CRYOGENIC ENGINEERING

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Lecture No - 39

Earlier Topics

- Introduction to Cryogenic Engineering
- Properties of Cryogenic Fluids
- Properties of Materials at Cryogenic Temperature
- Gas Liquefaction and Refrigeration Systems
- Gas Separation
- Cryocoolers
- Cryogenic Insulations
- Vacuum Technology

Current Topic

Topic : Instrumentation in Cryogenics

- Need of Cryogenic Instrumentation
- Measurement of Thermophysical Properties
- Various Sensors

- The current topic will be covered in 3 lectures.

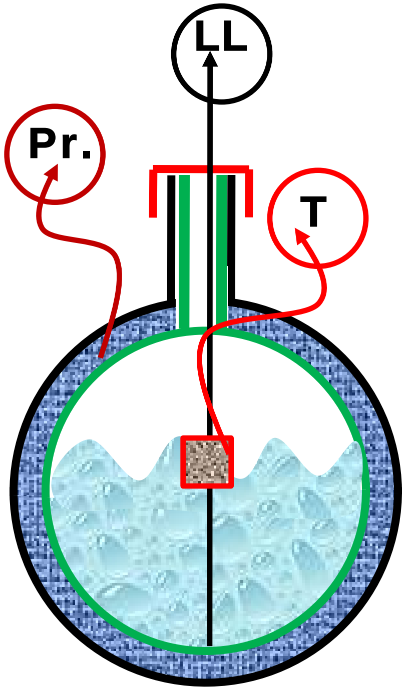
- Tutorials and assignments are also included.

Outline of the Lecture

Topic : Instrumentation in Cryogenics

- Need of Cryogenic Instrumentation
- Measurement of Thermo physical Properties
  - Temperature

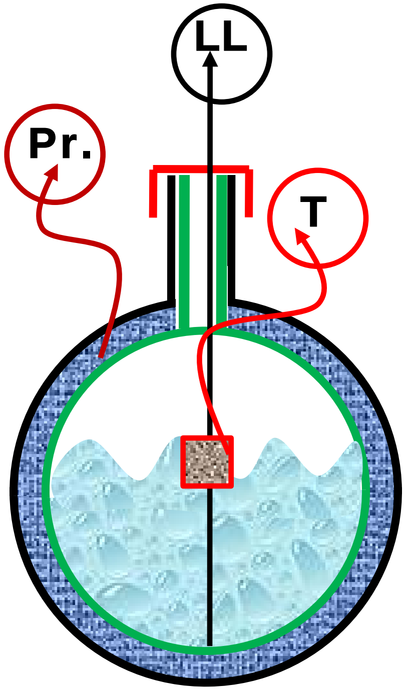
Introduction



- In the earlier lecture, we have seen that the cryogenic vessels are insulated, closed containers.

- Instrumentation is needed
  - To monitor the vacuum in insulation, as there is a continuous gas in leak.
  - To monitor the liquid level so as to avoid any over flow of the cryogen.
  - To monitor a sample's temperature.

Introduction



- This justifies the of instrumentation for a safe Cryogenic operation.
- It is clear that conventional methods like bourdon pressure gauge or thermometer cannot be used due to the following reasons.
  - Working at extremely low temperatures.
  - Sustainability to thermal and mechanical fatigues.
  - Calibration at low temperatures.

Special Requirements

- There are a few special requirements that are to be qualified by the sensors, to use them in Cryogenic Technology. They are

- **Remote Arrangements** : Cryogenic vessels are closed containers. The sensors should be capable of remote operation from outside.

- **Vacuum** : The sensors should be able to withstand low pressures prevalent in vacuum.

- **Cryogen** : The sensors should be chemically inert towards the cryogen under use.

Special Requirements

- **Magnetic Field** : The property of the sensor should be intact even in magnetic atmospheres.

- **Accuracy** : The accuracy, the calibration are very important at such low temperatures.

