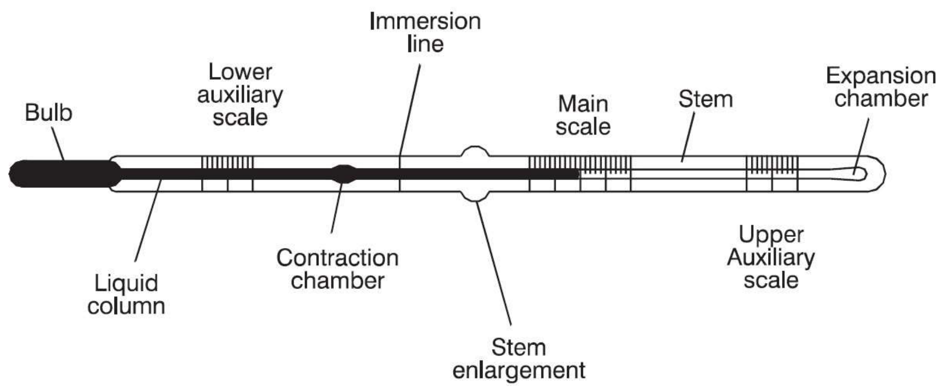
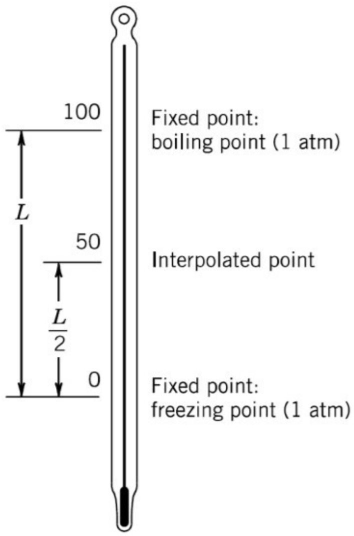
Measurement of Temperature and Heat Flux

Liquid-in-glass Thermometer





- Works on Thermal Expansion of liquid inside a glass tube. Mercury or alcohol is used as the liquid medium.
- Usually calibrated using ice at 0°C or boiling water at 100°C both at 1 atm.
- Inexpensive, simple, portable, no need for additional indicator.
- High heat capacity, but time lag exists.
- Not suitable for distant reading.
- Not suitable for surface temperature measurement.
- Alcohol is limited to low-temperature measurements. Its high coefficient of expansion makes it more sensitive.
- Mercury cannot be used below its freezing point of -37.8°C. Its upper limit is usually 315°C, but it may be extended to 540°C by filling gas above the mercury.

Liquid-in-glass Thermometer

A liquid-in-glass thermometer works based on the principle of thermal expansion, which states that liquids expand more than solids when their temperature increases:

•**How it works**

•The thermometer contains a liquid, like alcohol or mercury, in a thin, hollow glass tube. When the temperature around the thermometer increases, the liquid expands and rises up the tube. The height of the liquid column indicates the temperature.

