Heat

Nature of Heat:

Heat is the transfer of energy (every in transit) from one body to another due to the temperature difference between the two bodies. When the body absorbs the heat, its internal energy increases and when it losses heat, its internal energy decreases.

Temperature:

Definition:

“Temperature is the degree of hotness or coolness of a body “.

OR

“The measurement of average translational kinetic energy of the molecules is called temperature “.

Thermometer:

Definition:

An instrument which is used for the measurement of temperature is called the nanometer. Any property of a substance which changes uniformly with temperature can be used to measure the temperature.

Temperature scales:

The three scales commonly used to measure the temperature are:

i. Centigrade or Celsius scale.

ii. Kelvin's or absolute scale.

iii. Fahrenhelt scale.

1. Centigrade or Celsius scale, in the melting point of ice is taken as $0^{o}C$ and boiling point of water is taken as $100^{o}C$. The interval between them is divided into 100 equal parts. Each part is called one degree centigrade which is written as $1^{o}C$.

2 The lowest temperature which can be reached is $-273^{o}C$. This temperature is taken $0^{o}C$ on Kelvin's scale. The size of the degree on the scale is also same as that on centigrade scale.

3 In Fahrenheit scale, the melting point of ice is taken as $32^{o}C$ and boiling point of water is taken as 212^{o}, and the internal given then is divided into 180 parts. Each part is called one degree. Fahrenheit which is written as $1^{o}F$.

Temperature Scales

Fahrenheit	Celsius	Kelvin	
212	100	373	Boiling point of water at sea-level
194	90	363	
176	80	353	
158	70	343	
140	60	333	
122	50	323	
104	40	313	
86	30	303	
68	20	293	Average room temperature
50	10	283	
32	0	273	Melting (freezing) point of ice (water) at sea-level
14	-10	263	
-4	-20	253	
-22	-30	243	
-40	-40	233	
-58	-50	223	
-76	-60	213	
-94	-70	203	
-112	-80	193	-89°C (-129 °F) Lowest recorded temperature. Vostok, Antarctica July, 1983
-130	-90	183	
-148	-100	173	

Reference: Ahrens (1994)

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Inter Conversion of Scale:

The conversion of temperature in centigrade (Tc) into the temperature in Kelvin (Tk) is performed by the relation.

Celsius to Kelvin:

$$K = {}^{\circ}C + 273.$$

$$T_k = T_c + 273$$

$$\text{OR } T_c = T_k - 273$$

Temperature in Fahrenheit (Tf) is converted into temperature in centigrade (Tc) by the formula.

Fahrenheit to Celsius:

$${}^{\circ}C = ({}^{\circ}F - 32) / 1.8$$

$$T_f = 9/5\,(T_c) + 32$$

$$T_c = 5/9\,(T_f - 32)$$

Ordinary Liquid in Glass Thermometer:

It consist of a glass slem with a capillary tube having a small bulb at one end. The bulb end part of the capillary tube is filled with liquid (mercury or alcohol). The upper end of the capillary tube is sealed to prevent the liquid from evaporation. Air is reserved from the upper end before sealing , when the bulb is sealed , the mercury expands and rise in the capillary tube. The stem is calibrated in degrees to measure the temperature. The thermometer used in the laboratory has a range from – $10^{o}c$ to $110^{o}C$.

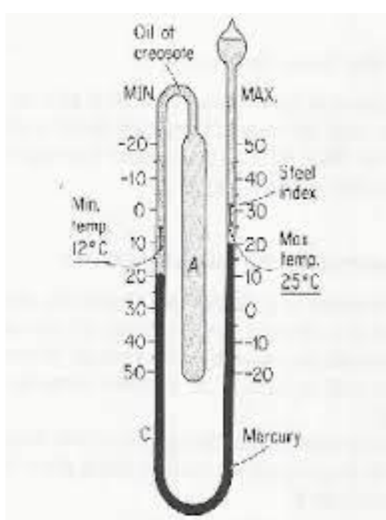
Fig. 10.

