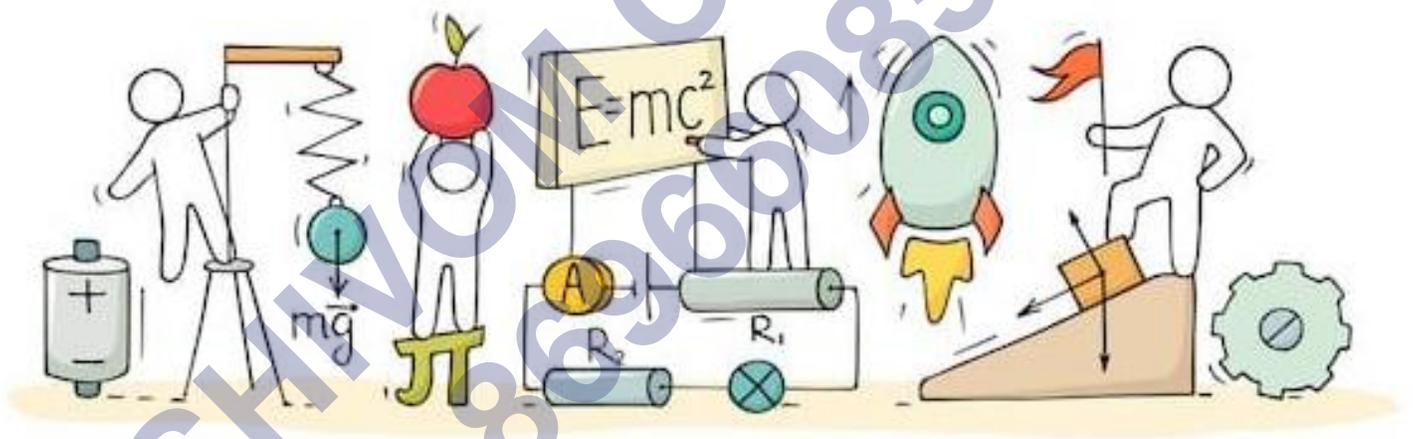


# PHYSICS

## Chapter 11: Thermal Properties of Matter



## Thermal Properties of Matter

### Introduction

You might have noticed that you feel hotter on a sunny afternoon as compared to a windy night. This is because of the difference in temperatures. Temperature is very high in the afternoon as compared to night. This chapter basically gives us the

Examples: information about thermal properties of matter where we will study about the properties of different substances by virtue of heat / heat transfer.

In simple terms, we can say that when temperature is more heat is more and when temperature is less heat is less.

Hot Sunny day (Temperature is more) and ice-cold water (Temperature is less).



### Thermal Properties of Matter

Thermal properties are those properties of a material which is related to its conductivity of heat. In other words, these are the properties which are exhibited by a material when heat is passed through it. Thermal properties come under the broader topic of physical properties of materials.

Thermal properties of a material decide how it reacts when it is subjected to heat fluctuation (excessive heat or very low heat, for example). The major components of thermal properties are:

Heat capacity

Thermal Expansion

Thermal conductivity

Thermal stress

### Heat Capacity

Heat capacity of a material can be defined as the amount of heat required to change the

temperature of the material by one degree. The amount of heat is generally expressed in joules or calories and the temperature in Celsius or Kelvin. In order to calculate the heat capacity of materials with a given dimension, Molar heat capacity or Specific heat capacity is used.

Heat capacity can be measured by the following formula:

$$Q = mc\Theta$$

is the amount of heat transferred, is the change in temperature.

### Heat Transfer: Thermal Conductivity

#### Heat Transfer

Heat is a very curious form of energy. It helps us stay warm, prepare hot and tasty food but its applications far exceed the domestic uses mentioned here. Understanding the properties of heat and heat transfer is the key to many fields of science. Thermodynamics is a massive field that deals only with the flow of heat through a system that is heat transfer through a system. Even nuclear energy uses the heat developed by the atom to create electricity. So it is clear that heat is quite important to us. That makes it imperative for us to take a closer look at heat.

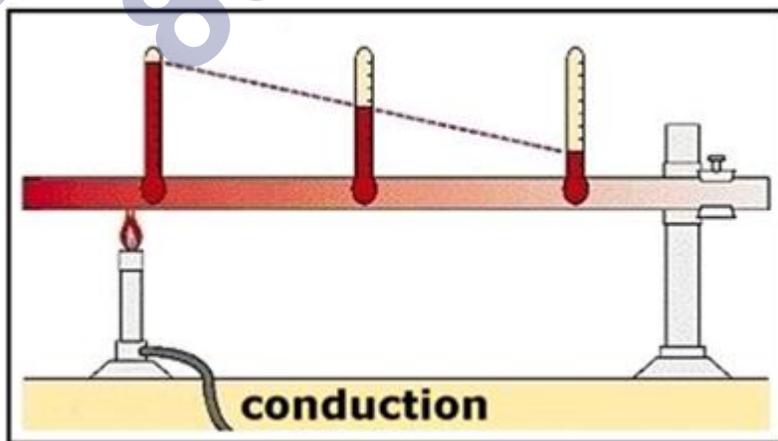
Heat transfer can occur only through three means:

Conduction

Convection

Radiation

#### Heat Transfer: Conduction



Heat Conduction refers to the transfer of heat between bodies due to physical contact between them. The transfer of heat by conduction actually occurs at a molecular level. Absorption of heat by a body causes the molecules of that body to gain excess energy. What do you do when you're too energetic? You get very jittery and shaky, don't you? You just want to move around

to expend this energy. That is exactly what molecules do too.

In the process of gaining energy and vibrating excessively, they bump into their neighbours and transfer a little of its extra energy to them. This extra energy appears in the neighbouring molecules and heats them up too. This is how heat is transferred as long as heat is still being supplied.

### Factors Affecting Thermal Conductivity

The rate of thermal conductivity depends on four basic factors:

**Temperature Gradient:** This is a physical quantity that illustrates to us in which direction and at what rate the temperature changes the most rapidly around a particular location. It basically tells us about the temperature difference between places and the direction of the transfer due to it. It is important to remember that heat always flows from the hottest to the coldest spot. This flow will continue till the temperature difference disappears and a state of thermal equilibrium is reached.

Cross-section and path length are dependent on the physical dimensions of the body. If the size of the body is large, then the heat required to heat it is also larger. With large bodies, we also have to consider the heat loss to the environment. Also, a greater surface area between the hot and the cold body implies a greater rate of heat transfer.

The physical properties of the body play an immense role in thermal conductivity through the body. Not all bodies are blessed with the same thermal behaviour. We measure the rate of transfer of heat through the material using a parameter called the Thermal Conductivity of the material (K). The more the value of K, the more easily and quickly it can conduct heat. The SI Unit of K is  $\text{J s}^{-1}\text{m}^{-1}\text{K}^{-1}$ . The thermal conductivity of a material is measured on a scale. This scale has two extremes; on the end of high thermal conductivity we have Silver with a perfect score of a 100 in heat conduction. On the other end of the scale, we have a vacuum, which is absent of molecules and hence is incapable of conducting heat. Everything else is ranked between this, for example, Copper (92), iron (11), water (0.1), Air (0.006), and Wood (0.03). Materials that are poor conductors of heat are called insulators.

### Thermal Expansion

When heat is passed through a material, its shape changes. Generally, a material expands when heated. This property of a material is called Thermal Expansion. There can be a change in the area, volume and shape of the material. For example, railway tracks often expand and as a result, get misshapen due to extreme heat.

### Thermal conductivity

It is the property of a material to conduct heat through itself. Materials with high thermal conductivity will conduct more heat than the ones with low conductivity. Some materials do

not conduct heat at all because of the insulating properties of materials.

### Thermal stress

The stress experienced by a body due to either thermal expansion or contraction is called thermal stress. It can be potentially destructive in nature as it can make the material explode.

### Measurement of Temperature

Temperature is measured with the help of thermometer. Mercury and Alcohol are commonly used liquids in the liquid-in-glass thermometers.

To construct a thermometer two fixed points are to be chosen as a reference points. These fixed points are known as freezing (ice point) and boiling point (steam point). The water freezes and boils at these two points under standard pressure.

