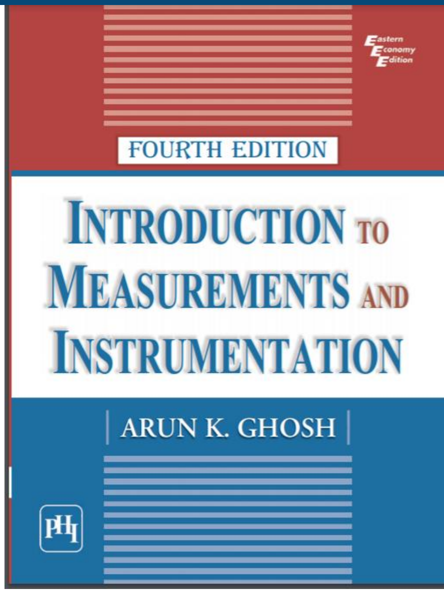
NUST

SCHOOL OF ELECTRICAL ENGINEERING
& COMPUTER SCIENCE

- Course: **EE383 Instrumentation and Measurements**
- Session: Spring 2021
- **Lectures: Week 15**
-

INSTRUMENTATION
& MEASUREMENT



Week 15

- **Chapter 10**

  Temperature Measurement

Book: Introduction to Measurements and Instrumentation, Arun K. Ghosh

Temperature Measurement

- **The change in temperature of a body produces various primary effects:**
  - Change in its physical or chemical state, e.g. phase transition
  - Change in its physical dimensions
  - Variation in its electrical properties
  - Generation of thermoelectricity
  - Variation in its optical properties
  - Change in the frequency of vibration of piezoelectric crystals
  - Change in the velocity of sound
  - Change in the intensity of the emitted radiation

- **Any of these effects can be exploited to measure the temperature**

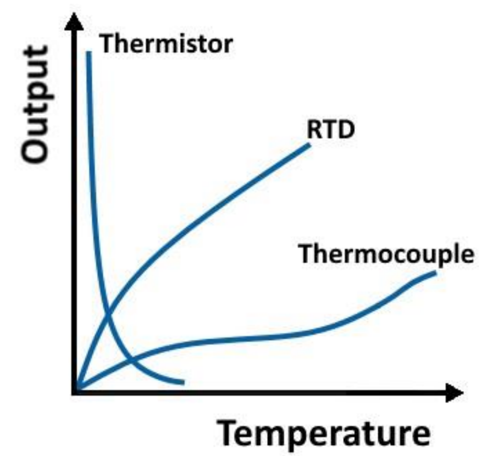
Use: Temperature Sensor?

- Temperature sensors appear in building, chemical process plants, engines, appliances, computers, and many other devices that require temperature monitoring

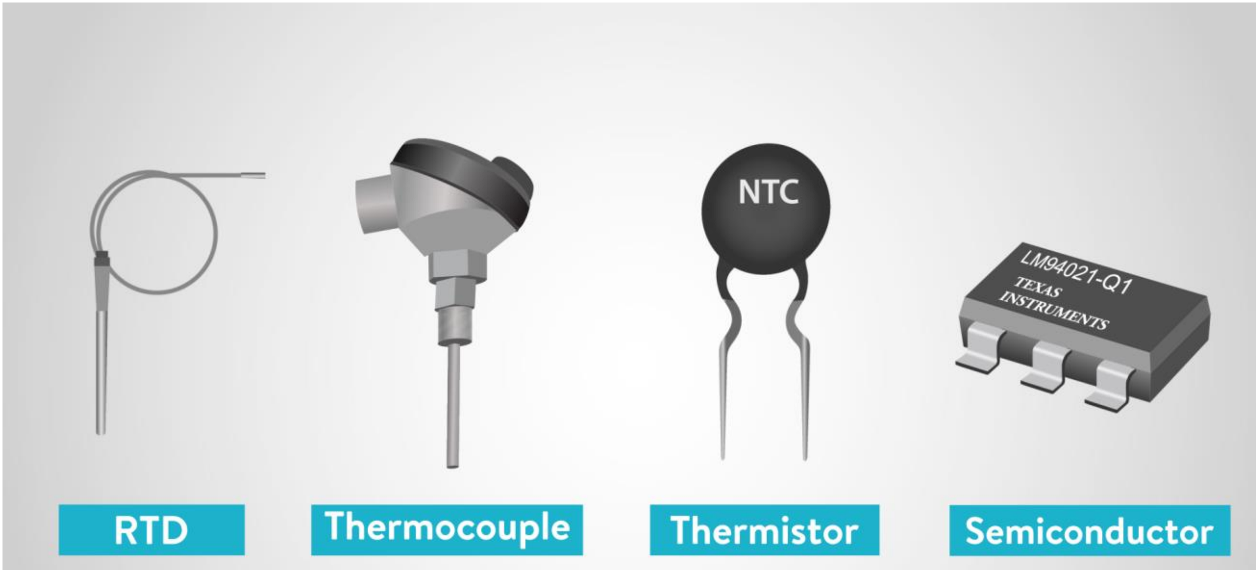
- Many physical phenomena depend on temperature, so we can often measure temperature indirectly by measuring pressure, volume, electrical resistance, and strain

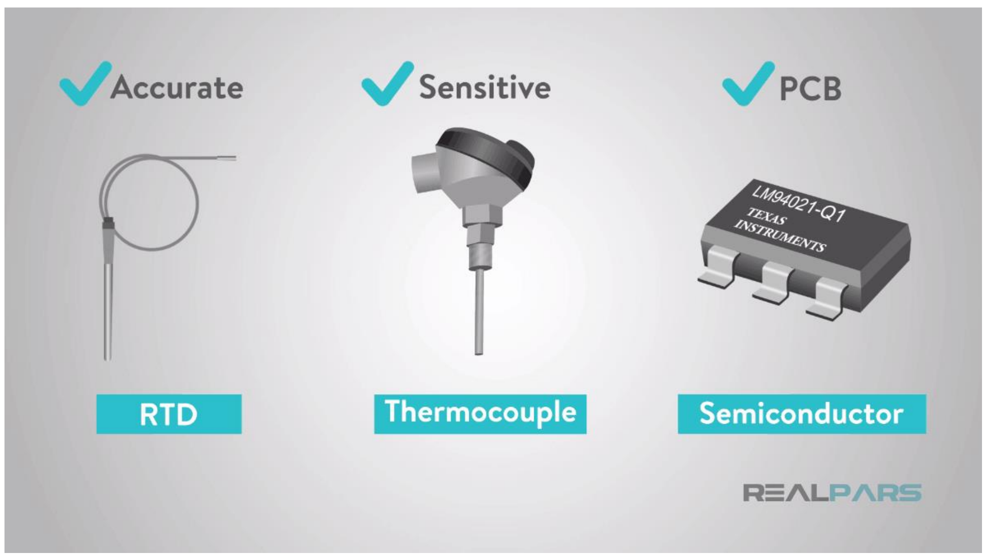
Types of Temperature Sensors

- Most commonly used temperature sensors are.
  - Resistance Temperature Detectors (RTD) $<-40^\circ C\ to\ 1200^\circ C>$
  - Thermistors $<-55^\circ C\ to\ 150^\circ C>$
  - Thermocouples $<-200^\circ C\ to\ 1800^\circ C>$

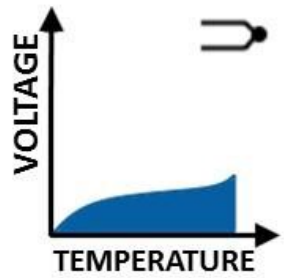
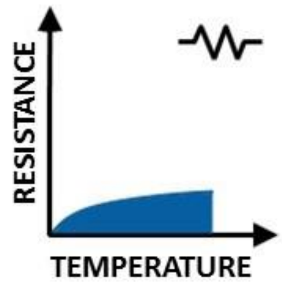
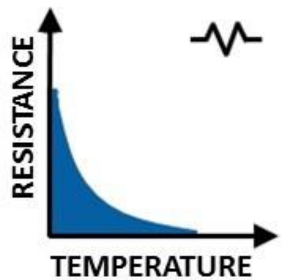


Types of Temperature Sensors





Types of Temperature Sensors

	Advantages	Disadvantages
THERMOCOUPLES 	✓ Simple ✓ Rugged ✓ Inexpensive ✓ No external power ✓ Wide temperature range ✓ Variety of styles	× Nonlinear response × Small sensitivity × Small output voltage × Requires CJC × Least stable
RTD 	✓ Most stable ✓ Good Linearity ✓ Most accurate	× Low sensitivity × Externally powered × Costly × Small output resistance × Self-heating error
THERMISTOR 	✓ Fast ✓ High output ✓ Minimal lead resistance error	× Limited temperature range × Externally powered × Nonlinear × More fragile × Self-heating error

Temperature Measurement

- **The change in temperature of a body produces various primary effects:**
  - Change in its physical or chemical state, e.g. phase transition
  - Change in its physical dimensions
  - Variation in its electrical properties
  - Generation of thermoelectricity
  - Variation in its optical properties
  - Change in the frequency of vibration of piezoelectric crystals
  - Change in the velocity of sound
  - Change in the intensity of the emitted radiation

- **Any of these effects can be exploited to measure the temperature**

Change in Electrical Properties

- Variation of resistance with temperature
  - **Variation of resistance in metals: resistance thermometer**
  - **Variation of resistance in semiconductors: thermistor**

Resistance Temperature Detectors (RTDs)

Resistance Temperature Detectors (RTDs)

- Resistivity of metals is a function of temperature.

- The relation between electrical resistance R_T of metal and corresponding temperature T is generally given as.

$$R_T = R_0(1 + \alpha T)$$

Platinum Resistance Thermometer

- **Electrical resistance of a metal, R_T, at a temperature T**

$$R_T = R_0(1 + C_1T + C_2T^2 + \cdots + C_nT^n)$$

C's are constants and R_0 is the resistance at temperature $T = 0℃$

- **Nonlinear: inconvenient form**

- **Linear, if all the terms in C_2T^2 and higher powers of T are negligible**

$$R_T \approx R_0(1 + C_1T)$$

Platinum Resistance Thermometer

- Variation of resistance with temperature
    - Resistance temperature detectors (RTDs)

- Platinum resistance thermometer is widely used to measure temperature
- First constructed by William Siemens (1871) and later perfected by Callendar and Griffiths (1887)

Platinum Resistance Thermometer

- ❑ **Electrical resistance of a metal, $\boldsymbol{R_T}$, at a temperature $\boldsymbol{T}$**

$$R_T = R_0(1 + C_1T + C_2T^2 + \cdots + C_nT^n)$$

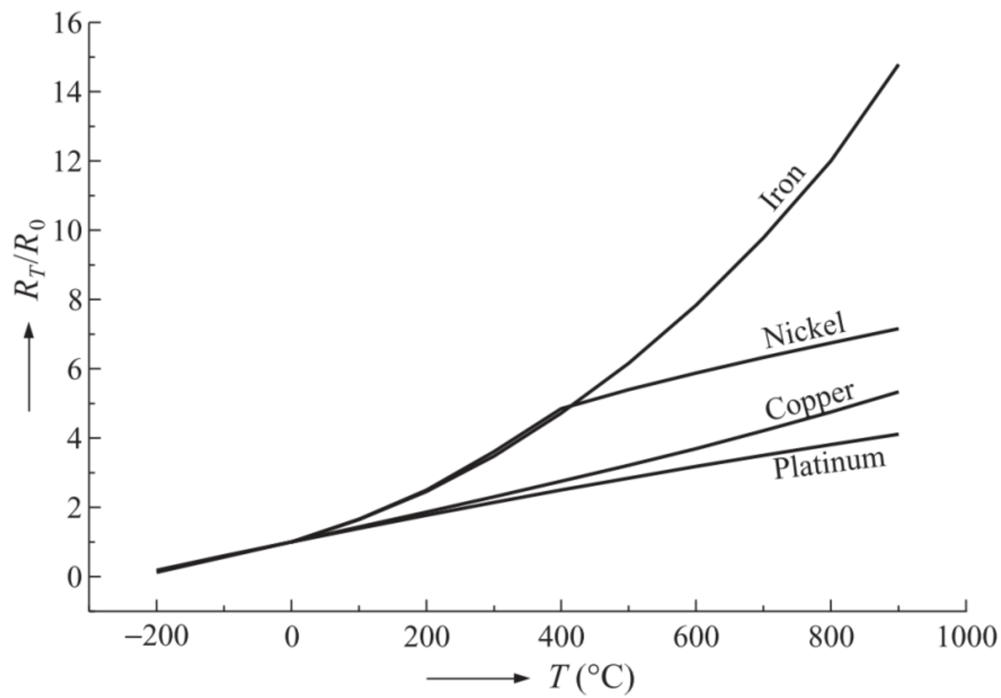


Fig. 10.6 Resistance-temperature characteristics of metals.