Clinical thermometer:

Clinical thermometer is used to measure the temperature of human body. The normal body temperature is about 98.4oF. The bulb of the thermometer is placed under the tongue to measure the temperature of a body. The clinical thermometer has a narrow bend or construction in its capillary tube bore near the bulb to prevent the mercury level from falling when the bulb is removed from the patient's mouth.

Maximum and Minimum Thermometer:

The purpose of this thermometer is to read maximum and minimum temperature reached over a period of time. It consist of a bulb A continuously alcohol is connected through a U shaped tube from B to C (containing mercury) to a second bulb D nearly full with alcohol. Above D, the space is evacuated. Left limb of U-shaped tube is calibrated according to the expansion of alcohol in AB. The right limb of U-tube is also calibrated. So that both mercury surfaces point to the same member. If mercury in AB contracts, the pressure in CD well drive the mercury back. On each mercy surface, there is a small iron index provided with a spring. Due to fall in temperature the alcohol in A contracts and the left index moves up and is left there. Due to rise in temperature, the alcohol in A expands and the right index moves and is left there. The lower end of left index gives minimum temperature and the lower end of right index gives maximum temperature over a period of time. The indices are brought in contact with mercury by using small bouquet.



Transfer of Heat:

There are three ways by which heat is transferred from one place to another. They are

i. Conduction.

ii. Convection.

iii. Radiation.

Conduction:

Definition:

"The process in which heat is transferred from one place to another by the vibration and collision of molecules or atoms, called conduction."

Explanation:

When the heat is provided to one end of the heat conductor. Its temperature rise which increase the kinetic energy of the molecules. Due to increase kinetic energy, molecules start vibration with greater amplitude and make collision with neighboring molecules. This collision causes the transference of energy from molecule to molecule. In this way that is transferred from one end to other.

Example:

Solid heat conductor transfer heat by the process of conductor.

Convection:

Definition:

The process, in which heat is transferred from one place to another by the actual motion of molecules, is called convection. Since the molecules of liquids and gases are free to more, therefore in liquid and gasses heat is transferred from one place to another by convection.

Example:

In fluid (liquids and gasses) heat is transferred by the process of convection.

Radiation:

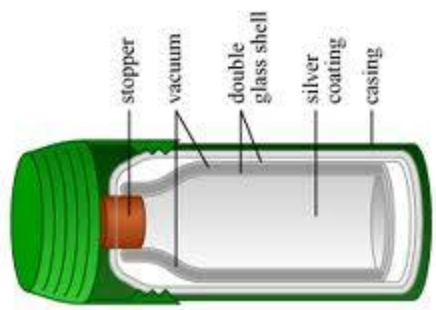
Definition:

The process in which heat is neither transferred by the vibration and collision neither of molecules, nor by the actual motion of molecules but it is transferred without any material medium, is called Radiation. In this process hot body radiates energy in the form of electromagnetic waves.

Heat reaches from sun to earth, by radiation.

Thermos Flask:

It is used to maintain constant temperature. A thermos flask consists of a double walled glass. The inner surface of the outer wall and the outer surface of the inner wall are polished (silvered). The space between to the two walls is evacuated and then sealed. The vacuum between the two walls reduces the probability of transfer of heat by conduction and convection.



Thermal Conductivity:

Definition:

The ability of a substance to conduct heat energy is called thermal conductivity. Consider a metal block of length ΔL and the cross section area A, Such that it one end is constantly maintained at lower temperature T_1 and other end at a higher temperature T_2. If ΔQ heat is conducted from hot end to the cold end in □ t second, then it is found that.

i. Heat is proportional to the cross sectional area

$$\Delta Q \propto A.$$

ii. Heat is proportional to the difference of the temperature.

$$\Delta Q \propto \Delta T \text{ OR } \Delta Q \propto (T2 - T1)$$

iii. Heat is proportional to the time of the flow.