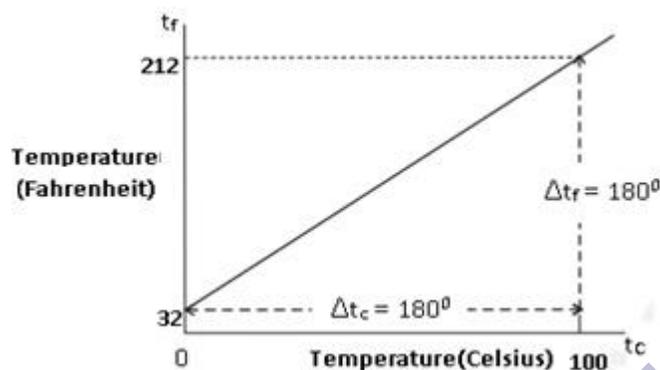
The ice and steam point in Fahrenheit Temperature scale are  $32^{\circ}\text{F}$  and  $212^{\circ}\text{F}$  resp. It has 180 equal intervals between two reference points.

On Celsius Scale values are  $0^{\circ}\text{C}$  and  $100^{\circ}\text{C}$  for ice and steam point resp. It has 100 equal intervals between two reference points.



### Mercury-in-Thermometer

Graphically the relation between the temperature in Celsius and in Fahrenheit is given by the following graph:



And whose equation is:

$$\frac{t_f - 32}{180} = \frac{t_c}{100}$$

Where  $t_f$  = Fahrenheit temperature

$t_c$  = Celsius temperature

### Ideal-gas Equation and Absolute Temperature

A thermometer that uses any gas, however, gives the same readings regardless of which gas is used because all gases have same expansion at low temperature.

Variables that describe the behaviour of gas are:

Quantity(mass)

Pressure

Volume

Temperature i.e. (P,V,T) where ( $T = t + 273.15$ ;  $t$  is the temperature in  $^{\circ}\text{C}$ )

### Gases which have low density obey certain laws:

1. Boyle's Law–  $PV = \text{constant}$  (when temperature  $T$  is constant)

2. Charles' Law-  $V/T = \text{constant}$  (when pressure  $P$  is constant)

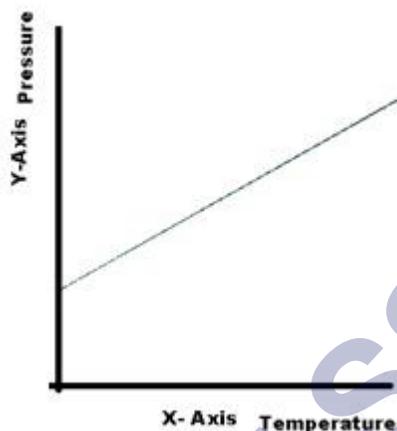
If combine both the above laws the equation becomes  $PV = RT$  where  $R$  is called universal gas constant and its value =  $8.31 \text{ J mol}^{-1} \text{ K}^{-1}$ .

$PV = RT$  is the ideal gas equation which is applicable only at low temperature.

For any quantity of dilute gas,

$PV = \mu RT$  where  $\mu$ , is the number of moles in the sample of gas.

In a constant volume gas thermometer temperature varies with respect to pressure. Temperature changes linearly with increase in pressure.



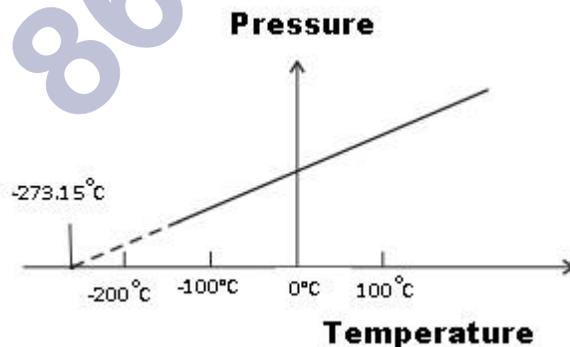
### Absolute Zero

Absolute Zero is defined as minimum absolute temperature of an ideal gas.

If we plot pressure versus temperature, we get a straight line and if we extend the line backwards to the x-axis as shown in the graph below. The minimum temperature is found to be  $273.15^\circ\text{C}$  (experimentally) and this value is known as absolute zero.

The relation between the temperature in kelvin and in Celsius scale is given by

$$T = t_c + 273.15$$



### Thermal Expansion

Thermal expansion is the phenomenon of increase in dimensions of a body due to increase in its temperature.

### Examples of Thermal Expansion

The water is cold at the top of the lake because it expands and becomes less dense. So when this water freezes it insulates the water below it from the outside which means cold air is like a blanket. It is because of this property many fish can survive in the winter.



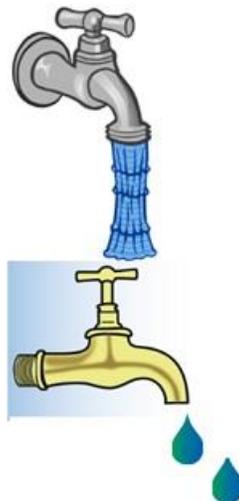
(1)



(2)

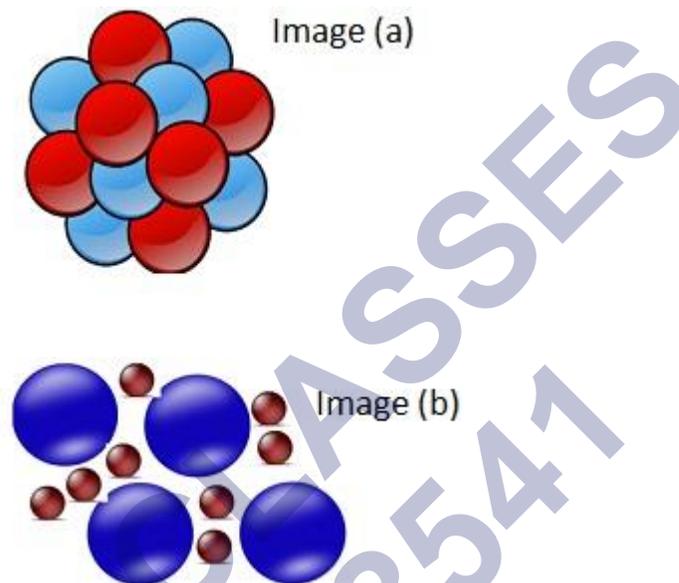
Even though the top layer of water is frozen as we can see in the image (1), the plant and animal life is not getting affected as shown in the image (2).

As soon as we turn on a hot water tap, the water comes very fast as water is still cold. But as soon as hot water starts coming, the flow of water becomes less and in some cases it stops. This is because the hot water heats the metal valve inside the tap which expands to block off any more flow of water.



### Reason why Thermal Expansion happens is:

When any object is heated particles start moving in random motion and thus average distance between the molecules increases and as a result the object appears to be expanded when heated. As we can see the picture below atoms are tightly packed but when we apply heat they will start moving in random motion.



As we can see in the Image (a) molecules are very tightly packed but when heated the molecules start moving apart in random motion, which can be seen in Image (b).

When an object is cooled it contracts which is referred to as negative thermal expansion.

### Types of Thermal Expansion

Linear Expansion: The expansion in length

Area Expansion: The expansion in area

Volume Expansion: The expansion in volume

### Linear Expansion

Linear Expansion means expansion in length due to an increase in temperature. Linear expansion means fractional change in length i.e. how the length is changing with respect to original length.



Linear Expansion  $\frac{\Delta l}{l} = \alpha_l \Delta T$

As we can see from above images the length has been increased from  $l$  to  $l + \Delta l$ .

Coefficient of Linear Expansion is a parameter which tells us how the size of the object changes with change in temperature. It is defined as degree of linear expansion divided by the change in temperature.

If the solid is in the form of long rod, then for small change in temperature,  $\Delta T$ , the fractional change in length,  $\Delta l/l$ , is directly proportional to  $\Delta T$ .

Mathematically can be written as:

$$\frac{\Delta l}{l} = \alpha_l \Delta T$$

Where  $\alpha_l$  = the coefficient of linear expansion

It is denoted by  $\alpha_l$

It is characteristic of the material of the rod. It varies for different substance.

