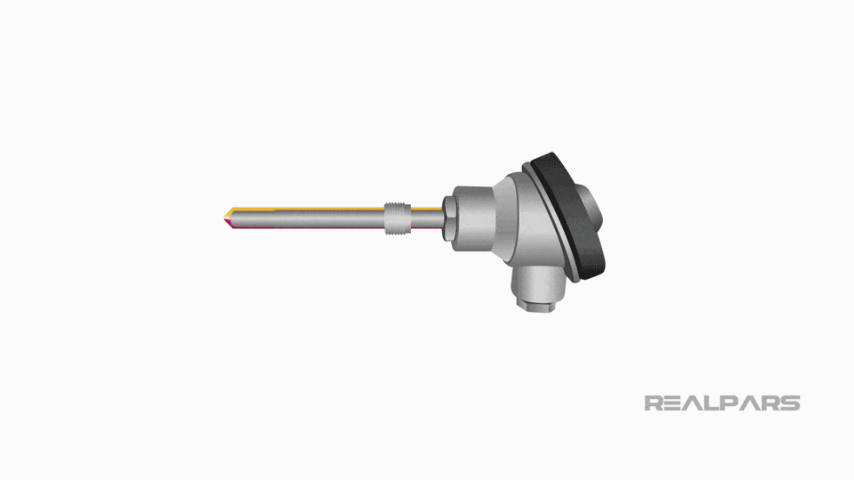
UNIT – 1

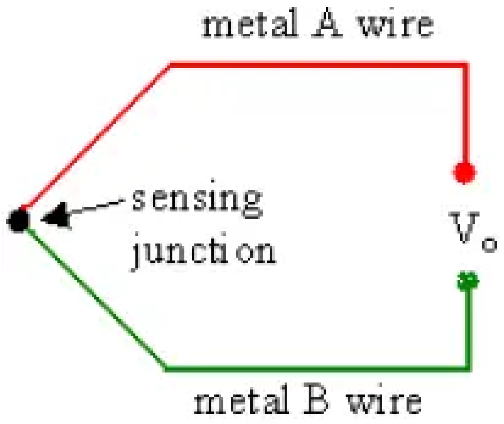
SCIENCE OF MEASUREMENT AND TRANSDUCERS

LVDT, RTD, Thermistor & Thermocouple

Thermocouple Working Principle

A thermocouple is made up of two dissimilar metals, joined together at one end, that produce a voltage (expressed in millivolts) with a change in temperature. The junction of the two metals, called the sensing junction, is connected to extension wires. Any two dissimilar metals may be used to make a thermocouple.

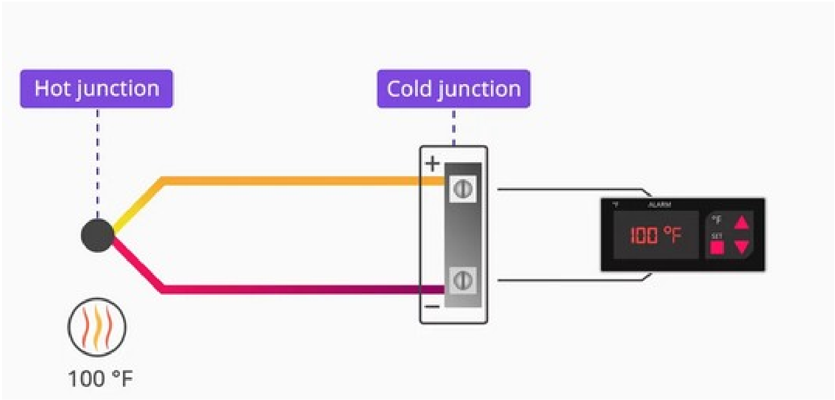


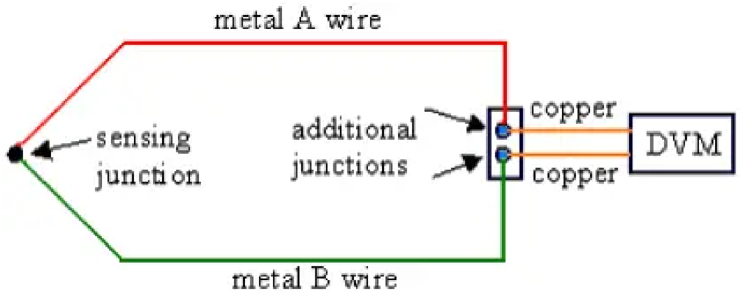


When two dissimilar metals are connected together, a small voltage called a *thermo-junction voltage* is generated at the junction. This is called the ***Peltier effect***.

If the temperature of the junction changes, it causes voltage to change too, which can be measured by the input circuits of an electronic controller.
The output is a voltage proportional to the temperature difference between the junction and the free ends. This is called the ***Thompson effect***.

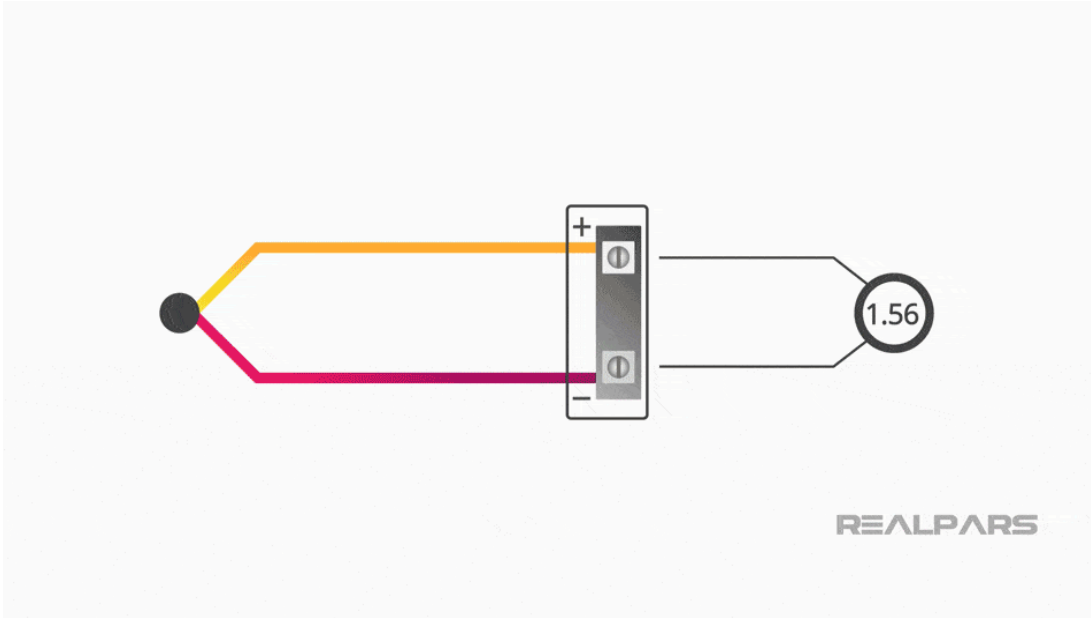
Both of these effects can be combined to measure temperature. By holding one junction at a known temperature (reference junction) and measuring the voltage, the temperature at the sensing junction can be deduced. The voltage generated is directly proportional to the temperature difference. The combined effect is known as the *thermo-junction effect* or the ***Seebeck effect***.

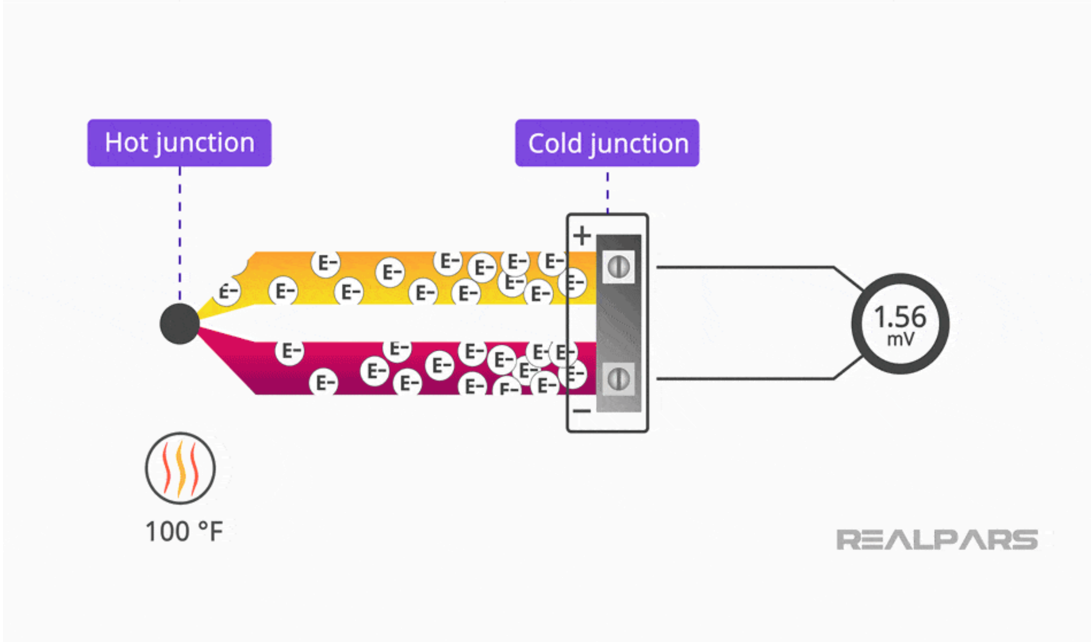




Hot Junction, Measurement Junction, Sensing Point, or Sensing Junction

The wiring terminals on the measuring instrument are most often called the **Cold Junction**.


+
−
1.56
REALPARS


Hot junction
Cold junction
+
−
1.56
mV
100 °F
REALPARS

A ***type K*** thermocouple has the color *yellow*, and uses *chromel – alumel,* which are the trade names of the Ni-Cr and Ni-Al wire alloys.

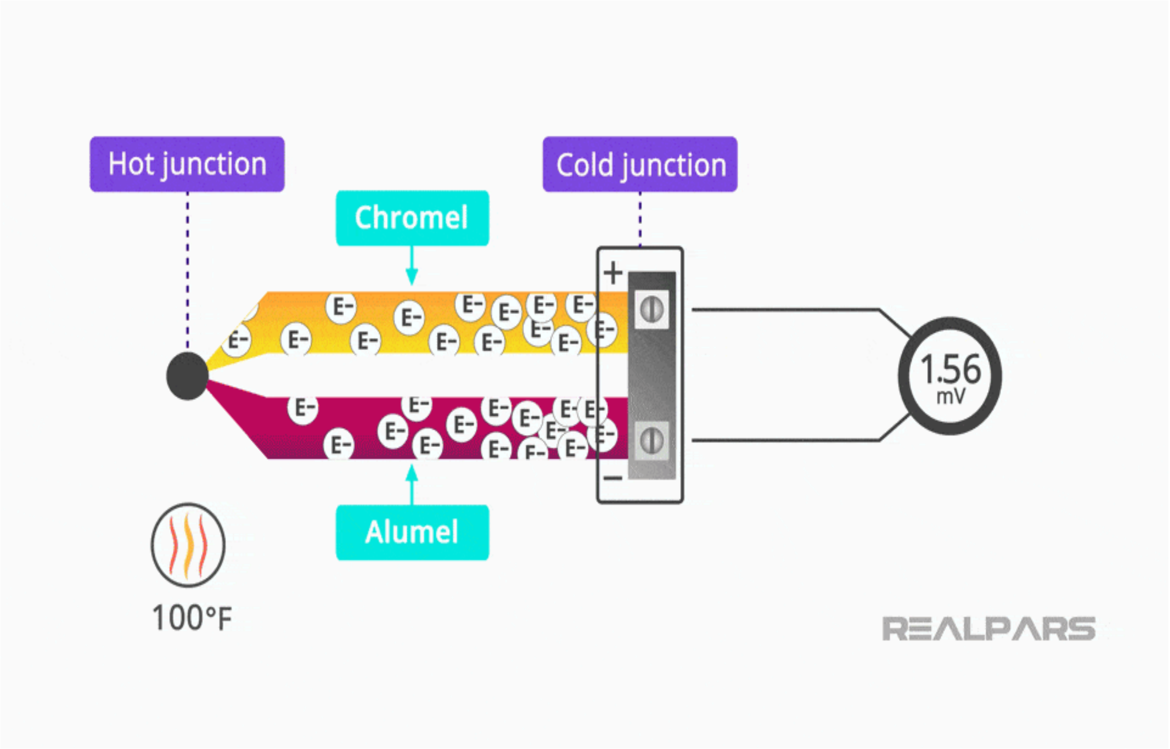
A ***type J*** thermocouple has the color *black*, and uses *iron* and *constantan* as its component metals. **(Constantan is an alloy of nickel and copper.)**

A ***type T*** thermocouple has the color *blue*, and uses *copper* and *constantan* as its component metals.

