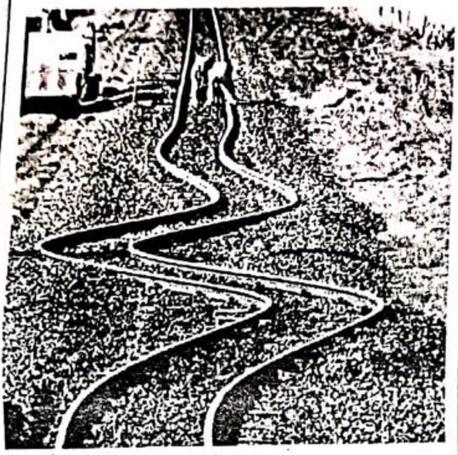
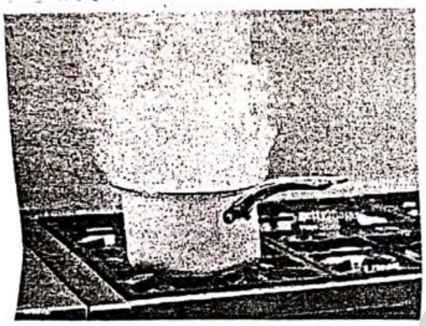
# O Level Physics Syllabus Content for CAIE 2019-22 Exams

## CHAPTER 11:
## Thermal Properties of Matter





**Syllabus Content**

11.1 Specific heat capacity

11.2 Melting and boiling

11.3 Thermal expansion of solids, liquids and gases

**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 use the formula thermal energy = mass × specific heat capacity × change in temperature.

d) Describe melting/solidification and boiling/condensation in terms of energy transfer without a change in temperature.

e) State the meaning of melting point and boiling point.

f) Explain the difference between boiling and evaporation.

g) Define the terms latent heat and specific latent heat.

h) Explain latent heat in terms of molecular behaviour.

i) Calculate heat transferred in a change of state using the formula thermal energy = mass × specific latent heat.

j) Describe qualitatively the thermal expansion of solids, liquids and gases.

k) Describe the relative order of magnitude of the expansion of solids, liquids and gases.

l) List and explain some of the everyday applications and consequences of thermal expansion.

m) Describe qualitatively the effect of a change of temperature on the volume of a gas at constant pressure.

**ABDUL HAKEEM 0300-4810136**
**O / AS & A Level Physics**

# Thermal Properties of Matter

When a body is heated, its internal energy will increase because its molecules will move faster; the amount of thermal energy gained by the body depends on:

1. Temperature rise, θ, which is a measure of the average kinetic energy gained by each molecule,
2. The mass of the body, m, which is proportional to the number of molecules in the body, and
3. The type of material of the body which is expressed by a constant, c, the specific heat capacity of material.

Now the amount of heat energy gained by a body is expressed as: Heat gained = m. c. θ (Measured in Joules). Specific Heat Capacity of a Substance, c, is the amount of heat energy required to raise the temperature of 1 kg of the substance by 1°C.

The value of the specific heat capacity, c, depends on the type of material only; it is given in units of (J / kg K) or (J / kg °C).

**Example:** A tank holding 60 kg of water is heated by a 3 kW electric heater. If the specific heat capacity of water is 4200 J / (kg K), estimate the time for the temperature to rise from 20°C to 70°C.

**Solution:** Electric energy supplied = Heat energy received

$P x.t = mc\theta$

$3000x\ t = 60\ x\ 4200\ x\ (70-20)$

t= 4200s = 70 mins

Specific Heat Capacity of Water is particularly high (4200 J/kg K) which makes it useful to store and carry heat energy (heat radiators). Also, the temperature of the sea rises and falls more slowly than that of the land (sea and land breezes). Living creatures can resist the change in temperature since they contain a large amount of water.

Thermal Capacity of a Body is the amount of heat energy required to raise the temperature of the whole body by 1 k.

The thermal capacity of a body depends on its mass, m, and on the type of its materials (c). Thermal capacity of a body = m .C (Measured in J / k or J/C)

**Experiment:**

Measuring Specific Heat Capacity (By an electric method). If a heater of known power, P, is immersed in a liquid, the electrical energy flowing in the heater will be totally transferred to heat energy in the liquid (assuming no loss of heat to the surroundings).

