CH0302 Process Instrumentation

Lecture 8 – Temperature Measurements

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Introduction – Temperature Measurements Instruments

- Thermal Expansion
- Thermoelectric
- Resistance
- Radiation

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Introduction – Resistance thermometry

Name	Georg Simon Ohm
Born	16 March 1789
Died	6 July 1854 (aged 65), Munich
Occupation	Physicist
Known for	Ohm's Law

Introduction - Resistors and resistance

Ohm's law states that the voltage (V) across a resistor is proportional to the current (I), where the constant of proportionality is the resistance (R) $V = I \cdot R.$

The ohm (symbol: Ω) is the SI unit of electrical resistance, named after Georg Simon Ohm.

Symbolic representation of resistor

(a) Resistor
(b) Rheostat
(c) Potentiometer

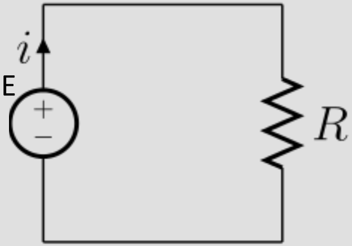
Introduction - Resistors and resistance

Introduction - Resistors and resistance

Symbolic representation of a Resistor

(a) Resistor
(b) Rheostat
(c) Potentiometer

POWER SOURCE (Battery), V



$$V \,\alpha\, I$$

$$V = iR$$

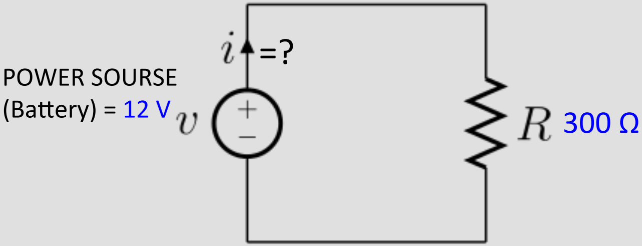
Example:

Suppose 300 ohm resistor is connected across the terminals of a 12 volt battery, then what is the flow of current through the resistor?

Using ohm's law

Example:

Solution:



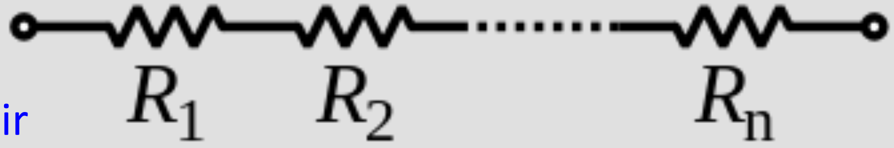
V= I.R

i.e. I = V/R

A current of 12 /300 = 0.04 amperes flows through that resistor.

Series and parallel resistors

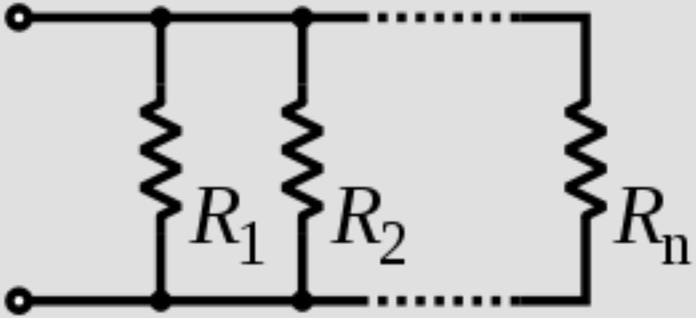
The total resistance of resistors connected in series is the sum of their individual resistance values.



$$R_{total} = R_1 + R_2 + \ldots\ldots\ldots + R_n$$

Series and parallel resistors

The total resistance of resistors connected in parallel is the reciprocal of the sum of the reciprocals of the individual resistors.



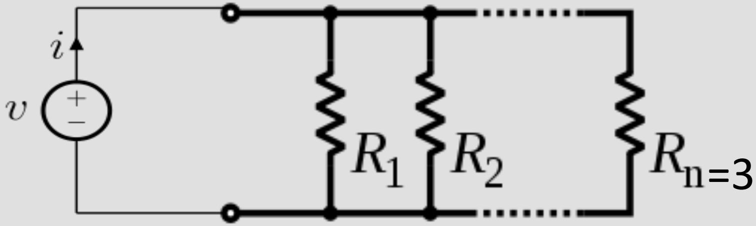
$$R_{\text{total}} = 1/R_1 + 1/R_2 + \ldots\ldots\ldots + 1/R_n$$

Series and parallel resistors

Example:

Assume a 10 ohm resistor connected in parallel with a 5 ohm resistor and a 15 ohm resistor. What is the total resistance produced by the resistors?

Series and parallel resistors

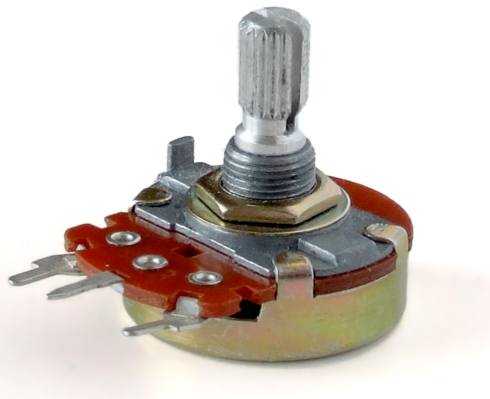


Solution:

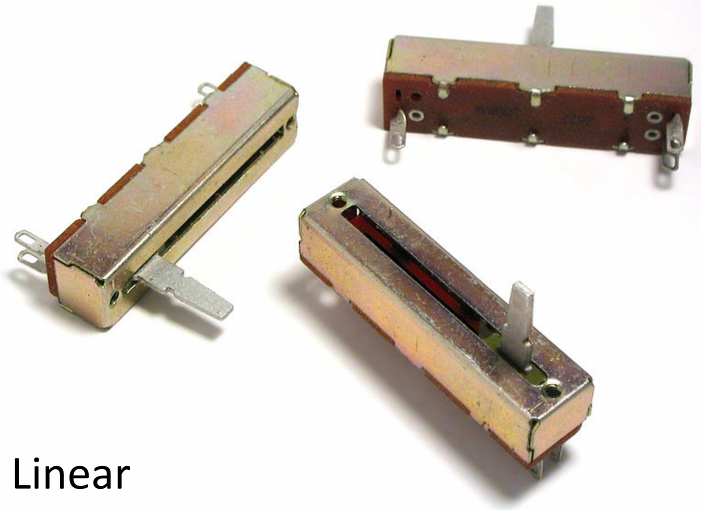
$$R_{total} = 1/R_1 + 1/R_2 + \ldots\ldots\ldots + 1/R_n$$

The resistors in parallel will produce the inverse of 1/10+1/5+1/15 ohms of resistance, or 1/(.1+.2+.067)=2.725 ohms.

