IRE 215: Sensor Technology

Temperature Measurement

Contents

Introduction

In solids, thermal energy causes molecular vibration.

In liquids and gases, average speed with which molecules move is a measure of the thermal energy imparted to the material.

Thermal energy per molecule of a material is related by the statement that the material has a certain *degree of temperature*.

The different sets of units are referred to as *temperature scales*.

Types of Temperature Scales

Absolute Temperature Scale: An absolute temperature scale is one that assigns a zero temperature to a material that has no thermal energy, that is, no molecular vibration.

There are two such scales in common use: the Kelvin scale in kelvin and Rankine scale in degrees Rankine .

$$(1\,\text{K}) = \frac{180}{100}(1^\circ\text{R}) = \frac{9}{5}(1^\circ\text{R})$$

where
$$T(\text{K}) = \text{temperature in K}$$
$$T(^\circ\text{R}) = \text{temperature in }^\circ\text{R}$$

Types of Temperature Scales

Relative Temperature Scales: When these scales indicate a zero of temperature, the thermal energy of the sample is not zero.

Two scales are the Celsius (related to the kelvin) and the Fahrenheit (related to the Rankine).

$$T(°\mathrm{C}) = T(\mathrm{K}) - 273.15$$

$$T(°\mathrm{F}) = T(°\mathrm{R}) - 459.6$$

To transform from Celsius to Fahrenheit,

$$T(°\mathrm{F}) = \frac{9}{5}T(°\mathrm{C}) + 32$$

Types of Temperature Scales

EXAMPLE Given temperature of 144.5°C, express this temperature in **(a)** K and **(b)** °F.

a. $T(\mathrm{K}) = T(^\circ\mathrm{C}) + 273.15$

$T(\mathrm{K}) = 144.5 + 273.15$

$T(\mathrm{K}) = \mathbf{417.65\ K}$

b. $T(^\circ\mathrm{F}) = \frac{9}{5}T(^\circ\mathrm{C}) + 32$

$T(^\circ\mathrm{F}) = \frac{9}{5}(144.5^\circ\mathrm{C}) + 32$

$T(^\circ\mathrm{F}) = \mathbf{292.1^\circ F}$

Types of Temperature Measuring Instruments

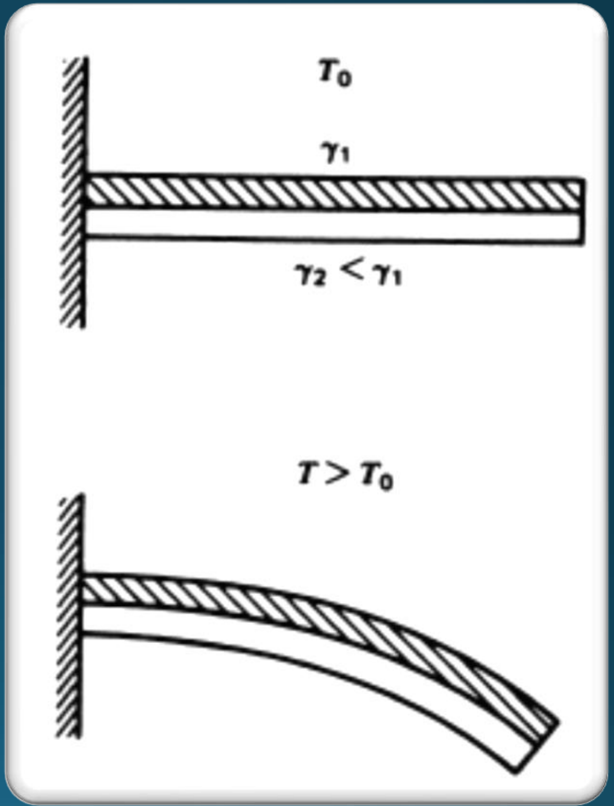
1. Change in Dimension
2. Change in Electrical Properties
3. Change in EMF

Change in Dimensions

1. Bimetal Strips
2. Liquid in Glass Thermometers
3. Pressure Gauge Thermometers

Bimetal Strips

- Two materials with grossly different thermal expansion coefficients are bonded together.
- When heated, the different expansion rates cause the assembly curve.
- This effect can be used to close switch contacts or to actuate an ON/OFF mechanism when the temperature increases to some appropriate set point.
- The effect also is used for temperature indicators, by means of assemblages, to convert the curvature into dial rotation.