Electric energy given by heater = heat energy gained by liquid **OR**

$P \times t = m . c . \theta$

$c = \frac{P.t}{m.\theta}$ (in J / kg K)

In practice, heat is lost to the surroundings such as the container, the air around it, the thermometer ......... so the rise in temperature θ is smaller than it should, and the value obtained for c is greater than the true value.

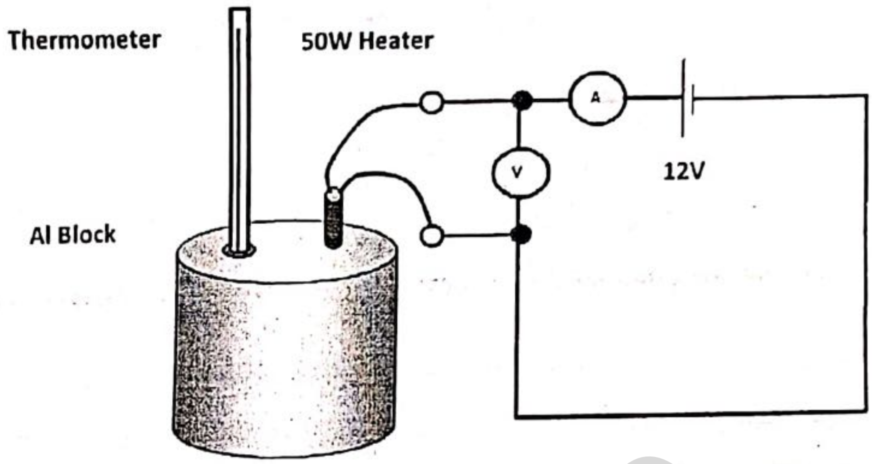



Figure: Apparatus for measuring the Specific heat capacity of water

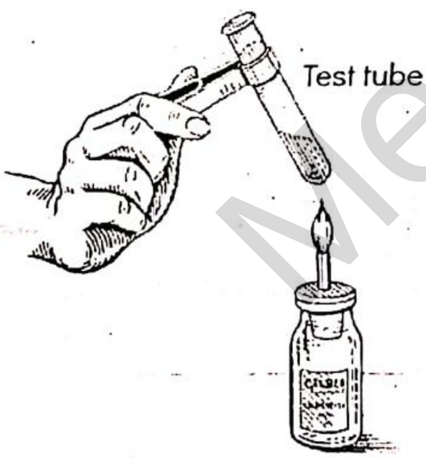
A similar method can be used to calculate the specific heat capacity of a solid except that the heater and thermometer are placed in holes drilled in the solid block. Heat losses may be reduced by wrapping and covering the block by a thermal insulator material (like expanded polystyrene or felt).

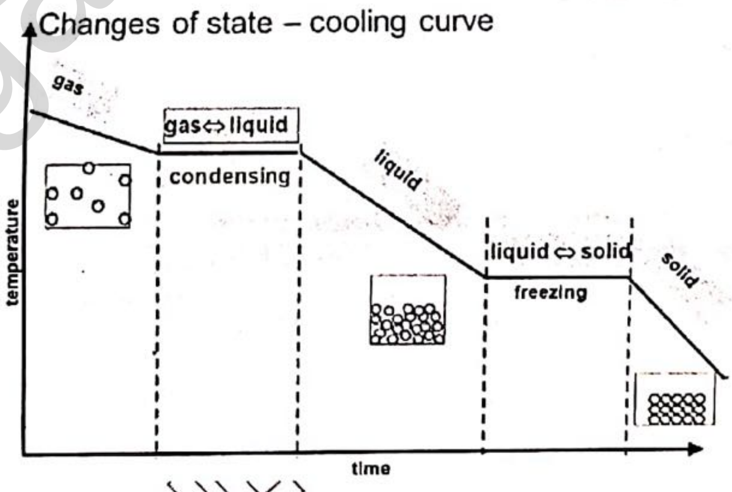
## Latent Heat

### Melting Point:

When a pure solid is heated, its temperature rises until it reaches the "melting point" where it remains constant until all the solid changes to liquid.