A **potentiometer** is an instrument for measuring the potential (voltage) in a circuit



Radial



Linear

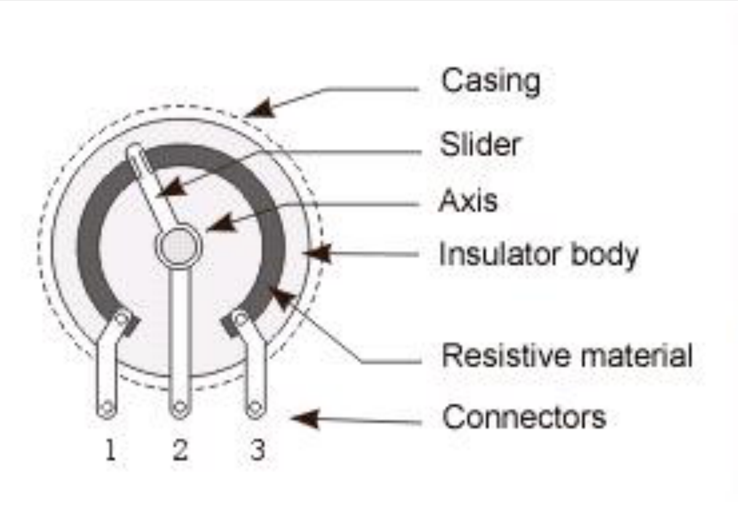
Potentiometer

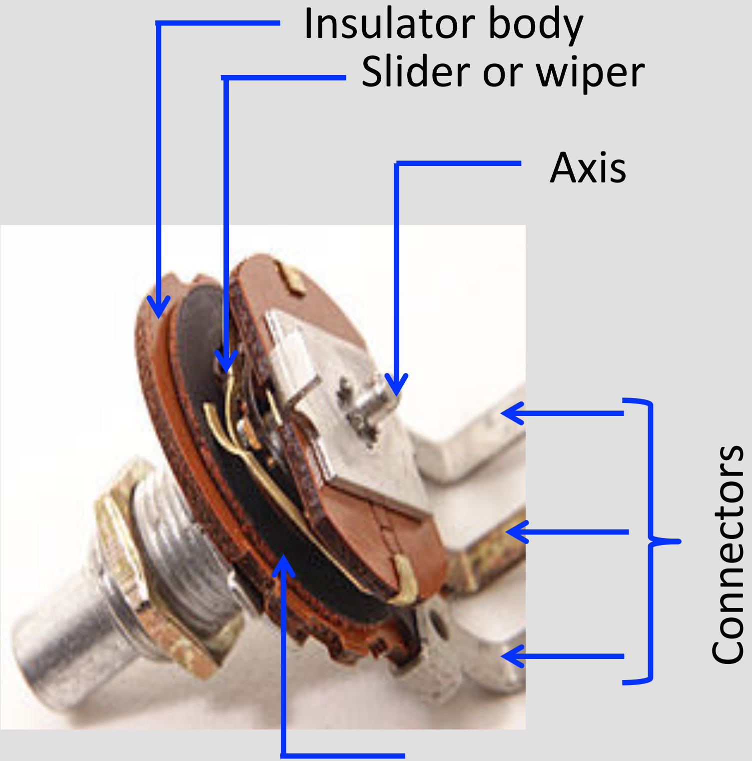
Single-turn potentiometer

Single-turn potentiometer with metal casing removed to expose wiper contacts and resistive track