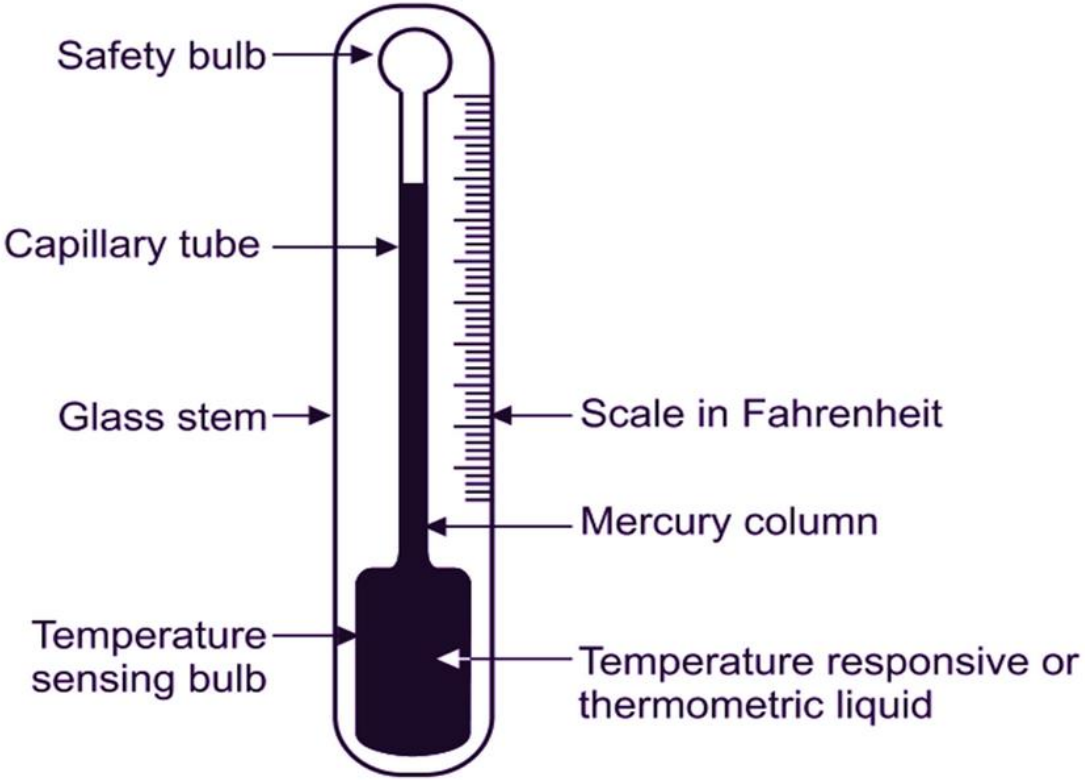


Bimetal strip example

- wo welded Fe-Ni strips with different nickel contents.
- With slot to hold e.g. in insulating support.
- Temperature range: - 20 °C...+ 400 °C.
- Bending: approx. 0.45 mm / °C.
- Dimensions (mm): 150 x 25 x 0.3.

