18ECO133T

Sensors and Transducers

3 Credit Course

UNIT III

- Thermal sensors: Introduction
- Thermal Expansion type.
- Acoustics temperature sensors
- Thermo-emf sensor.
- Materials for thermos-emf sensors
- Thermocouple construction, Types.
- Thermo-sensors using semiconductor device
- Pyroelectric thermal sensors
- Introduction, characteristics, Application
- Radiation sensors, Introduction, Characteristics
- Geiger counters, Scintillation detectors
- Application on radiation sensors

THERMAL SENSORS - INTRODUCTION

- Thermal sensors are primarily temperature sensors also called thermodynamic sensors.
- Any physical quantity say Q is usually expressed as its magnitude in number N and in unit U so that

$$\boldsymbol{Q = NU}$$

- If it is possible to relate temperature T directly in the above form of above equation, from the first principles, in a sensing system, then it is called a primary sensor.
- Even though the principles of thermal sensing are well established, newer innovations are added to the stock of sensors dependent on these principles with improved quality and better practical approaches.
- Many of the commonly used practical 'thermometers' are, however, not primary in that sense and may be called secondary as the relationship between Q and T used by them is largely empirical.

CLASSIFICATION OF SENSORS

- Primary Sensors
  - Gas Thermometer
  - Vapour Pressure type
  - Ultrasonic type
  - Dielectric constant type
  - Magnetic type
  - Noise type
  - Nuclear Orientation type

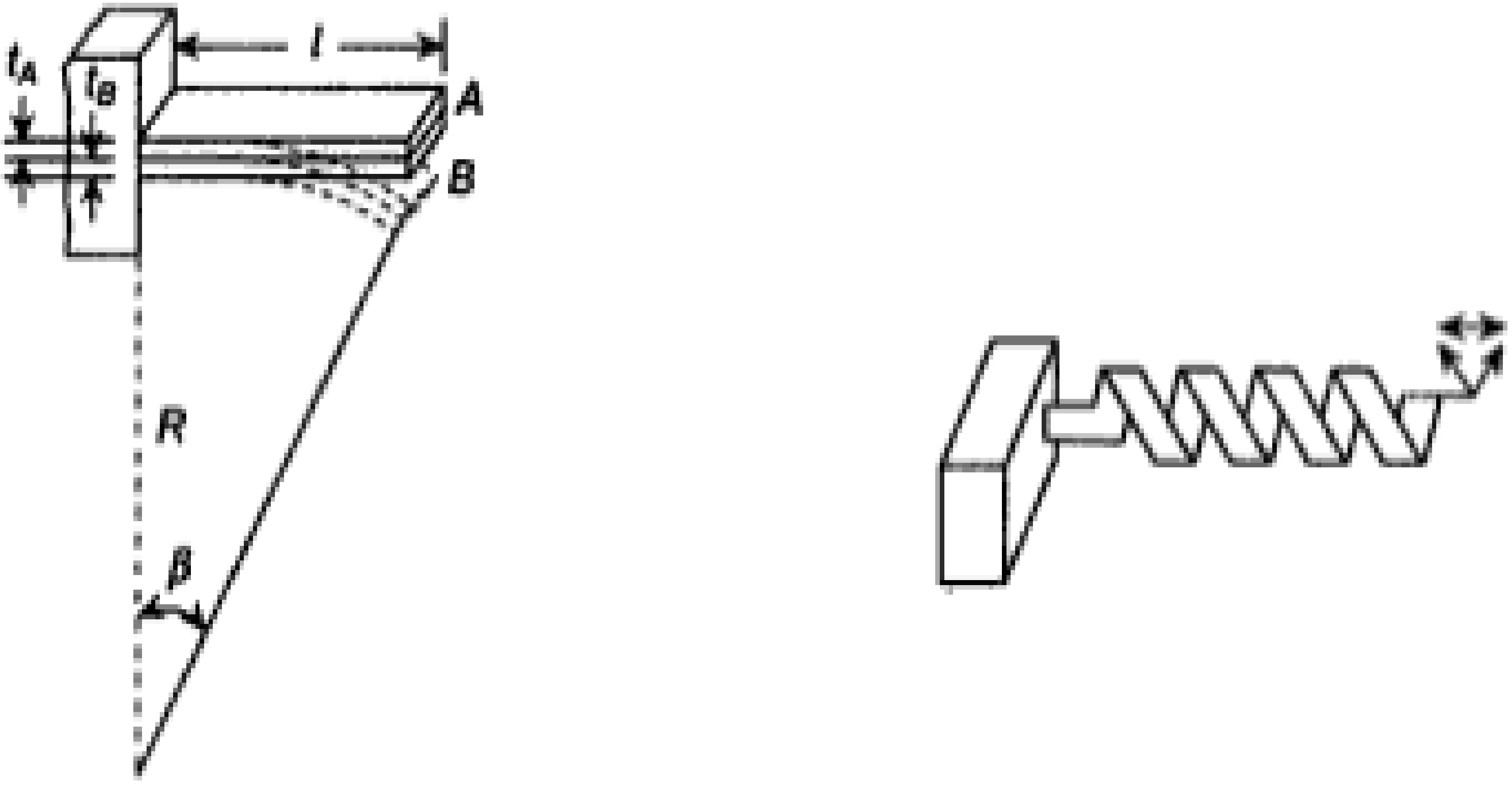
CLASSIFICATION OF SENSORS

- Secondary Sensors
  - Thermal Expansion type
  - Thermo emf type
  - Diode, Transistors or semiconductor type
  - Adapted Radiation type
  - Resistance Thermometer type

- There *are* different kinds of heat flux sensors which measure heat flux in terms of temperature difference.
- *Even* in temperature measurement. there are special types of sensors such as pneumatic type, pyroelectric type and so on.

THERMAL EXPANSION TYPE THERMOMETRIC SENSORS

- The thermal expansion types thermometric sensors are, perhaps. the oldest varieties still used commercially to a certain extent.
- Earliest of this kind is the solid expansion type bimetallic sensor which uses the difference in thermal expansion coefficients of different metals.
- Two metal strips A and *B* of thickness ta and tb, thermal expansion coefficients $\boldsymbol{a_A}$ and $\boldsymbol{a_B}$ are firmly bonded together at a temperature, usually the lowest or the reference temperature, to form a cantilever or a helix with one end fixed as shown in Figs 3.4(a) and 3.4(b) respectively.



(a) (b)

Fig. 3.4 (a) Cantilever type bimetal thermometer, (b) helix type bimetal thermometer.

$$R = \frac{(t_A + t_B)\left[3\left(1 + \frac{t_B}{t_A}\right)^2 + \left(1 + \left(\frac{t_B}{t_A}\right)\left(\frac{Y_B}{Y_A}\right)\right)\left\{\left(\frac{t_B}{t_A}\right)^2 + \frac{t_A Y_A}{t_B Y_B}\right\}\right]}{6(\alpha_A - \alpha_B)(T_h - T_b)\left(1 + \frac{t_B}{t_A}\right)^2} \tag{3.8}$$

where Y is the Young's modulus,
T_h is the raised temperature, and
T_b is the bonding temperature.

Equation (3.8) is simplified using $t_A = t_B = t$ and $Y_A \approx Y_B$. This gives

$$R = \frac{4t}{3(\alpha_A - \alpha_B)(T_h - T_b)} \tag{3.9}$$

The angular deflection, β, per unit temperature change, that is, sensitivity (for small β) is given by

$$S_T^\beta = \frac{\beta}{(T_h - T_b)} = 3l\,\frac{\alpha_A - \alpha_B}{4t} \tag{3.10}$$

where l is the length of the cantilever.

- When the temperature of the cantilever or the helix is raised by heating or lowered by cooling. one strip expands or contracts more and free end of either of the two moves as shown.
- The cantilever, in fact, bends into a circular arc with radius of curvature *R* given by the relation
- S_T^B increases linearly with length and inversely with strip thickness for a given pair of metal elements. Usually element B is made of invar *(e* Ni-Fe alloy) of a_s 1.7 x 10^4/°C which is quite low and element A is brass or steel of different alloying compositions. Such sensors can work precisely but not very accurately in a range -50-400°C.
- Besides cantilever and helix forms, they are also made in spiral and disc forms in different control applications.

LIQUID-IN- GLASS THERMOMETER

In liquid-in-glass thermometer—the liquid in majority of the cases being **mercury**. With mercury, this thermometer is almost the basic temperature measuring unit in home (as clinical thermometer), in laboratories and even in industries.

It utilizes the expansion property of the liquid kept in a bulb to which a capillary. closed at the fer end, is attached through which the expanded liquid rises and an indication in mm, calibrated directly in temperature scale, is obtained.

- The schematic is shown in Fig. 3.5 The range of mercury thermometer is normally -35-300°C and the upper limit is 357°C. its boiling point.

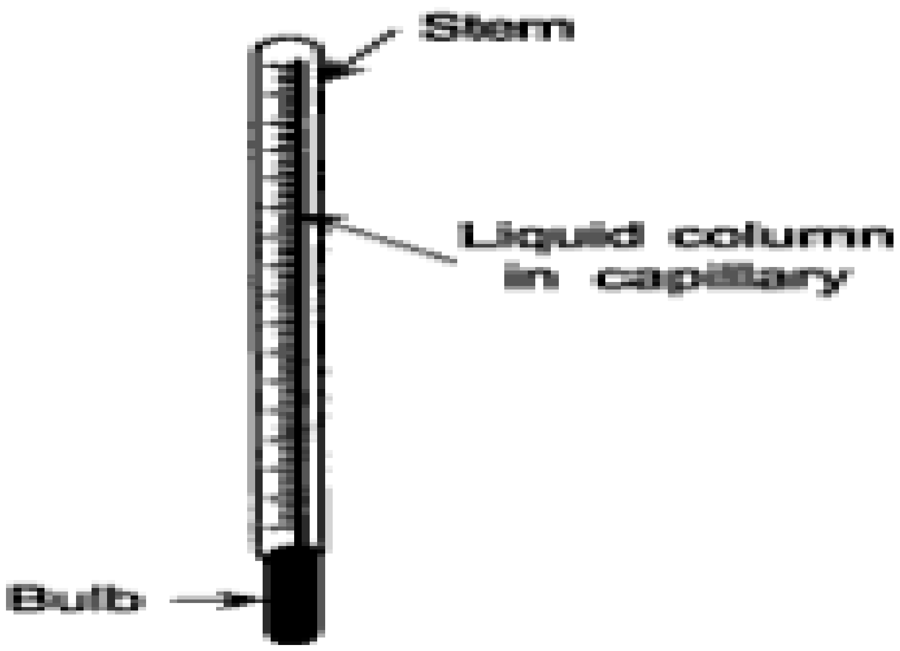


Fig. 3.5 Liquid-in-glass thermometer.

