

# Measurement of Pressure

## 2.1 Introduction:

Measurement of pressure is of considerable importance in process industries. The no. of instruments available for measurement of pressure are much larger than the instruments available for other types of measurements. Pressure is defined as the force per unit area exerted by the fluid, on the wall of container. The forces that arise  $\therefore$  of the strains in solids are denoted as stresses. So, pressure measurement is limited to fluid systems only. The instruments used in measurement of pressure may be mechanical, electrical or electronic.

### 2.1.1. Manometer:

Manometer is the simplest & well known gravitational type of mechanical device. It is also called a liquid column manometer & is used for low differential pressure measurement. The usual range of pressure that falls for this device is used for most cases as it is very simple in construction & highly accurate of all the types. Basically there are two types of Manometers.

1. U-Type Manometer
2. Well-Type Manometer

#### 1) U-Type Manometer:

Let  $d_m$  = Manometric fluid density

$d_l$  = Density of fluid over manometer

$P_1$  = Gas pressure

$P_2$  = Atmospheric pressure

If  $d_l \ll d_m$ , the differential pressure can be defined by the relation:

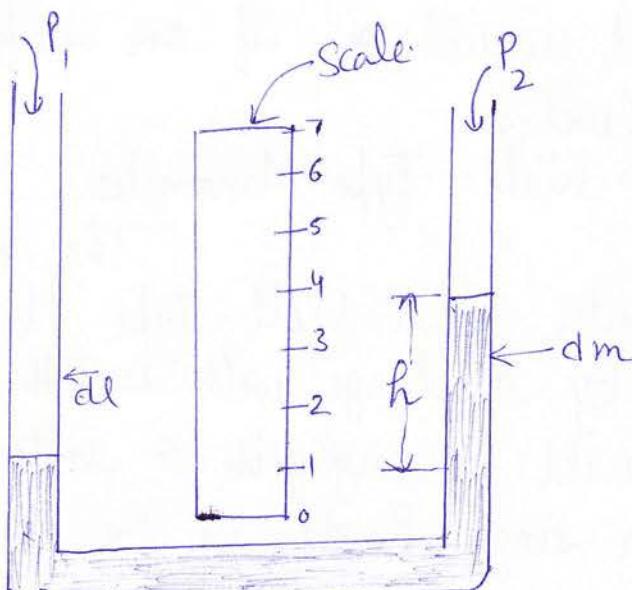


Fig. 2.1 Schematic diagram of U-Type Manometer

$$P_1 - P_2 = h(dm - dl) \quad \dots (2.1)$$

An enhanced version of a manometer is shown in Fig. 2.2 with a seal liquid over the manometer liquid to separate the process fluid from the manometer fluid for any probable source of trouble like absorption, mixing or explosion & so on. Seal pots with large diameter are also placed for ~~ring~~ the range.

The  $= n$  for measurement of differential pressure is

$$P_1 - P_2 = h(dm - dl) \quad \dots (2.2)$$

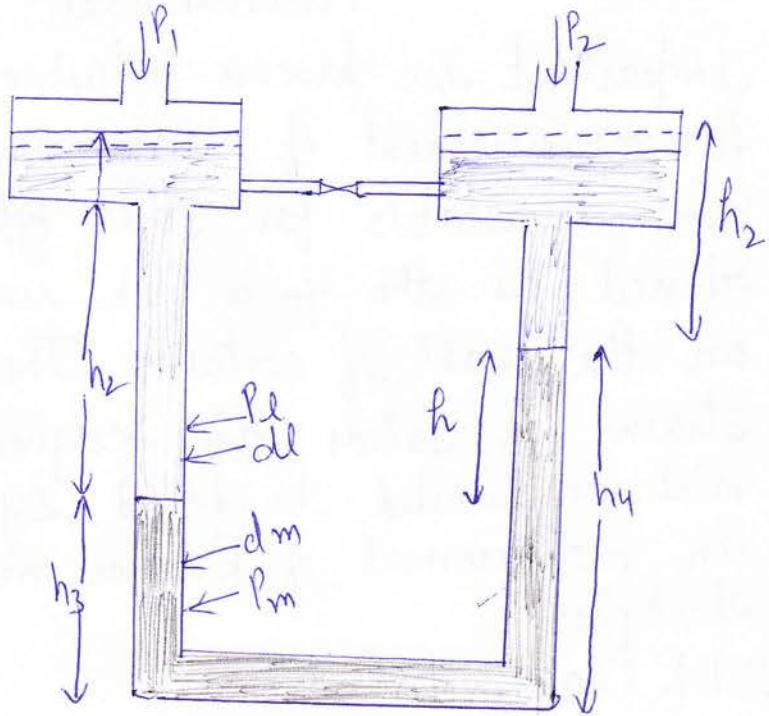


Fig. 2.2 U-Type Manometer with Large Seal pots.

Advantage of U-Type Manometer:

The U-Type Manometer is the simplest form of manometers & is used for experimental work in laboratories.

Limitation: There is no fluid reference in U-type Manometer. This tends to the measurement of the height more difficult than it would be if one surface could be maintained at some fixed level.

⇒ Well-Type Manometer:

The main difference b/w a U-Type Manometer & a Well-Type Manometer is that U-tube is substituted by a large well such that the variation the level in the well will be negligible & instead of measuring a differential height, a single height in the remaining column is measured. If  $a_1$  &  $a_2$  are areas of the well & capillary, & if  $(h_1 - h_2)$  is the difference in height in the well due to pressure difference  $(P_1 - P_2)$  at balance, then

$$P_1 - P_2 = dm \cdot h \left( 1 + \frac{a_2}{a_1} \right) \quad \dots \quad 2.3$$

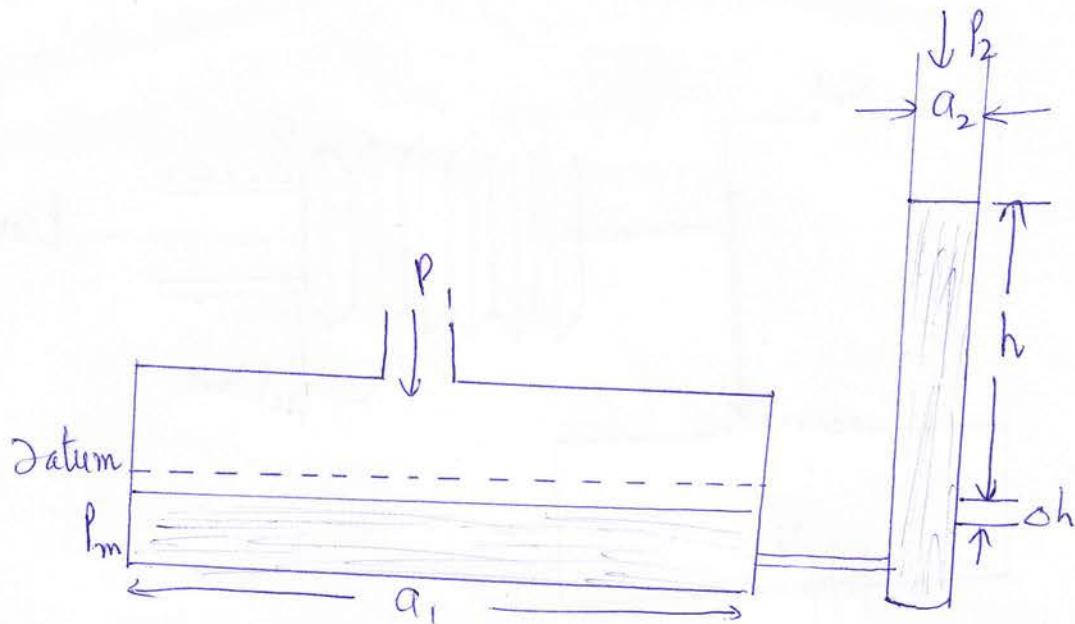


Fig. 2.3 Well-Type Manometer

In a single leg instrument, highly accuracy is achieved by setting the zero level of the well at the zero level of the scale before reading is taken.