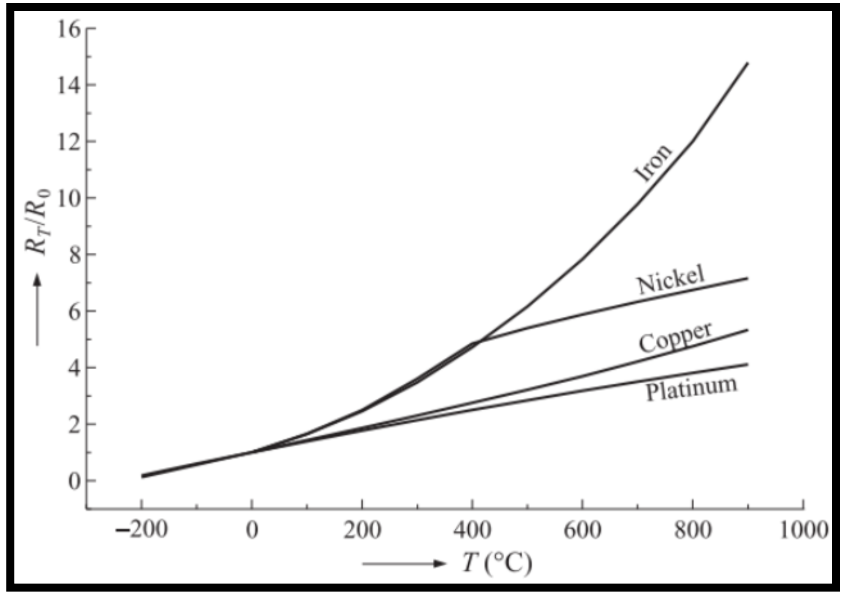
❖ Curve is nearly linear for copper, nickel and platinum over a fairly long range

Resistance Temperature Detectors (RTDs)

- Copper and platinum have a nearly linear temperature-resistance characteristics over a long range.

- However, copper is easily susceptible to chemical reactions such as oxidation, sulphate formation etc., therefore platinum is most commonly used RTD material.

- Platinum resistance thermometers are also known as PRTs.



Platinum Resistance Thermometer

- **Electrical resistance of a metal, R_T, at a temperature T**

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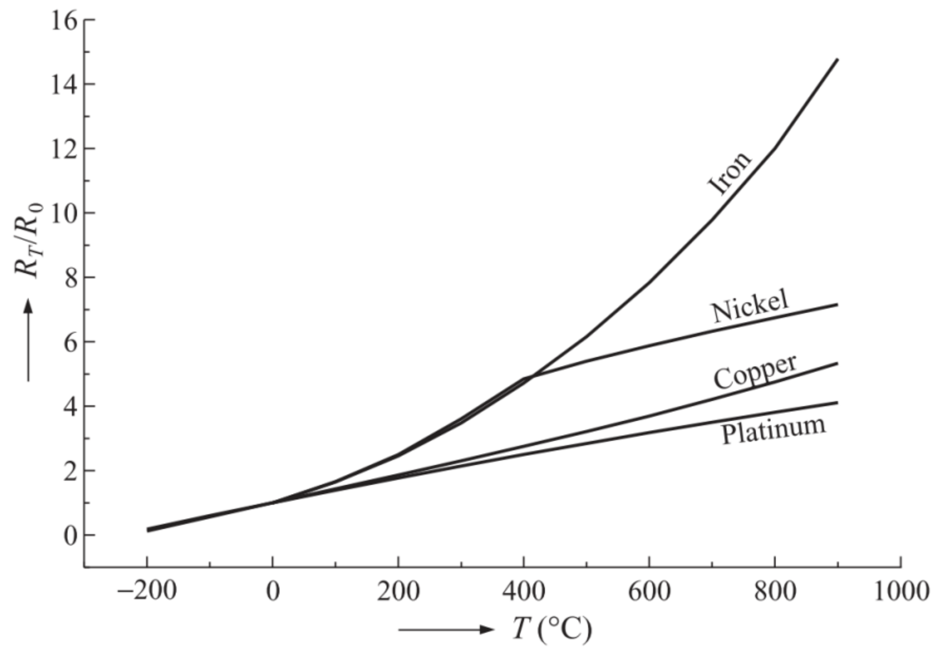


Fig. 10.6 Resistance-temperature characteristics of metals.

- Copper and nickel
  - Cheaper than platinum RTDs
  - Susceptible to oxidation and corrosion seriously limiting the accuracy and longevity

Platinum Resistance Thermometer

- ❑ **Electrical resistance of a metal, R_T, at a temperature T**

$$R_T = R_0(1 + C_1T + C_2T^2 + \cdots + C_nT^n)$$

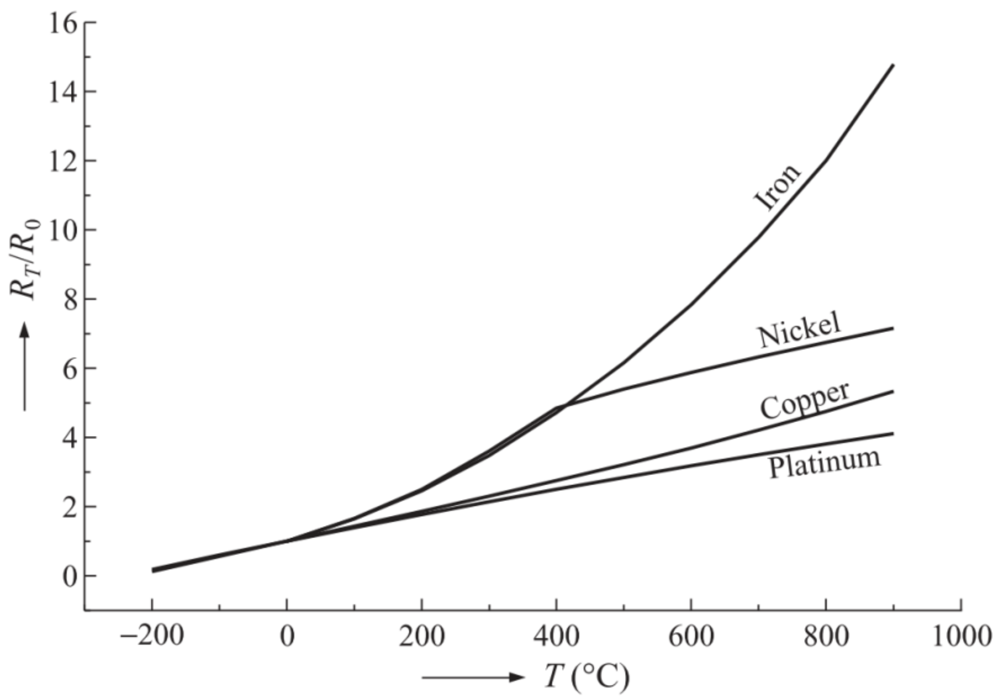


Fig. 10.6 Resistance-temperature characteristics of metals.

- ❑ Platinum
  - ❑ Most linear resistance-temperature characteristic
  - ❑ Good chemical inertness

Platinum Resistance Thermometer

- **Electrical resistance of a metal, R_T, at a temperature T**

$$R_T = R_0(1 + C_1T + C_2T^2 + \cdots + C_nT^n)$$

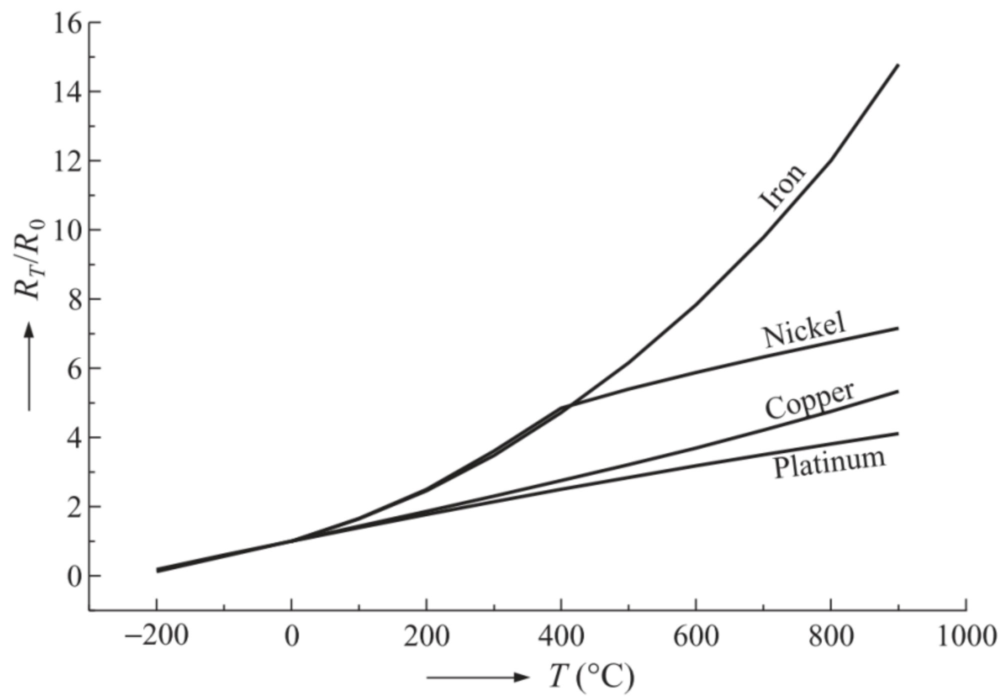


Fig. 10.6 Resistance-temperature characteristics of metals.

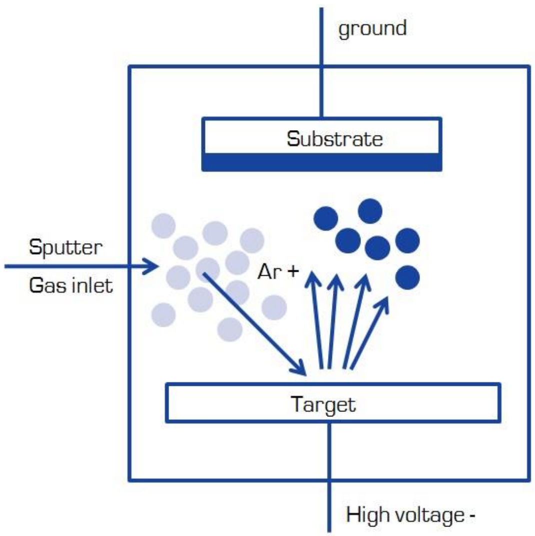
- **Platinum: - 270 to +1000℃**
- **Nickel: -200 to + 430 ℃**
- **Copper: -200 to + 260 ℃**
- **Tungsten: - 270 to +1100℃**

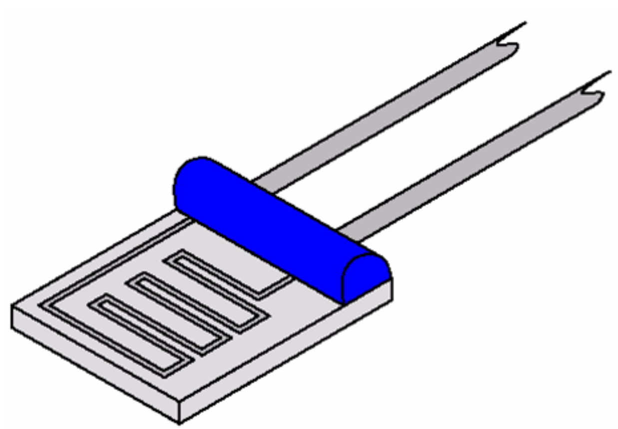
Platinum Resistance Thermometer

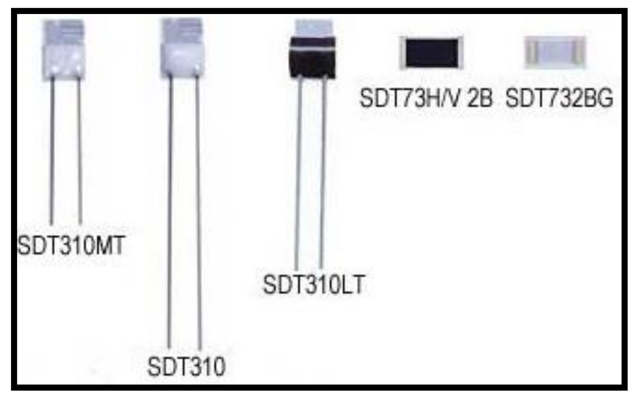
- PRTs
- **Two types**
  1. Thin film PRT
  2. Wire wound PRT