- The range can be extended upto 600°C by filling the volume above mercury with pressurized dry nitrogen.
- The volume of the bulb is made 100 to 400 times larger than the capillary volume. Other liquids used as expansion media are given in Table 3.3 with their corresponding ranges**.**

LIQUID	RANGE(DEGREE CENTIGRADE)
PENTANE	-200-30
ALCOHOL	-80-70
TOLUENE	-80-100
CREOSOTE	-5-200

- When the measurement is made, the thermometer should be immersed upto the meniscus in the capillary which means that the thermometer is to be moved for varying temperatures.
- Alternatively, the entire thermometer is immersed, or, only the bulb is immersed. The last alternative is the most common one and for this purpose. a correction has to be applied for the mercury column above the immersion line because the column is at a different temperature *c* than the measured value *t*.,.

- The correction term is

$$\Delta t = \gamma_d n\,(t_m - t_c) \qquad (3.11)$$

where γ_d is the differential thermal expansion coefficient of volume between mercury and glass and

n is the number of degrees indicated by the column, that is, exposed degrees.

γ_d has a value of about $1.6 \times 10^{-5}/°C$.

- An extension of this is the industrial type liquid filled-in system which consists of a metallic bulb attached to a metallic capillary. The other end of capillary is fitted with a Bourdon. The expansion of the liquid in the bulb is transmitted to the Bourdon which uncurls in the usual manner.
- A number of compensations are necessary to obtain correct indication by the measurement system using such a sensor.
- The correction methods are available in standard texts on industrial instrumentation.

ACOUSTIC TEMPERATURE SENSOR

When a longitudinal (acoustic) wave propagates through an ideal gas, it has a speed C_l given by

$$C_l = \left(\frac{\gamma RT}{M}\right)^{1/2} \tag{3.12}$$

where M is the molecular weight of the gas and $\gamma = C_p/C_v$ is the ratio of specific heats ($\gamma = 5/3$ for monoatomic gases).

Knowing the gas and measuring velocity C_l, temperature T can be given by

$$T = \frac{MC_l^2}{\gamma R} \tag{3.13}$$

- The realization of this technique is made in acoustic helium interferometer whose working is explained through Fig. 3.6.
- A quartz crystal excited to its resonance frequency is used to transmit this wave through a gas (He) column. to be faced by a piston. The wave is reflected at the piston surface to form a pattern as shown.

- When the path length l has a multiple number of half-wavelengths and correspondingly the gas column is set to resonate at each such half-wavelength gap, with the piston moving away from the crystal at each resonant peak, the crystal gives out maximum energy and hence the voltage V_Q across the crystal defines peaks as shown in Fig. 3.6(c).
- If the piston moves by a distance d to give n such peaks, $d = n\lambda/2$ from which C, is determined and thence temperature T. The piston movement must be accurately monitored to within, say 1 μm.

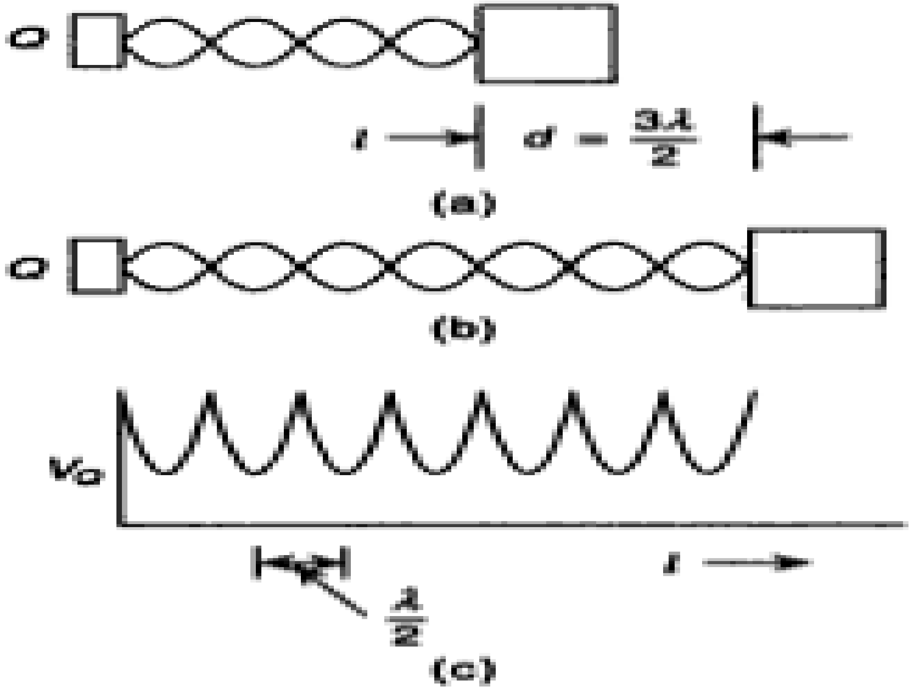


Fig. 3.6 Principles of acoustic temperature sensor: (a) the system, (b) the system with changed position of piston for maintaining resonance, and (c) the crystal output peak positions.

In non-ideal gas, correction as per Van der Waal's equation

$$V - b\left(P + \frac{a}{V}\right) = MRT \tag{3.14}$$

has to be applied, where M is the molecular weight of the gas, and a and b are functions of 'molecular' constants. The corrected velocity C_c is then given by

$$C_c = \sqrt{\frac{\gamma RT}{M}\left[1 + \frac{\alpha P}{RT}\right]} \tag{3.15}$$

where α is a function of a, b, T, and V.

- There is a nonresonant acoustic sensor that utilizes the pulse-echo transit time difference which changes with temperature. Figure 3.7 is a schematic representation of the sensory pans of the measurement system.
- An ultrasonic pulse is transmitted through the sensor, a part of which is reflected at the entrance (a discontinuity) and a part at the end, as shown.
- The reflected pulses are received by the transreceiver coil at an interval of called the transit time.

- The pulse that travels the entire length of the sensor is delayed more/less depending on the change in the sensor temperature.
- This temperature dependence is **a** function of the path length *I.* sensor material. temperature range, and vibration mode even if the first echo is considered.
- The materials which show distinctive r,, are listed in Table 3.4 with their temperature ranges.

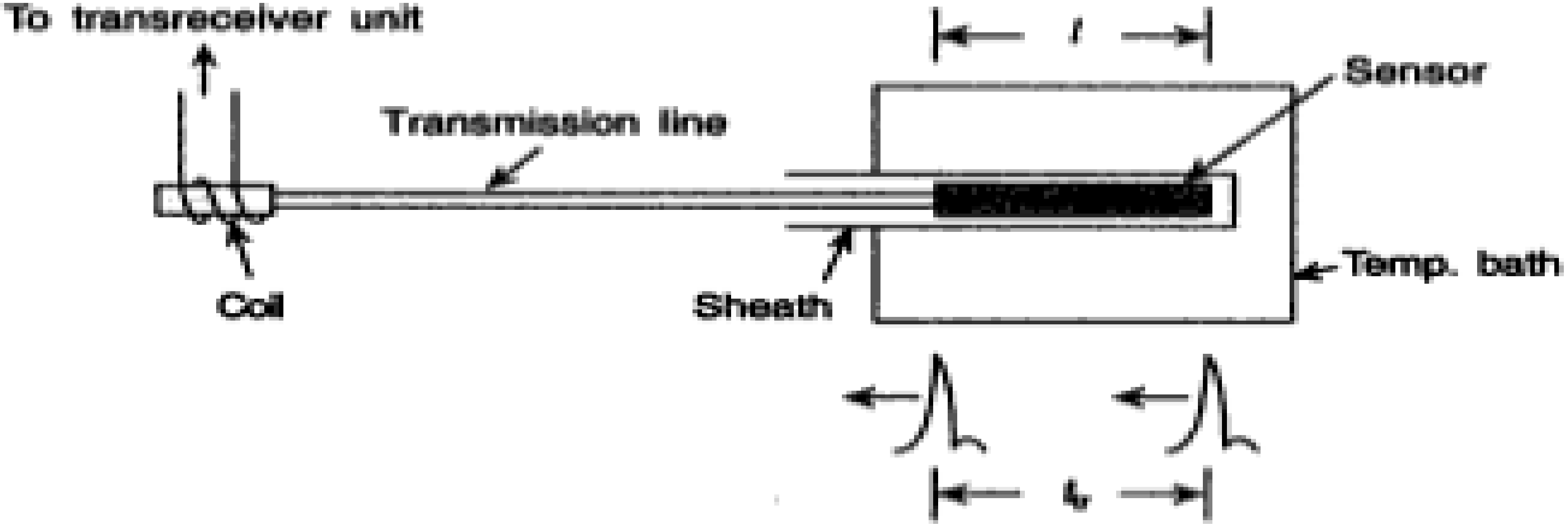


Fig. 3.7 Pulse-echo transit time difference technique of temperature measurement.

Table 3.4 Materials versus temperature range

Material	*Temperature range* (°C)
Aluminium	≤500
Stainless steel	≤1100
Sapphire	≤1600
Molybdenum, Ruthenium	≤2100
Wolfrum, Rhenium, ThO_2–W(2%)	≤2700

The nature of the plot between t_{tr} and temperature T is shown in Fig. 3.8.

