6 HEAT AND TEMPERATURE; THERMAL EXPANSION OF SOLIDS AND LIQUIDS

HEAT

OBJECTIVES

At the end of the topic, students should be able to:

- explain the concept of heat and temperature using kinetic theory of matter.
- distinguish between heat and temperature; temperature point and temperature interval;
- construct a device for measuring the temperature of a body;use the variation of:
  - â€¢ gas pressure with temperature;
  - â€¢ the expansion of solid, liquid and or gas with temperature;
  - â€¢ electrical resistance of a material with temperature to measure temperature of a body;
- describe the absolute scale of temperature and explain the meaning of the absolute zero of temperature;
- convert a given temperature on Celsius scale to a temperature on the Kelvin scale.

Rub an empty tin of milk against a rough floor for some minutes; you will notice that the tin becomes hot. The work done in rubbing the tin is converted to heat. This shows that there is a link between **motion** and **heat**. ***Heat is energy in motion and flows when a temperature difference exists between conductors in contact***.

Heat energy always flows from a point at higher temperature to another at lower temperature. Heat energy is also called thermal energy.

Heat is energy transferred due to temperature difference between two points.

The unit of heat is joule (J). Note that energy, heat and work have the same unit. If you light a match and burn it completely it produces about 2000J.

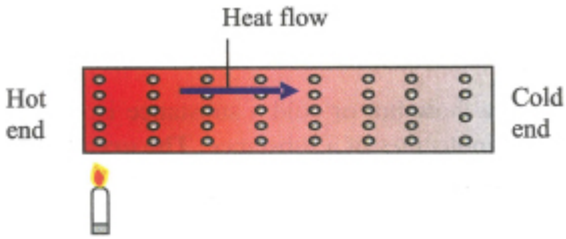

Figure 6.1 Heat flows from hot to cold end of a body

The amount of heat energy possessed by a body depends on the following factors:

- **Rise in temperature of the substance**: The bigger the mass of the substance, the greater the quantity of heat in it. The higher the temperature of the substance, the more heat energy it contains. A hot body has a higher temperature and energy while a cold body has a low temperature and energy. A hot body becomes cold when it loses energy or heat and its temperature falls.
- **Mass of the substance:** A big mass of a substance has high quantity of heat energy; a small mass of the same substance has smaller quantity of heat energy.
- **Nature of the substance:** The heat contained in a unit mass of water is more than the heat contained in a unit mass of copper for the same rise in temperature. 1kg of water requires 4200J to increase its temperature by 1Â°C while 1kg of copper requires only 380J to increase its temperature by 1Â°C.

Kinetic theory explanation of heat

All substances consist of tiny particles called atoms. According to the kinetic theory, atoms are in constant motion. When heat energy is given to the substance, its atoms move or vibrate faster. If heat is removed from the substance, the atoms move or vibrate slowly. Heat is related to the speed or kinetic energy of the molecules of the substance.

Intermolecular forces bond the molecules of a substance together, giving them potential energy. When a substance absorbs heat, the kinetic energy and the potential energy of the substance increase.

Heat is the sum of the kinetic and potential energies of a substance.

Heat is also the **internal** or **thermal energy** of a body because **it is the sum of the kinetic and potential energies of its molecules**.

Effects of heat

Application of heat to a substance may result in one or more of the following effects.

(i) rise or increase in temperature of the body;

(ii) expansion or increase in size of the body;
(iii) change of state (melting or vaporization) of the body;
(iv) change in chemical composition of the substance;
(v) change in colour, resistance and density of the substance.

Temperature

One of the effects of heat is the rise in temperature of the substance.

Temperature is the degree of hotness or coldness of a substance.

Temperature helps us to know how hot or cold a substance is. Temperature is the measure of average kinetic energy of the molecules of a substance. **The greater the average kinetic energy of the molecules, the faster they move and *therefore the higher the temperature of the substance.*** Rise in temperature of a body is linked to the random motion and increase in the speed or average kinetic energy of its molecules; therefore, an application of heat increases the speed (kinetic energy) of the molecules. **Increase in average kinetic energy of the molecules of the substance is proportional to the rise in its temperature.** If heat is removed from the substance, the average kinetic energy of its molecules drops leading to a fall in the temperature of the substance.

The unit of temperature is degree Celsius (Â°C) or Kelvin (K).

Differences between heat and temperature

Heat and temperature are two terms that confuse many people today. People speak of heat and temperature as if they are the same. However, some differences clearly distinguish them as shown in table 13.1.

	Heat	**Temperature**
1.	Heat is energy transferred due to temperature difference between two points.	Temperature is the degree of hotness or coldness of a body.
2.	Heat is measured by the total energy (sum of kinetic and potential energies) of the body.	Temperature is measured by the average kinetic energy of the body.
3.	Heat always flows from a point at higher temperature to a point at lower temperature.	Temperature difference between two points decides the direction heat will flow.

4.	The quantity of heat in a body is proportional to the mass of the body.	Temperature is independent of the mass of the body. The temperature of steam is 100Â°C irrespective of its mass.
5.	Heat is measured in joules (J).	Temperature is measured in degree Celsius (Â°C) or Kelvin (K).
6.	The quantity of heat is measured with calorimeter.	Temperature is measured with thermometer.

Table 6.1 Difference between heat and temperature

Practice Questions 13a

1. Two pieces of metals rubbed against each other become hot. What is the source of the heat energy produced?
2. Heat is energy transferred due to temperature difference. Explain.
3. The resistance of a platinum resistance thermometer is 30 Î© at ice point, 40Î© at steam point and 34.5 Î© on certain hot day. What is the temperature of the day on Celsius temperature scale?
4. (a) Name four physical (thermometric) properties of a substance that may be used to measure temperature.
   (b) Name the thermometer which uses the property named above and give one advantage of each thermometer named.
5. Use kinetic theory to explain the following terms (i) heat (ii) temperature (iii) rise in temperature.
6. State the differences between heat and temperature of body.
7. (a) Explain the following terms:
   (i) Fixed points of a thermometer.
   (ii) Scale of temperature.
   (b) State the lower and the higher fixed points on the Celsius scale of temperature.
   (c) How are the Celsius and the Kelvin scale of temperature related?

THERMOMETERS

OBJECTIVES

At the end of this topic, students should be able to:

- construct a device for measuring the temperature of a body;
- select liquids suitable for use in liquid-in-glass thermometers from a given list of liquids and their properties.

Thermometers are used to measure temperature of substances. The most popular type of thermometer is the liquid-in-glass thermometer. In this section, you will know more about liquid-in-glass thermometers.

Construction of a liquid-in-glass thermometer

To construct a liquid-in-glass thermometer a capillary tube with a fine (narrow) bore is used. One end of the capillary tube is heated in a flame to make it soft and air blown in from the other end to increase the size of the bulb. The bulb of the thermometer is filled with the liquid whose thermometric property is used to measure temperature. Care is taken to ensure that air bubbles are not trapped in the liquid.