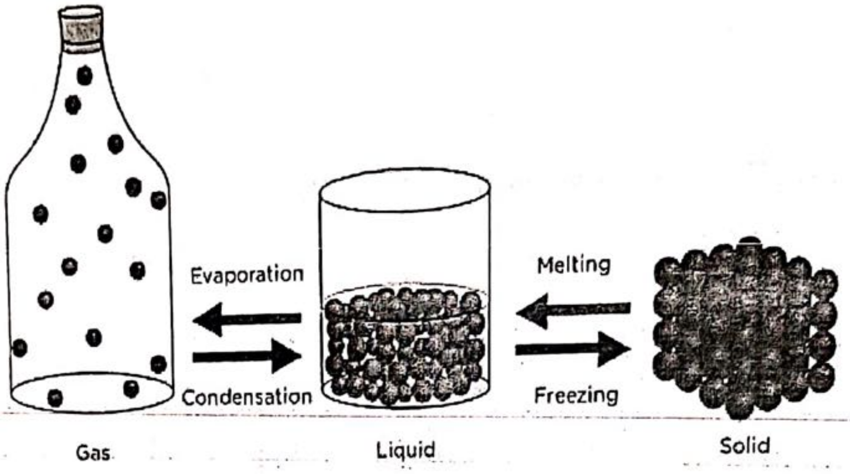
The heat energy absorbed during the melting process is called the "latent heat of fusion". It *is called "latent" or "hidden" because it does not raise the temperature during its absorption.*








**Kinetic Theory Explanation of Latent Heat of fusion**

The latent heat of fusion is the energy used up in overcoming intermolecular forces and separates the molecules during melting. The absorbed energy causes the molecules to move further apart increasing their potential energy. The kinetic energy of molecules does not change during melting, so the temperature stays the same.

**During melting:** (change from solid to liquid)

1- Temperature remains constant,
2- Average kinetic energy of molecules remains constant,
3- Distances between molecules increase,
4- Ave. potential energy of molecules increase.

*Specific latent heat of fusion "$l_f$"*

**"It is the thermal energy required to change 1 kg of a solid to a liquid without change in temperature".**

The amount of heat energy absorbed during fusion is: $E = m\, l_f$ (measured in Joules)

**Example:**

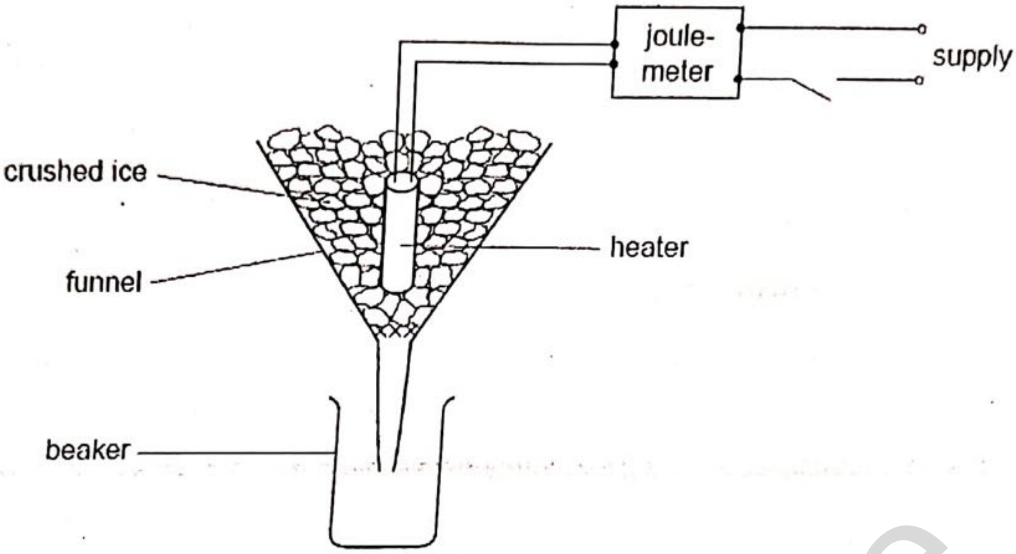
How much heat is extracted to change 0.2 kg of water at 15°C to ice at 0°C? (Specific latent heat of fusion of ice = 334 000 J / kg)

**Solution:** There are two states:

1. Heat extracted to cool the water to 0°C
   $= m\ c\ \theta$
   $= 0.2 \times 4200 \times 15$
   $= 12600$ J

2. Heat extracted to change water to ice
   $= m\ L$
   $= 0.2 \times 334\,000$
   $= 66800$ J

3. Total heat extracted = 12600 + 66800 = 79400 J




***Experiment:***

1. Measuring the specific latent heat of ice
2. Place an electric heater in the melting ice packed in a funnel.
3. Switch on the heater and turn on the stop-watch and collect the water from melting the ice for several minutes.
4. Switch off the heater and the Stop-watch; then find the mass, M, of water collected.
5. The energy supplied by the heater equals the heat used to melt ice:

$P \times t = m \times l_f$

$l_f = \frac{Pxt}{m}$

*$l_f$ is measured in "J / kg"*

*In this experiment some heat is absorbed by ice from the surroundings, therefore "m" becomes greater than it should, thus the value of $L_f$ obtained is smaller than the true value.*

***Melting and Freezing***

1. When a liquid is cooled it changes to a solid at the "freezing point". The freezing point is the same as the "melting point".
2. Only pure substances have clearly defined melting points. Many materials are mixtures of several substances and the cooling curve has no "horizontal section" during melting.
3. The melting point of ice can be lowered by:
   **(a)** Increasing the pressure on the ice (ice skating melts ice, snow balls formed by pressure).
   **(b)** Adding impurities to the ice (salt reduces temperature of melting ice to -18°C, adding anti-freeze to car radiators in winter, spreading salt on icy roads).

## Boiling Point

When a liquid is heated, its temperature rises until it reaches the "boiling point" where it remains constant until all the liquid changes to vapour. The heat energy absorbed during boiling is called the "latent heat of vaporization".

## Kinetic Theory Explanation of Latent Heat of Vaporization

The latent heat of vaporization is the energy required to force the molecules far apart from each other to change the liquid into vapour. The molecules travel freely in random directions and their potential energy increases greatly but the average kinetic energy does not change which keeps the temperature constant during the change.

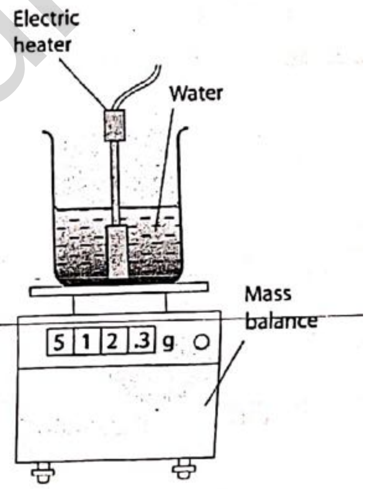
### During Boiling: (change from liquid to gas)

1- Temperature remains constant,
2- Average K.E. remains constant,
3- Distances between molecules increase,
4- Ave. P.E. of molecules increase.

Specific Latent Heat of Vaporization "$L_v$". It is the heat energy required to change 1 kg of the liquid to the vapour state without change in temperature. The amount of heat energy absorbed during vaporization is: $E = m\ L_v$ (Measured in Joules)

### Experiment:

### Measuring the specific latent heat of vaporization of water:




1. When the water is boiling, the mass reading on the balance is noted and a stopwatch started.
2. After several minutes, stop the stop watch and take the new reading of the mass
3. The difference in mass readings gives the mass of the water which has changed to steam.
4. *The energy supplied by the heater equals the heat used to* change water into steam

$P \times t = mL_v$

$L_v = \frac{Pxt}{m}$ in (J / Kg)

In the experiment, some heat is lost to the surroundings and the measured "m" is smaller than it should, thus the value of $L_v$ obtained is greater than the true value.

### Vaporization and Condensation:

1. When a vapor is cooled it changes to a liquid at the same temperature "boiling point".
2. The boiling point of a liquid increases by:
   (a) Increasing the pressure above it (case of cooking in a pressure cooker).
   (b) Adding impurities (such as salt).

### Boiling and Evaporation

1. Boiling occurs at a definite temperature (the boiling point) but evaporation occurs at all temperatures.
2. Boiling occurs within all the volume of the liquid, but evaporation occurs at the surface of the liquid.

3. In boiling, bubbles appear within the liquid, but there are no bubbles in evaporation.

## Thermal Expansion

### A. Expansion of Solids

When a solid is heated, its molecules gain kinetic energy and vibrate more vigorously. As the vibrations become larger, the molecules are pushed further apart and the solid expands slightly in all directions.

When the solid is cooled the reverse happens. Different materials expand by different amounts. Experiments show that aluminum expands more than brass and brass more than steel and steel more than glass, etc ...