$$\Delta Q \propto \Delta t$$

iv. Heat is inversely proportional to the length

$$\Delta Q \propto 1 / \Delta L$$

Combining them, we get: $\Delta Q \propto (\boldsymbol{A}(\boldsymbol{T_1} - \boldsymbol{T_2})\Delta \boldsymbol{t})/\Delta \boldsymbol{L}$

$$\Delta Q = K(\boldsymbol{A}(\boldsymbol{T_1} - \boldsymbol{T_2})\Delta \boldsymbol{t})/\Delta \boldsymbol{L}$$

$$\Delta Q = K(\boldsymbol{A}\Delta \boldsymbol{T}\Delta \boldsymbol{t})/\Delta \boldsymbol{L} \qquad \textbf{where } \Delta \boldsymbol{T} = (\boldsymbol{T_1} - \boldsymbol{T_2})$$

The constant K is called thermal conductivity of the material of rod. Different materials have different value for K. (i.e. if we take 1 meter cube of the substance)

If ΔL = 1m , A = $1m^2$, $\Delta T = 1^{o}C$, $\Delta t = 1$ *second*, substituting these values

$$\Delta Q = K \times 1 \times 1 \times 1 \text{ or } \Delta Q = K$$

It shows that, "the thermal conductivity is the quality of heat conducted per second per meter cube of a substance whose opposite faces are maintained at a temperature difference of $1^{o}C$ ".

Thermal Expansion:

Definition:

Increase in the size of the object due to heat is called thermal expansion.

Thermal Expansion in Solid:

When solid is heated its temperature rises and its molecules start vibrating with greater amplitude. Due to this, the average distance between the molecules increases and the solid expands.

There are two expansions in solids.

i. Linear thermal expansion. ii. Volumetric thermal expansion.

Linear Thermal Expansion:

Definition:

" Increase in the length of the rod due to heat is called linear thermal expansion."

Consider a metal rod having length L, when the temperature is increased by $\Delta \boldsymbol{T}$, let the increase be $\Delta \boldsymbol{T}$. It is found that,

$$\Delta \boldsymbol{L} \propto \Delta \boldsymbol{L_1}$$

$$\Delta \boldsymbol{L} \propto \Delta \boldsymbol{T}$$

Combining them, we get:

$$\Delta \boldsymbol{L} \propto \Delta \boldsymbol{T} \boldsymbol{L_1}$$

$$\Delta \boldsymbol{L} = \alpha \, \Delta \boldsymbol{T} \boldsymbol{L_1}$$

$$\alpha = \frac{\Delta \boldsymbol{L}}{\Delta \boldsymbol{T} \boldsymbol{L_1}}$$

Where "α " is the coefficient of linear expansion. It can be written as:

It shows that, change in length per unit length per degree rise in temperature is called coefficient of linear expansion.

Consider

$$\Delta \boldsymbol{L} = \alpha \, \Delta \boldsymbol{T} \boldsymbol{L_1}$$

But $\Delta L = L_2 - L_1$ & $\Delta T = T_2 - T_1$

$$L_2 - L_1 = \alpha \, L_1 (T_2 - T_1)$$

$$L_2 = L_1 + \alpha \, L_1 (T_2 - T_1)$$

$$L_2 = L_1 \{1 + \alpha \, (T_2 - T_1)\}$$

It gives the final length after the rise in temperature.

Volume Thermal Expansion:

Definition:

"Increase in volume of the object (space /cube) due to heat is called volumetric thermal expansion."

Consider an object having volume V1. When the temperature is increased by ΔT, let the

Increase by ΔV., it is found that,

$$\Delta V \propto V_1$$

$$\Delta V \propto \Delta T$$

Combining them, we get

$$\Delta V \propto V1 \, \Delta T$$

$$\Delta V = \beta \, V_1 \, \Delta T$$

Where “” is the coefficient of linear expansion. Above equation can be written as:

$$.\beta = \frac{\Delta V}{V_1 \Delta T}$$

It shows that, “change in volume per unit volume per degree rise in temperature is Called coefficient of volumetric expansion.