Platinum Resistance Thermometer

- ❑ **Thin film PRT**
  - ❑ Deposition of a thin film of platinum onto a substrate (usually ceramic) by sputtering
  - ❑ Thickness control is achieved by limiting the period of sputtering process
    - ❑ As thin as 1 micron
  - ❑ Laser is used to trim the platinum layer to a precise resistor/resistance

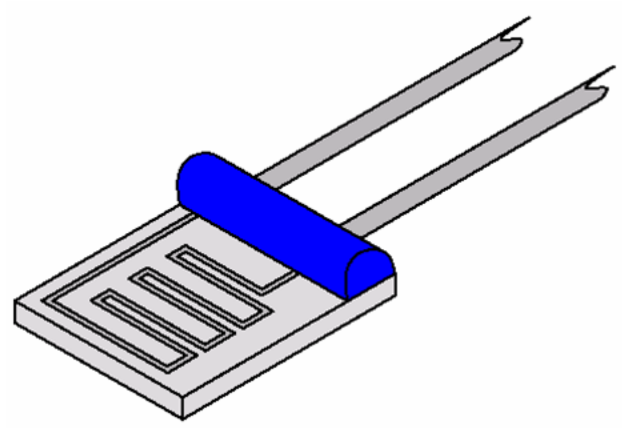






Platinum Resistance Thermometer

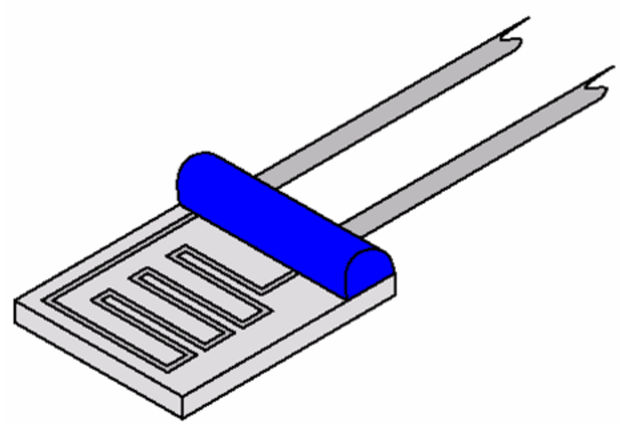
- Thin film PRT



- Features
  - relatively low cost and having versatile shapes and designs

Platinum Resistance Thermometer

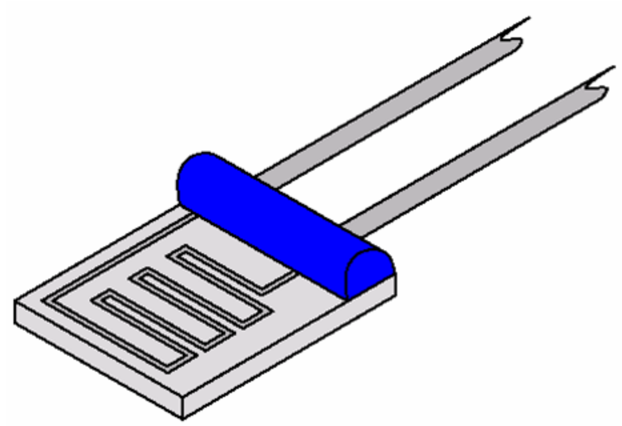
- **Thin film PRT**



- Features
  - **small size**
    - much smaller than their wire-wound counterparts
    - Pencil tip: faster response and tip sensitive
    - The tip sensitivity of a thermocouple has always been an advantage over the PRT. Now this advantage has been all but eliminated

Platinum Resistance Thermometer

- Thin film PRT



- **Drawbacks**
  - Differential expansion between the substrate and platinum film gives rise to strain gauge effects and stability problems

Platinum Resistance Thermometer

- Wire-wound PRT

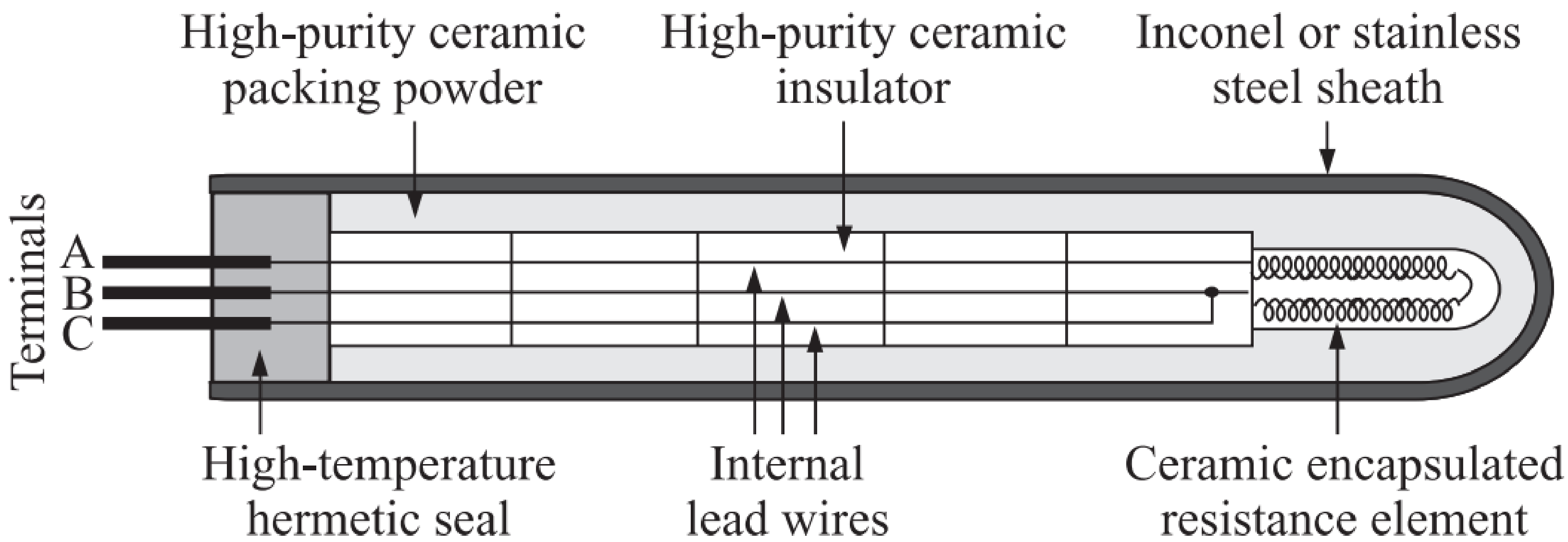


Fig. 10.7 Diagram of a three-wire platinum resistance thermometer.

Platinum Resistance Thermometer

- Wire-wound PRT

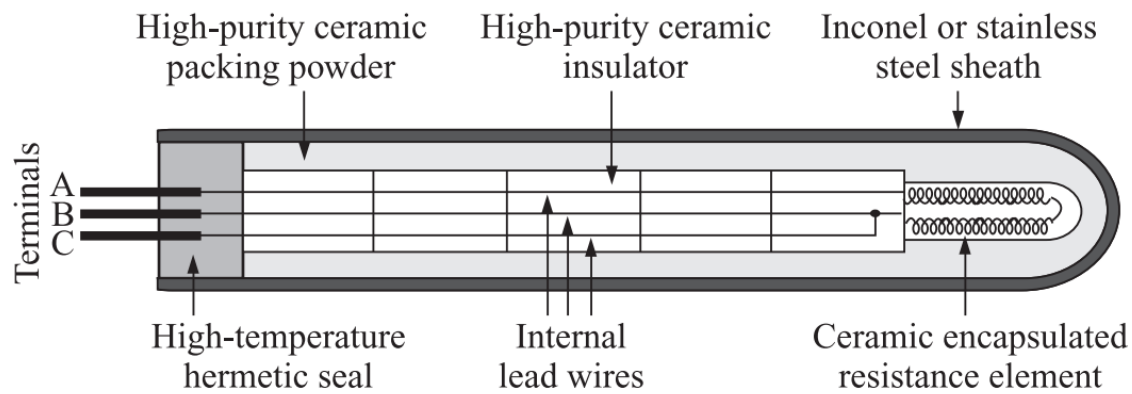


Fig. 10.7 Diagram of a three-wire platinum resistance thermometer.

- **Construction**
  - Pure platinum wire, free from silicon, carbon, tin and other impurities
    - doubled to avoid induction effects and wound on a thin insulating mica former
  - The ends of this wire are joined to terminals A and B on the top of the instrument
  - Another exactly similar lead, with its lower end shorted to B, is connected to terminal C, to compensate for the resistance of the leads
  - Enclosed in a tube, with proper spacers to prevent leads from short-circuiting, and the tube is sealed at the top to prevent moisture

Platinum Resistance Thermometer

- **Wire-wound PRT**

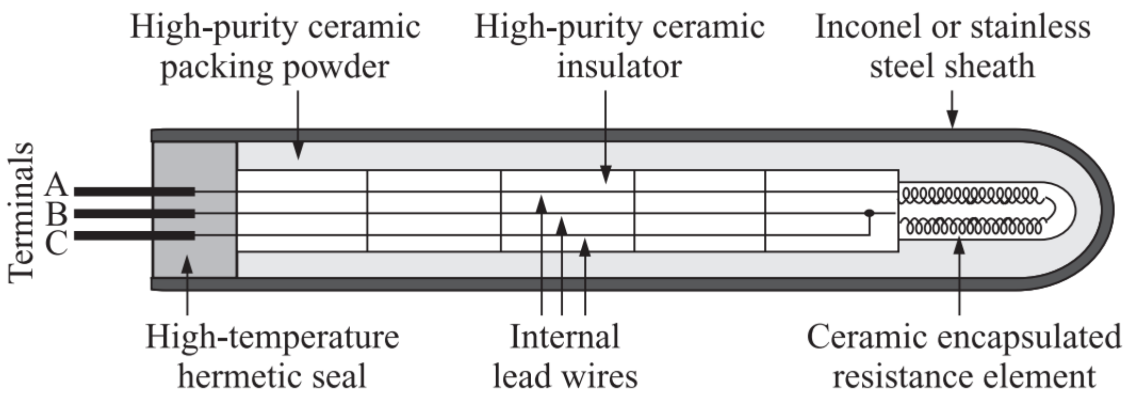
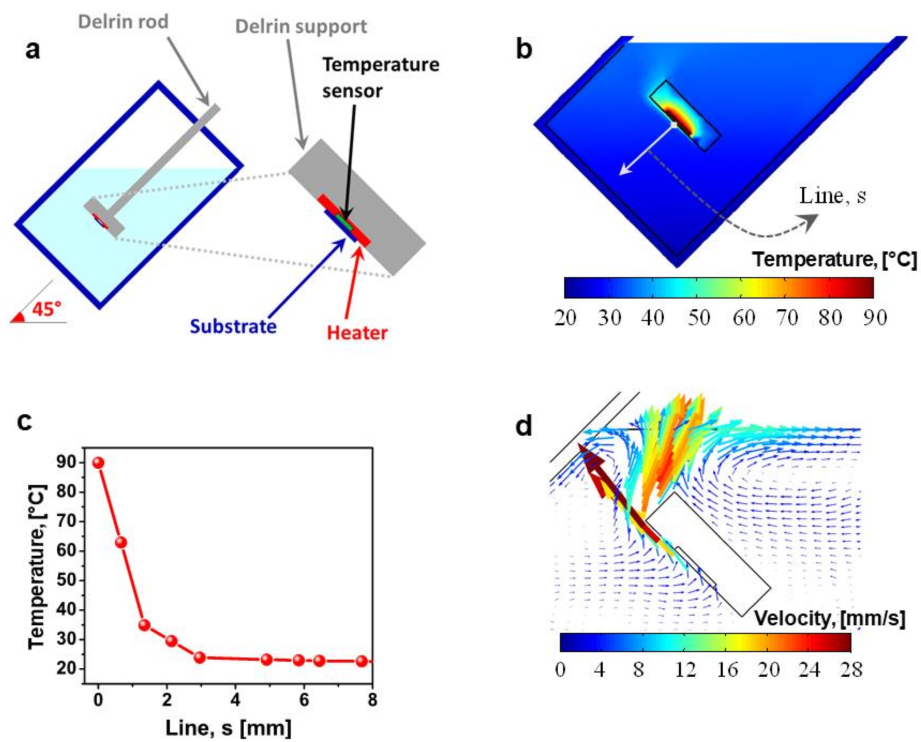


Fig. 10.7 Diagram of a three-wire platinum resistance thermometer.