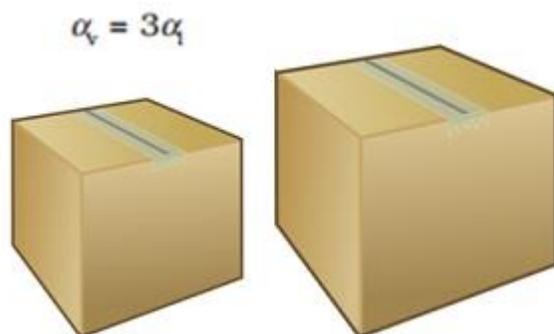
### Example

Automatic hot water kettle switches off on its own when the water boils.

Metals expand more and have higher value of coefficient of linear expansion.

Relation between  $\alpha_v$  and  $\alpha_l$

Relation between coefficient of linear expansion and coefficient of volume expansion =



To derive the above relation consider a block of cube initially its length is  $l$ , suppose temperature is increased  $T + \Delta T$  as a result length will also increase from  $(l + \Delta l)$

$$\text{Then } \alpha_l = \frac{\left(\frac{\Delta l}{l}\right)}{\Delta T}$$

$$\text{Therefore, } \alpha_l \Delta T = \Delta l$$

Also as the temperature increases by  $\Delta T$  the volume also increases  $V + \Delta V$

Where  $\Delta V$  = change in volume which we can write as

$$\Delta V = (l + \Delta l)^3 - l^3$$

By solving we get  $\Delta V = 3l^2\Delta l$  (we are neglecting  $(\Delta l)^2$  and  $(\Delta l)^3$  as they are very small as to compared to  $l$ ).

$$\text{Therefore, } \Delta V = \frac{(3V \Delta l)}{l}$$

$$= 3V\alpha_l \Delta T$$

Which gives  $\alpha_v = 3\alpha_l$  the relation between coefficient of volume expansion and coefficient of linear expansion.

### Heat Capacity

The change in temperature of a substance, when a given quantity of heat is absorbed or rejected by substance is characterised by a quantity called the heat capacity of that substance.

It is denoted by  $S$ .

$$\text{It is given as } S = \Delta Q / \Delta T$$

Where  $\Delta Q$  = amount of heat supplied to the substance and  $T$  to  $T + \Delta T$  change in its temperature.

### Specific heat capacity:

Every substance has a unique value for the amount of heat absorbed or rejected to change the temperature of unit mass of it by one unit. This quantity is referred to as the specific heat capacity of the substance.

Mathematically can be written as:

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

Where  $\Delta Q$  = amount of heat absorbed or rejected by a substance

$\Delta T$  = temperature change

### Specific Heat Capacity

Specific heat is defined as the amount of heat per unit mass absorbed or rejected by the substance to change its temperature by one.

Mathematically can be written as:

$$s = \frac{S}{m} = \frac{1}{m} \frac{\Delta Q}{\Delta T}$$

Where

$\Delta Q$  = amount of heat absorbed or rejected by a substance

$m$  = mass

$\Delta T$  = temperature change

It depends on the nature of the substance and its temperature.

The SI unit of specific heat capacity is  $\text{J kg}^{-1} \text{K}^{-1}$ .

### Molar specific heat capacity:

Heat capacity per mole of the substance is defined as the amount of heat (in moles) absorbed or rejected (instead of mass  $m$  in kg) by the substance to change its temperature by one unit.

Mathematically can be written as:

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

Where,

$\mu$  = amount of substance in moles

$C$  = molar specific heat capacity of the substance.

$\Delta Q$  = amount of heat absorbed or rejected by a substance.

$\Delta T$  = temperature change

It depends on the nature of the substance and its temperature. The SI unit of molar specific heat capacity is  $\text{J mol}^{-1} \text{K}^{-1}$

## Calorimetry

**Calorimetry is made up of 2 words:**

Calorie which means heat and metry means measurement. Therefore Calorimetry means measurement of heat.

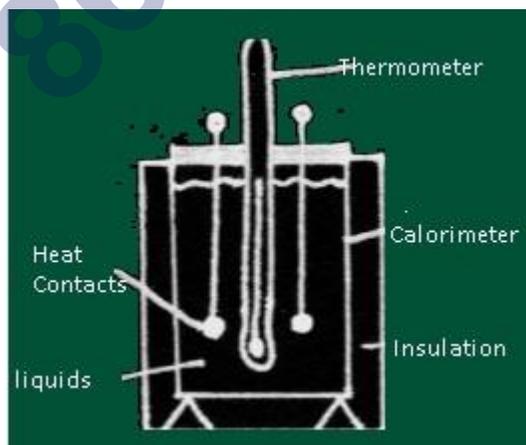
Calorimetry is defined as heat transfers from a body at a higher temperature to a body at a lower temperature provided there is no loss of heat to the atmosphere.

Principle of Calorimetry is heat lost by one body is equal to the heat gained by another body.

The Device which measures Calorimetry is known as Calorimeter.

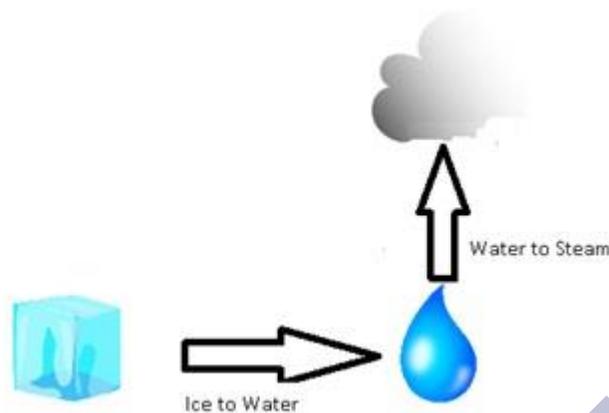
Description of Calorimeter

A calorimeter consists of metallic vessel and a stirrer both are made of same material (copper or aluminum) and the vessel is kept in a wooden jacket so that there is no heat loss. A mercury thermometer can be inserted through a small opening in the outer jacket.



## Change of State

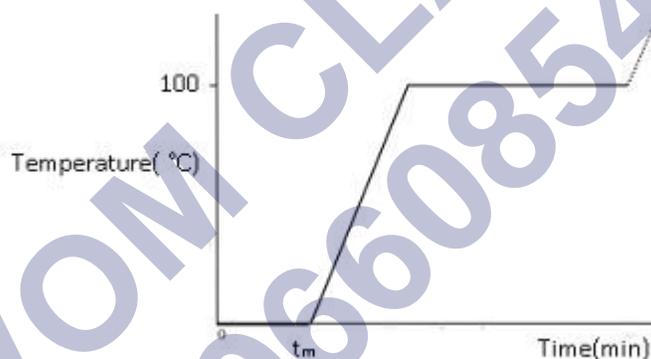
The transition from either solid to liquid or gas and gas to either liquid or solid is termed as change of state.



We can from the above image solid (ice) changes to liquid (water) and liquid changes to vapour (gas).

Change from solid (ice) to liquid (water) is known as Melting.

Change from liquid (water) to solid (ice) is known as Fusion.



**Thermal Equilibrium:** At this state there is no loss or gain of heat takes place.

The temperature at which the solid and the liquid states of the substance are in thermal equilibrium with each other is called its melting point.



It is depends on the

substance

Pressure.

The melting point of a substance at standard atmospheric pressure is called its normal melting point.

### Regelation:

Regelation can be defined as phenomenon in which the freezing point of water is lowered by the application of pressure.

### Example:

Girl skating on snow

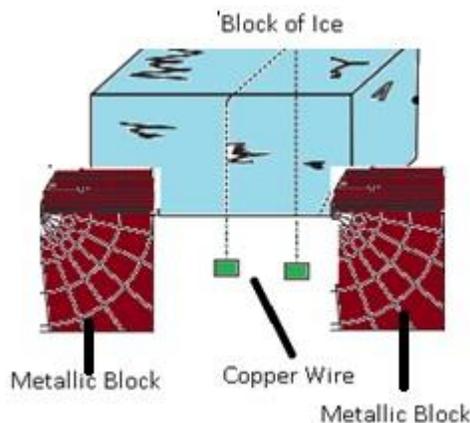


Glaciers



### Cause of regelation:

If we have a block of ice and a copper wire pulled by two masses if we will observe that copper wire can pass through ice block this is because copper is good conductor of heat so as it passes through the ice it gets refreeze as the copper will generate heat and this heat will pass quickly to the ice below and it starts melting because there is increase in pressure which lowers temperature as a result the wire will move through the ice. This happens because of regelation.