Consider:

$$\Delta V = V_1 \Delta T$$

But $\Delta V = V_2 - V_1$ & $\Delta T = T_2 - T_1$

$$V_2 - V_1 = V_1 (T_2 - T_1)$$
$$V_2 = V_1 + V_1 (T_2 - T_1)$$
$$V_2 = V_1 \{1 + (T_2 - T_1)$$

It gives the final volume after the rise in temperature.

Relation Between Coefficients of Linear And Cubical Expansions:

The coefficient of volumetric (cubical) expansion is three times the coefficient of linear expansion. i.e.

$$\beta = 3\,\alpha$$

Bimetallic strips:

Two metals of slightly different coefficient of thermal expansitives combined together to form bimetallic strips when this strips is heated, it bend.

Bimetal strips:

In bi metal thermometer the bimetallic strips is in the form of long spiral whose one end is fixed and other end is connected to a pointer. When temperature raises the spiral get into lighter position due to different nature of two metals. Due to this pointer moves over a scale and gives the temperature.

Thermostat:

A device which is used to maintain the constant temperature is called thermostat. It is used in refrigerator, air conditioner, electric oven etc. to control the temperature.

Fire Alarm:

The bimetallic strip is also used in fire alarm. Due to fire when the temperature rises, the bimetallic strip bends and touches the contact due to which the current flows and either the bulb glows or the bell rings giving the warning about life.

Thermal Expansion of Liquid:

Liquid do not have definite shape. Therefore, there is only one expansion in case of Liquids. This is called volumetric expansion.

Real and apparent expansion:

When a liquid in a vessel is heated, not only the liquid expands but the vessel also expands. Thus the observed increase in volume of liquid is not the actual increase in volume of the liquid because we should consider the increase in volume of the vessel.

Thus,

Real expansion = apparent expansion + expansion of the vessel.

Anomalous expansion of water:

When water is heated from 0^oC to 4^oC the water does not expand but it contracts and its density increase. When water is further heated from 4 to 100^oC, its volume increases and density decreases. Since volume decreases when the temperature is raised from 0^oC to 4^oC. Therefore when temperature is lowered from 4^oC to 0^oC the volume increases. This is called anomalous expansion of water.

Effect of anomalous expansion of water:

i. In winter season:

At 0oC the surface water of ponds, lakes freezes to ice but at the bottom the temperature of water remains at 4oC, this helps fish and other forms of marine life to survive in winter season. In winter season the water supply pipe lines burst when the temperature falls below at 4oC. Below 4oC, the water expands and causes the pipeline to burst.

ii. In rainy season:

Lot of water seeps through cracks in rocks, in winter this water expands on freezing and exerts very high pressure raising the rocks to breaks.

Thermal expansion in gasses:

Gasses also expand on heating. For example, in summer when the temperature is very high the tubes of bicycles get burst. Due to very high temperature the air in the tube expands and exerts very high pressure on the walls of the tube, causing it to burst.

Gas laws:

There are four fundamental quantities, pressure, volume, temperature and mass to explain the behavior of gasses. The relation ship between these quantities.

Boyle's Law:

Statement # 1:

"When mass and temperature of a gas are kept constant, the volume of a given mass is inversely proportional to the applied pressure."

Statement #2:

"When mass and temperature of a gas are kept constant, the product of pressure and volume always remains constant."

Statement #3:

If 'P' is the applied pressure and 'V' is the volume then mathematically Boyle's law is given as:

$$V \propto 1/P$$

$$V = \text{constant} \times 1/P$$

$$PV = \text{constant}$$

If 'P_1' and 'V_1' are the initial pressure and initial volume.

$$P_1V_1 = K \ldots\ldots\ldots\ldots.1$$

If "P_2' and 'V_2' are the final pressure and final volume.

$$P_2 V_2 = K \ldots\ldots\ldots\ldots 2$$

Equating 1 and 2

$$P_1V_1 = P_2V_2$$

Charle's law:

When mass and pressure are kept constant, the volume of a given mass of gas is directly proportional to the absolute temperature.

