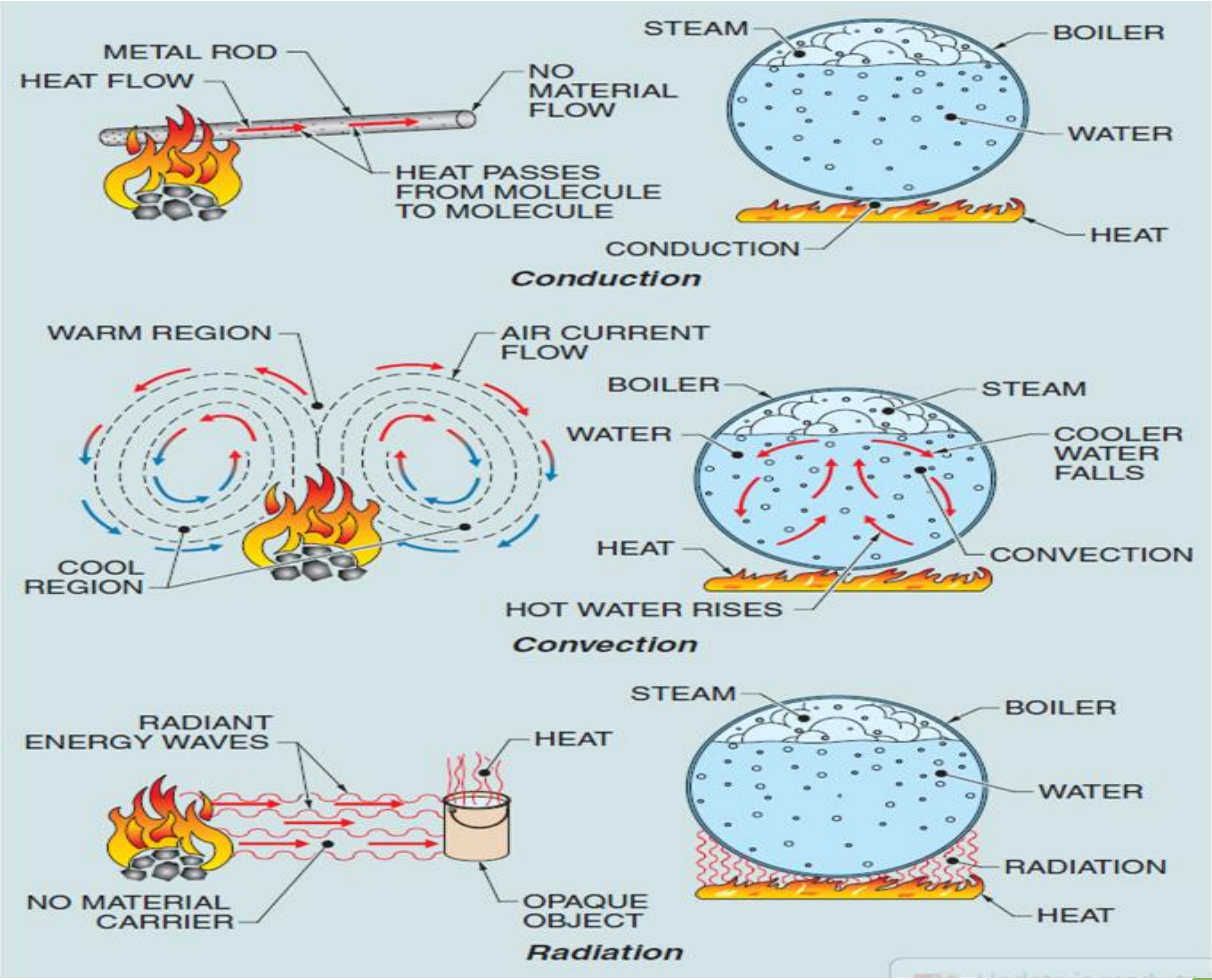
PROCESS INSTRUMENTATION

TEMPERATURE MEASURMENTS

CONCEPT OF HEAT AND TEMPERATURE

- Heat is a form of energy called Thermal Energy.
- Heat Transfer : is the movement of thermal energy from one body to another.
- Temperature: is the degree of heat measured on a definite scale



METAL ROD
HEAT FLOW
NO MATERIAL FLOW
HEAT PASSES FROM MOLECULE TO MOLECULE
STEAM
BOILER
WATER
HEAT
CONDUCTION
Conduction
WARM REGION
AIR CURRENT FLOW
COOL REGION
BOILER
STEAM
WATER
COOLER WATER FALLS
HEAT
CONVECTION
HOT WATER RISES
Convection
RADIANT ENERGY WAVES
HEAT
NO MATERIAL CARRIER
OPAQUE OBJECT
STEAM
BOILER
WATER
RADIATION
HEAT
Radiation

CONCEPT OF HEAT AND TEMPERATURE

There are two concepts to describe the heat of object

- Latent heat: it is energy required to change physical form of matter i.e., from solid to liquid or liquid to gas. Latent heat can not be described in terms of temperature.

- Sensible heat : it is the energy which will change the temperature of a body.

- When an object gets energy which results in the increase of temperature of that object, its sensible heat is increasing.

CONCEPT OF HEAT AND TEMPERATURE

- It is normally NOT possible to measure temperature directly.
- Usually effects of temperature are measured.
- Almost all temperature sensors are designed on the basis of some effect of temperature.
- Most commonly used effects of temperature are:

1) Change in resistance
2) Change in volume
3) Change in length
4) Change in viscosity
5) Change in pressure of gas, vapor or liquid

TEMPERATURE SCALES

- The temperature scales in common use are Celsius scale (°C) and Fahrenheit scale (°F).
- These scales are based on the melting point of ice and the boiling point of water.
- On Celsius scale melting point of ice is 0°C and boiling point of water is 100°C .
- On Fahrenheit scale melting point of ice is 32°F and boiling point of water is 212°F.

Conversion between Celsius and Fahrenheit Temperature scales

Sometime we are required to convert temperature from one scale to another. This can easily be done by using the following equations:

1. **To convert from Fahrenheit (˚F) to Celsius (˚C), we should use the following equation:**

$$T\,°\mathrm{C} = \frac{5}{9}\left(T\,°\mathrm{F} - 32\right)$$

2. **To convert from Celsius (˚C) to Fahrenheit (˚F), we should use the following equation:**

$$T\,°\mathrm{F} = \frac{9}{5} \times T\,°\mathrm{C} + 32$$

Example 1:- Find the following temperature in Fahrenheit scale:

i) -15 °C ; ii) 46 °C

Answer 1 : i) -15 °C □ $= \frac{9}{5} \times (-15) + 32 = 5\,°F$

ii) 46 °C $= \frac{9}{5} \times (46) + 32 = 114.8\,°F$
□

Example 2:- Find the following temperature in Celsius scale:

i) 14 °F ; ii) 104 °F

Answer 2 : i) 14 °F □ $= \frac{5}{9} \times (14 - 32) = -10\,°C$

ii) 104 °F $= \frac{5}{9} \times (104 - 32) = 40\,°C$
□

Kelvin Temperature or (Absolute Temperature)

It has been experimentally determined that the lowest possible temperature is (**–273.15°C**). This is known as **absolute zero** temperature.

A scale known as **Kelvin temperature** was chosen to measure absolute temperature. The zero of Kelvin scale is –273.15

Kelvin temperature (**°K**) is given by:

T°K = T°C + 273.15°

Example 3:- Find the temperature in Kelvin scale for :
i) 0˚C ; ii) 45˚C ; iii) -15˚C

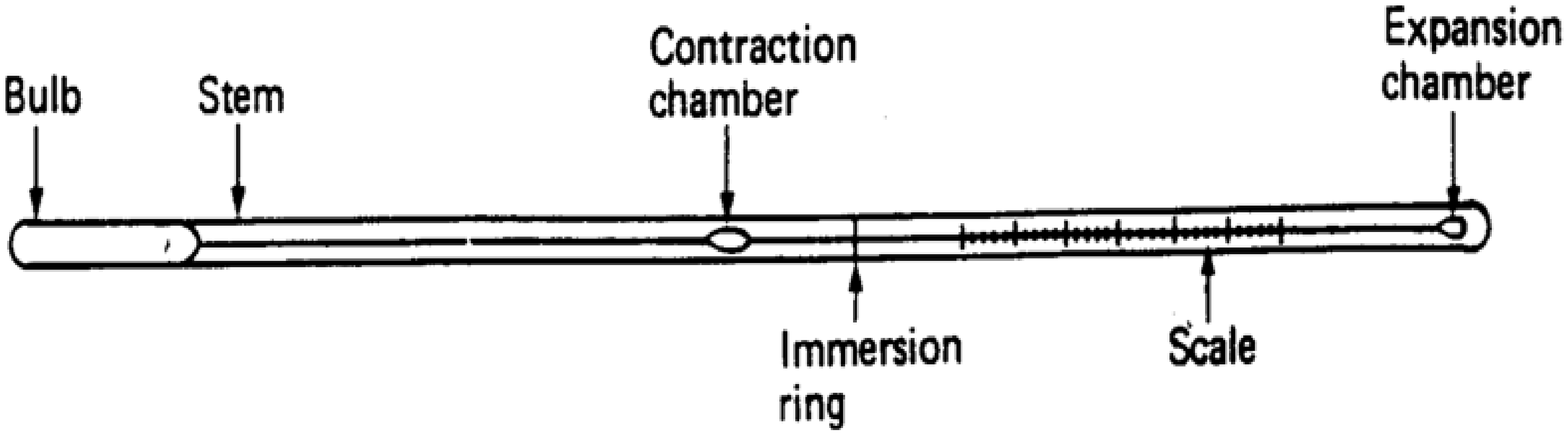
Answer : i) 0˚C ◻ = 0°C + 273.15° = 273.15 °K

ii) 45˚C ◻ = 45°C + 273.15° = 318.15 °K

iii) -15˚C ◻ = -15°C + 273.15° = 258.15 °K

LIQUID IN GLASS THERMOMETER

- **Thermometer** is a sensor used to measure temperature based on the thermal expansion of liquid when temperature changes occurs.



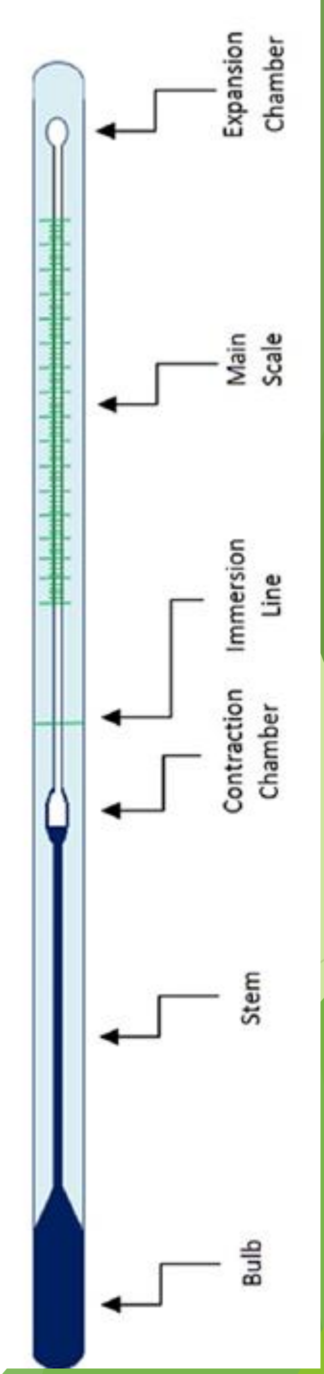
LIQUID IN GLASS THERMOMETER

The structures of typical liquid-in glass thermometer

- **The Bulb** is usually a thin-walled glass chamber that serves as a tank for the liquid.
- **The Stem** is a glass tube that contains the capillary for the liquid.
- **Capillary** is a narrow path which the liquid can rise and fall.
- **The Scale** is a series of markings that is used to read the temperature measurements.
- **Immersion Line** indicates the proper immersion depth on partial immersion thermometers.
- **The Contraction Chamber** it increases the volume of the capillary and

prevents total contraction of the fluid into the bulb at low temperatures.