The image above explains how a copper wire can pass through the block of ice.

**Vaporisation:** Transition from liquid to vapour.

The change of state from liquid to vapour (or gas) is called vaporisation.



The temperature at which the liquid and the vapour states of the substance coexist is called its boiling point.

Boiling point at standard atmospheric pressure is known as normal boiling point.

It depends on nature of substance & pressure

It increases with increase in pressure and vice versa.

Example: As altitude increases, the density of the air becomes thinner, and thus exerts less pressure. At high altitudes, external pressure on water is therefore decreased and will hence take less energy to break the water. If less energy is required it means less heat and less temperature which means that water will boil at a lower temperature.

**Sublimation: Transition from Solid to Vapour.**

During the sublimation (solid changes to vapour without going through liquid state) process both the solid and vapour states of a substance coexist in thermal equilibrium.

**Example:**

Dry ice (solid  $\text{CO}_2$ ) sublimates iodine.

Naphthalene balls sublimates to gaseous state.



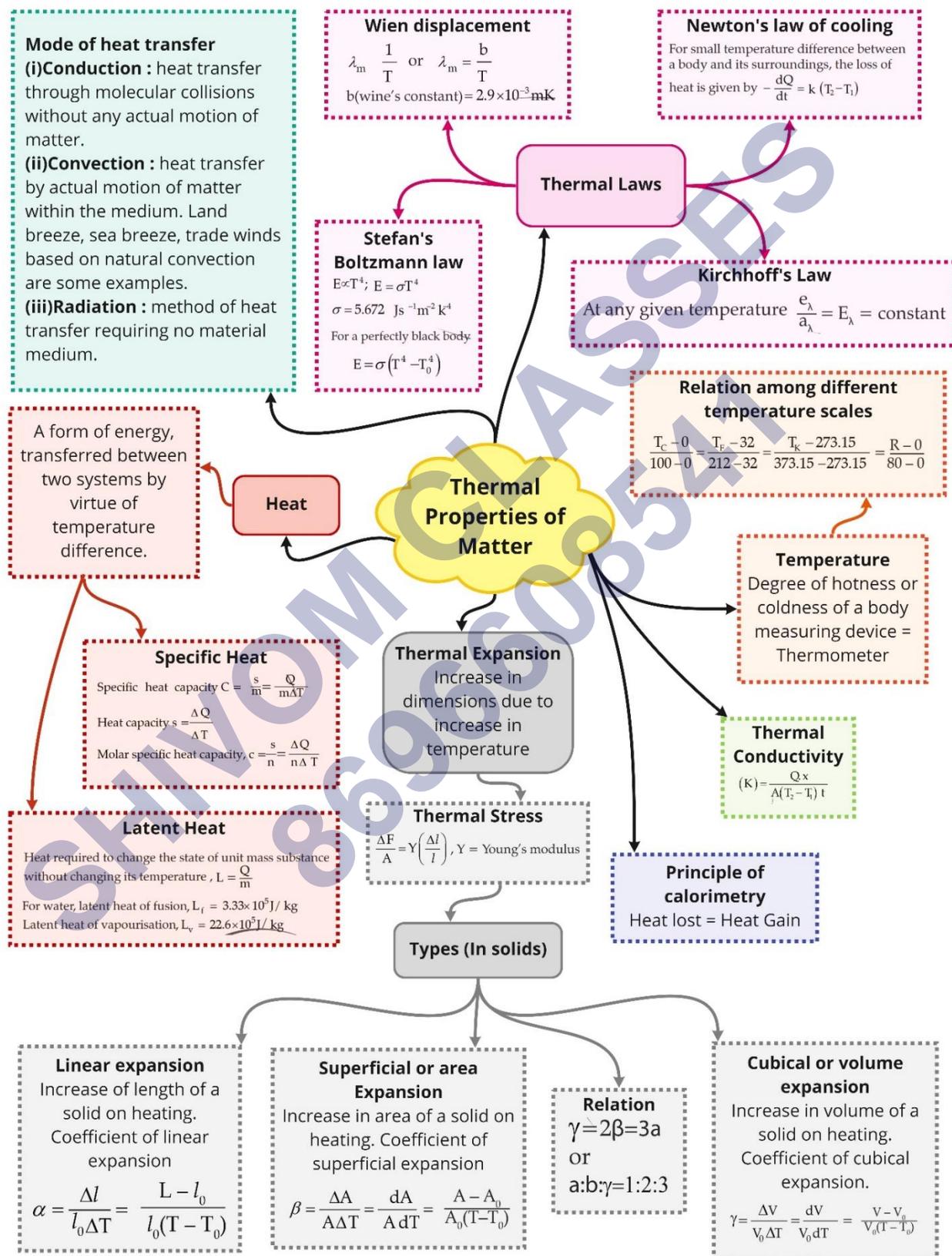
## Top Formulae

<b>Ideal gas equation connecting pressure (P), volume (V) and absolute temperature (T)</b>	$PV = \mu RT$ , where $\mu$ is the number of moles and R is the universal gas constant.
<b>Relation between temperatures on various scales</b>	If $T_C$ , $T_F$ and $T_K$ are temperature values of a body on the Celsius scale, Fahrenheit scale and Kelvin scale, then $\frac{T_C - 0}{100} = \frac{T_F - 32}{180} = \frac{T_K - 273.15}{100}$
<b>Relation between critical temperature and pressure at triple point</b>	If the triple point of water is chosen as the reference point, then $T_K = 273.16 \left( \frac{P}{P_{tr}} \right)$ , where P is the pressure at unknown temperature T and $P_{tr}$ is the pressure at triple point.
<b>Coefficients of expansion</b>	(i) Coefficient of linear expansion $\alpha = \frac{\Delta L}{L(\Delta T)}$ (ii) Coefficient of area expansion $\beta = \frac{\Delta S}{S(\Delta T)}$ (iii) Coefficient of volume expansion $\gamma = \frac{\Delta V}{V(\Delta T)}$
<b>Relation between coefficients of expansion</b>	$\beta = 2 \alpha ; \gamma = 3 \alpha$
<b>Variation of density with temperature</b>	$\rho = \rho_0 (1 - \gamma \Delta T)$
<b>Specific heat capacity of a substance</b>	$s = \frac{1}{m} \frac{\Delta Q}{\Delta T}$ where m is the mass of the substance and $\Delta Q$ is the heat required to change its

	temperature by $\Delta T$ .
<b>Molar specific heat capacity</b>	$C = \frac{1}{\mu} \frac{\Delta Q}{\Delta T}$ where $\mu$ is the number of moles of the substance.
<b>Change of heat</b>	$\Delta Q = m s \Delta T$ where $s$ is the specific heat of the substance.
<b>Molar specific heat of substance</b>	$C = m \times s$
<b>Method of mixtures</b>	Heat gained = Heat lost i.e. mass $\times$ specific heat $\times$ rise in temperature = mass $\times$ specific heat $\times$ fall in temperature
<b>Change of state</b>	$\Delta Q = mL$ where $L$ is the latent heat of the substance.
<b>Relation between specific heat capacity at constant volume and pressure</b>	$C_p - C_v = \frac{R}{J},$ where $R = \frac{PV}{T}$ = gas constant for one gram mole of the gas.
<b>Specific heat capacities of mono and polyatomic gases</b>	For monatomic gases, $C_v = \frac{3}{2} R$ ; $C_p = \frac{5}{2} R$ For diatomic gases, $C_v = \frac{5}{2} R$ , $C_p = \frac{7}{2} R$ For triatomic gases (non-linear molecule), $C_v = 3 R$ , $C_p = 4 R$ For triatomic gases (linear molecule) $C_v = \frac{7}{2} R$ , $C_p = \frac{9}{2} R$
<b>Rate of conduction of heat</b>	$\frac{\Delta Q}{\Delta t} = KA \frac{\Delta T}{l},$

