Chapter Thermometry and Thermal Expansion

Day - 1

CLASSIFICATION OF THERMAL PHYSICS

- (1) Thermometry and Thermal Expansion
- (2) Calorimetery
- (3) Thermodynamics (First law and Second Law)
- (4) Kinetic Theory of Gases
- (5) Heat transfer
  - Conduction
  - Convection
  - Radiation

THERMOMETRY

Process to measure the temperature

THERMOMETER

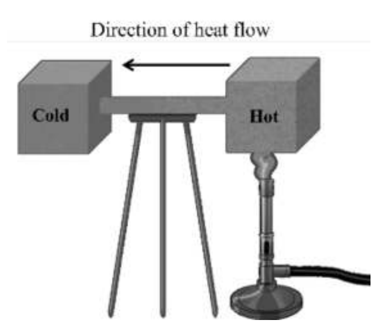
Device use to measure the temperature

TEMPERATURE

(1) Degree of hotness or coldness

(2)It determines the direction of flow of heat. Heat flow from higher temperature to lower temperature.

(3) Average kinetic energy of gas molecule $K_{av} = \frac{3}{2}kT$ Here T is absolute temperature, K is Boltz man's constant



TEMPERATURE SCALES

(1) Degree Celsius (^oC)

(2) Fahrenheit Scale (^oF)

(3) Kelvin Scale (K)

$$\frac{C}{5}=\frac{F-32}{9}=\frac{K-273}{5}=\frac{R}{4}=\frac{R_a-492}{9}$$

(4) Reaumer Scale (R)

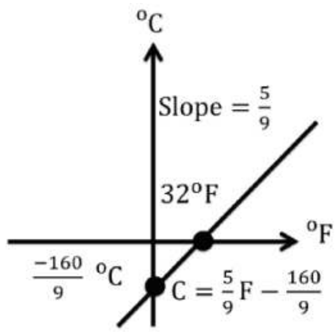
(5) Rankine Scale (Ra)

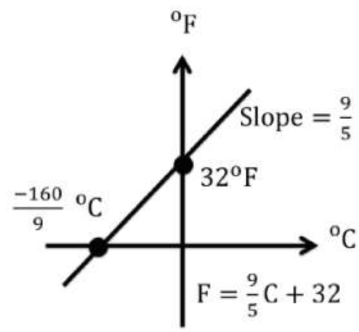
(6) Minimum passible temperature in nature is 0 K. In K scale negative reading is not possible.

(7) More correctly C^o + 273.15 K

Applications

(1) Graphically ^oC Vs ^oF





TEMPERATURE DIFFERENCE

$\Delta C = C_1 - C_2$

$$\Delta F = ?$$

$$\frac{C_1}{5}=\frac{F_1-32}{9}$$

$$\frac{C_2}{5}=\frac{F_2-32}{9}$$

Subtract these equation

$$\frac{C_1-C_2}{5}=\frac{F_1-F_2}{9}$$

$\frac{\Delta C}{5}=\frac{\Delta F}{9}$

$$\Delta C = C_1 - C_2$$

$$\Delta K = ?$$

$$C_1 + 273 = K_1$$

$$C_2 + 273 = K_2$$

$$C_1 - C_2 = K_1 - K_2$$

$$\Delta C = \Delta K$$

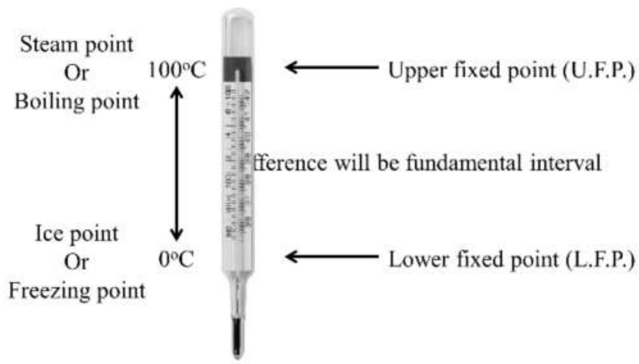
Difference in ^oC will be exact similar to difference in K Scale

