CHAPTER – 11

THERMAL PROPERTIES OF MATTER

Heat and Temperature

Heat is the form of energy, which is transferred from one body to another because of their temperature difference.

Temperature is the degree of hotness of a body.

SI unit of heat is joule (J)

SI unit of temperature is Kelvin (K)

Measurement of temperature

The device used to measure temperature is called thermometer.

There are two types of thermometers

i. Liquid – in –glass type thermometers.
ii. Constant volume gas thermometers.

Liquid – in –glass type thermometers

Principle: - Thermal expansion of liquids. I.e., when temperature increases, volume of liquids increases.

Commonly used liquids: - Mercury, Alcohol.

Question1: - Why mercury is used in thermometer?

Ans: - Mercury is used because of the following properties of it.

i. It has high thermal expansivity.
ii. It has a shining surface.
iii. It does not wet glass.

Constant volume gas thermometer

Principle: -

We have $PV = nRT$, for a low density gas.

i.e., $PV \propto T$

If volume is kept constant $P \propto T$

I.e., when temperature increases, pressure also increases.

In constant volume gas thermometers temperature is read in terms of pressure.

Common units of temperature

The commonly used units are **Degree Celsius**, **Kelvin** and **Fahrenheit**.

Formulae for unit conversion

$$t_K = t_C + 273$$

$$t_F = \frac{9}{5} t_C + 32$$

Problem1: -Convert the ice point (0^0C) and the steam point (100^0C) into Kelvin and Fahrenheit scales.

Soln: -

Ice point (0^0C)	Steam point (100^0C)
$t_C = 0$	$t_C = 100^0C$
$t_K = 0 + 273 = 273K$	$t_K = 100 + 273 = 373K$
$t_F = \frac{9}{5} \times 0 + 32 = 32^0F$	$t_F = \frac{9}{5} \times 100 + 32$ $= 180 + 32$ $= 212^0$ F

Problem2: Temperature of a normal human body is 98.6^0F. What is the corresponding temperature shown in the Celsius scale?

Ans:

Boyle's law

Boyle's law states that '**at constant temperature, the volume of a given mass of gas is inversely proportional to pressure**'.

$$V \alpha \frac{1}{P} \quad \Rightarrow PV = \text{constant}$$

$$\boxed{P_1V_1 = P_2V_2}$$

Charles' Law

Charles's law states that '**at constant pressure, the volume of a given mass of gas is directly proportional to absolute temperature**'.

$$V \alpha T \Rightarrow \frac{V}{T} = \text{constant}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Ideal gas equation

A low density gas obeys the following two equations :

$$V \alpha \frac{1}{P} \text{ and } V \alpha T$$

So if we combine these equations,

$$V \alpha \frac{T}{P} \Rightarrow PV \alpha T$$

$$\Rightarrow PV = nRT,$$

$$\text{or } \frac{PV}{T} = \text{Constant}$$

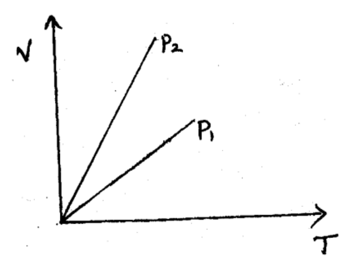
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Where n is the no. of moles (n) and R is the universal gas constant.

$R = 8.31\ Jmol^{-1}K^{-1}$.

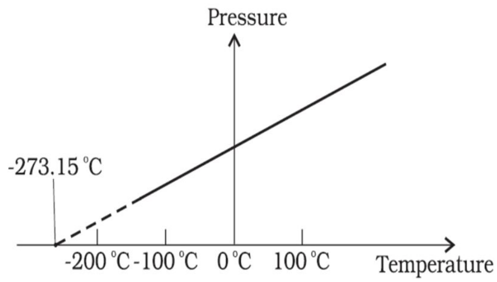
The equation $PV = nRT$ is known as ideal gas equation and is obeyed by low density gases.

Problem3: The volume temperature graph of certain amount of perfect gas at two pressures P_1 and P_2 are shown. Which pressure is larger P_1 or P_2?



Ans:

Absolute zero (O^0K)



When temperature decreases, the pressure of a low density gas decreases. At -273.15^0C (or O^0K) the pressure become zero. This temperature is known as absolute zero.

Thermal expansion

When temperature increases, volume of substances (solids, liquids and gases) increases. This is called thermal expansion.

1. Linear expansion

When temperature increases, length of a solid (rod like structure) increases. This is called linear expansion.

$$\frac{\Delta \ell}{\ell} \alpha\ \Delta T$$

$$\Rightarrow \frac{\Delta \ell}{\ell} = \alpha_\ell\ \Delta T$$

α_l is a constant called coefficient of linear expansion.