	<p>where <math>\frac{\Delta T}{\Delta x}</math> = temperature gradient = rate of fall of temperature with distance, A = area of the hot surface, K = coefficient of thermal conductivity.</p>
<b>Latent heat</b>	<p>If conducted heat is used in changing the state of m gram of the substance, then</p> $\Delta Q = mL = KA \left( \frac{\Delta T}{\Delta x} \right) \Delta t,$ <p>where L is the latent heat of the substance.</p>
<b>Specific heat: Change in temperature</b>	<p>If the conducted heat is used in increasing the temperature of the substance through range <math>\Delta \theta</math>, then</p> $\Delta Q = sm \Delta \theta = KA \left( \frac{\Delta T}{\Delta x} \right) \Delta t$

Class : 11th Physics  
Chapter- 11 : Thermal Properties of Matter



## Important Questions

### Multiple Choice questions-

Question 1. Two stars A and B radiate maximum energy at  $3600^\circ\text{A}$  and  $3600^\circ\text{A}$  respectively. Then the ratio of absolute temperatures of A and B is

- (a) 256 : 81
- (b) 81 : 256
- (c) 3 : 4
- (d) 4 : 3

Question 2. Which of the following will radiate heat to large extent?

- (a) Rough surface
- (b) Polished surface
- (c) Black rough surface
- (d) Black polished surface

Question 3. Two spheres made of same material have radii in the ratio 2 : 1. if both the spheres are at same temperature, then what is the ratio of heat radiation energy emitted per second by them?

- (a) 1 : 4
- (b) 4 : 1
- (c) 3 : 4
- (d) 4 : 3

Question 4. The earth intercepts approximately one billionth of the power radiated by the sun. if the surface temperature of the sun were to drop by a factor of 2, the average radiant energy incident on earth per second would reduce by factor of

- (a) 2
- (b) 4
- (c) 8
- (d) 16

Question 5. A bucket full of hot water is kept in a room and it cools from  $75^\circ\text{C}$  to  $70^\circ\text{C}$  in  $t_1$  minutes from  $70^\circ\text{C}$  to  $65^\circ\text{C}$  in  $t_2$  minutes and from  $65^\circ\text{C}$  to  $60^\circ\text{C}$  in  $t_3$  minutes; then

- (a)  $t_1 - t_2 = t_3$

- (b)  $t_1 < t_2 < t_3$
- (c)  $t_1 > t_2 > t_3$
- (d)  $t_1 < t_2 > t_3$

Question 6. A sphere, a cube and a thin circular plate, all made of the same material and having the same mass are initially heated to a temperature of  $3000^\circ\text{K}$ , which of these will cool fastest?

- (a) Sphere
- (b) Cube
- (c) Plate
- (d) None

Question 7. A perfectly black body emits radiation at temperature  $T^1\text{K}$ . If it is to radiate 16 times this power, its temperature  $T^2$  will be

- (a)  $T^2 = 16 T^1$
- (b)  $T^2 = 8 T^1$
- (c)  $T^1 = 4 T^1$
- (d)  $T^2 = 2 T^1$

Question 8. Unit of Stefan's constant is given by

- (a)  $\text{W}/\text{m K}^2$
- (b)  $\text{W}/\text{m}^2 \text{K}^2$
- (c)  $\text{W}^2/\text{m}^2 \text{K}^4$
- (d)  $\text{W}/\text{mK}$

Question 9. The good absorber of heat are

- (a) Non-emitter
- (b) Poor-emitter
- (c) Good-emitter
- (d) Highly polished

Question 10. A black body is at a temperature of  $500\text{K}$ . It emits energy at a rate which is proportional to

- (a) 500
- (b)  $(500)^2$
- (c)  $(500)^3$
- (d)  $(500)^4$

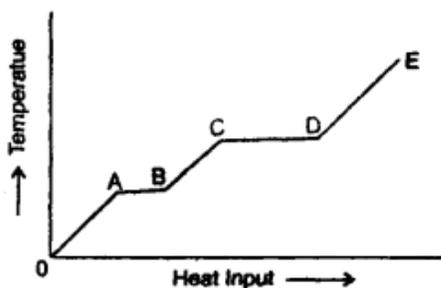
### Very Short:

1. The fact that the triple point of a substance is unique is used in modern thermometry. How?
2. Is it possible for a body to have a negative temperature on the Kelvin scale? Why?
3. (a) Why telephone wires are often given sag?  
(b) The temperature of a gas is increased by  $8^{\circ}\text{C}$ . What is the corresponding change on the Kelvin scale?
4. There is a hole in a metal disc. What happens to the size of the hole if the metal disc is heated?
5. Milk is poured into a cup of tea and is mixed with a spoon. Is this an example of a reversible process? Why?
6. The top of a lake is frozen. Air in contact with it is at  $-15^{\circ}\text{C}$ . What do you expect the maximum temperature of water in contact with the lower surface ice? What do you expect the maximum temperature of water at the bottom of the lake?
7. How does the heat energy from the sun reaches Earth?
8. Why does not the Earth become as hot as the Sun although it has been receiving heat from the Sun for ages?
9. Why felt rather than air is employed for thermal insulation?
10. What are the three modes of transmission of heat energy from one point to another point?
11. Why a thick glass tumbler cracks when boiling liquid is poured into it?
12. What is the basic principle of a thermometer?
13. Out of mass, radius and volume of a metal ball, which one suffers maximum and minimum expansion on heating? Why?
14. The higher and lower fixed points on a thermometer are separated by 160 mm. If the length of the mercury thread above the lower point is 40 mm, then what is the temperature reading?
15. Two thermometers are constructed in the same way except that one has a spherical bulb and the other an elongated cylindrical bulb. Which of the two will respond quickly to temperature changes.

### Short Questions:

1. Why gas thermometers are more sensitive than mercury thermometers?

2. Why the brake drum of an automobile gets heated up when the automobile moves down a hill at constant speed?
3. A solid is heated at a constant rate. The variation of temperature with heat input is shown in the figure here:

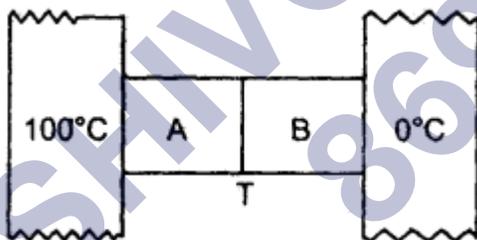


- (a) What is represented by AB and CD?
- (b) What conclusion would you draw if  $CD = 2AB$ ?
- (c) What is represented by the slope of DE?
- (d) What conclusion would you draw from the fact that the slope of OA is greater than the slope of BC?
4. Define:
  - (a) Thermal conduction.
  - (b) Coefficient of thermal conductivity of a material.
5. On what factors does the amount of heat flowing from the hot face to the cold face depend? How?
6. State Newton's law of cooling and define the cooling curve. What is its importance?
7. Explain why heat is generated continuously in an electric heater but its temperature becomes constant after some time?
8. A woollen blanket keeps our body warm. The same blanket if wrapped around ice would keep ice cold. How do you explain this apparent paradox?
9. A liquid is generally heated from below. Why?
10. If a drop of water falls on a very hot iron, it does not evaporate for a long time. Why?
11. On a hot day, a car is left in sunlight with all the windows closed. After some time, it is found that the inside of the car is considerably warmer than the air outside. Explain why?
12. It takes longer to boil water with a flame in a satellite in gravitational field-free space, why? How it will be heated?

13. Find  $\gamma$  for polyatomic gas and hence determine its value for a triatomic gas in which the molecules are linearly arranged.
14. Food in a hot case remains warm for a long time during winter, how?
15. You might have seen beggars sleeping on footpaths or in open in winter with their hands and knees pulled inside. Similarly dogs too curl while sleeping in winter. How does such action help anybody?