- **The Expansion Chamber** it protects the thermometer from rupture at high temperatures.



LIQUID IN GLASS THERMOMETER

Working Principle

- The operation of a liquid-in-glass thermometer depends on volumetric Expansion of the liquid.
- The liquid is usually **Mercury**. For any change in temperature, volume of mercury inside the bulb slightly expands or contracts.
- with this effect, the mercury drives up or down the capillary and the temperature is measured with the help of the scale of the thermometer.

LIQUID IN GLASS THERMOMETER

Basic liquid in-glass thermometers:

- **Mercury** freezes at -38.9 ˚F, used commonly for both low and high temperature
- **Organic fluids**, such as Alcohol freezes at(-80˚F), Toluene freezes (-130˚F), or Pentane freezes (-330˚F) are used for very low temperatures measurements.
- Organic fluids are also used in Inexpensive thermometers or in applications in which the release of mercury is not safe when if the thermometer is broken.

LIQUID IN GLASS THERMOMETERS

Advantages

- It can be read directly with the help of the scale.
- very accurate
- cheap to manufacture.
- Easy to carry and handle.

Consequently, these thermometers are often used in

laboratories to monitor baths and to check calibrations of other temperatures

Disadvantages:

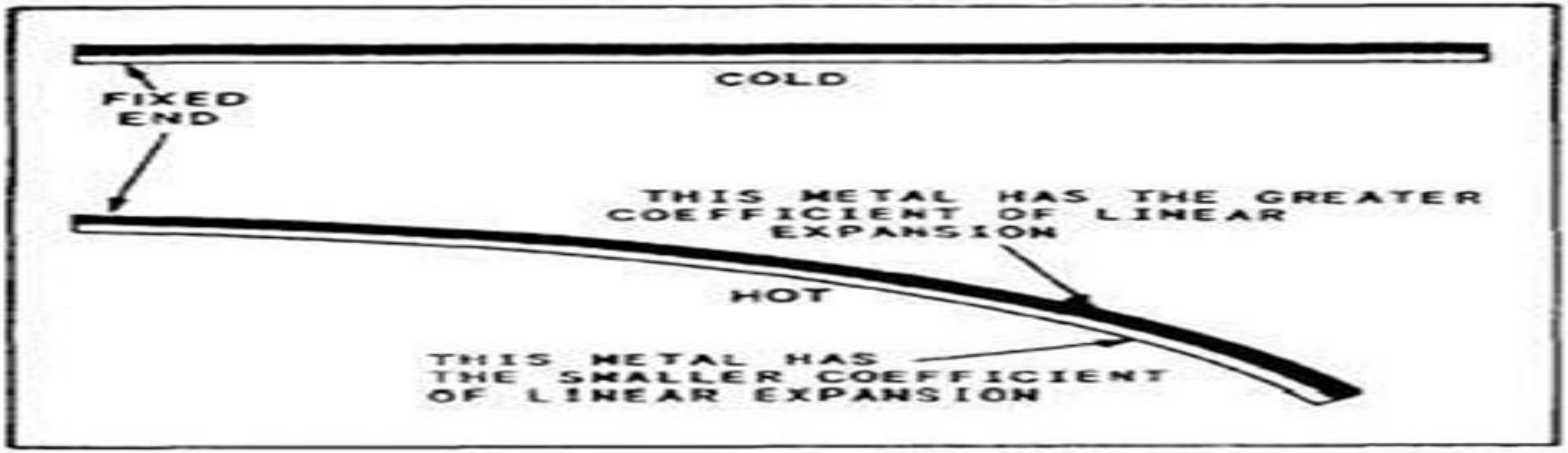
- Not sensitive enough.
- Can't be used for high range of temperature.
- Mercury poses a potential toxic hazard if the glass container is ruptured.

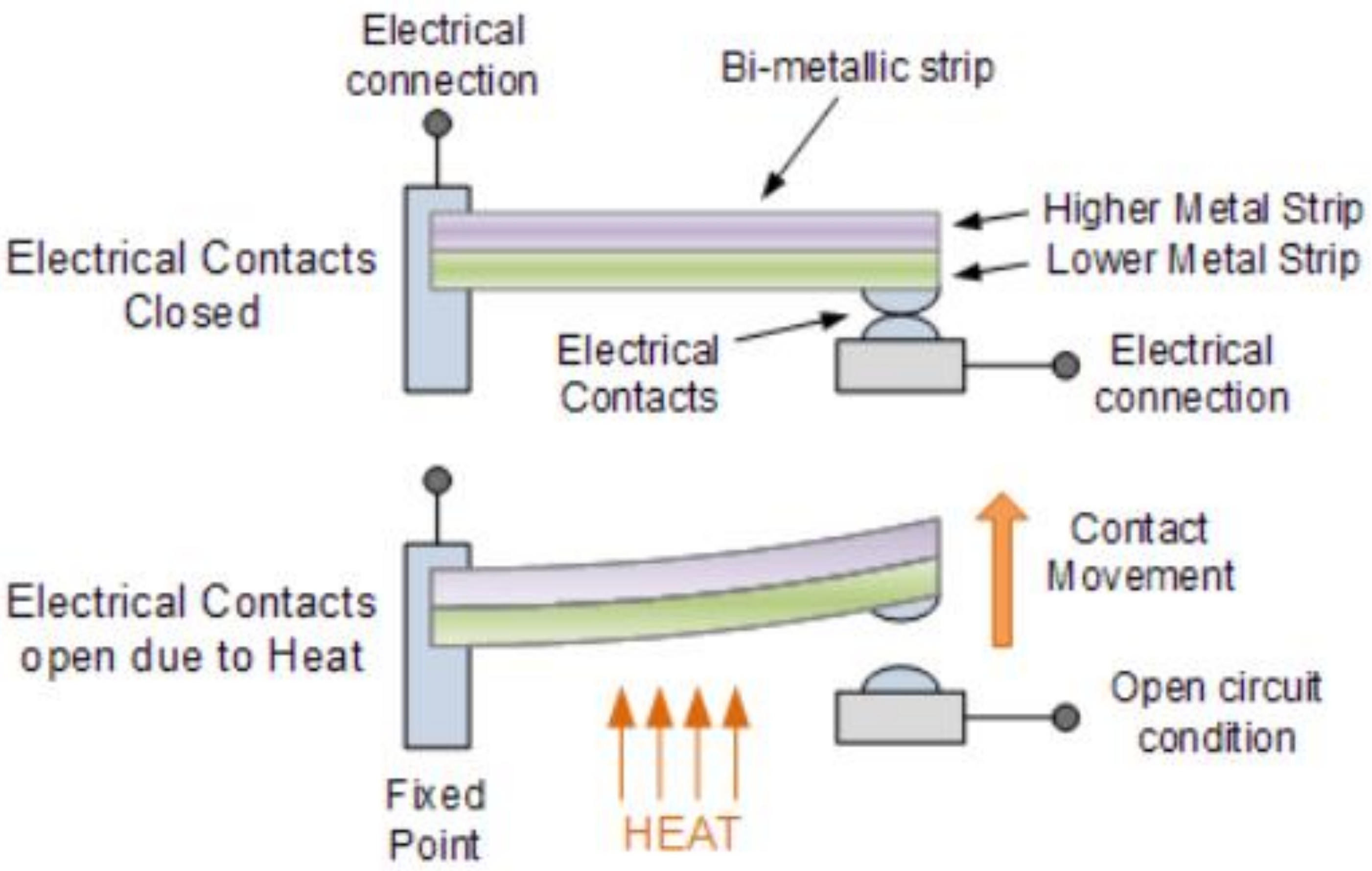
BIMETALLIC ELEMENT THERMOMETERS

- **BIMETALLIC Thermometer** is a sensor used to measure temperature based on the expansion of metals when heated.
- This means that as temperature change the length of strip or rod of the metal will also change. But this increase of length is very small for per degree change of temperature and it is very difficult to measure it.

BIMETALLIC ELEMENT THERMOMETERS

- In order to get considerable measurement or actuation from expansion of metal, two different metal strips of same dimensions are **bonded** together.
- One metal has a high co-efficient of linear expansion (α) and other has a low co-efficient of linear expansion.
- The difference between the two co-efficient should be high. This forms a bimetallic strip when the bimetallic strip is heated one metal expands much more than the other.
- Thus, when these two bonded metal have change in temperature, the strip will curve up or down





https://www.youtube.com/watch?v=2wg5u_90ekQ

BIMETALLIC ELEMENT THERMOMETERS

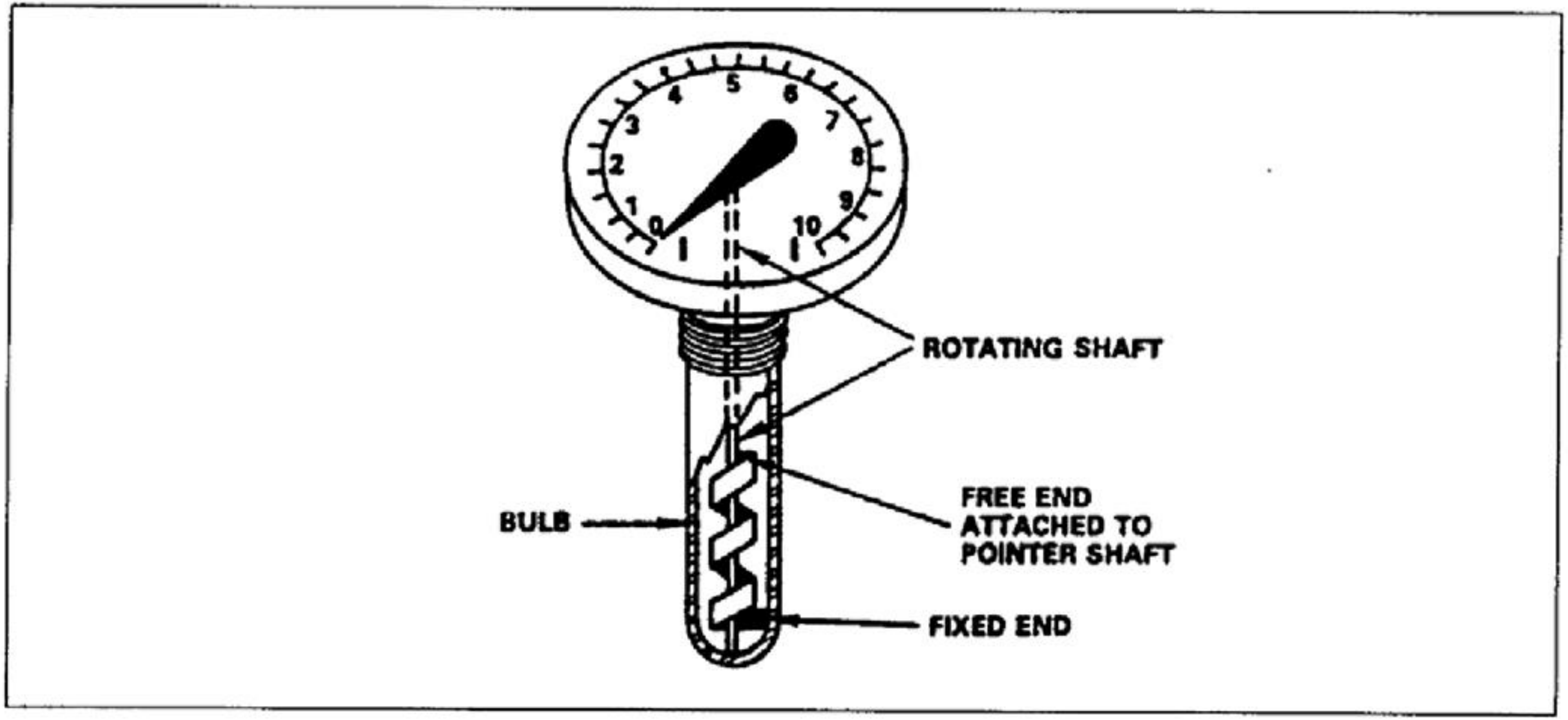
- The amount by which the strip curves depends on the two metals

