convert the following temperature readings to Kelvin scale.

(a) 240 °C (b) 30 °C (c) 120 °C

Solution

1. (a) $\theta = ?$, $T = 1010$ K, (b) $\theta = ?$, $T = 233$ K, (c) $\theta = ?$, $T = 273$ K,

$$\begin{aligned}\theta &= T - 273 \\ &= 1010 - 273 \\ \therefore \theta &= 737 \text{ °C}\end{aligned}$$

$$\begin{aligned}\theta &= T - 273 \\ &= 233 - 273 \\ \therefore \theta &= -40 \text{ °C}\end{aligned}$$

$$\begin{aligned}\theta &= T - 273 \\ &= 373 - 273 \\ \therefore \theta &= 100 \text{ °C}\end{aligned}$$

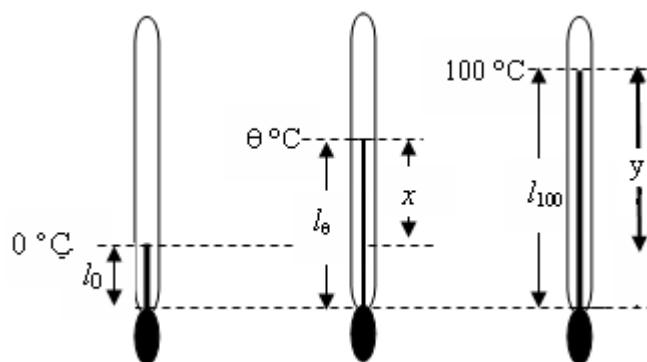
2. (a) $\theta = 240$ °C, $T = ?$ (b) $\theta = 30$ °C, $T = ?$ (c) $\theta = 120$ °C, $T = ?$

$$\begin{aligned}T &= \theta + 273 \\ &= 240 + 273 \\ \therefore T &= 513 \text{ K}\end{aligned}$$

$$\begin{aligned}T &= \theta + 273 \\ &= 30 + 273 \\ \therefore T &= 303 \text{ K}\end{aligned}$$

$$\begin{aligned}T &= \theta + 273 \\ &= 120 + 273 \\ \therefore T &= 393 \text{ K}\end{aligned}$$

- (c) **Calculating the temperature values when the lengths of the thermometric liquid for the lower and upper fixed points are given**



From the diagram: l_0 = the length of mercury column at $0\text{ }^{\circ}\text{C}$.

l_{100} = the length of mercury column at $100\text{ }^{\circ}\text{C}$.

l_{θ} = the length of mercury column at unknown temperature, $\theta\text{ }^{\circ}\text{C}$.

$$x = (l_{\theta} - l_0)$$

$$y = (l_{100} - l_0)$$

$$\text{Temperature, } \theta, \text{ in } ^{\circ}\text{C} = \frac{\text{Mercury length above the lower fixed point}}{\text{Fundamental difference}} \times 100$$

$$= \frac{l_{\theta} - l_0}{l_{100} - l_0} \times 100$$

$$\therefore \theta = \frac{x}{y} \times 100$$

Worked Examples

1. A mercury thermometer is calibrated by immersing it in melting pure ice and then in boiling pure water. If the mercury columns are 6 cm and 16 cm respectively, find the temperature when the mercury column is 8 cm long.

Solution $l_0 = 6\text{ cm}$, $l_{100} = 16\text{ cm}$, $l_{\theta} = 8\text{ cm}$, $\theta = ?$

$$\theta = \frac{l_{\theta} - l_0}{l_{100} - l_0} \times 100 = \frac{8 - 6}{16 - 6} \times 100 = \frac{2}{10} \times 100 = 20\text{ }^{\circ}\text{C}$$

2. The length of mercury column of a thermometer at ice point and steam point are 2.0 cm and 22.0 cm respectively. The reading of the thermometer when the mercury column is 9.0 cm long is

A. $45.0\text{ }^{\circ}\text{C}$

B. $40.9\text{ }^{\circ}\text{C}$

C. $35.0\text{ }^{\circ}\text{C}$

D. $31.8\text{ }^{\circ}\text{C}$

Solution $l_0 = 2.0\text{ cm}$, $l_{100} = 22.0\text{ cm}$, $l_{\theta} = 9.0\text{ cm}$, $\theta = ?$

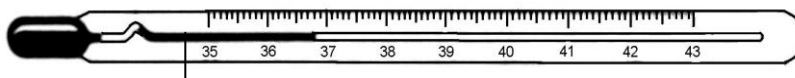
$$\theta = \frac{l_{\theta} - l_0}{l_{100} - l_0} \times 100 = \frac{9.0 - 2.0}{22.0 - 2.0} \times 100 = \frac{7.0}{20.0} \times 100 = 35\text{ }^{\circ}\text{C}$$

Therefore the answer is **C**.