Sensitivity of thermometers

A good thermometer should be sensitive to small changes in temperature. The following features make a thermometer more sensitive.

- **Fine or narrow bore:** a thermometer becomes sensitive if the bore is narrow. Sensitivity means that the thermometer responds fast to small changes in temperature.
- **Thin wall of the glass bulb:** the wall of the glass bulb is thin to allow heat to pass with ease to the liquid inside the bulb.
- **Cylindrical shape of the bulb:** the glass bulb is cylindrical in shape to expose greater liquid surface to heat and to allow the thermometer to enter through different holes.

over alcohol as a thermometric liquid;

(b) Explain why a mercury thermometer cannot measure any temperature less than – 40 Â°C.

Past questions

1. A platinum resistance thermometer has a resistance of 4 Î© at 0 Â°C and 12 Î© at 100 Â°C. Assuming that the resistance changes uniformly with temperature, calculate the resistance of the thermometer when the temperature is 45 Â°CÂ°
   A. 6.0 Î©
   B. 6.4 Î©
   C. 7.6 Î©
   D. 8.4 Î©
   E. 16.0 Î©

NECO

2. The ice and the steam points of a certain thermometer are – 20Â° and 100Â° respectively. Calculate the Celsius temperature corresponding to 70Â° on the thermometer.
   A. 84.0 Â°C
   B. 75.0 Â°C

C. 64.0 Â°C
D. 58.0 Â°C

WASSCE

3. The purpose of the constriction in a clinical thermometer is to
   A. prevent the mercury from expanding beyond the bulb.
   B. prevent the mercury from falling back into the bulb until required.
   C. enable the mercury to expand slowly.
   D. serve as the lower limit of the scale to be read.

WASSCE

4. Which of the following statements about a gas thermometer and the liquid-in-glass thermometer is correct?
   A. Mercury thermometers cannot be calibrated against a constant gas thermometer.
   B. Mercury thermometers are much more accurate than the gas thermometers.
   C. Gas thermometers have a wider temperature range than mercury thermometers.
   D. Gas thermometers are less cumber-some than mercury-in-glass thermo-meters.

WASSCE

5. Absolute zero temperature can be defined as the temperature
   A. at which the average kinetic energy of its particles making up a body is zero.
   B. at which pure water changes to ice at standard atmospheric pressure.
   C. of zero degree on the Celsius scale.
   D. at which pure water and steam co-exist.

WASSCE

6. Mercury has an advantage over other liquids as thermometric liquid because it
   A. has low expansively.
   B. has higher conductivity.
   C. vaporises easily.
   D. has relatively low freezing point.

WASSCE

7. An ungraduated thermometer reads 2.0 cm and 12.0 cm at ice and steam points respectively. Determine the true temperature in Kelvin, when the thermometer reads 5.0 cm.
   A. 303.0 K
   B. 300.0 K
   C. 278.0 K
   D. 30.0 K

WASSCE

8. A resistance thermometer has a resistance of 20 Î© at 0 Â°C and 85 Î© at 100 Â°C. If its resistance is 52 Î© in a medium, calculate the corresponding temperature.
   A. 49.2 Î©
   B. 60.6 Î©
   C. 80.0 Î©
   D. 84.7 Î©

WASSCE

EXPANSION OF SOLIDS

OBJECTIVES

At the end of the topic, students should be able to:

- explain expansion in terms of the kinetic molecular theory;
- explain linear expansion, area expansion and volume expansion;
- solve problems on linear expansion, area expansion and volume expansion;
- state some advantages and disadvantages of expansion.

When objects are heated they get bigger. This means they expand.

When they are cooled, the get smaller i.e. they contract. The change in size is so small that you cannot notice it. The temperature of a substance can be increased by heating it directly or by pouring hot fluid (e.g. water or gas) on it for a considerable period of time. Most substances expand when they are hot and contract when cooled.

Expansion means increase in size of the body.

The increase in size of a solid may be very small and difficult to observe for small changes in temperature. However, many evidences exist to prove that solids expand. Careful and detailed experiments over the years show that solids expand at different rates. Good conductors like metals, e.g. iron, expand faster than bad conductors e.g. plastic, when they are heated through the same rise in temperature.

Evidence of expansion

Ball and ring experiment

When the ball and ring are both cold, the ball passes freely through the ring. If the ball is heated strongly with a flame, the size increases and will not be able to pass through the ring again. If the ball is allowed to cool, the size shrinks and it will pass through the ring again. This simple experiment shows that solids expand if they are made hotter.

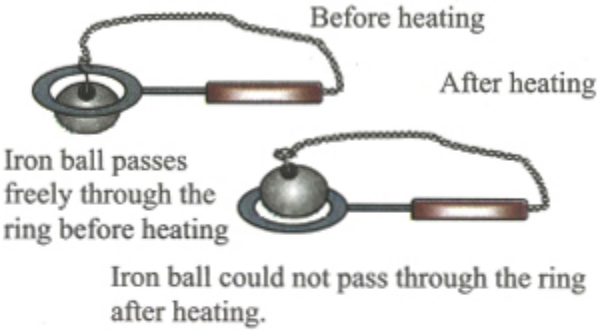

Figure 6.1 Ball and ring experiment

Kinetic theory explanation of expansion

According to kinetic theory, solids are made up of molecules, which vibrate constantly about their mean (rest) position. These molecules have kinetic energy because of their vibrations when the solid is heated; the molecules gain kinetic energy and vibrate faster. The increased vibration makes the molecules move further apart and occupy more space. The increase in average displacement of the molecules inside the solid leads to increase in the size of the body.

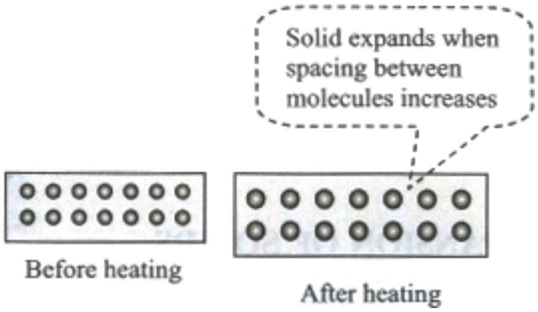

Figure 6.2 Explaining expansion with kinetic theory

Linear expansion

Expansion in one direction is referred to as linear expansion. The expansion of solids varies from substance to substance; copper for example expands faster than iron. The amount by which a substance expands depends on the following factors:

- ***Rise in temperature of the substance:*** The hotter the substance the greater the expansion produced.
- ***Original length of the substance:*** The longer the material, the more it expands.
- ***Nature of the substance:*** The nature of the substance is called **linear expansivity** (Î±). A substance with higher linear expansivity expands faster than one with low linear expansivity when they are subjected to the same rise in temperature. The expansion of a substance varies from substance to substance.

$$\text{Expansion} = \text{Original Length} \times \text{Linear expansivity} \times \text{Rise in Temperature}$$

This is mathematically represented as

$$e = \alpha lo \Delta\theta$$

where

e = *l* - lo = expansion, *lo* = original length,
l = new length after expansion, Î± = linear expansivity, Î”*Î¸* = rise in temperature = final temperature – initial temperature

Linear expansivity (Î±)

If 1m length of a solid is heated and the temperature increases by 1 Â°C, it will expand by a certain length, though very small and unseen by naked eye.