•**What's inside**

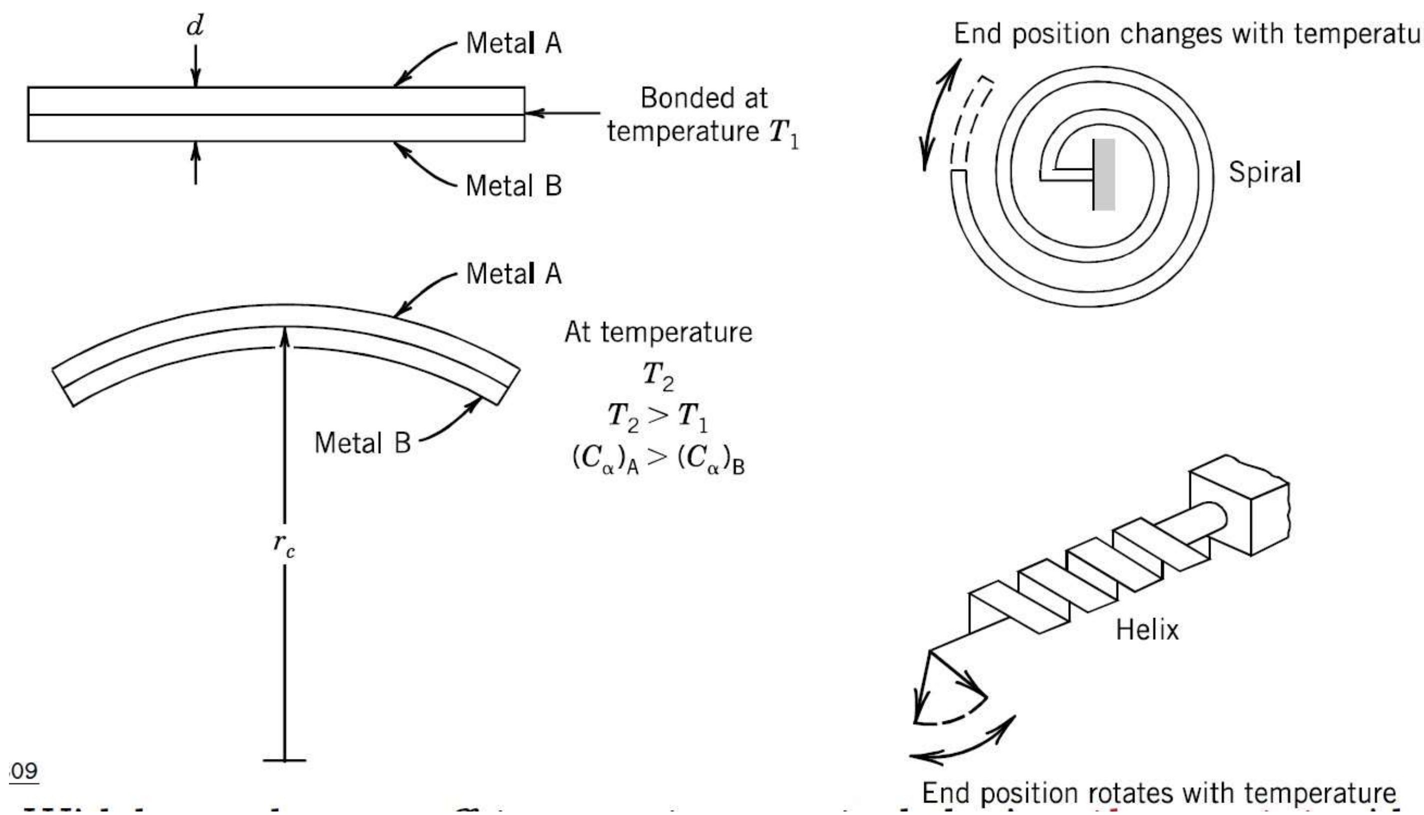
•The thermometer has a bulb at one end that contains the liquid, and a glass tube with a capillary that's connected to the bulb. The tube is enlarged at the bottom into a bulb that's partially filled with liquid.

•**Different liquids**

•The liquid used in a thermometer can vary, but common choices include mercury, toluene, and low-hazard biodegradable liquids. The range of temperatures that can be measured depends on the liquid used. For example, a thermometer with mercury can measure temperatures from −35°C to +600°C, while an alcohol thermometer can measure temperatures from −80°C to +70°C

Measurement of Temperature and Heat Flux

Bimetallic Strip Thermometer



- Widely used as on-off temperature-control device, **thermostat**.
- Also used for measuring ambient and oven temperatures.

Bimetallic Strip Thermometer

A bimetallic strip thermometer measures temperature based on the principle that different metals expand at different rates when heated:

1. Construction

A bimetallic thermometer is made of two different metal strips that are joined together to form a bimetal strip. The strips are usually made of steel and copper, or steel and brass.

2. Expansion

When the temperature changes, the different metals expand at different rates, causing the bimetal strip to bend. The metal with the higher coefficient of thermal expansion will be on the outside of the curve when the strip is heated.