A **type S** thermocouple uses Pt/Rh-Pt

A **type E** thermocouple uses Ni/Cr-Con

*A **type N** thermocouple uses Ni/Cr/Si-Ni/Si*



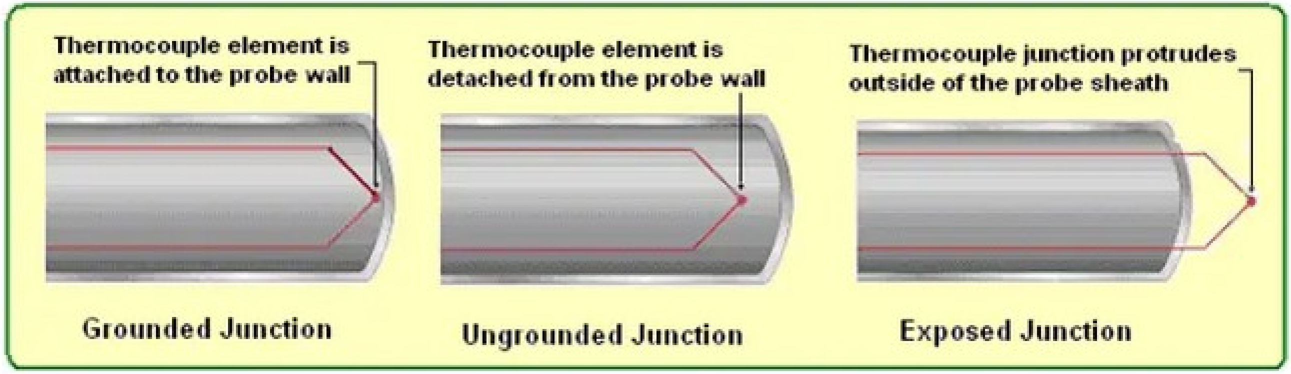
Temperature V/s Voltage Reference Table for Type J

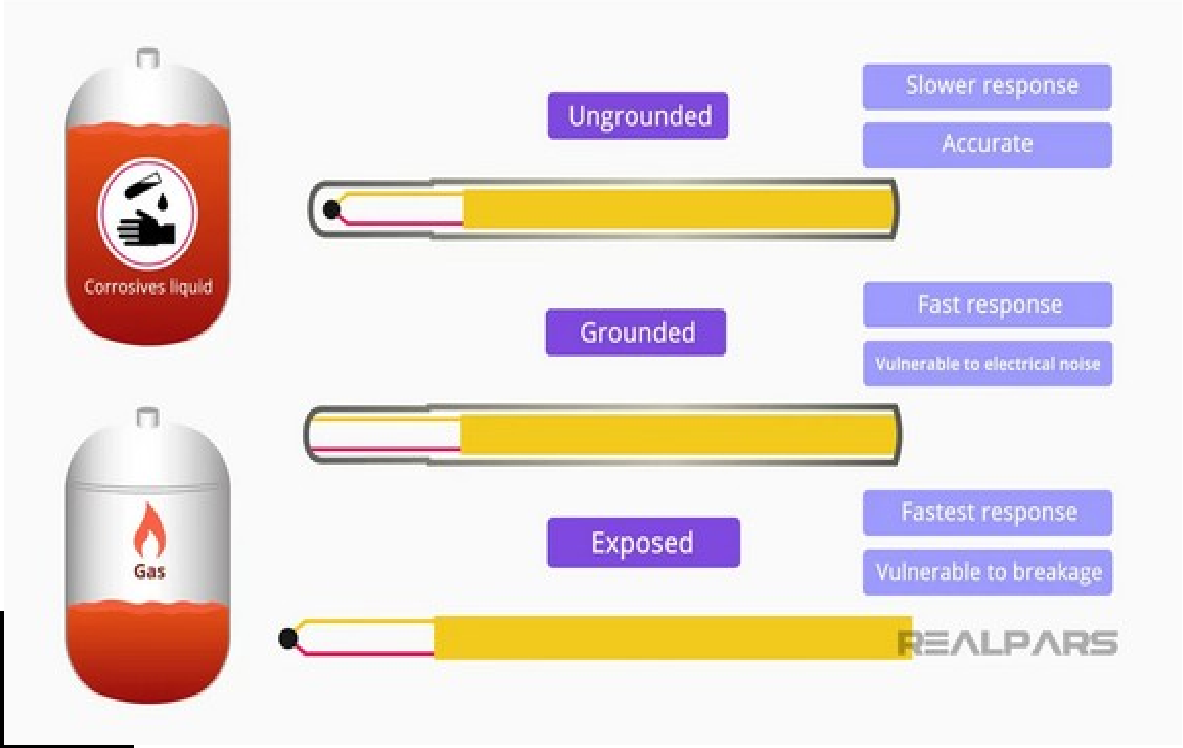
Temperature (°C)	voltage (mV)
0.0	0.000
10.0	0.507
20.0	1.019
30.0	1.537
40.0	2.059
50.0	2.585
60.0	3.116

The following criteria are used in selecting a thermocouple:

- ✓Temperature range.
- ✓Chemical resistance of the thermocouple or sheath material.
- ✓Abrasion and vibration resistance.
- ✓Installation requirements

(may need to be compatible with existing equipment; existing holes may determine probe diameter).


Thermocouple element is attached to the probe wall
Thermocouple element is detached from the probe wall
Thermocouple junction protrudes outside of the probe sheath
Grounded Junction
Ungrounded Junction
Exposed Junction


Corrosives liquid
Ungrounded
Slower response
Accurate
Grounded
Fast response
Vulnerable to electrical noise
Gas
Exposed
Fastest response
Vulnerable to breakage
REALPARS

Linear Variable Differential Transducer/Transformer (LVDT)

- The differential transformer is a passive inductive transformer (known as LVDT) is used to measure displacement directly
- The transformer consists of a single primary winding P1 and two secondary windings S1 and S2 wound on a hollow cylindrical former (as shown in fig. 13.19)
- The secondary windings have an equal number of turns and are identical placed on either side of the primary windings
- The primary winding is connected to an ac source (50 Hz to 20 kHz)
- A movable soft iron core slides within the hollow former and therefore affects the magnetic coupling between the primary and the two secondaries
- The displacement to be measured is applied to an arm attached to the soft iron core (the core is made up of a nickel iron alloy which is slotted longitudinally to reduce eddy current losses)
- Assume the output voltages of secondary windings S1 and S2 are E_{s1} and E_{s2}

Linear Variable Differential Transducer/Transformer (LVDT)

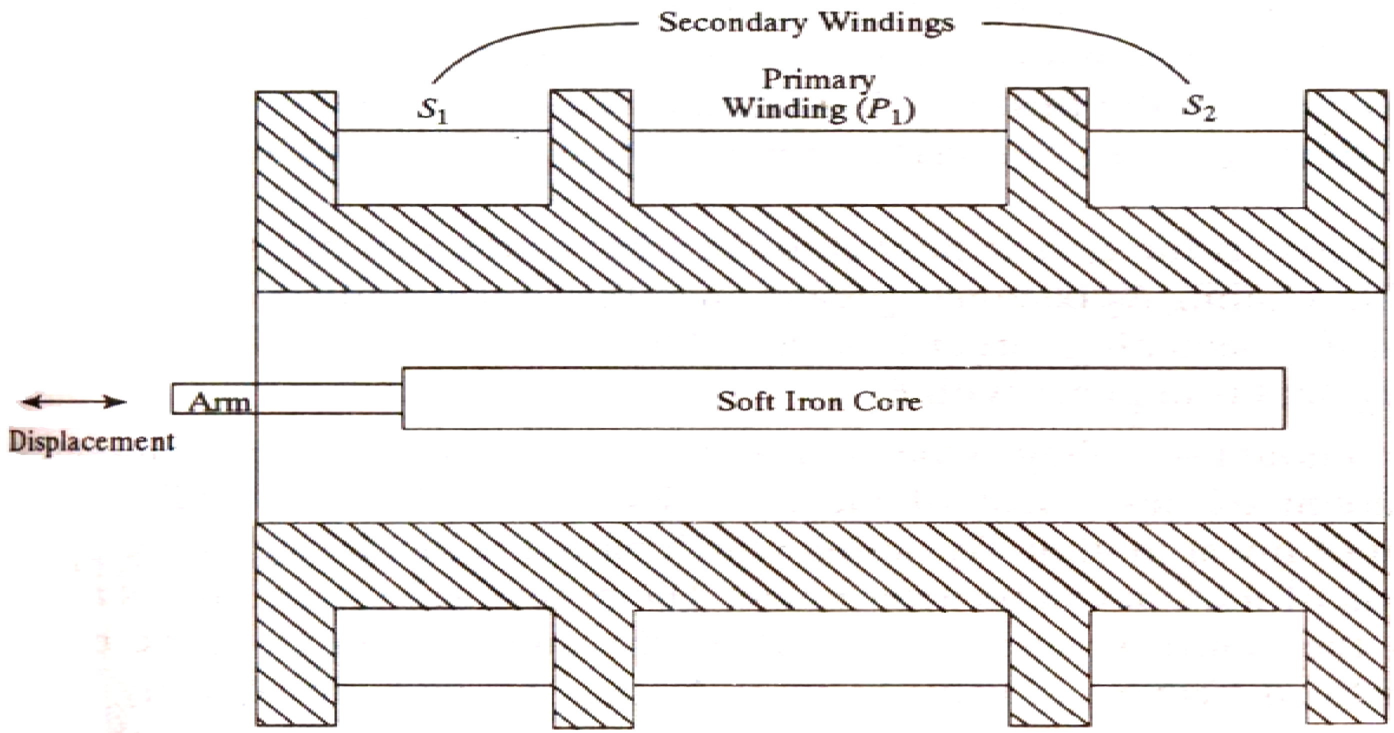
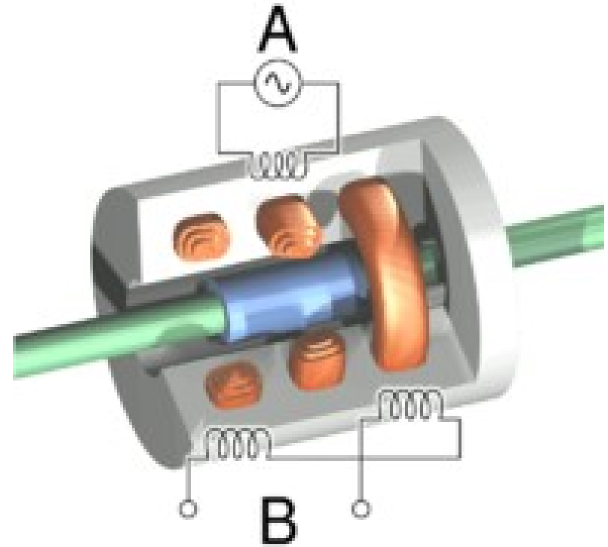
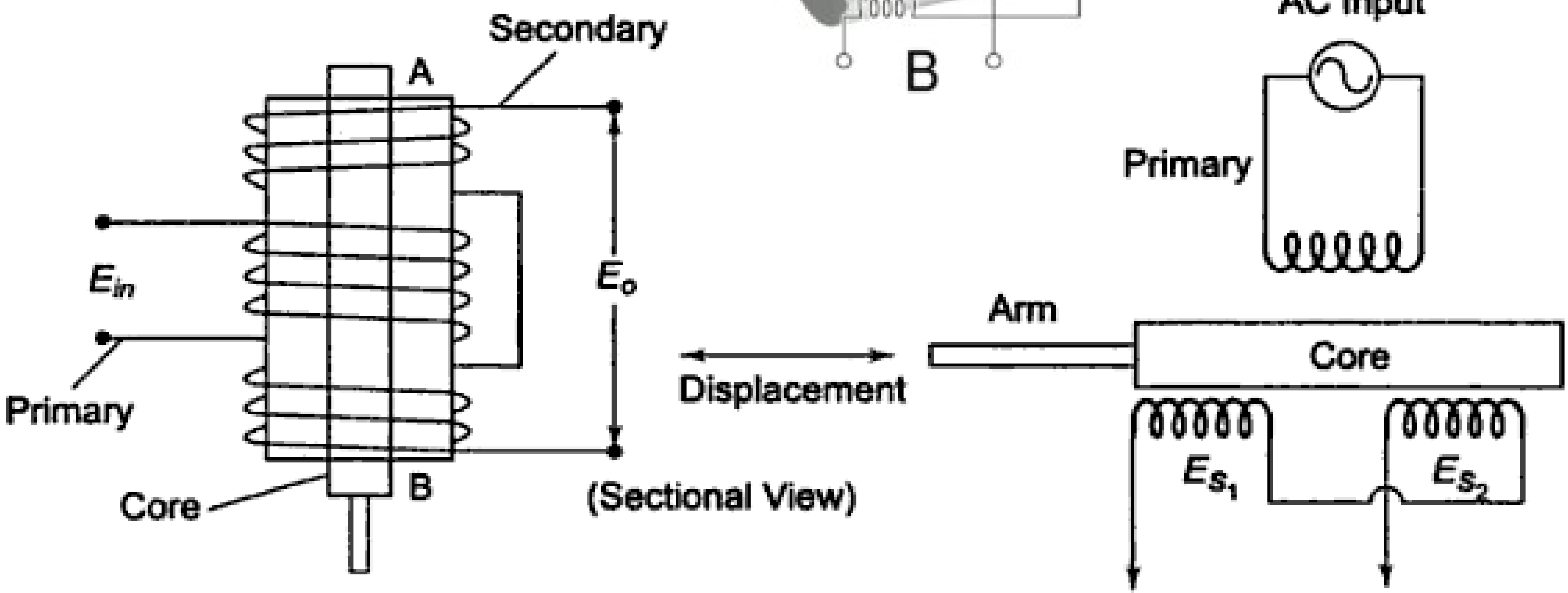