Potentiometer

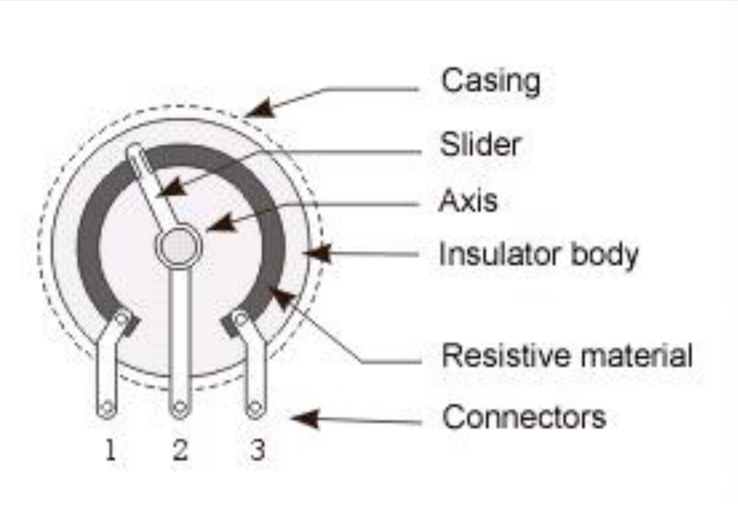
Single-turn potentiometer

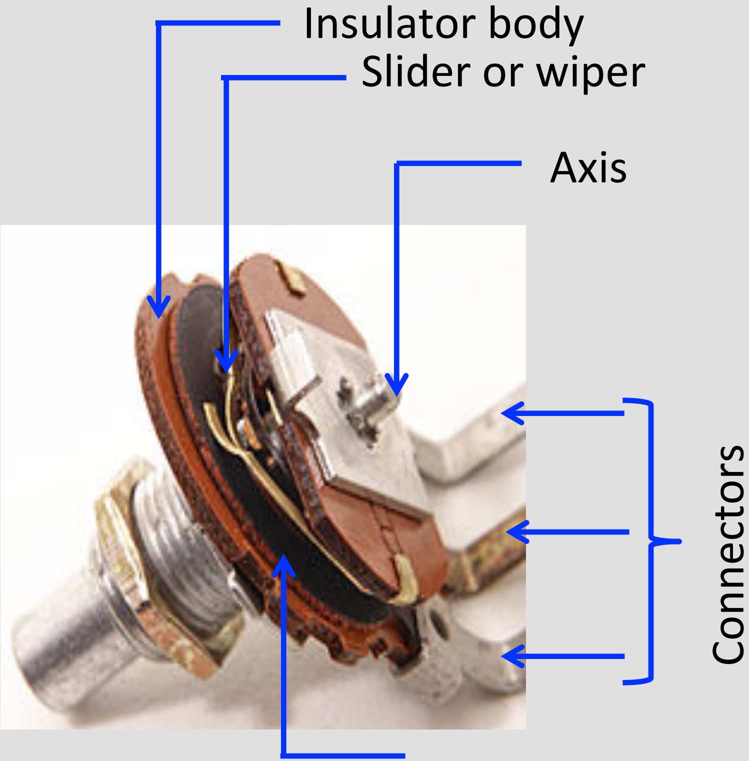




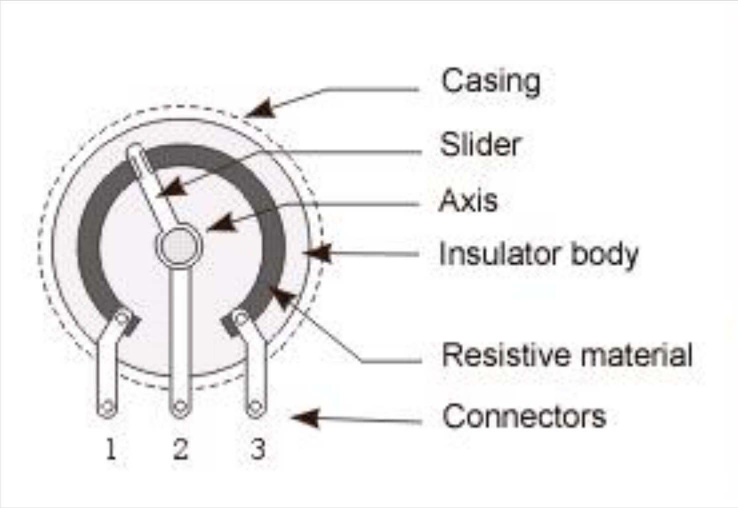
Potentiometer

Single-turn potentiometer

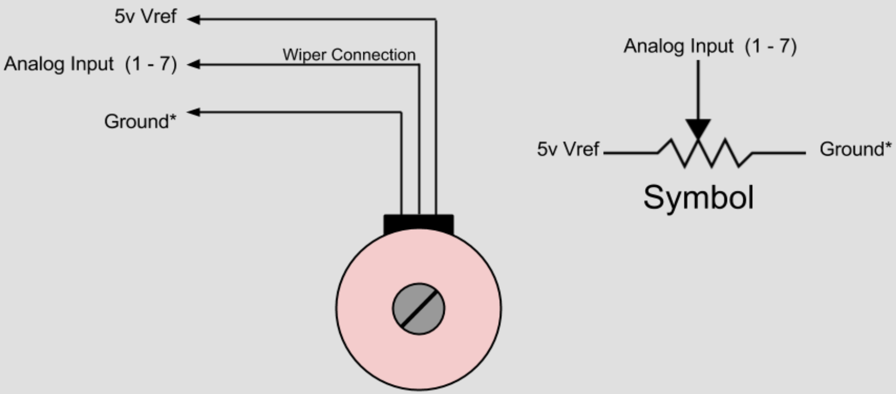




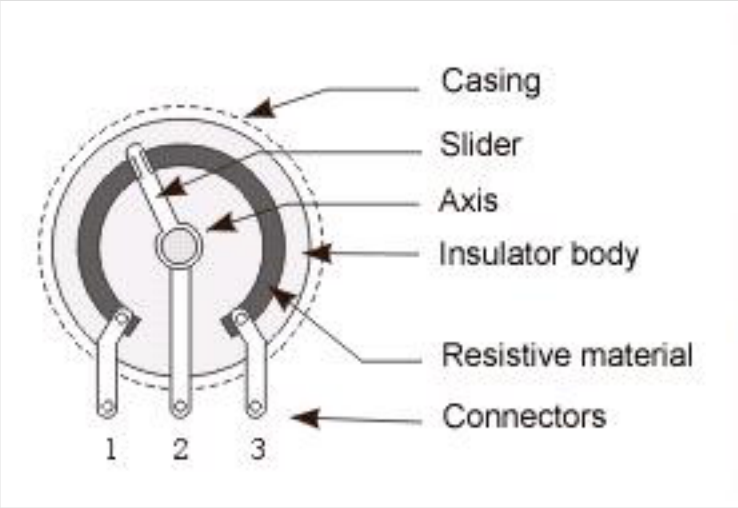
Potentiometer Constructional features

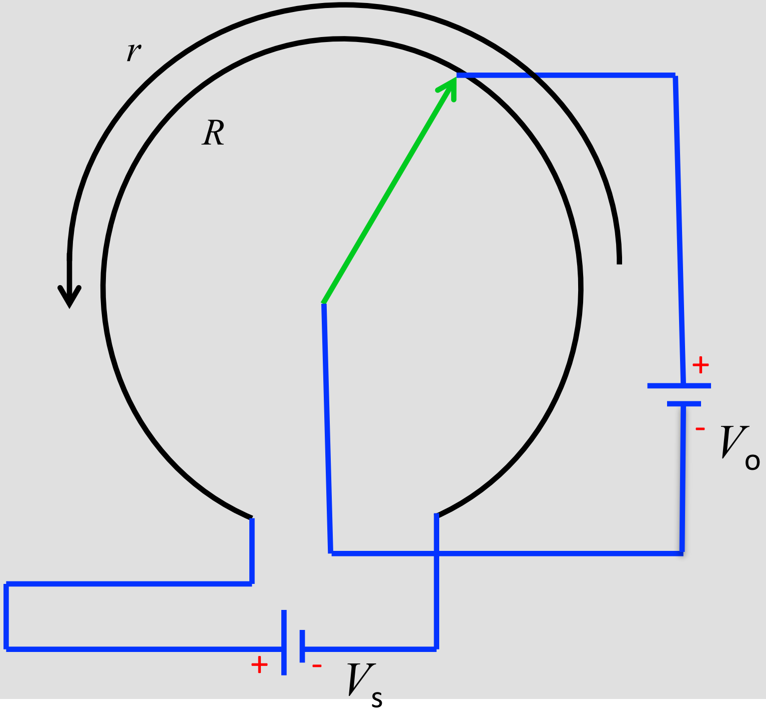


Connectors 1, 2 ,and 3



Potentiometer Constructional features





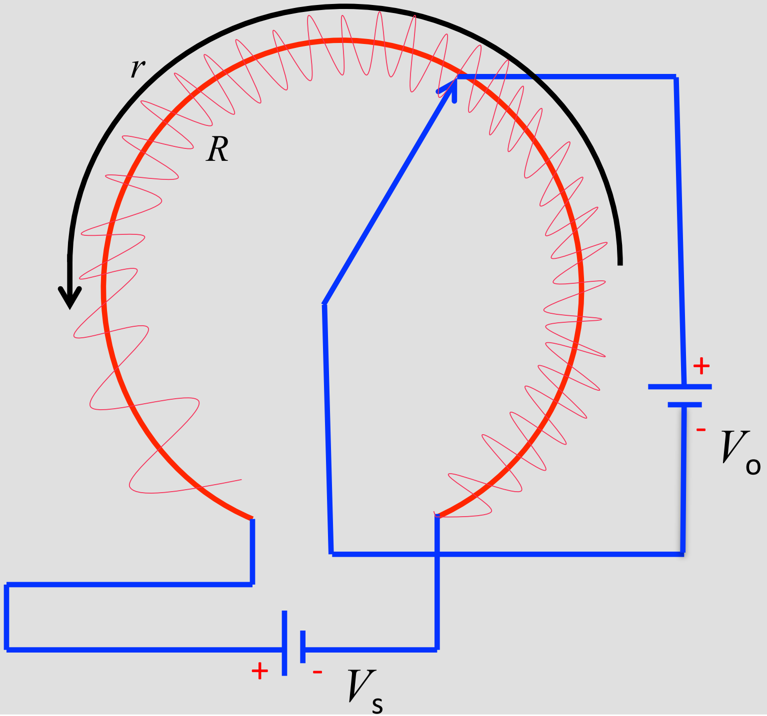
Potentiometer Constructional features

$$V_{out} = \left(\frac{r}{R}\right) V_s$$

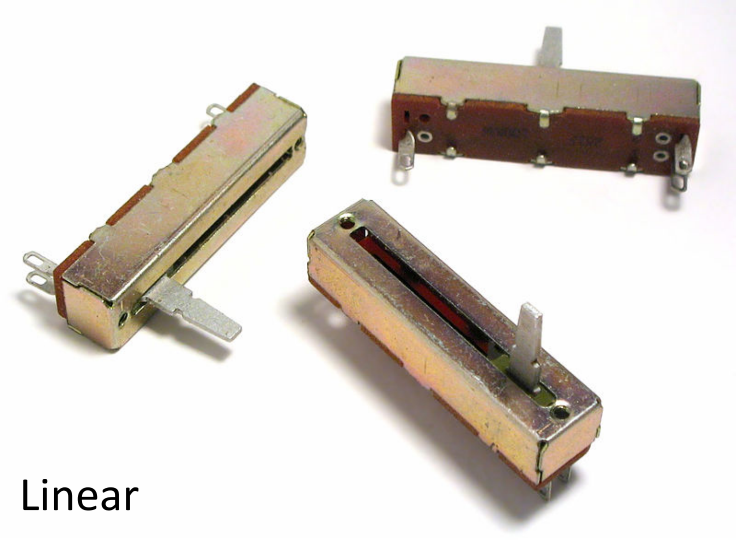
$$r,\ 0 \longrightarrow R\ (radial\ direction)$$

$$V_{out}\ \alpha\ \theta$$

V_{out} – Output voltage, volts
V_s – Supply voltage, volts
R – Total resistance, ohm



Potentiometer Simple circuit



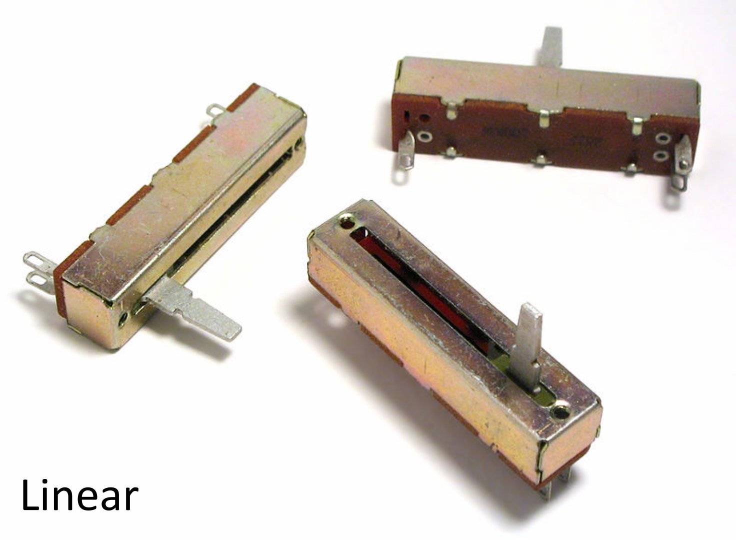
$$V_{out} = \left(\frac{r}{R}\right) V_s$$

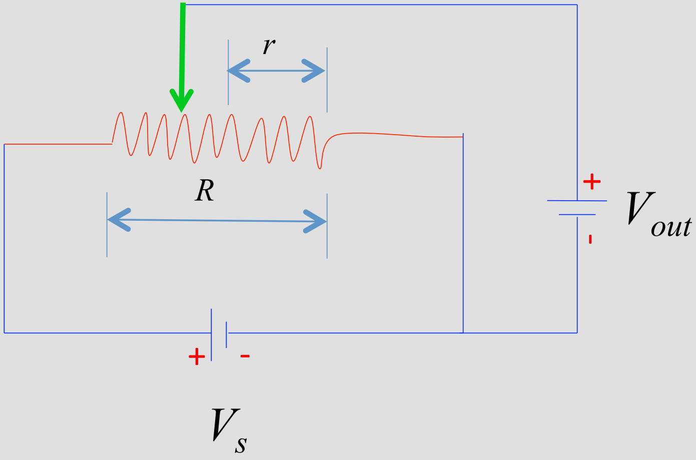
$$r \; 0 \longrightarrow R$$

$$V_{out} \, \alpha \, \theta$$

V_{out} – Output voltage, volts
V_s – Supply voltage, volts
R – Total resistance, ohm