The expansion produced by a unit length (1m) of a solid when it is heated through 1 Â°C rise in temperature, is called linear expansivity. In other words, linear expansivity is the expansion produced per unit length of a solid per unit rise in temperature.

This is mathematically expressed as, $\alpha = \frac{e}{l_o \times \Delta\theta}$

Î± = linear expansivity, *lo* = original length, Î”*Î¸* = change in temperature, *e* = *l* – *lo* = expansion. The unit of linear expansivity is per Kelvin (K^{-1}) or per degree Celsius ($^0C^{-1}$). The length (*l*) of the substance after expansion is the sum of the original length and the expansion produced.

$$\text{New length} = \text{Original length} + \text{Expansion}$$

$$l = lo + \alpha\, lo\, \Delta\theta \qquad l = lo\,(1 + \alpha\Delta\theta)$$

Measurement of linear expansivity of a solid

This can be done by using a steam jacket which is an equipment for determining expansion of solids.

To measure the linear expansivity of a solid, the three quantities on the right hand side of the formula above must be measured.

Procedure

(a) Use a metre rule to measure and record the original length (*lo*) of the rod (R).

(b) Fix the rod in the steam jacket with the end F fixed and the end O free to expand.

(c) Attach a thermometer (T) to the rod (R), read and record the initial temperature (Î¸$_1$) of the rod.

(d) Screw up the micrometer to touch the end O of the rod, read and record the initial reading X_l of the micrometer.

(e) Unscrew the micrometer to allow the rod to expand freely and pass steam for some minutes to heat the rod.

(f) Screw up the micrometer after some minutes to measure the expansion produced. This process is repeated many times until the final reading of the micrometer is constant. The rod is fully expanded when the micrometer reading is constant.

(g) Read and record the final readings of the micrometer X_2 and the thermometer (Î¸$_2$).

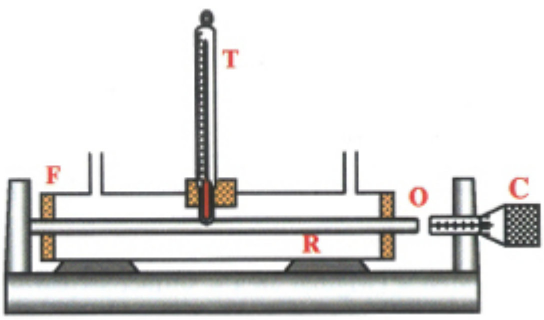

Figure 6.2 A steam jacket

Calculation

Expansion produced (e) = $l - l_0$
Rise in temperature $\Delta\theta = \theta_2 - \theta_1$
Original length = l_0

$$\text{Linear expansivity} = \frac{\text{expansion}}{\text{original length x rise in temperature}}$$

$$\alpha = \frac{l - l_0}{l_0 \times \Delta\theta}$$

Superficial expansivity and cubic expansivity

Superficial or area expansivity (b)

Heating a solid increases its size. If the expansion occurs in two directions (length and breadth) the surface area of the solid increases, increase in surface area when a solid is heated is called **superficial expansion**.

Superficial expansivity is the surface expansion per unit area per unit rise in temperature.

Alternatively, superficial expansivity is surface expansion produced when 1 m^2 of a solid is heated through 1 Â°C rise in temperature.

Mathematically, we express the superficial expansivity as:

$$\beta = \frac{A - A_0}{A_0 \times \Delta\theta}$$

A = area of the surface after expansion, A_0 = original area of the surface, Î”*Î¸* = rise in temperature and *Î²* = superficial expansivity.

A – A_0 = area expansion.

The unit of superficial (area) expansivity is per Kelvin (K^{-1}) or per degree Celsius (Â°C^1).

Î”A = A_0 Ã— *Î²* Ã— Î”*Î¸*

New area = Original area + surface expansion

A = A_0 + A_0 Ã— *Î²* Ã— Î”*Î¸*

A = A_0 (1 + *Î²*Î”*Î¸*)

Now, compare linear expansivity with superficial. Note the similarities and the difference.

The superficial or area expansivity is related to the linear expansivity. This means that area expansivity is two times linear expansivity.

Î² = 2*Î±*

That is, superficial or area expansivity is twice the linear expansivity.

The cubic or volume expansivity of a solid

The cubic or volume expansion is obtained when a solid expands in three directions (length, breadth and height).

The increase in volume produced when a unit volume (1 m^3) of a solid is heated through a unit rise in temperature (1 Â°C) is called the cubic or volume expansivity. In other words, cubic expansivity is the increase in volume, per unit volume per unit rise in temperature.

Mathematically, cubic expansivity is defined as;

$$\gamma = \frac{V - V_0}{V_0 \times \Delta\theta}$$

V – V_0 = volume expansion, V = volume of the solid after expansion, V_0 = original volume of the solid, Î”*Î¸* = rise in temperature and Î³ = cubic expansivity.

The unit of cubic (volume) expansivity is per Kelvin (K^{-1}) or per degree Celsius (Â°C^{-1}).
Increase in volume = Original volume Ã— Cubic expansivity Ã— Rise in temperature

$$\Delta V = V_0 \times \gamma \times \Delta\theta$$

New volume = Original volume + Increase in volume

$$V = V_0 + V_0 \times \gamma \times \Delta\theta$$
$$V = V_0 (1 + \beta\gamma\Delta\theta)$$

Cubic expansivity is three times the size of linear expansivity.

$$\gamma = 3\alpha$$

Proof of Î³ = 3Î± and *Î²* = 2Î±

Consider a square and a cube each of sides *lo* cm at room temperature. When its temperature rises by Î”*Î¸*, the new length of the square and cube is 1 cm.

Original area of the square $A_o = l_o^2$ cm^2.

New area $A = l^2$ cm^2

$$= l_0^2 (1 + \alpha \Delta\theta)^2$$
$$= l_0^2 \{1 + 2\alpha\Delta\theta + (\alpha \Delta\theta)^2\}$$

But α is very small, therefore α^2 is very small (i.e. $(\alpha\Delta\theta)^2 = 0$)

$$l^2 = l_0^2(1 + 2\alpha\Delta\theta)$$

$$A = A_0(1 + \beta\Delta\theta)$$

New volume $V = l^3$ cm^3

$$V = l_0^3 (1 + \alpha \Delta\theta)^3$$
$$V = l_0^3 \{1 + 3\alpha\Delta\theta + 3(\alpha \Delta\theta)^2 + (\alpha \Delta\theta)^3\}$$

But α is very small, therefore α^2 and $\alpha^3$are very small {i.e. $(\alpha \Delta\theta)^2$and $(\alpha \Delta\theta)^3$ are = 0}

$$l^3 = l_0^3(1 + 3\alpha\Delta\theta)$$

$$V = V_0(1 + \gamma\Delta\theta)$$

Worked examples

1. The steel railway track from Kano to Kaduna is 200km long. What is the expansion produced when the temperature rises from 20Â°C to 40Â°C given that the linear expansivity of steel is 0.000011 K^{-1}?