Liquid in Glass Thermometer

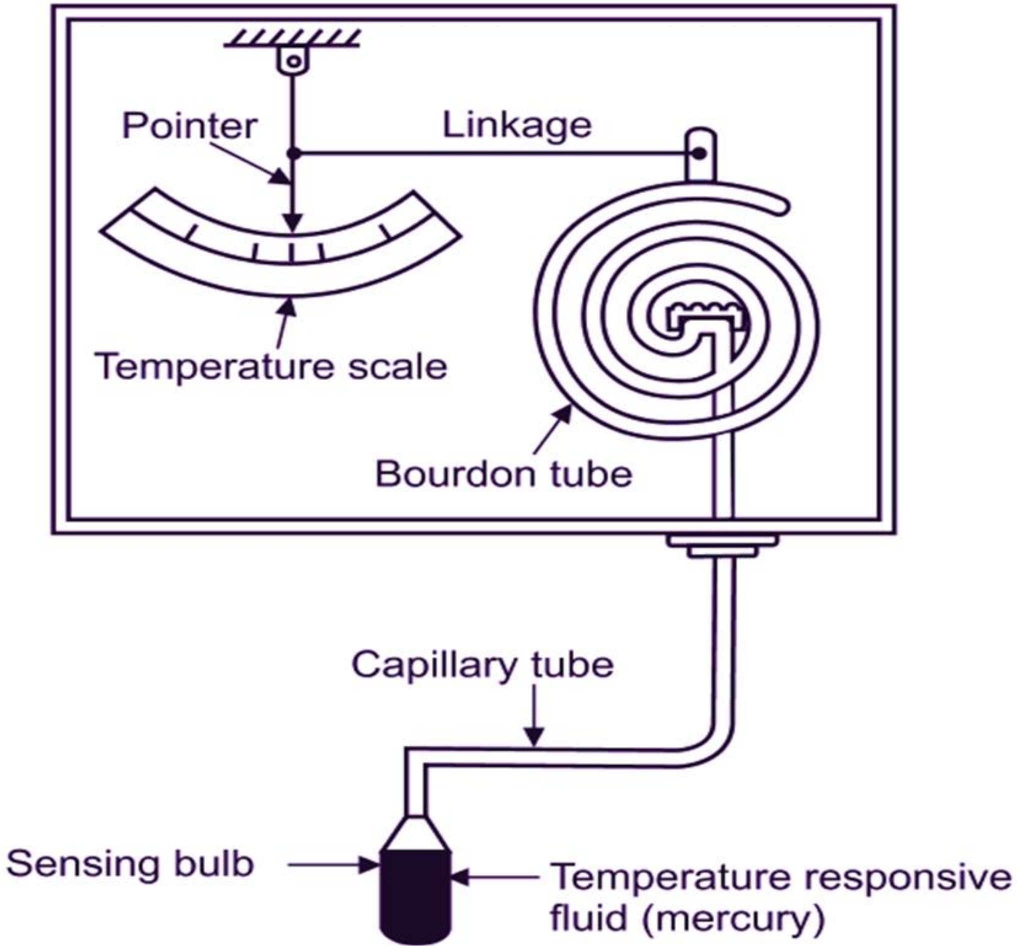
- If the temperature increases, liquid expands in volume.
- It causes the liquid to rise in the capillary tube.



Liquid in Metal/ Pressure Gauge Thermometer

- If the temperature increases, liquid expands in volume.

- Due to expansion of liquid, the Bourdon tube pushes pointer to move on the temperature scale.