Potentiometer Simple circuit





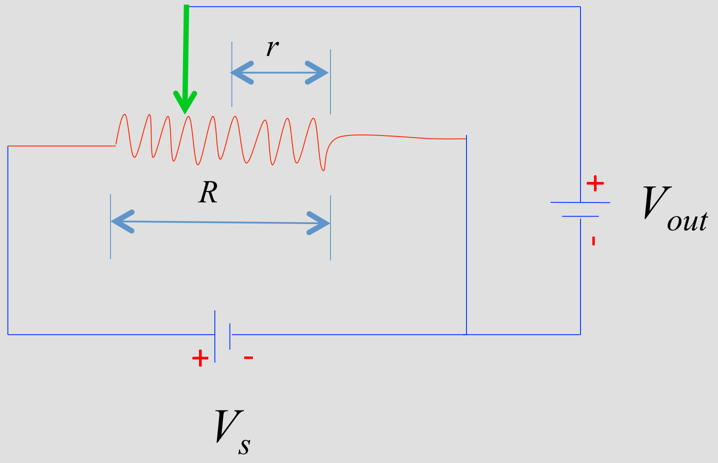
Potentiometer Simple circuit

$$V_{out} = \left(\frac{r}{R}\right) V_s$$

r 0 $\longrightarrow R$

$V_{out}\ \alpha\ L$ (distance)

V_{out} – Output voltage, volts
V_s – Supply voltage, volts
R – Total resistance, ohm



Thermal Resistance

Thermal Resistance Temperature Measurement

- The change of electrical resistance of a substance with temperature.
- Therefore the resistance of most of the metallic substance increases with temperature, that is decreasing its conductivity.
- Industrial type of RTD (Resistance Temperature Detectors) uses Platinum, copper and nickel

Thermal Resistance Temperature Measurement

- The variation of electrical resistance of a substance with temperature is given as

$$R = R_o\left[1 + a_1 t + a_2 t^2 + a_3 t^3 \ldots . a_n t^n\right]$$

For a small temperature range the order more than 1 in this relation is assumed to be zero and the resulting linear form is applicable

R = is resistance in ohms
R_o = is resistance in ohms at 0°C
t = temperature in 0°C
$a_1, .. a_n$ = coefficient of resistance