## 2.1.2 Force Summing Devices & Electrical Transducers:

Mechanical devices that change shape when force or load is applied, are called force summing devices & are in form of Diaphragm, capsule, bellows or Bourdon tube.

For the measurement of force or pressure, the applied force, pressure is first converted into displacement by means of some elastic means (force summing devices) & then displacement is converted into electrical quantity/signals (Electrical Transducers) which can be indicated or recorded by some electrical/electronic devices. The transducers, used in measurement of pressure as 1° transducer are inductive, capacitive, Stain Gauges, L.V.D.T, Potentiometers etc. Some schemes used for measurement of pressure will be:

- 1) The scheme utilizing bellows as a 1° detector & potentiometer as 2° transducer for the measurement of pressure.

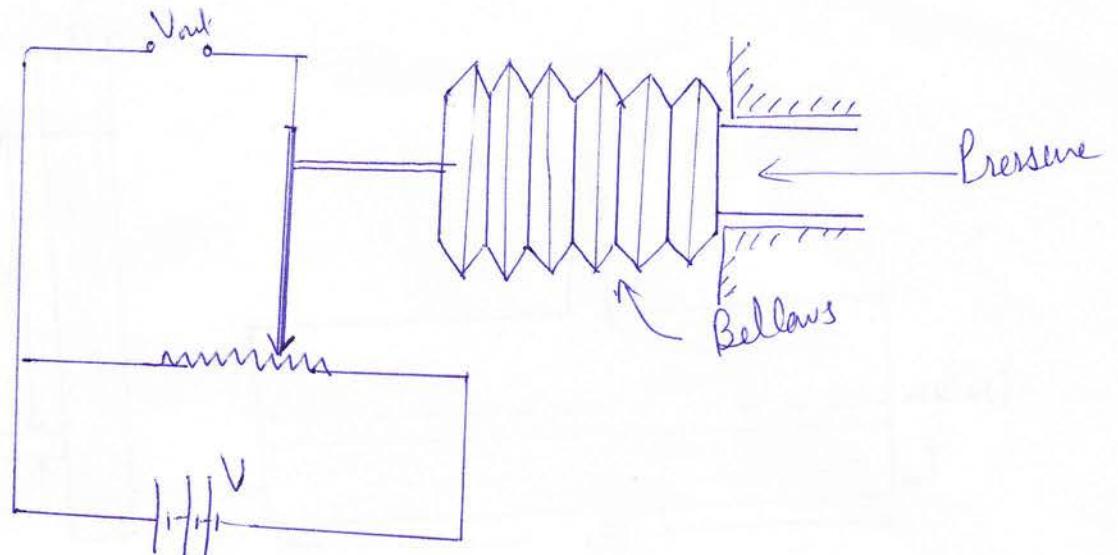


Fig. 2.4 Potentiometer & Bellows for the Measurement of Pressure

In this device/technique, one end of bellows is fixed & pressure is applied inside the bellows which in turn expands or compresses the bellows depending upon the nature of pressure. A rod fitted on the other hand of bellows moves & transmits the motion to the potentiometer acting as 2<sup>o</sup> transducer. This arrangement is used for measurement of low pressure.

The main advantages of bellows are moderate cost, capability of providing high force & wide range of measurement of pressure.

- 1) Ambient temp. compensation is required
- 2) Unsuitable for measurement of very high pressure.

Another type of pressure measurement C-Type Bourden tube is connected with potentiometer.

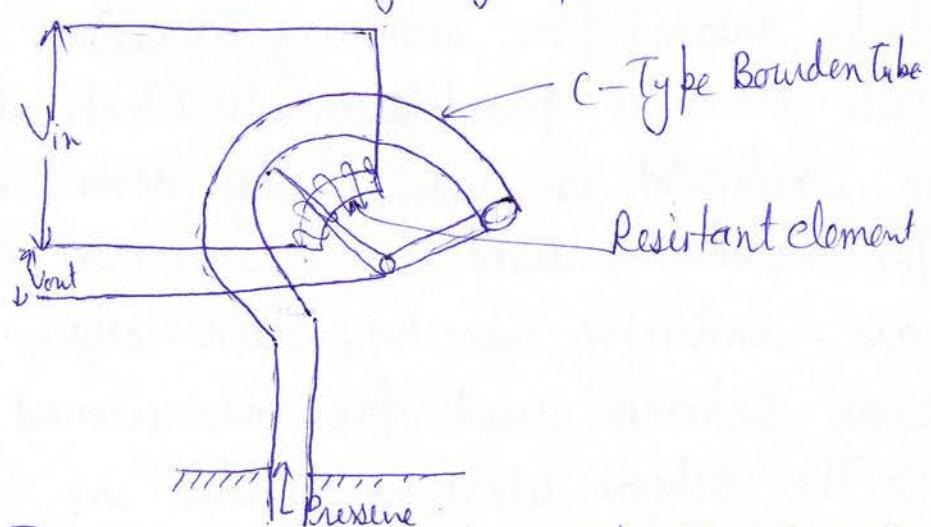


Fig. 2.5 Arrangement of C-Type Bourden tube & Potentiometer for measurement of pressure

2. In 2<sup>nd</sup> scheme, bellows are connected with an LVDT & Fig. 2-6 shows how a bellows could be linked to an LVDT for measurement of pressure. The pressure under measurement is applied to the outside of a bellows forcing it to contact against the push of a compressing spring. As it moves, it actuates a mechanical linkage which moves the core of an LVDT to furnish an electrical o/p signal.