2. Area Expansion (or superficial expansion)

When temperature increases area of a solid substance increases. This is called area expansion.

$$\frac{\Delta A}{A} \alpha\ \Delta T$$

$$\Rightarrow \frac{\Delta A}{A} = \alpha_A\ \Delta T$$

α_A is called coefficient of area expansion.

3. Volume expansion

When temperature increases, the volume of a substance (solid, liquid or gas) increases. This called volume expansion.

$$\frac{\Delta V}{V} \alpha\ \Delta T$$

$$\frac{\Delta V}{V} = \alpha_v\ \Delta T$$

But we can prove that

$\boxed{\alpha_A = 2\alpha_\ell}$ and $\boxed{\alpha_V = 3\alpha_\ell}$

Anomalous expansion of water

Water contracts on heating from 0^0C to 4^0C. This is called abnormal expansion of water.

On cooling below room temperature up to 4^0C the density of water increases. Below 4^0C the density of water decreases.

Water has highest density at 4^0C.

Important environmental effect of anomalous expansion of water.

Water bodies, such as lakes and ponds, freeze at the top first. As a lake cools towards 4^0C, water near the surface become denser and sinks; the warmer, less dense water near the bottom rises. However, once the colder water on top reaches a temperature below 4^0C, it becomes less dense and remains at the surface itself. So a water body will not freeze from top to bottom. If water did not have this property, lakes and ponds would freeze from top to bottom.

Problem4: Railway lines are laid with gaps to allow for expansion. If the gap between steel rails 66m long is 3.63cm at 10^0C, then at what temperature will the lines just touch? Coefficient of linear expansion for steel is $11\times10^{-6}/^0C$

Ans:

Specific heat capacity (s)

It is the amount of heat required to raise the temperature of 1kg substance by 1^0C or 1K.

Specific heat capacity,

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

$\Delta T \rightarrow$ Change in temperature

$m \rightarrow$ Mass of the substance

or $\boxed{\Delta Q = ms\Delta T}$

SI unit of specific heat capacity is $JKg^{-1}K^{-1}$.

Heat capacity (S)

It is the amount of heat required to raise the temperature of a substance by 1^0C or 1K.

$$S = \frac{\Delta Q}{\Delta T}$$ SI unit is J/K

Molar specific heat capacity

It is the amount of heat required to raise the temperature of 1mole of a substance by 1^0C or 1K.

SI unit J/mol. K

$$C = \frac{\Delta Q}{n\Delta T}$$

$n \rightarrow$ no. of moles

Molar specific heat capacity is of two types for gases:

i. **Specific heat capacity at constant volume (C_V)**

It is the amount of heat required to raise the temperature of one mole of a gas at constant volume by 1^0C or 1K.

ii. **Specific heat capacity at constant pressure (C_P)**

It is the amount of heat required to raise the temperature of one mole

of a gas at constant pressure by 1^0C or 1K.

Mayer's Relation

$$C_p - C_v = R$$

Note: -

Water has highest specific heat capacity compared to other substances.

Specific heat capacity of water = **$4186 JKg^{-1}K^{-1}$**

Advantages of high specific heat capacity of water

i. Water is used to as a coolant in automobile radiators.
ii. Sea breeze & land breeze.

Calorimetry

Calorimetry is the measurement of heat.

Calorimeter: -

Calorimeter is a device used to measure heat.

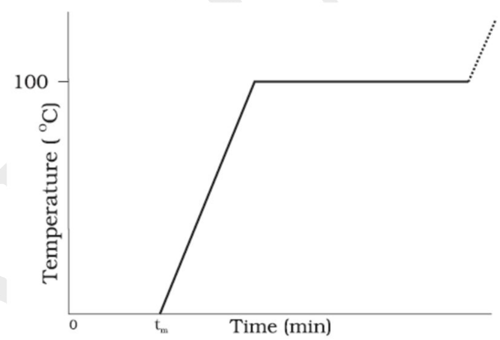
Principle of calorimeter

When a hot body and cold body come in contact, the heat lost by the hot body is equal to the heat gained by the cold body.

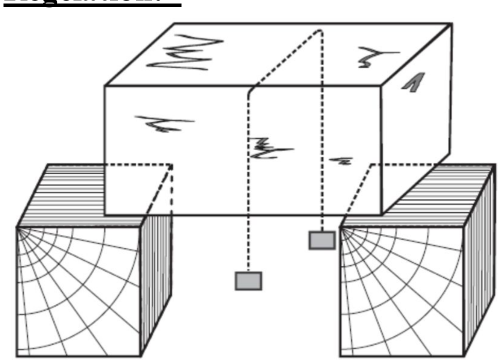
Calorimeter consists of a metallic vessel and stirrer both of same material like copper or aluminium. The vessel is kept inside a wooden jacket which contains heat insulating materials like glass wool etc. There is an opening in the outer jacket through which a mercury thermometer can be inserted into the calorimeter. When a solid hot body is inserted in the calorimeter, the heat lost by the hot body can be calculated by finding the heat gained by the materials of the calorimeter.