Fig. 13.19 Construction of a Linear Variable Differential Transducer (LVDT)

Linear Variable Differential Transducer/Transformer (LVDT)





(a) Construction

(b) Basic Circuit

Fig. 13.20 Secondary Winding Connected for Differential Output

Linear Variable Differential Transducer/Transformer (LVDT)

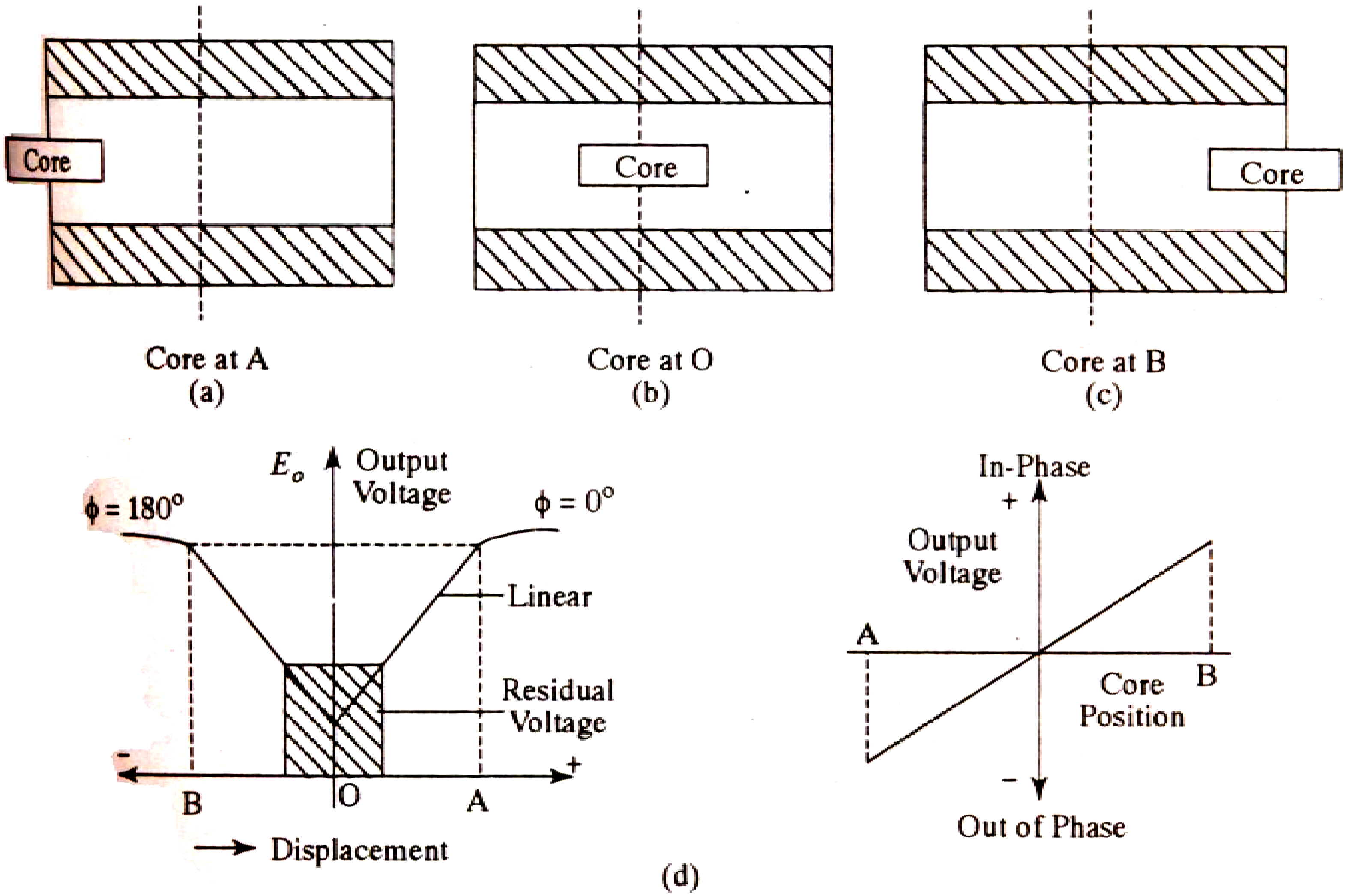


Fig.13.21 (a),(b),(c) Various Core Position of LVDT (d) Variation of Output Voltage vs Displacement

Linear Variable Differential Transducer/Transformer (LVDT)

- In order to convert the output from S1 to S2 into a single voltage signal, the two secondaries S1 and S2 are connected in series opposition (as shown in fig. 13.20)
- And hence, the differential output voltage $E_0 = E_{s1} – E_{s2}$
- When the core is at its normal position, the flux linking with both secondaries is equal and equal emfs are induced in them
- Hence, at null position $E_{s1} = E_{s2}$ and this results $E_0 = 0$ (fig. 13.21b)
- Now, if the core is moved to left of null position, more flux links with winding S1 and less with winding S2
- Hence, output voltage E_{s1} of the secondary winding S1 is greater than E_{s2}, which results E_0 in phase with E_{s1} (also with E_{in})
- Similarly, if the core is moved to the right of null position, the flux linking with S2 becomes greater than that linked with S1 and this results in E_{s2} becoming larger than E_{s1}
- The output voltage E_0, in this case, is out of phase with E_{s1}

Linear Variable Differential Transducer/Transformer (LVDT)

- The amount of voltage change in either secondary winding is proportional to the amount of movement of the core
- Hence we have an indication of the amount of linear motion
- By noting which output is increasing or decreasing, the direction of motion can be determined
- The output ac voltage inverts as the core passes the centre (null) position
- The farther the core moves from the centre, the greater the difference between E_{s1} and E_{s2} and consequently the greater the value of E_0
- Hence, the amplitude of E_0 is the function of displacement of the core and the polarity or phase of E_0 indicates the direction of motion
- Output signal may also be applied to a recorder or to a controller that can restore the moving system to its normal position
- The output voltage of an LVDT is a linear function of core displacement within a limited range of motion (approximately 5mm from the null position) and beyond this range, the curve starts to deviate

Linear Variable Differential Transducer/Transformer (LVDT)

- Ideally, the output voltage at the null position should be zero but in actual practice there exists a small voltage (residual voltage) at the null position
- This may be on account of presence of harmonics in the input supply voltage and also due to the harmonics produced in the output voltage due to the use of iron core
- There may be either an incomplete magnetic or electrical imbalance or both which result in a finite output voltage (generally less than 1% of maximum output voltage in linear region) at the null position
- Other causes of residual voltage are stray magnetic fields and temperature effects
- However, with improved technological methods and with the use of better ac sources the residual voltage can be reduced to negligible value
- Mostly, the LVDTs produce higher output voltage for small changes in core position
- Several commercial models that produce 50 mV/mm to 300 mV/mm are available

Linear Variable Differential Transducer/Transformer (LVDT)

- LVDTs are available with ranges as low as ±0.05” to as high as ±25” and are sensitive enough to be used to measure displacements of well below 0.001”
- They can operate at temperatures as low as -265^{0}C and as high as 600^{0}C and are also available in radiation resistance designs for nuclear operations

Advantages of LVDT:

(1) **Linearity**: The output voltage of this transducer is practically linear for displacements up to 5 mm.

(2) **Infinite Resolution**: The change in output voltage is stepless. The effective resolution depends more on the test equipment than on the transducer.

(3) **High Output**: It gives a high output. Therefore, there is frequently no need for intermediate amplification devices.

(4) **High Sensitivity**: The transducer possess a sensitivity as high as 40 V/mm.

Linear Variable Differential Transducer/Transformer (LVDT)

(5) Ruggedness: These transducers can usually tolerate a high degree of vibration and shock.

(6) Less Friction: There are no sliding contacts.

(7) Low Power Consumption: Most LVDTs consume less than 1 W of power.