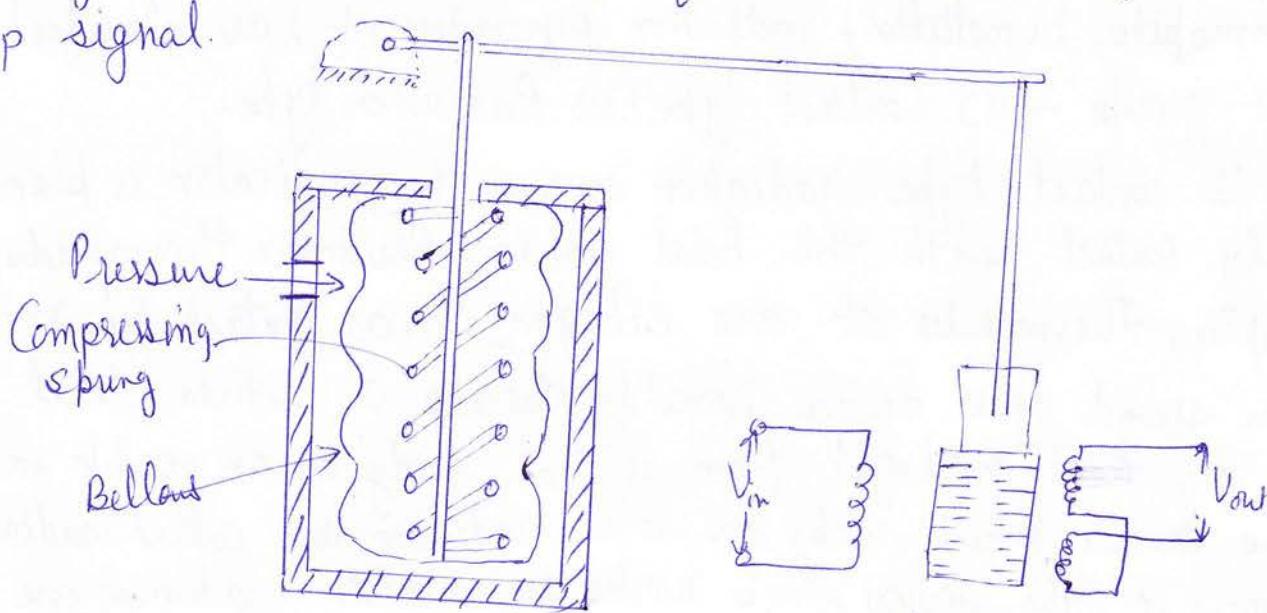


Fig. 2-6 Measurement of Pressure with an LVDT

3. Piezoelectric crystal along with bellows used in pressure measurement. When the pressure is applied to the crystal through the bellows, it causes a deformation in the structure of crystal & so an emf (which is function of deformation) is produced. The o/p emf may be measured to indicate the value of applied force/pressure.

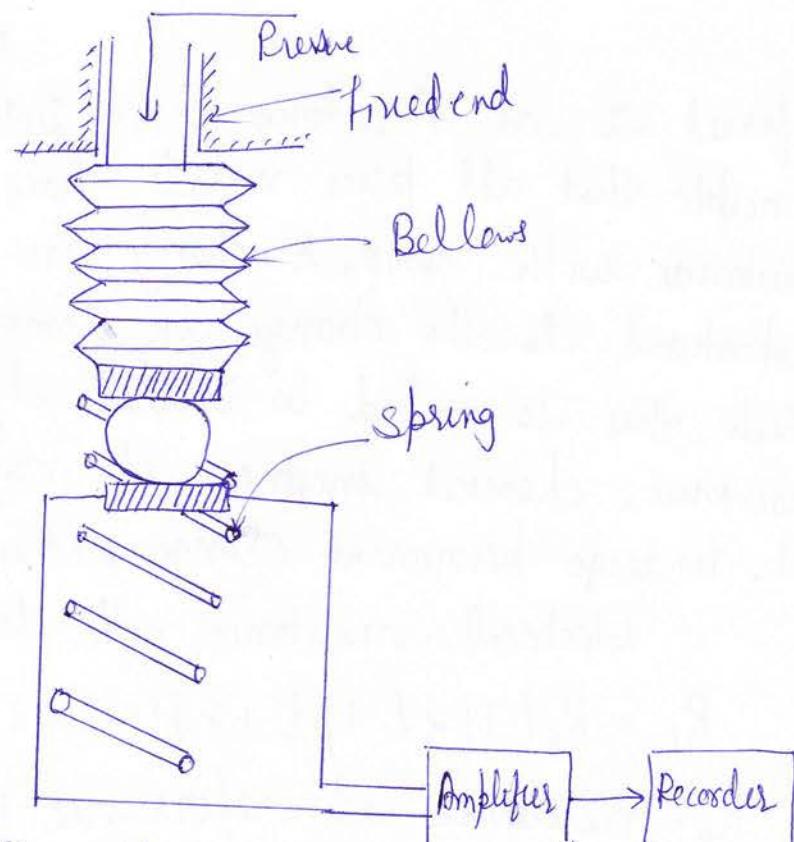


Fig. 2-7 Measurement of Pressure with Piezoelectric Crystal in combination with a Bellows.

## 2.2 Measurement of Temperature:

The most important of the measurement variables encountered in industrial processes is temp. This is

because there are changes in physical or chemical state of most substances when they are heated or cooled. So, measurement of temp. is very common in instrumentation. The devices (thermistors, thermocouples, thermometers, bimetallic, radiation pyrometers etc.) are classified into two groups - (i) Contact type (ii) Radiation type.

In contact type radiation devices, the indicator is placed in directly contact with the heat source. Resistance thermometers, Thermocouples, Thermometers etc. are categorized as contact type devices.

In second types devices directly operates on either total radiation, i.e., heat & light from a hot body, or on visible radiations. The devices which works on total radiation are called radiation type devices & the devices which works on visible radiations are called optical type devices.

### 2.2.1 Metallic Resistance Thermometers:

Metallic Resistance Thermometers referred to as Resistance-Temp Detector (RTD) operate upon the principle that all pure metals have the property of varying their resistance with temp., & change in resistance is almost directly proportional to the change in temp. The range of temp. over which this is valid is decided by the temp. coefficient of resistance, chemical inertness its crystal structure which should not undergo permanent changes within this range.

Electrical resistance with temp. for metals is shown

$$R_t = R_0 (1 + \alpha t + \beta t^2 + \gamma t^3 + \dots + \omega t^n) \quad \dots \quad (2.4)$$

$R_0$  - Resistance at reference temp ( $0^\circ\text{C}$ )

$\alpha$  = Temp. coeff. of Resistance

$R_t$  = Resistance at temp.  $t$ .

$\beta, \gamma, \dots, \omega$  = Coefficients determined on the basis of two/more known resistance temp points

For accuracy, neglect the terms having higher (2 or more) powers of temp.

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

The RTD is applicable for measurement of small temp differences as well as for wide ranges of temp. The main draw back is its large size & complex instrumentation.

Materials used for RTD:

- 1. Platinum, nickel & copper are most commonly used resistance materials. These materials provide a definite resistance value at each temp within its range.
- 2. Gold & silver are rarely used due to their low resistivity.
- 3. Tungsten has relatively high resistivity, but its use is limited for high temp stem applications, as it is extremely brittle & difficult to work.

Theory:

The resistance of Pt increases with the  $\downarrow$  in temp according to the law

$$R_t = R_0(1 + \alpha t + \beta t^2) \quad \text{--- (2.5)}$$

$$\left. \begin{array}{l} \alpha = 0.0037 \\ \beta = 0.00000057 \end{array} \right\} \text{for Pt}$$

For simplicity

$$R_t = R_0(1 + kt) \quad \text{--- (2.6)}$$

$k$  = Fundamental coefficient. Its value is determined by testing a Pt resistance thermometer with melting ice ( $0^\circ\text{C}$ ) & boiling water ( $100^\circ\text{C}$ )