Change of state

Change of State of Ice on Heating



Melting: - The change of state from solid to liquid.
Fusion: - The change of state from liquid to solid.
Melting point: - The temperature at which a solid is converted into liquid.
Regelation: -



When pressure is applied, ice melts at low temperature. If pressure is removed, water refreezes. This refreezing is called regelation.

Application of regelation: - Skating is possible on snow due to the formation of water below the skates. Water is formed due to the increase of pressure and it acts as a lubricant.

Vaporisation: -

The change of state from liquid to gas is called vaporisation.

Boiling point: - It is the temperature at which a liquid is converted into gas.

Sublimation: -

The change from solid state to vapour state without passing through the liquid state is called sublimation.

Eg: - dry ice (solid CO_2), iodine, Camphor, naphthalene tablets etc.

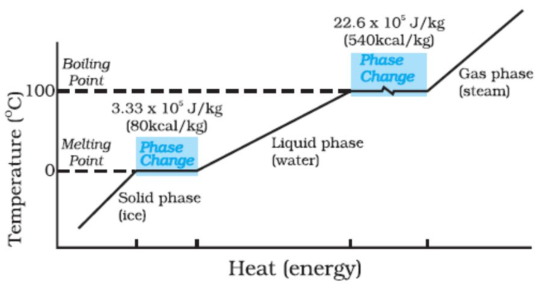


Fig. 11.12 Temperature versus heat for water at 1 atm pressure (not to scale).

Latent heat of fusion (L_f)

It is the amount of heat required to convert one kilogram solid substance completely into liquid at its melting point, without any change in temperature.

$$L_f = \frac{Q}{m} \Rightarrow Q = mL_f.$$

Latent heat of Vaporisation (L_V)

It is the amount of heat required to convert one kilogram liquid substance completely into gas at its boiling point, without any change in the temperature.

$$L_V = \frac{Q}{m} \Rightarrow Q = mL_V.$$

Questions2: Water kept in earthern pots gets cooled. Why?

Ans: Water molecules moves out through the minute pores in the earthern pot. When these water molecules come in contact with air, they evaporate by absorbing heat from the water in the pot. So water in earthern pots get cooled.

Problem5: Find out the work done to convert **10g** of ice at **-5 ^{0}C** to steam at **100^0**. Specific heat capacity of ice is **2100J/kg K**, specific latent heat of fusion of ice is **336x10^{3}J/kg**, Latent heat of vaporisation of steam is **2250x10^{3}J/kg** and specific heat capacity of water is **4200J/kg K**.

Soln:

Modes of Heat transfer

There are three distinct modes of heat transfer.

i. Conduction
ii. Convection
iii. Radiation

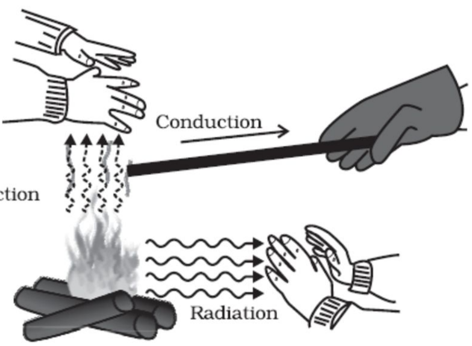
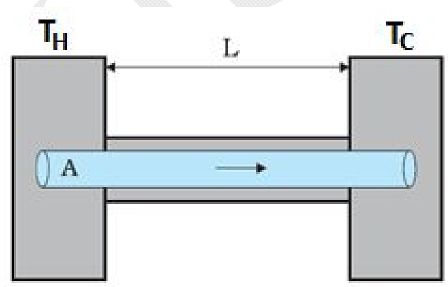


Fig. 11.13 *Heating by conduction, convection and radiation.*

Conduction

Conduction is the transfer of heat between two adjacent parts of a body because of their temperature difference.



$T_H \rightarrow$ Temperature of hot reservior
$T_C \rightarrow$ Temperature of cold reservior

The rate of flow of heat (H) is directly proportional to the temperature difference (T_H-T_C) and the area of cross section A and is inversely proportional to the length L:

$$H = KA\left(\frac{T_H - T_C}{L}\right)$$

$K \rightarrow$ Thermal conductivity of material.

SI unit of thermal conductivity is $JS^{-1}M^{-1}K^{-1}$

Question3: Which is the best thermal conductor?

Ans: - Silver

Question4: Why cooking pots have copper coating on the bottom?

Ans: - Copper is a good conductor of heat. So heat is uniformly distributed over the bottom of the pot.