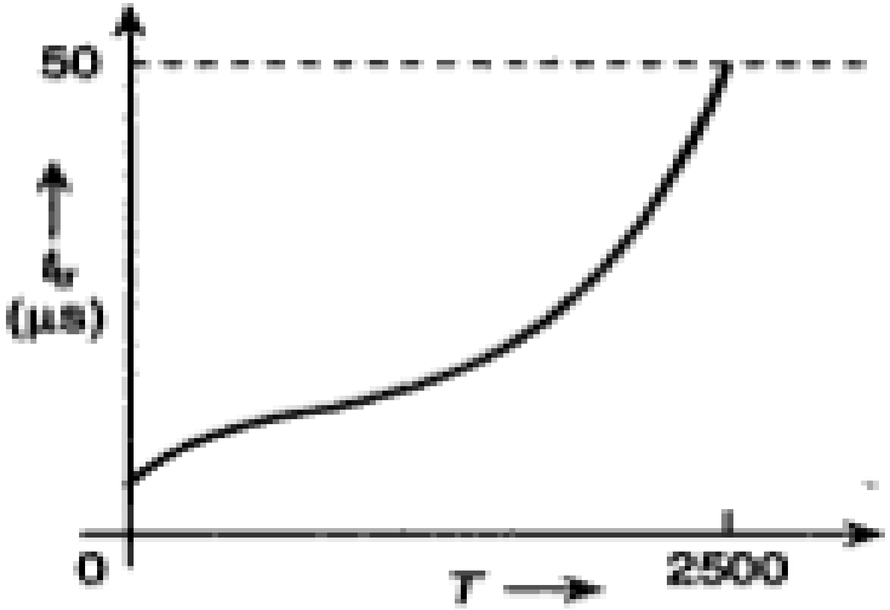


Fig. 3.8 Transit time versus temperature plot.

- The sensor may be made in the form of a thin wire with restrictions or constrictions at intervals of space where the reflections would occur.
- The wire diameter varies from 0.03-3 mm and spacing between restrictions varies from 5-10 mm in a sensor length of 15-50 mm, and a number of echos can then be produced.
- There should not be any inhomogeneity in the material faced by the wave except for the restrictions.

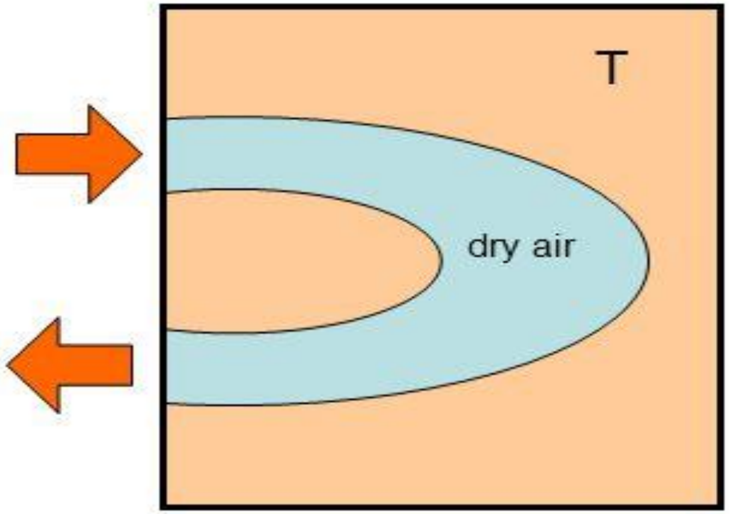
Acoustic Temperature sensors

<u>advantages:</u>
•thermally stable
•waterproof
•good in hostile environments

<u>disadvantages:</u>
•expensive
•complicated circuitry

ultrasound

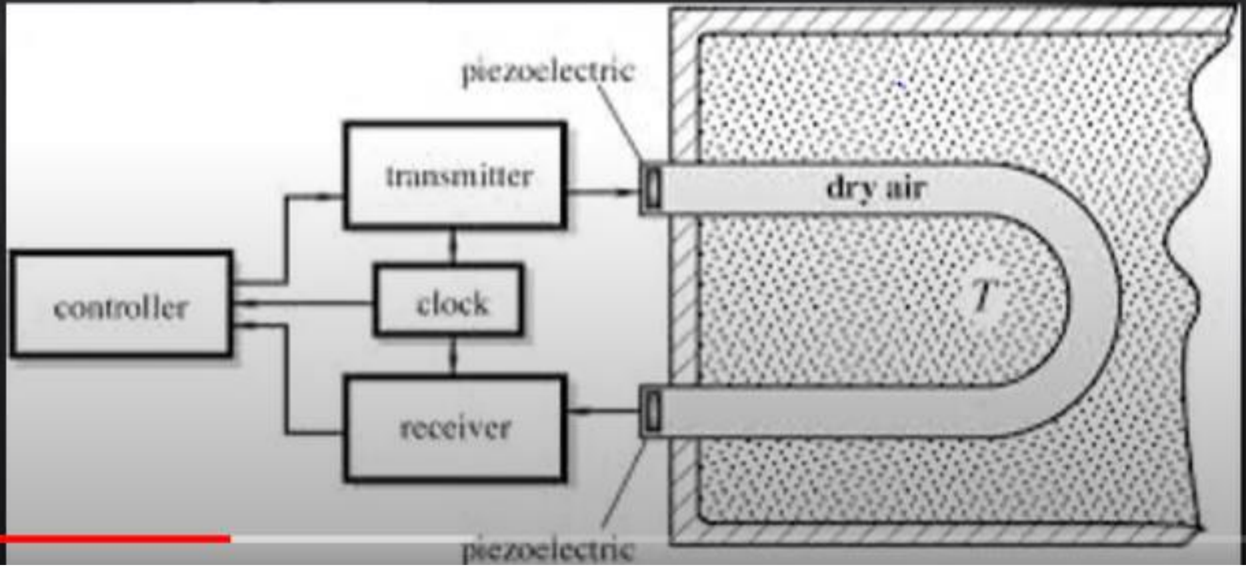
$$\upsilon = 331.5\sqrt{\frac{T}{273.15}}(m/s)$$



How it work?

The controller will send the acoustic waves through the transistor And let the waves pass through the dry air. And from the dry air it will come back and receive by the receiver.

The transmitting and receiving crystals may also be incorporated into a sealed enclosure with a known content whose temperature has to be measured.

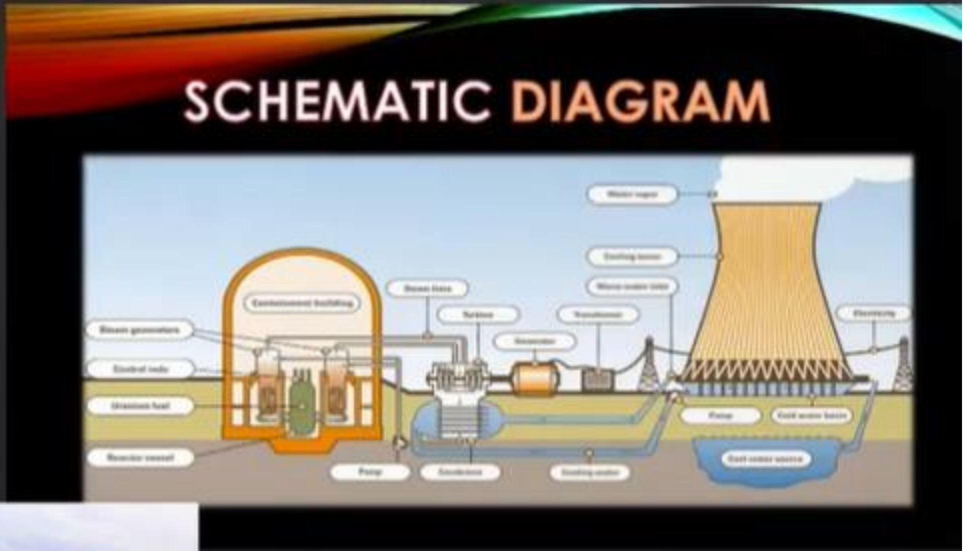


How we measured?

- Operating principle
  - Relationship between temperature of the medium
  - And Speed of sound
- $V=331.5 * \sqrt{(T/273.15)}$
  - V = velocity(meter per second)
  - T = temperature(Kelvin)

Where we need to used it?

- ❖Space craft
- ❖Nuclear Turbine
- ❖Airplane



THERMOEMF SENSORS

- Thermoemf temperature semen are thermocouples which arc most extensively used in industry, over a wide range of temperatures. The range, however, is made wide using different materials The measurement does not involve separate supply.
- A resolution of 0.1-0.2°C at ambient condition is obtained which increases at high values to about $\pm$5°C.
- It was discovered by J. Seebeck that when two conductors C1, and C2 of different compositions *arc made* up into a closed electrical circuit as shown in Figure.
- Refer pdf

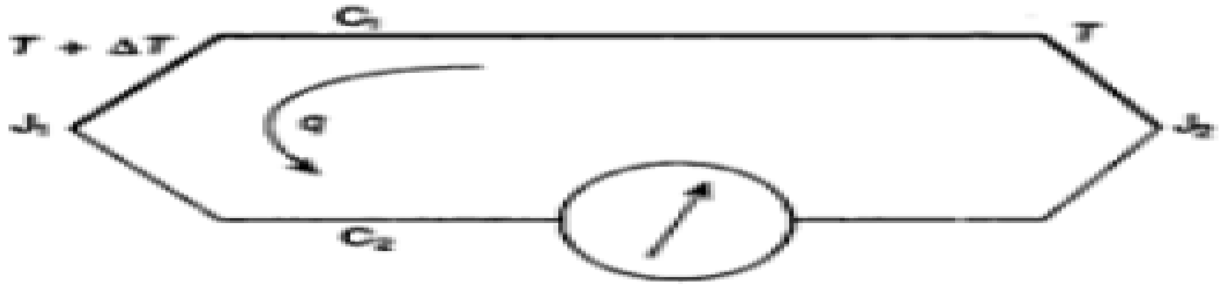


Fig. 3.19 Basic thermocouple.