FAULTY THERMOMETER

Faulty thermometer gives wrong reading

$$\frac{\mathrm{x - L.F.P}}{\mathrm{F.I.}} = \frac{\mathrm{y - L.F.P.}}{\mathrm{F.I.}}$$

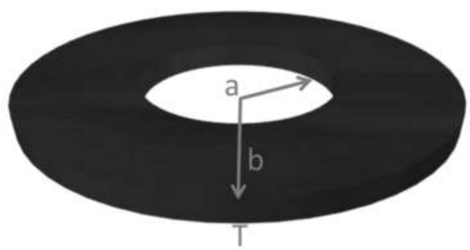
Here if x correct reading then LFP and FI will correspond to correct Thermometer and if y is wrong reading then LFP and FI will correspond To Faulty thermometer.

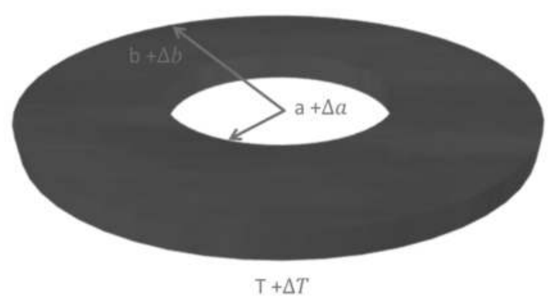


ZEROTH LAW OF THERMODYNAMICS

This fundamental law states that if two bodies A and B are separately in thermal equilibrium with a third body C, then A and B are in thermal equilibrium with each other

CASE-1 CAVITY





CASE-2 Effect of temperature on apparent weight when immersed in a liquid

$Wapp = Wair - F_{upthrust}$

$= V\sigma g - V\rho g$

$F_{upthrust} \propto V\rho$

$\frac{F'}{F} = \frac{V'\rho'}{V\rho} = \left(\frac{V+\Delta V}{V}\right) \left(\frac{1}{1+r_L\Delta T}\right)$

$\frac{F'}{F} = \left(\frac{V + r_S V \Delta T}{V}\right)\left(\frac{1}{1 + r_L \Delta T}\right)$

$F' = F\left(\frac{1 + r_S \Delta T}{1 + r_L \Delta T}\right)$

$if\ r_S > r_L,\ F' > F \Rightarrow Wapp < Wapp$

$if\ r_S < r_L,\ F' < F \Rightarrow Wapp > Wapp$

$if\ r_S = r_L,\ F' = F \Rightarrow Wapp = Wapp$

Case:-3 Effect of temperature on immersed fraction of a solid in floating condition

$W = F_{upthrust}$

$V\rho_S g = V_i \rho_L g$

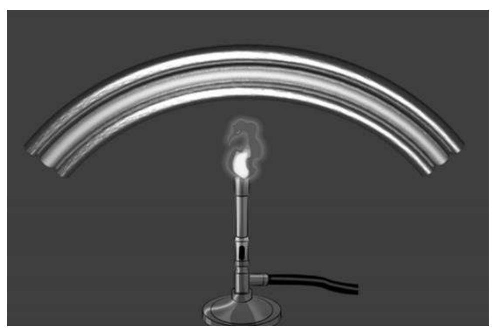
$\frac{V_i}{V} = \frac{\rho_S}{\rho L} = f$ (fraction and solid immersed)

$f' = \frac{\rho_S'}{\rho_L'}$

$\frac{f'}{f} = \left(\frac{\rho_S'}{\rho_S}\right)\left(\frac{\rho_L}{\rho_L'}\right)$