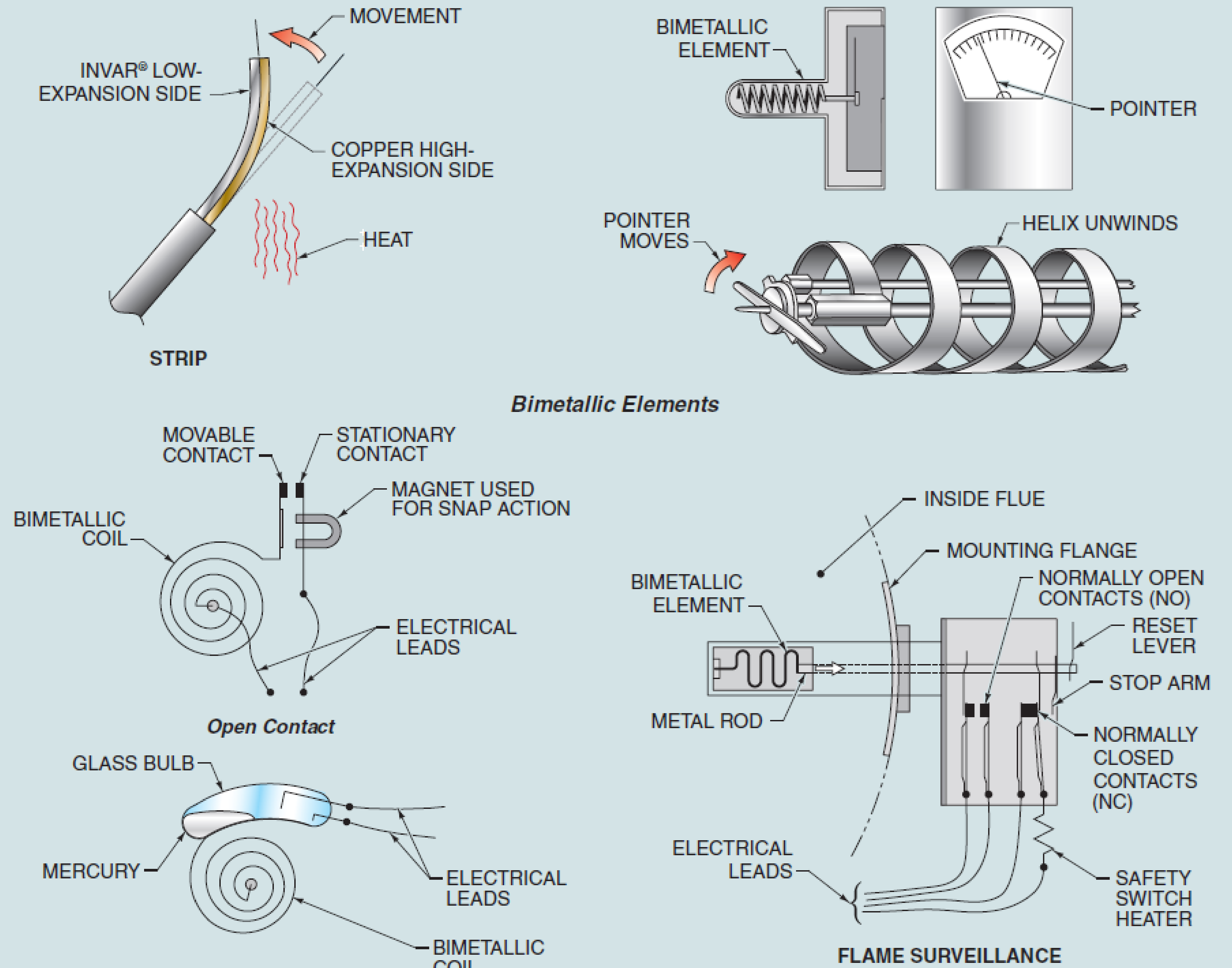
  used, the length of the strip and change in temperature.
- Because the longer the length of a bimetallic strip, the greater the movement,
- therefore bimetallic thermometers usually have a strip in the form of helix or spiral.
- For industrial thermometer helical form of strip is used. One end of the

  strip is attached to the inside of a protective sheath and the other end is attached

  to a spindle which position the pointer over a scale to give a reading of temperature.

https://www.youtube.com/watch?v=ha0cF3fuvQE


5
4
6
3
7
2
8
1
9
0
10
ROTATING SHAFT
FREE END
ATTACHED TO
POINTER SHAFT
BULB
FIXED END


MOVEMENT
INVAR® LOW-EXPANSION SIDE
COPPER HIGH-EXPANSION SIDE
HEAT
STRIP
BIMETALLIC ELEMENT
POINTER
POINTER MOVES
HELIX UNWINDS
Bimetallic Elements
MOVABLE CONTACT
STATIONARY CONTACT
MAGNET USED FOR SNAP ACTION
BIMETALLIC COIL
ELECTRICAL LEADS
Open Contact
GLASS BULB
MERCURY
ELECTRICAL LEADS
BIMETALLIC COIL
INSIDE FLUE
MOUNTING FLANGE
BIMETALLIC ELEMENT
NORMALLY OPEN CONTACTS (NO)
RESET LEVER
STOP ARM
METAL ROD
NORMALLY CLOSED CONTACTS (NC)
ELECTRICAL LEADS
SAFETY SWITCH HEATER
FLAME SURVEILLANCE

BIMETALLIC ELEMENT THERMOMETERS

▶ Advantages

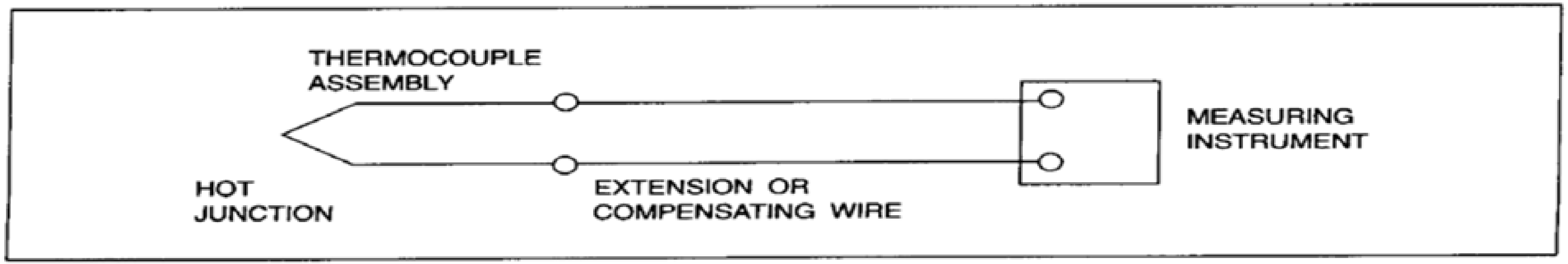
- Does not require any external power source.
- Robust
- Inexpensive
- measure temperature in the range of -30 C to 600 C.

▶ Disadvantages

- Not suitable for low temperature
- Not very Accurate

Thermocouple

- A thermocouple is electrical thermometer consists of two dissimilar metal wires joined at one end to form (Hot Junction).
- The other end wires are connected to voltmeter to form a (reference Junction).
- When the two junctions are at different temperature, current will flow through the circuit.
- The millivoltage that results from the current flow is measured to determine the temperature of the measuring junction.
- This voltage is known as Seebeck voltage(Vab)



Thermocouple

For small changes in temperature, the Seebeck voltage is linearly proportional to change in temperature. It is given by :

$$V_{ab} = \propto (T_1 - T_2)$$

Where $\propto$, Seebeck coefficient is the constant of proportionality.

Example :-

Find the Seebeck voltage for a thermocouple with a $\alpha = 40\ \mu V/°C$,

if the junction temperatures are 40°C and 80°C.

Solution 5:-

$$V_{ab} = \alpha\,(T_2 - T_1)$$

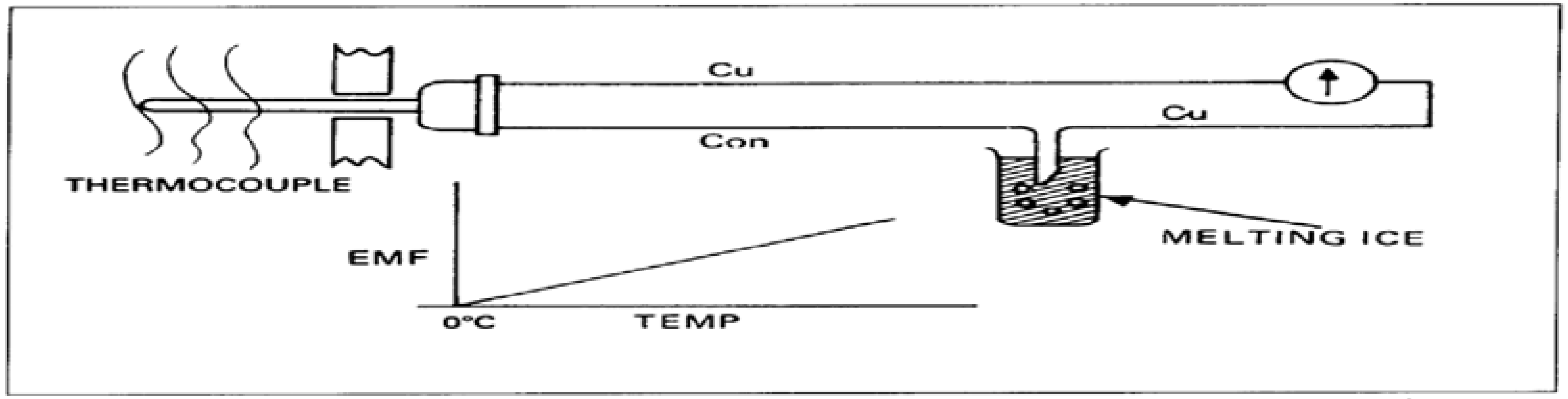
$$V_{ab} = (40\ \mu V/°C)\times(80°C - 40°C) = 1.6\ mV$$

Thermocouple

Reference Junction Compensation

1. Constant Temperature

- The reference junction is held at a constant or reference temperature.
- In many applications, the junction is kept at the temperature of the melting ice(AT 0 C), which allows temperature to be read directly from an indicator without the need of calculating a correction.
- In laboratory this can be achieved using an ice bath.
- In Industry refrigeration units are often used.
- In other cases reference temperature is kept above zero by placing it in oil bath or oven kept at a constant temperature.