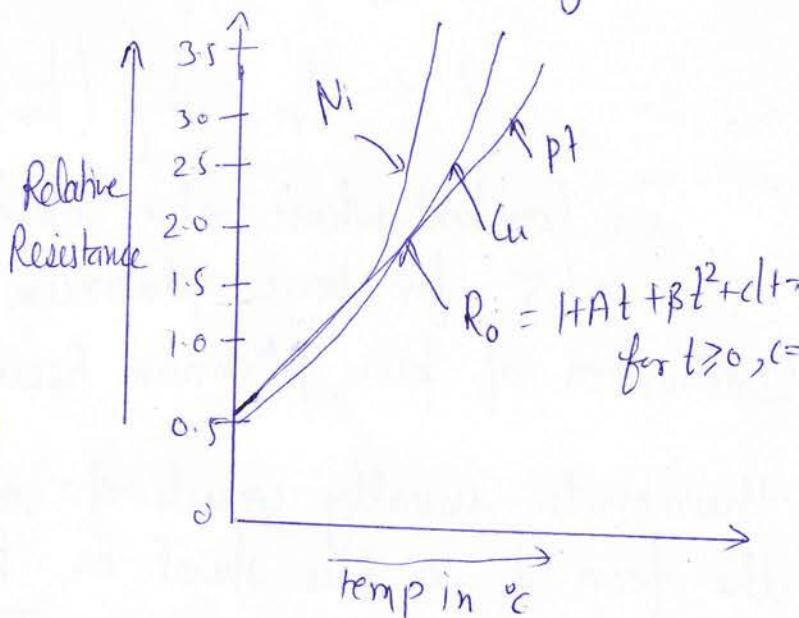


Fig. 2.8 Resistance Variation with Temp for Pt, Ni & Cu

$$R_{100} = R_0 (1 + 100k)$$

$$k = \frac{R_{100} - R_0}{100R_0} \quad \dots \quad (2.7)$$

Thus the value of  $k$  is determined. Now the resistance at  $t$  temp.

$$R_t = R_0 (1 + k t_p) \quad t_p = \text{Platinum temp}$$

$$R_t = R_0 \left( 1 + \frac{R_{100} - R_0}{100R_0} t_p \right)$$

$$= R_0 + \frac{R_{100} - R_0}{100} t_p$$

$$\Rightarrow t_p = \frac{100(R_t - R_0)}{R_{100} - R_0} \quad \dots \quad (2.8)$$

$R_{100} - R_0$  = Fundamental Interval

If  $R_t$  is the resistance of an actual temp. of  $t^\circ\text{C}$  then value of  $t$  is given by

$$t = t_p + \delta \left[ \left( \frac{t}{100} \right)^2 - \left( \frac{t_p}{100} \right)^2 \right]$$

$\delta$  = Constant whose value depends upon purity of Pt  
 $= 1.5$  for pure platinum

Construction of pure platinum Resistance Thermometer:

The platinum resistance thermometer usually consists of a thin platinum wire wound in the form of a free spiral or held in place by an insulated carrier s.a. mica or ceramic. The diameter of wire varies from 0.02 mm to 0.2 mm, & preferred value is 0.1 mm. The wire should be smooth, free from defects. The resistance wire is generally enclosed in a protective tube made of glass, quartz, stainless steel for protection of mechanical damages & chemical reactions. These protective tubes may be filled with air at high pressure. Joints inside

The thermometer tube are usually welded as metallic soldering gives off fumes at high temp. & degrades the platinum.

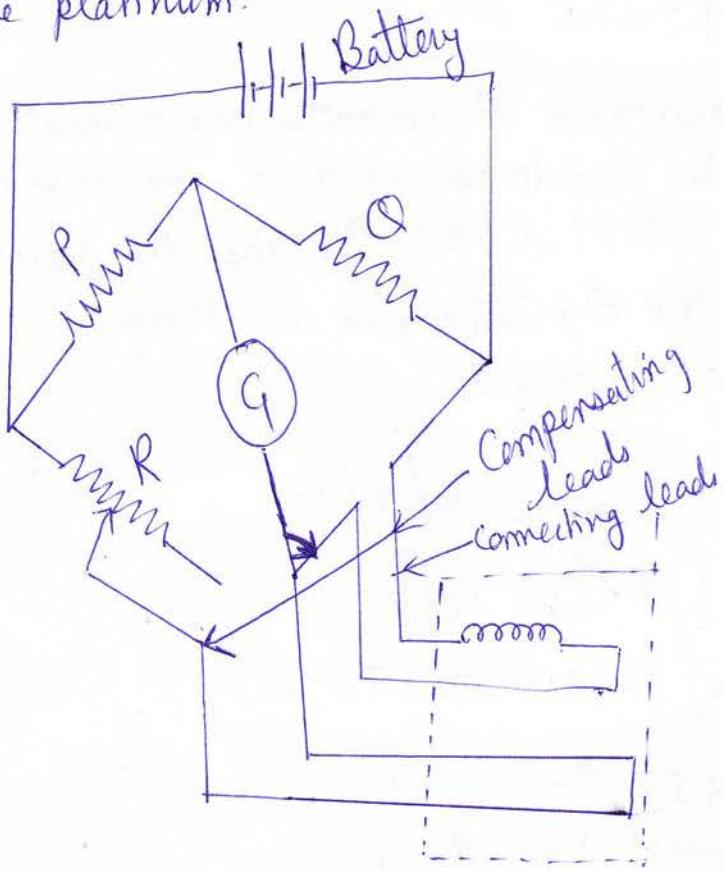


Fig. 2.9 Metallic (Pt) Resistance Thermometer for measurement of temp.

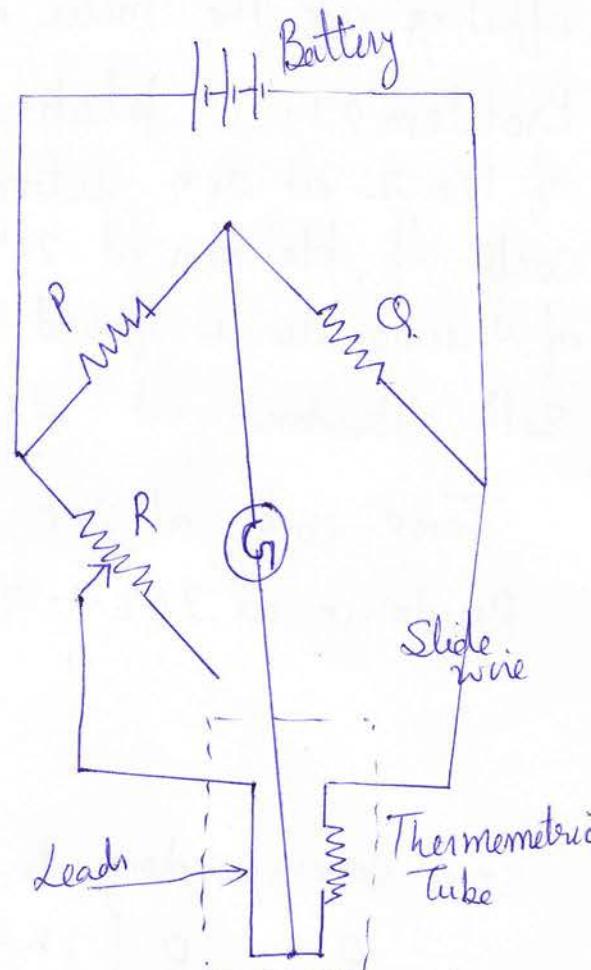


Fig. 2.10 Modified ckt. for RTD

The bridge ckt (in fig. 2.9) employed for measurement of change in resistance is situated at a considerable distance away from the thermometer & so an error is introduced in the result due to resistance of long leads. Such an error can be reduced to small proportion by adopting a large resistance for Pt coil & by choosing leads for material of low temp. P & Q are two ratio arms, R is known variable resistance in the third arm along with the compensating leads & 4<sup>th</sup> arm is made up of slide wire which is connected to Pt coil through connecting leads.