<u>Disadvantages of LVDT</u>:

(1) Large displacements are required for appreciable differential output

(2) They are sensitive to stray magnetic fields (but shielding is possible)

(3) The receiving instrument must be selected to operate on ac signals, or a demodulator network must be used if a dc output is required

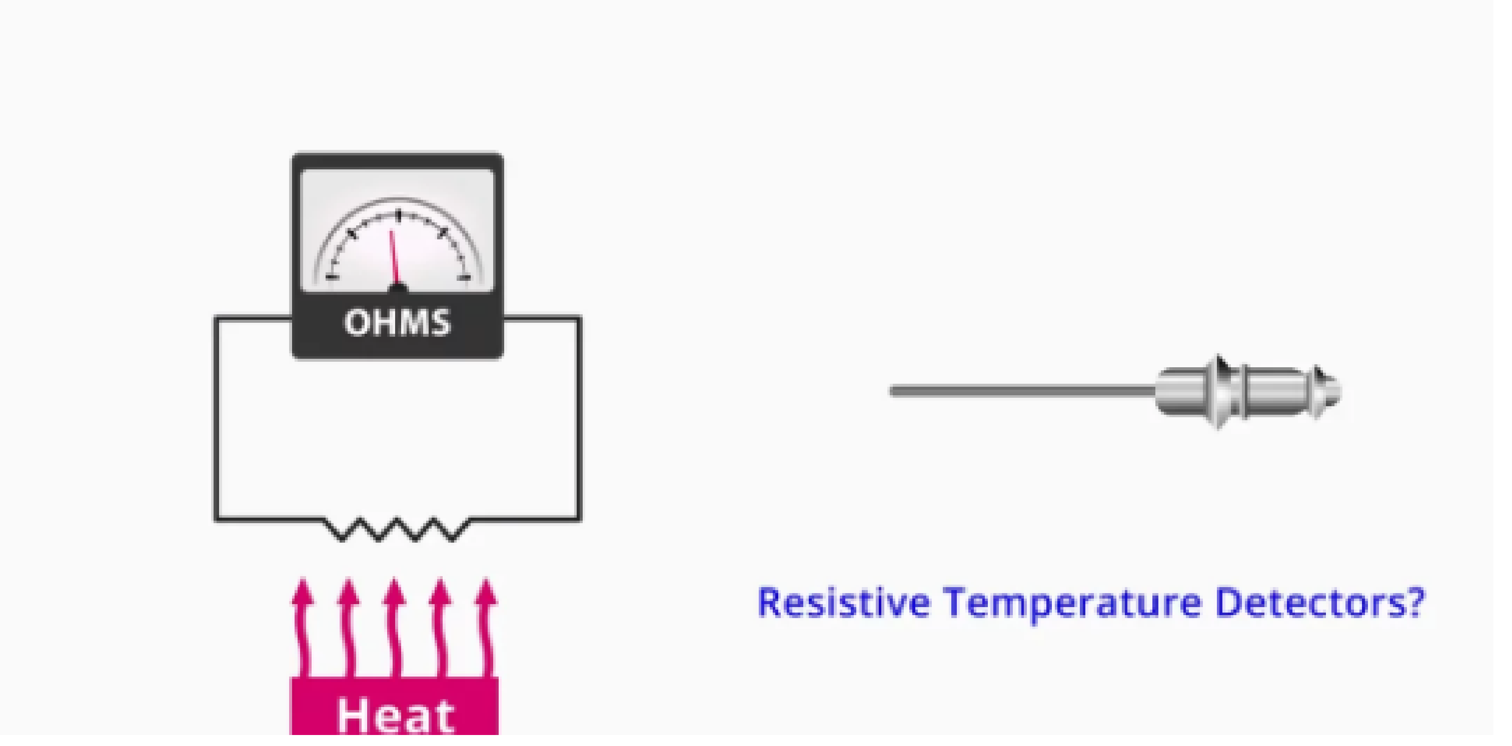
(4) The dynamic response is limited mechanically by the mass of the core and electrically by the applied voltage

(5) Temperature affects the transducer

Thermoelectric Transducers

- Generally used thermoelectric transducers are:

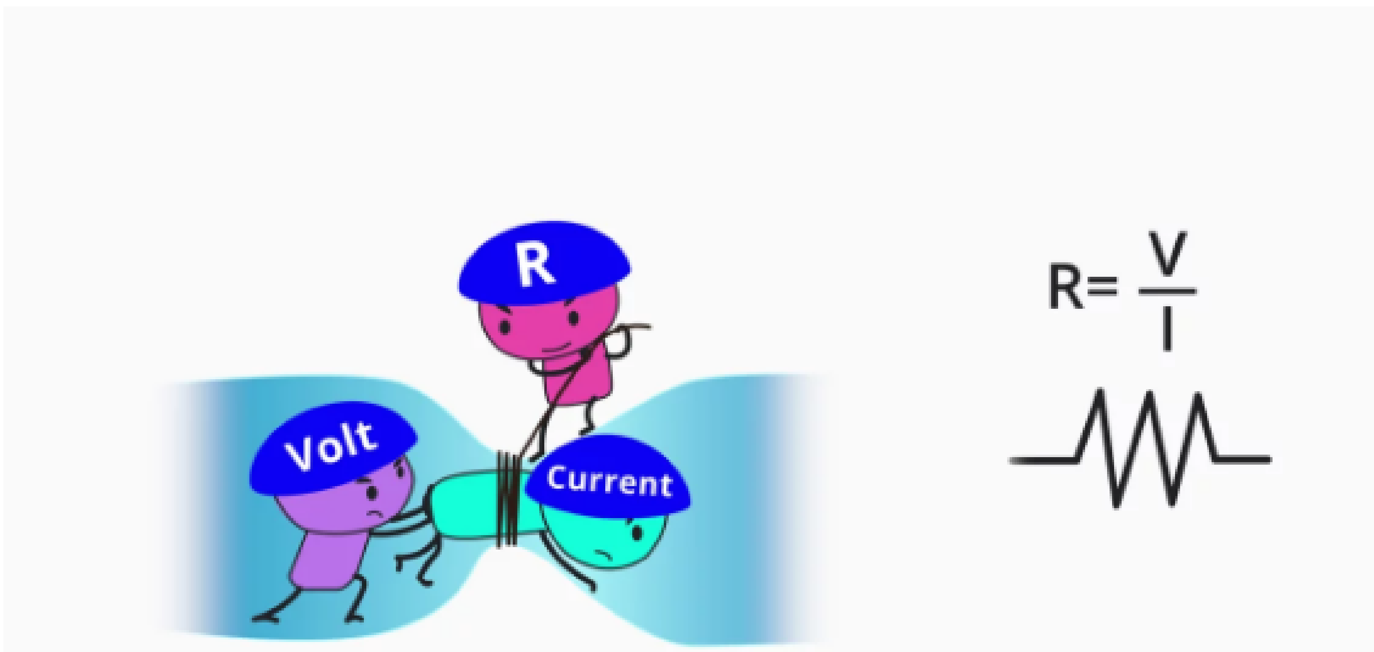
(a) Resistance Thermometer (Resistance Temperature Detector, RTD)



what electrical resistance and specific electrical resistance are ?

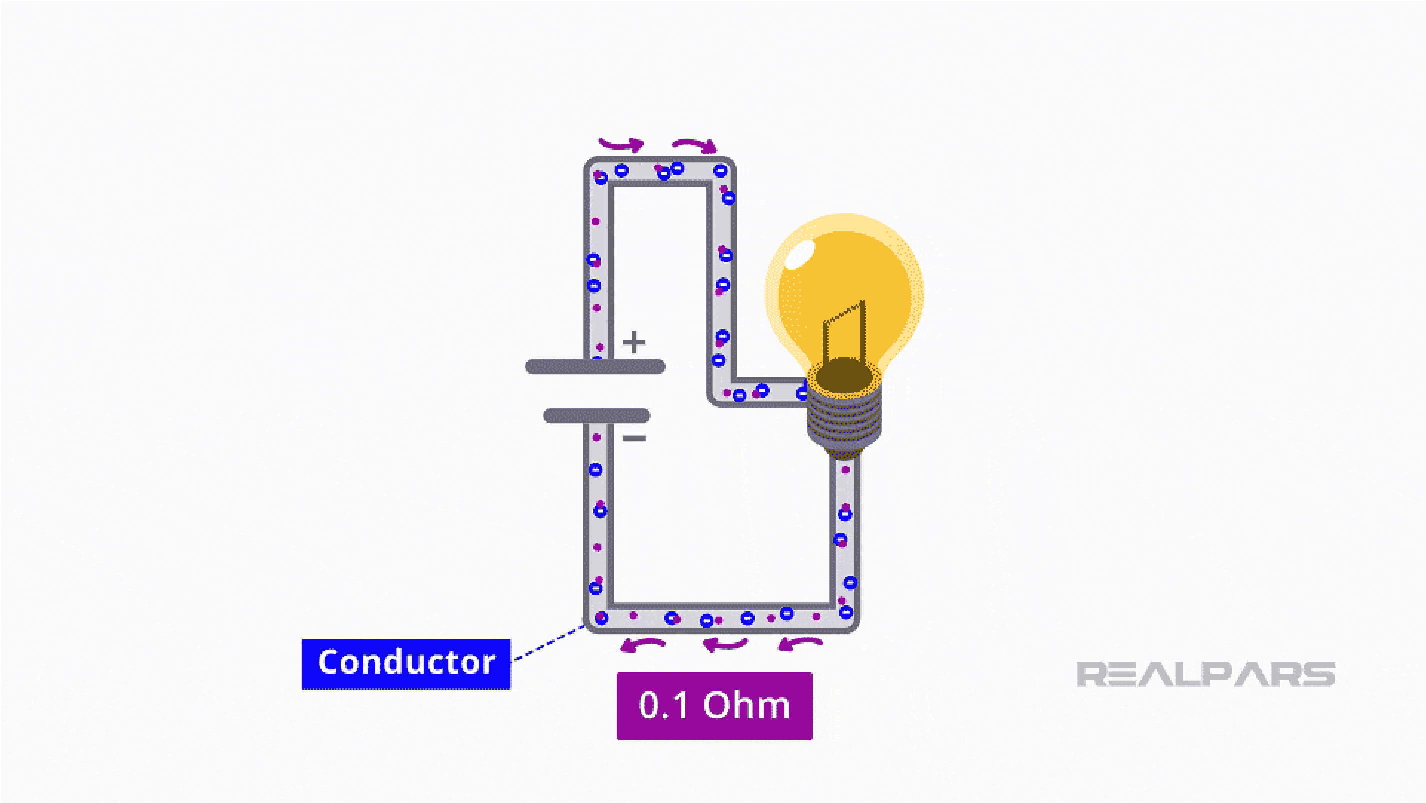
Electrical resistance

Electrical resistance is defined as the ability of a body to oppose the flow of electric current.

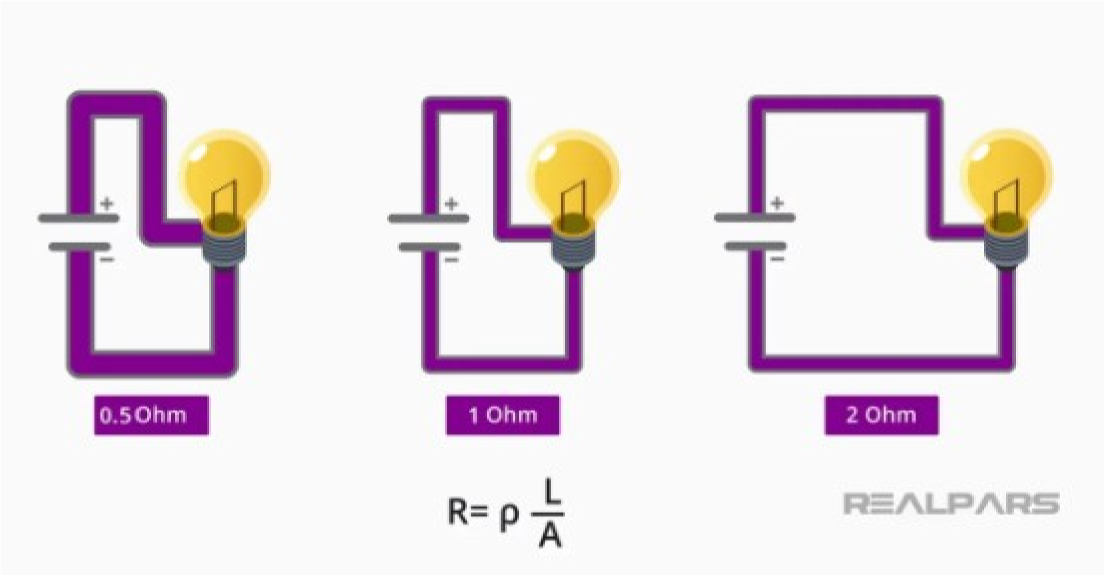


Resistance Temperature Detector

- A substance that has free electrons and where the charge can move relatively freely is called a conductor.



Effective factors



Electrical resistance varies depending on the **length**, **width**, and **nature of the conductor material**, as well as the **temperature** to which it is subjected.

Resistance is directly proportional to the length of the conductor, that is, the longer the length, the greater the resistance.

It is also inversely proportional to the area of the conductor, since the larger the area, the easier the passage of electrons and, consequently, the lower the resistance of the material.