- The Seebeck emf has been found to be the algebraic sum of two potentials named after their discoverers—Peltier and Thomson
- The 'Peltier effect states that *one of the junctions is heated and other cooled lf a current* is *allowed to flow in the circuit, the amount of the temperature rise in one junction and the amount of temperature fall in the other as also which will be heated and which cooled, will depend on the current intensity and direction, besides the compositions of the conductors.*
- The electrons travelling across the junctions actually do some work or some energy forces them to easel across the junctions, that is, the thermal energy of the electrons is either higher or lower which *causes* the junctions to get heated or cooled.

The heat flow H_f (power) across the circuit is proportional to current f in the circuit so that.

$$H_f = \pi I \tag{3.48}$$

where π is a constant called Peltier coefficient and is measured in volts.

Thomson, on the other hand, found that *with a current flowing in a single conductor* C_i, *its heat content changes and a temperature gradient exists along the length. Accordingly, the heat flow is proportional to current* I *as well as the temperature gradient* ΔT (see Fig. 3.20). Hence,

$$H_f = \sigma I \Delta T \tag{3.49}$$

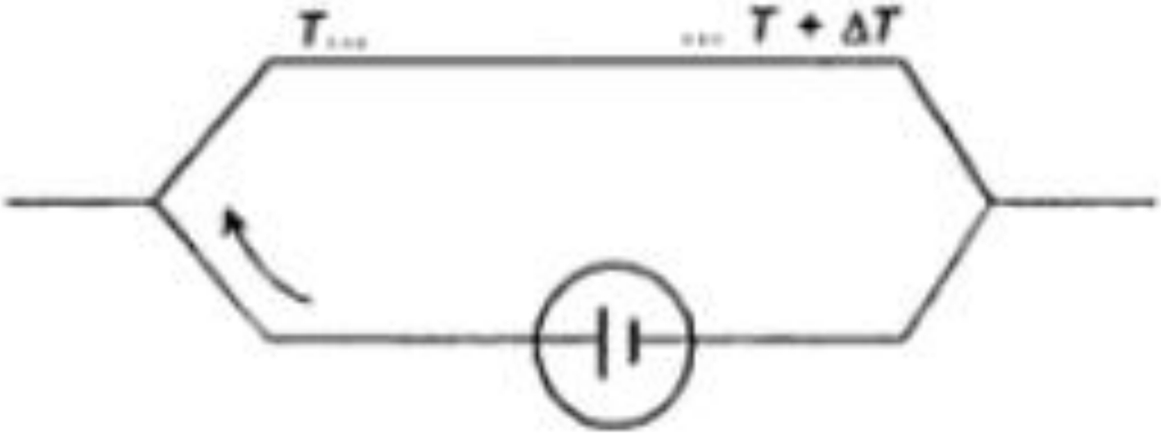


Fig. 3.20 Thermocouple with a source.

Here, σ is a constant called the Thomson coefficient and has the unit V/K.

In Eq. (3.48), π is a potential whereas in Eq. (3.49), σ is the potential per degree temperature. These two equations can be combined to obtain the thermocouple emf. Thus,

$$E = \pi(T + \Delta T) - \pi(T) - (\sigma_{c1}\Delta T - \sigma_{c2}\Delta T) \tag{3.50a}$$

$$= \pi_1 - \pi_2 - \int_1^2 \sigma_{c1}\, dt + \int_1^2 \sigma_{c2}\, dt \tag{3.50b}$$

which can be modified by making ΔT very small to obtain

$$P = \frac{dE}{dT} = \frac{d\pi}{dT} - (\sigma_{c1} - \sigma_{c2}) \tag{3.51}$$

The quantity dE/dt is called the thermoelectric power P, for the two conductors and is defined as the thermal rate of change of emf acting around a couple with change of temperature in one junction.

Now, if a charge q passes around the couple in an anticlockwise direction consisting of metals C_1 and C_2, its junctions J_1 and J_2 at temperatures $T + \Delta T$ and T, then heat (energy) absorbed at $T + \Delta T$ is $q\pi_1$ and heat released at T is $q\pi_2$. Heat released out in metal C_1 at temperature $T + (\Delta T/2)$ is $q\sigma_{c1}\ \Delta T$ and heat absorbed in metal C_2 at temperature $T + (\Delta T/2)$ is

$q\sigma_{c2}\Delta T$. Assuming all these processes are reversible, as is usually the case, the sum total Σ (Heat/Temperature) = 0. Hence,

$$\frac{q\pi_1}{T+\Delta T} - \frac{q\pi_2}{T} - \frac{q\sigma_{c1}\Delta T}{T+(\Delta T/2)} + \frac{q\sigma_{c2}\Delta T}{T+(\Delta T/2)} = 0 \tag{3.52}$$

With reference to Fig. 3.21, it is now easily shown that

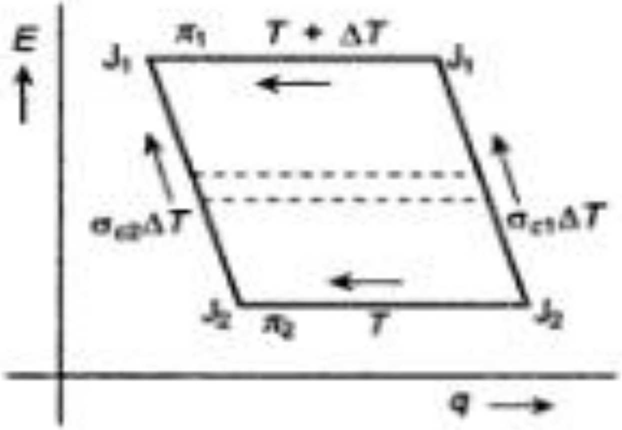


Fig. 3.21 Charge–voltage cycle of a thermocouple.

$$\frac{\pi_1}{T+\Delta T} - \frac{\pi_2}{T} = \int_{T}^{T+\Delta T} \frac{d}{dT}\left(\frac{\pi}{T}\right)dT$$

and

$$\frac{\sigma_{c1}\Delta T}{T+(\Delta T/2)} - \frac{\sigma_{c2}\Delta T}{T+(\Delta T/2)} = \int_{T}^{T+\Delta T} \frac{(\sigma_{c1}-\sigma_{c2})dT}{T}$$

so that

$$\int_{J_2}^{J_1} \frac{d}{dT}\left(\frac{\pi}{T}\right)dT - \int_{J_2}^{J_1} \frac{(\sigma_{c1}-\sigma_{c2})dT}{T} = 0$$

On differentiating, we get

$$\frac{d}{dT}\left(\frac{\pi}{T}\right) = \frac{\sigma_{c1} - \sigma_{c2}}{T}$$

or,

$$\sigma_{c1} - \sigma_{c2} = T\frac{d}{dT}\left(\frac{\pi}{T}\right) \tag{3.53}$$

Using Eq. (3.51),

$$\frac{dE}{dT} = \frac{d\pi}{dT} - T\frac{d}{dT}\left(\frac{\pi}{T}\right) = \frac{\pi}{T}$$

so that

$$\pi = T\frac{dE}{dT} \tag{3.54}$$

showing that the Peltier coefficient for the junction of a pair of conductors is the product of the absolute temperature of the junction, T, and the thermal rate of change of emf for the whole circuit with that junction temperature change.

The emf values and range of thermocouple can be ascertained from the thermoelectric diagram for different set of conductors. Such a diagram was proposed by Professor Tait in 1871. It is the plot of P with respect to T. For the two conductors forming a couple, the two straight lines for conductors C_1 and C_2 are shown in Fig. 3.22. If we know the equations of the lines, emf is easily obtained for the couple. If they are straight lines, then the equations, from the figure, are

$$P_{c1} = m_1 T + K_1 \tag{3.55a}$$

and

$$P_{c2} = m_2 T + K_2 \tag{3.55b}$$

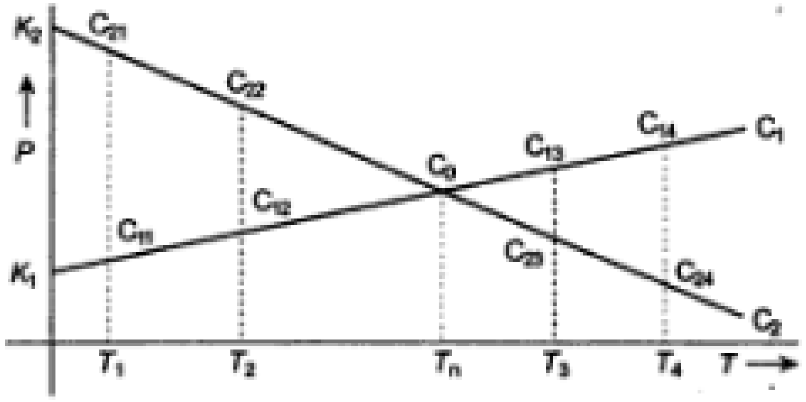


Fig. 3.22 P–T plots for the two components of a couple.

so that the emf, for the two conductors with junction temperature T_1 for the cooler and T_2 for the hotter one, is given by

$$[E]_1^2 = \int_1^2 [P_{c1} - P_{c2}]dT = \int_1^2 [(m_1 - m_2)T + (K_1 - K_2)]dT$$

which on integration, yields

$$E = \frac{1}{2}(m_1 - m_2)(T_2^2 - T_1^2) + (K_1 - K_2)(T_2 - T_1) \tag{3.56}$$

Keeping T_1 fixed and T_2 varying, E–T_2 curve is obtained to be a parabola. Equation (3.56) is then transformed to

$$E = (T_2 - T_1)\left[\frac{(T_2 + T_1)}{2}(m_1 - m_2) + (K_1 - K_2)\right] \tag{3.57}$$

It is to be noted that at $T_1 = T_2$, $E = 0$.