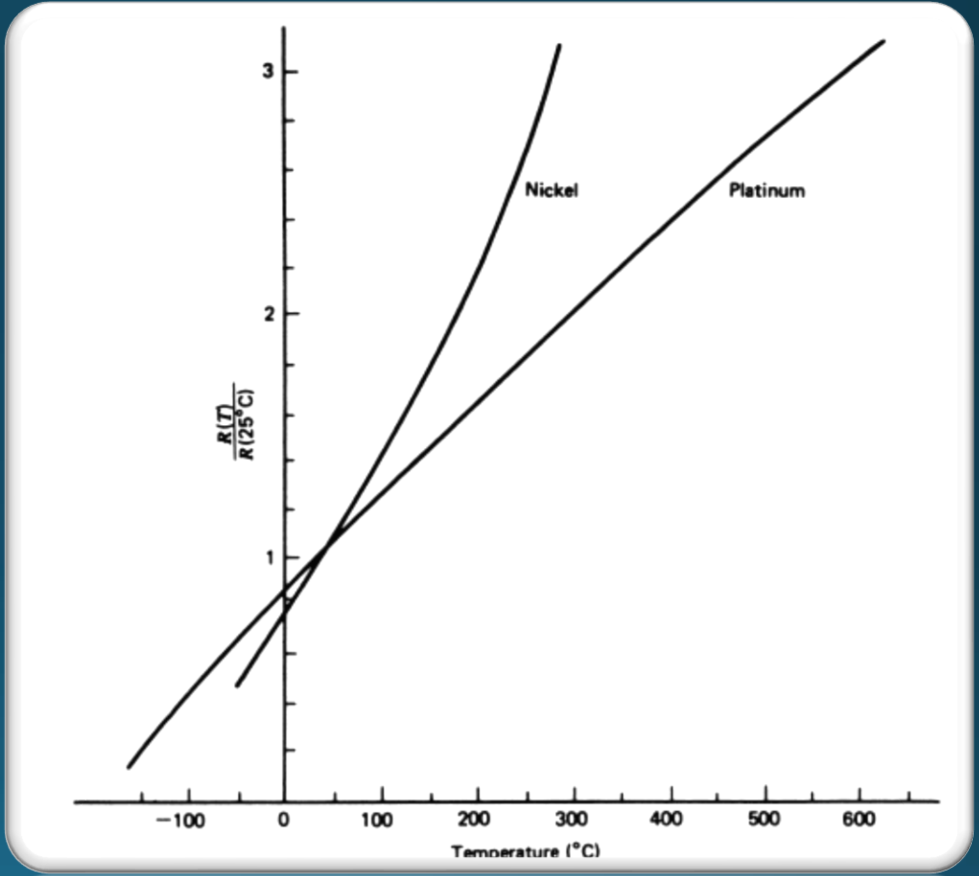
Change in Electrical Properties

1. RTDs (Resistance Temperature Detector)

2. Thermistors

Metal Resistance versus Temperature

- Metals are electrically conductive because of their free electrons.
- As electrons move throughout the material, they collide with the stationary atoms or molecules of the material.
- When a thermal energy is present in the material and the atoms vibrate, the conduction electrons tend to collide even more with the vibrating atoms.
- This impedes the movement of electrons and absorbs some of their energy, that is, the material exhibits a *resistance* to electrical current flow.
- Thus, metallic resistance is a function of the vibration of the atoms and thus of the temperature.



Resistance Temperature Detector (RTD)

- A *resistance-temperature detector* (RTD) is a temperature sensor which is based on the principle of increasing metal resistance with the increment of temperature.
- An RTD is simply a length of wire whose resistance is to be monitored as a function of temperature.
- The construction is typically such that the wire is wound on a form (in a coil) to achieve small size and improve thermal conductivity to decrease response time.
- There is power dissipated by the device itself that causes a slight heating effect, a *self-heating*, which may cause an erroneous reading or upset the environment.
- Thus, the current through the RTD must be kept sufficiently low and constant to avoid self-heating.

Resistance Temperature Detector (RTD)

- The self-heating temperature rise can be found from the power dissipated by the RTD, and the dissipation constant from