- Feature
  - Wire-wound PRTs can have a greater accuracy, especially for wide temperature ranges

Platinum Resistance Thermometer

- **PT-100**
  - Usually, the devices have a nominal resistance of 100 Ω at 0 ˚C
  - Known as Pt-100 RTDs.
    - sensitivity of 0.385 Ω/ ˚C



Interference/ Errors in RTD Measurements

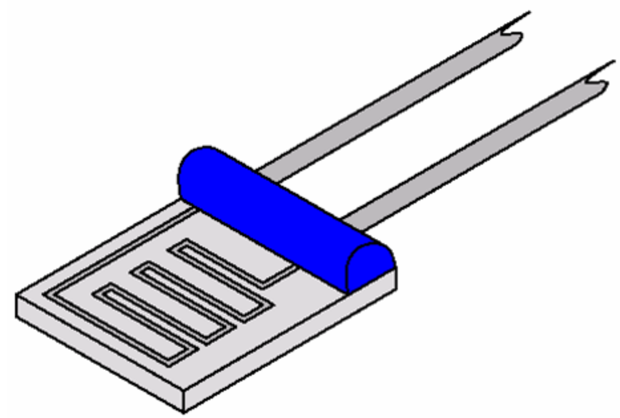
- **Error due to self heating**
  - Since RTD has to be used in bridge measurement circuits, the current passing through it dissipates power and can causes self heating.
  - A typical values of self heating error are between $0.1°C/mw$ to $1°C/mw$ according to ambient conditions.
- **How to minimize self heating**
  - By limiting the excitation current as much as possible.
  - By making the RTD as large as practically feasible.

Platinum Resistance Thermometer

- **Measurements with RTDs: two interferences**

  1. Self-heating

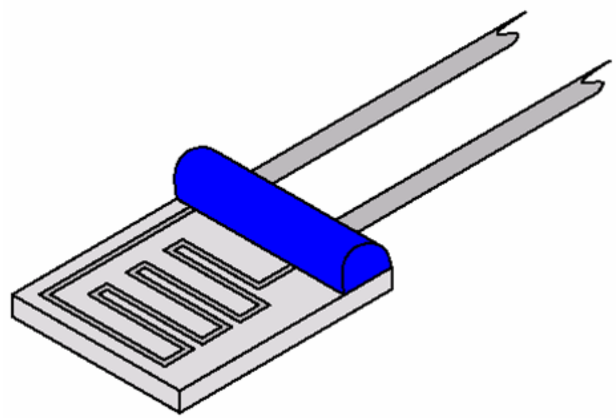
  2. Lead wire resistance



RTDs: Self-heating

- Resistive heating due to the excitation current
  - 1 mA through a 100 Ω RTD generates 100 μW

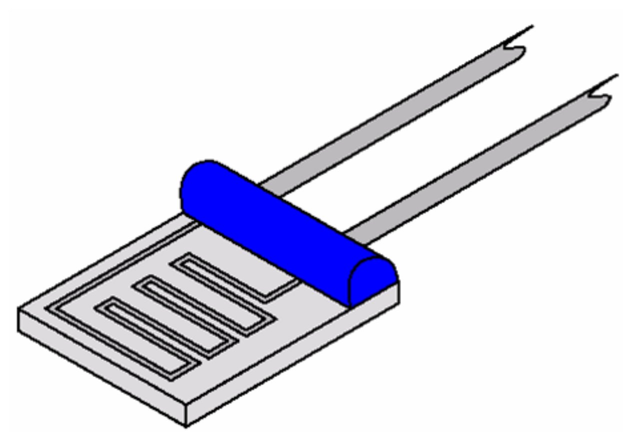
$$P = I^2R$$



RTDs: Self-heating

- Resistive heating due to the excitation current
  - 1 mA through a 100 Ω RTD generates 100 μW
- Self-heating error for an RTD, typically
  - 1 ℃/mW in free air
  - 0.1 ℃/mW in air flowing at 1 m/s

$$P = I^2 R$$



RTDs: Self-heating

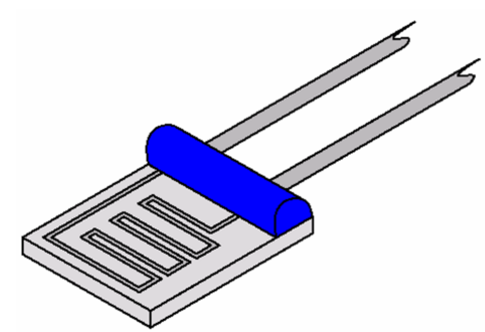
- **Self-heating errors: how to reduce?**

  1. using the minimum excitation current that provides the desired resolution

  2. using the largest physically practical RTD

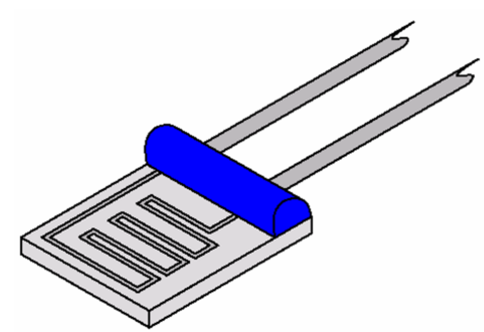
RTDs: Lead wire resistance

- Because of the low resistance of the RTD, the lead wire resistance also interfere in the measurement



RTDs: Lead wire resistance

- Because of the low resistance of the RTD, the lead wire resistance also interfere in the measurement
  - For example, lead wires with a resistance of 1 Ω connected to a 100 Ω platinum RTD cause a 1% measurement error

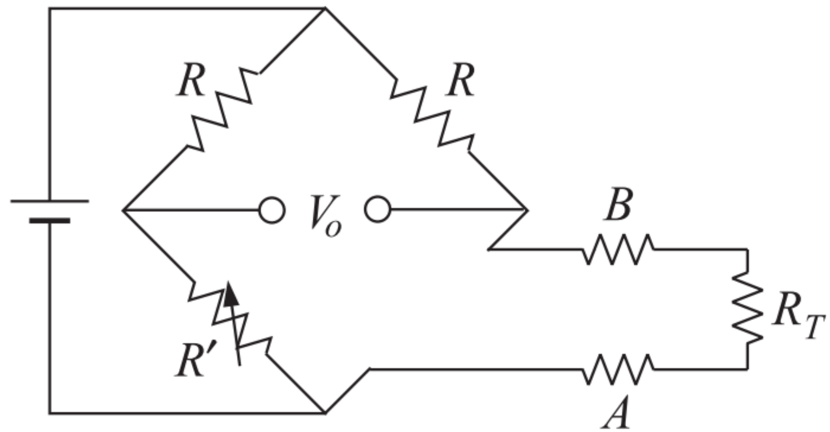


RTDs: Lead wire resistance

- How to reduce the errors?
  - Measuring the resistance of the RTD by balancing a bridge circuit

RTD's Resistance Measurement

- ❑ **Two-wire connection**
  - ❑ Two wires to connect the thermometer to a Wheatstone bridge

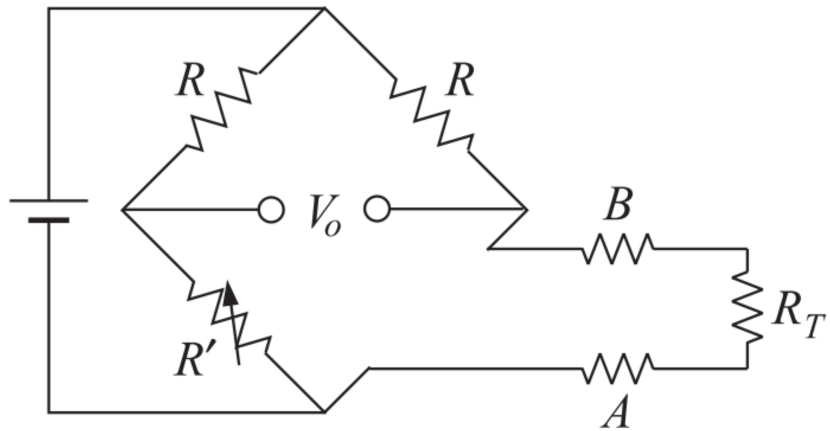


(a)

where R_T is the resistance of the RTD
A, B are resistances of the lead wires
R' is the adjustable resistance

RTD’s Resistance Measurement

- **Two-wire connection**
  - Two wires to connect the thermometer to a Wheatstone bridge



(a)

RTD's Resistance Measurement

- **Two-wire connection**
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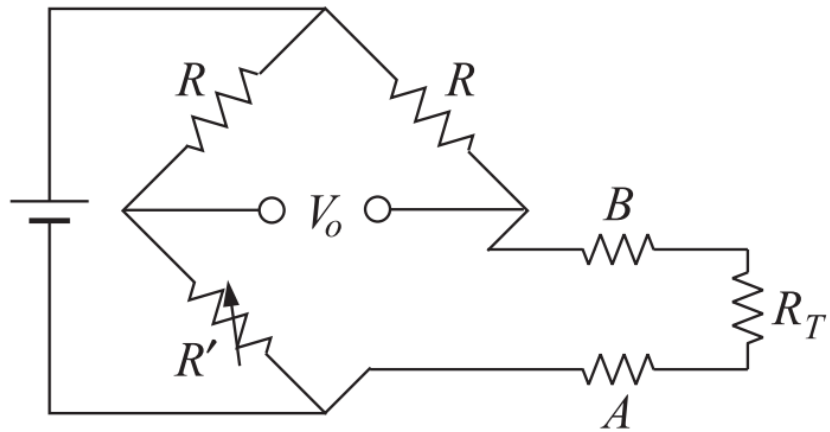


(a)

when balanced,

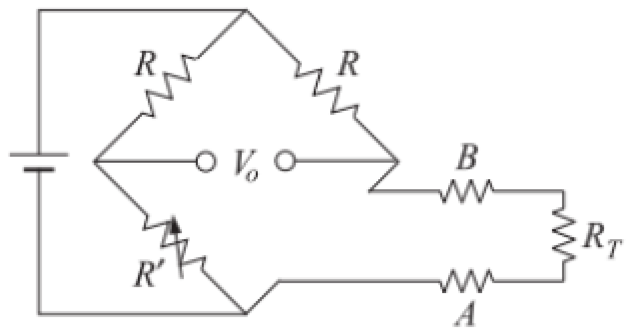
$$R + R' = R + A + R_T + B$$

$$R' = R_T + (A + B)$$

- Resistance of the connecting wires is included
  - Errors in the measurement
  - ✓ Used if high accuracy is not required

Connecting RTDs in Bridge Measurement Circuit

- **Two-wire connection**
  - Two wires are used to connect RTD in a Wheatstone bridge.



  - If the bridge is balanced.

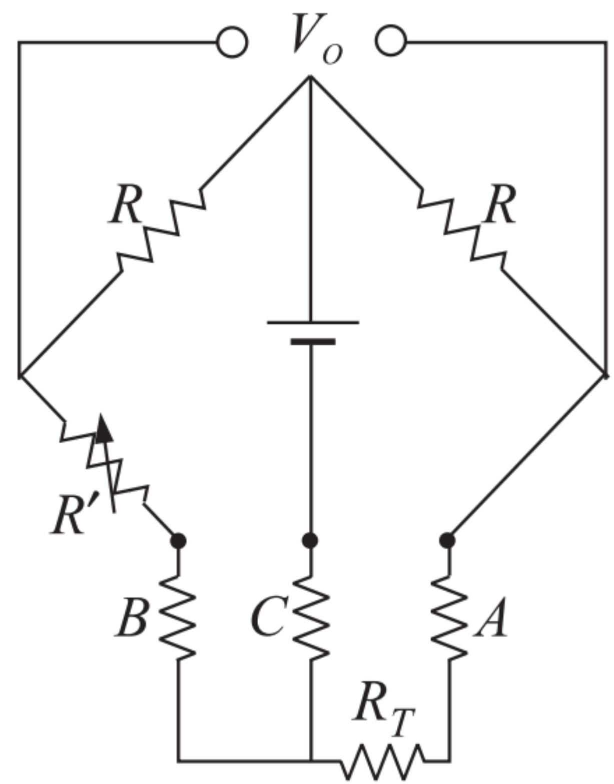
$$R + R' = R + A + R_T + B$$

$$R' = R_T + (A + B)$$

  - Temperature variations may lead to change in resistance of lead wires, which result in unbalanced bridge i.e., erroneous temperature measurements.