Thermal Resistance Temperature Measurement

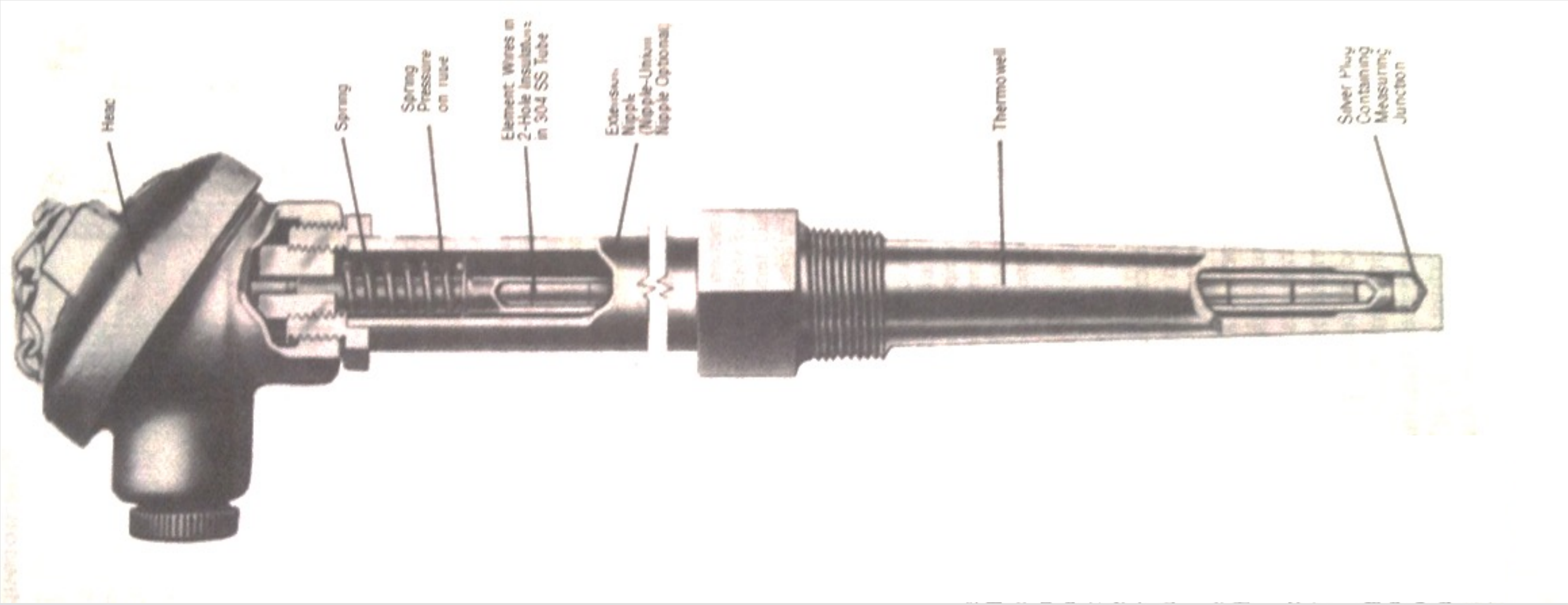
The variation of electrical resistance for a platinum resistor with temperature is given as

$$T = \left[\frac{R_t - R_0}{R_{100} - R_0}\right] + \delta\left[\frac{T}{100} - 1\right]\frac{T}{100}$$

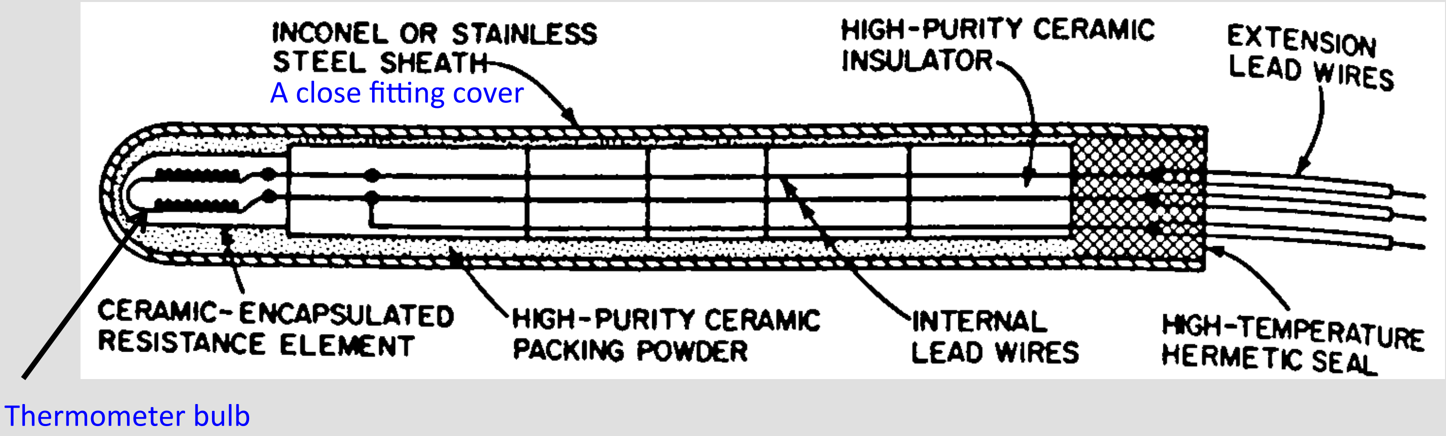
Resistance – temperature relation for platinum elements given by this equation which is proposed by Callender

R_t = is resistance at any temperature *T*, in ohms
R_o = is resistance in ohms at 0°C
R_{100} = is resistance in ohms at 100°C
T = temperature of measuring medium , degree centrigrade
δ = Constant, characteristics of resistive element, (-)