Also at,

$$\frac{1}{2}(T_2 + T_1) = \frac{K_2 - K_1}{m_1 - m_2} \tag{3.58}$$

$E = 0$, that is, E is zero when the average temperature of the junction is $(K_2 - K_1)/(m_1 - m_2)$. This temperature is called the *neutral temperature* and occurs when $P_{e1} = P_{e2}$ which occurs at the intersection of the two straight lines. If this temperature is represented by T_n, Eq. (3.56) may be rewritten as

$$E = (m_1 - m_2)(T_2 - T_1)\left(\frac{T_1 + T_2}{2} - T_n\right) \tag{3.59}$$

The plot of E versus T drawn in Fig. 3.23 shows that emf E_n at T_n is maximum after which there is a decrease of E again with difference of temperature increasing. From Fig. 3.22, the emf E for the couple for junction temperatures T_1 and T_2 would be the area $C_{21}C_{22}C_{12}C_{11}$. If one junction temperature is T_1 and the other T_3 beyond T_n, then the effective emf would be

$$E_{eff} = \text{Area } (C_{21}C_0C_{11}) - \text{Area } (C_{13}C_0C_{23}) \tag{3.60}$$

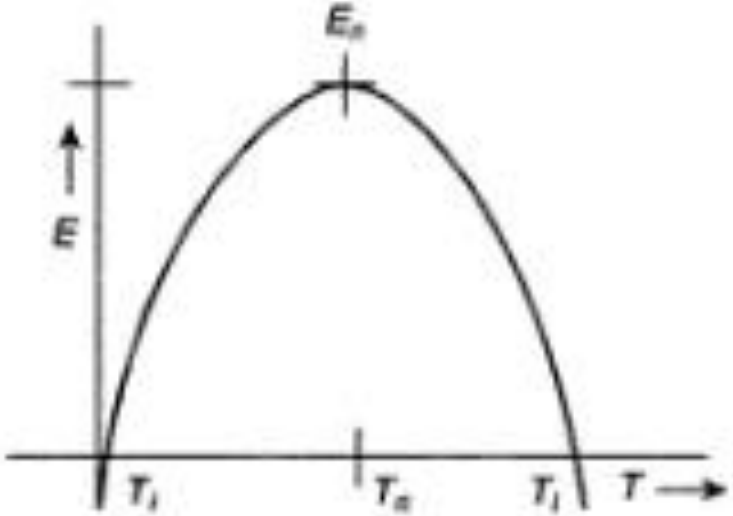


Fig. 3.23 Generalized E–T diagram of a thermocouple.

Raising the temperature beyond T_3, say to T_4, it is possible that the emf becomes reversed and hence, T_n is sometimes known as the *temperature of inversion*. The couple is normally to be operated within a hot junction temperature of T_n.

Most metals have emf-T curves as approximate parabolas so that the thermoelectric lines are usually straight. Some exceptions are the cases of nickel and iron which have several points of inflexions. Figure 3.24 shows thermoelectric lines of some common elemental materials in which inflexions of the lines of nickel and iron have been clearly shown. Seebeck himself prepared a table of 25 elemental materials in the order that when any two form a circuit, current flows across the hot junction from the element occurring earlier to that occuring later in the table. The table is reproduced here as Table 3.8.

Table 3.8 Thermoelectric materials

S.No.	*Element*	*S.No.*	*Element*
1	Bi	14	Mo
2	Ni	15	Rh
3	Co	16	Ir
4	Pd	17	Au
5	Pt	18	Ag
6	U	19	Zn
7	Cu	20	W
8	Mn	21	Cd
9	Ti	22	Fe
10	Hg	23	As
11	Pb	24	Sb
12	Sn	25	Te
13	Cr		

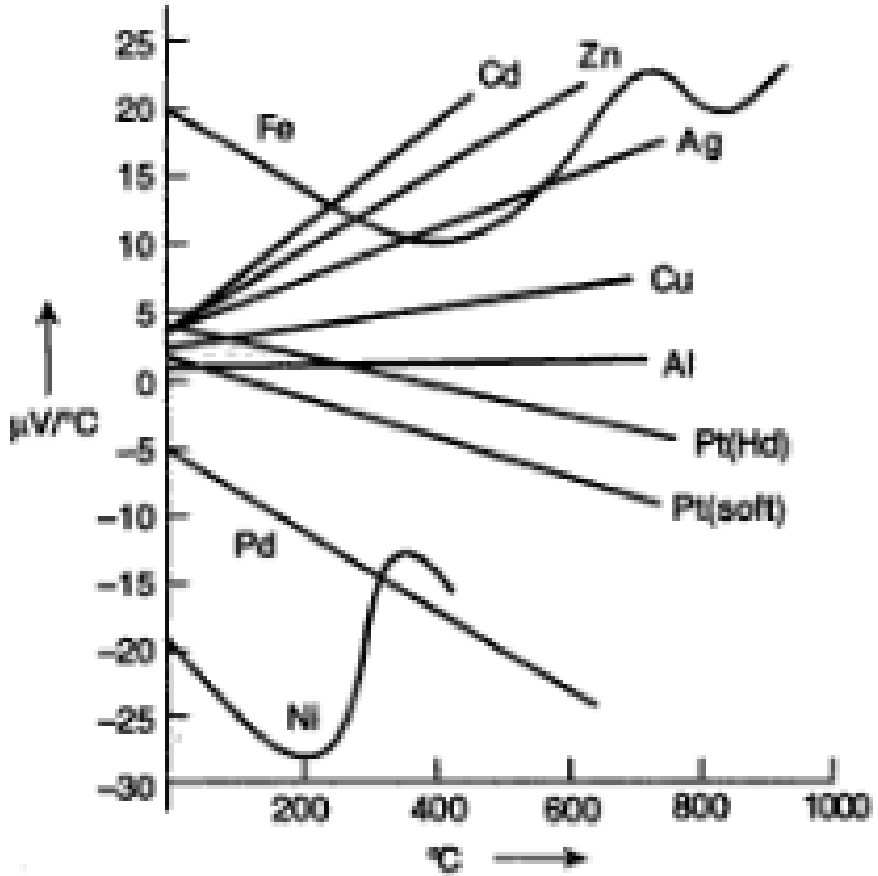


Fig. 3.24 Thermoelectric lines of different elements.

Presently, commercial thermocouple elements are also chosen from alloys for better performance.

- While making a measurement with thermocouple sensors. it is necessary to introduce measuring Instruments which therefore, are likely to affect the thermoemf property of the couple. Some new junctions, in effect are formed because of these insertions.
- The ideal conditions leading to the thermoemf generation for a couple are rarely met in practice and more often than not empirical situations arise and calibration of the measuring system with the thermoemf transducer becomes necessary.

Some laws of the behavior of the thermocouple have accordingly been derived. These *are*

1. Low of Intermediate temperature: The emf for a couple. each element of which is homogeneous in constitution, with junctions at temperatures *T1*, and T2 is not affected by temperatures elsewhere in the circuit.

2. Law of Intermediate metals: If a third homogeneous metal is inserted anywhere in the couple without affecting the junctions J1, and J2 and their temperatures T1 and T2, and the new junctions of the asserted metal having identical temperature, the thermoemf of the couple remains unaffected.

3. Law of homogeneous circuits: If the circuit is made of a single homogeneous metal, no current flows through the application of heat done and no thermoemf develops.

MATERIALS FOR THERMOEMF SENSORS

Materials for Thermoemf Sensors

Material choice is guided by quite a few important factors:

(a) high thermoemf per unit temperature change. that is. high thermoelectric power.

(b) low electrical resistance of the couple.

(c) linearity of *E*-*T* curve over the range of Interest.

(d) high melting point of the couple materials *for* wider range,

(e) material should be available as pure and homogeneous, workable in desired shapes and should not be easily contaminable.

(f) should be usable over king period of time without getting brittle. or acquiring scales. or change of composition (for alloy type materials).

(g) should be properly annealed to make it free from Mains/stresses produced during cold drawing process.

- Elemental materials listed by Seebeck are not all suitable for commercial pairing to form thermocouples. Throe categories of thermocouple do mist in practice. namely

i. the base metal type consisting of couple members made of elemental base metals *or* alloys thereof.

ii. the noble / Precious metal type made from noble metals or alloys thereof. and

iii. nonmetallic types.

- Thermocouples *are* usually Identified by capital letters of the English alphabet. The base metal types are identified by letters E, I, K, N, and T; and the noble metals thermocouples are identified by G, C, D, B, R, and S. Nonmetallic thermocouples are special kind and will be considered separately.
- Several countries *have* included this standardized nomenclature f type tenets in specification schedule providing temperature range, tolerance, service. (intermittent or continuous). and quality (standard or special). International Electrotechnical Commission (IEC) publication 584 with various parts (1, 2, 3) is such a standardizing document. Table 3.9 shows a specification sheet of the various types of couples.

Table 3.9 Thermocouple specifications

Type	Materials (Composition in brackets, positive first)	Compensating cable colour	Range (°C) (intermittent in parantheses)	Tolerance	dE/dT µV/°C (range)	Remarks
B	Pt(70) Rh(30) Pt(94) Rh(6)	Grey Red	600–1500 (1750)	±0.0025 $\lvert t \rvert$	5–12	Most stable better life expectance than R, S types at higher *T*
C	W(95) Re(5) W(74) Re(26)	White, red trace Red	0–2300 (2600)	±1%	5–10	Used for short duration in neutral or reduced atmosphere
D	W(75) Re(25) W(97) Re(3)	White, yellow trace Red	0–2300 (2600)	±1%	5–10	Used for short duration in neutral or reduced atmosphere
E	Chromel (Tophel) Ni(90) Cr(10) Constantan (Cupron) Cu(57) Ni(43) Mn, Fe, C(traces)	Purple Red	−40–800 (1000)	±1.5°C/ ±0.004 $\lvert t \rvert$	15–60 atmosphere	Works in oxidizing
G	W(100) W(74) Re(26)	White, blue traces Red	0–2300 (2600)	±1%	5–10	Used for short duration

(Cont.)

Table 3.5 Cont.