$\frac{f'}{f} = \left(\frac{1 + r_L \Delta T}{1 + r_S \Delta T}\right)$

Case-4



CONSTANT –VOLUME AIR THERMOMETER

$P_{100} = P_0[1 + (\beta \times 100^oC)]$

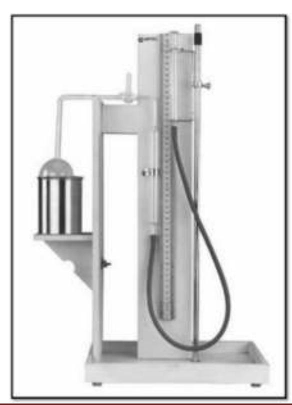
$Pt = P_0\,(1 + \beta\, t)$

Where β is coefficient of pressure expansions. From eq. (i) we have

$\beta = \frac{P_{100} - P_0}{P_0 \times 100^o C}$

β Can be calculated from eq. Now, from Eq. we have

$$t = \frac{P_t - P_0}{P_0 \times \beta}$$



Substituting the value of β from eq. (iii) we have

$$t = \left(\frac{P_t - P_0}{P_{100} - P_0}\right) \times 100^oC$$

MERITS OF GAS THERMOMETER

1. Gas thermometer is more sensitive than liquid thermometer because the expansion Of gases is many times greater than that of any liquid.
2. The expansion coefficient of all gases is nearly the same. hence thermometers employing different gases give same readings.
3. As compared to liquid thermometers, a gas thermometer is capable of measuring very low as well as very high temperatures. For example, mercury thermometer can measure from -30°C to 300°C, while hydrogen gas thermometer can measure from -200°C to 500°C.

DEMERITS OF GAS THERMOMETER

1. Its use is inconvenient due to its very large size.
2. For measuring temperature it is necessary to know the atmospheric pressure which changes with time and places. Hence gas thermometer cannot be marked in degrees.

Due to these demerits the gas thermometer is used only as a standard thermometer for the calibration of other thermometers.

STANDARD CONSTANT VOLUME GAS (HYDROGEN) THERMOMETER

$$\beta = \frac{P_{100} - P_0}{P_0 \times 100^0C} = \frac{P_t - P_0}{P_0 \times t}$$

$$t = \left(\frac{P_t - P_0}{P_{100} - P_0}\right) \times 100^0C$$

PLATINUM RESISTANCE THERMOMETER

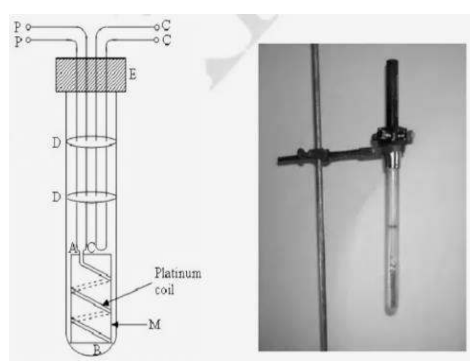
If R_0 and R_{100} be the resistance of the plating wire at 0°C and 100°C respectively, then According to the formula $R_t = R_0\,(1+ \alpha \times 100^oC)$

$$R_{100} = R_0\,(1 + \alpha \times 100^oC)$$

$$\alpha = \frac{R_{100} - R_0}{R_0 \times 100^0C}$$

If the resistance at the unknown temperature t be R_t then

$$R_t = R_0\,(1 + \alpha\, t)$$

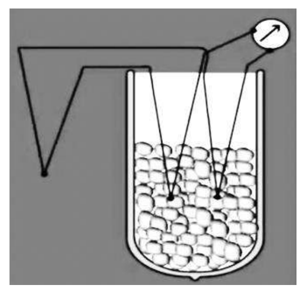


$$t = \frac{R_t - R_0}{R_0 \times \alpha}$$

$$t = \frac{R_t - R_0}{R_{100} - R_0} \times 100^oC$$

ADVANTAGE

1. Its use is easier than that of a gas thermometer.
2. It gives a precise measurement of temperature because the resistance of the wire can be measured with high accuracy.
3. It has a wide range from -200^{o}C to 1200^{o}C.
4. It is quite sensitive. Its sensitivity is 0.01^{o}C upto 600^{o}C and 0.1^{o}C upto 1200^{o}C.
5. It is free from change of zero as pure and annealed platinum wire has always the same resistance at the same temperature.
6. This thermometer, once calibrated with standard hydrogen thermometer, can be used as a reliable thermometer.
7. The thermo –couple thermometer has a small thermal capacity so that it rapidly attains the temperature of the experimental body. Hence it can be used to measure varying temperatures.
8. It has a wide range from -200^{o}C to 1600^{o}C.
9. It can be used as a direct –reading instrument.
10. It is cheap and can be easily designed.