The expansion in length of a rod is increased by:

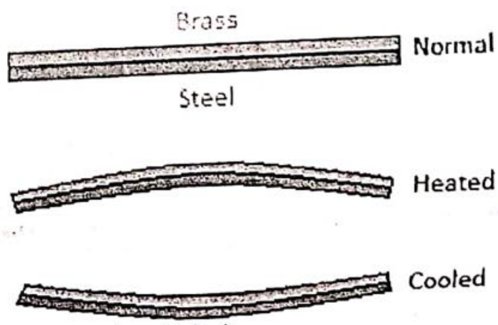
**(a)** The increase of the original length, l,
**(b)** The increase of the amount of temperature rise, $\theta$,
**(c)** The type of material.

Solids in general have the smallest values of expansivity, while gases have the greatest expansivity and liquids lie in between.

#### Avoiding Expansion Problems

Gaps are left between sections of railway lines to avoid damage of the rails as they expand in hot weather. Roads which are made of slabs of concrete must have gaps between them to allow for expansion. Telephone wires are hung loose between poles to allow for contraction in cold weather. One end of a bridge is fixed while the other end rests on rollers which permit movement.

#### Uses of Expansion: The Bimetal Strip




Two thin strips of different metals can be welded together to form a bimetal strip. When the bimetal strip in the figure is heated, the brass expands more than iron and strip bends with brass on the outside (the longer side) of the curve.

#### Thermostat:

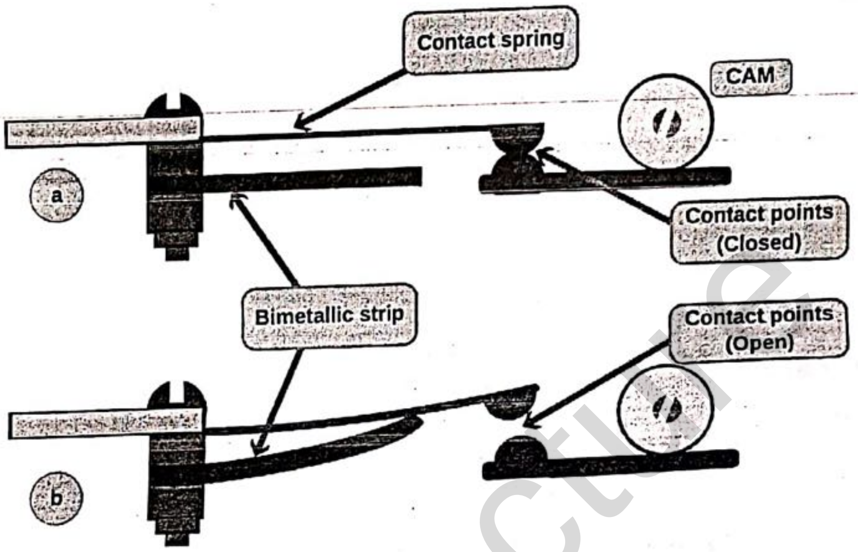
A bimetallic thermostat is a device which is widely used in electric irons, domestic hot water system, fish tanks, toasters, etc.

Once the temperature knob is adjusted, the temperature of the appliance will remain approximately constant.

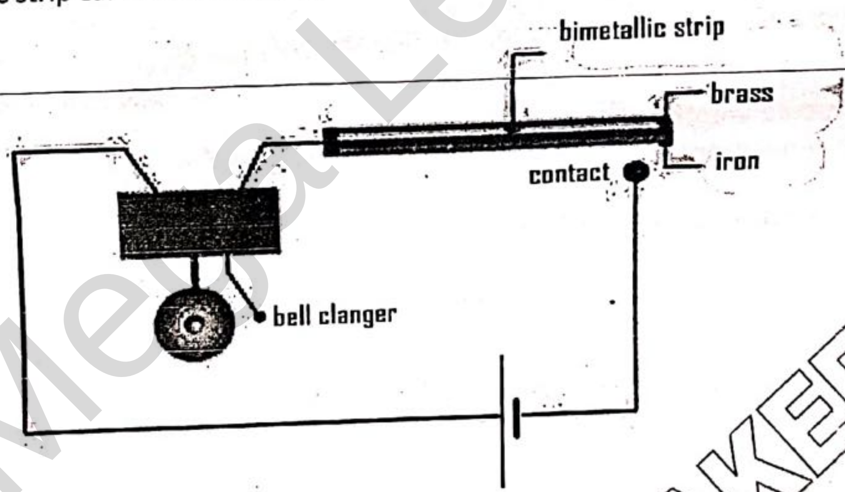
In a thermostat a bimetallic strip is a part of a heater's circuit. It curves and breaks contact when the temperature reaches a certain value, thus switching off the current in the heater.