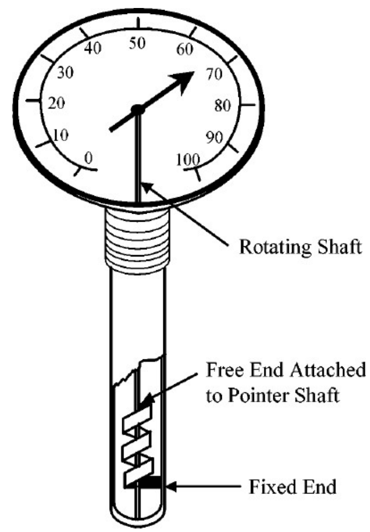
3. Mechanical deformation

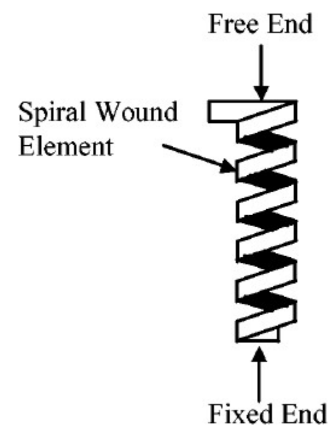
The bending of the bimetal strip creates a mechanical deformation that can be detected as a rotary movement.

4. Temperature measurement

The rotary movement is transmitted to a pointer shaft, which moves the thermometer's pointer to indicate the temperature.

Bimetallic Strip Thermometer

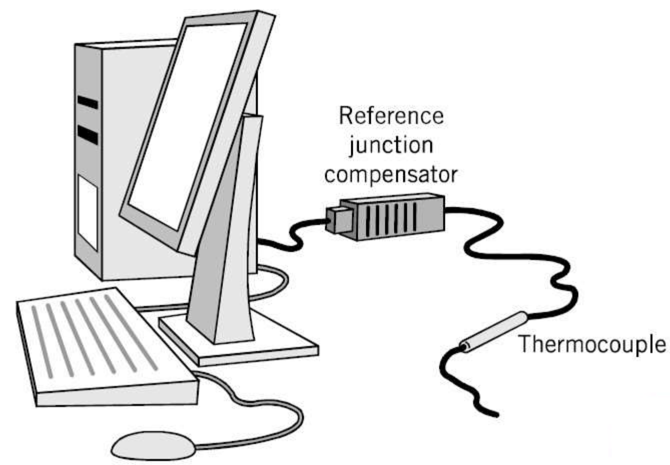


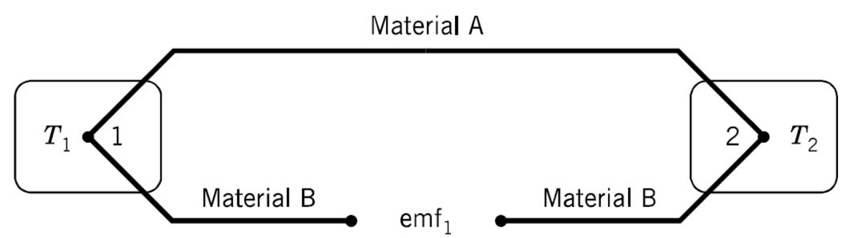


- Low cost, negligible maintenance and longer stable operation.
- Good resistance to mechanical shock.
- Close linearity withing temperature range (-30°C to 550°C).
- Compact, low thermal inertia and reduced lag.
- Accuracy 1-2% of the scale range.

Measurement of Temperature and Heat Flux

Thermocouple



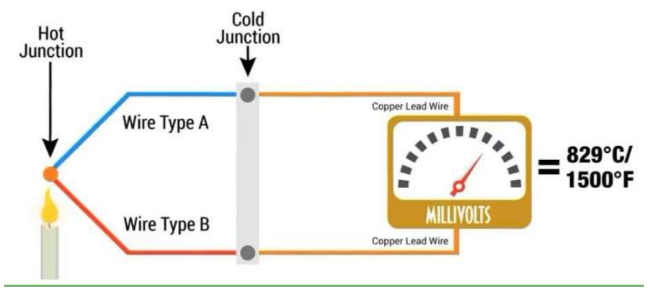


- **Thermocouple** works on the principle of thermoelectric effect, i.e., the direct conversion of temperature difference to electric voltage or vice versa.
- Thermocouple is made of junctions consisting of any two dissimilar materials.
- When two junctions are kept in different temperatures ($T_1 \neq T_2$) , an emf is generated between two junctions (called 'Seeback Effect')