Other types of thermometers

Other types of thermometers include:

- (i) Clinical thermometer - Used by doctors in hospitals and clinics.



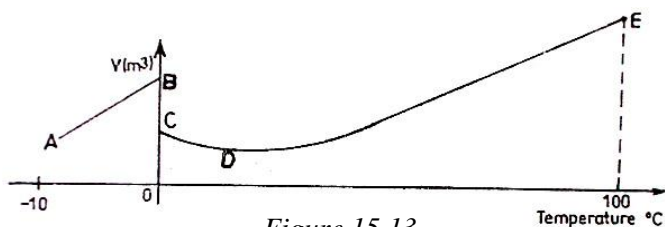
- (ii) Constriction - Causes break to the mercury thread and stops the thread above it from moving back in to the bulb.
- It enables the doctors to take the reading at their own time.

NB: Before use on another patient the thermometer is shaken to let the mercury thread to move in to the bulb.

- (iii) Thermocouple
(iv) Resistance thermometer
(v) Thermistor
(vi) The constant-volume gas thermometer
(vii) The maximum six fixed thermometer

Self-Check 5.0

- The distance between the fixed points on mercury in glass thermometer is 25cm. What is the temperature in degrees Celsius if the mercury thread is 8cm long?
A. $\frac{100 \times 25}{8}$ B. $\frac{100 \times 8}{25}$ C. $\frac{25 \times 8}{100}$ D. $\frac{100 \times 25}{10}$
- Which one of the following fluids is the best conductor of heat?
A. Air B. alcohol C. water D. mercury
- The graph in the figure shows water being heated from -10°C to 100°C .



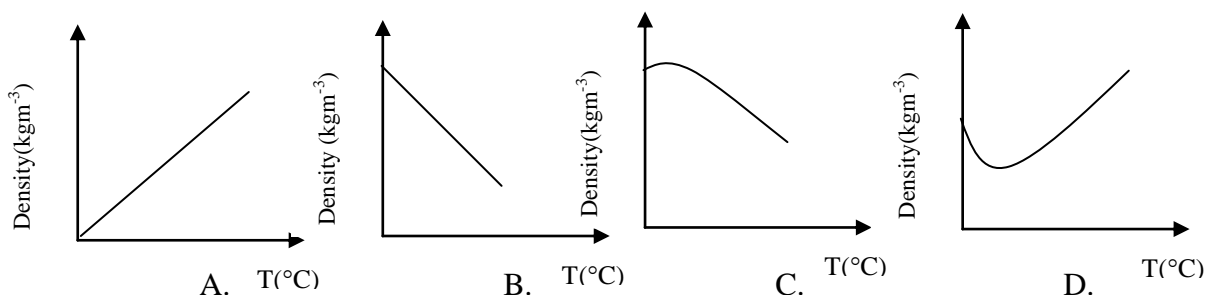
At what point does the substance have maximum density?

- A. E
B. C
C. D
D. B
- A bimetallic strip operates on the principle that metals
A. are heat controllers. B. are good heat conductors.
C. have different rates of expansion. D. have the same rates of expansion.
 - In order to make a mercury thermometer more sensitive, the
A. degree markings must be further apart.
B. diameter of capillary tube must be reduced.
C. volume of the mercury bulb must be reduced.
D. capillary tube must be open to air.
 - A tight bottle top becomes easier to unscrew when hot water flows over it because the
A. cap expands more than the glass
B. glass in the neck of the bottle contracts
C. hot water acts as oil between the glass and the bottle
D. increased pressure of the air in the bottle causes the cap to expand

7. Which of the following changes occur when a metal block is heated?

	Volume	Mass	Density
A	increases	remains the same	decreases
B	increases	increases	increases
C	remains the same	remains the same	decreases
D	increases	remains the same	increases

8. The distance between the lower and the upper fixed points on the Celsius scale in unmarked mercury-in-glass thermometer is 25cm. If the mercury level is 5cm below the upper fixed point, then the temperature is
 A. 5°C B. 20°C C. 80°C D. 95°C
9. The unusual expansion of water when it is cooled between 4°C and 0°C is due to
 A. water molecules coming closer together to form a compact structure
 B. formation of a new arrangement of molecules which requires a large volume
 C. the increased repulsive forces between the water molecules
 D. differences in the sizes of water and ice molecules
10. Which one of the following graphs shows how the density of water varies with temperature between 0°C and 100°C ?