RTD’s Resistance Measurement

- **Three-wire connection**
  - Callendar and Griffiths’ bridge



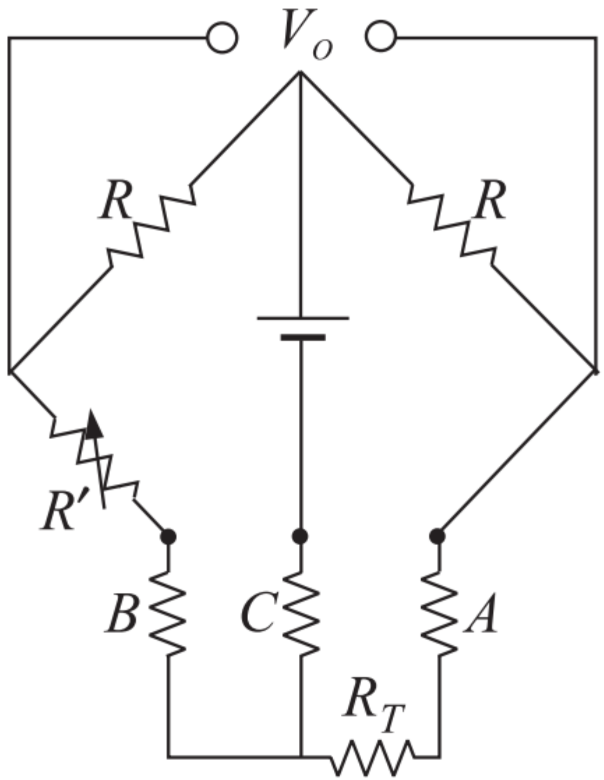
R_T is the resistance of the PRT at temperature T

R' is the resistance used to balance the bridge

A, B, C are resistances of the lead wires

RTD's Resistance Measurement

- **Three-wire connection**
  - Callendar and Griffiths' bridge
  - To minimise the effects of the lead resistances
  - There is a lead resistance in each arm of the bridge in order to cancel each other



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RTD's Resistance Measurement

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  - ❑ Callendar and Griffiths' bridge
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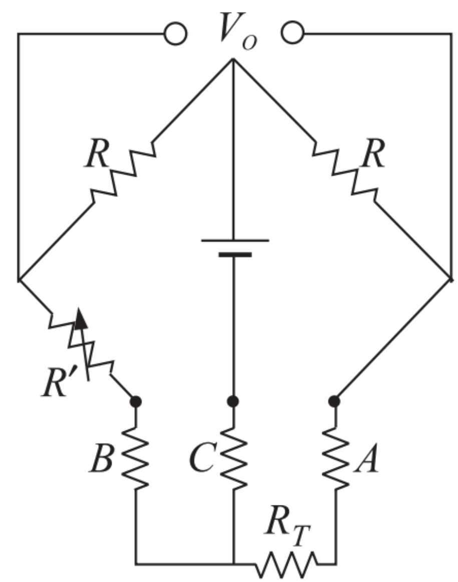


for the balanced bridge,

$$R + R' + B + C = R + R_T + A + C$$

for *A* = *B* $$R' = R_T$$

- ✓ **High quality connection cables for the two lead resistances to be equal**
- ✓ **This configuration allows for up to 600 m of cable**

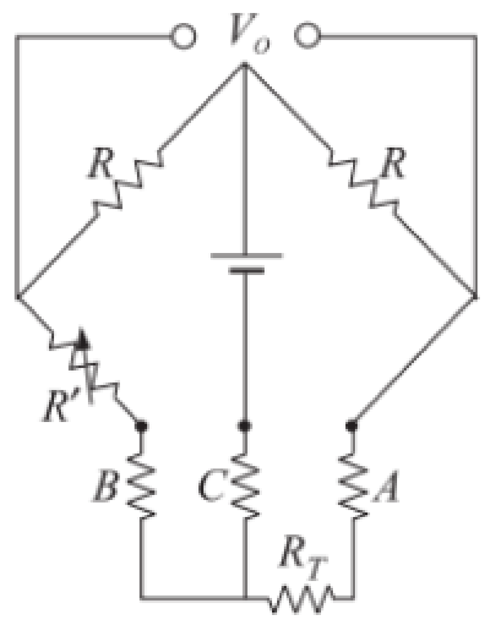
Connecting RTDs in Bridge Measurement Circuit

- **Three-wire connection**
  - The impact of lead wire temperature variation can be minimized by using three wire connection as shown.
  - If the bridge is balanced.

$$R + R' + B + C = R + R_T + A + C \qquad \boxed{A = B.}$$

$$R' = R_T$$

- Lead wire temperature variation has no influence on temperature measurement.



Example 10.3

Design an electronic circuit using RTD which may provide 0–200 mV output corresponding to 0–2000°C. Assume that $R_0 = 100\ \Omega$ and $R_{200} = 180\ \Omega$.

Example 10.3

Design an electronic circuit using RTD which may provide 0–200 mV output corresponding to 0–2000°C. Assume that $R_0 = 100\,\Omega$ and $R_{200} = 180\,\Omega$.

Solution

We assume a linear relation between the temperature and resistance as

$$R_T = R_0(1 + \alpha T)$$

So, from the given data we get

$$\alpha = \frac{R_T - R_0}{T} = \frac{180 - 100}{100} = 0.004$$

and

$$R_{2000} = 100(1 + 0.004 \times 2000) = 900\,\Omega$$

Example 10.3

We consider a Wheatstone bridge where all the arms contain 100 Ω resistances at 0°C. At 2000°C, the resistance of one of the arms, containing the RTD, turns out to be 900 Ω. The problem to solve is that what input voltage to the bridge should yield a variation of 0 to 200 mV for this variation of resistance. From Fig. 10.11, we get

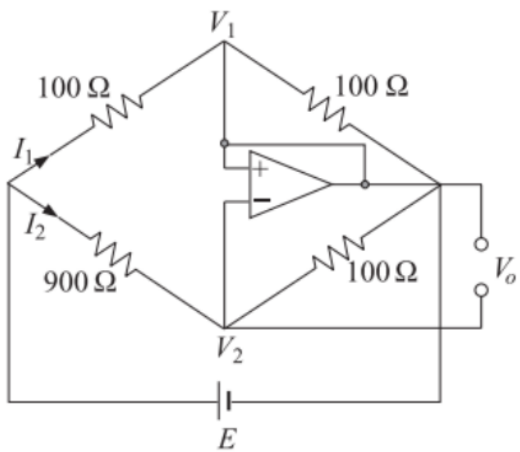


Fig. 10.11 Wheatstone bridge (Example 10.3).

$$I_1 = \frac{E}{200} \qquad I_2 = \frac{E}{1000}$$

$$V_1 = I_1 \times 100 \qquad V_2 = I_2 \times 900$$

We need to figure out the supply voltage E.

We see,

$$V_1 - V_2 = 0.2 \text{ (given)}$$

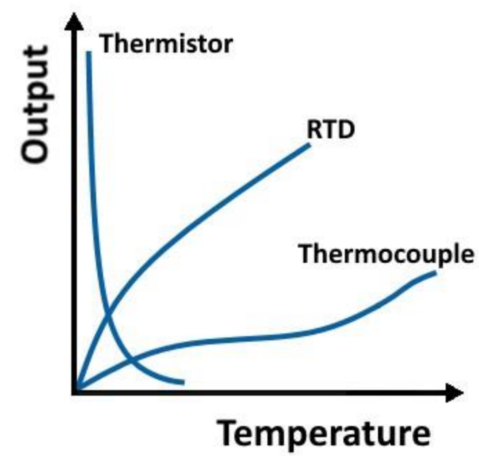
$$= E\left(\frac{900}{1000} - \frac{100}{200}\right)$$

$$\Rightarrow \qquad E = \frac{0.2}{0.9 - 0.5} = 0.5 \text{ V}$$

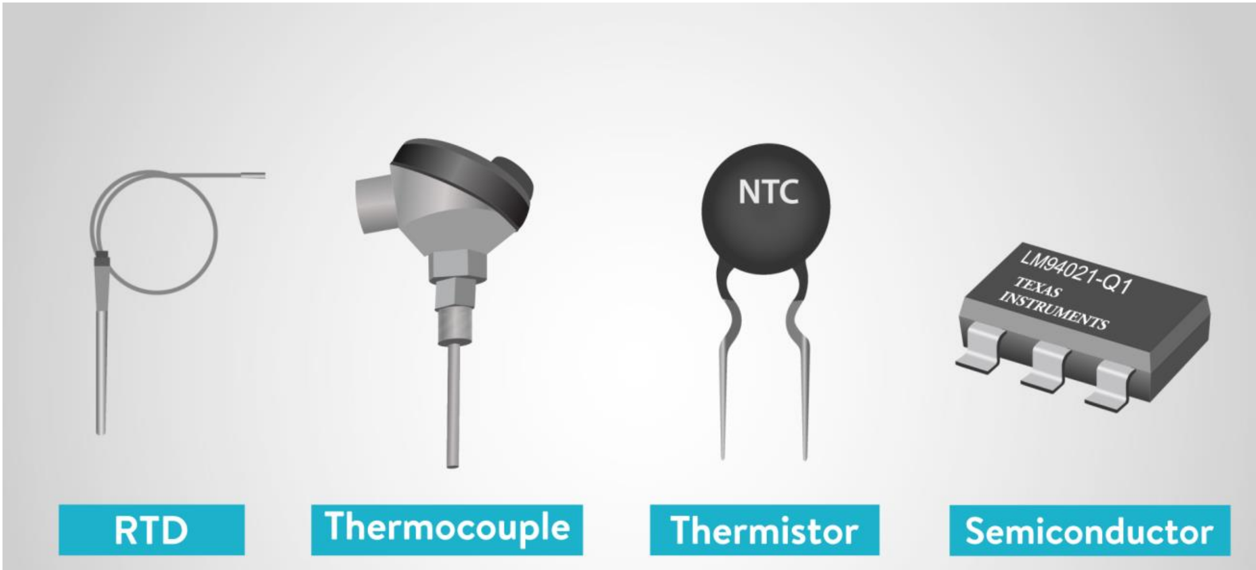
Thermistors

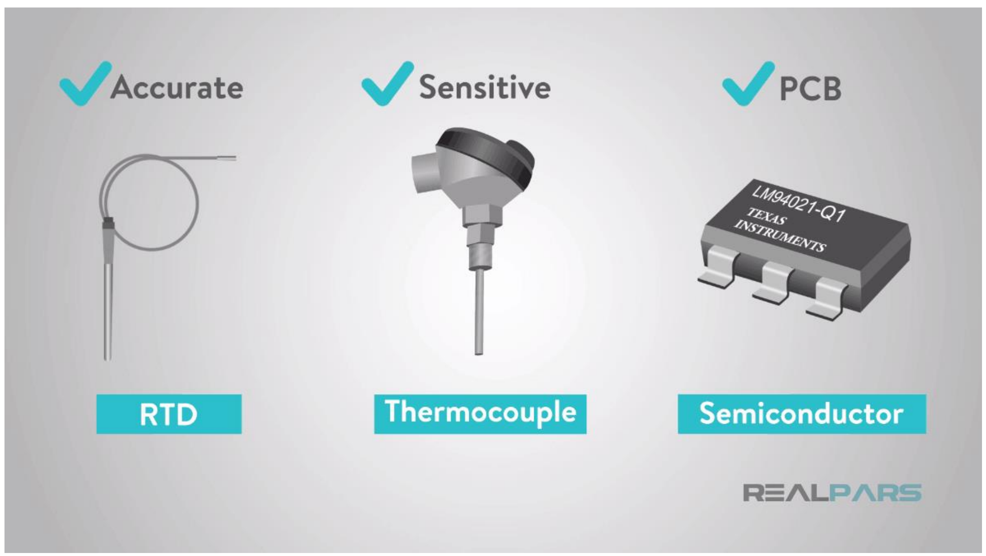
Recall: Types of Temperature Sensors

- Most commonly used temperature sensors are.
  - Resistance Temperature Detectors (RTD) $<-40°C\ to\ 1200°C>$
  - Thermistors $<-55°C\ to\ 150°C>$
  - Thermocouples $<-200°C\ to\ 1800°C>$

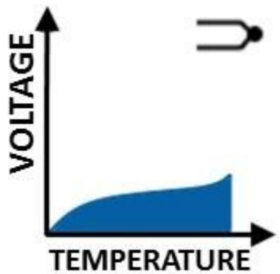
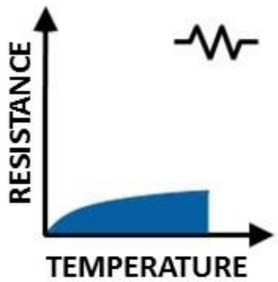
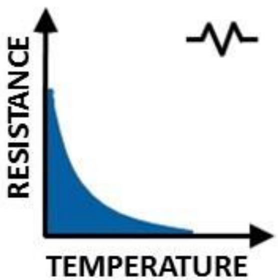