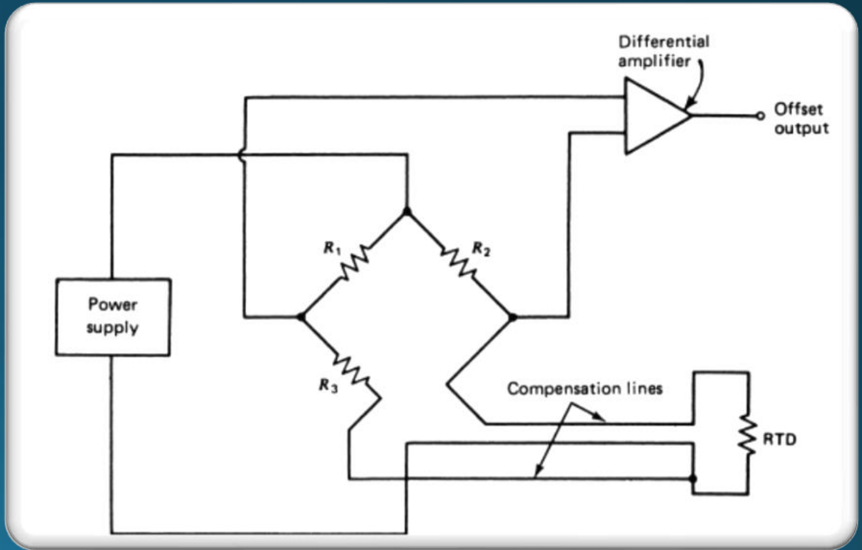
$$\Delta T = \frac{P}{P_D}$$

ΔT = temperature rise because of self-heating in°C
P = power dissipated in the RTD from the circuit in W
P_D = dissipation constant of the RTD in W/°C

- Very small fractional changes of resistance with temperature (0.4%), the RTD is generally used in a *bridge* circuit.

The dissipation constant (δ) indicates the power necessary for increasing the temperature of the thermistor element by 1°C through self-heating in a heat equilibrium.

****Thermal equilibrium** is a state in which two or more objects or systems that are in thermal contact no longer exchange heat with each other. In other words, they reach the same temperature. Once thermal equilibrium is achieved, there is no net flow of heat between the systems.

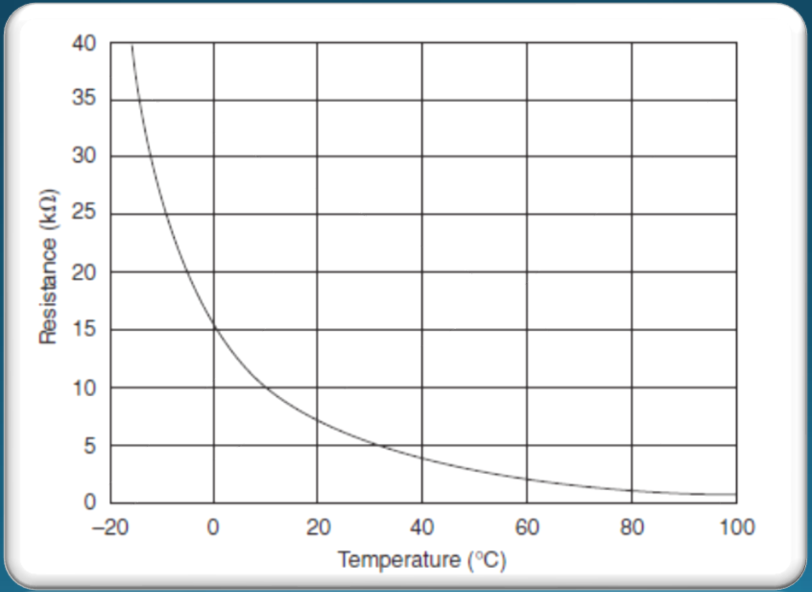


Thermal contact refers to the condition in which two or more objects or systems are in physical proximity such that heat can be transferred between them. The nature of the contact affects how efficiently heat is transferred.

Semiconductor Resistance versus Temperature

- No conduction electrons are contributed from the valence band to the conduction band at a temperature of 0 K.

- Due to small band gap, some electrons enter to the conduction band. As a result, resistance decreases.