Question5: Why people usually prefer to give a layer of earth insulation on the ceiling during hot summer days?

Ans: - Concrete roofs get very hot during summer days. Layer of earth has very low thermal conductivity than concrete. Therefore layer of earth reduce heat transfer and keeps the room cooler.

Question6: A brass tumbler feels much colder than a wooden tray on a chilly day. Why?

Ans: Brass has greater conductivity than wood. So when we touch a brass tumbler, it absorbs more heat from our body. So it feels much colder than wood.

Questions7: All thermal conductors are electrical conductors also." Do you agree with this statement? If your answer is No, clarify it.

Ans:

No. Mica is a good conductor of heat but it is a bad conductor of electricity.

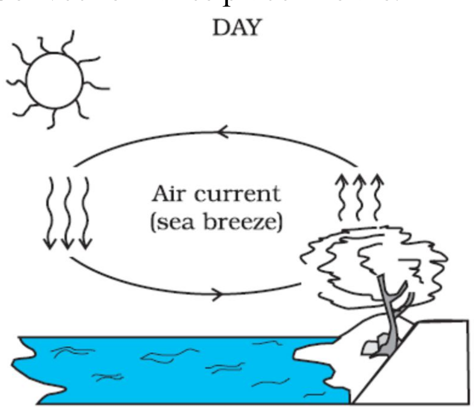
Convection

Convection is the mode of heat transfer by actual motion of matter. Convection is possible only in fluids.

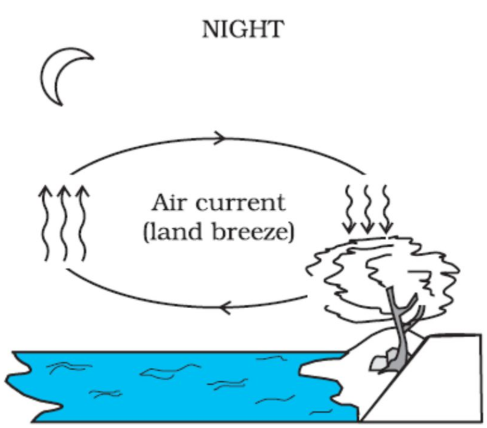
Eg: - When water in a vessel is heated from the bottom, the hot water moves up.

Wind is another example for convection.

Convection takes place in stars.



Land warmer than water



Water warmer than land

Radiation

Radiation is the mode of heat transfer without the need of any material medium.

Heat radiation can propagate through vacuum with a speed of $\mathbf{3\times10^8 m/s}$.

Note: -

Black bodies absorb and emit radiation better than bodies of lighter colours.

Applications: -

1. We wear white or light coloured clothes in summer so that they absorb least heat from the sun.
2. During winter we use dark coloured clothes which absorb more heat from the sun and keep our body warm.
3. The bottoms of the utensils for cooking food are blackened so that they absorb maximum heat from the fire and give it to the food materials.

Newton's Law of cooling

According to Newton's law of cooling, the rate of loss of heat, $\frac{-dQ}{dt}$ of a body is directly proportional to the temperature difference $\Delta T = T_2 - T_1$ between the body and the surroundings.

$$\frac{-dQ}{dt} = K(T_2 - T_1)$$

$K \rightarrow$ is a positive constant depending on the area and nature of the surface of the body.

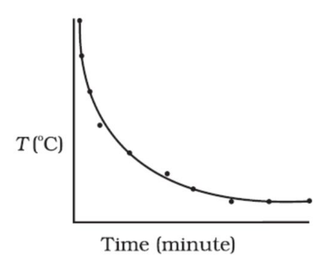
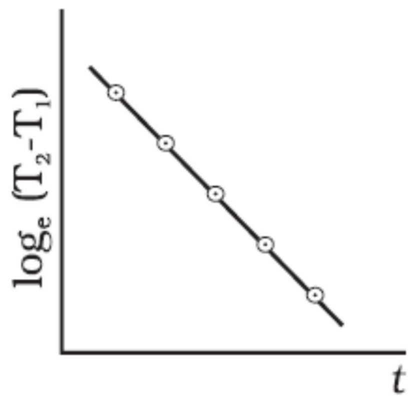


Fig. 11.18 Curve showing cooling of hot water with time.

From the graph we can see that cooling is faster initially,
then the speed of heat loss decreases.



Question8: (a) You are in a restaurant waiting for your friend and ordered coffee. It has arrived. Do you add sugar in your friend's coffee and then wait for him or do you add sugar after he arrives? Explain with respect to the concept of cooling.

Ans: For the coffee to be hotter when the friend arrives, the better option is: **first mix sugar and then wait for the friend**. When we mix sugar with coffee the temperature of the coffee decreases. So according to Newton's law of cooling the rate of loss of heat decreases.