Recall: Types of Temperature Sensors



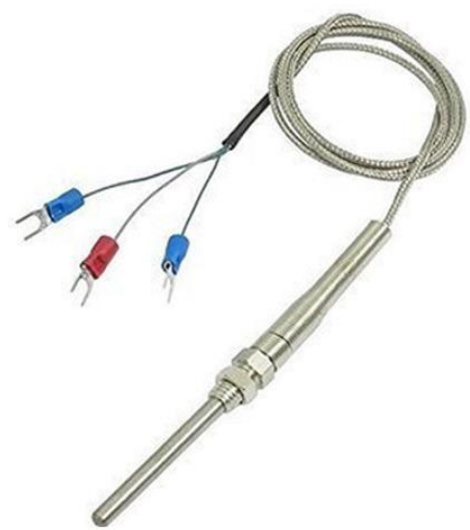


Recall: Types of Temperature Sensors

	Advantages	Disadvantages
THERMOCOUPLES 	✓ Simple ✓ Rugged ✓ Inexpensive ✓ No external power ✓ Wide temperature range ✓ Variety of styles	× Nonlinear response × Small sensitivity × Small output voltage × Requires CJC × Least stable
RTD 	✓ Most stable ✓ Good Linearity ✓ Most accurate	× Low sensitivity × Externally powered × Costly × Small output resistance × Self-heating error
THERMISTOR 	✓ Fast ✓ High output ✓ Minimal lead resistance error	× Limited temperature range × Externally powered × Nonlinear × More fragile × Self-heating error

Thermistor

- Thermally sensitive resistors



Thermistors

- **A thermistor is a type of resistor whose resistance varies significantly with temperature, more so than in standard resistors.**

- If ΔR is the change in resistance corresponding to a change of temperature ΔT, then.

$$\Delta R = \alpha_T \Delta T$$

- Thermistor can be divided into two categories depending on whether α_T is positive or negative.
  - Positive Temperature Coefficient (PTC) → **Self Resetting Overcurrent Protection**
  - **Negative Temperature Coefficient (NTC)** → **Temperature sensor**

Thermistor

- **Thermally sensitive resistors**
  - If ΔR is the change in resistance corresponding to a temperature change of ΔT and to a first approximation they are related as

$$\Delta R = \alpha_T \Delta T$$

where α_T is called the temperature coefficient of resistivity

Thermistor

- **Two categories**

  1. PTC thermistors
     - thermistors with a positive temperature coefficient
  2. NTC thermistors
     - thermistors with a negative temperature coefficient

Thermistor

- **Two categories**

  1. PTC thermistors
     - thermistors with a positive temperature coefficient
  2. NTC thermistors
     - thermistors with a negative temperature coefficient

- PTC thermistors are mostly used for switching in temperature controllers rather than proportional temperature measurement

Thermocouple

Thermocouple

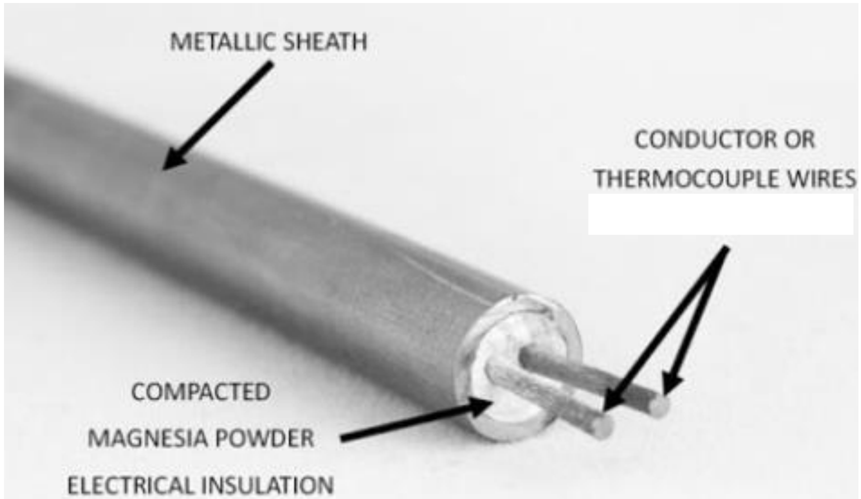
- It is a temperature sensor that relies on the principle that any two different metals (A and B) are connected together, an emf that is the function of temperature will be developed at the junction of these two metals.

$$e = a_1 t + a_2 t^2 + a_3 t^3 + \ \ldots$$

- The temeprature-emf relationship is non linear.
- Therefore, thermocouple charts are widely used to correlate produced emf with the measured temperature.

Thermocouple Construction

- The thermocouple is constructed by joining homogenously two dissimilar metals at one end to form the measuring junction. Junction maybe formed by welding, soldering or crimping the two metals.
- Mineral Insulation is provided to protect the thermocouple against the environmental factors.
  - The thermocouple wire is embedded in ceramic insulation and covered with metallic sheath.



Thermoelectricity

- A thermal gradient in some metals and alloys generate electricity and vice versa

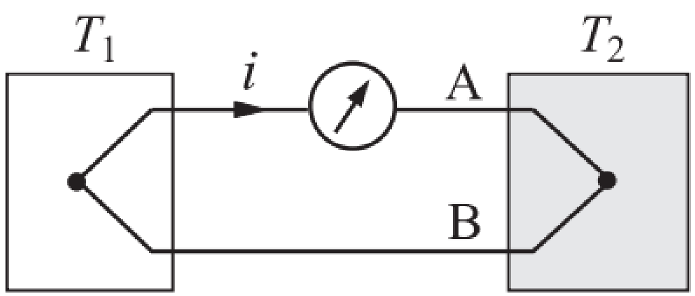
Thermoelectricity

- **A thermal gradient in some metals and alloys generate electricity and vice versa**

  1. Seebeck effect
  2. Peltier effect
  3. Thomson effect

Thermoelectricity

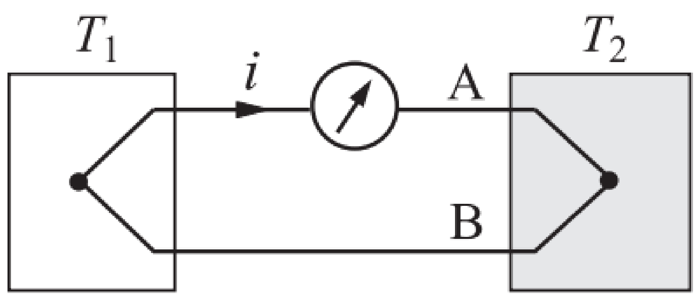
- **Seebeck effect: thermocouple**
  - Two wires or strips of dissimilar metals welded together at both ends to form a circuit
  - For a temperature difference between the junctions, an electric current flows through the circuit



(a) Seebeck effect

Thermoelectricity

- **Seebeck effect: thermocouple**
  - Two wires or strips of dissimilar metals welded together at both ends to form a circuit
  - For a temperature difference between the junctions, an electric current flows through the circuit

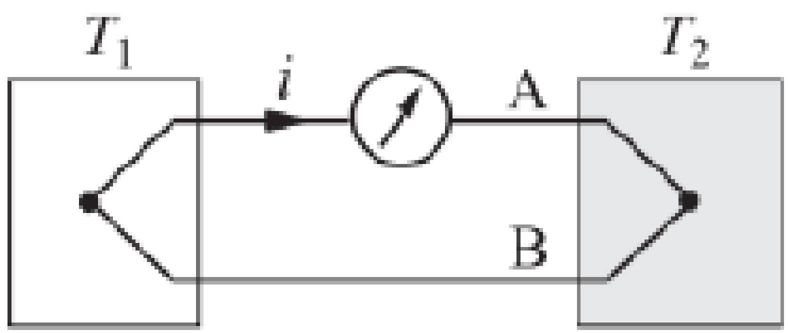


(a) Seebeck effect

- Thermo-emf
  - A microvoltmeter of very high input impedance in the circuit can measure the resulting emf which is generally called the thermo-emf

Principle of Operation

- Seebeck Effect
  - If two wires or strips of dissimilar metals are welded together at both ends to form a complete circuit and if two junctions are maintained at different temperatures, an electric current flows through the circuit.
  - The device thus formed is a thermocouple and phenomenon is called seebeck effect.
  - A microvoltmeter of high input impedance is included in the circuit to measure emf called the *thermo-emf*.



Common Thermocouple

TABLE 7.2 Standard Thermocouple Types and Useful Temperature Range

Letter Designation	Metals	Approximate Temperature Range (degrees Celsius)
Type K	Chromel/Alumel	−200 to 1250
Type J	Iron/Constantan	0 to 750
Type T	Copper/Constantan	−200 to 350
Type E	Chromel/Constantan	−200 to 900
Type S	Platinum/Platinum 10% Rhodium	0 to 1450
Type R	Platinum/Platinum 13% Rhodium	0 to 1450

Thermoelectricity

- **Explanation of Thermoelectric Effects**

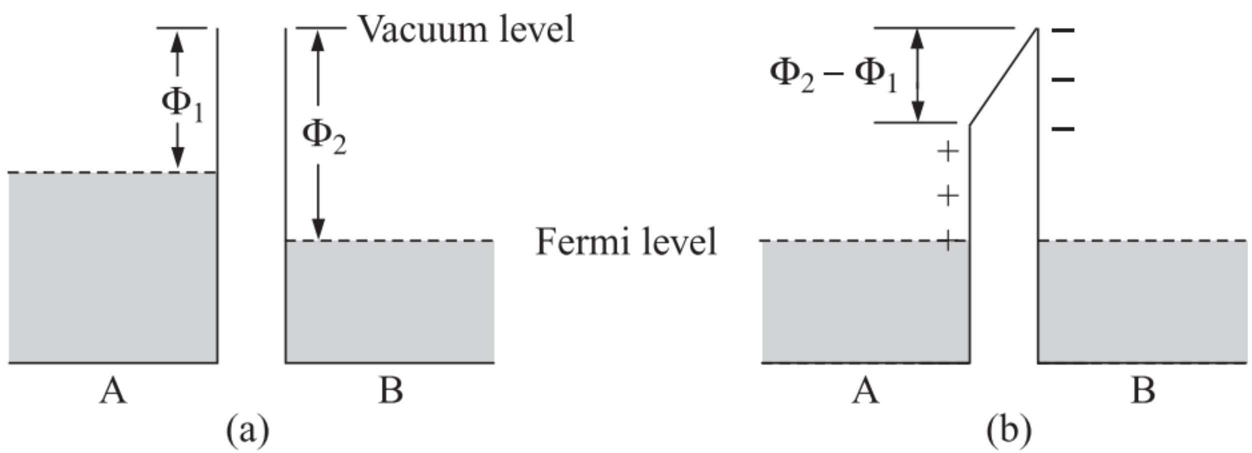


Fig. 10.20 (a) Metals A and B and their energy bands, and (b) metals A and B and their energy bands when A and B are joined together.

- **Seebeck effect**

Thermoelectricity

❑ Explanation of Thermoelectric Effects

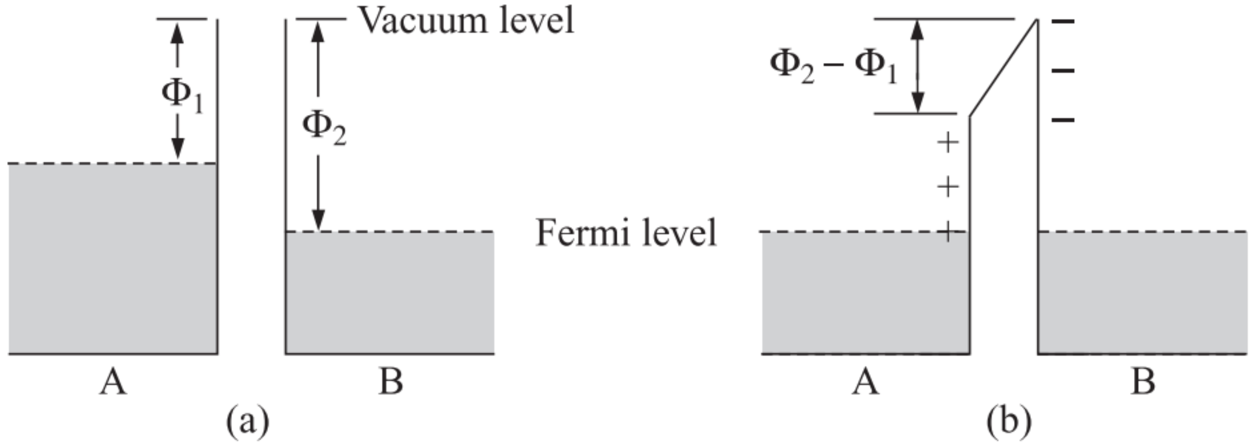


Fig. 10.20 (a) Metals A and B and their energy bands, and (b) metals A and B and their energy bands when A and B are joined together.