In the modified (fig. 2.10) ckt. of RTD, a three core cable is used for leads, compensation is being affected by a connecting lead in each of the two bridge arms. This is essential so that the same amount of lead wire is used

in both branches of the bridge. The arrangement is generally preferred as of lead length may be lengthened or shortened without affecting off the meter reading.

**Problem 2.1:** A platinum resistance thermometer has a resistance of  $120\ \Omega$  at  $25^\circ\text{C}$ . Determine its resistance at  $75^\circ\text{C}$ . The temp. coeff. of platinum at  $25^\circ\text{C}$  is  $0.00392/\text{per }^\circ\text{C}$ . In case the resistance of thermometer is found to be  $180\ \Omega$ , determine the temp.

**Sol:** Resistance at  $25^\circ\text{C}$   $R_1 = 120\ \Omega$

Temp coeff. at  $25^\circ\text{C}$   $\alpha = 0.00392\ \Omega/\text{per }^\circ\text{C}$

$$\begin{aligned}\text{Resistance at } 75^\circ\text{C} \quad R_2 &= R_1 [1 + \alpha(t_2 - t_1)] \\ &= 120 [1 + 0.00392(75 - 25)] \\ &= 143.52\ \Omega\end{aligned}$$

Temp. corresponding to resistance  $180\ \Omega$

$$R_3 = R_1 [1 + \alpha_1(t_3 - t_1)]$$

$$180 = 120 [1 + 0.00392(t_3 - 25)]$$

$$t_3 = 152.55^\circ\text{C}$$

## 2.2.2. Semiconductor Devices Transducers / Thermistors:

Thermistors are also called thermal resistors & the name is derived from thermally sensitive resistors, as the resistance of a thermistor varies as a function of temp. Thermistors are generally semiconductor devices, that behaves as resistors with high +ve temp coeff (usually  $-0.04\ \text{per }^\circ\text{C}$  at room temp. of  $25^\circ\text{C}$ ) & are at least 10 times sensitive as the platinum resistance thermometer.

Thermistor has a very non-linear resistance-temp relation. The resistance  $R$  of a thermistor at a temp.  $T$  can be given:

$$R = \alpha e^{\beta/T} \quad \dots (2.7)$$

Where  $\alpha$  &  $\beta$  are constants depending upon the material & manufacturing technique used.

Now resistance for Temperatures

$$T_1 \text{ & } T_0 \quad \beta \left( \frac{1}{T_1} - \frac{1}{T_0} \right)$$

$$R_1 = R_0 e^{\beta \left( \frac{1}{T_1} - \frac{1}{T_0} \right)} \quad \dots (2.8)$$

Where  $R_1$  &  $R_0$  are resistances inc at absolute temp.  $T_1$  &  $T_0$

$\beta$  = Thermistor constant

$T_0$  = Reference temp or  $25^\circ\text{C}$

$\beta$  is assumed to remain constant for all practical purposes but has generally a rising tendency with temp.

$$\text{Temp coeff, } \alpha = \frac{dR_1/R_1}{dT} = -\frac{\beta}{T} \quad \dots 2.9$$

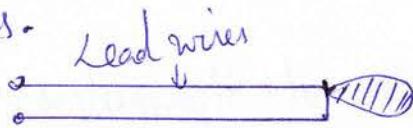
$$\beta = 4000^\circ\text{C}$$

$$T = 25^\circ\text{C} = 298\text{ K}$$

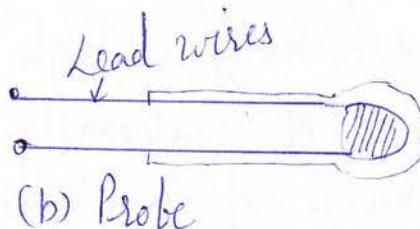
$$\alpha = \frac{4000}{(298)^2} = -0.045 \Omega/\Omega/\text{C}^\circ$$

Materials Used in Thermistors:

Modern thermistors are manufactured from the oxides of metals like nickel, cobalt, copper, iron, zinc etc. These oxides & their sulphides & silicates are milled, mixed in appropriate proportion, pressed into desired shape with appropriate binders.



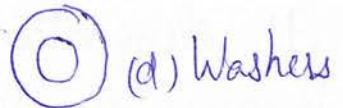
(a) Bead



(b) Probe



(c) Disc



(d) Washers

Fig 2.12 Commercial forms of thermistors.

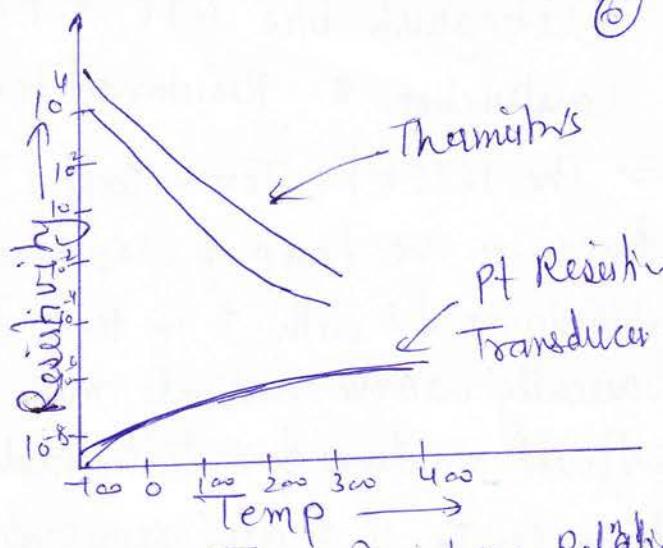


Fig 2.11 Temp-Resistance Relationship of thermistors

Distinguish b/w NTC & PTC Thermistors as regards to their Construction & Resistance/ temp characteristics:

⇒ The NTC (-ve Temp coeff.) Thermistors have a -ve temp of resistance, i.e., their resistance  $\downarrow$  with  $\uparrow$  in temp. These are basically ceramic materials made by sintering different mixtures of metallic oxide of Magnesia, Ni, Co, Cu, Fe, U & are semiconductors. They are available in forms of beads, discs, washers etc.

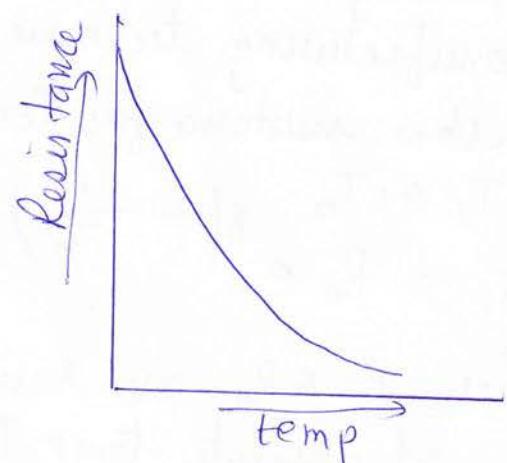


Fig 2.13 NTC Thermistor

PTC (+ve temp coeff.) Thermistors on the other hand have a +ve temp. coeff. of resistance, i.e., their resistance  $\uparrow$  with  $\uparrow$  in temp. They are doped poly crystalline & semiconductor barium titanate. The break point of PTC Thermistors can be adjusted by changing the composition of material. The ckt. symbols for thermistors are as under:

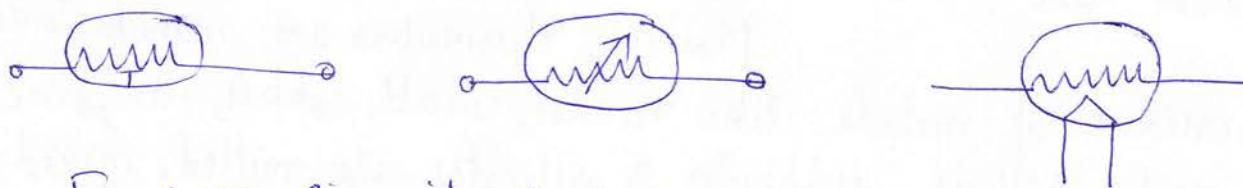


Fig 2.15 Circuit Symbols for Thermistor

#### Salient Features of Thermistors:

1. High resistance temp. coeff. characteristic of thermistors results in inherent high sensitivity & high level of O/P.
2. GI eliminates the need of extremely sensitive read-out devices.
3. Because of large change of resistance per degree of temp variation in thermistor, they can provide good accuracy & resolution when used for measurement of temp.