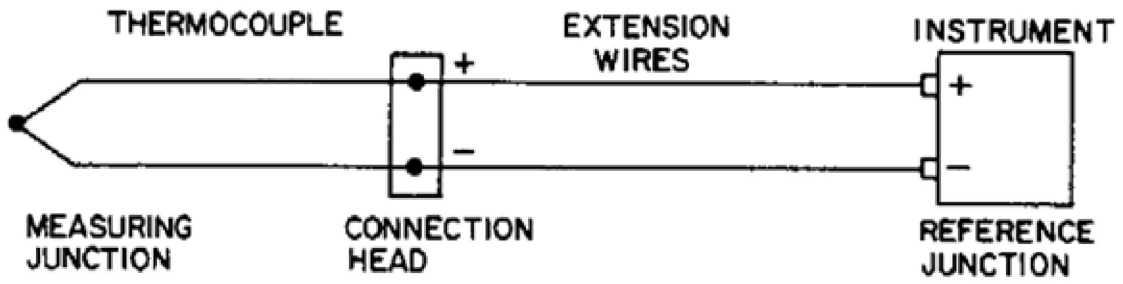
Types of Thermocouple

- Thermocouples can be divided into three functional classes: base metal, and noble metal.
- Base metal thermocouples are useful for measuring temperatures under 1000 ˚C. This class includes thermocouples made of iron/constantan (Type J), copper/constantan (Type T), Chromel-Constantan(Type E)and alloys of copper, nickel, iron, chromium, manganese, aluminum, and other elements.
- Noble metal thermocouples are useful to about 1500 ˚C. This class includes tungsten-rhenium alloy thermocouples as well as those made of platinum, molybdenum, and their alloys.

Type	Materials	Normal Range
J	Iron-constantan	-190°C to 760°C
T	Copper-constantan	-200°C to 371°C
K	Chromel-alumel	-190°C to 1260°C
E	Chromel-constantan	-100°C to 1260°C
S	90% platinum + 10% rhodium-platinum	0°C to 1482°C
R	87% platinum + 13% rhodium-platinum	0°C to 1482°C

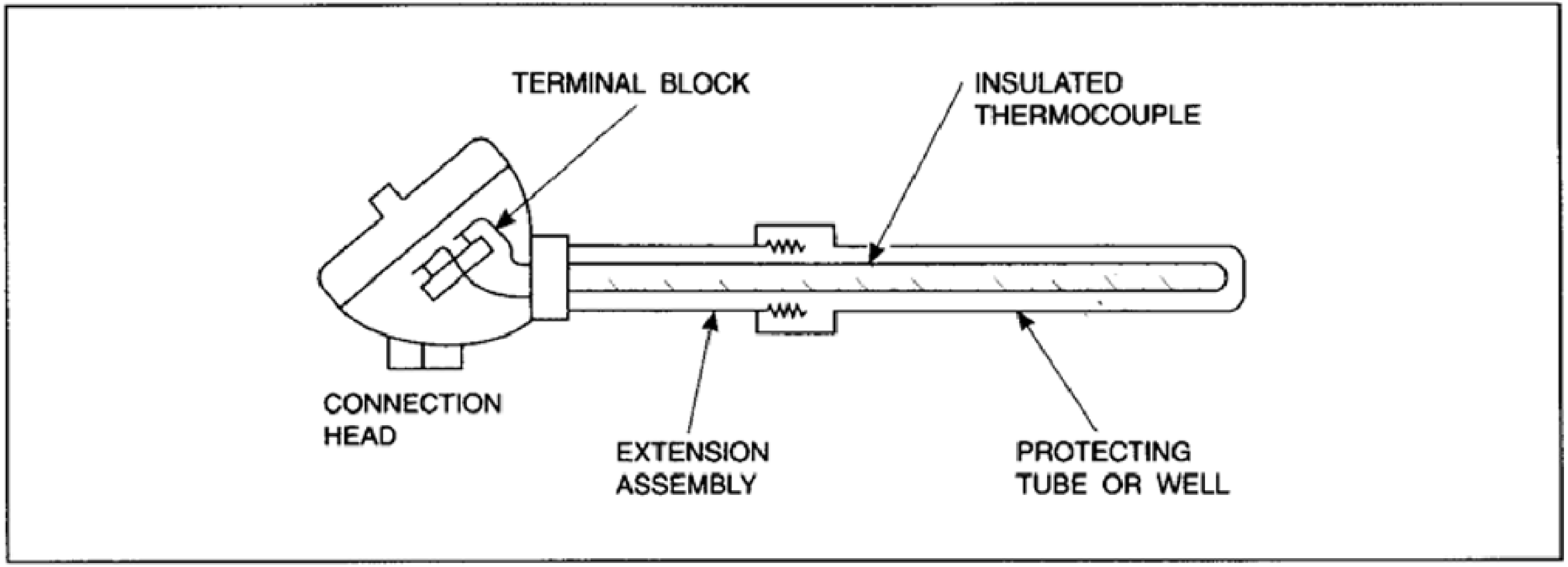
Thermocouple Extension Wires

- Extension Wires
- Precision Grade Wire, Standard Grade wire and Extension grade wires.
- Under normal working conditions measuring instrument attached to a thermocouple is located at a distance, this means that reference junction is located at quite a distance from actual measuring point.
- If the thermocouple is made of cheaper material then there is no problem in extending the thermocouple and extension grade wires are used.
- But if we are using an expensive thermocouple, if the length of extension wire increases, it becomes very expensive.
- To solve this problem, extending the wires using standard grade wire which is slightly cheaper and it has good accuracy.
- This may cause slight errors but these can be ignored in most of the applications.



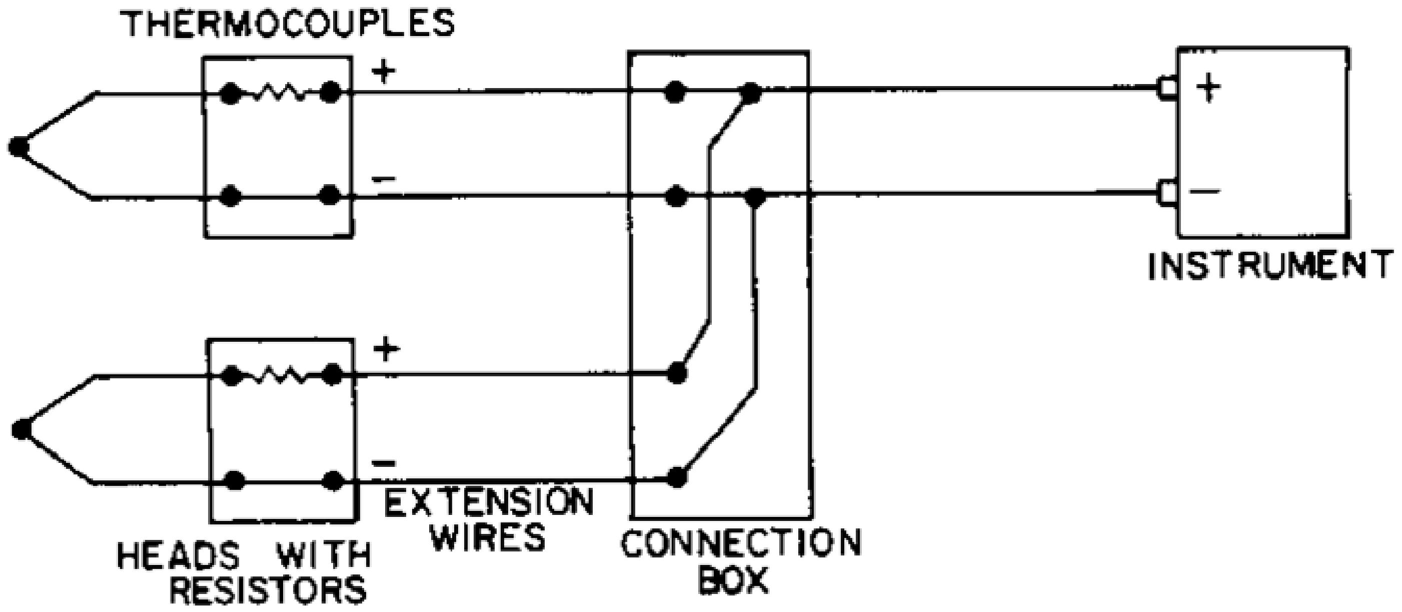
Thermocouple Consturction

- *Thermocouple Assembly Components*



Thermocouple Connection

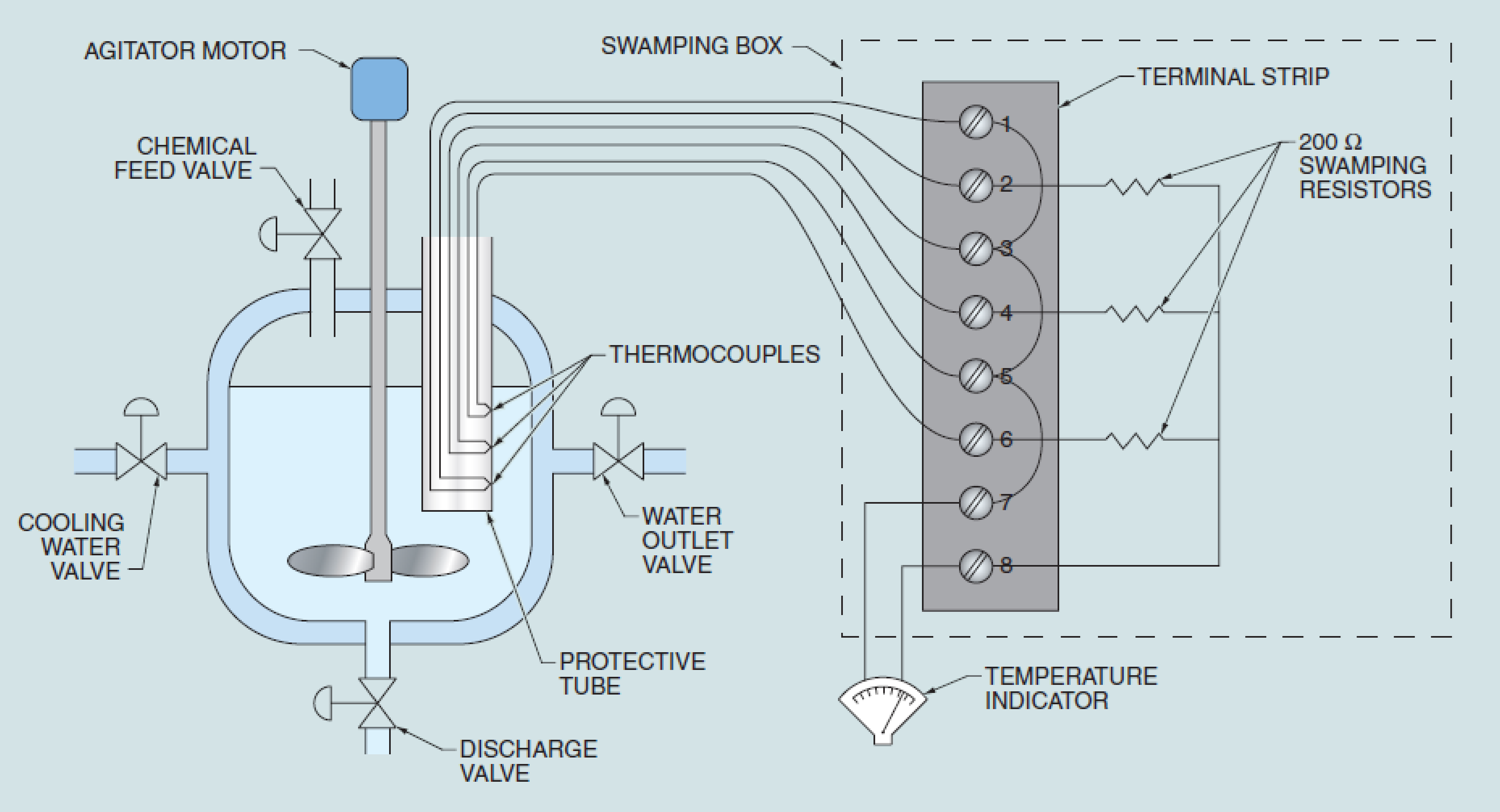
- Thermocouples in Parallel



Averaging thermocouple: a set of parallel-connected thermocouples used to measure the average temperature of process.