SECTION B

1. (a) State: (i) Any two thermometric liquids you know.
 (ii) The properties of a thermometric liquid.
 (iii) Advantages of mercury over alcohol as used a thermometer.
- (b) Define the following terms.
 (i) Lower fixed point.
 (ii) Upper fixed points.
 (a) Describe how the fixed points of a thermometer are determined in the laboratory.
2. The interval between the ice and steam points on a thermometer is 192 mm. Find the temperature when the length of the mercury thread is 67.2 mm from the ice point.
3. The distance between the lower and upper fixed points on the Celsius scale in unmarked mercury-in-glass thermometer is 25 cm. If the mercury level is 5 cm below the upper fixed, calculate the temperature value.
4. Convert the following temperature readings to Celsius scale.
 (a) 750 K (b) 400 K (c) 973 K
5. Convert the following temperature readings to Kelvin scale.
 (a) 340°C (b) 130°C (c) 20°C

5.3 TRANSFER OF HEAT

Heat can travel in three ways:

1. Conduction
2. Convection
3. Radiation

Conduction:

It is the flow of heat through matter from place of higher temperature to place of lower temperature without movement of matter as a whole.

The transfer of heat requires a material medium.

Convection:

It is flow of heat through a fluid from places of higher temperature to places of lower temperature by movement of the fluid itself.

Radiation:

It is the flow of heat from one place to another by means of electromagnetic waves.

The transfer of heat does not require a material medium.

Conduction in Solids

Heat transfer in solids can occur as an excess energy of the vibration being passed along from atom to atom and this happens in all solids. Metals are made of atoms which have free electrons. As a result metals allow heat to pass through them easily and they are called **good conductors of heat**.

On the other hand, non-metals do not have free electrons and they don't allow heat to pass through them. Non-metals are classified as **poor conductor or insulators**.

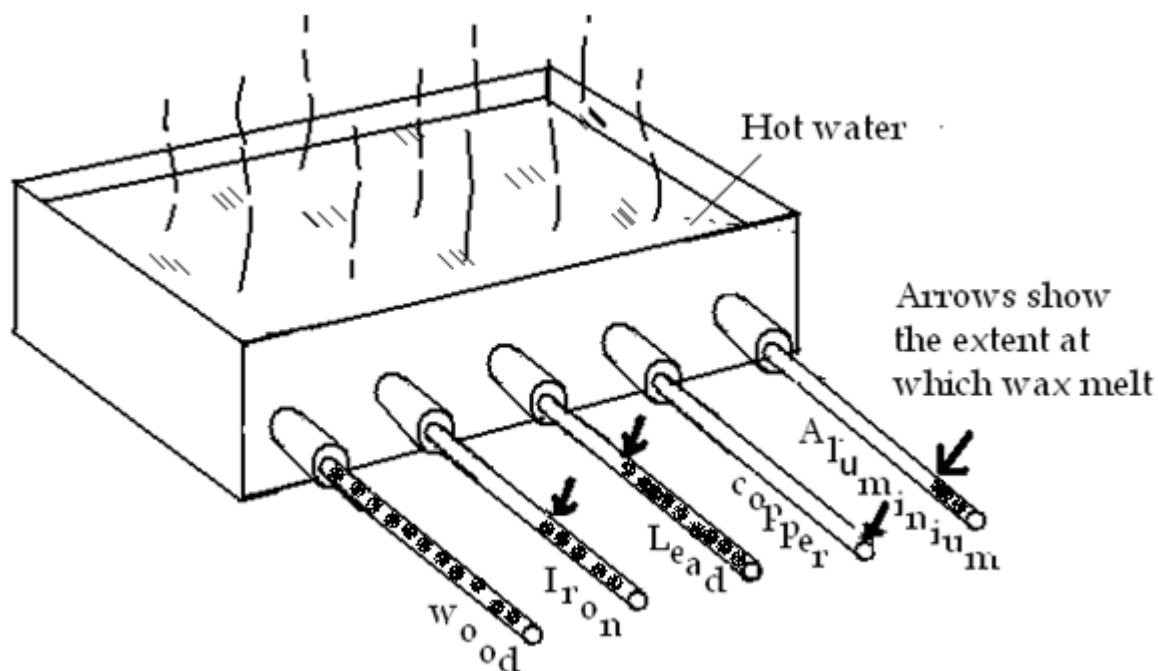
Good conductors of Heat:

Copper, Iron, Aluminum, Silver, Mercury etc

Poor conductors of Heat:

Plastic, Rubber, Wood, Grass, Gases, liquids, etc

Comparison of thermal conductivities



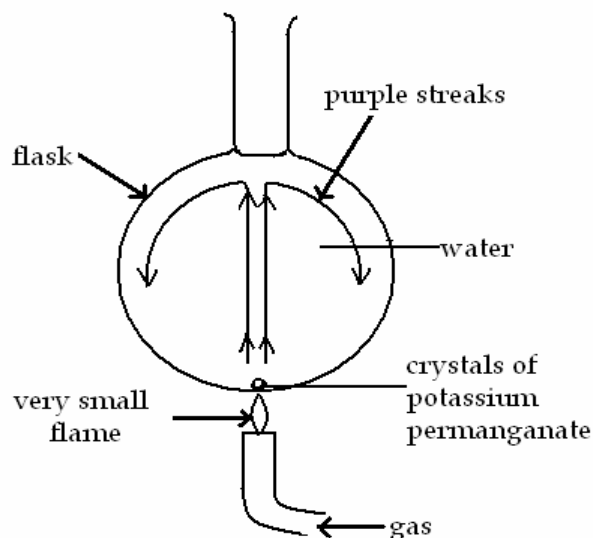
Rods of different materials having the same length and diameter are passed through corks inserted inside of a metal trough as shown in the figure above. These rods are first dipped into molten paraffin wax then passed through corks attached to a water tight container containing hot water. Small lengths of the rods rest in the water, while the long portions just out. It is realized after a short time that wax begins to melt along the rods. It melts fastest along copper rod and slowest along wood.

This shows that copper is the best conductor of all these rods and wood is the poorest of them.

Convection in liquids

The transfer of heat by convection can be demonstrated by using simple experiment as seen in the figure below. A crystal of potassium permanganate is placed at the bottom of a beaker full of water.

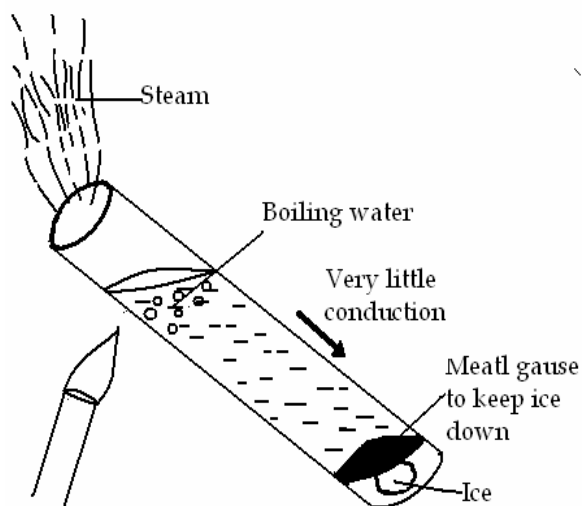
When the beaker is heated gently from the bottom, potassium permanganate spreads out and then descends to the bottom in a cyclic manner. In the course of heating the water on top becomes hot. This shows that heat has been transferred from the bottom to upwards.



The transfer of heat in this case can be explained as: When the liquid is heated, the liquid expands and becomes less dense. The less dense liquid rises and carries the heat it absorbed with it, thus transferring the heat upwards. The cold water sinks to the bottom in order to take up the position of the warm liquid. At the bottom of the beaker, the cold liquid also becomes less dense as it absorbs heat and it rises. This cyclic process is repeated on and on until the liquid boils. The movement of the liquid from the bottom upwards then downwards from the top of the liquid forms what is called **convection current**.