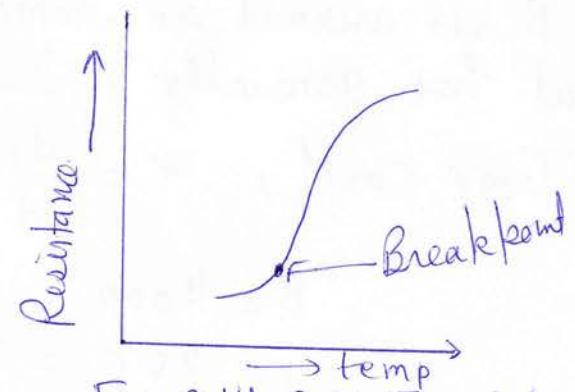


Fig. 2.14 PTC Thermistor

4. Thermistors are compact, rigid & inexpensive.

⑦

Limitations of Thermistors:

1) The high degree of non-linearity in the resistance-temp function usually limits the range of read-out in instrumentation.

2) Over wide ranges of temp, these are less stable.

Applications of Thermistors:

A few common applications of thermistors are:

1. Measurement of power at high frequencies

2. Measurement of thermal conductivity

3. Measurement of level, flow & pressure of fluids.

4. Measurement of temp.

Problem 2.3: A thermistor has a temp. coeff of resistance of 0.05 over a temp. range of 25°C & 50°C. Determine the resistance of thermistor at 40°C if the resistance of thermistor at 25°C is 120.

Sol:

$$R_{25} = 120 \Omega, \alpha = 0.05$$

$$R_{40} = R_{25} (1 + \alpha(t_2 - t_1))$$

$$= 120 (1 + 0.05(40 - 25))$$

$$\boxed{R_{40} = 180 \Omega}$$

### 2.2.3 Pyrometers:

The pyrometer is a device that is used for measurement of high temp when physical contact with the probe is impractical & corrosive vapours or liquid would destroy thermocouples, resistance thermometers & if made to come in contact with the measured medium. The pyrometers used are radiation pyrometers & optical pyrometers.

#### 1. Radiation Pyrometers:

Radiation pyrometers can measure temp.

upto  $35^{\circ}\text{C}$  & are usually used when the temp. to be measured exceeds  $120^{\circ}\text{C}$ .

These pyrometers operate on the basis of Stefan-Boltzmann law which states that the energy radiated by a heated black body is proportional to  $4^{\text{th}}$  power of absolute temp.

$$W = k(T^4 - T_0^4) \quad \dots \quad (2.10)$$

$W$  = Energy per sq. meter per sec. received by cold body

$k$  = Const =  $1.27 \times 10^{-4}$  gm calories/sec/sq meter.

$T$  = Absolute temp of hot body

$T_0$  = Absolute temp of Surroundings

As  $T_0 \ll T$

$$\text{So } W = kT^4 \quad \dots \quad (2.11)$$

The above relation is correct for a black body & if the radiating body is not perfect then corrections are usually applied.

The pyrometer is made of such a construction that the heat is focussed onto a blackened Hot junction of a thermocouple which absorbs all/almost all, of the radiations falling on it. Thus the temp. of the hot junction of the thermocouple is directly proportional to the temp. of hot body whose temp. is to be measured. The indicated instrument is used to measure thermo emf set up in the thermocouple is calibrated to read the temp. directly.

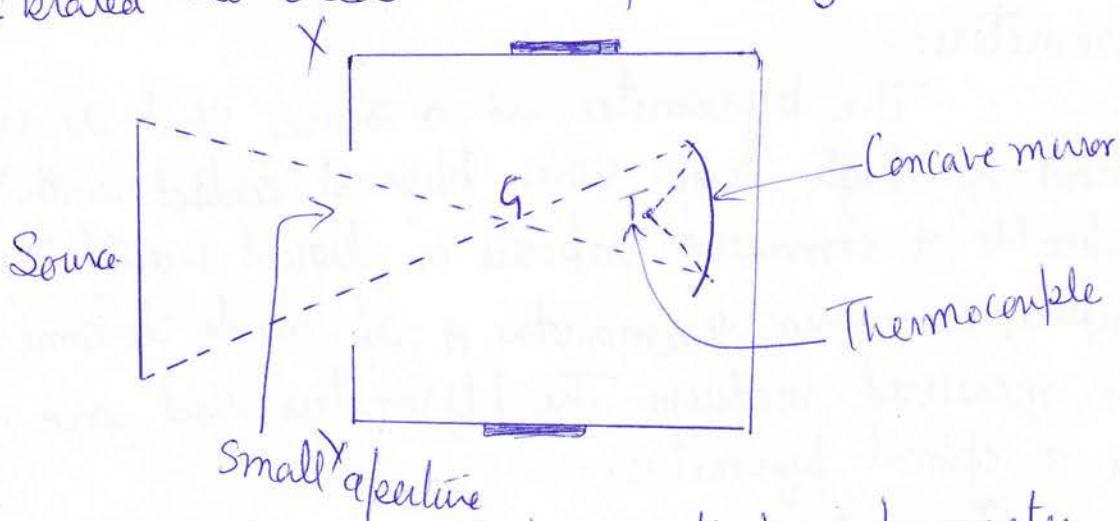


Fig. 2.16 Fixed Focus Type radiation pyrometer

## Advantages of Radiation Pyrometers:

- 1) They can measure very high temp. safely & can be placed at distances away from the heat body.
- 2) They can be used for measuring temp. of moving object, larger areas etc.
- 3) They having rapid time response.
- 4) Have high differential sensitivity

## Limitations/Drawbacks:

1. Their initial as well as installation costs are high.
2. They require maintenance.
3. Each pyrometer has individual calibration, which is done by employing hot bodies whose temperatures are known.

2. Optical Pyrometers: Optical pyrometers make use of the variation in colour of a hot body & interpret the phenomenon in terms of temp. When a body is heated, it initially becomes white. The actual measurement of temp. is based upon the determination of the change in colour of hot body, & comparing it with known values with a heated filament.

A red glass is used to render the light monochromatic which is very helpful in comparing brightness.