When the temp. Drops below the required value, the strip straightens back switching on the heater. The temperature range required is controlled by the screw, for higher temperature turn the control screw to bring the contacts closer.

Flashing indicators on a car also use bimetallic strips. A heating coil heats the strip which bends and breaks contact, therefore, breaking current. The strip cools and straightens back restoring current and so the lamp flashes on and off

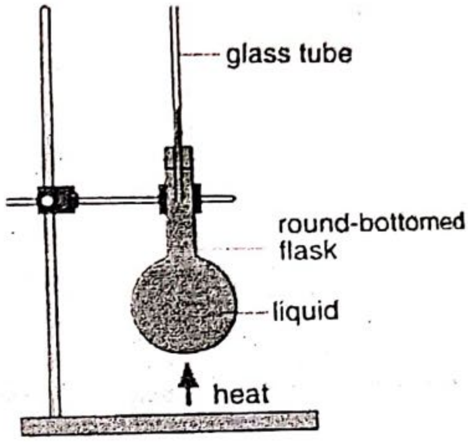



The bimetallic strip can also be used as a fire alarm.

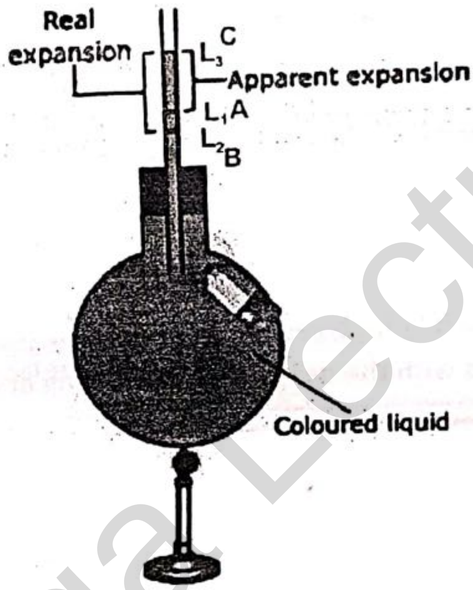


## B. Expansion of Liquids

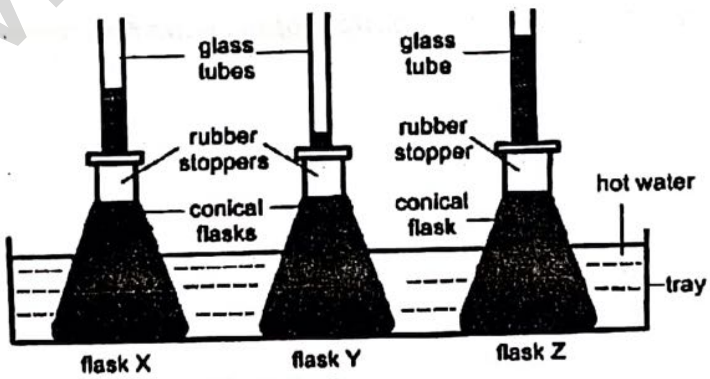
When a liquid is heated as shown in the figure, its level initially drops due to the expansion of the flask. When heat reaches the liquid it compensates for the expansion of the flask and rises much more than the original level. This shows that the expansivity of liquids is much greater than the expansivity of solids.



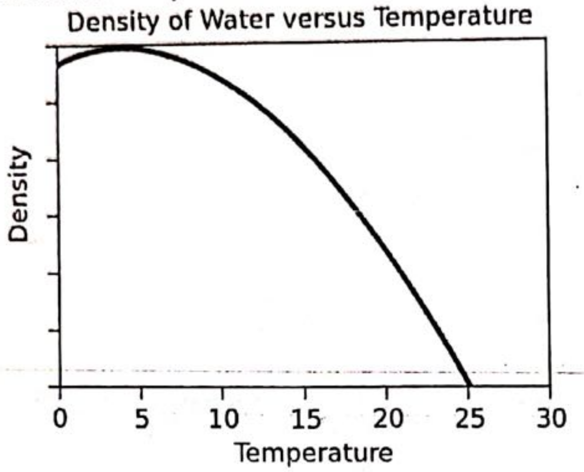

Different liquids expand by different amounts (although the volumes are equal and the rise in temperature is the same)