Type	Materials (Composition in brackets, positive first)	Compensating cable colour	Range (°C) (intermittent in parantheses)	Tolerance	dE/dT μV/°C (range)	Remarks
J	Fe(100) Constantan	White Red	–200–1000 (1100)	±1.5°C/ ±0.004 | t |	45–57	Better in reducing atmosphere, within 600°C in any atmosphere
K	Ni(98) Cr(2)/ Ni (100) Constantan	Yellow Red	–40–1000	±1.5°C/ ±0.004 | t |	40–55	Better in oxidizing atmosphere
N	Chromel Ni(90) Cr(10) Alumel Ni(94) Mn(3) Al(2) Si(1)	Yellow Red	–200–1200 (1300)	±1.5°C/ ±0.004 | t |	40–55	Better in oxidizing atmosphere
R	Pt(87) Rh(13) Pt(100)	Black Red	0–1400 (1600)	±1°C/ ±0.0025 | t |	5–12	Most stable in all atmospheres
S	Pt(90) Rh(10) Pt(100)	Black Red	0–1400 (1600)	±1°C ±0.0025 | t |	5–12	Most stable in all atmospheres and a little better linearity
T	Cu(100) Constantan	Blue Red	–200–350 (500)	±0.5°C/ ±0.004 | t |	15–60	Oxidation occurs beyond stipulated range

In the Table 3.9 R, S, and B types are shown to have almost similar entries in the appropriate columns. However, the difference lies in their linearity to a very small extent and slight variation in thermoemfs stated as range in the table. Figure 3.25 shows the relative differences in *E*–*T* plots. The *E*–*T* characteristics of the types, in general, are shown in Fig. 3.26.

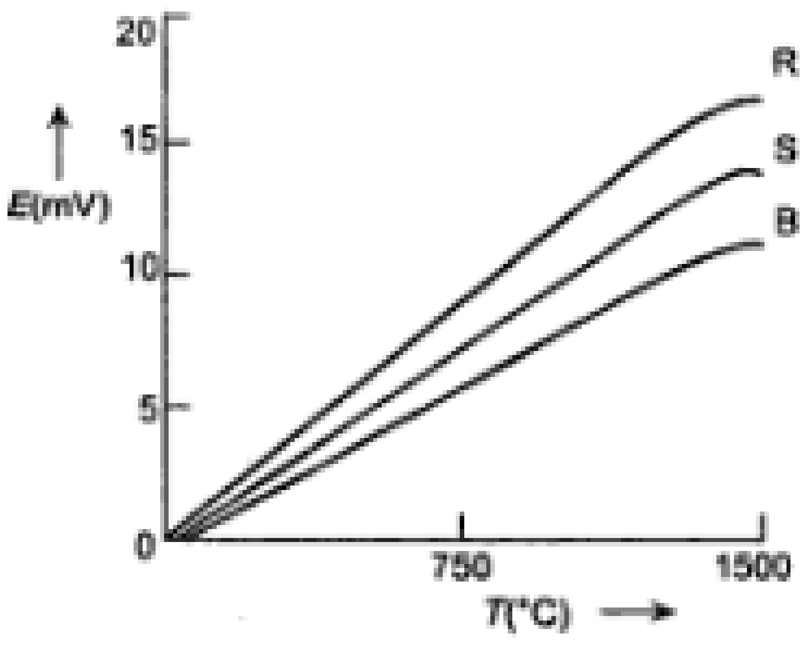


Fig. 3.25 emf–temperature characteristics of R, S, B type thermocouples.

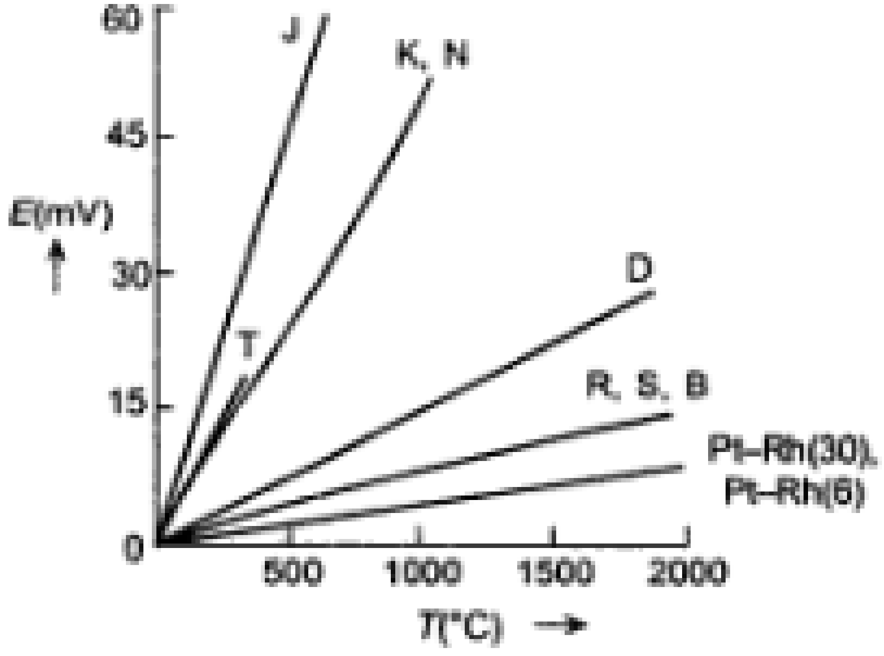


Fig. 3.26 emf–temperature curves for different types of thermocouples.

Besides the couples listed in Table 3.9, there are other thermocouples employed for short term services at high temperatures. W–Re (97–3), W–Re (75–25) is one such couple already listed in the table. It is important that materials with high melting point be employed for the purpose with the other basic requirement satisfied. Ir and Ir–Rh (60–40) is another type which can be intermittently used up to 2000°C. Long term uses cause both Ir and Rh to get oxidized in free atmosphere. Also, being brittle in nature, it breaks with prolonged use as recrystallization occurs during the process. However, it can be used under all atmospheric conditions and has a relatively better linear E–T characteristics upto about 2000°C.

W–Re, and W–Re thermocouples, listed already, are also used at high temperatures, mainly intermittently, but only in neutral and/or reducing atmosphere. At high temperatures, they also tend to recrystallize and turn brittle. Preparation of the junction is important to avoid this. It is welded in a protective atmosphere without being subjected to stresses. Another set of couples for high temperature applications are Mo–Re (95–5), Mo–Re (59–41) and Mo (100), Mo–Re (59–41). They are used in special cases such as temperature measurements in nuclear reactors. The E–T curves for such high temperature thermocouples are shown in Fig. 3.27.

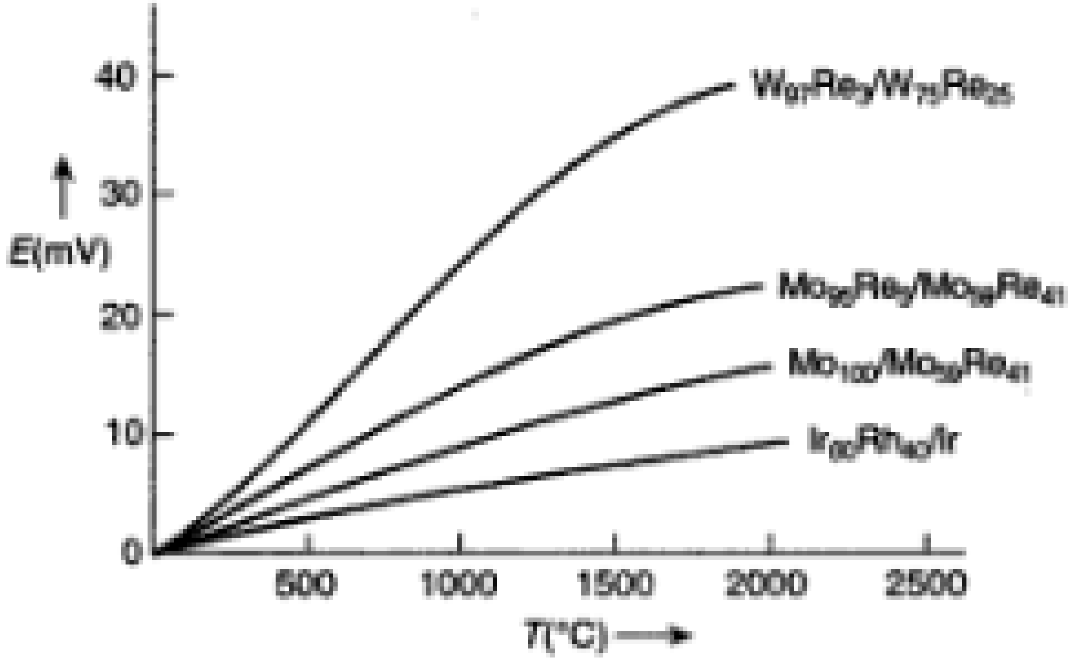


Fig. 3.27 emf–temperature curves for high temperature thermocouples.