Solution

Original length lo = 200 km = 200 000 m

Rise in temperature $\Delta\theta$ = 40 -20 = 20 °C

Expansion = $\alpha\, lo\, \Delta\theta$

$= 0.000011 \times 200000 \times 20$

$= 44$ m

2. (a) What is meant by the term the linear expansivity of copper is 0.000018 K^{-1}?
   (b) If a 100 cm of copper rod is heated through 35 Â°C, what is the length of the rod?
   (c) At what temperature will the length be 100.24 cm?

Solution

(a) The statement means that when a unit length of copper is heated by 1 Â°C, it expands by 0.000018 m.

(b) Original length *lo* = 100 cm, rise in temperature Î”*Î¸* = 35 Â°C

$$l = l_0(1 + \alpha\Delta\theta)$$
$$l = 100(1 + 0.000018 \times 35)$$
$$l = 100 \times 1.00063$$
$$l = 100.063 \ cm$$

(c) $e = \alpha l_0 \Delta\theta$

$100.24 - 100 = 0.000018 \times 100 \times \Delta\theta$

$0.24 = 0.0018 \times \Delta\theta$

$\Delta\theta = 133.3 \ °C$

3. (a) The length of a rod is 80.15 cm at 20Â°C and 80.19 cm at 75 Â°C, what is the linear expansivity of the rod?

Solution

$$\alpha = \frac{e}{l_0 \times \Delta\theta} = \frac{80.19 - 80.15}{80.15 \times 55} = 9.07 \times 10^{-6}\ K^{-1}$$

4 A metal sphere of radius 3 cm made of brass is heated from 30 Â°C to 100 Â°C; calculate the initial and final volume of the metal sphere. {Linear expansivity of brass is 0.000019 K^{-1}.}

Solution

$$\text{Original volume } V_0 = \tfrac{4}{3}\pi r^3 = \tfrac{4}{3} \times \tfrac{22}{7} \times 3^3 = 113.1\ cm^3$$

$$V = V_0(1 + \gamma\Delta\theta)$$
$$V = 113.1(1 + 3 \times 0.000019 \times 70)$$
$$V = 113.1 \times 1.00399$$
$$V = 113.55\ cm^3$$

Useful applications of expansion

Expansion can be useful. Expansion becomes an advantage if they are used to improve our comfort. Some of the uses of expansion are:

- Riveting
- Fitting metal tyre to the wheel of a train
- Bimetallic strip
- Electrical thermostat
- Gas thermostat

Riveting

The joining of two metal strips with iron nails (rivets) such that they are held tightly together, is known as riveting. The two metal strips are so tightly held that even water cannot pass through them. To rivet two metals, a hole is drilled through them and a red hot metal nail (rivet) is passed through the hole. The other end is hammered until the rivet grips the two metal strips tight. If the rivet cools, the force of contraction pulls the metal strips tightly together.

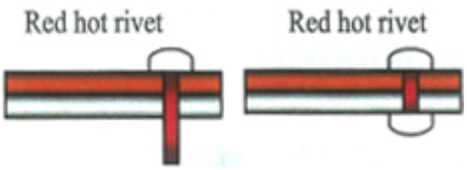

Figure 6.3 Riveting of two metal strips

Fitting metal tyre to its wheel

Metal tyres are fitted to the wheels very tightly to avoid slipping off when the train is in motion. To do this, the wheel is made slightly bigger than the tyre. At normal temperature the tyre will not fit into the wheel but when the tyre is expanded by heating, it fits into the wheel. On cooling, the tyre contracts and grips the wheel tightly.

Bimetallic strips

A bimetallic strip is made of two different metal strips of the same length and width welded or riveted together. When the bimetallic strip is heated, it curves, with the metal which expands more on top of the other. If cooled below the room temperature, the bimetallic strip curves with the metal which contracts more inward. If the bimetallic strip is made of iron and brass, it will curve with the brass outward when hot because brass expands faster than iron if their length and temperature rise are the same.

Bimetallic strip has many uses. One of such applications is the **thermostat.** A **thermostat is a device used to control or regulate temperature.** A thermostat ensures that the temperature of electrical appliances is kept constant.

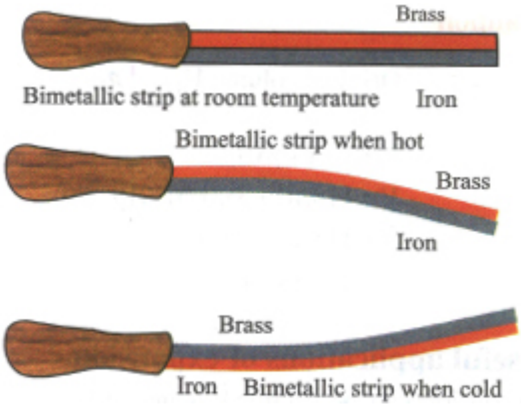

Figure 6.4 Bimetallic strips

Electric thermostat

A thermostat is used to keep an object at the same temperature; it ensures that the object does not get too cold or too hot. Electric thermostat regulates the temperature of appliances like electric iron, stove, and refrigerators. A simplified diagram of an electric thermostat is shown in Figure 6.5. The passage of electric current through the bimetallic strip makes it hot, therefore, the bimetallic strip curves away from the contact point. This breaks the contact and the heating process stops as no current passes through the heating element of the appliance. When the bimetallic strip cools, it straightens itself and contact is remade, making current to flow through the heater again.

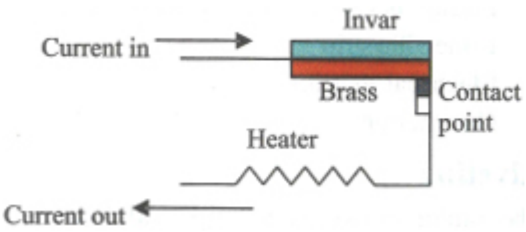

Figure 6.5 Electric thermostat

Gas thermostat

The bimetallic strip of gas thermostat consists of a brass tube and an invar rod. The brass tube expands while the invar rod does not expand for the same temperature change. Figure 6.6 illustrates the gas thermostat, one end of the invar rod is fixed to the brass tube, which is free to expand, and the other end is connected to a valve. When the temperature of the oven rises, the brass tube expands while the invar rod does not expand, therefore, the valve is pulled towards the left to close the gap. The flow of gas is stopped. When the temperature of the oven cools, the brass tube contracts, the valve is pushed to the right to open the gap allowing the gas to flow again.