Swamping Resistance: used to maintain equal values of resistance between the junctions, so the resultant voltage will be more accurate.

Averaging Thermocouples



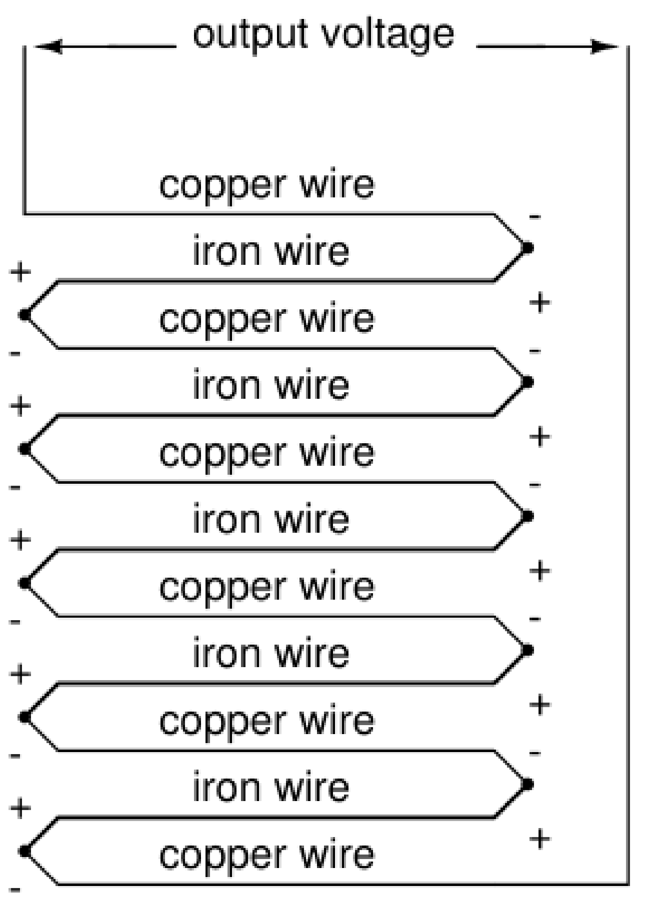
Thermocouple Connection

- Thermocouples in Series

Thermopile

Set of thermocouples connected in series to provide higher voltage output.

Also, to measure small values of temperature and provide a higher sensitivity.



Thermocouple Tables

- Since the thermocouples produces output signal in (millivolts) representing the measured temperature.
- comprehensive tables of voltage versus temperature have been determined for many types of thermocouples,
- The tables give the voltage that results for a particular type of thermocouple when the reference junctions are at 0°C, and the measurement junction is at a given temperature.

Example 1: For a type K thermocouple at 200°C with a 0°C reference the voltage produced is:

□ V(200°C) = 8.13 mV

Example 2: if we measure a voltage of 30.22 mV with a type J thermocouple and a 0°C reference, we find from the JTC table that

T (30.22 mV) = 550°C

- In some cases, the TC voltage does not fall exactly on a table values.
- Then, it is necessary to interpolate between table values that bracket the desired value.
- An approximate value of temperature can be found using the following interpolation equation:

$$T_m = T_L + \left[\frac{T_h - T_L}{V_h - V_L}\right](V_m - V_L)$$

Where, the measured voltage V_m lies between a higher voltage V_h and lower voltage V_L which are in the tables.

The temperatures corresponding to these voltages are T_h and T_L respectively.

Example

A voltage of 6.22 mV is measured with a type J thermocouple at a 0°C reference. Find the temperature of the measurement junction.

Solution

From the J table, we seen that V_m = 6.22 mV lies between V_L = 6.08 mV and V_h = 6.36 mV,

Which corresponding to temperatures of T_L = 115°C and T_h = 120°C, respectively.

Therefore, the junction temperature is found as follows:

$$T_m = T_L + \left[\frac{T_h - T_L}{V_h - V_L}\right](V_m - V_L)$$

$$T_m = 115\ ^\circ C + \frac{(120\ ^\circ C - 115\ ^\circ C)}{(6.36\ \text{mV} - 6.08\ \text{mV})}(6.22\ \text{mV} - 6.08\ \text{mV})$$

$$T_m = 115\ ^\circ C + \frac{5\ ^\circ C}{0.28\ \text{mV}}\, 0.14\ \text{mV}$$

∴The measured temperature is : T_m = 117.5°C

Type J : Iron-Constantan Conversion Table

C°	0	5	10	15	20	25	30	35	40	45
−150	−6.50	−6.66	−6.82	−6.97	−7.12	−7.27	−7.40	−7.54	−7.66	−7.78
−100	−4.63	−4.83	−5.03	−5.23	−5.42	−5.61	−5.80	−5.98	−6.16	−6.33
− 50	−2.43	−2.66	−2.89	−3.12	−3.34	−3.56	−3.78	−4.00	−4.21	−4.42
− 0	0.00	−0.25	−0.50	−0.75	−1.00	−1.24	−1.48	−1.72	−1.96	−2.20
+ 0	0.00	0.25	0.50	0.76	1.02	1.28	1.54	1.80	2.06	2.32
50	2.58	2.85	3.11	3.38	3.65	3.92	4.19	4.46	4.73	5.00
100	5.27	5.54	5.81	6.08	6.36	6.63	6.90	7.18	7.45	7.73
150	8.00	8.28	8.56	8.84	9.11	9.39	9.67	9.95	10.22	10.50
200	10.78	11.06	11.34	11.62	11.89	12.17	12.45	12.73	13.01	13.28
250	13.56	13.84	14.12	14.39	14.67	14.94	15.22	15.50	15.77	16.05
300	16.33	16.60	16.88	17.15	17.43	17.71	17.98	18.26	18.54	18.81
350	19.09	19.37	19.64	19.92	20.20	20.47	20.75	21.02	21.30	21.57
400	21.85	22.13	22.40	22.68	22.95	23.23	23.50	23.78	24.06	24.33
450	24.61	24.88	25.16	25.44	25.72	25.99	26.27	26.55	26.83	27.11
500	27.39	27.67	27.95	28.23	28.52	28.80	29.08	29.37	29.65	29.94
550	30.22	30.51	30.80	31.08	31.37	31.66	31.95	32.24	32.53	32.82
600	33.11	33.41	33.70	33.99	34.29	34.58	34.88	35.18	35.48	35.78
650	36.08	36.38	36.69	36.99	37.30	37.60	37.91	38.22	38.53	38.84
700	39.15	39.47	39.78	40.10	40.41	40.73	41.05	41.36	41.68	42.00

Example

A voltage of 17.35 mV is measured with a type K thermocouple at a 0°C reference. Find the temperature of the measurement junction.

Solution

From the K table, we seen that V_m = 17.35 mV lies between V_L = 17.24 mV and V_h = 17.46 mV,

Which corresponding to temperatures of T_L = 420°C and T_h = 425°C, respectively.

Therefore, the junction temperature is found as follows:

$$T_m = T_L + \left[\frac{T_h - T_L}{V_h - V_L}\right](V_m - V_L)$$

∴The measured temperature is : T_m = 117.5°C

Type K : Chromel-Alumel Conversion Table

C°	0	5	10	15	20	25	30	35	40	45
−150	−4.81	−4.92	−5.03	−5.14	−5.24	−5.34	−5.43	−5.52	−5.60	−5.68
−100	−3.49	−3.64	−3.78	−3.92	−4.06	−4.19	−4.32	−4.45	−4.58	−4.70
− 50	−1.89	−2.03	−2.20	−2.37	−2.54	−2.71	−2.87	−3.03	−3.19	−3.34
− 0	0.00	−0.19	−0.39	−0.58	−0.77	−0.95	−1.14	−1.32	−1.50	−1.68
+ 0	0.00	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.61	1.80
50	2.02	2.23	2.43	2.64	2.85	3.05	3.26	3.47	3.68	3.89
100	4.10	4.31	4.51	4.72	4.92	5.13	5.33	5.53	5.73	5.93
150	6.13	6.33	6.53	6.73	6.93	7.13	7.33	7.53	7.73	7.93
200	8.13	8.33	8.54	8.74	8.94	9.14	9.34	9.54	9.75	9.95
250	10.16	10.36	10.57	10.77	10.98	11.18	11.39	11.59	11.80	12.01
300	12.21	12.42	12.63	12.83	13.04	13.25	13.46	13.67	13.88	14.09
350	14.29	14.50	14.71	14.92	15.13	15.34	15.55	15.76	15.98	16.19
400	16.40	16.61	16.82	17.03	17.24	17.46	17.67	17.88	18.09	18.30
450	18.51	18.73	18.94	19.15	19.36	19.58	19.79	20.01	20.22	20.43
500	20.65	20.86	21.07	21.28	21.50	21.71	21.92	22.14	22.35	22.56
550	22.78	22.99	23.20	23.42	23.63	23.84	24.06	24.27	24.49	24.70
600	24.91	25.12	25.34	25.55	25.76	25.98	26.19	26.40	26.61	26.82
650	27.03	27.24	27.45	27.66	27.87	28.08	28.29	28.50	28.72	28.93
700	29.14	29.35	29.56	29.77	29.97	30.18	30.39	30.60	30.81	31.04
750	31.23	31.44	31.65	31.85	32.06	32.27	32.48	32.68	32.89	33.09
800	33.30	33.50	33.71	33.91	34.12	34.32	34.53	34.73	34.93	35.14
850	35.34	35.54	35.75	35.95	36.15	36.35	36.55	36.76	39.96	37.16
900	37.36	37.56	37.76	37.97	38.16	38.36	38.56	38.76	38.95	39.15
950	39.35	39.55	39.75	39.94	40.14	40.34	40.53	40.73	40.92	41.12
1000	41.31	41.51	41.70	41.90	42.09	42.29	42.48	42.67	42.87	43.06
1050	43.25	43.44	43.63	43.83	44.02	44.21	44.40	44.59	44.78	44.97
1100	45.16	45.35	45.54	45.73	45.92	46.11	46.29	46.48	46.67	46.85

Type T : Copper-Constantan Conversion Table

C°	0	5	10	15	20	25	30	35	40	45
−150	−4.60	−4.71	−4.82	−4.92	−5.02	−5.11	−5.21	−5.29	−5.38	
−100	−3.35	−3.49	−3.62	−3.76	−3.89	−4.01	−4.14	−4.26	−4.38	−4.49
− 50	−1.80	−1.97	−2.14	−2.30	−2.46	−2.61	−2.76	−2.91	−3.06	−3.21
− 0	0.00	−0.19	−0.38	−0.57	−0.75	−0.93	−1.11	−1.29	−1.46	−1.64
+ 0	0.000	0.193	0.389	0.587	0.787	0.990	1.194	1.401	1.610	1.821
50	2.035	2.250	2.467	2.687	2.908	3.132	3.357	3.584	3.813	4.044
100	4.277	4.512	4.749	4.987	5.227	5.469	5.712	5.957	6.204	6.453
150	6.703	6.954	7.208	7.462	7.719	7.987	8.236	8.497	8.759	9.023
200	9.288	9.555	9.823	10.09	10.36	10.64	10.91	11.18	11.46	11.74
250	12.02	12.29	12.58	12.86	13.14	13.43	13.71	14.00	14.29	14.57
300	14.86	15.16	15.45	15.74	16.04	16.33	16.63	16.93	17.22	17.52
395	17.82	18.12	18.43	18.73	19.03	19.34	19.64	19.95	20.26	20.57