Thermocouple

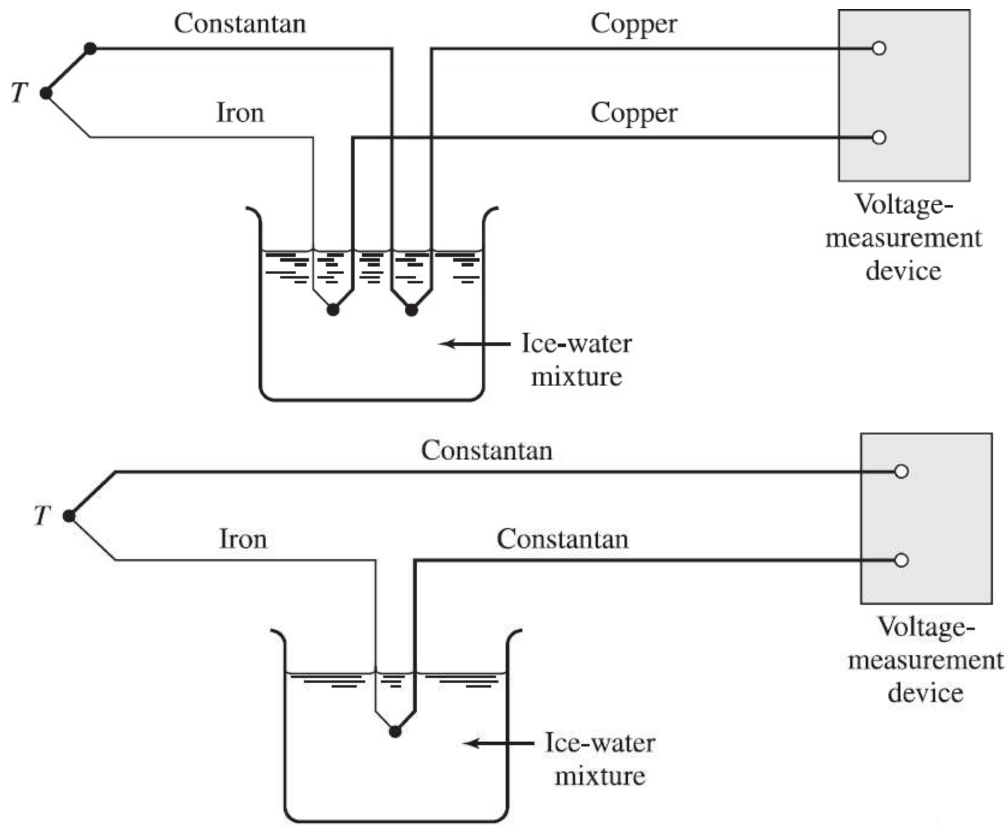
The working principle of a thermocouple is based on the Seebeck effect, which states that when two dissimilar metals are joined at one end and exposed to different temperatures, an electromotive force (e.m.f.) is generated

1. Two dissimilar metal wires are joined at one end, which is the measuring point.
2. The other end is the connection point, which connects to the voltage reader.
3. When the temperature at the measuring point changes, so does the electron density of each metal wire.
4. This varying electron density is the voltage, which is measured at the connection point.



Measurement of Temperature and Heat Flux

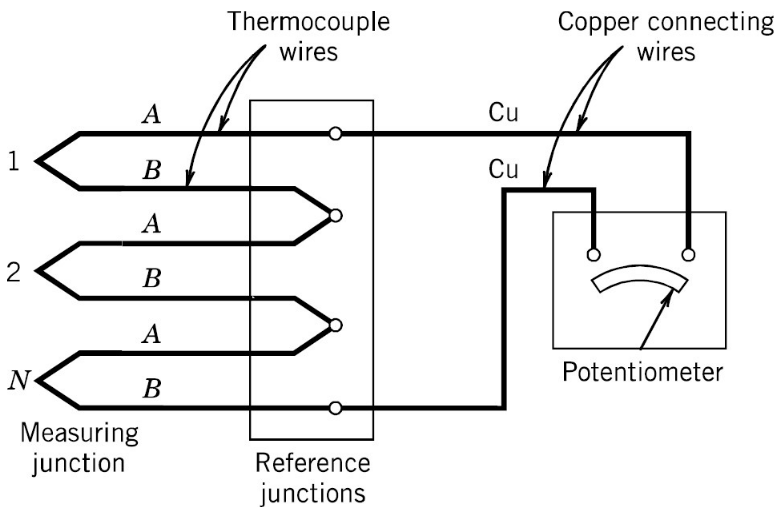
Thermocouple Temperature Measurement Circuits