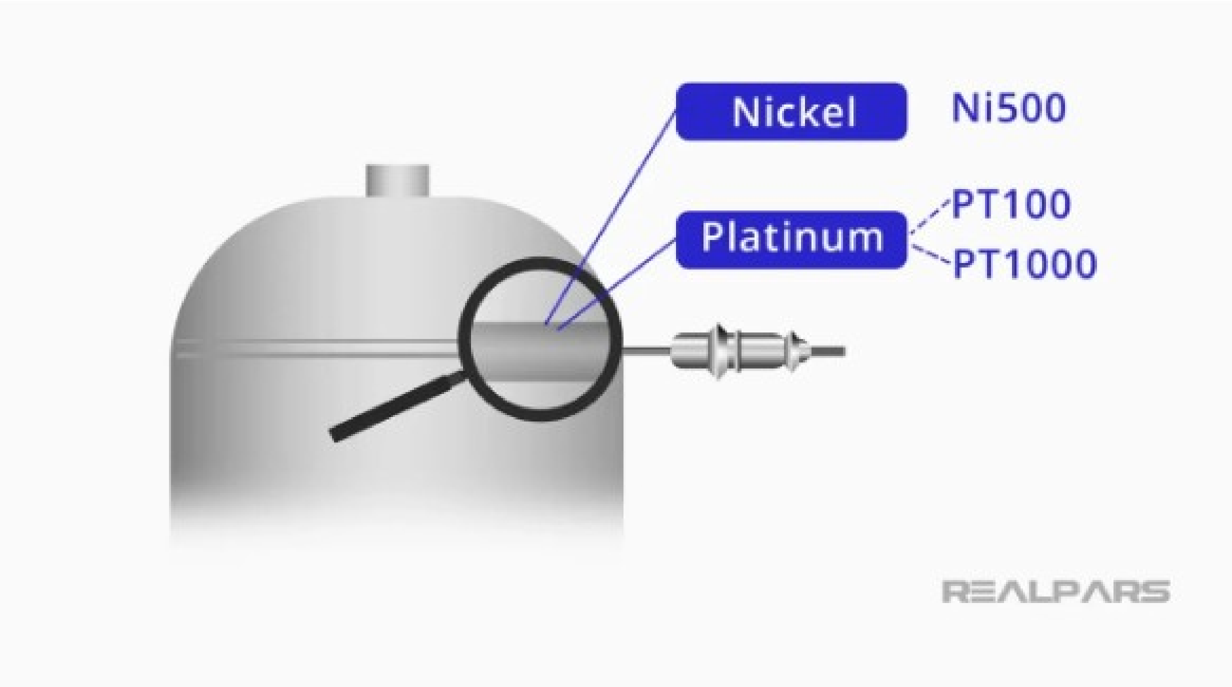
How does an RTD work?

- Specific electrical resistance is also known as electric resistivity is a property of material defining **how strongly can the material oppose** the flow of electric current

- When the **conductor is heated**, its atoms absorb this heat energy, resulting in an increase in vibration.

- Now, when the electric current is crossing the conductor, the number of collisions between electrons and atoms increases, making it harder for the current to flow throw it.

- RTD sensors use this variation in electrical resistance to measure the change in temperature.



resistance at zero degrees Celsius

RTD components

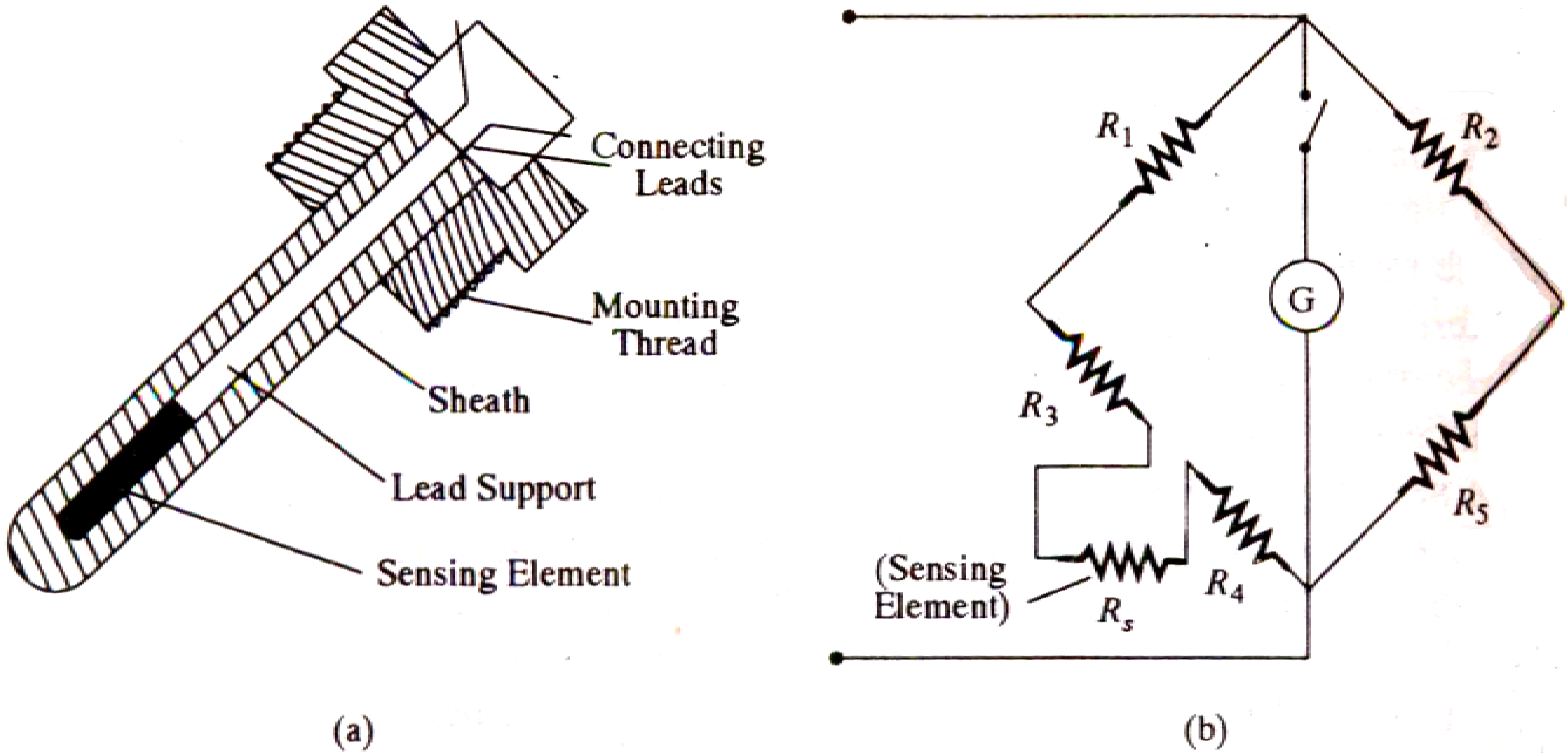
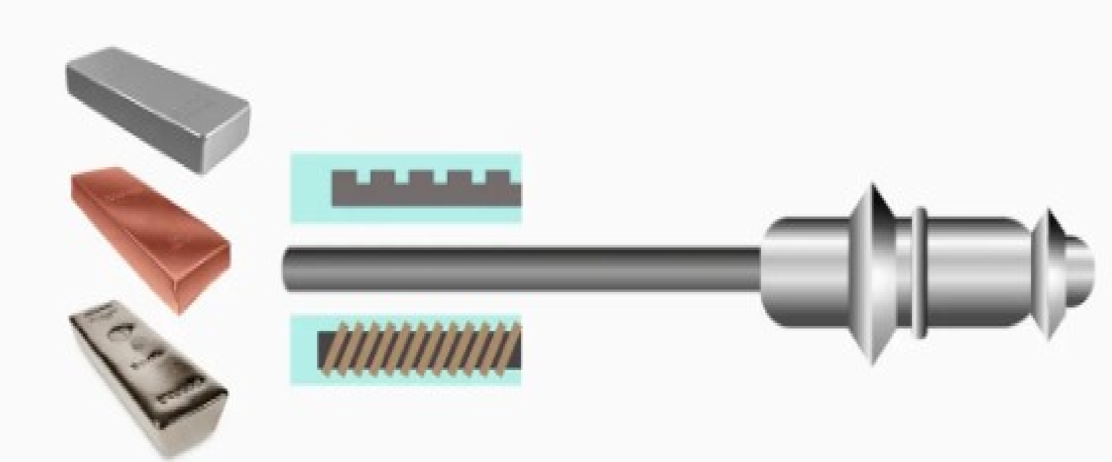
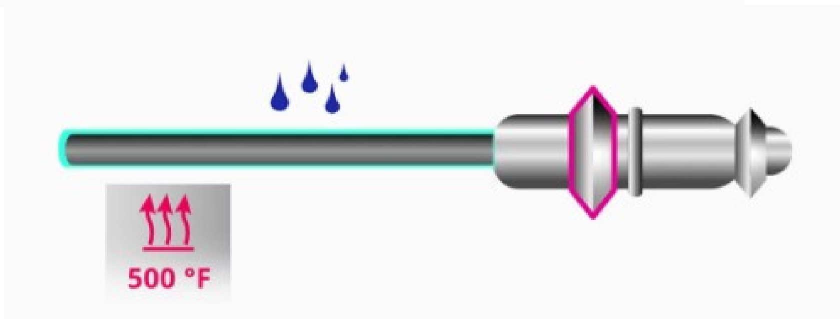
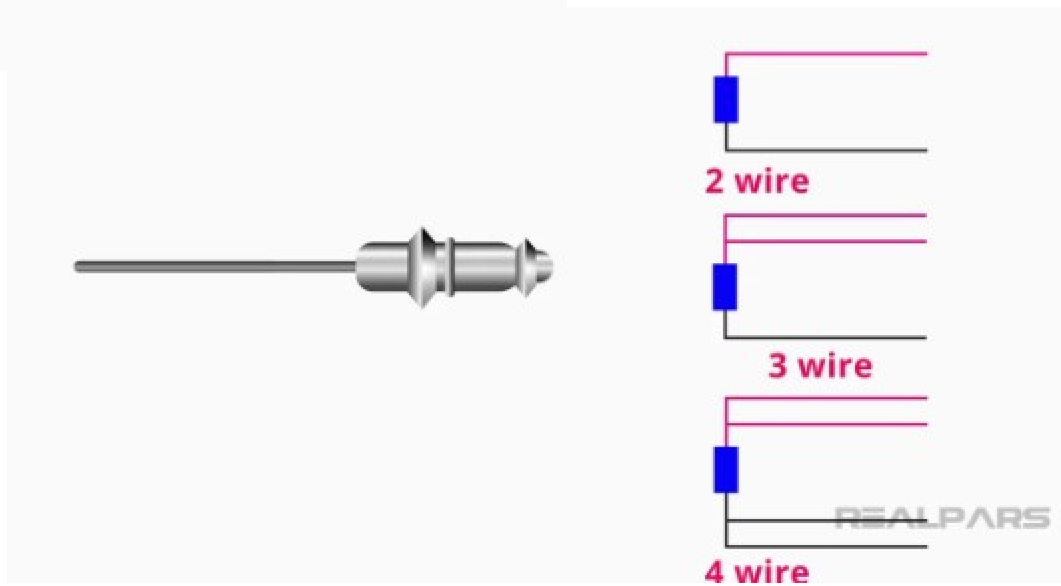
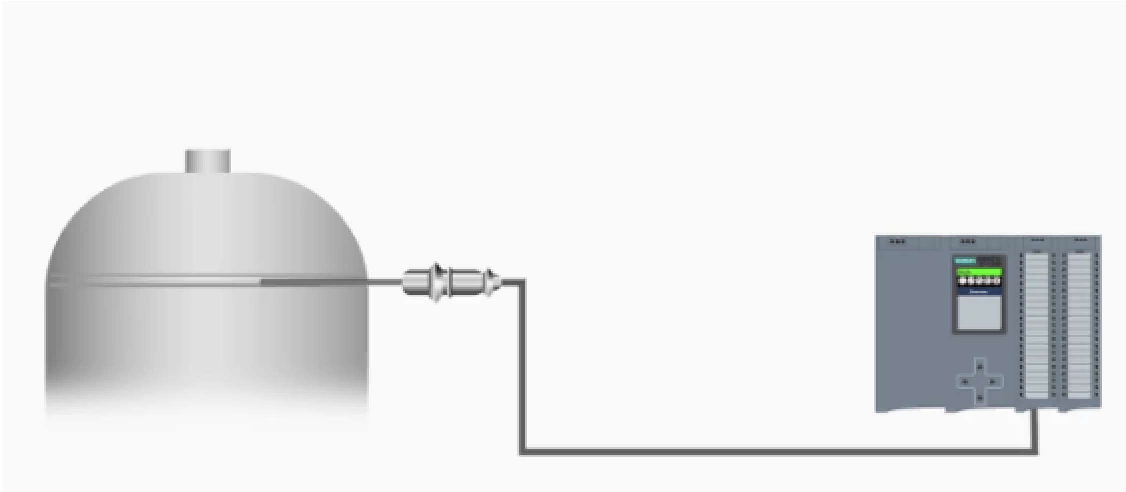