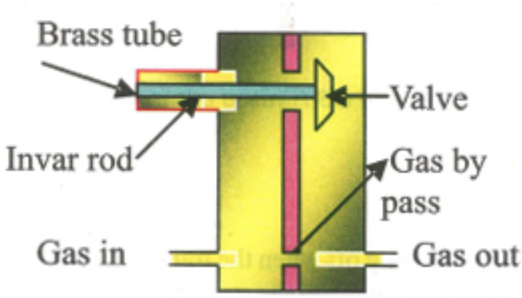

Figure 6.6 Gas thermostat

Other applications of bimetallic strips are:

- relays as used in alarm devices to warn about changes in a given surrounding
- balance wheel of wrist watches and clocks to regulate time
- electric flashers to flash light at regular intervals
- bimetallic thermometer to measure temperatures

Expansion can be troublesome

Expansion becomes a nuisance when it causes damages. Where expansion or contraction causes trouble, it becomes a disadvantage. Some disadvantages of expansion are discussed below.

Deformation of bridges

Bridges are made from steel bars which expand when temperature increases, and contract when temperature decreases. To avoid deforming the bridge when the temperature changes, the steel bars are placed on rollers at one end and a gap provided to allow for expansion or contraction of the bridge.

For the same reason, gaps are created on the road at intervals to allow for expansion. In hot countries, we give gaps in walls to avoid cracking as temperature increases.

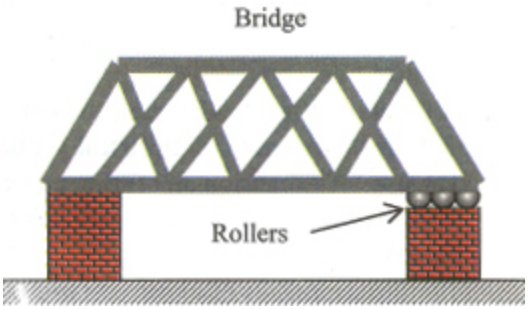

Figure 6.7 Bridge on rollers to allow for expansion

Cracking of a thick glass cup

Thick glass cup sometimes cracks if hot water is poured suddenly in it. This happens because glass, as a poor conductor of heat, allows the inside to expand more than the outside. The unequal expansion between the inside and the outside of the glass creates a large force to crack it. Pyrex glass beakers do not crack because pyrex glass does not expand as other types of glasses.

To prevent the cracking of the thick glass, hot liquid is poured slowly to allow for equal expansion of glass or a good conductor like stainless spoon, when put in the cup is used to conduct heat away from the glass cup.

Buckling of railway track

Gaps are provided between railway tracks to prevent buckling when the temperature rises or the track will be distorted. This allows the steel rails to expand and contract as the temperature changes. Other disadvantages of expansion are:

- sagging of high tension wires during hot season and the breaking of the same wire at cold season. This is avoided by making provision for the expansion and contraction of the wires as the temperature changes.
- expansion of pendulum of a wall clock or the balance wheel of a wrist watch. Expansion of the pendulum of wall clocks or balance wheels of wristwatches makes them lose time. Contractions of these nature make the clock or watch to gain time; therefore, expansion or contraction is a disadvantage.

Summary

- Expansion means increase in size of the body.

- The expansion produced by a unit length (1 m) of a solid when it is heated through 1 Â°C rise in temperature is called linear expansivity.
- New length = Original length + expansion
  Superficial expansivity is surface expansion produced when lm^2 of a solid is heated through 1Â°C rise in temperature.
- Î² = 2Î± = The increase in volume produced when a unit volume ($1m^3$) of a solid is heated through a unit rise in temperature (1Â°C) is called the cubic or volume expansivity.
- Î³ = 3Î±
- A thermostat is a device used to control or regulate temperature. A thermostat ensures that the temperature of electrical appliances is kept constant.
- The uses of expansion are: fitting metal tyre to its wheel, riveting a joining of two metal strips with iron nails (rivets) such that they are held tightly together (known as riveting), bimetallic strips, etc.
- The disadvantages of expansion are: deformation of bridges, cracking of a thick glass cup, buckling of railway track, expansion of pendulum of a wall clock or the balance wheel of a wrist watch.

Practice questions 7a

1. What is linear expansion? How can you explain linear expansion using kinetic theory?
2. What do you understand by the statement, â€œthe linear expansivity of steel is 0.000011 K^{-1}?â€
3. Explain the following observations.
   (a) A tight bottle top can be opened easily by warming it.
   (b) Thick glass cup cracks when hot liquid is poured into it suddenly.
   (c) Railway tracks have gaps between the ends of each length.
4. The diagram below shows a bimetallic strip made up of brass and invar:

Bimetallic strip at room temperature

   Draw diagrams to show the shape of the bimetallic strip when it is:
   (i) heated above the room temperature
   (ii) cooled below the room temperature.

5. State what happens to the size of a hole in a washer as it is gradually heated.
6. State three useful applications of expansion and two demerits of expansions. Describe one of the applications named.
7. (a) Define the terms linear and cubic expansivities of a solid.
   (b) What is the relationship between the two expansivities?
   (c) An aluminium cube of sides 10 cm each is heated from 20 Â°C to 110 Â°C. What is the new volume of the aluminium cube if the linear expansivity of aluminium is 2.6 Ã— 10^4 K^{-1}?
8. A steel metre rule has correct length at 28 Â°C. On the day the temperature is 40 Â°C, it measures the length of a table as 158 m, what is the true length of the table? [Î± = 0.000012 K^{-1}]
9. A bimetallic strip is made of brass and iron both having the same length at 30 Â°C. When the temperature is 50Â°C, the brass has a length of 0.50018 m. Calculate;
   (i) the length of the bimetallic strip at 30 Â°C
   (ii) the change in length of the iron
   (iii) final length of the iron, [Î± iron = 0.000019 K^{-1}] [Î± iron = 0.000012 K^{-1}]

EXPANSION OF LIQUIDS

OBJECTIVES

At the end of this topic, students should be able to:

- explain real and apparent cubic expansivities of a liquid;
- explain the anomalous or unusual expansion of water;
- explain why water freezes from the top.

Liquids have definite volume but no definite shape; therefore, it becomes very difficult to determine its linear expansivity and superficial expansivity. Liquids expand faster than solids when they are heated to the same rise in temperature because they have weak binding forces joining their molecules. These weak binding forces in liquids are easily broken by heat.

Proof that liquids expand

Liquids expand when heated and they occupy more space due to expansion. The apparatus above is used to demonstrate this. The flask is filled with water and a narrow capillary tube pushed into the flask to allow the liquid to expand. When the flask is heated gently, the level of water drops and then begins to rise. **The water level drops because the flask expands before heat is conducted to the liquid inside.** Different liquids expand at different rates. Alcohol expands faster than water; water expands faster than mercury when they are subjected to the same rise in temperature. The denser the liquid, the less it rises in a capillary tube.