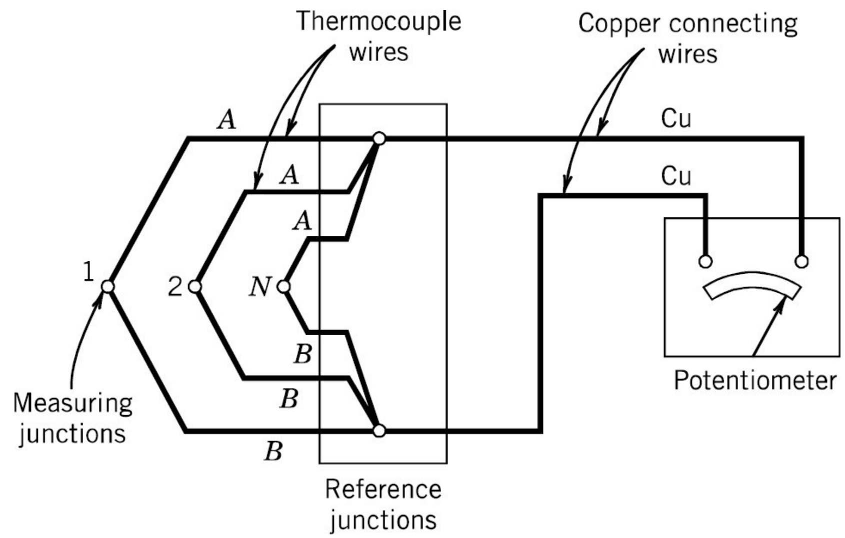
- Two dissimilar material junctions consisting of Iron and Constantan (Cu-Ni alloy) thermocouple circuit to measure the temperature of a mixture of Ice and Water.

Measurement of Temperature and Heat Flux

Thermocouple Temperature Measurement Circuits



Thermopile Arrangement

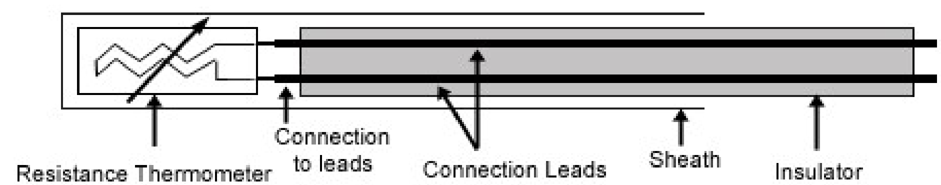


Thermocouples Arranged in Parallel

- Thermopile, a multiple-junction thermocouple circuit, is used to amplify the output of the circuit.

- When a spatially averaged temperature is desired, multiple thermocouple junctions arranged in parallel are used.

Resistance Temperature Detector (RTD)



Resistance Thermometer (RTD)

- **RTD**s works on resistance thermometry, i.e., the measurement of resistance to detect temperature.
- Mostly consist of a length of fine wire wrapped around a ceramic or glass core.
- The RTD wire is a pure material, typically platinum, nickel, or copper. The material has an accurate resistance/temperature relationship which is used to provide an indication of temperature, such as follows:

$$R = R_0(1 + aT + bT^2)$$

where, R is the resistance at temperature T , R_0 is the resistance at reference Temperature T_0;

a and b are experimentally determined constants.

Resistance Temperature Detector (RTD)

A Resistance Temperature Detector (RTD) works by measuring how a material's electrical resistance changes in response to temperature:

1. An electrical current is passed through the RTD's resistance element.
2. The resistance of the current is measured in Ohms.
3. The resistance value is converted to a temperature reading.