Assembly view of a industrial type RTD

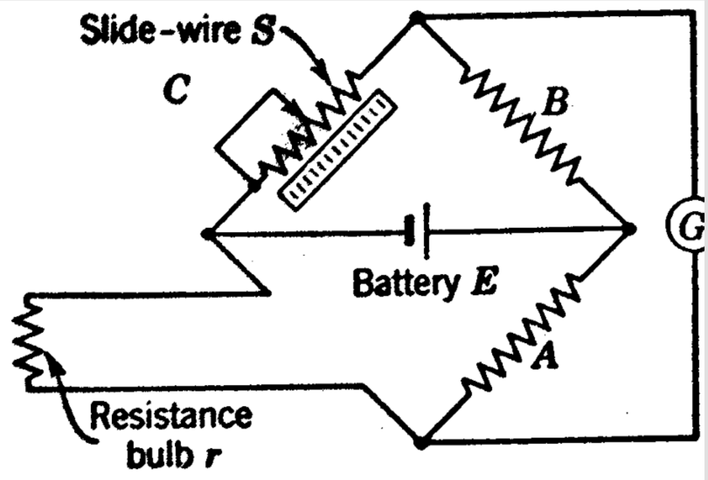


Various parts of a industrial type platinum RTD

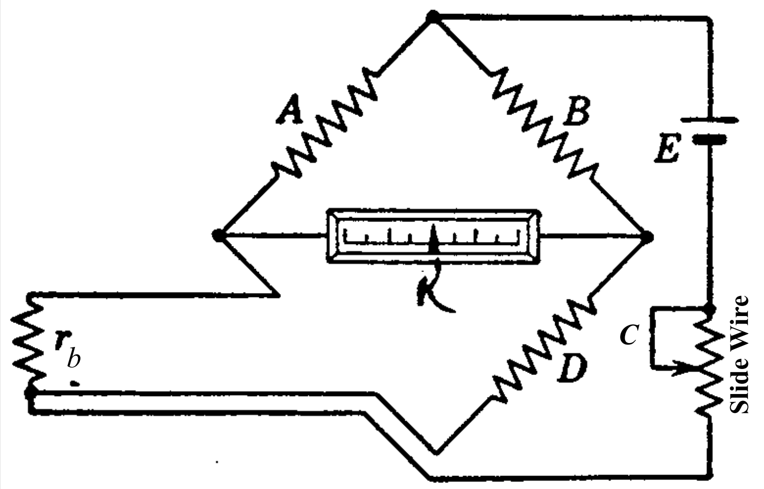


Thermal Resistance Temperature Measurement

- Wheat Stone Circuit (Null type)



- Wheat Stone Circuit (Deflection type)



RTD Bulb or Thermometer bulb in RTD

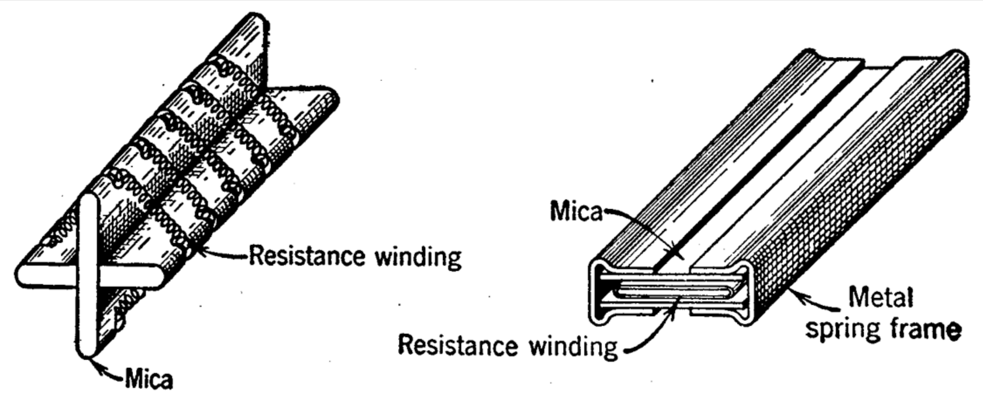


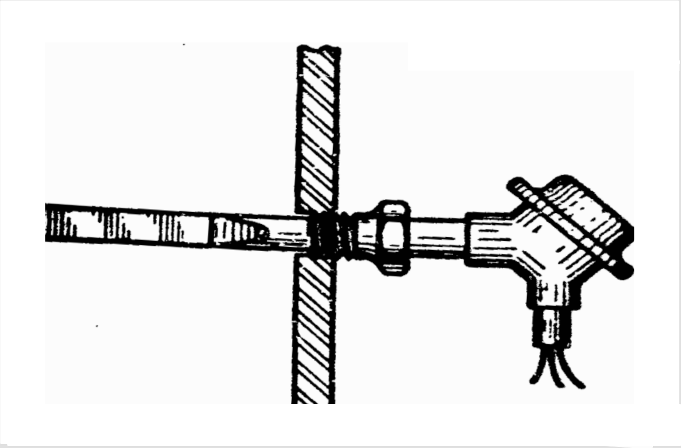
Fig 1. Coil of fine wire wound in a frame of insulating material
Fig 2. A strip of thin sheet of foil

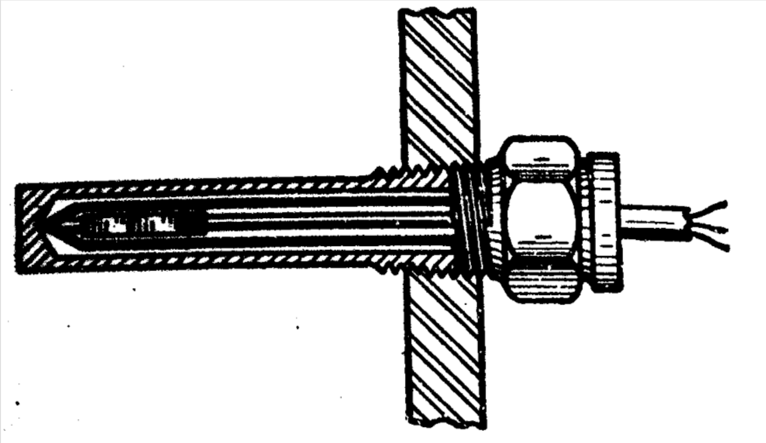
RTD Bulb or Thermometer bulb in RTD

Industrial Resistance thermometer bulb is made in various forms but essentially it consists of

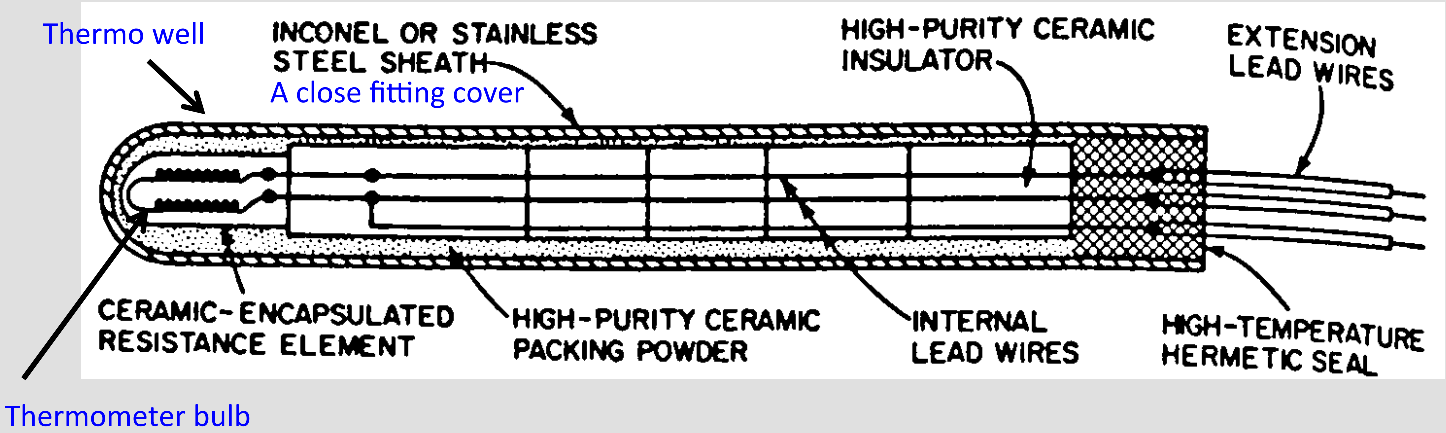
1. A coil of fine wire wound on the frame of insulating material
2. A strip of metal sheet of thin nickel foil
3. A woven wire mesh cloth