### Long Questions:

1. Calculate the increase in the temperature of the water which falls from a height of 100 m. Assume that 90% of the energy due to fall is converted into heat and is retained by water.  $J = 4.2 \text{ J cal}^{-1}$ .
2. A clock with a steel pendulum has a time period of 2s at  $20^\circ\text{C}$ . If the temperature of the clock rises to  $30^\circ\text{C}$ , what will be the gain or loss per day? The coefficient of linear expansion of steel is  $1.2 \times 10^{-5} \text{ C}^{-1}$
3. The thermal conductivity of brick is  $1.7 \text{ W m}^{-1} \text{ K}^{-1}$  and that – of cement is  $2.9 \text{ W m}^{-1} \text{ K}^{-1}$ . What thickness of cement will have the same insulation as the brick of thickness 20 cm.
4. Two metal cubes A and B of the same size are arranged as shown in the figure. The extreme ends of the combination are maintained at the indicated temperatures. The arrangement is thermally insulated. The coefficient of thermal conductivity of A and B are  $300 \text{ W/m}^\circ\text{C}$  and  $200 \text{ W/m}^\circ\text{C}$  respectively. After a steady-state is reached, what will be the temperature of the interface?



5. The heat of combustion of ethane gas is 373 Kcal per mole. Assuming that 50% of heat is lost, how many litres of ethane measured at STP must be burnt to convert 50 kg of water at  $10^\circ\text{C}$  to steam at  $100^\circ\text{C}$ ? One mole of gas occupies 22.4 litres at S.T.P. Latent heat (L) of steam =  $2.25 \times 10^6 \text{ JK}^{-1}$ .

### Assertion Reason Questions:

1. **Directions:** Each of these questions contain two statements, Assertion and Reason. Each of these questions also has four alternative choices, only one of which is the correct answer. You have to select one of the codes (a), (b), (c) and (d) given below.
  - (a) If both assertion and reason are true and the reason is the correct explanation of the assertion.

- (b) If both assertion and reason are true but reason is not the correct explanation of the assertion.
- (c) If assertion is true but reason is false.
- (d) If the assertion and reason both are false.

**Assertion:** Specific heat capacity is the cause of formation of land and sea breeze.

**Reason:** The specific heat of water is more than land.

2. **Directions:** Each of these questions contain two statements, Assertion and Reason. Each of these questions also has four alternative choices, only one of which is the correct answer. You have to select one of the codes (a), (b), (c) and (d) given below.

- (a) If both assertion and reason are true and the reason is the correct explanation of the assertion.
- (b) If both assertion and reason are true but reason is not the correct explanation of the assertion.
- (c) If assertion is true but reason is false.
- (d) If the assertion and reason both are false.

**Assertion:** A brass disc is just fitted in a hole in a steel plate. The system must be cooled to loosen the disc from the hole.

**Reason:** The coefficient of linear expansion for brass is greater than the coefficient of linear expansion for steel.

✓ **Answer Key:**

### Multiple Choice Answers-

1. Answer: (d) 4 : 3
2. Answer: (c) Black rough surface
3. Answer: (b) 4 : 1
4. Answer: (d) 16
5. Answer: (b)  $t_1 < t_2 < t_3$
6. Answer: (c) Plate
7. Answer: (d)  $T^2 = 2 T_1$
8. Answer: (b)  $W / m^2 K^2$
9. Answer: (c) Good-emitter
10. Answer: (d)  $(500)^4$

### Very Short Answers:

1. Answer: In modern thermometry, the triple point of water is a standard fixed point.
2. Answer: No. Because absolute zero of temperature is the minimum possible

temperature on the Kelvin scale.

3. Answer: (a) It is done to allow for safe contraction in winter.  
(b) 8 K.
4. Answer: The size of the hole increases on heating the metal disc.
5. Answer: No. When milk is poured into tea, some work is done which is not recoverable. So the process is not reversible.
6. Answer: 0°C, 4°C.
7. Answer: It reaches by radiation.
8. Answer: Earth loses heat by convection and radiation.
9. Answer: In the air, loss of heat by convection is possible. But convection currents cannot be set up in felt.
10. Answer: Conduction, Convection and Radiation.
11. Answer: Its inner and outer surfaces undergo uneven expansion due to the poor conductivity of glass, hence it cracks.
12. Answer: The variation of some physical property of a substance with temperature constitutes the basic principle of the thermometer.
13. Answer: Volume and radius suffer maximum and minimum expansions respectively as  $\gamma = 3\alpha$ .
14. Answer: The temperature reading =  $\frac{100 \times 40}{160} = 25$ .
15. Answer: The thermometer with a cylindrical bulb will respond quickly as the area of the cylindrical bulb is greater than the area of the spherical bulb.

### Short Questions Answers:

1. Answer: This is because the coefficient of expansion of a gas is very large as compared to the coefficient of expansion of mercury. For the same temperature change, the gas would undergo a much larger change in volume as compared to mercury.
2. Answer: Since the speed is constant so there is no change of kinetic energy. The loss in gravitational potential energy is partially the gain in the heat energy of the brake drum.
3. Answer: (a) The portions AB and CD represent a change of state. This is because the supplied heat is unable to change the temperature. While AB represents a change of state from solid to liquid, the CD represents a change of state from liquid to vapour state.  
(b) It indicates that the latent heat of vaporisation is twice the latent heat of fusion.  
(c) Slope of DE represents the reciprocal of the thermal or heat capacity of the

substance in vapour state i.e. slope of DE =  $\frac{dT}{dQ} = \frac{1}{mC}$  ( $\therefore dQ = mC\Delta T$ ).

(d) Specific heat of the substance in the liquid state is greater than that in the solid-state as the slope of OA is more than that of BC i.e.  $\frac{1}{mC_1} > \frac{1}{mC_2}$  where  $C_1, C_2$  are specific heats  $mC_1, mC_2$  of the material in solid and liquid state respectively.

4. Answer: (a) It is defined as the process of the transfer of heat energy from one part of a solid to another part at a lower temperature without the actual motion of the molecules. It is also called the conduction of heat.

(b) It is defined as the quantity of heat flowing per second across the opposite faces of a unit cube made of that material when the opposite faces are maintained at a temperature difference of 1K or 1°C.

5. Answer: If  $Q$  is the amount of heat flowing from hot to the cold face, then it is found to be:

1. directly proportional to the cross-sectional area ( $A$ ) of the face

$$\text{i.e. } Q \propto A \dots(1)$$

2. directly proportional to the temperature difference between the two faces, i.e.

$$Q \propto \Delta\theta \dots(2)$$

3. directly proportional to the time  $t$  for which the heat flows i.e.  $Q \propto t \dots (3)$

4. inversely proportional to the distance 'd' between the two faces.

$$\text{i.e. } Q \propto \frac{1}{\Delta x} \dots(4)$$

Combining factors (1) to (4), we get

$$Q \propto \frac{A\Delta\theta}{\Delta x} t$$

or

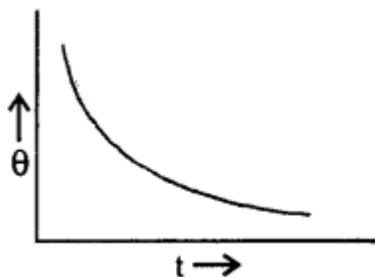
$$Q \propto K A \frac{\Delta\theta}{\Delta x} t$$

where  $K$  is the proportionality constant known as the coefficient – of thermal conductivity.

6. Answer: Newton's law of cooling: States that the rate of loss of heat per unit surface area of a body is directly proportional to the temperature difference between the body and the surroundings provided the difference is not too large.

Cooling Curve: It is defined as a graph between the temperature of a body and the time. It is as shown in the figure here.

The slope of the tangent to the curve at any point gives the rate of fall of temperature.