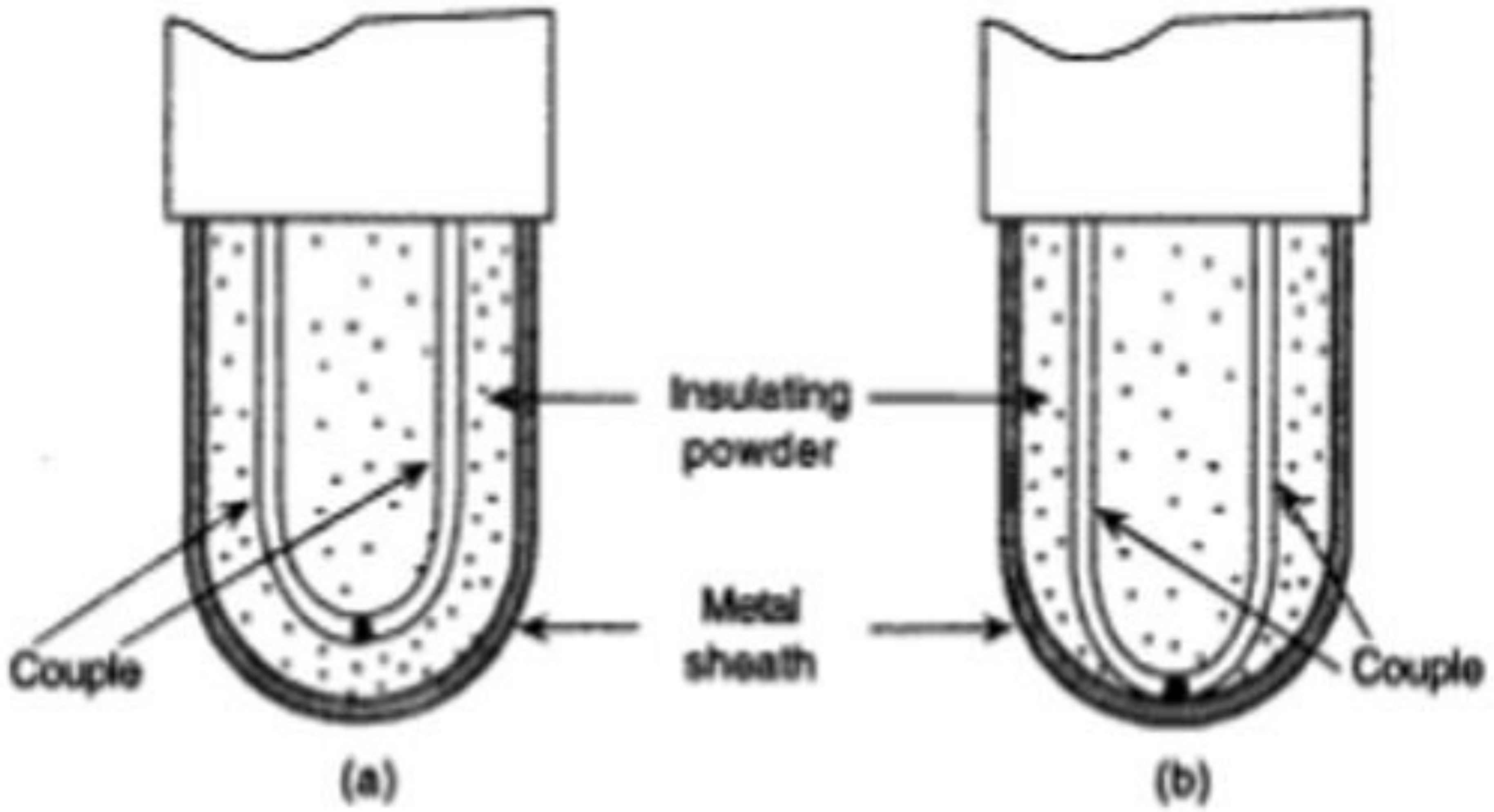
Gold and silver, as such, have not been used as thermocouple members, although gold and gold alloys are now being increasingly used for low temperature applications. Au, Pt thermocouples are being used for calibrating other thermocouples upto about 900–1000°C. Also gold–constantan thermocouples are used for the same purpose over a slightly lower range. They are nonmagnetic and used in magnetic fields and pure noble elements (such as, Au–Pt) can be made extremely homogeneous.

Au–Fe, Ni–Cr thermocouple is being used at very low temperatures as is Au–Fe, Au–Ag thermocouple. Here, iron is found only in traces (≤0.03%) while Ni–Cr is basically constantan. These thermocouples are ductile and care should be taken to see that no strain/stress is produced in them. Co–Au (2.11), Au–Ag (0.37) thermocouple is also employed at low temperatures. It has low electrical resistance but is easily deformable.

Nonmetallic thermocouples have been proposed to be used in atmospheres containing carbon, since metals form carbide and metals such as W and Mo become more brittle and break under such a condition. For high temperatures, upto about 2200°C, in carbon-containing conditions, B_4C, C thermocouple is used. This thermocouple is to be specially prepared, particularly the junction. It has almost a linear *E–T* response curve with a large thermoelectric power, of about 0.25 mV/°C, but is slightly dithering above 400°C.

Thermocouple

- A thermocouple is a **device for measuring temperature**.
- It comprises two dissimilar metallic wires joined together to form a junction.
- When the junction is heated or cooled, a small voltage is generated in the electrical circuit of the thermocouple which can be measured, and this corresponds to temperature.



ig. 3.28 The MI thermocouples: (a) the usual design, and (b) design with the junction in contact with the sheath.

- https://www.youtube.com/watch?v=v7NUi88Lxi8 -How Thermocouples Work - basic working principle + RTD

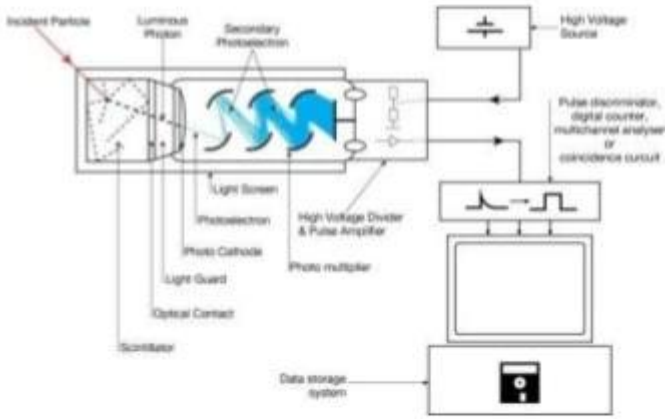
3.10.3 Thermocouple Construction

Depending on the use under different conditions, construction of a couple complete with protection varies. Usually, the couple is kept separated by small insulator beads (single-hole, twin-hole, 4-hole types are common) to enable flexibility with the junction kept free and on the other side, the free ends of the members are passed through an insulator disc onto terminal lugs which also are shaped as per standardized recommendations. The entire thermocouple with such insulator sleevings is now enclosed in a porous ceramic tube and finally enclosed in a metal sheath for protection against the likes of mechanical shocks. The use of ceramic tube is optional for low temperatures or for non-noble metals. For salt-bath and corrosive atmospheres, the sheath materials must be properly chosen and replaced after stipulated periods.

Another way of construction is by embedding the thermocouple member in an insulating powder such as MgO, Al_2O_3 and so on, in an enclosing sheath made of prescribed materials. The insulation powder is tightly packed to allow no movement of the couple. Different shapes can be given to such thermocouples. A typical case of insulated junction type thermocouple is shown in Fig. 3.28(a). In case of Fig. 3.28(b), the junction is in contact with the sheath and the sheath, in this case, is insulated from the mounting fixtures. While thermocouple of Fig. 3.28(a) has slow response, that of Fig. 3.28(b) has a much faster response. Such thermocouples are sometimes known as mineral insulated (MI) or sheathed thermocouples. Sheaths used for different commonly used thermocouples are listed in Table 3.10.

Structure of Scintillation counter

- It consists of a scintillator which generates photons in response to incident radiation. a sensitive photomultiplier tube (PMT) which converts the light to an electrical signal and electronics to process this signal.
- Sciontillator consists of a transparent crystal, usually a phosphor, plastic or organic liquid.



RADIATION SENSORS

- Radiation detectors, also called radiation sensors, are instruments that sense and measure radiation emissions or levels of radiation produced by a source.

- When radiation passes inside a detector, it **causes ionization of gas atoms**, separating atoms into positive ions and electrons. Separated electrons and positive ions are attracted to the electrodes, causing a current to flow. This is converted into electric signals, which are then measured as the amount of radiation.

TYPES OF RADIATION SENSORS

- There are three different main types of radiation detectors. These are detectors **based on gas ionization, scintillation detectors, and semiconductor detectors**.

- Detectors based on gas ionization are the ionization chamber, proportional counter, and Geiger–Müller counter.

USE OF RADIATION SENSORS

- A radiation detector is a device used to track, detect, or identify high-energy particles or radiation from natural or artificial sources such as cosmic radiation, nuclear decay, particle accelerators, and X-rays.

Radiation Sensors

- Radiation sensors are also called as Sensistors.
- It can be classified as

1. Photoelectric cell such as Photo emissive cell.
2. Photoemf cell such as Photovoltaic, barrier layer, boundary layer type
3. Photoconductive cell such as light sensitive resistors.

RADIATION SENSORS

- Photosensistor was considered as a combination of two electrodes in an electrolyte.
- According to the radiation changes, frequency or wavelength ,the electrodes change in Size and shape and the nature of electrolyte also changes i.e gas, liquid or solid.
- One of the fundamental laws on which some of these sensors are based is the Photoelectric effect.

RADIATION SENSORS

- Radiation energy propagating through space in quanta when collides with matter, certain integral number of quanta called photons are emitted, reflected and others absorbed depending on the material characteristics.
- The intensity of incident radiation determines the number of electrons released.
- The mechanism is explained by the band structure.

Radiation Sensors

- If the photon energy is sufficient to raise an electron in the material to a vacant conductivity band level , the electrical conductivity of the material increases.
- Two situations may now arise:

1. The incident radiation energy hv is just sufficient to transfer an electron into a vacant conductivity level and not beyond. This process leads to increased photoelectric conductance of a substance and the effect is sometimes referred to as **Inner photoelectric Effect.**

Radiation Sensors

- If incident radiation energy hv is high enough, it then causes the electron to be detached and emitted from the material. This is known as the **Outer photoelectric effect** and is effective in gaseous systems.

APPLICATION OF RADIATION SENSORS

- They are widely used in medical applications for image generation **(X-rays and tomography)**, as well as high-energy physics experiments, plant laboratories, airports security (X-rays machines), and radiation sensing for nuclear installations.
- https://youtu.be/TnvAQ9ZHDyE -GM counter
  https://youtu.be/ogJX9JOndI8 - Scintillation detector

GEIGER COUNTERS

- Its also called as Geiger –Muller Counter.
- Mostly used Gas filled counter.
- A **Geiger counter** is an instrument used for detecting and measuring ionizing radiation. Also known as a **Geiger–Müller counter** .
- It is widely used in applications such as radiation dosimetry, radiological protection, experimental physics, and the nuclear industry

GEIGER COUNTERS

- It detects ionizing radiation such as alpha particles, beta particles, and gamma rays using the ionization effect produced in a Geiger–Müller tube, which gives its name to the instrument.[1] In wide and prominent use as a hand-held radiation survey instrument, it is perhaps one of the world's best-known radiation detection instruments.