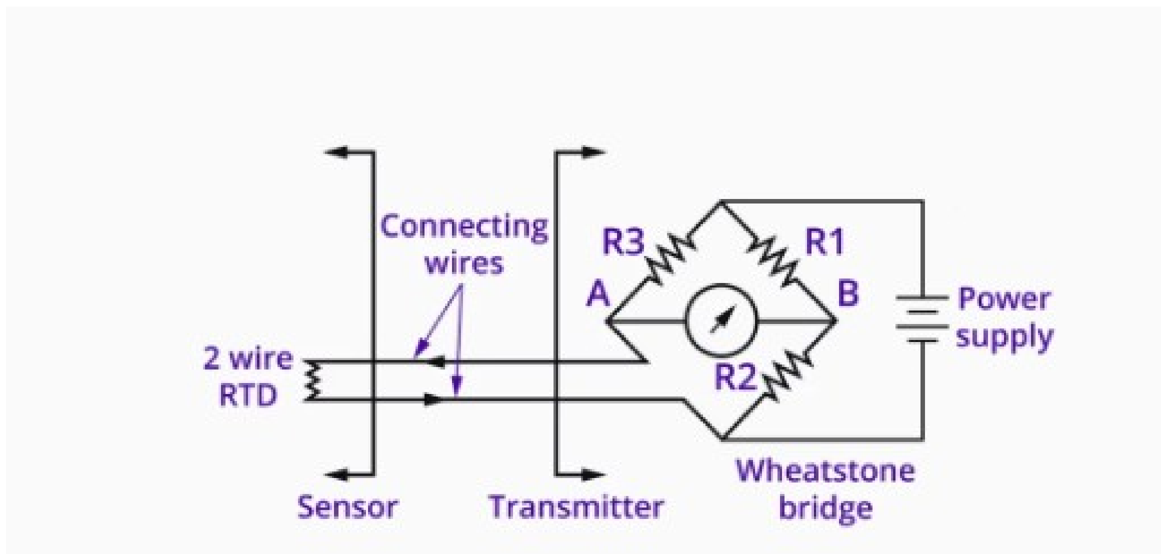
Fig. 13.11 (a) Industrial Platinum Resistance Thermometer (b) Bridge Circuit




500 °F

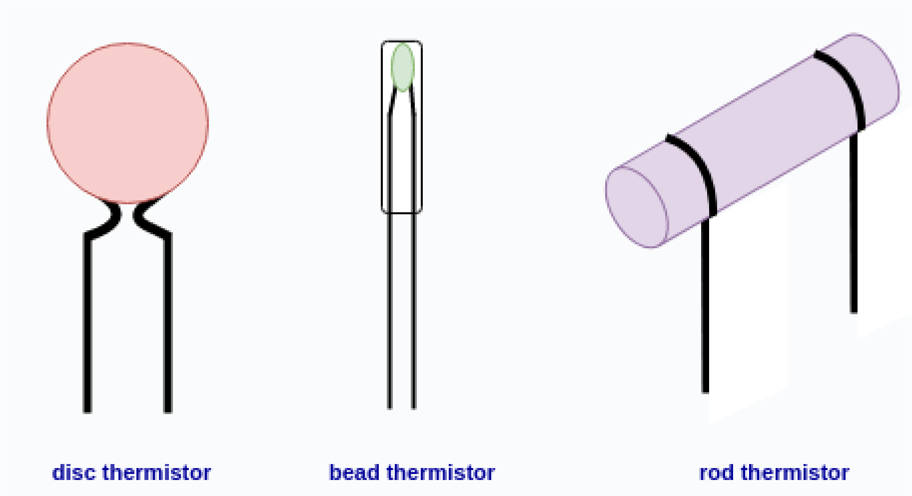

2 wire
3 wire
4 wire




Connecting
wires
R3
R1
A
B
Power
supply
2 wire
RTD
R2
Sensor
Transmitter
Wheatstone
bridge

Thermistor

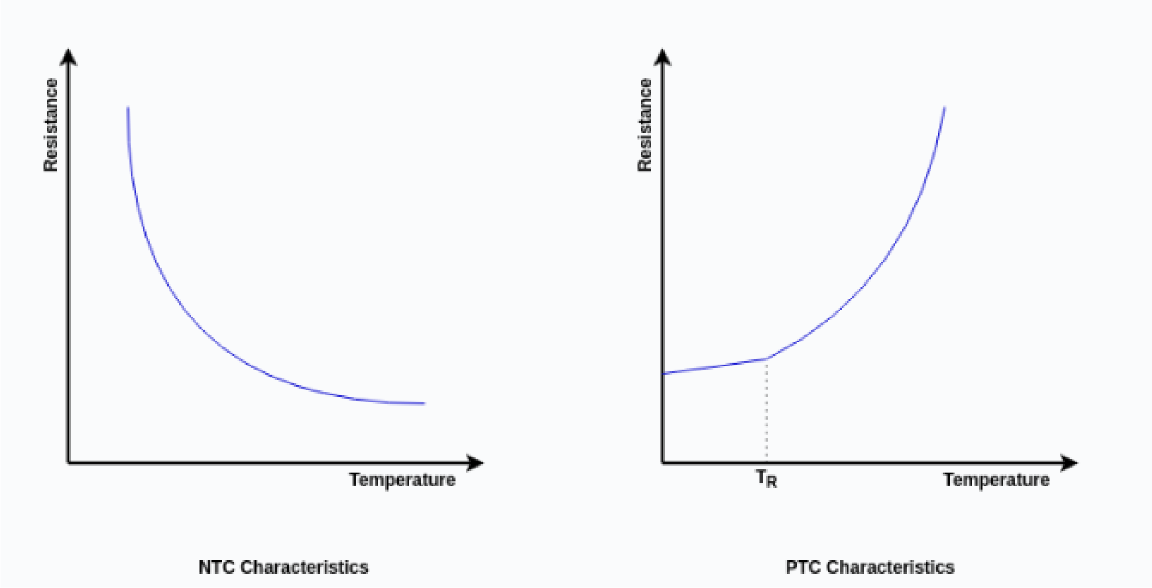
- The Thermistor or simply Thermally Sensitive Resistor is a temperature sensor that works on the principle of varying resistance with temperature. They are made of semiconducting materials. The circuit symbol of the thermistor is shown in the figure.

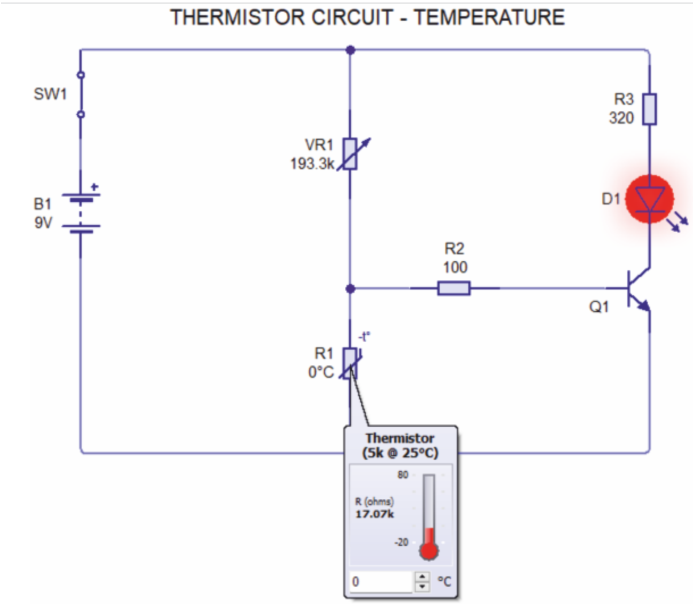


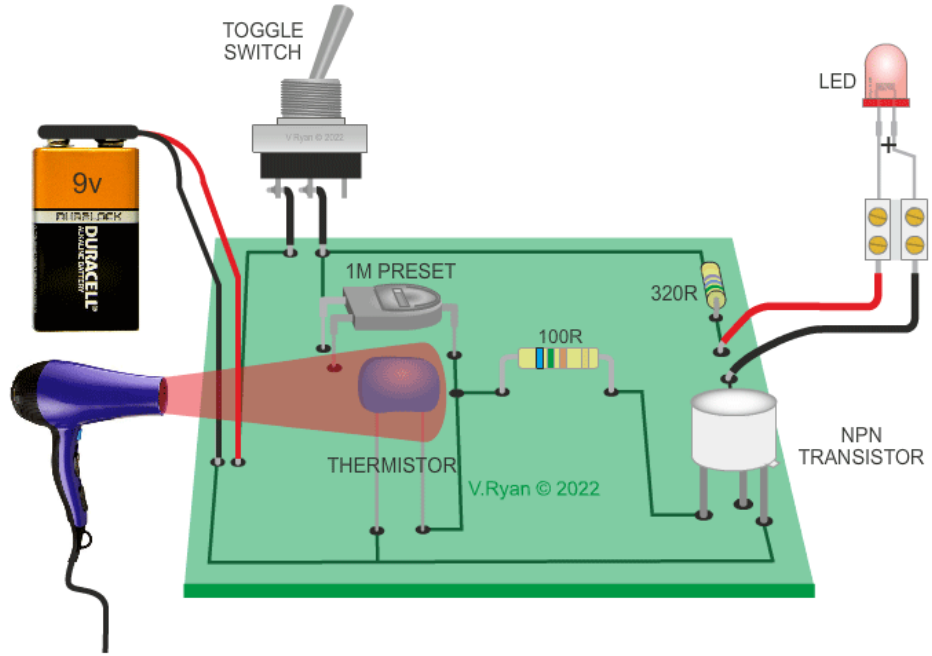
Types of Thermistors

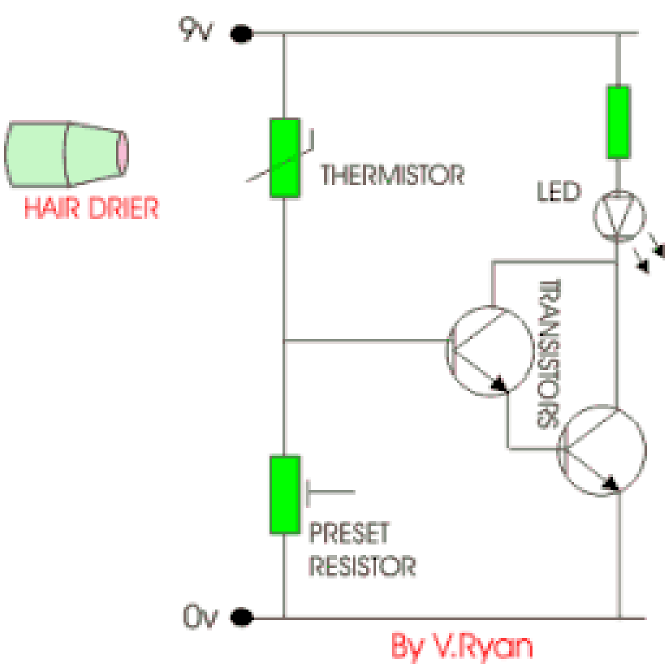
- The two basic types of thermistors available are the NTC and PTC types.