Type S : Platinum-Platinum/10% Rhodium Table

C°	0	5	10	15	20	25	30	35	40	45
+ 0	0.000	0.028	0.056	0.084	0.113	0.143	0.173	0.204	0.235	0.266
50	0.299	0.331	0.364	0.397	0.431	0.466	0.500	0.535	0.571	0.607
100	0.643	0.680	0.717	0.754	0.792	0.830	0.869	0.907	0.946	0.986
150	1.025	1.065	1.166	1.146	1.187	1.228	1.269	1.311	1.352	1.394
200	1.436	1.479	1.521	1.564	1.607	1.650	1.693	1.736	1.780	1.824
250	1.868	1.912	1.956	2.001	2.045	2.090	2.135	2.180	2.225	2.271
300	2.316	2.362	2.408	2.453	2.499	2.546	2.592	2.638	2.685	2.731
350	2.778	2.825	2.872	2.919	2.966	3.014	3.061	3.108	3.156	3.203
400	3.251	3.299	3.347	3.394	3.442	3.490	3.539	3.587	3.635	3.683
450	3.732	3.780	3.829	3.878	3.926	3.975	4.024	4.073	4.122	4.171
500	4.221	4.270	4.319	4.369	4.419	4.468	4.518	4.568	4.618	4.668
550	4.718	4.768	4.818	4.869	4.919	4.970	5.020	5.071	5.122	5.173
600	5.224	5.275	5.326	5.377	5.429	5.480	5.532	5.583	5.635	5.686
650	5.738	5.790	5.842	5.894	5.946	5.998	6.050	6.102	6.155	6.207
700	6.260	6.312	6.365	6.418	6.471	6.524	6.577	6.630	6.683	6.737
750	6.790	6.844	6.897	6.951	7.005	7.058	7.112	7.166	7.220	7.275
800	7.329	7.383	7.438	7.492	7.547	7.602	7.656	7.711	7.766	7.821
850	7.876	7.932	7.987	8.042	8.098	8.153	8.209	8.265	8.320	8.376
900	8.432	8.488	8.545	8.601	8.657	8.714	8.770	8.827	8.883	8.940
950	8.997	9.054	9.111	9.168	9.225	9.282	9.340	9.397	9.455	9.512
1000	9.570	9.628	9.686	9.744	9.802	9.860	9.918	9.976	10.04	10.09
1050	10.15	10.21	10.27	10.33	10.39	10.45	10.51	10.56	10.62	10.68
1100	10.74	10.80	10.86	10.92	10.98	11.04	11.10	11.16	11.22	11.28
1150	11.34	11.40	11.46	11.52	11.58	11.64	11.70	11.76	11.82	11.88
1200	11.94	12.00	12.06	12.12	12.18	12.24	12.30	12.36	12.42	12.48
1250	12.54	12.60	12.66	12.72	12.78	12.84	12.90	12.96	13.02	13.08
1300	13.14	13.20	13.26	13.32	13.38	13.44	13.50	13.59	13.62	13.68
1350	13.74	13.80	13.86	13.92	13.98	14.04	14.10	14.16	14.22	14.28
1400	14.34	14.40	14.46	14.52	14.58	14.64	14.70	14.76	14.82	14.86
1450	14.94	15.00	15.05	15.11	15.17	15.23	15.92	15.35	15.41	15.47
1500	15.53	15.59	15.65	15.71	15.77	15.83	15.89	15.95	16.01	16.07
1550	16.12	16.18	16.24	16.30	16.36	16.42	16.48	16.54	16.60	16.66
1600	16.72	16.78	16.83	16.89	16.95	17.10	17.07	17.13	17.19	17.25
1650	17.31	17.36	17.42	17.48	17.54	17.60	17.66	17.72	17.77	17.83
1700	17.89	17.95	18.01	18.07	18.12	18.18	18.24	18.30	18.36	18.42

List of different types of thermocouple with the materials used to construct and normal temperature measurement ranges.

Type	Materials	Range
J	Iron-constantan	-190°C to 760°C
T	Copper-constantan	-200°C to 371°C
K	Chromel-alumel	-190°C to 1260°C
E	Chromel-constantan	-100°C to 1260°C
S	90% platinum + 10% rhodium-platinum	0°C to 1482°C
R	87% platinum + 13% rhodium-platinum	0°C to 1482°C

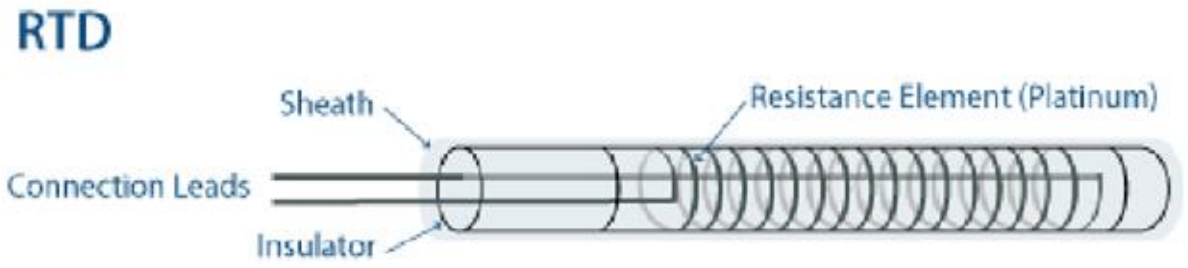
Thermocouple

- **Advantages**
- Linear
- Used for High temperature measurements
- Inexpensive
- No external power is required

- **Disadvantages**
- Not Sensitive.
- Slow time response.
- Requires reference compensation

RESISTANCE TEMPERATURE DETECTOR (RTD)

- Electrical Thermometer consisting of resistance that varies with temperature
- It responds to temperature change by changing its resistance.



- The principle of operation of an RTD is based on the fact that the electrical
- resistance of some metals varies directly with temperature changes.

RESISTANCE TEMPERATURE DETECTOR (RTD)

- There are 3 types of RTD based on its material:
- Platinum which has the highest range of temperature measurements
- Nickel which has middle range of temperature measurements
- Copper has the lowest range

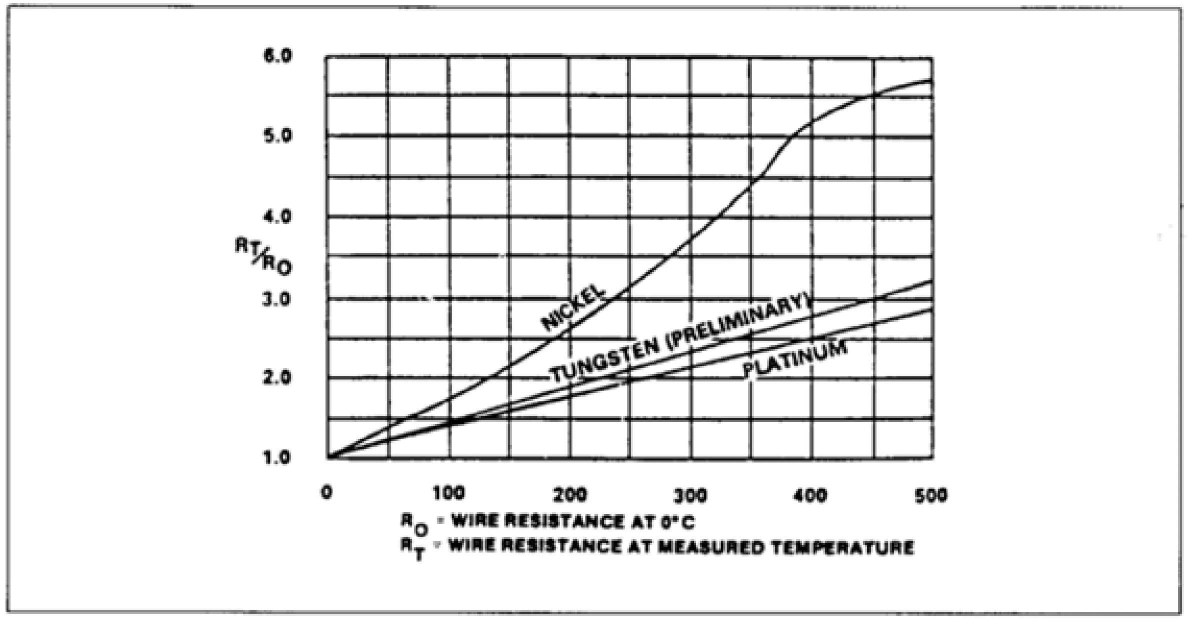
RESISTANCE TEMPERATURE DETECTOR (RTD)

Advantages

- Linear
- Moderate Sensitivity
- Used for General Purposes measurements
- accurate

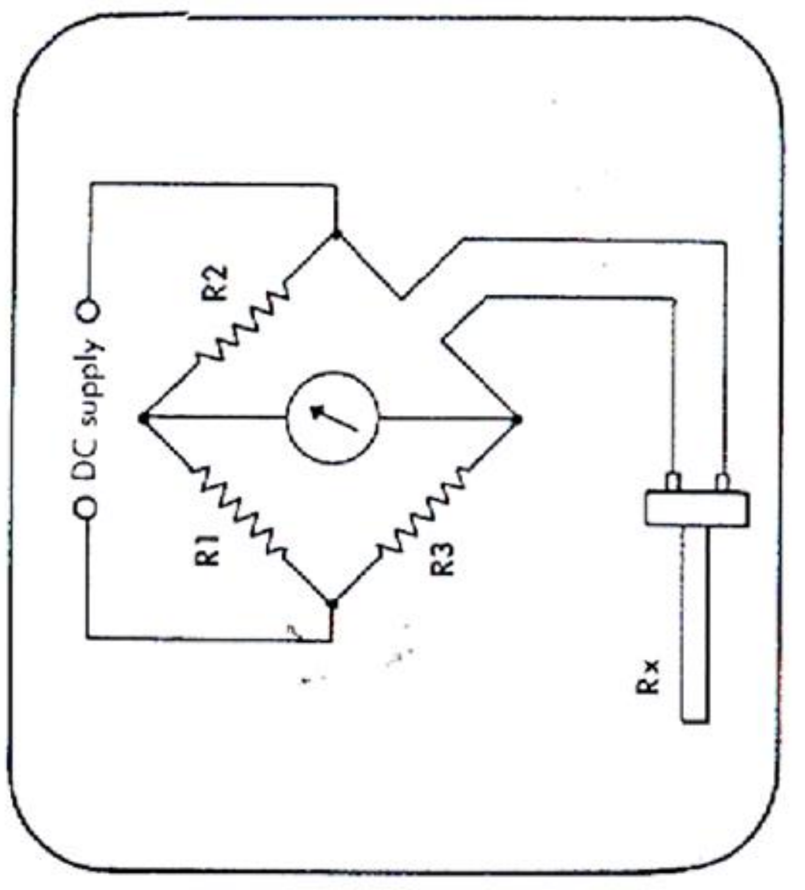
Disadvantages

- Expansive
- Self heating
- External Power source is required
- Lead Compensation is required