7. Answer: When the electric heater is switched on, a stage is quickly reached when the rate at which heat is generated by an electric current becomes equal to the rate at which heat is lost by conduction, convection and radiation and hence a thermal equilibrium is established. Thus temperature becomes constant.
8. Answer: Wool is a bad conductor of heat. Moreover wool encloses air in it which is a bad conductor. There can also be no loss of heat by convection. The woollen blanket keeps us warm by preventing the heat of the human body to flow outside and hence our body remains warm.
9. Answer: When a liquid is heated, it becomes rarer due to a decrease in density and it rises up. Liquid from the upper part of the vessel comes down to take its place and thus convection currents are formed. If the liquid is heated at the top, no such convection currents will be formed and only the liquid in the upper part of the vessel will become hot. However, the temperature in the lower part of the vessel will rise slightly due to a small amount of heat conducted by the hot liquid in the upper part of the vessel.
10. Answer: When a drop of waterfalls on a very hot iron, it gets insulated from the hot iron due to the formation of a thin layer of water vapour, which is a bad conductor in nature. It takes quite a long to evaporate as heat is conducted from hot iron to the drop through the layer of water vapour very slowly.
- On the other hand, if a drop of waterfalls on an iron which is not very hot, then it comes in direct contact with the iron and evaporates immediately.
11. Answer: Glass possesses the property of selective absorption of heat radiation. It also transmits about 50% of heat radiation coming from a hot source like the sun and is more or less opaque to the radiation from moderately hot bodies (at about  $100^{\circ}\text{C}$  or so). Due to this, when a car is left in the sun, heat radiation from the sun gets into the car but as the temperature inside the car is moderate, it cannot escape through its windows. Thus glass windows of the car trap the sun rays and because of this, the inside of the car becomes considerably warmer.
12. Answer: Water boils with flame by the process of convection. Hot lighter particles raise up and heavier particles move down under gravity. In a gravity-free space in the satellite, the particles cannot move down hence, water can't be heated by convection. It will be heated by conduction.

13. Answer: The energy of a polyatomic gas having  $n$  degrees of freedom is given by

$$E = n \times \frac{1}{2} kT \times N = \frac{n}{2} RT$$

$$\therefore C_v = \frac{dE}{dT} = \frac{n}{2} R$$

$$\begin{aligned} \therefore C_p &= C_v + R = \frac{n}{2} R + R \\ &= \left( \frac{n}{2} + 1 \right) R \end{aligned}$$

$$\therefore \gamma = \frac{C_p}{C_v} = \frac{\frac{n}{2} + 1}{\frac{n}{2}} = 1 + \frac{2}{n}$$

In case of a triatomic gas,  $n = 7$

$$\therefore \gamma = 1 + \frac{2}{7} = \frac{9}{7}$$

14. Answer: The hot case is a double-walled vessel. The space between the walls is evacuated in a good hot case. The food container placed inside the hot case is made of crowning steel, thus neither the outside low-temperature air can enter the container nor the heat from inside can escape through the hot case by conduction or convection. The highly polished shining surface of the food container helps in stopping loss of heat due to radiation. Thus, the heat of the food is preserved for a long time and food remains hot in winter.

15. Answer: The heat radiated or emitted from a body at a given temperature depends on

1. the temperature difference between the body and the surrounding,
2. area of the body in contact with the surroundings and
3. the nature of the body.

For man and animals in winter (1) and (2) factors remain what they are. So, in order to preserve, their body heat they curl up to reduce the surface area in contact with cold air.

### Long Questions Answers:

1. Answer: Here,  $h = 100$  m

Let  $m$  (kg) = mass of water

$\therefore$  Its P.E. at a height  $h = mgh$

Energy of fall retained by water i.e. useful work done is given by,

$W = 90\%$  of  $mgh$

$$= \frac{900}{100} mgh$$

$$= \frac{90}{100} m \times 9.8 \times 100$$

$$= 882 \text{ m J.}$$

$$\therefore \text{Heat retained, } Q = WJ = \frac{m \times 882 J}{4.2 J \text{ cal}^{-1}}$$

$$= m \times 210 \text{ cal ... (i)}$$

Specific heat of water  $C = 10 \text{ cal kg}^{-1} \text{ }^\circ\text{C}^{-1}$

Let  $\Delta\theta$  ( $^\circ\text{C}$ ) be the rise in the temperature of water.

$$\therefore \text{Heat gained, } Q = mC\Delta\theta$$

$$= m \times 10^3 \times \Delta\theta$$

$$= m \times \Delta\theta \times 10^3 \text{ cal ... (ii)}$$

$\therefore$  From (1) and (ii), we get

$$m \times 210 = m \times \Delta\theta \times 10^3$$

or

$$\Delta\theta = \frac{210}{10^3} = 0.21^\circ\text{C.}$$

2. Answer: Here  $\alpha = 1.2 \times 10^{-1} \text{ }^\circ\text{C}^{-1}$

$$\Delta t = 30 - 20 = 10^\circ\text{C}$$

$$T = 2\text{s.}$$

Using the relation,  $\Delta l = l \alpha \Delta t$ , we get

$$\frac{\Delta l}{l} = \alpha \Delta t$$

$$= 1.2 \times 10^{-5} \times 10 = 1.2 \times 10^{-4} \text{ ... (i)}$$

$$\therefore T = 2\pi \sqrt{\frac{l}{g}} \text{ ... (ii)}$$

If  $T'$  be the time period of the pendulum, when  $l$  increases by  $\Delta l$ , then

$$T' = 2\pi\sqrt{\frac{l+\Delta l}{g}}$$

$$= 2\pi\sqrt{\frac{l}{g}\left(1+\frac{\Delta l}{l}\right)} \quad \dots (iii)$$

$$\frac{(iii)}{(ii)} \text{ gives } \frac{T'}{T} = \sqrt{1+\frac{\Delta l}{l}} = \sqrt{1+1.2\times 10^{-4}}$$

$\therefore$  loss in time in one oscillation  $T' - T$

Hence loss in time in one day is given by

$$= \frac{T' - T}{T} \times 24 \times 3600 \text{ s}$$

$$= \left(\frac{T'}{T} - 1\right) \times 24 \times 3600 \text{ s}$$

$$= \left[\sqrt{1+1.2\times 10^{-4}} - 1\right] \times 24 \times 3600 \text{ s}$$

$$= \left[1 + \frac{1}{2} \times 1.2 \times 10^{-4} - 1\right] \times 24 \times 3600 \text{ s}$$

$$= \frac{1.2 \times 10^{-4} \times 24 \times 3600}{2} \text{ s}$$

$$= 5.18 \text{ s.}$$

3. Answer: Here,  $K_B = 1.7 \text{ W m}^{-1} \text{ K}^{-1}$

$$K_C = 2.9 \text{ W m}^{-1} \text{ K}^{-1}$$

$$d_B = 20 \text{ cm}$$

$$d_C = ?$$

We know that the heat flow is given by

$$Q = KA \frac{\Delta\theta}{d} t$$

For the same insulation by the brick and the cement,  $Q$ ,  $A$ ,  $\Delta\theta$  and  $t$  don't change

Thus  $\frac{K}{d}$  should be a constant.

$$\begin{aligned}
 \text{i.e. } \frac{K_B}{d_B} &= \frac{K_C}{d_C} \\
 \text{or } d_C &= \frac{K_C}{K_B} \times d_B \\
 &= \frac{2.9}{1.7} \times 20 = 34.12 \text{ cm.}
 \end{aligned}$$

4. Answer: Let  $T$  ( $^{\circ}\text{C}$ ) be the temperature of the interface =?

Here,  $K_1 = 300 \text{ Wm}^{-1} \text{ }^{\circ}\text{C}^{-1}$  for A

$K_2 = 200 \text{ Wm}^{-1} \text{ }^{\circ}\text{C}^{-1}$  for B

$\therefore \Delta\theta_1 = 100 - T$  for A

$\Delta\theta_2 = T - 0$  for B .