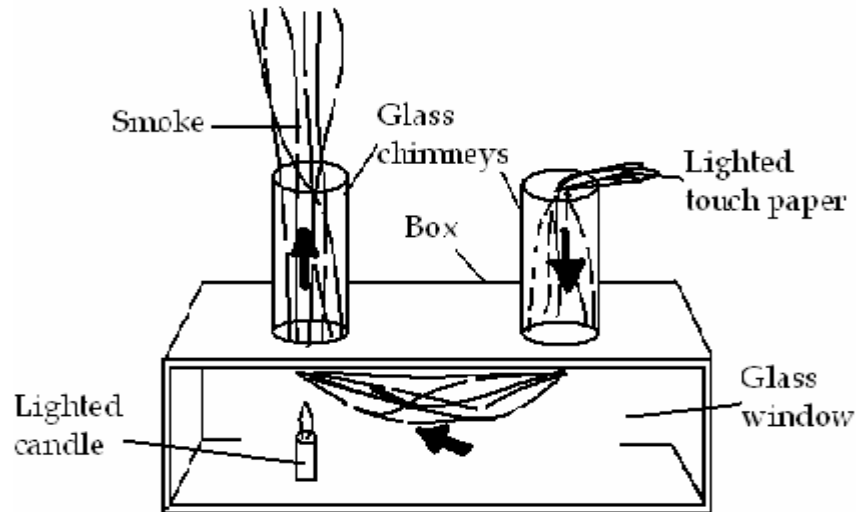
When a liquid is heated from the top as in the figure below, no convection is setup. This is because the warm liquids remain on top as it is already less dense than the liquid at the bottom.

However, after a long time, ice placed at the bottom of the tube may be seen to melt as some heat transfer down by conduction.



Convection in Gases (in Air)

Convection is much faster in gases than in liquids. This is due to much greater change in density when the gas is heated. Convection current in gases can be demonstrated by using the arrangement in the figure below.

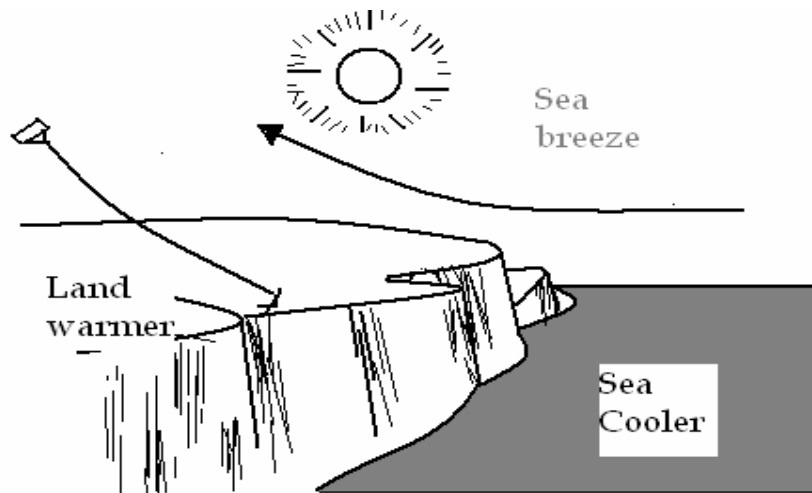


The direction of the convection current created by the candle is made visible by the smoke from the touch paper.

Application of air convection

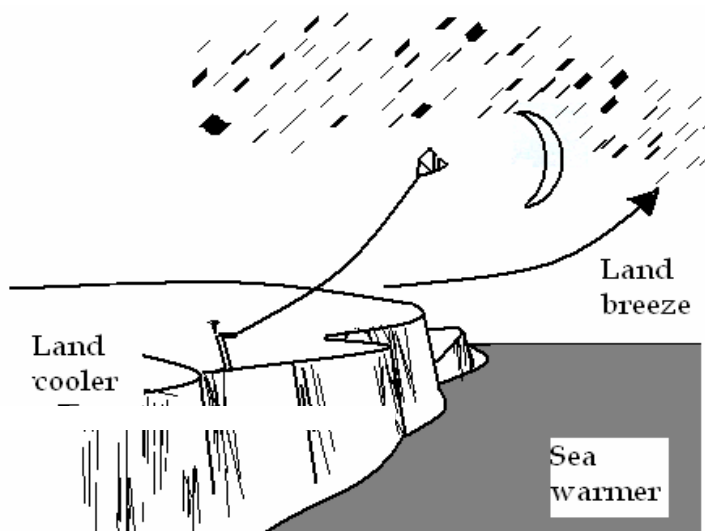
Sea and Land Breezes: During the day the temperature of the land increases more quickly than that of the sea(because the specific heat capacity of the land is much smaller). The hot air above the land rises and is replaced by colder air from the sea. Breeze from the sea results figure (a)

a)