- It can be made to have longer operating life time by particularly using Halogen gas filling.

GEIGER COUNTERS

- The commercially available varieties are

1. End-Window type.
2. Cylindrical type.
3. Needle type.

END-WINDOW TYPE

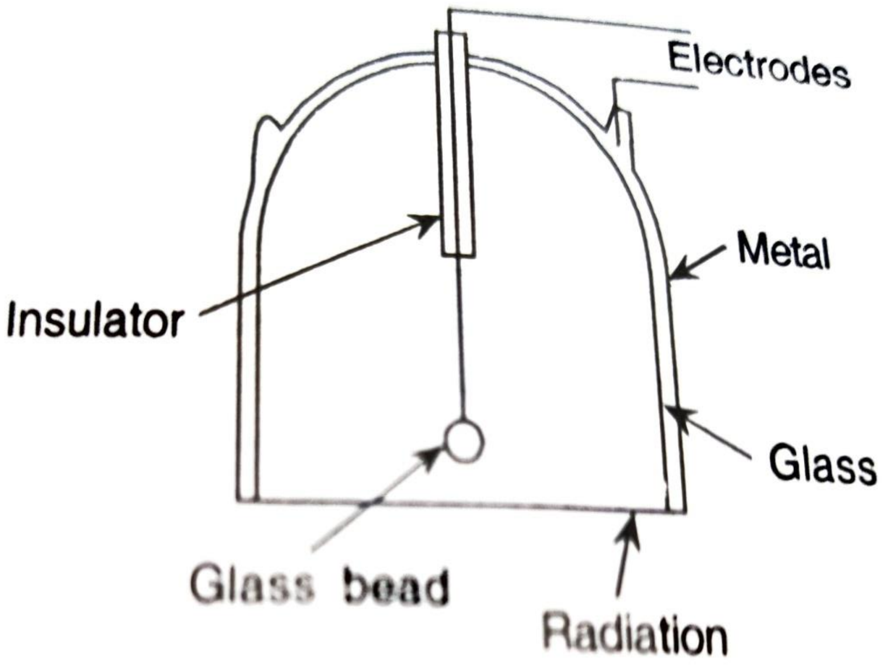


Fig. 5.49 A typical Geiger–Muller counter.

END-WINDOW TYPE

- In the end window type, a metal coated glass tube of cylindrical form has a thin tungsten wire of 0.002-0.01 cm diameter passing through the centre acting as the collector electrode with the body as the other.
- The end window s usually made of mica sheet of a thickness less than 1 mg/cm^2.
- To avoid spark over the central electrode, it terminates into a glass bead .
- Radiation is received by the end window.

CYLINDRICAL& NEEDLE TYPE

- In the cylindrical GM counters,radiation is received by the side walls.
- In the Needle type GM counter, where insertion in a narrow channel s required.

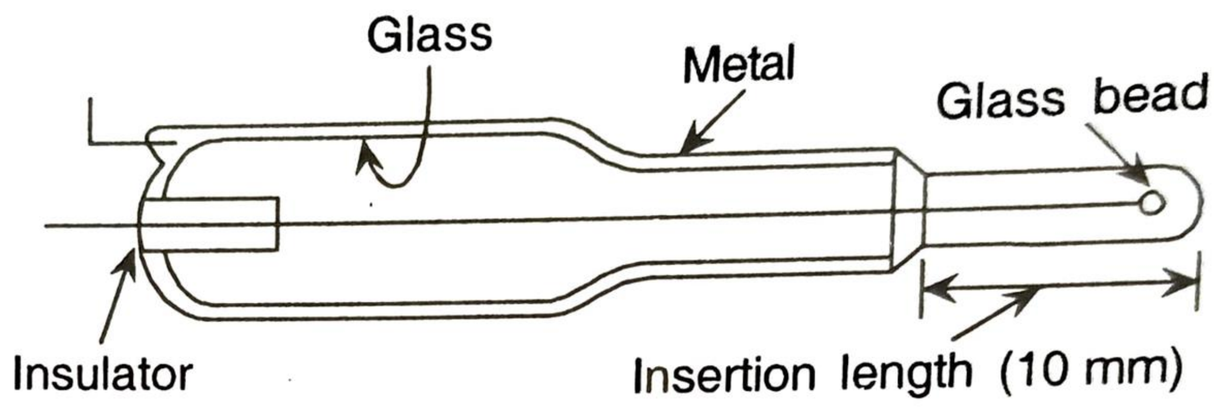


Fig. 5.50 Needle type design of a GM counter.

GEIGER COUNTER

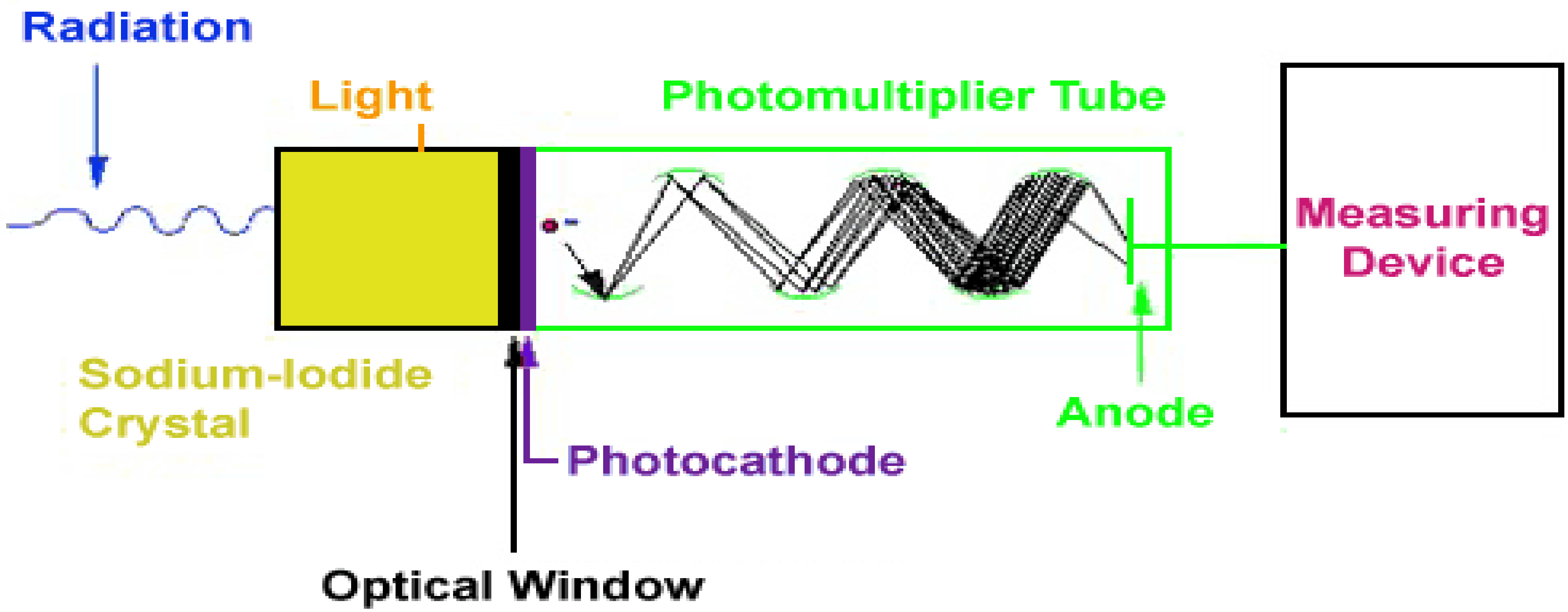
- The GM counter chamber uses a gas at a low pressure of about 0.1-0.15 kg/cm² that consists of 90% insert gas such as Ar & Ne and 10% ethyl alcohol or other organic vapours like methane.
- This mixture ensures charge transit through electrons only.
- One important thing in gas filled counters is the discharges mechanism.
- In the GM counter, the Townsend discharge occurs and with the bulk of electrons in the discharge being collected by the anode, a positive ion sheath or cloud is left to reduce the field and stop the discharge. This is known as **Quenching of the discharge**.

SCINTILLATION DETECTORS

- Certain single crystals of organic or inorganic materials, activated glasses/liquids or plastic fluors have the property that when they receive high energy radiation, they produce very short duration light pulses or flashes called “**Scintillations**”.

- These materials are known as **Scintillators**.

SCINTILLATION DETECTOR



SCINTILLATION DETECTORS

- The basic principle behind this instrument is the use of a special material which glows or "scintillates" when radiation interacts with it.
- The most common type of material is a type of salt called sodium-iodide. The light produced from the scintillation process is reflected through a clear window where it interacts with device called a photomultiplier tube.
- The first part of the photomultiplier tube is made of another special material called a photocathode.
- The photocathode produces electrons when light strikes its surface.

SCINTILLATION DETECTORS

- These electrons are then pulled towards a series of plates called dynodes through the application of a positive high voltage.
- When electrons from the photocathode hit the first dynode, several electrons are produced for each initial electron hitting its surface.
- This "bunch" of electrons is then pulled towards the next dynode, where more electron "multiplication" occurs.
- The sequence continues until the last dynode is reached, where the electron pulse is now millions of times larger then it was at the beginning of the tube.

Application of Radiation Sensors

- They are widely used in medical applications for image generation **(X-rays and tomography)**, as well as high-energy physics experiments, plant laboratories, airports security (X-rays machines), and radiation sensing for nuclear installations.
- https://youtu.be/TnvAQ9ZHDyE -GM counter
  https://youtu.be/ogJX9JOndI8 - Scintillation detector