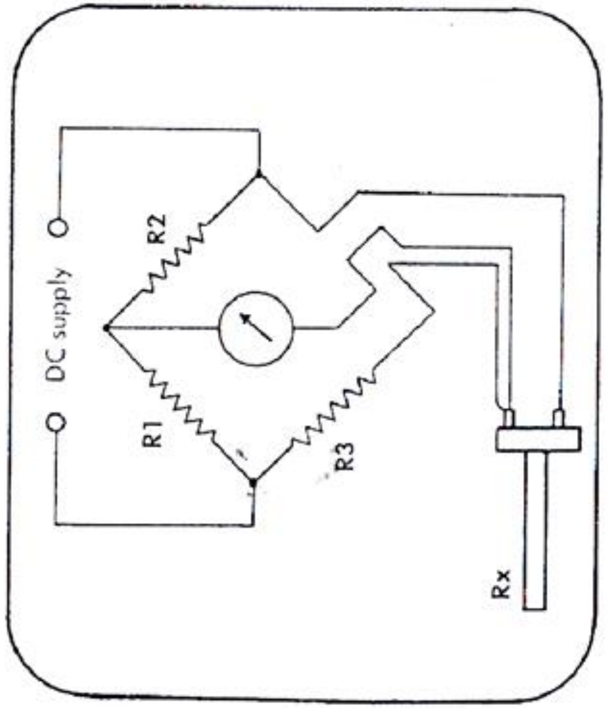


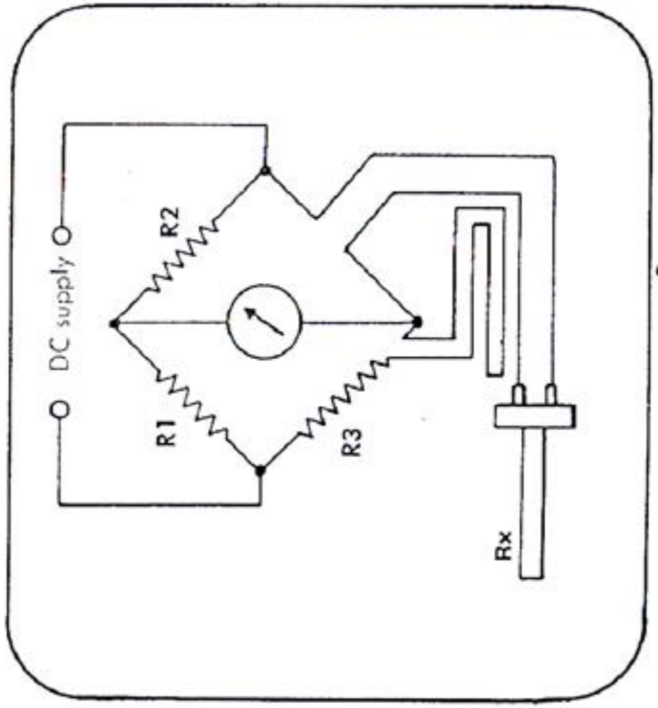
RTD Readout Instrumentation

Initially, RS is adjusted to match the resistance value the sensor exhibits at some
reference temperature, such as 0 C. The bridge then operates in the nonbalanced
mode. In this mode, the three circuit resistors are fixed and the sensor
(RT) acts as a variable resistor. A change in the resistance of the sensor will
cause a proportional change in the measured voltage drop (E). The voltage
output of the circuit (E) is then converted to a temperature that corresponds to
the resistance of the sensor.

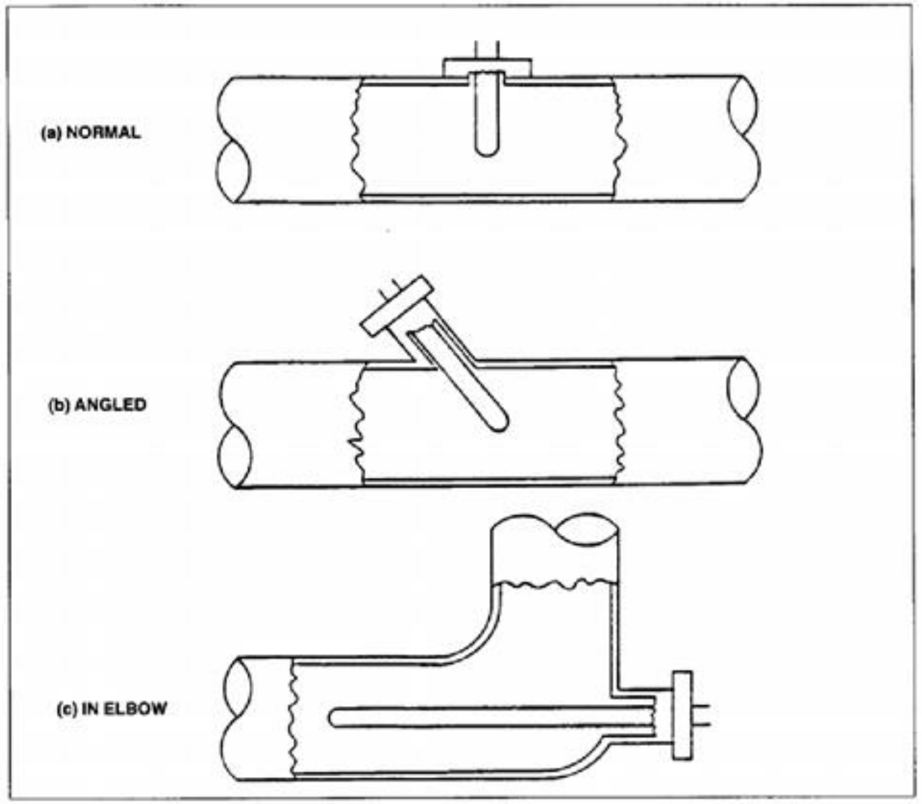


Over long distances, the resistance of the copper leads may
be significantly greater than the resistance of the RTD sensor, resulting in
measurement errors.


DC supply
R2
R1
R3
Rx


DC supply
R2
R1
R3
Rx

USE OF THERMOWELLS



THERMISTORS

- A temperature sensitive resistor consisting of solid-state semiconductors made from from complex metal oxides such as oxides of nickel, and magnesium.
- They are available with positive temperature co-efficint of resistance (PTC) And negative temperature co-efficient of resistance (NTC).
- For temperature measurement NTC thermistors are commonly used.
- The resistance of this thermistor decrease as the temperature is increased.

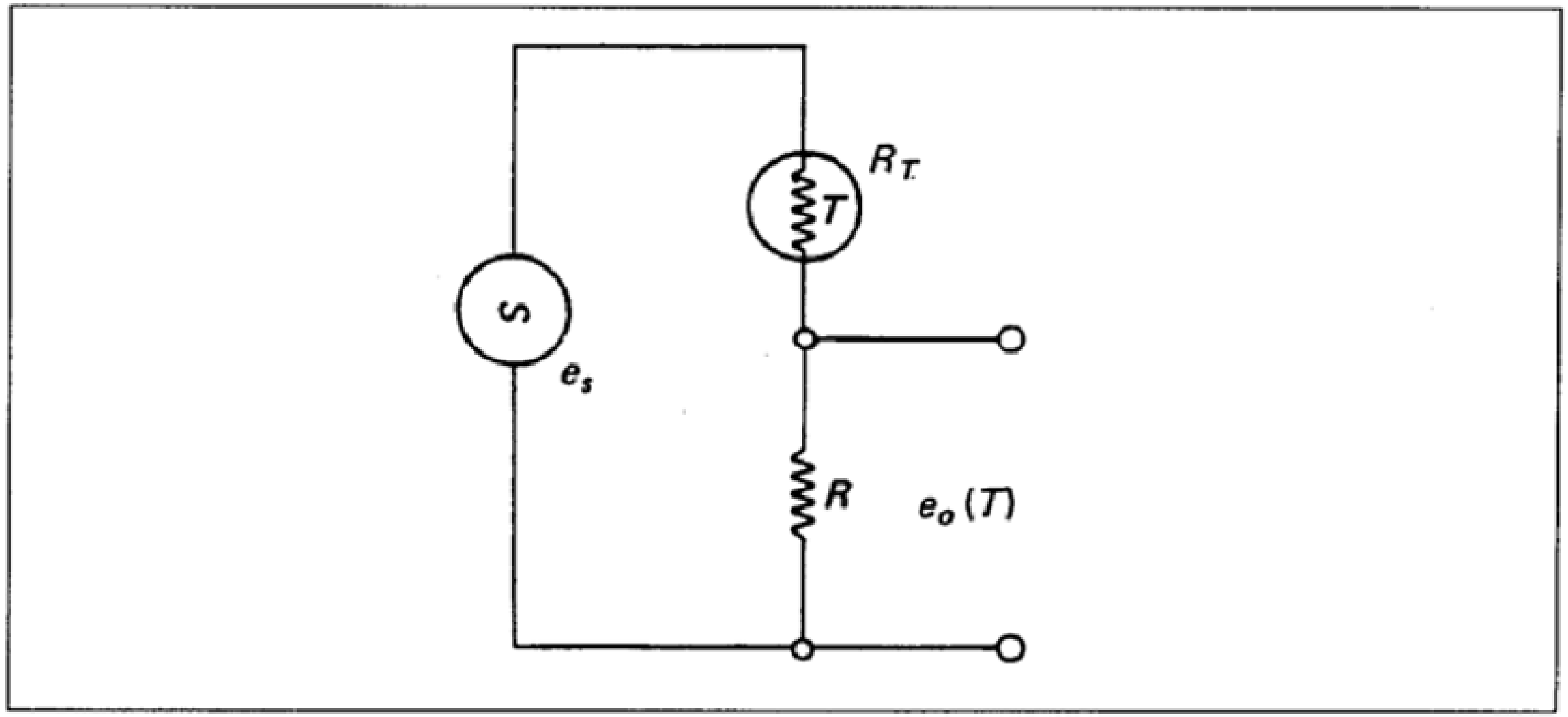
THERMISTORS

- This large co-efficient make thermistors more sensitive to small changes
- in temperature and therefore ideally suited for the applications that require
- precise measurement. Thermistors have a very nonlinear relationship between
- resistance and temperature. For this reason the range of operating temperature,
- for which they can be used is much smaller than that of RTD.
- However a thermistor provides stable and repeatable performance if used within
- its specified temperature range.