At night the opposite happens. The sea has more heat to lose and cools more slowly. The air above the sea is warmer than that over the land and a breeze blows from the land figure(b).

b)

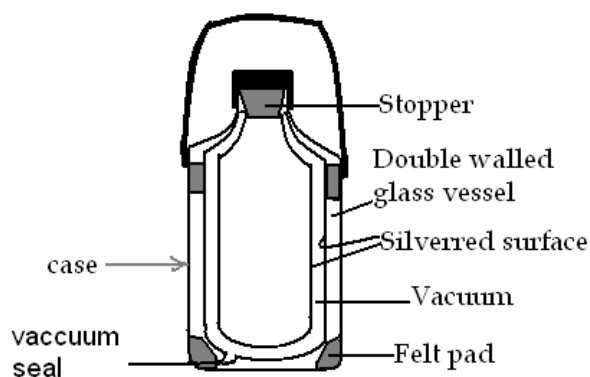


Laws of Radiation

1. Bodies only radiate heat if their temperature is higher than the surrounding and they absorb heat from the surrounding if their temperature is lower.
2. Radiate heat travels in a straight line.
3. Good absorbers of heat radiations are also good emitters of heat radiation.

Application of Heat Radiation

Vacuum Flask



A vacuum or Thermos flask keeps hot liquids hot and cold liquids cold. The thermos consists of double walled glass vessel having a vacuum between walls. Both walls are silvered on the vacuum side. The liquid can be kept hot or cold because heat loss by;

- Conduction and convection are eliminated by the vacuum space between the double walled glass vessel.
- Convection from the hot liquid upwards to the outside is reduced by the cork or plastic stopper.
- Radiation is prevented by the silvered glass wall. In this case, any heat when tries to escape through vacuum is reflected back.

NB: *A thermos flask can be considered useless when the vacuum seal breaks. This is because the vacuum will no longer be there and heat can be lost by radiation, convection or conduction through the broken seal.*

TEST FIVE

SECTION A

1. The transfer of heat by the actual movement of molecules matter takes place
 - A. Only in liquids.
 - B. Only in gasses
 - C. In solids and liquids
 - D. In liquids and gasses
2. The process of using a material of low thermal conductivity to prevent heat loss is called
 - a) cooling
 - b) lagging
 - c) absorption
 - d) contraction
3. 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.
4. The rate of evaporation from a body is increased by
 - (i) temperature
 - (ii) pressure
 - (iii) liquid with greater cohesive forces
 - (iv) dryness of air around the body
 - (a) (i) and (ii) only
 - (b) (ii) and (iii) only
 - (c) (i) and (iv) only
 - (d) (iii) only.
5. A dull black surface feels hotter even though it is at the same temperature as a shiny surface because it
 - (a) Has more heat than the shiny surface
 - (b) Emits more heat than a shiny surface
 - (c) Reflects more heat than a shiny surface
 - (d) Conducts more heat than a shiny surface.
6. A sea breeze occurs
 - (a) when cool air blows towards the land

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SECTION B

1. (a) Explain why the sea remains cooler than land during daytime and warmer than land at night.
(b) State any one factor on which the rate of heat transfer along a metal bar depends.

2.



The above figure shows a thermos flask.

- (a) Name the parts labelled A and B
(b) State the use of part labelled A
(c) Why do the contents of the flask ultimately get cold?
3. (a) Name two main features of a vacuum flask, which enable it to keep a liquid warm.
(b) What is the use of a vacuum in a thermos flask?
4. What are the functions of the following in a refrigerator?
 - i) Compressor
 - ii) Cooling fins?
5. (a) Differentiate between conduction and convection.
(b) Describe an experiment which can be performed to show convection in a liquid
6. (a) What is meant by conduction?
(b) Draw a diagram of a thermos flask and explain how it is able to keep a liquid cool for a long time.
7. Explain the following observation
A bare cement floor feels colder than a carpeted one.

SOLUTION TEST FIVE

1. D 2. B 3.A 4.C 5. B 6.A 7.C 8. B 9.C 10.D