- **Losses** : The heat release, for example, i^2R losses, conduction via leads should be very low.

- **Material Properties** : Thermal, mechanical properties of sensors must be in allowable limits.

Thermo physical Properties

- There are various thermo physical properties that are measured or monitored in Cryogenics. They are
  - Temperature
  - Liquid Level
  - Pressure
  - Mass Flow Rate
  - Viscosity and Density
  - Electrical and Thermal Conductivity
- In this topic, only the first three properties are covered, which are very important.

Temperature

- The various measuring units of temperature are Kelvin, degree Centigrade, degree Fahrenheit etc.
- The measurement of temperature is based on zeroth law of thermodynamics. It states that when two bodies are in thermal equilibrium, they are at the same temperature.
- Temperature is measured to monitor thermal expansion and most importantly pressure rise.
- The calibration of a temperature sensor is done using some fixed points.

Temperature Scales

- The international temperature scale is defined up to the triple point of $\mathbf{H_2}$. Its value is **13.84 K**.
- Recently, various scales are developed to measure much lower temperatures.
- Germanium Resistance Thermometer – **4.2 K** to **13.84 K**.
- He^4 Vapor Pressure Scale – **1.5 K** to **4.24 K**. It was invented in 1958 and it is often called as T_{58} (He^4).

Temperature Scales

- He^3 Vapor Pressure Scale – **0.8 K** to **1.5 K**. This scale is also called as T_{62} (He^3).

- For the temperatures between **0.006 K** to **0.8 K**, the scale is based on the properties of Cerium magnesium nitrate (salt).

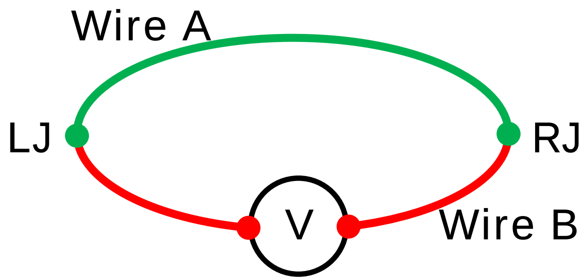
- The variations in magnetic susceptibility of this salt are calibrated in terms of temperature.

Temperature Measurement

- Various sensors that are often used in Cryogenics to measure temperature are
  - Thermocouples
  - Metallic Resistance Thermometer
  - Semiconductor Resistance Thermometer
  - Constant Volume Gas Thermometer
  - Vapor Pressure Thermometer
  - Magnetic Thermometer

Thermocouple

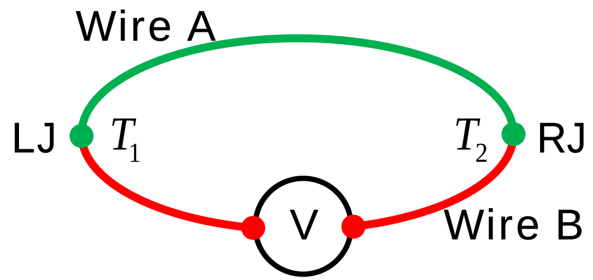
- Consider two conducting wires of different materials, **A** and **B**.



- These metal wires are joined together as shown above.

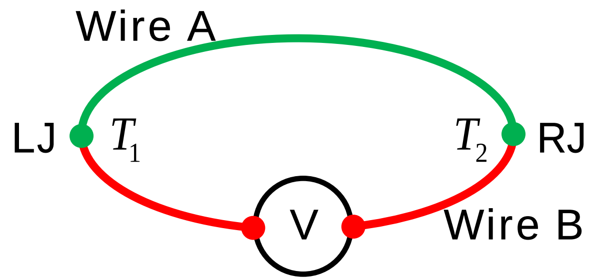
- The left and right joints are **LJ** and **RJ** respectively. A voltmeter **V** is in series with wire **B**.