Circuit symbols of NTC and PTC thermistors are shown in the following figure.



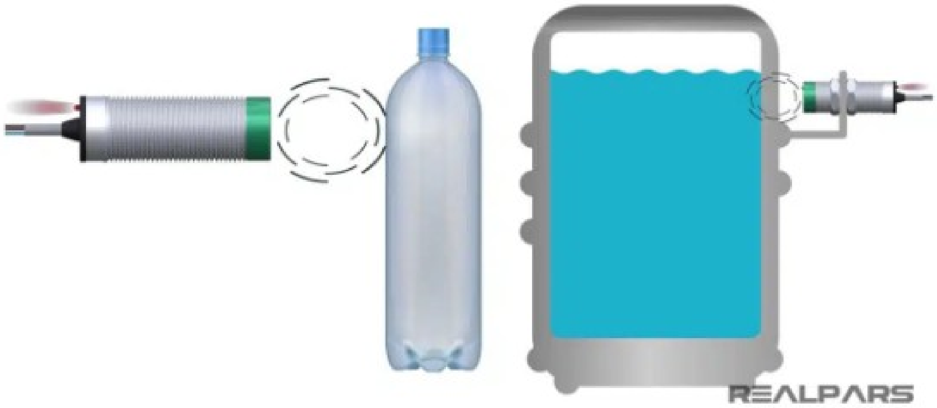

THERMISTOR CIRCUIT - TEMPERATURE
SW1
B1
9V
VR1
193.3k
R3
320
D1
R2
100
Q1
R1
0°C
Thermistor
(5k @ 25°C)
80
R (ohms)
17.07k
-20
0
°C


TOGGLE
SWITCH
LED
9v
DURACELL
1M PRESET
320R
100R
THERMISTOR
V.Ryan © 2022
NPN
TRANSISTOR


9v
HAIR DRIER
THERMISTOR
LED
TRANSISTORS
PRESET
RESISTOR
0v
By V.Ryan

What is a capacitive sensor?

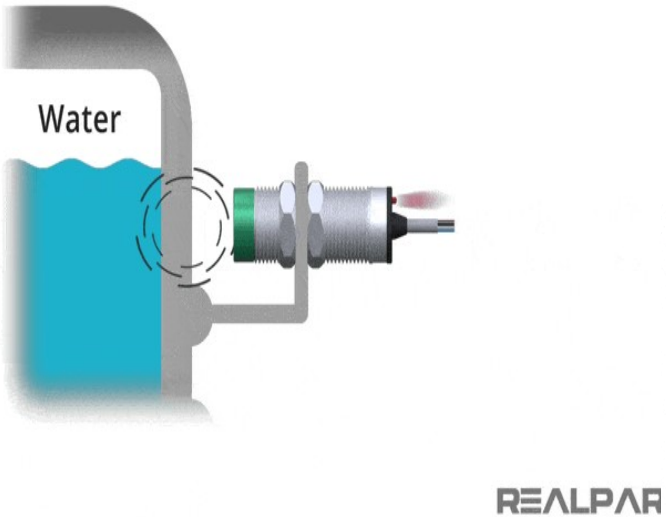
- A capacitive sensor is an electronic device that can detect solid or liquid targets without physical contact.

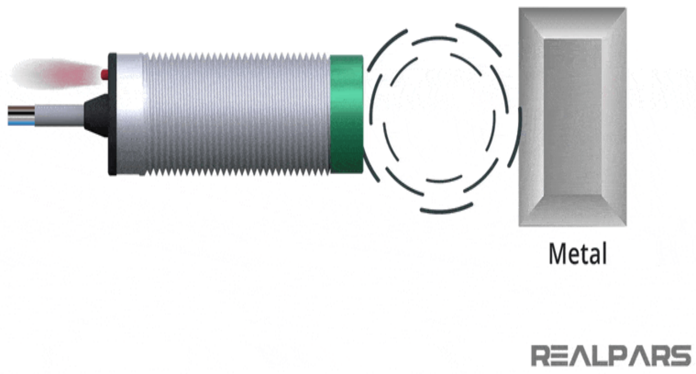


To detect these targets, capacitive sensors emit an electrical field from the sensing end of the sensor.

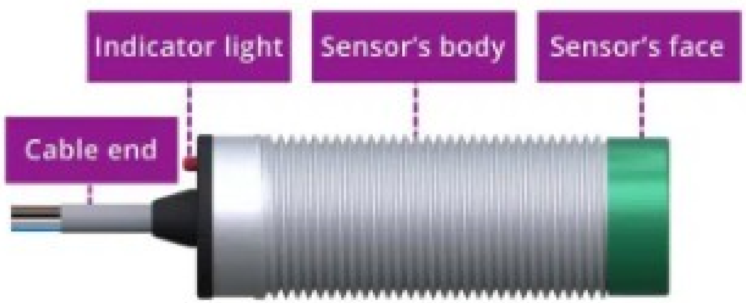
Any target that can disrupt this electrical field can be detected by a capacitive sensor.

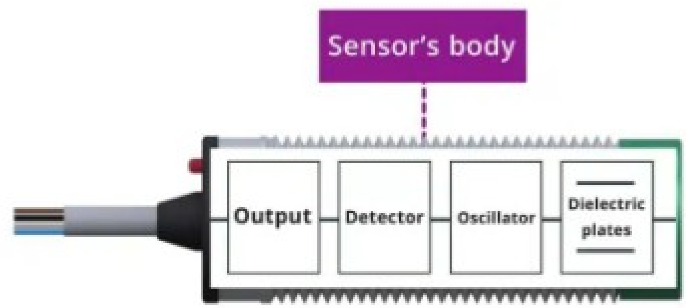
Types of materials capacitive sensors can detect