❑ Seebeck effect

- ❑ For two junctions at different temperatures, the electrons at the hot junction gain energy so that the Fermi level at the hot junction is higher than that at the cold junction
  - ❑ an electron flow from the hot junction to the cold junction

Thermoelectricity

- **Explanation of Thermoelectric Effects**

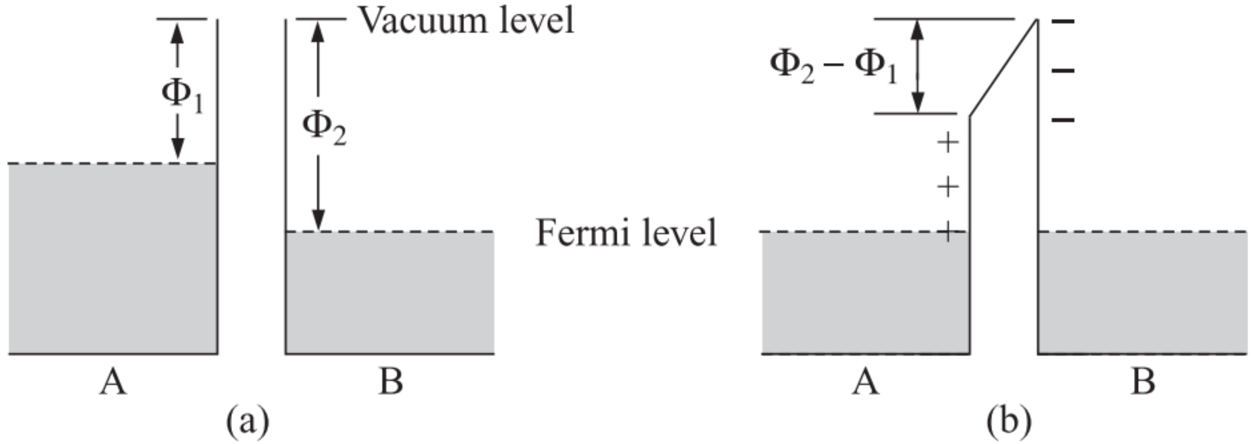
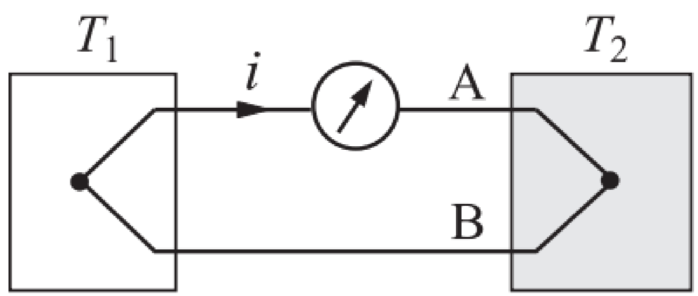


Fig. 10.20 (a) Metals A and B and their energy bands, and (b) metals A and B and their energy bands when A and B are joined together.

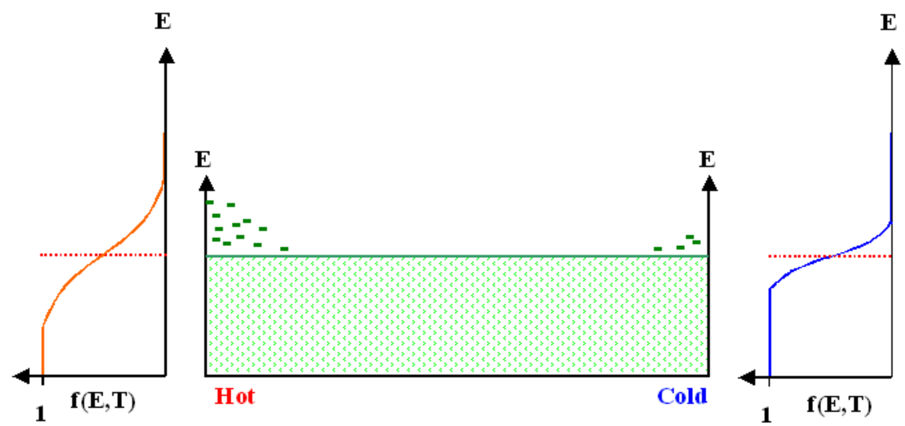
- **Peltier effect**
  - Due to an external current flow, heat is generated because electrons release some energy when moving down the potential hill
    - in the reverse case, they have to acquire energy from the surroundings to climb the hill

Thermoelectricity

- Thermocouple: Seebeck effect
  - Two wires or strips of dissimilar metals welded together at both ends to form a complete circuit
  - For a temperature difference between the junctions, an electric current flows through the circuit

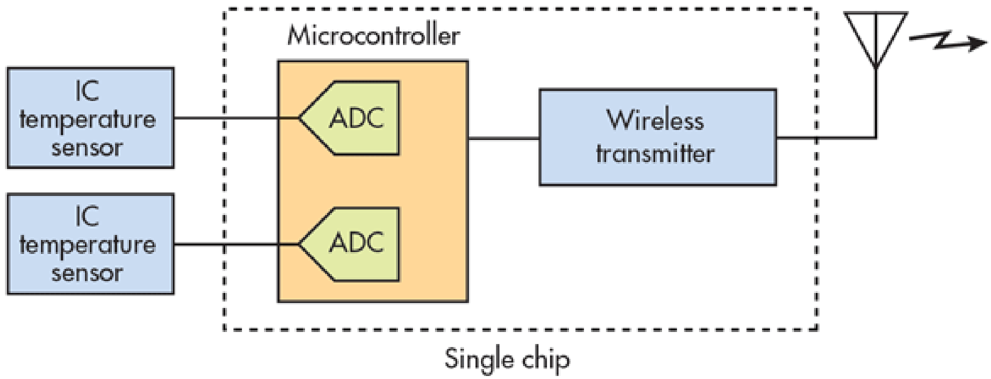


(a) Seebeck effect



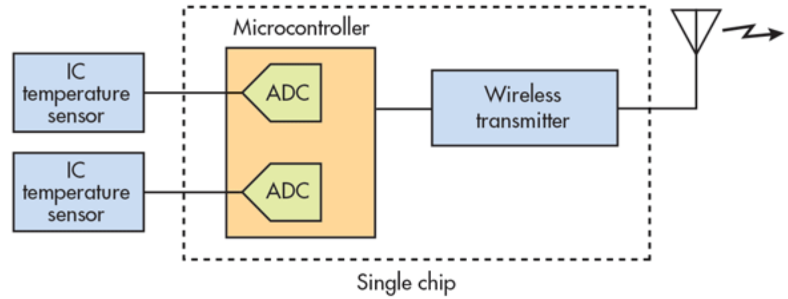
Integrated Circuit Sensors

- Integrated circuit (IC) temperature sensors
  - mobile phones: battery pack,..
  - Notebook computers:CPU, battery, ac adapter, and PCMCIA card cage
  - PC, automobile ….



Integrated Circuit Sensors

- **Integrated circuit (IC) temperature sensors**



- Main feature
  - better noise immunity through higher-level output signals
  - in some cases, logic outputs compatible with digital systems
  - require no linearization or cold-junction compensation

Integrated Circuit Sensors

- **Principle of operation**
  - **forward voltage of a silicon diode depends on its temperature**

$$V_F = \frac{kT}{e} \ln \frac{I_F}{I_S} \quad \text{for } I_F \gg I_s$$

where
T is the ambient temperature in degrees kelvin
k is the Boltzmann's constant (1.3807×10^{-23} J/K)
e is the charge of an electron (1.602×10^{-19} coulomb)
I_F is the forward current
I_S is the saturation current

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- **Major issue**
  - Temperature dependence of the leakage current in Si p-n junctions
  - these currents double with every 10 ℃ rise in temperature
  - Limited temperature range (200 ℃)

Integrated Circuit Sensors

- **Representative IC temperature sensor**
  - **LM 35:10 mV/ ℃ and -55 ℃ to 150 ℃**

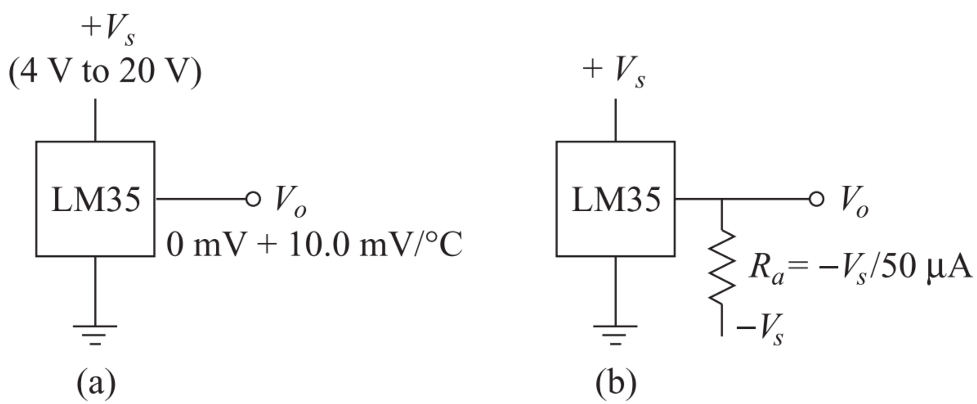

Fig. 10.28 LM35 connections: (a) single power supply (for +2°C to +150°C), and (b) plus-minus supplies (for full range).

Comparison of some temperature sensors

Table 10.7 Advantages and disadvantages of widely used temperature sensors

Device	*Advantages*	*Disadvantages*
RTD	Linear. High stability. Wide range of operating temperature. Interchangeable over wide temperature range.	Rather low sensitivity. Relatively slow response. Low resistance requires three- or four-wire measurement. Sensitive to shock and vibration. Voltage source required. Expensive.
Thermistor	High stability. Fast response. High sensitivity. High resistance eliminates the need for four-wire measurement. Small size. Interchangeable.	Nonlinear. Limited operating temperature. Interchangeable over relatively narrow temperature ranges. Voltage source required. Inexpensive.
Thermocouple	Simple. Wide range of operating temperature. No external power supply required. Rugged. Inexpensive.	Nonlinear. Relatively low stability. Low sensitivity. Low voltage output can be affected by RI and EMI. Cold junction compensation required.
IC	Linear. High sensitivity. Inexpensive.	Limited range of operating temperature. Power supply required. Subject to self-heating. Limited configurations.

Radiation Pyrometer

- **Contact type temperature measurement**
  - **based on the heat conduction process for temperature measurement**

Radiation Pyrometer

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  - based on the heat conduction process for temperature measurement

1. The sensor has to be at the same temperature as the measurand; in case of very high temperature, this may melt or even burn the sensor

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3. How to measure the temperature of a moving object like a missile?

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3. How to measure the temperature of a moving object like a missile?
4. How to measure the average temperature, rather than a point temperature?

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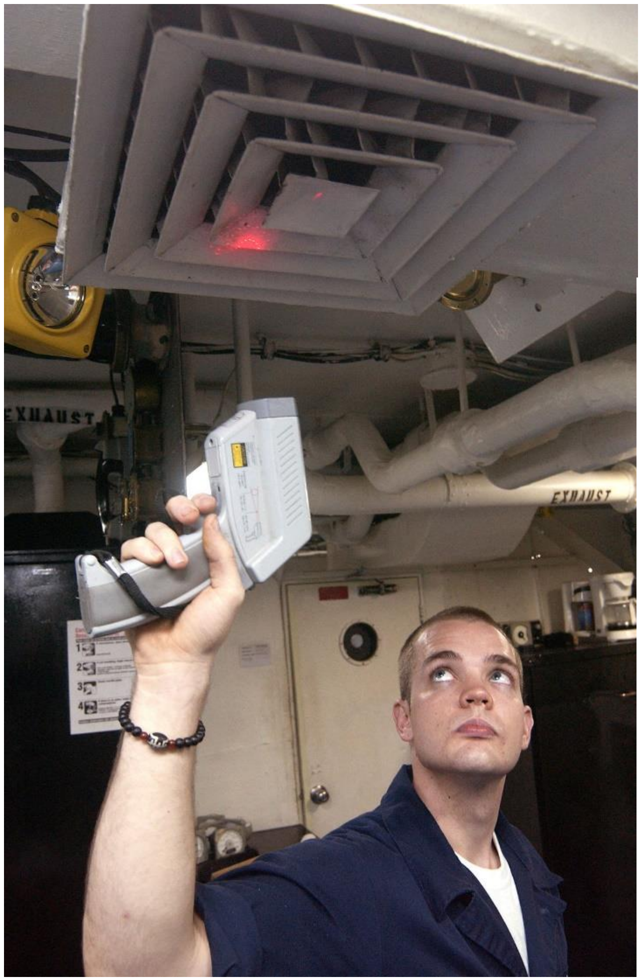
2. A highly corrosive measuring environment may destroy the thermometer
3. How to measure the temperature of a moving object like a missile?
4. How to measure the average temperature, rather than a point temperature?
5. Conduction being a slow process: a fast temperature measurement?