Thermocouple



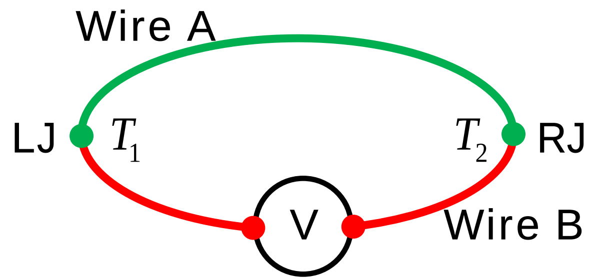
- Consider a situation, in which left and right joints are maintained at $\mathbf{T_1}$ and $\mathbf{T_2}$ respectively. ($\mathbf{T_1 \neq T_2}$)
- Due to the temperature difference, a net voltage or an electromotive force is developed in the loop. This is called as **Seebeck** effect.
- It is named after a German physicist, Thomas Johann Seebeck (1821).

Thermocouple



- The voltage (**e**, mV) is directly proportional to the temperature difference (**t**, ºC).
- Mathematically, we have $e = f(t)$
- Rearranging, we can also expresses it as $t = g(e)$
- Here, **f** and **g** are some functional correlations.

Thermocouple



- In practice, reference point like ambient temperature or ice point is maintained at left end.
- The temperature at the right end is calculated using the functional correlations.
- These functional correlations are also dependent on wire materials, wire dimensions and reference point.

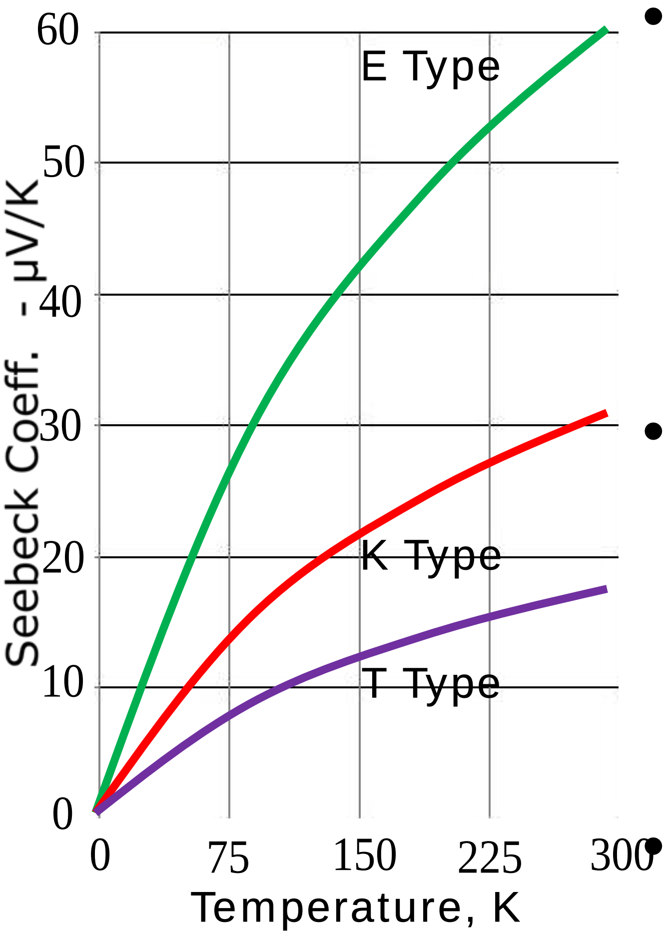
Thermocouple

- Some approximate values for different types of thermocouples are as given below.
- **T type**
  - Cu and Cu – Ni alloy (Copper – Constantan).
  - Range : 3 K to 673 K.
  - Sensitivity : 4.6 μV/K at 20 K.
- **K type**
  - Ni – Cr and Ni – Al alloys (Chromel – Alumel).
  - Range : 3 K to 1543 K.
  - Sensitivity : 4.1 μV/K at 20 K.