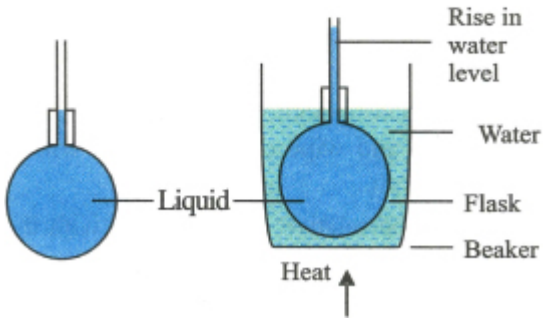

Fig 6.8 Liquids expand when heated

Cubic (volume) expansivity of a liquid

A liquid is heated in a vessel, which also expands. The observed expansion of a liquid in the flask is called the **apparent expansion** because the expansion of vessel in which the liquid is heated is not considered.

Real cubic expansivity of a liquid

Real cubic expansivity of a liquid is the increase in volume per unit volume of liquid when the temperature rises by 1Â°C.

Apparent cubic expansivity of a liquid

Apparent cubic expansivity of a liquid is the observed increase in volume when a unit volume of a liquid is heated through 1Â°C rise in temperature when the liquid is heated in an expansible vessel.

If the expansion of the vessel containing the liquid is considered, the sum of the cubic expansivity of the vessel and the apparent cubic expansivity of the liquid is equal to the real cubic expansivity.

$$\gamma_r = \gamma_a + \gamma_v \quad \text{or} \quad \gamma_r = \gamma_a + 3\alpha$$

Î³$_r$ = real cubic expansivity of a liquid

Î³$_a$ = apparent cubic expansivity of a liquid

Î³$_{\text{Î½}}$ = cubic expansivity of the vessel

Î± = linear expansivity of the vessel

Experimental determination of apparent cubic expansivity of a liquid

Apparatus: Relative density bottle, a beaker containing water, thermometer, stirrer, tripod stand, thread and retort stand.

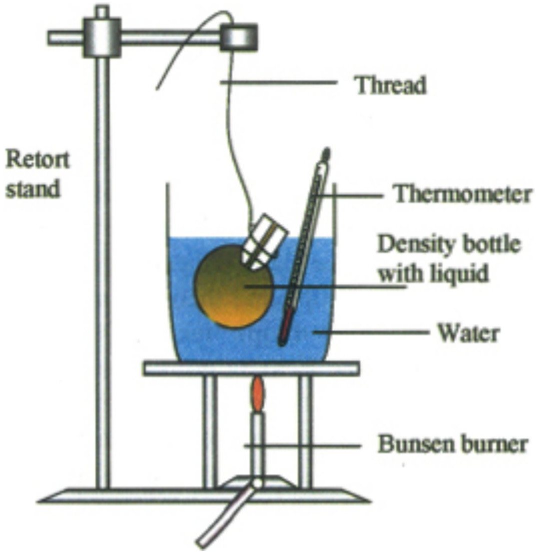

Figure 6.9 Determining apparent cubic expansivity of a liquid

Procedure

a. Clean up the relative density bottle, weigh and record its mass (m).

b. Fill the density bottle with liquid, replace the stopper and wipe clean the body with a clean cloth.

c. Weigh the relative density bottle with the liquid and record its mass (m_1).

d. Immerse the relative density bottle in the beaker of water and allow to stay for some minutes so that the liquid and the water in the beaker will reach the same temperature. Measure and record the initial temperature of the liquid (Î¸$_1$).

e. Heat the beaker and its content gently and stir continuously to make the temperature uniform. Keep heating until the liquid is fully expanded. Measure and record the final temperature of the beaker and its contents (Î¸$_2$).

f. Remove the relative density bottle from the beaker and allow to cool to room temperature, measure and record its mass (m_2).

Calculations

$$\text{Mass of liquid expelled} = (m_1 - m_2)$$

$$\text{Mass of liquid before heating} = (m_1 - m)$$

$$\text{Mass of liquid after heating} = (m_2 - m)$$

$$\text{Rise in temperature} = (\theta_2 - \theta_1)$$

$$\gamma_a = \text{Apparent cubic expansivity}$$

$$y_a = \frac{\text{Mass of liquid expelled}}{\text{Mass of remaining liquid x rise in temperature}}$$

$$\gamma_a = \frac{m_1 - m_2}{(m_2 - m)(\theta_2 - \theta_1)}$$

Precautions

(a) The beaker and its content should be warmed gently to avoid spilling out the liquid.

(b) The water in the beaker is stirred continuously to keep the temperature uniform.

(c) Clean cloth is used to wipe clean the body of the relative density bottle before weighing.

Worked example

1. In an experiment to determine the cubic expansivity of a liquid, a student raised the temperature of 65.8 g of the liquid in a density bottle from 30 Â°C to 79 Â°C and observed 0.483g was expelled. Calculate the cubic expansivity of the liquid. {Linear expansivity of glass vessel = 0.0000085 K^{-1}}

Solution

Mass of liquid expelled = 0. 483 g

Mass of liquid remaining = 65.8 g – 0.483 g

= 65. 317 g

Rise in temperature = 79 – 30 = 49 °C

$$y_a = \frac{\text{Massof liquid expelled}}{\text{Massof remaining liquid x rise in temperature}}$$

$$y_a = \frac{0.483\text{g}}{65.317\text{g} \times 49^{\circ}\text{C}} = 1.51 \times 10^{-4}\ \text{K}^{-1}$$

$$\gamma_r = \gamma_a + \gamma_v$$

$$= 1.5 \times 10^{-4} + 3 \times 0.0000085$$

$$= 0.00015 + 0.0000255$$

$$= 0.0001755\ \text{K}^{-1}$$

The peculiar expansion of water

One reason, water is considered a bad thermometric liquid is its irregular expansion. Water, unlike most liquids, does not always expand when it is heated from 0 Â°C. If water is heated from 0 Â°C, the volume decreases (contracts) until the temperature is 4 Â°C. At 4 Â°C, water has the lowest possible volume and maximum density. From 4 Â°C to the boiling point, water behaves like most liquids and expands as it gets hotter. This behaviour is peculiar to water and is called the **anomalous** or **unusual** expansion of water. Figure 7.9 is the graph of volume against temperature compare with the graph of density against temperature from 0 Â°C.