Thermistor

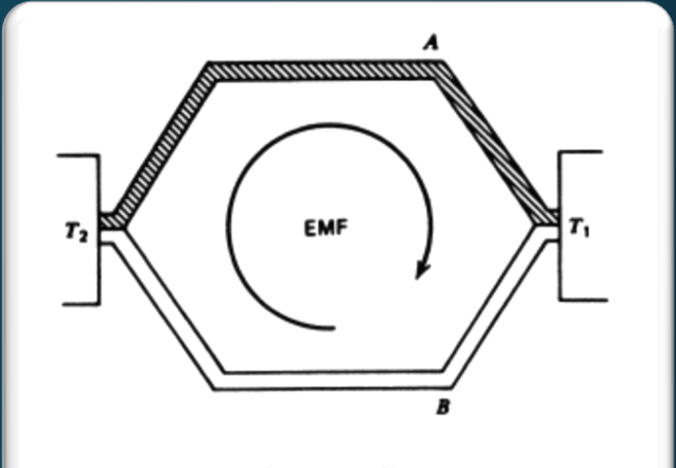
- A thermistor is a temperature sensor that has been developed from the principles of semiconductor resistance change with temperature.
- Thermistors can be fabricated in many forms including discs, beads, and rods.
- In most cases, the thermistor is encapsulated in plastic, epoxy, Teflon, or some other inert material. This protects the thermistor itself from the environment.
- A bridge circuit is used because the nonlinear features of the thermistor make its use difficult as an actual measurement device.

Generation of EMF

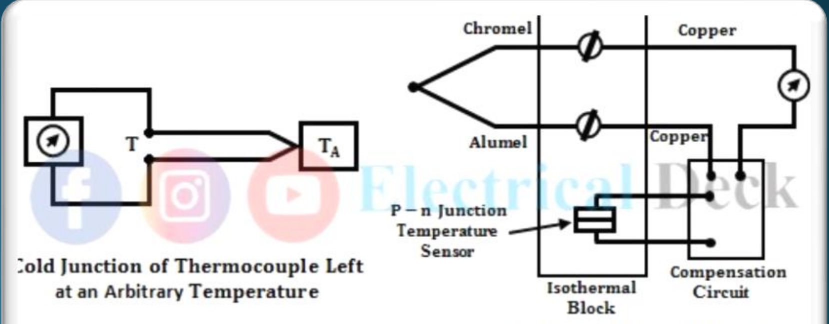
1. Thermocouple

Thermoelectric Effects: Seebeck Effect

- When a temperature differential is maintained across a given metal, the vibration of atoms and motion of electrons is affected so that a difference in potential exists across the material.
- This potential difference is related to the fact that electrons in the hotter end of the material have more thermal energy than those in the cooler end, and thus tend to drift toward the cooler end.
- This drift varies for different metals at the same temperature because of differences in their thermal conductivities.
- If a circuit is closed by connecting the ends through another conductor, a current is found to flow in the closed loop. It is known as Seebeck effect.
- Thermocouples are fabricated based on Seebeck effect.
- Cold junction compensation circuit is required for thermocouples.



a) Seebeck effect



Cold Junction of Thermocouple Left at an Arbitrary Temperature

Compensation Circuit for Cold Junction Temperature

Thermoelectric Effects: Seebeck Effect

Seebeck Effect Using solid-state theory, the aforementioned situation may be analyzed to show that its emf can be given by an integral over temperature

$$\varepsilon = \int_{T_1}^{T_2} (Q_A - Q_B)\, dT$$

where
ε = emf produced in volts
T_1, T_2 = junction temperatures in K
Q_A, Q_B = thermal transport constants of the two metals

In practice, it is found that the two constants, Q_A and Q_B, are nearly independent of temperature and that an approximate linear relationship exists as