DISADVANTAGE

1. This thermometer has a large thermal capacity so that it takes appreciable heat from the experimental body. Hence the measured temperature is slightly lower than the actual temperature of the body.
2. The tube of this thermometer has a low thermal conductivity. Therefore it takes time to acquire the temperature of the experimental body. Moreover, some time is taken in measuring resistance by Wheatstone bridge. Hence temperature cannot be measured quickly.
3. Through the melting point of platinum is 1800^{o}C, yet temperatures higher than 1200^{o}C cannot be measured by a platinum thermometer. The reason is that at higher temperature the platinum begins to vaporizes, resulting in considerable change in the resistance of the wire.

Thermo –couple Thermometer

$E = at + bt^2$

If the temperature of the hot junction is sufficiently below the neutral temperature, then The graph between E and t can be considered a straight line. Then

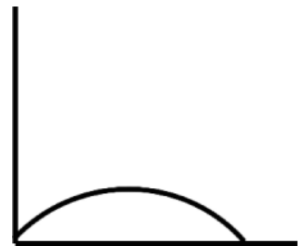
E =at

$$E_{100} = a \times 100^{o}C$$

$$E_t = a \times t$$

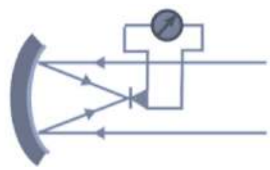
$$\frac{E_t}{E_{100}} = \frac{t}{100^{o}C}$$

$$\therefore \quad t = \frac{E_r}{E_{100}} \times 100^{o}C$$



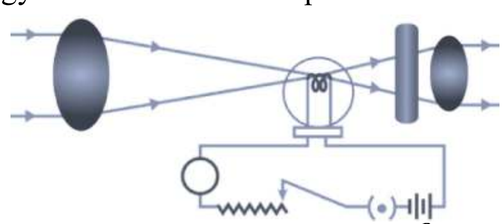
Total radiation pyrometer

The main advantage of this thermometer is that the experimental hot body is not kept in Content with it. Hence there is no definite higher of its temperature –range. It can measure temperature from 800^{o}C to 3000^{o}C -4000^{o}C. However, it cannot be used to measure temperature the emission of radiation is so poor that if cannot be measured accurately.

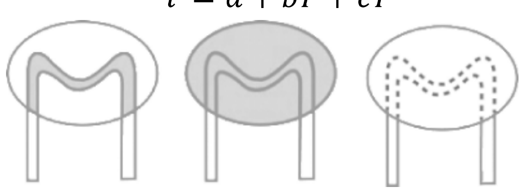


OPTICAL PYROMETER

For the radiation emitted from a hot body, the product of the wavelength λm of the radiation having maximum energy and the absolute temperature T of the hot body is constant



$$i = a + bT + cT^2$$



RANGE OF DIFFERENT THERMOMETERS

Thermometer	Lower limit	Upper limit
Mercury thermometer	-30^{o}C	300^{o}C
Gas thermometer	-268^{o}C	1500^{o}C

Platinum resistance thermometer	-200°C	1200°C
Thermo –couple thermometer	-200°C	1600°C
Radiation thermometer	-800°C	No limit
Disappearing –filament Thermometer	600°C	2700°C

Example. A scientist proposes a new temperature scale in which the ice point is 25 X (X is the new unit of temperature) and the steam point is 305 X. The specific heat capacity of water in this new scale is (in $Jkg^{-1} X^{-1}$):

(a) 4.2×10^3 (b) 3.0×10^3

(c) 1.2×10^3 (d) 1.5×10^3

Solution: Given, 305 X -25 X = 100°C

(∵ X is the new unit of temperature)

(305 -25) X = 100°

⇒ 1°C = 2.8 X

The specific heat capacity of water

$$= 4200 \frac{J}{kg \circ C} = 4200 \times \frac{J}{kg \times 2.8\ X}$$

= 1500 J / kg –X

$= 1.5 \times 10^3\ J\ kg^{-1}\ X^{-1}$