Typical installation of RTD’s in Industrial applications

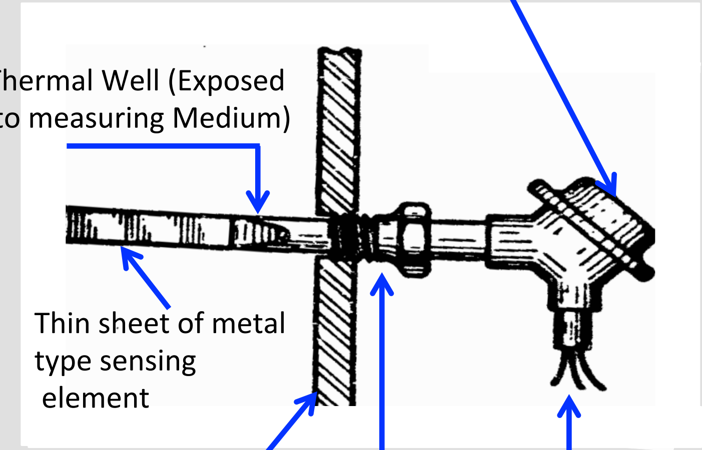


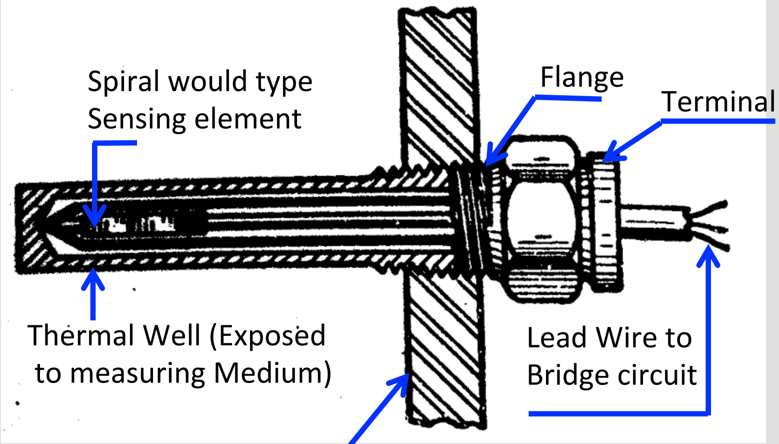


Various parts of a industrial type platinum RTD



Typical installation of RTD’s in Industrial applications





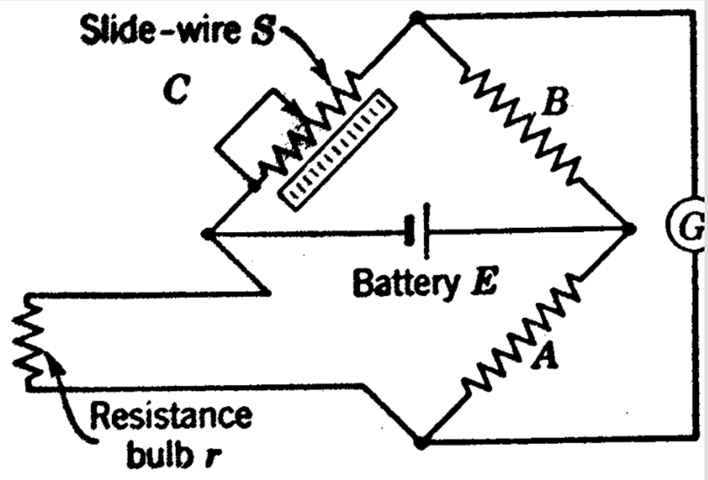
Thermal Resistance

Thermal Resistance Temperature Measurement

- Wheat stone bridge circuit (Null and Deflection type bridge circuit)

Thermal Resistance Temperature Measurement

- Wheat Stone Circuit (Null type)



Applying Ohm's law,

$$i_a A = i_b B \qquad (1)$$

$$i_a r = i_b S \qquad (2)$$

$$r = \left(\frac{A}{B}\right) S$$ Combining (1) and (2)

Thermal Resistance Temperature Measurement

- Wheat Stone Circuit (Deflection type)

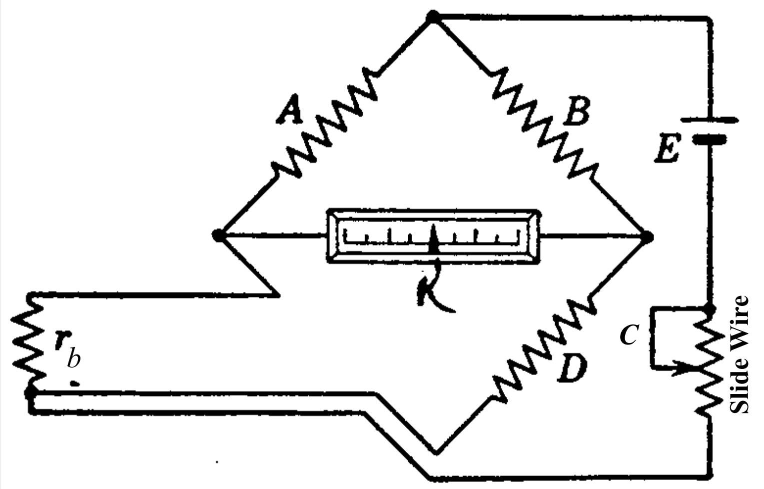
Applying Ohm's law,

$$i_a A = i_b B \qquad (1)$$

$$i_a r_b = i_b D \qquad (2)$$

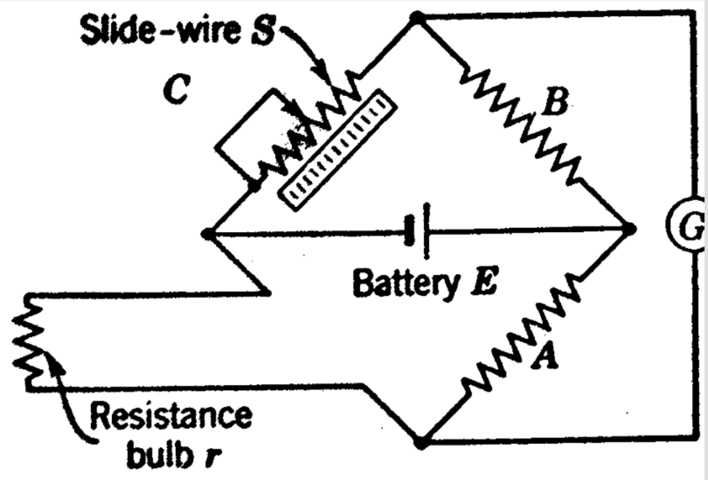
$$r_b = \left(\frac{D}{B}\right) A$$

Combining (1) and (2)