Thermocouple

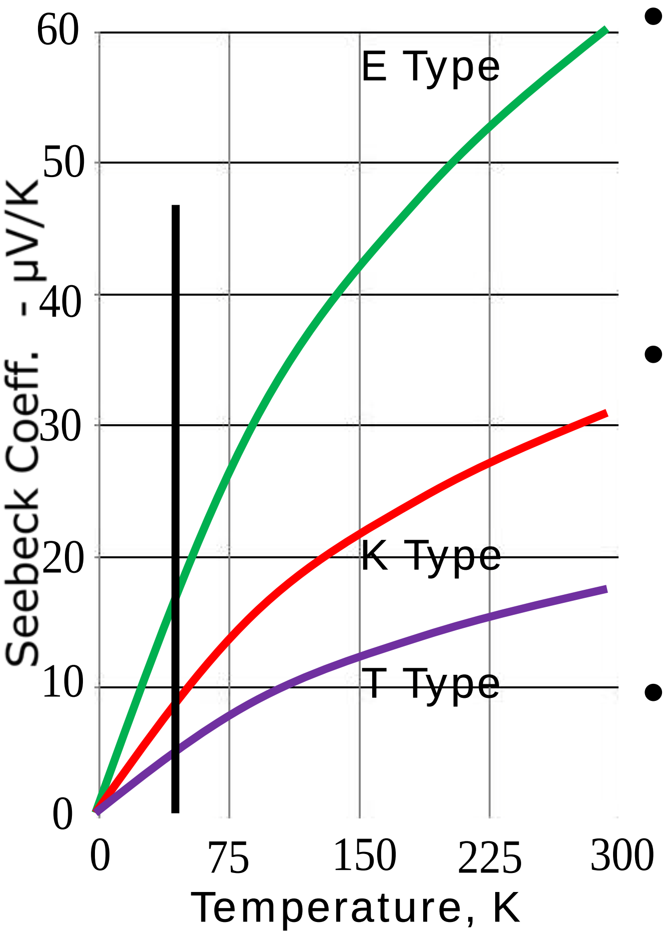
- The different types of thermocouples in use are
- **E type**
  - Ni – Cr and Cu – Ni alloys (Chromel – Constantan).
  - Range : 3 K to 953 K.
  - Sensitivity : 68 μV/K at 20 K.
  - This combination produces the highest Seebeck effect.

Thermocouple



- The adjacent figure shows the variation of Seebeck coefficient with temperature for **E**, **K** and **T** type thermocouples.
- For any given temperature, **E** type thermocouple has more Seebeck coefficient than **T** type thermocouple.
- It is important to note that the sensor should have maximum coefficient for greater accuracy.

Thermocouple



- Hence, **E** type thermocouple has more accuracy than the **T** type thermocouple.

- From the figure, it is clear that for the temperatures below **50 K**, the curves are steep.

- It is undesirable to use these sensors in this temperature range.

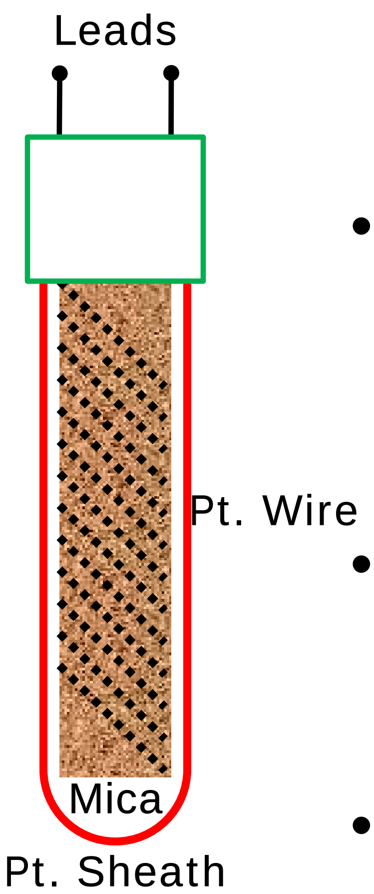
Thermocouple

- The disadvantages of a thermocouple are
  - The emf or the voltage generated is very small, typically in the order of milli volts. A series combination of various thermocouples is used.
  - The voltage drop across the length of the lead wires induces substantial error in measurement.
  - The thermal conduction along the lead wires contribute to the heat in leak.