Mathematical form:

If 'V" is the volume and 'T' is the temperature then mathematically Charle's law given are:

$$V \propto T$$

$$V = KT$$

$$V/T = K$$

If 'V_1' and 'T_1' are the initial pressure, volume temperature.

$$\frac{V_1}{T_1} = K \text{ ……………………1}$$

If 'V_2' and 'T_2' are the initial pressure, volume and temperature.

$$\frac{V_2}{T_2} = K \text{ ……………….. 2}$$

Equating 1 and 2

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

Pressure law:

Statement:

When mass and volume of a gas are kept constant, the pressure of given mass of a gas is directly proportional to the absolute temperature.

Mathematical form:

If 'P' is the pressure and 'T' is the absolute temperature then mathematically it is given as

$$P \propto T$$

$$P = \text{constant } T$$

$$\frac{P}{T} = \text{constant}$$

General gas equation:

Definition:

The combine mathematical form of Boyle's law and Charle's law is called general gas equation:

From Boyle's law $PV = K$ …………………i

From Charle's law $V/T = R$ ………………ii

Combining 1 and 2 $\frac{PV}{T} = K$ ………….1

If 'P_1' , 'V_1 ' and 'T_1' are the initial pressure , volume and temperature.

$$\frac{P_1V_1}{T_1} = K\text{…………1}$$

If 'P2' , 'V2' and 'T2' are the initial pressure, volume and temperature.

$$\frac{P_2V_2}{T_2} = K$$

Combining 1 and 2

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

If we take the mass of the gas as 1 mole, can be written as

$$\frac{PV}{T} = R$$

Where 'R' is the universal gas constant and has a value R = 8.313 J / mol
For 'n' no of moles

$$\frac{PV}{T} = nR$$

This is called general gas equation.

$$PV = nRT$$

Specific Heat:

Definition:

Amount of heat required to raise the temperature of 1kg of a substance by 1K or $1^{o}C$ is called specific heat. OR
Amount of heat per unit mass per degree rise in temperature is called specific heat.
Mathematical form:
Mathematically is given as: $C = \frac{\Delta Q}{m\Delta T}$
Where C = specific heat
ΔQ = amount of heat supplied.
m = mass of substance
ΔT = rise in temperature
Above equation can also be written as $Cm\Delta T = \Delta Q$

$$\Delta Q = Cm\Delta T$$

$$\Delta Q = Cm\,(T_2 - T_1)$$

Unit:

The unit of specific heat is J/kgC or j/Kg K

Law of heat exchange:

Heat always from hot body to cold body but the total amount of energy remains same. OR "Heat lost by hot body is equal to the heat gained by cold body".
Thus:

Heat Loss = Heat Gain

Measurement of specific heat of solid:

An instrument which is used for the measurement of heat is called calorimeter. It is a copper vessel enclosed in a wooden box insulating material in between. The vessel is covered by a wooden lid with a hole for the thermometer and another hole for stirrer to stir the contents of the calorimeter.
The specific heat of solid say zinc can be determined as explained below:
Mass of calorimeter = mc
Mass of calorimeter + water = M
Mass of water = mw = M - mc
Mass of zinc = m
Initial temperature of cal = T_1
Initial temperature of zinc = T_2
Final temperature of mixture = T_3
Specific heat of calorimeter = Cc
Specific heat of water = Cw

Specific heat of zinc = C

According to law of heat exchange Heat lost by = heat gained by

Hot zinc calorimeter + water

$$\mathbf{Cm(T_2 - T_3) = Cc\ mc\ (T_3 - T_1) + Cw\ mw\ (T_2 - T_1)}$$

$$C = \frac{\mathbf{Cc\ mc\ (T3 - T1) + Cw\ mw\ (T2 - T1)}}{\mathbf{m(T2 - T3)}}$$

Above relation is used to determine the specific heat of zinc.