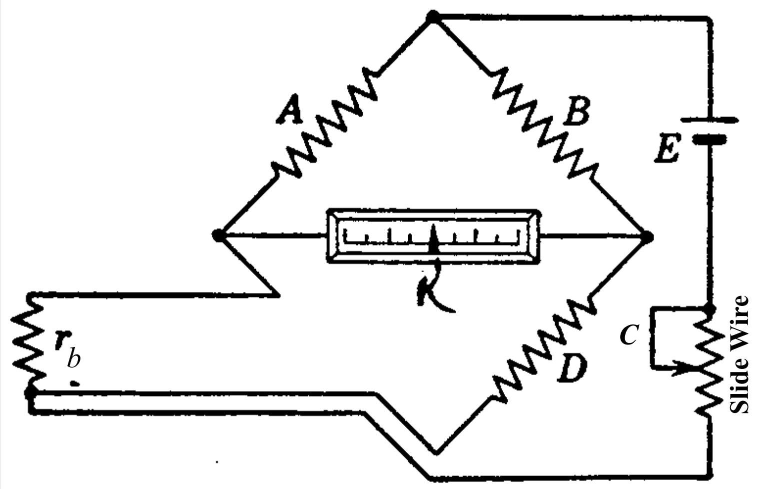


Thermal Resistance Temperature Measurement

- Wheat Stone Circuit (Null type)



- Wheat Stone Circuit (Deflection type)



Introduction – Radiation Type Thermometers

- **Radiation** is the emission or transmission of energy in the form of waves that is electromagnetic waves.

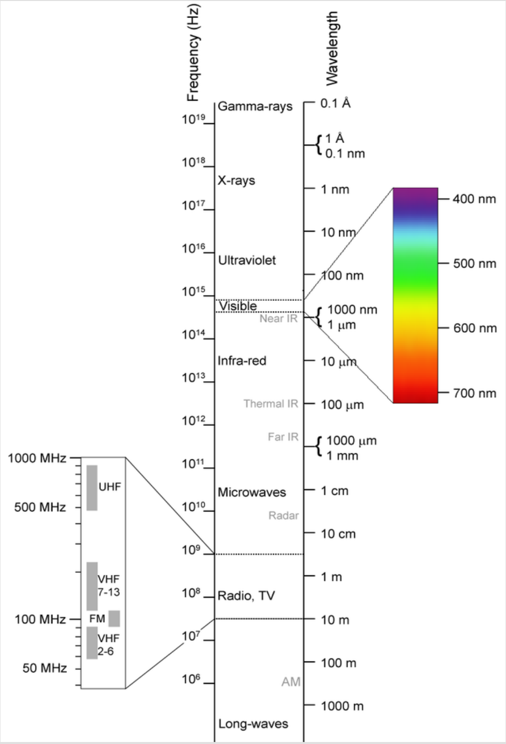
- Radiative property of an object varies with temperature.

- Radiation – Temperature measuring device converts radiant energy from the heated body into a sensible indication of temperature.

Introduction – Radiation Type Thermometers

- Radiant energy is the energy transmitted in the form of electromagnetic waves.

- The electromagnetic waves are exemplified by radio and radar radiation; infrared or visible and ultraviolet radiation; X- ray and gamma ray radiation.



Black Body

A black body is the one that absorbs all the radiation falling on it without transmitting or reflecting .

Black body concept is important because it is the basis on which radiation laws and the radiation type thermometers were developed.

Introduction – Radiation Type Thermometers

The fundamental equation that relates radiation emission and the temperature of a body is given by

$$E = \varepsilon\sigma T^4$$

E – the emissive power per unit W/m^2

ε – emissivity defined by the ratio of total radiation from a non-black body to that of geometrically similar black body at the same temperature. A Black body has the emissivity of exactly 1.

σ – Stephen Botlzmann constant, 5.669 x 10^{-8} W/m^2 K^4

T – absolute temperature of the surface of the object

Introduction – Radiation Type Thermometers

The same relation expressed as given below when two bodies exchanging radiation

$$E = \sigma A(T_2^4 - T_1^4)$$

E – the emissive power per unit W/m²

ε – emissivity defined by the ratio of total radiation from a non-black body to that of geometrically similar black body at the same temperature. A Black body has the emissivity of exactly 1.

σ – Stephen Botlzmann constant, 5.669 x 10^{-8} W/m² K^4

T_2 *and* T_1 – absolute temperature of the surface of the object at higher and lower temperatures respectively.

In more convenient form, $$Q = KA\left[\left(\frac{T_2}{100}\right)^4 - \left(\frac{T_1}{100}\right)^4\right]$$

Q = Radiant energy, J/s

K = Radiation Constant, 0.172

A = Area, m^2

T = Temperature in ^oC

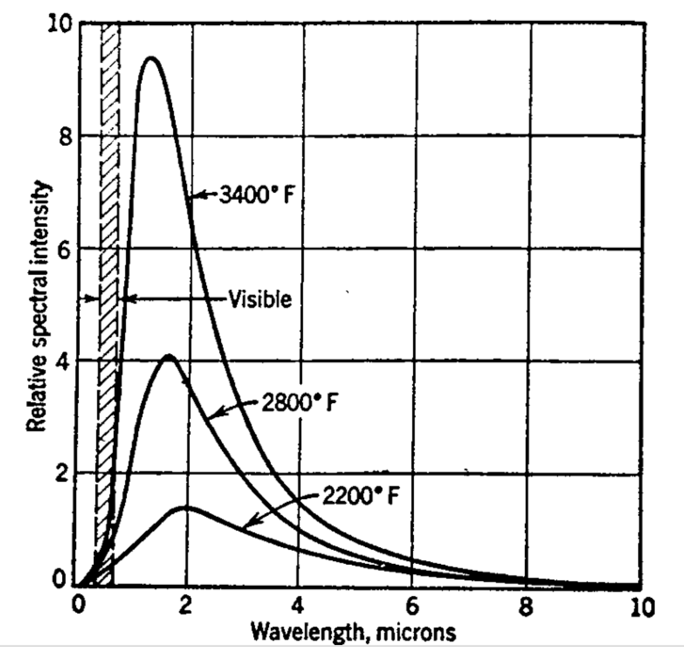
Introduction – Radiation Type Thermometers

Two principles that are used to construct the radiation temperature measuring devices are

1st – Measure total energy of radiation from a heated body and obtain a radiation pyrometer.
i.e. total energy of radiation represented by area under the curve in the graph and is given by Stefan-Boltzmann law.

2nd- Measure the spectral radiant intensity of radiated energy from a heated body at a given wavelength.

For instance, if a vertical line is drawn on the graph as shown here, the variation of radiation intensity with temperature can be found. This serves the basis for optical pyrometer.



Thank You