The current flowing through the std. through the std. lamp clamp is adjusted till the brightness of the lamp & filament is

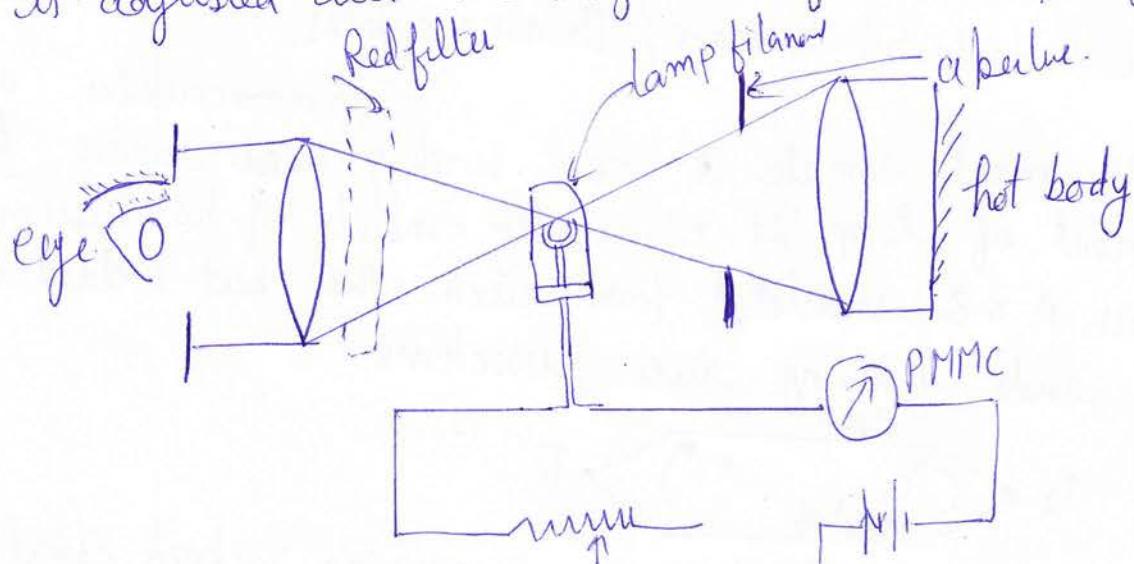


Fig. 2-17 Disappearing filament Type Optical pyrometer

equal that of the hot body & viewed through red glass by means of eye piece. When two brightnesses are equal, the filament disappears into the surrounding fields of light from the hot body. The current producing the equality of brightness indicates the actual temp. of the hot body which is given directly by the indicating instruments calibrated in terms of temp.

An absorption screen is introduced b/w the hot body & the lamp (when temp  $< 1400^{\circ}\text{C}$ ) as lamp cannot be used above  $1400^{\circ}\text{C}$ .

**Problem 2.4:** The temp. of a hot body, when measured by radiometer, is found to be  $2450^{\circ}\text{C}$  assuming a surface emissivity of 0.85. Later on it was found that true surface emissivity is 0.78. Determine actual temp. & error in temp. measurement.

**Soln:** Absolute temp. with emissivity 0.85

$$T_m = 2450^{\circ}\text{C} = 2723^{\circ}\text{K}$$

Actual absolute temp with emissivity 0.78

$$\begin{aligned} T_a &= T_m \left( \frac{k_m}{k_n} \right)^{1/4} \\ &= 2723 \left( \frac{0.85}{0.78} \right)^{1/4} = 2782\text{ K} \end{aligned}$$

$$\text{Actual temp} = 2782 - 273 = 2509^{\circ}\text{C}$$

$$\text{Error in temp.} = 2450 - 2509 = -59^{\circ}\text{C}$$

## 2.2.4 Thermo Electric Sensors / Thermocouples:

Thermocouples are perhaps the most simple & most widely used devices for measurement of temp. It essentially consists of two dissimilar metal wires A & B, insulated from each other but welded together at their ends forming two junctions.

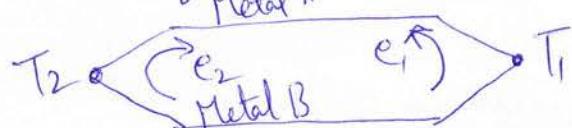


Fig. 2.18 Thermo electric Sensors using Seebeck effect.

The operation of a thermo couple is based on Seebeck effect, i.e., two wires of different metals are joined together at each end & form a complete electrical ckt. the current flows in the ckt when two junctions are kept at different temperatures. This current is caused by an emf, called thermoelectric emf, set up in the ckt & is function of temp difference of two junctions.

The reverse of Seebeck effect is also true & that has been explained by Peltier effect. & according to this effect when an electric current flows across a junction of two dissimilar metals, heat is either generated or absorbed, depending upon the direction of flow of current.

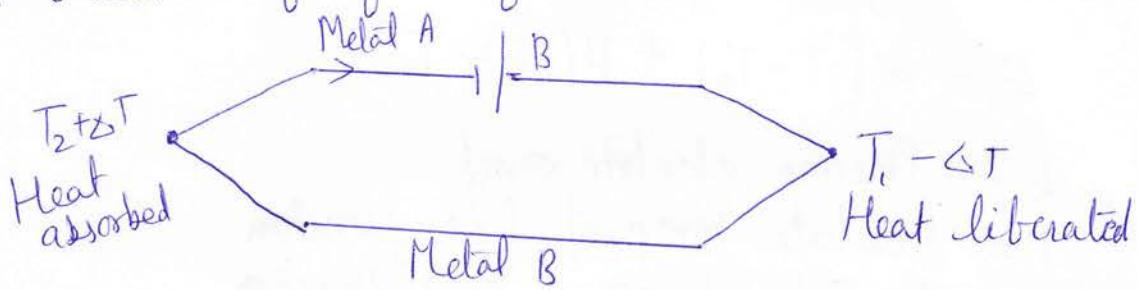


Fig. 2.19 Thermo couple using Peltier Effect.

When an electric current flows in the same direction as the Seebeck current, heat is absorbed at hot junction & liberated at cold junction.

Another reversible heat-flow effect, the Thomson effect, influences the temp of conductors b/w the junctions rather than the junctions themselves. When current flows through a conductor having a temp gradient along its length, heat is liberated at any end where the current flows in the same direction as the heat flow, while heat is absorbed at any point where these are opposite. This effect is also present if POT is employed for measurement of thermocouple voltage because this effect also depends on current flow.

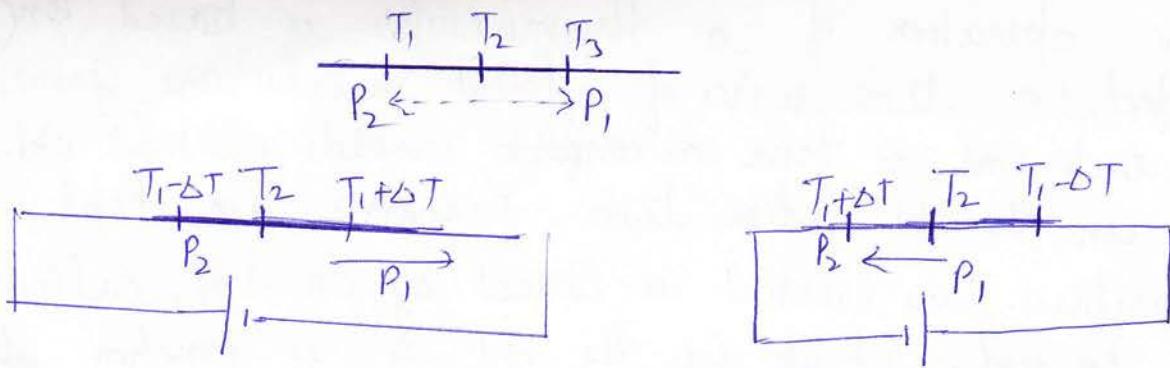


Fig. 2.20 Thomson Effect in Thermocouple Transducer

The total emf set up is made up of a part due to the Peltier effect, which is localized at each junction & a part (much small) caused by the Thomson effect, which is distributed along each conductor b/w the junctions.

$$E = \alpha(T - T_0) + \beta(T^2 - T_0^2)$$

where  $E$  = Thermo electric emf

$T$  = Absolute temp of hot junction

$T_0$  = Absolute temp of cold junction

$\alpha, \beta$  = Constants whose values depend upon the metals are used for coupling.