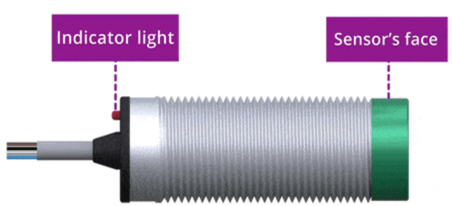


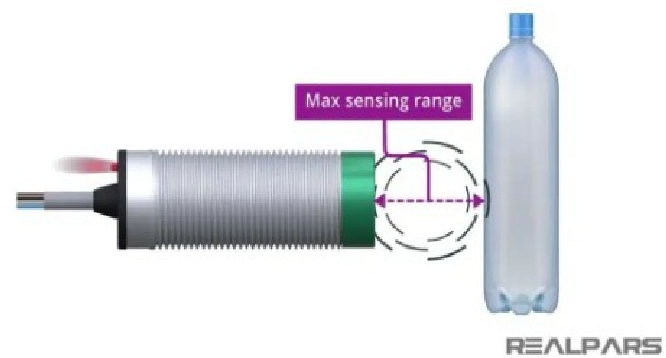


Capacitive sensor main parts

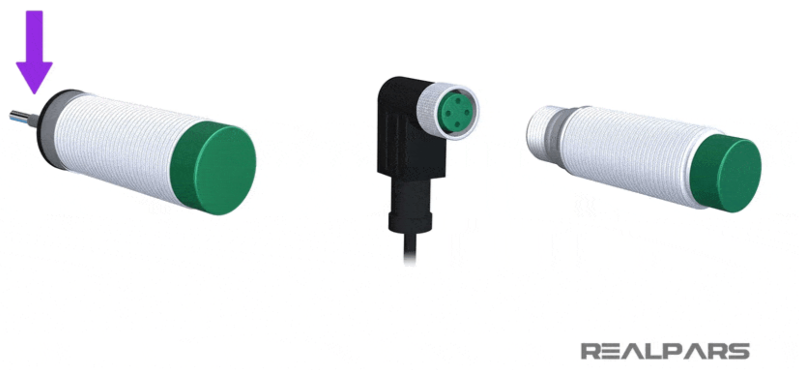


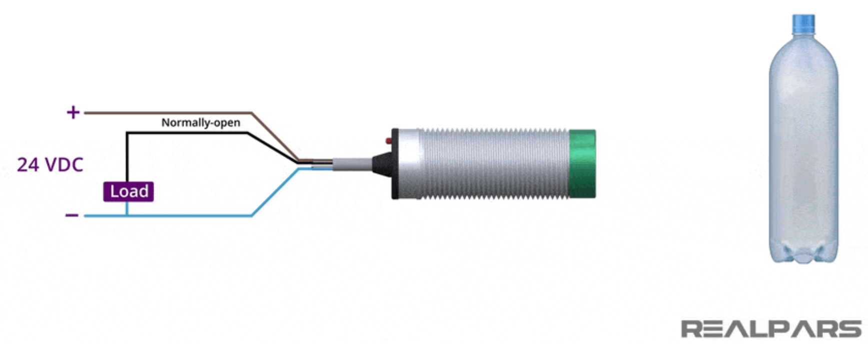


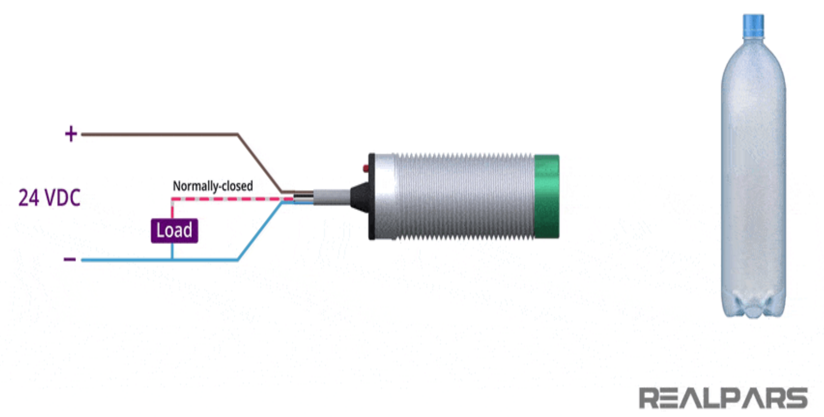




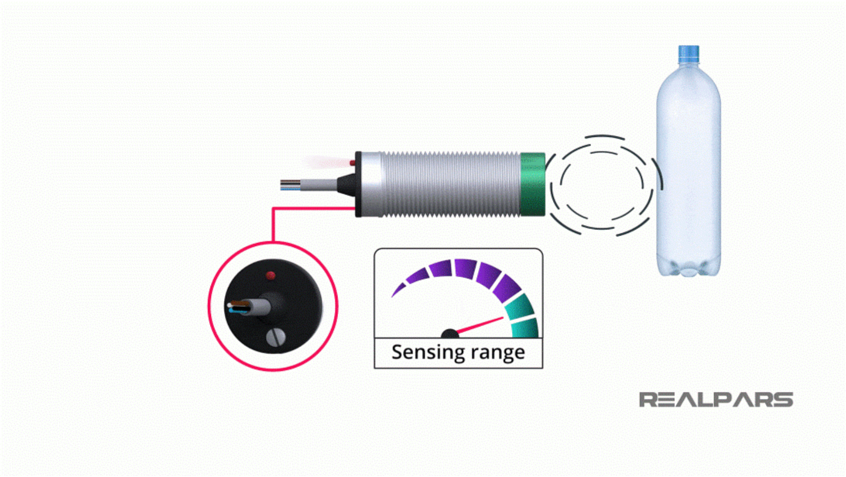
Sensor connection

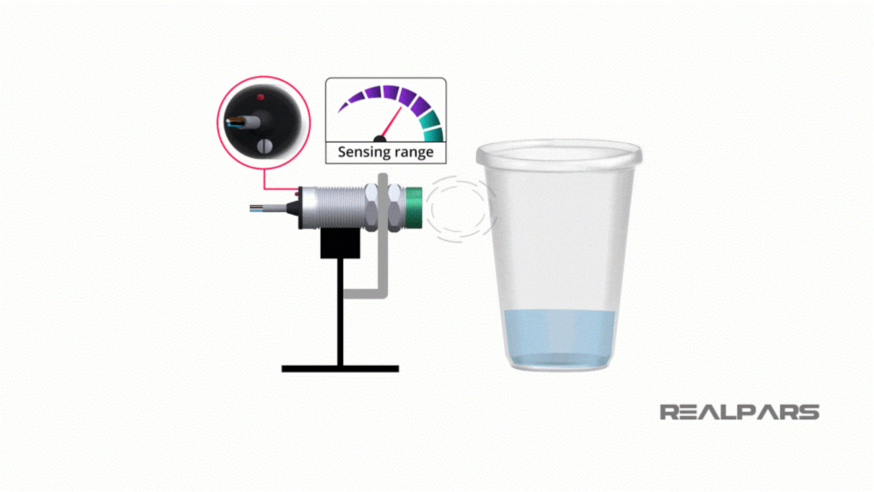


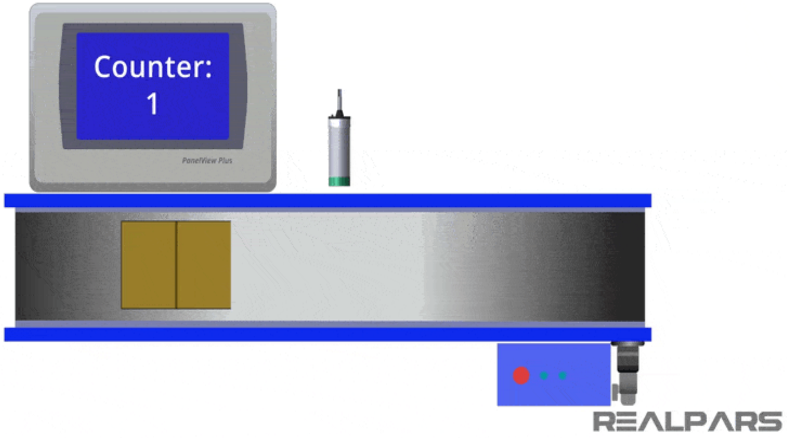


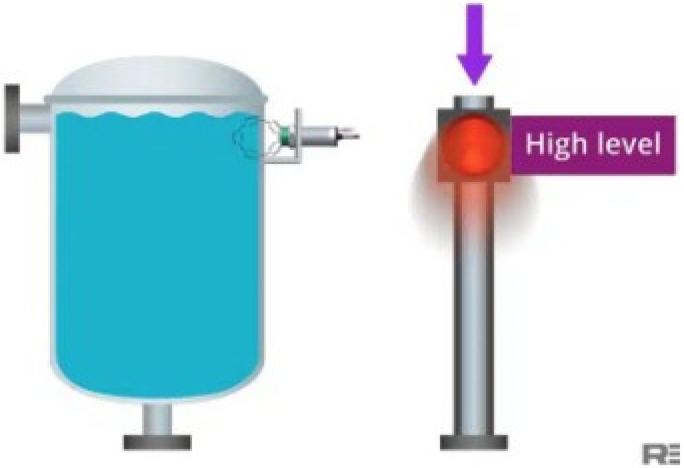


Applications









Thermoelectric Transducers

- Generally used thermoelectric transducers are:

(a) Resistance Thermometer (Resistance Temperature Detector, RTD)

(b) Thermistor (Thermally Sensitive Resistor)

(a) <u>Resistance Thermometer (RTD)</u>:

- The resistance of a conductor changes when its temperature is changed; this property is utilized for the measurement of temperature
- The resistance thermometer is an instrument used to measure electrical resistance in terms of temperature, i.e., it uses the change in the electrical resistance of the conductor (sensing element) to determine the temperature
- The characteristics of the sensing element determines the sensitivity and operating temperature range of the instrument
- The sensing element may be any material that exhibits a relatively large resistance change with change in temperature
- Also the material used should be stable in its characteristics, i.e., neither its resistance nor temperature coefficient of resistance should undergo permanent change with use or age

Resistance Thermometer (-contd.)

- Another desirable characteristic for a sensing element is a linear change in resistance with change in temperature
- The speed with which a resistive element responds to changes in temperature is important when the measured temperature is subjected to rapid variations
- Smaller the given sensing element, the less heat required to raise its temperature and the faster its response
- **Platinum, Nickel, & Copper** are the metals most commonly used to measure temperature
- The resistance of platinum tends to increase less rapidly at higher temperatures than for other metals, hence it is commonly used material for resistance thermometers
- The temperature range over which platinum has stability is -260^0 C to 1100^0C
- The changes in resistance caused by changes in temperature are detected by a Wheatstone bridge as shown in fig. (13.11b)

Resistance Thermometer (-contd.)

- The temperature sensing element (platinum, nickel or copper) contained in a bulb along with the balancing bridge, forms the essential components of a temperature measuring system
- The sensing element R_s is made of a material having a high temperature coefficient and R_1, R_2 and R_5 are made of resistances that are practically constant under normal temperature changes. As the sensing element is away from the indicator and its leads have a resistance R_3 and R_4
- Therefore, under balanced condition

$$\frac{R_1}{R_2} = \frac{R_3 + R_s + R_4}{R_5}$$

- Now, if resistance R_s changes, balance can not be maintained and the galvanometer shows a deflection which can be calibrated to give a suitable temperature scale

Resistance Thermometer (-contd.)

Advantages of Resistance Thermometer:

- The measurement is very accurate
- It has a lot of flexibility with regard to choice of measuring equipment
- The temperature sensitive resistance element can be easily installed and replaced
- Resistive elements can be used to measure differential temperature
- Resistance thermometers have a wide working range without loss of accuracy
- They are best suited for remote indication
- The resistive element response time is of the order of 2 to 10 seconds
- The limits of error of a resistive element are ±0.25% of the scale reading
- Stability of performance over long periods of time

Limitations of Resistance Thermometer:

- High cost
- Need for bridge circuit and power device
- Possibility of self heating
- Large bulb size compared to a thermocouple

Thermistor

- The electrical resistance of most materials changes with temperature
- By selecting materials that are very temperature sensitive, devices can be made that are useful in temperature control circuits and for temperature measurement
- Thermistors (Thermally Sensitive Resistors) are non-metallic (semiconductor material) resistors made by sintering mixtures of **metallic oxides** such as **Mn, Ni, Co, Cu, & U**
- Thermistors have a negative temperature coefficient (NTC), i.e., resistance decreases as temperature rises as shown in fig. (13.12)
- The resistance at room temperature (25^0C) for a typical commercial thermistor ranges from 100 Ω to 10 MΩ
- They are suitable for use only up to about 800^0C
- In some cases the resistance of a thermistor at room temperature may decrease by 5% for each 1^0C rise in temperature
- This high sensitivity to temperature changes makes the thermistor extremely useful for precision temperature measurements, control and compensation

Thermistor (-contd.)

- Thermistors can be made in the form of disc, rod, washer and bead etc.
- The smallest thermistors are made in the form beads (~ 0.15 mm in diameter)
- These may come in a glass coating or sealed in the tip of solid glass probes having a diameter of 2.5mm and length of 6-50mm
- The probes (100 Ω to 10 MΩ) are used for measuring the temperature of liquids
- When greater power dissipation is required the disc rod or washer thermistors are used
- Disc thermistors (diameter of about 1.25 mm - 25 mm, thickness of 0.25 – 0.75 mm) are mainly used for temperature control and have a resistance values from 1 Ω to 1 MΩ
- These are sintered and coated with silver on two flat surfaces
- Washer thermistors are made like disc thermistors, except that a hole is formed in the centre in order to make them suitable for mounting on a bolt

Thermistor (-contd.)

- Rod thermistors are extruded through dies to make long cylindrical units of having a diameter of 1.25, 2.75 or 4.25mm and a length of 12.5- 50mm connecting leads are attached to the end of the rods
- Their resistance varies from 1 - 50 kΩ
- The advantage of rod thermistors over other configurations is the ability to produce high resistance units with moderately high power handling capability
- Thermistors can be connected in series/parallel combinations for applications requiring increased power handling capability
- Thermistors are chemically stable and can be used in nuclear environments
- Their wide range of characteristics also permits them to be used in limiting and regulation circuits as time delays, for integration of pulses, as memory units
- A thermistor in one arm of a Wheatstone bridge provides precise temperature information
- Accuracy is limited only by the readout devices

Thermistor (-contd.)

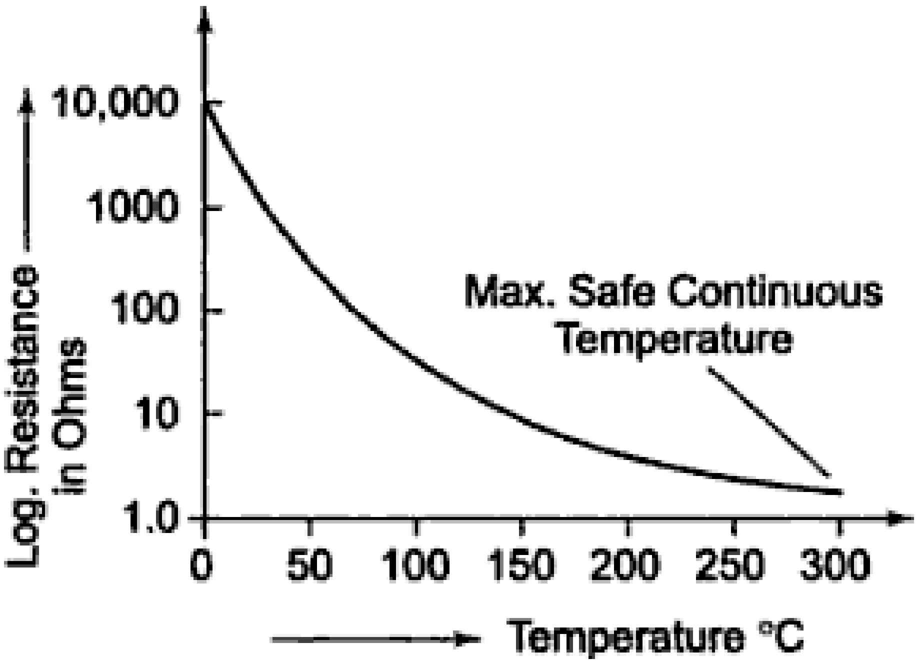


Fig. (13.12) Resistance vs Temperature Graph of Thermistor

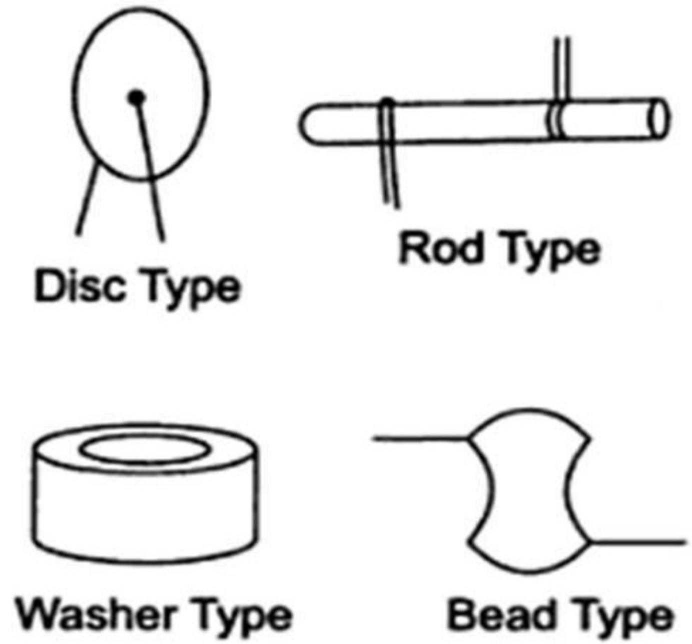


Fig. (13.13) Various Configurations of Thermistor

Thermistor (-contd.)

<u>Advantages</u>:

- Small size and low cost
- Fast response over narrow temperature
- Good sensitivity
- Contact and lead resistance problems not encountered due to large value of R

<u>Limitations</u>:

- Non-linearity in resistance versus temperature characteristics
- Unsuitable for wide temperature range
- Very low excitation current to avoid self-heating
- Need for shielded power lines, filters, etc. due to high resistance