Resistance Temp. Detectors

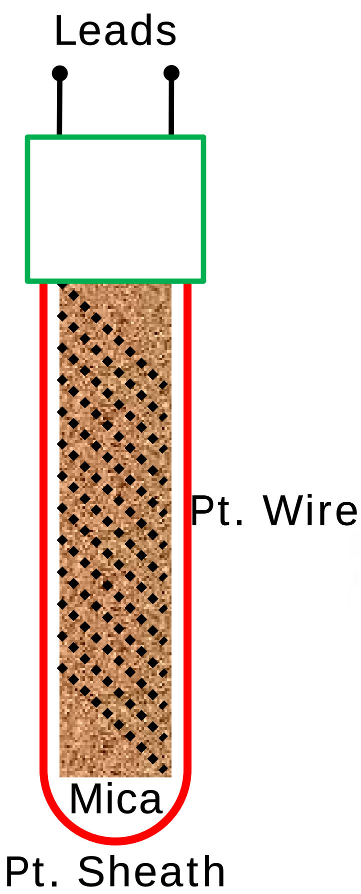
- Resistance of a conductor or a semi conductor changes with the change in temperature.
- Resistance Temperature Detectors, also called as RTDs, use this property to measure the temperature.
- Platinum, copper, lead or indium wires are used in metallic RTDs.
- Non metallic RTDs use GaAlAs diodes, Carbon glass and Ruthenium Oxide.

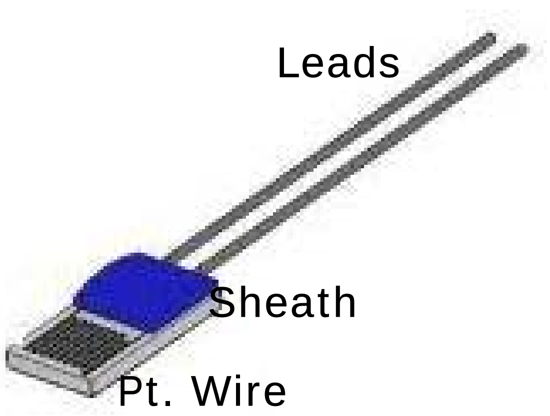
Resistance Temp. Detectors



- The schematic of a Platinum RTD is as shown in the figure.
- A conducting wire, say a platinum wire, of very long length is wound on a notched mica insulator.
- This assembly is housed inside a closed platinum sheath.
- An ohm meter is used to measure the resistance, thereby, the corresponding temperature.