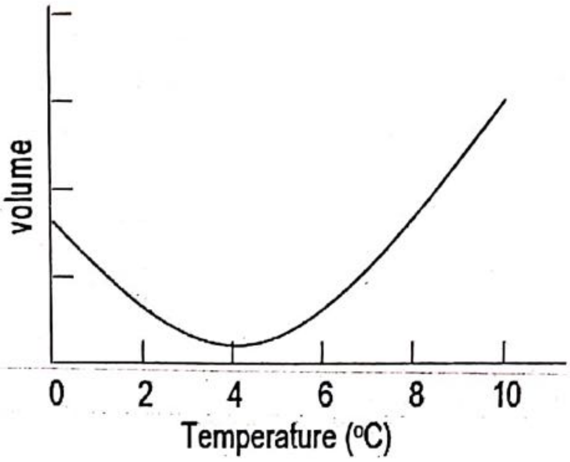



- Like solids, different liquids expand unequally.



**Anomalous Expansion of Water**

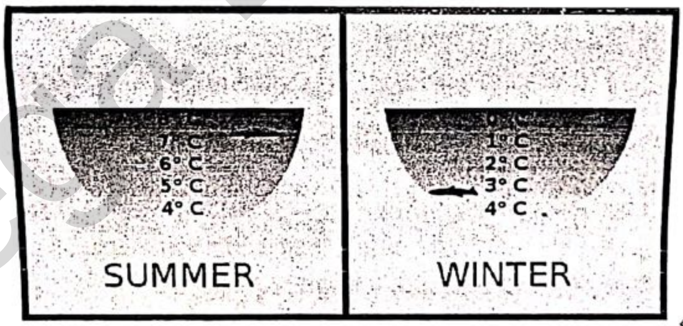



1. When water is heated from 0°C, its volume decreases until 4°C. From 4°C up, the volume of water increases gradually. The minimum volume occurs at 4°C.
2. The density of water increases from 0°C to 4°C; above 4°C the destiny of water decreases gradually. The maximum density occurs at 4°C.
3. When water freezes, the volume of ice produced is increased greatly (and the destiny is decreased considerably). The density of ice is smaller than the density of water

**Which Explains why:**

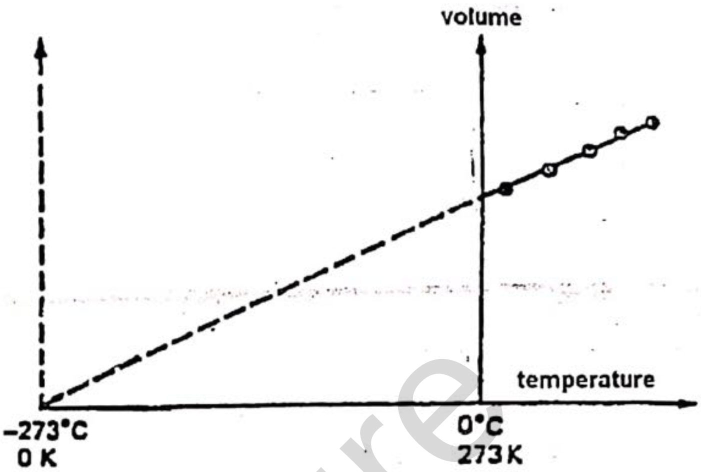
***(a)*** ice floats on water, and
***(b)*** *Bottles of water placed in a freezer may burst when water is frozen.*
*The surface of a lake freezes with the deepest water staying at 4°C.*




*The 'warm' water stays at the bottom of the pond because it is most dense.*

## C. Expansion of Gases

The expansion of a gas is much larger than that of a liquid or a solid under the same rise in temperature.




In the experiment shown, the air is trapped in a capillary tube by a bead of liquid. Its pressure is always constant and is equal to atmospheric pressure plus the pressure of liquid above it.

The temperature of the air is increased by heating the water around it slowly while stirring. The volume of air is recorded at different temperatures (the length of air column is taken to be proportional to the volume because the tube cross-section is considered constant). The graph shows that the volume of the gas increases with the rise in temperature when the pressure remains constant.

The relation is not directly proportional unless we use the Kelvin scale where the graph meets the temperature axis at 0 K when extended backwards. This relation is called Charles's law which states that:

"The volume of a fixed mass of a gas is directly proportional to its absolute temperature, when the pressure is kept constant".