THERMISTORS

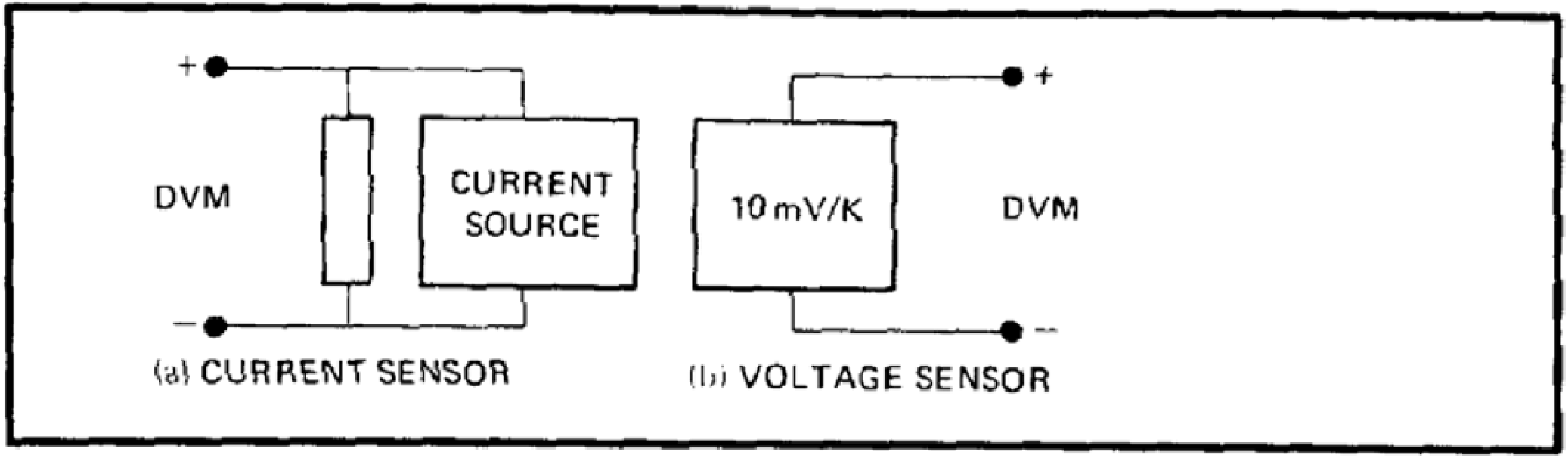
- **Advantages**
- Best Sensitivity
- Used for sensitive temperature measurments
- Accurate

- **Disadvantages**
- Non-Linear
- Self heating
- External Power source is required



$$\frac{1}{T} = A + B * \ln R + C * (\ln R)^3$$

INTEGRATED CIRCUIT (IC) TEMPERATURE SENSOR

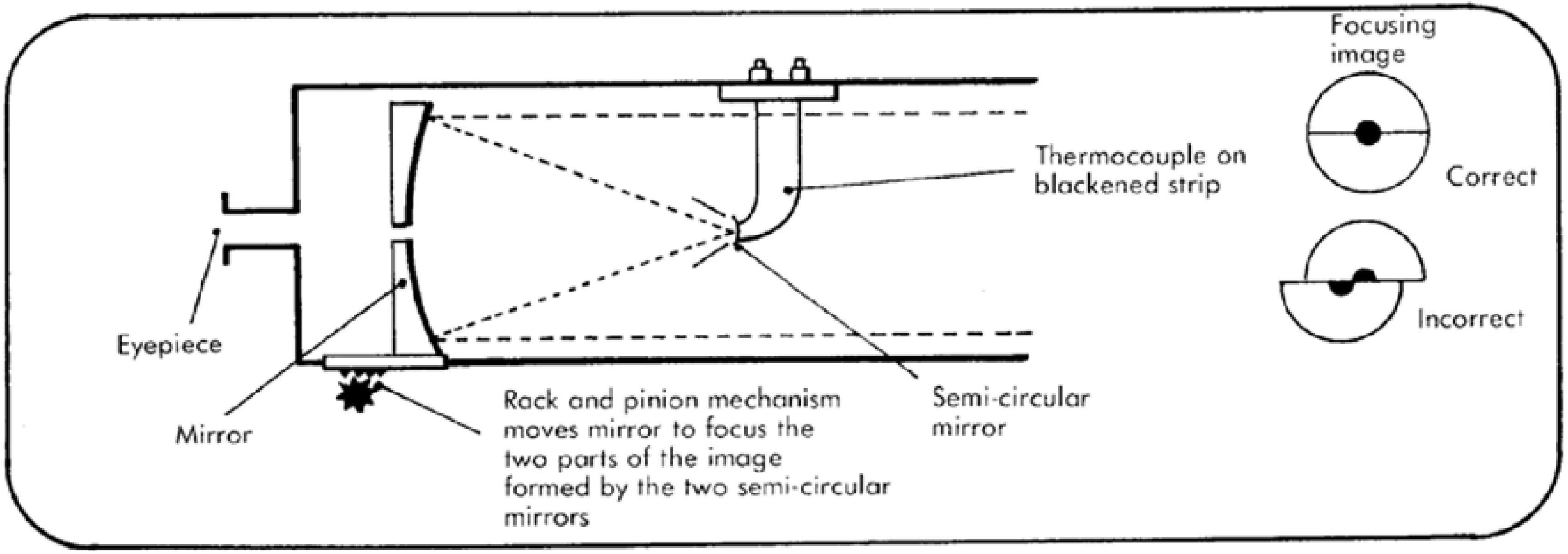


PYROMETERS

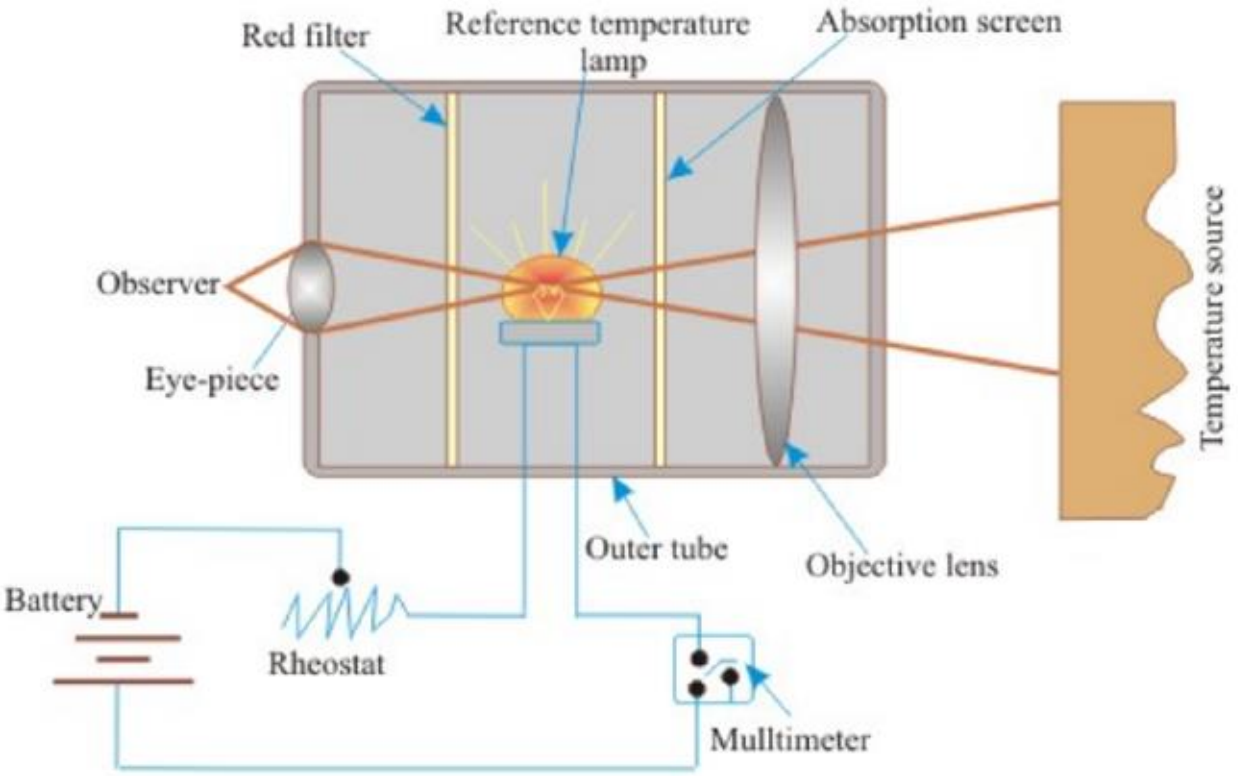
- pyrometer consists of optical components that used to collect the radiant energy emitted by target object.
- A radiation detector that converts the radiation energy into an electrical signal and an indicator that provides readout of the measurement.

Total Radiation Pyrometer

- Radiation from hot source are reflected from a mirror and focused onto the hot junction of a small gauge thermocouple or a thermopile.
- The output of thermocouple or thermopile is indicated or recorded on an instrument having a scale of temperature.

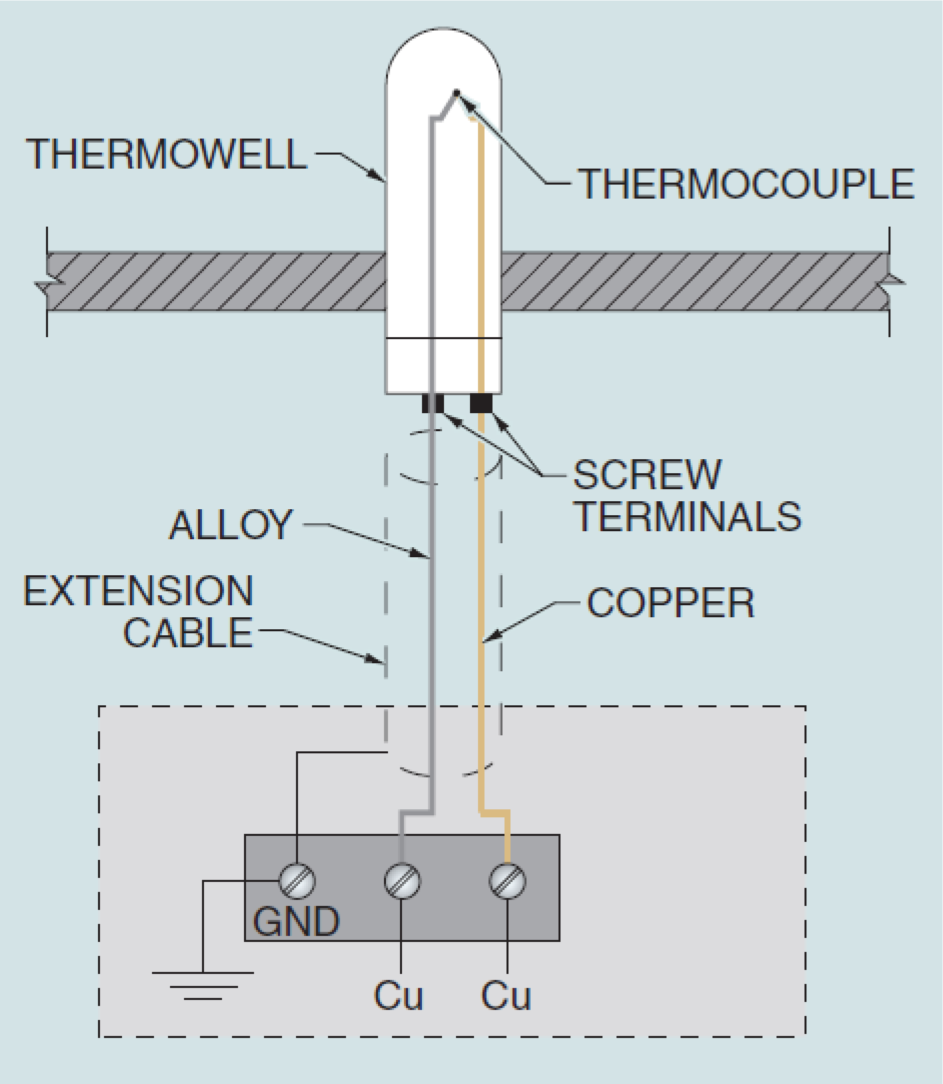


Optical Pyrometer



THERMOWELLS

- temperature instruments
- cannot be used without protection from
- the environment in which they are used. A
- *thermowell* is a closed tube used to protect
- a temperature instrument from process
- conditions and to allow instrument maintenance
- to be performed without draining the
- process fluid.


THERMOWELL
THERMOCOUPLE
SCREW
TERMINALS
ALLOY
EXTENSION
CABLE
COPPER
GND
Cu
Cu