$x$  = size of each cube A and B

$\therefore x_1 = x_2 = x$

Let  $a$  = area of cross-section of the faces between which there is the flow of heat

If  $\left(\frac{\Delta Q_1}{\Delta t}\right)_A$  and  $\left(\frac{\Delta Q_2}{\Delta t}\right)_B$  be the rate of flow of heat for A and B respectively, then in steady state,

$$\begin{aligned}
 \left(\frac{\Delta Q_1}{\Delta t}\right)_A &= \left(\frac{\Delta Q_2}{\Delta t}\right)_B \\
 \text{or } \frac{K_1 a \Delta\theta_1}{x} &= \frac{K_2 a \Delta\theta_2}{x} \quad \left(\because \Delta Q = K \frac{\Delta\theta}{d} \text{ at}\right) \\
 \text{or } K_1 \Delta\theta_1 &= K_2 \Delta\theta_2 \\
 \text{or } 300(100 - T) &= 200(T - 0) \\
 \text{or } (300 + 200)T &= 30000 \\
 \text{or } T &= \frac{300 \times 100}{500} \\
 \therefore T &= 60^{\circ}\text{C.}
 \end{aligned}$$

5. Answer: Here

$$L = 2.25 \times 10^6 \text{ JK}^{-1}$$

$$= \frac{2.25}{4.2} \times 10^6 \text{ cal}^{\circ}\text{C}^{-1}$$

$Q$  = Heat of Combustion

$$= 373 \times 10^3 \text{ Cal/mole}$$

$$C = 103 \text{ J Kg}^{-1} \text{ }^{\circ}\text{C}^{-1}$$

$$m = 50 \text{ kg}$$

$$\Delta\theta = 100 - 10 = 90^\circ\text{C}$$

$$V = 22.4 \text{ litres}$$

If  $Q_1$  = Total heat energy required to convert 50 kg of water at  $10^\circ\text{C}$  to steam at  $100^\circ\text{C}$

$$Q_1 = mC\Delta\theta + mL$$

$$= 5.0 \times 1000 \times 90 + 50 \times \frac{2.25 \times 10^6}{4.2}$$

$$= 4.5 \times 10^6 + 26.79 \times 10^6$$

$$= 31.29 \times 10^6 \text{ cal}$$

As 50% of heat is lost,

$$\therefore \text{total heat produced} = \frac{100}{50} \times 31.29 \times 10^6$$

Let  $n$  = no. of moles of ethane to be burnt, then

$$n = \frac{2 \times 31.29 \times 10^6}{373 \times 10^3} \text{ mole}$$

$\therefore$  Volume of ethane =  $nV$

$$= \frac{2 \times 31.29 \times 10^6}{373 \times 10^3} \times 22.4 \text{ litres}$$

$$= 3758.2 \text{ litres.}$$

### Assertion Reason Answer:

- (a) If both assertion and reason are true and the reason is the correct explanation of the assertion.
- (a) If both assertion and reason are true and the reason is the correct explanation of the assertion.

### Case Study Questions-

- we can say that heat is the form of energy transferred between two (or more) systems or a system and its surroundings by virtue of temperature difference. The SI unit of heat energy transferred is expressed in joule (J) while SI unit of temperature is Kelvin (K), and degree Celsius ( $^\circ\text{C}$ ) is a commonly used unit of temperature. When an object is heated, many changes may take place. Its temperature may rise; it may expand or change state. A measure of temperature is obtained using a thermometer. Many physical properties of materials change sufficiently with temperature. Some such properties are used as the basis for constructing thermometers. The two familiar temperature scales are the Fahrenheit temperature scale and the Celsius temperature scale. The ice and steam point have values  $32^\circ\text{F}$  and  $212^\circ\text{F}$ , respectively, on the Fahrenheit scale and  $0^\circ\text{C}$  and  $100^\circ\text{C}$  on

the Celsius scale. On the Fahrenheit scale, there are 180 equal intervals between two reference points, and on the Celsius scale, there are 100. A relationship for converting between the two scales may be obtained from a graph of Fahrenheit temperature ( $t_F$ ) versus Celsius temperature ( $t_C$ ) in a straight line. When temperature is held constant, the pressure and volume of a quantity of gas are related as  $PV = \text{constant}$ . This relationship is known as Boyle's law. When the pressure is held constant, the volume of a quantity of the gas is related to the temperature as  $V/T = \text{constant}$ . This relationship is known as Charles' law. Low-density gases obey these laws, which may be combined into a single relationship.  $PV = \mu RT$  where,  $\mu$  is the number of moles in the sample of gas and  $R$  is called universal gas constant:  $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$  we have learnt that the pressure and volume are directly proportional to temperature:  $PV \propto T$ . This relationship allows a gas to be used to measure temperature in a constant volume gas thermometer. The absolute minimum temperature for an ideal gas at which pressure becomes zero is found to be  $-273.15^\circ\text{C}$  and is designated as absolute zero. Absolute zero is the foundation of the Kelvin temperature scale or absolute scale temperature. The size of unit in Kelvin and Celsius temperature scales is the same. So, temperature on these scales are related by  $T = t_C + 273.15$

- i. **The SI unit of heat energy transferred is expressed in**
  - a. Joule (J)
  - b. Kelvin (K)
  - c. Newton (N)
  - d. None of these
- ii. **Temperature is measured using**
  - a. Thermometer
  - b. Barometer
  - c. Tachometer
  - d. None of these
- iii. **Relation between Kelvin (T) and Celsius temperature ( $t_C$ ) scale is given by**
  - a.  $T = t_C + 273.15$
  - b.  $T = t_C - 273.15$
  - c.  $T = t_C$
  - d. None of these
- iv. **What is heat energy**
- v. **What is absolute zero temperature**

2. A system is said to be isolated if no exchange or transfer of heat occurs between the system and its surroundings. When different parts of an isolated system are at different temperature a quantity of heat transfers from the part at higher temperature to the part at lower temperature. The heat lost by the part at higher temperature is equal to the heat gained by the part at lower temperature. Calorimetry means measurement of heat. When a body at higher temperature is brought in contact with another body at lower temperature, the heat lost by the hot body is equal to the heat gained by the colder body, provided no heat is allowed to escape to the surroundings. A device in which heat measurement can be done is called a calorimeter. It consists of a metallic vessel and stirrer of the same material, like copper or aluminium. The vessel is kept inside a wooden jacket, which contains heat insulating material. Matter normally exists in three states: solid, liquid and gas. A transition from one of these states to another is called a change of state. Two common changes of states are solid to liquid and liquid to gas (and, vice versa). These changes can occur when the exchange of heat takes place between the substance and its surroundings. The change of state from solid to liquid is called melting and from liquid to solid is called fusion. It is observed that the temperature remains constant until the entire amount of the solid substance melts. That is, both the solid and the liquid states of the substance coexist in thermal equilibrium during the change of states from solid to liquid. The temperature at which the solid and the liquid states of the substance is in thermal equilibrium with each other is called its melting point. The change of state from liquid to vapour (or gas) is called vaporisation. It is observed that the temperature remains constant until the entire amount of the liquid is converted into vapour. That is, both the liquid and vapour states of the substance coexist in thermal equilibrium, during the change of state from liquid to vapour. The temperature at which the liquid and the vapour states of the substance coexist is called its boiling point. The change from solid state to vapour state without passing through the liquid state is called sublimation, and the substance is said to sublime. Dry ice (solid  $\text{CO}_2$ ) sublimates, so also iodine. During sublimation both the solid and vapour states of a substance coexist in thermal equilibrium.

- i. **Device used for measurement of heat is**
  - a. Calorimeter
  - b. Thermometer
  - c. Both a and b
  - d. No one of these
- ii. **The change of state from solid to liquid is called**
  - a. Melting
  - b. Vaporization
  - c. Sublimation

- d. None of these
- iii. **Define melting point and boiling point**
- iv. **What is sublimation?**
- v. **Define fusion process**

## Case Study Answer-

### 1. Answer

- i. (a) Joule (J)
- ii. (a) Thermometer
- iii. (a)  $T = t_c + 273.15$
- iv. Heat energy is the form of energy transferred between two or more systems or its surroundings due to temperature difference from higher temperature to lower temperature. The SI unit of heat energy transferred is expressed in joule (J).
- v. The absolute minimum temperature for an ideal gas at which pressure becomes zero is found to be  $-273.15\text{ }^\circ\text{C}$  and is designated as absolute zero temperature. This is lowest temperature possible for ideal gas.

### 2. Answer

- i. (a) Calorimeter
- ii. (a) Melting
- iii. The change of state from solid to liquid is called melting process and temperature at which conversion of solid into liquid happens is called as melting point. The temperature at which the liquid and the vapour states of the substance coexist is called its boiling point.
- iv. The change from solid state directly into vapour state without passing through the liquid state is called sublimation, and the substance is said to sublime.
- v. The change of state from liquid state to solid state is called as fusion process.