$$\varepsilon = \alpha(T_2 - T_1)$$

where
α = constant in V/K
T_1, T_2 = junction temperatures in K

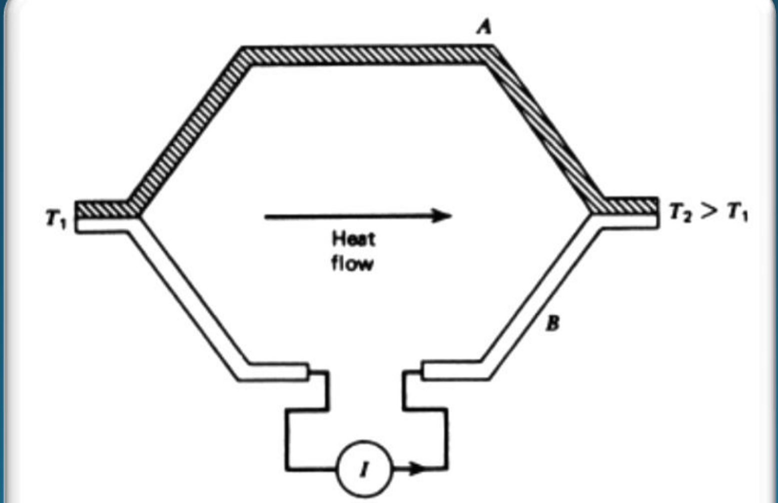
Thermoelectric Effects: Seebeck Effect

The **thermal transport constant** often refers to properties that govern the transport of heat in materials.

- Thermal conductivity
- Thermal diffusivity
- Heat capacity

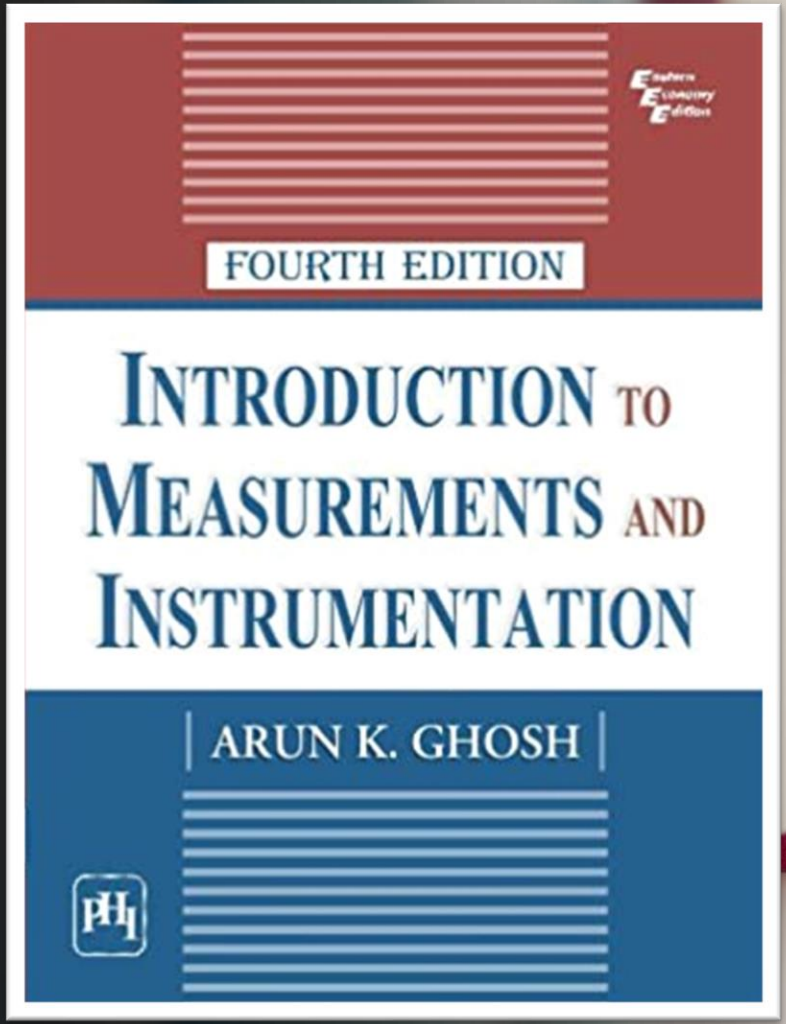
Thermoelectric Effects: Peltier Effect

- A closed loop of two different metals, *A* and *B,* is constructed and an external voltage is applied to the system to cause a current to flow in the circuit.
- Because of the different electro-thermal transport properties of the metals, it is found that one of the junctions will be *heated* and the other *cooled.*



b) Peltier effect

References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