RTDs work because the atoms in a metal absorb heat energy, causing them to vibrate more. This makes it harder for electrons to flow through the metal, increasing its electrical resistance.

Measurement of Temperature and Heat Flux

Resistance Temperature Detector (RTD)

- Platinum RTD is used as an interpolation standard from oxygen point (-182.96^{o}C, boiling) to the antimony point (630.74^{o}C, melting).

The advantages of platinum resistance thermometers include:

- High accuracy
- Low drift
- Wide operating range. In general, RTDs may be used for temperatures ranging from cryogenic to approximately 650^{o}C.
- Suitability for precision applications. By proper instrumentation, uncertainty in temperature measurement can be achieved as low as $\pm 0.005°C$.

Measurement of Temperature and Heat Flux

Thermistor

Thermistor also works on the principle of Resistance Thermometry. The formula is given as:

$$R = R_0 \exp\left[\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$$

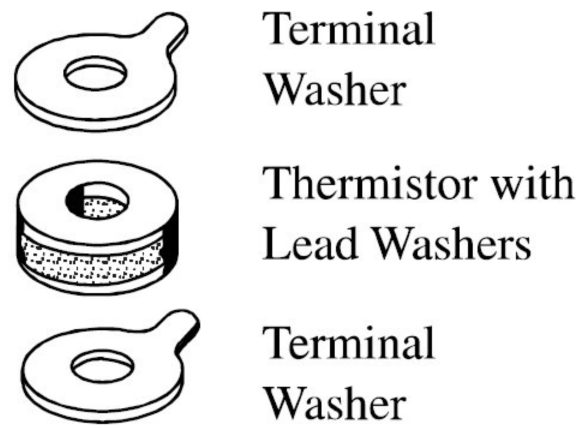
where, R is the resistance at temperature T , R_0 is the resistance at reference Temperature T_0;

β is experimentally determined constant.

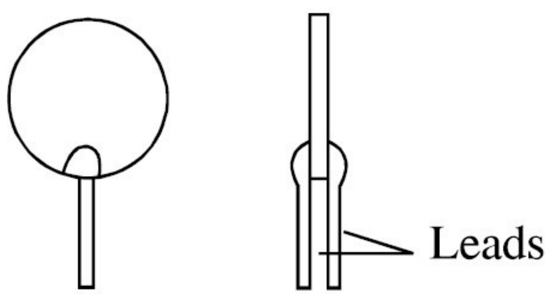
- Thermistors are generally produced using powdered metal oxides.
- Depending on materials used, thermistors are classified into two types: NTC (Negative Temperature Coefficient) thermistor where resistance decreases as temperature rises and PTC (Positive Temperature Coefficient) thermistor where resistance increases as temperature rises. NTC is commonly used as a temperature sensor.
- Thermistors differ from resistance temperature detectors (RTDs) in that the material used in a thermistor is generally a ceramic or polymer, while RTDs use pure metals. The temperature response is also different; RTDs are useful over larger temperature ranges, while thermistors typically achieve a greater precision within a limited temperature range, typically −90 °C to 130 °C.

Thermistor

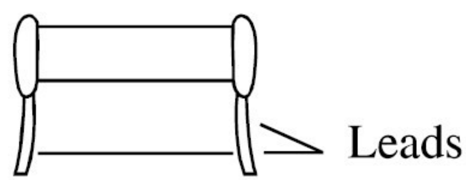
Bend Type



Washer Type



Disc Type



Rod Type

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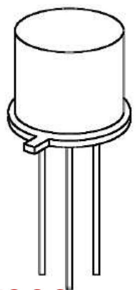
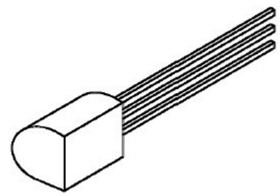
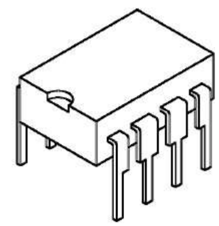
Integrated Circuit (IC) Temperature Sensor