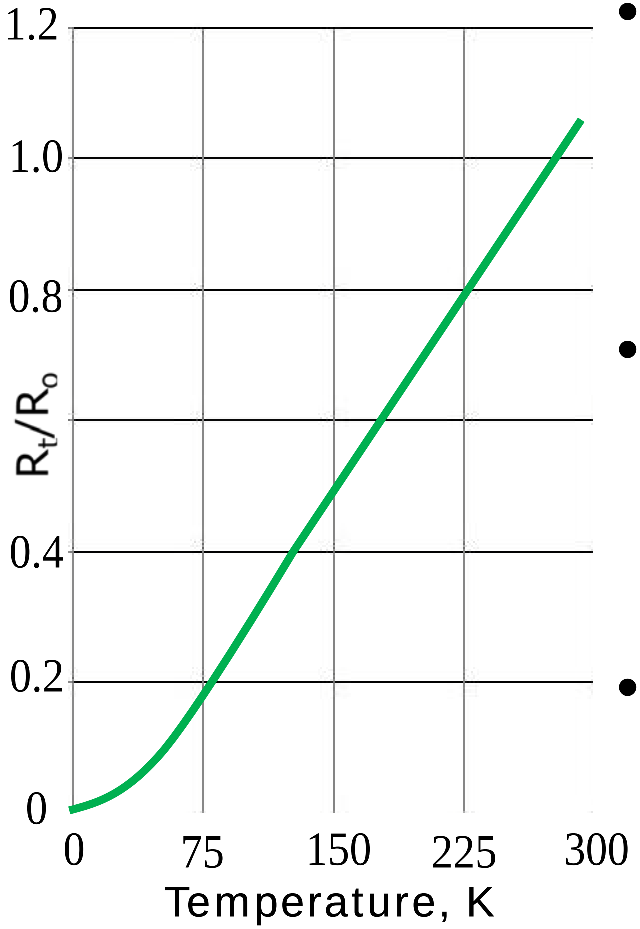
Resistance Temp. Detectors





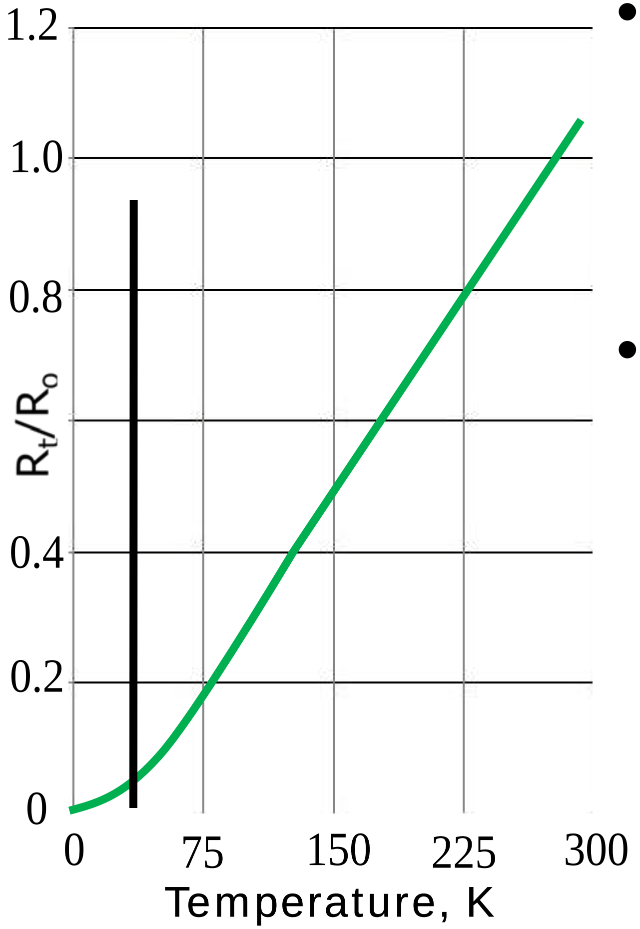
- The photograph of a RTD is as shown.
- The typical size of a RTD is 3 mm x 1.84 mm x 0.98 mm.