Construction of Thermo couples:

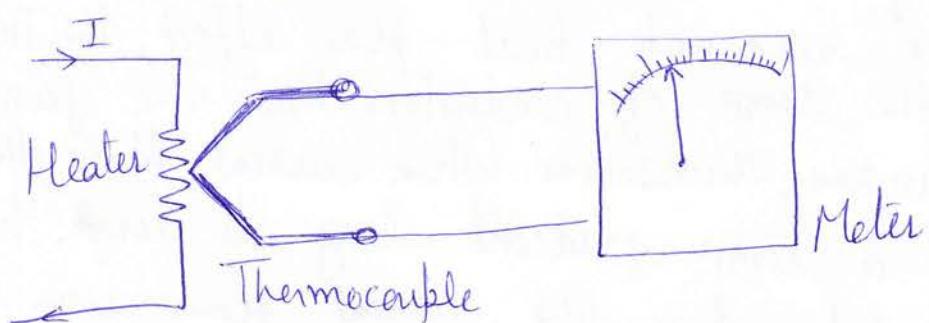


Fig. 2.24 Schematic diagram of a thermo couple.

1. A heater element that carries the current to be measured (in case of voltage measurement it carries a current proportional to the voltage to be measured). It is important that the resistance of the heater wire due to current flowing through the wire

2. A thermocouple having its hot junction in contact with the heater & its cold junction nearer at room temp.
3. A sensitive PMMC that operates on the thermal emf generated in the thermo couple.

### Materials Used in Thermo couples:

Platinum - Rhodium, Chromel - Alumel, Copper - Constantan & Iron - Constantan are some pairs of materials used in thermo couples.

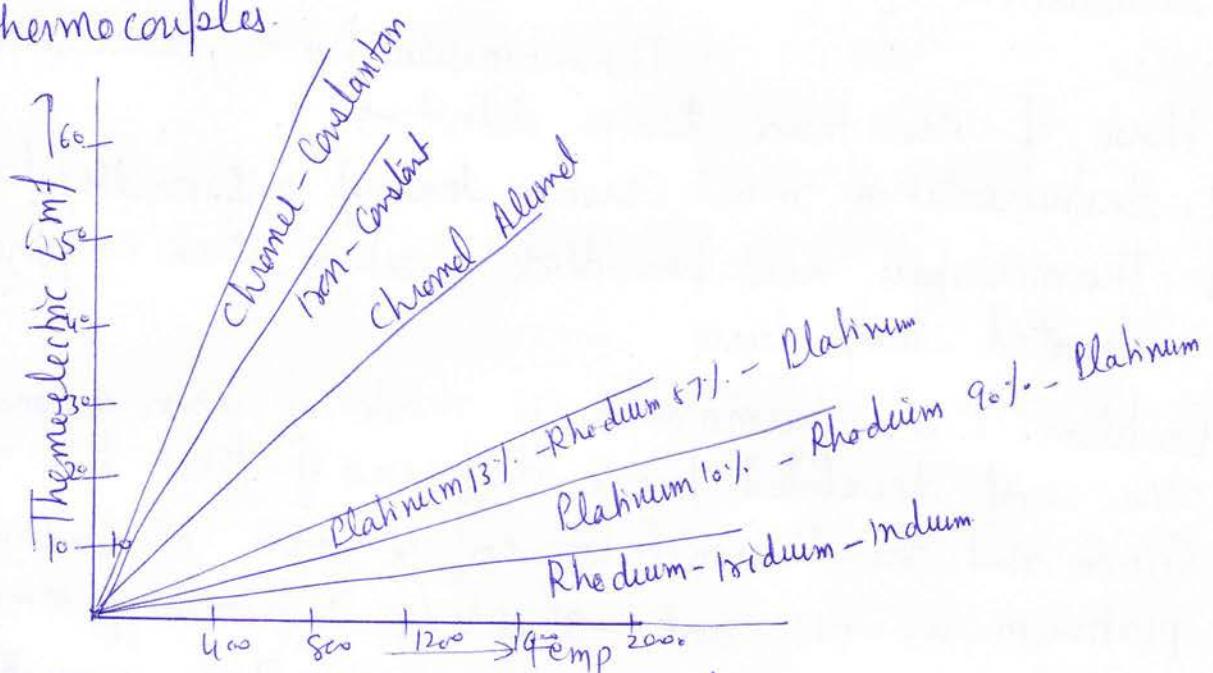


Fig. 2.22 Thermo couple Temperature - Emf curve

### Measurement of Thermo couple Output:

The o/p emf of a thermocouple as a result of difference b/w temperatures of measuring junctions & reference junction can be measured by measuring the o/p voltage with the help of d.c. P.O.T. It is the most commonly used method for the measurement of temp with thermocouple employs a d.c. self balancing potentiometer. There are no loading errors as at balance no current is drawn from the thermocouple whose emf. is being measured. The resistance variation problems are also absent in this arrangement.

## Merits / Advantages of Thermo couple:

1. Thermocouples can be made in very small sizes.
2. Thermocouples are cheaper than Resistance thermometers.
3. The temperature range of thermocouples is about  $14,00^{\circ}\text{C}$ .
4. Thermocouples can be made from wire pairs as small as 0.01 mm diameter for millisecond response.

## Limitations of Thermocouples:

1. Thermocouples have lesser accuracy than those of resistance temp. detectors.
2. Instrumentation must resolve tens of microvolts/degree of temp.
3. Thermocouples need periodical checking when employed at elevated temperatures.

Problem 2.5 A thermocouple is made of iron & Constantan. Find the emf developed per  $^{\circ}\text{C}$  difference of temp b/w the junctions. Given that the thermo-electric emf of iron & Constantan against platinum are +16 and  $-34 \mu\text{V}/^{\circ}\text{C}$  difference of temp.

$$\text{Soln: Emf of Iron wrt. Platinum, } E_{\text{Fe}}^{\text{Pt}} = 16 \times 10^{-6} \text{ V}/^{\circ}\text{C}$$

$$\text{Emf of Constantan } \dots \dots, E_{\text{Con}}^{\text{Pt}} = -34 \times 10^{-6} \text{ V}/^{\circ}\text{C}$$

$$\text{Emf of Platinum wrt Constantant } E_{\text{Pt}}^{\text{Con}} = 34 \times 10^{-6} \text{ V}/^{\circ}\text{C}$$

Emf of Iron-Constantan junction per  $^{\circ}\text{C}$  difference of temp

$$E_{\text{Fe}}^{\text{Con}} = E_{\text{FE}}^{\text{Pt}} + E_{\text{Pt}}^{\text{Con}}$$

$$= 16 \times 10^{-6} + 34 \times 10^{-6} = 50 \mu\text{V}/^{\circ}\text{C}$$