T099 can



TO-92 plastic moulding



DIP plug

Typical semiconductor temperature sensor in different packaging

- An IC Temperature Sensor consists of semiconductor materials. These are available in both voltage and current sensitive configurations. If the voltage increases, the temperature also rises, followed by a voltage drop between the transistor terminals of base and emitter in a diode. Some IC sensors produce an output current proportional to absolute temperature. The solid state sensor output can be analog or digital. An example is the LM35 series precision integrated-circuit temperature sensors.
- The sensor package is small with a low thermal mass and a fast response time. Generally output is linearly proportional to the absolute temperature.
- The most common temperature range is −55°C to 150°C. Widely used on circuit boards to monitor and control temperature, in computers to control CPU temperature, in telecommunications applications (cell phones & PDA™) and in many industrial immersion applications.

Integrated Circuit (IC) Temperature Sensor

Semiconductor temperature sensors measure temperature by detecting changes in the voltage or current of a diode or transistor:

•**Diode-based**

Measures the forward voltage drop across a diode, which decreases as the temperature increases.

The voltage drop is directly proportional to the temperature.

•**Transistor-based**

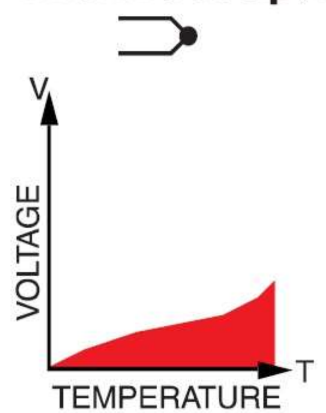
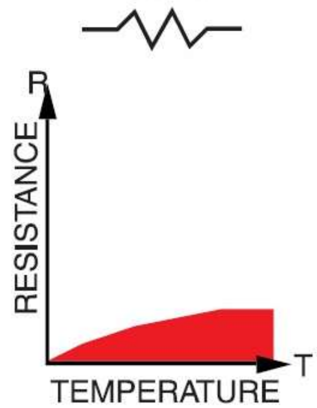
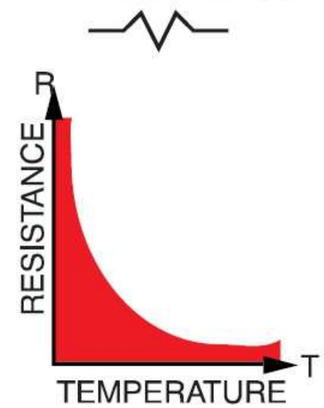
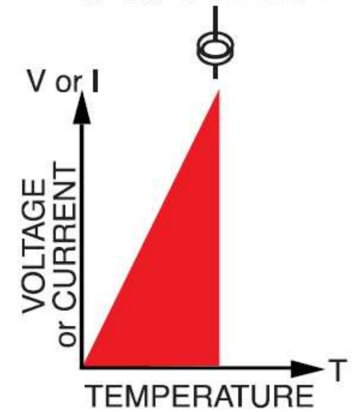
Measures the base-emitter voltage of a transistor, which varies predictably with temperature.

Semiconductor temperature sensors are integrated circuits that provide a voltage output that is proportional to the temperature.

The output can be read by microcontrollers or other digital systems.

Measurement of Temperature and Heat Flux

Thermocouple vs RTD vs Thermistor vs IC Sensor

	Thermocouple	RTD	Thermistor	I. C. Sensor
				
Advantages	☐ Self-powered ☐ Simple ☐ Rugged ☐ Inexpensive ☐ Wide variety ☐ Wide temperature range	☐ Most stable ☐ Most accurate ☐ More linear than thermocouple	☐ High output ☐ Fast ☐ Two-wire ohms measurement	☐ Most linear ☐ Highest output ☐ Inexpensive
Disadvantages	☐ Non-linear ☐ Low voltage ☐ Reference required ☐ Least stable ☐ Least sensitive	☐ Expensive ☐ Current source required ☐ Small Δ R ☐ Low absolute resistance ☐ Self-heating	☐ Non-linear ☐ Limited temperature range ☐ Fragile ☐ Current source required ☐ Self-heating	☐ T<200°C ☐ Power supply required ☐ Slow ☐ Self-heating ☐ Limited configurations