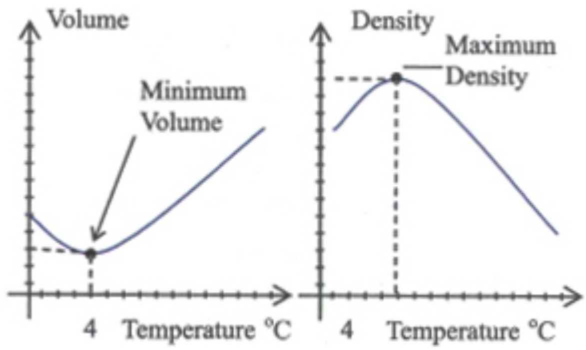

Figure 6.9 Graph of volume/density against temperature

Reason why water freezes from the top

When water is cooled from room temperature, it contracts until it has a minimum volume and maximum density at 4Â°C. At the bottom of a pond or a jug of water in a freezer is the densest water. If the water is cooled below 4Â°C, it becomes less dense and floats above the water at 4Â°C. The process continues until the temperature falls to 0Â°C, water at 0Â°C remains at the top where it begins to change to ice. This explains why water begins to freeze from the top. In very cold countries, deep ponds will freeze at the top but the bottom remains warm because it contains water at 4Â°C. Aquatic creatures like fish can still swim around under the ice.

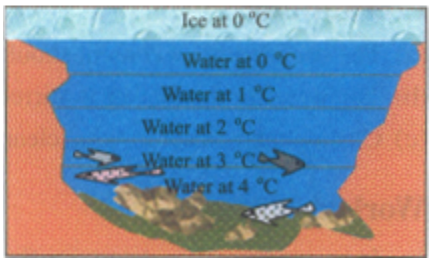

Figure 6.10 Water freezes from the top

Summary

- **Apparent cubic expansivity of a liquid**
  The observed increase in volume when a unit volume of a liquid is heated through 1Â°C rise in temperature when the liquid is heated in an expansible vessel.
- **Real cubic expansivity of a liquid**
  Real cubic expansivity of a liquid is the increase in volume per unit volume of liquid when the temperature rises by 1 Â°C.
- **Water behaves in an unusual way**
  Water contracts from 0Â°C to 4Â°C and expands from 4 Â°C to 100 Â°C. The maximum density of water occurs when the temperature is 4 Â°C.

Practice questions 7b

1. When a mercury thermometer is dipped in a boiling water, it is observed that the volume of j mercury first contracts before expanding. Explain the behaviour of mercury in this case.
2. Give a reason why liquids expand more than solids when they are heated to the same rise in temperature.
3. How will you demonstrate that liquids expand when they are hot?
4. (a) Define the *apparent* and *real cubic expansivity* of a liquid.

   (b) A relative density bottle of volume 25 cm^3 contains 338.7 g of mercury. Calculate:

   (i) the volume of the mercury in the bottle;

   (ii) the rise in temperature when the mercury just fills the density bottle.

   Density of mercury = 13.6 g cm^{-1}, apparent cubic expansivity of mercury =$1.8x10^{-4}$ $K^{-1,}$ cubic expansivity of glass = 3.0 x 10^{-6} K^{-1}}
5. Distinguish between the real and apparent cubic expansivity of a liquid. Write the equation linking them and state the meaning of the symbols used.

   The mass of mercury which fills a density bottle is 409 g. When the temperature is raised from 30 Â°C to 64.2 Â°C, 0.3 g of mercury is expelled from the bottle. Calculate the cubic expansivity of the mercury.

   {Cubic expansivity of glass is 3.0 x 10^{-6} K^{-1}}
6. (a) Describe the behaviour of water as it is warmed from 0 Â°C to 4 Â°C.

   (b) Using the behaviour of water in (a) above, explain why water freezes from the top.

   (c) Why is this important to aquatic life in winter?
7. (a) What do you understand by the term *anomalous behaviour of water?*

   (b) Explain why water is considered a bad thermometric liquid.

   (c) Explain why water at temperatures below 4 Â°C floats above water at 4 Â°C.

8 (a) Describe an experiment to determine the apparent cubic expansivity of a liquid.

   (b) State two precautions to ensure accurate results.

   (c) If the liquid in (a) above is water at 0 Â°C, explain how this will affect your result.

Past questions

1. If hot water is poured into a thick glass cup, the cup cracks because

A. glass cannot withstand high temperatures.

B. glass is an amorphous substance.

C. the inner and the outer walls of the cup expand at different rates.

D. coefficient of expansion of glass is high.

WASSCE

2. A steel bolt screwed into an aluminium casting unscrews more easily if the casting is subjected to heat and vibration because

A. steel is denser than aluminium.

B. steel is a better conductor than aluminium.

C. aluminium expands much more than steel when heated through the same temperature.

D. steel has a greater linear expansivity than aluminium.

WASSCE

3. In which of the following situations is the expansion of a solid an advantage?

A. Buckling of railway lines

B. Seizing of bearings in motor vehicles

C. Sagging of telephone wires

D. Using bimetallic strip thermometers

WASSCE

4. A metal bar 50 cm long at 15 Â°C is heated to 85 Â°C. If it expands by 0.088 cm, determine its linear expansivity.

A. 4.0 Ã— 10^{-5} Â°C

B. 2.5 Ã— 10^{-5} ^{o}C

C. 6.3 Ã— 10^{-2} ^{o}C

D. 1.2 Ã— 10^{-1} ^{o}C

WASSCE

5. A metal increases by 2.5 Ã— 10^{-5}cm of its length for every degree rise in its temperature. A rod of the metal 20 cm long at 25 Â°C is kept in a refrigerator until its temperature becomes -5 Â°C. Calculate the change in its length.

A. 0.010 cm

B. 0.015 cm

C. 20.010 cm

D. 20.015 cm

WASSCE

6. An iron rod of length 50 m and at a temperature of 60 Â°C is heated to 70 Â°C. Calculate its new length.

[Linear expansivity of iron = 1.2 Ã— 10^{-5} K^{-1}]

A. 50.006 m

B. 50.060 m

C. 51.600 m

D. 51.200 m

WASSCE

7. If L, S and V are the linear, area and volume expansivities of a given metal respectively, which of following equations is correct?

A. L – S = 0

B. V – 2S = 0

C. S – 2L = 0

D. 2S-L = 0

E. 3V-L = 0

WAEC

8. A piece of brass of mass 170 kg has its temperature raised from 0 Â°C to 30 Â°C. Calculate its increase in volume, given the density of brass at 0 Â°C as 8.5 Ã— 10^{3} kg m^{-3} and its cubic expansivity as 5.7 Ã— 10^{-5} K^{-1}.

A. 3.4 Ã— 10^{-5} m^{3}

B. 4.3 Ã— 10^{-5} m^{3}

C. 3.4 Ã— 10^{-4} m^{3}

D. 3.4 Ã— 10^{-3} m^{3}

E. 3.4 Ã— 10^{-2} m^{3}

WAEC

9. The cubic expansivity of brass between 27 Â°C and 100 Â°C is 5.7 Ã— 10^{-5} K^{-1}, what is its linear expansivity?

A. 2.85 Ã— 10^{-5} K^{-1}

B. 1.90 Ã— 10^{-5} K^{-1}

C. 1.86 Ã— 10^{-5} K^{-1}

D. 1.70 Ã— 10^{-5} K^{-1}

E. 1.62 Ã— 10^{-5} K^{-1}

WAEC

10. Steel bars, each of length 3 m at 28 Â°C, are used for constructing a rail line. If the linear expansivity of steel is 1.0x10^{-5} K^{-1}, what is the safety gap that must be left between successive bars if the highest temperature expected is 40 Â°C?