Any Example?



INFRARED THERMOMETER

Measuring distance: 3-5cm
Infrared thermometer
Error range: 32 ℃ -34.9 ℃ ± 0.3 ℃
35 ℃ -42 ℃ ± 0.2 ℃
42.1 ℃ -42.5 ℃ ± 0.3 ℃

Concept behind *Radiation Pyrometer?*

Radiation pyrometry is the method of measuring the temperature of a body by measuring the radiation emitted by it. A radiation thermometer can measure the temperature of an object without physical contact and has many advantages over other contact-type measurement devices. Such a measurement does not contaminate, damage, or interfere with the object being monitored. It can be mounted remotely from the hot target enabling it to operate for long periods of time with minimal maintenance.

Theoretically, all bodies above 0 K emit radiation and hence it is possible to measure temperature of a body by radiation pyrometry at all temperatures. But in practice, the method is applied to measure temperatures above 700°C when

Radiation Fundamentals

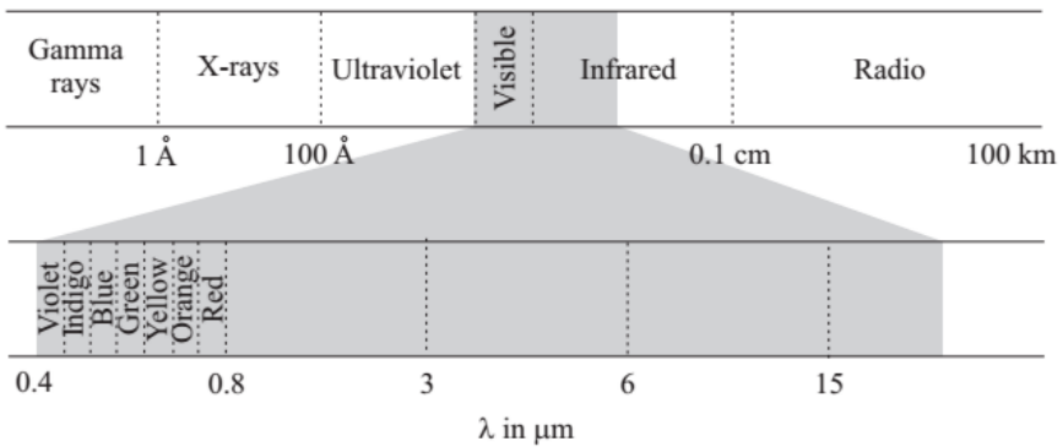
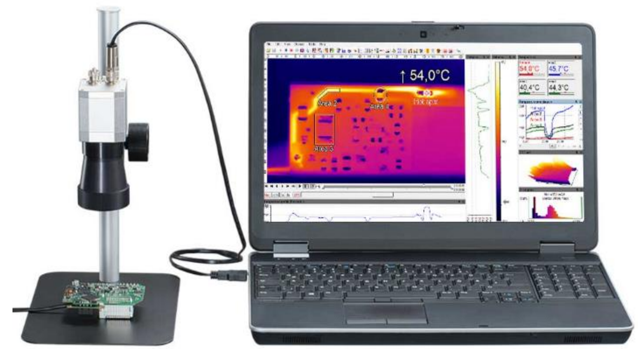


Fig. 10.36 The electromagnetic spectrum (not to scale). The lower part shows the portion of the spectrum that can be used for radiation pyrometry.

Radiation Pyrometer

- All bodies above 0 K emit radiation

- Measuring the temperature of a body by measuring the emitted radiation



Radiation Pyrometer

- All bodies above 0 K emit radiation
- Measuring the temperature of a body by measuring the emitted radiation

- Non-contact measurement
  - Does not contaminate, damage, or interfere with the object being monitored
  - Remotely monitoring the hot target enables it to operate for long periods of time with minimal maintenance

Radiation Pyrometer

- Electromagnetic spectrum
  - any object above 0 K is capable of radiating electromagnetic energy which is propagated through space at the speed of light

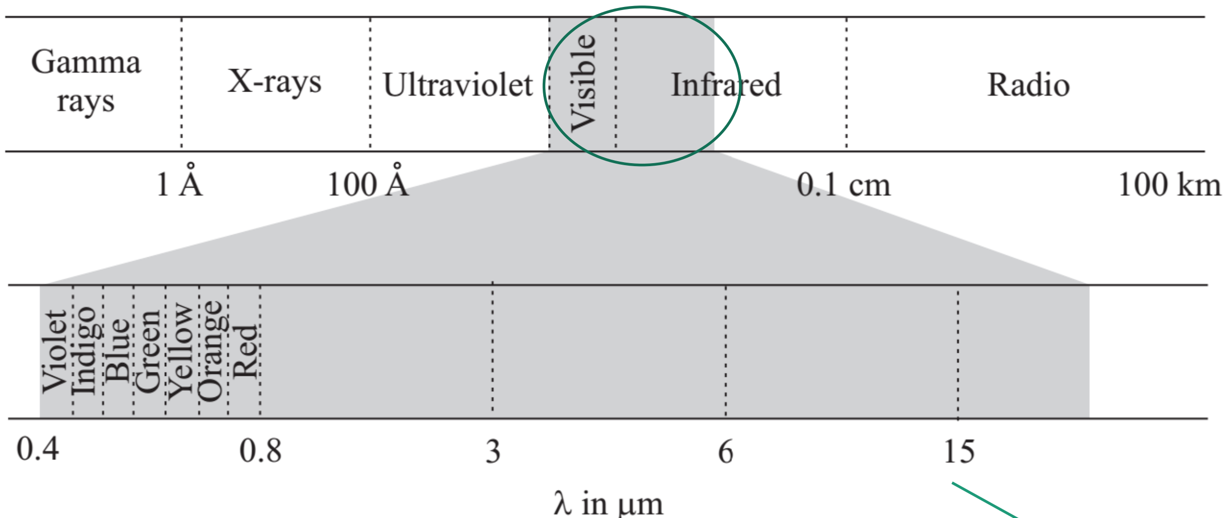


Fig. 10.36 The electromagnetic spectrum (not to scale). The lower part shows the portion of the spectrum that can be used for radiation pyrometry.

- Temperature measurement can be made using wavelength from **0.2 -20 mm**
  - Infrared radiation thermometers/pyrometers: **0.7 μm to 20 μm**

Radiation Pyrometer

- **Detectors for radiation pyrometer**
  - **thermocouple, thermistor,..**
  - **semiconductor photonic devices**
    - **photoconductors, PVs,…**

Photoconductor

- Light-induced increase in the conductivity, an effect exhibited by almost all semiconductors

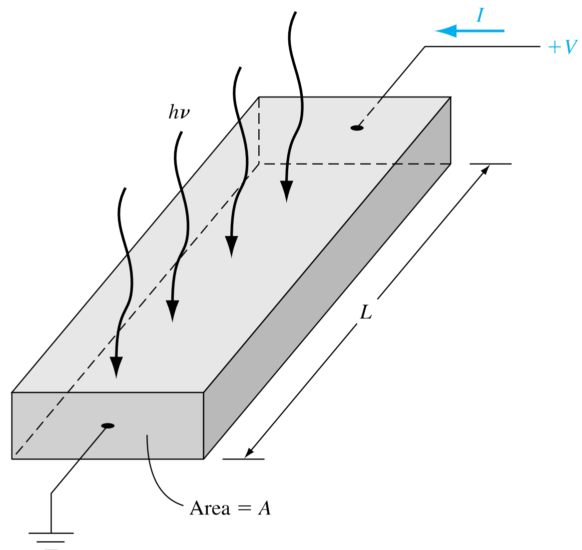


Figure 14.16 | A photoconductor.

- Known as photoresistor, or a photoconductor or sometimes a light dependent resistor (LDR)

Photovoltaic transducer

- The photovoltaic cell is a p–n junction structure where photons absorbed in the depletion layer generate electron-hole pairs
- Due to the local electric field within that layer, the two carriers drift in opposite directions and an electric current is induced in the external circuit**.**

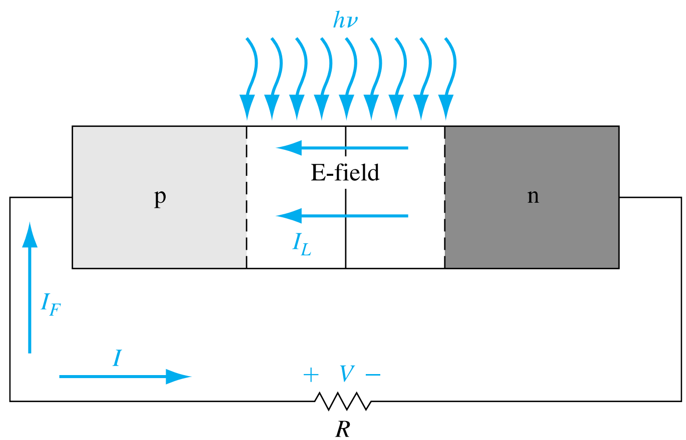


Figure 14.6 | A pn junction solar cell with resistive load.

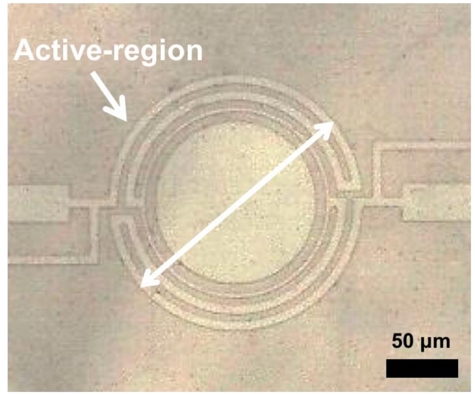
- **Solar cells**

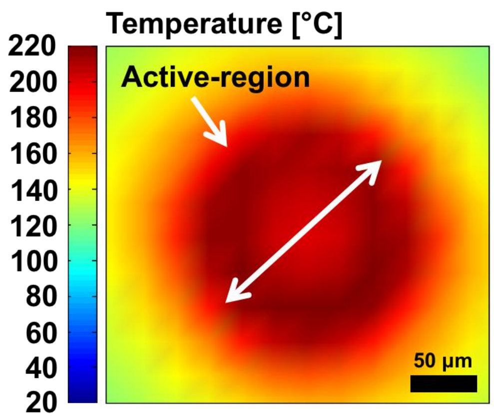
Ref: Semiconductor Physics and Devices: Basic Principles by Donald A. Neamen

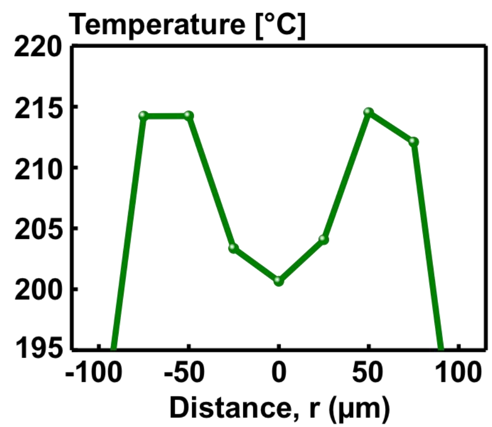
Example: Graphene Microheater

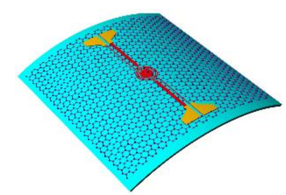
❑ Thermal Characterization

- **Temperature Distribution**









- Circular-symmetric temperature distribution
- Uniform temperature
  - ~15^{o}C temperature difference in active region

- Sens. Actuators B Chem 185 (2013) 274–281.

Queries