A. 1.0 Ã— 10^{-1} cm

B. 7.2 Ã— 10^{-2} cm

C. 6.0 Ã— 10^{-2} cm

D. 3.6 Ã— 10^{-2} cm

E. 1.8 Ã— 10^{-2} cm

WAEC

11. The linear expansivity of a metal Ï is twice that of another metal Q. When these materials are heated to the same temperature change,

their increase in length is the same. Calculate the ratio of the original length of P and Q.

A. 1:4
B. 1:2
C. 2:1
D. 4:1
E 6:1

WAEC

12. Which of the following statement(s) is/are correct?

I When a liquid expands its density falls.
II When a mercury-in-glass thermometer is placed in a hot liquid, the mercury level first descends and then rises.
III The apparent expansion of a liquid is greater than its real expansion.

A. I only
B. II only
C. III only
D. I and II only
E. II and III only

NECO

13. A brass cube of side 10 cm is heated through 30 Â°C. If the linear expansivity of brass is 2.0 Ã— 10^{-5} K^{-1}, what is the increase in its volume?

A. 0.06 cm^3
B. 0.18 cm^3
C. 0.60 cm^3
D. 1.20 cm^3
E. 1.80 cm^3

NECO

14. When water is heated between 0 Â°C and 4 Â°C, its density

A. increases for a while and then decreases.
B. decreases for a while and then increases.
C. increases.
D. decreases.
E. remains constant.

15. The cubic expansivity of mercury is 1.80x 10^{-4} K^{-1} and the linear expansivity of glass is 8.0 x 10^{-6} K^{-1}, calculate the apparent expansivity of mercury in glass container.

A. 1.00 Ã— 10^{-5} K^{-1}
B. 1.56 Ã— 10^{-5} K^{-1}
C. 1.72 Ã— 10^{-5} K^{-1}

D. 2.04 Ã— 10^{-5} K^{-1}

WASSCE

16. A solid material of volume 100 cm^3 is heated through a temperature difference of 40 Â°C. Calculate the increase in the volume of the material if its linear expansivity is 2.0 Ã— 10^{-6} K^{-1}
   A. 2.4 Ã— 10^{-2} cm^3
   B. 1.6 Ã— 10^{-2} cm^3
   C. 8.0 Ã— 10^{-3} cm^3
   D. 5.0 Ã— 10^{-6} cm^3
   E. 4.0 Ã— 10^{-6} cm^3

WAEC

17. The real and apparent cubic expansivities of a liquid in an expansible container are 3.0 Ã— 10^{-6} K^{-1} and 1.8 Ã— 10^{-6} K^{-1} respectively. Calculate the cubic expansivity of the material of the container.
   A. 6.00 Ã— 10^{-7} K^{-1}
   B. 1.20 Ã— 10^{-6} K^{-1}
   C. 1.67 Ã— 10^{-6} K^{-1}
   D. 1.80 Ã— 10^{-6} K^{-1}

WASSCE

18. The temperature of glass vessel containing 100 cm^3 of mercury is raised from 10 Â°C to 100 Â°C. Calculate the apparent cubic expansion of the mercury.
   {Real cubic expansivity of mercury is 1.82 Ã— 10^{-4} K^{-1} and cubic expansivity of glass = 2.4 Ã— 10^{-5} K^{-1}}
   A. 0.52 cm^3
   B. 1.42 cm^3
   C. 1.87 cm^3
   D. 5.22 cm^3
   E. 14.22 cm^3

WAEC

19. The expansion of solids can be considered a disadvantage in the
   A. fire alarm system
   B. thermostat
   C. riveting of steel plates
   D. balance wheel of a watch
   E. fitting of wheels on rims

WAEC

20. Which of the following statements is/are correct?
   I Pure water freezes at 0 Â°C under normal pressure.

II Water has its highest density at 4 Â°C.

III The volume of water is maximum at 4 Â°C.

A. I only

B. II only

C. I and II only

D. I and III only

E. II and III only

WAEC

21. A steel plug has a diameter of 5 cm at 30 Â°C. At what temperature will it fit exactly into a hole of constant diameter 4.997 cm? {Coefficient of linear expansion of steel is 11 x 10^{-6} K^{-1}}

A. 27.3 Â°C

B. -27.3 Â°C

C. -2.7 Â°C

D. 7.32 Â°C

E. 2.7 Â°C

JAMB

22. In what range of temperature is the expansion of water anomalous?

A. +208 Â°C to +212 Â°C

B. -80 Â°C to -76 Â°C

C. -4 Â°C to 0 Â°C

D. +96 Â°C to 10 0 Â°C

E. 0 Â°C to + 4 Â°C

JAMB

23. A thin aluminium plate has a surface area of 1.500 m^2 at 20 Â°C. What will be its surface area when it is cool to – 20 Â°C? {Linear expansivity of aluminium is 1.20 Ã— 10^{-5} K^{-1}}

A. 1.503 m^3

B. 1.500 m^3

C. 1.498 m^3

D. 1.497 m^3

E. 1.490 m^3

JAMB

24. One of the most important applications of expansion of bimetallic strip is found in the construction of

A. a thermostat

B. an altimeter

C. a thermocouple

D. a hygrometer

JAMB

25. A block of ice floats on water inside a container. If the ice gets

completely melted, the level of water in the container will

A. increase

B. remain the same

C. decrease

D. first decrease and then increase

JAMB

26. (a) What is meant by the statement â€˜The linear expansivity of a solid is 1.0 Ã— 10^{-5} K^{-1}â€™?

(b) (i) Describe an experiment to determine the linear expansivity of a steel rod.

(ii) Steel bars each of length 3 m at 29 Â°C are to be used for constructing a rail line. If the linear expansivity of steel is 1.0 Ã— 10^{-5} K^{-1}, calculate the safety gap that must be left between successive bars if the highest temperature expected is 41 Â°C.

(c) State **three** advantages and **two** disadvantages of thermal expansion of solids.

WAEC

27. (a) Define the *apparent cubic expansivity of a liquid*.

(b) (i) Describe, with the aid of a diagram, an experiment to determine the apparent cubic expansivity of a liquid.

(ii) State two precautions that should be taken to ensure accurate result.

(c) A density glass bottle contains 44.25 g of a liquid at 0 Â°C and 42.02 g at 50Â°C. Calculate the real cubic expansivity of the liquid. {Linear expansivity of glass = 1.0 Ã— 10^{-5} K^{-1}}

WAEC