Resistance Temp. Detectors



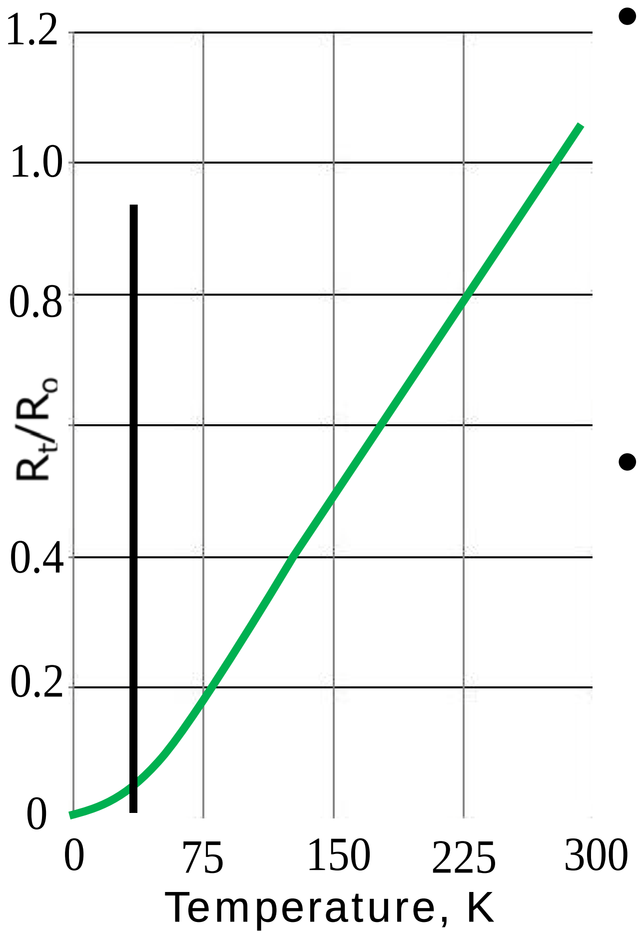
- The choice of the wire material is dependent on the variation of resistance with temperature.
- The adjacent figure shows the variation of $\mathbf{R_t / R_o}$ with the temperature.
- Here, $\mathbf{R_t}$ and $\mathbf{R_o}$ are the resistances at temperatures **T°C** and **0°C** respectively.

Resistance Temp. Detectors



- It is desirable to choose a material whose resistance varies linearly with temperature.
- From the adjacent figure, it is clear that the sensor is most preferred up to **30 K**, due to its linear variation.

Resistance Temp. Detectors

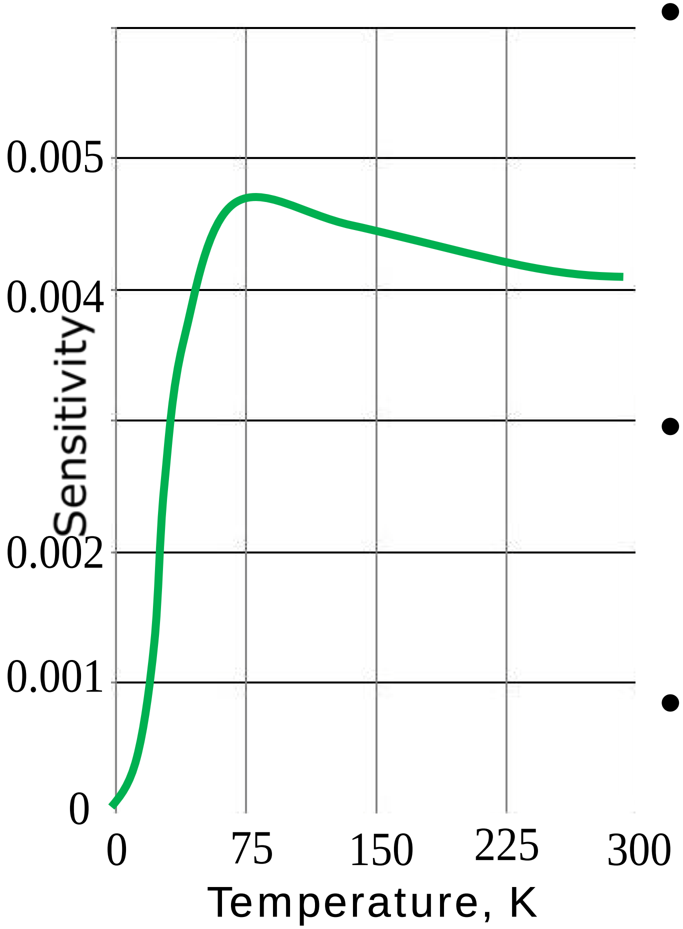


- The correlation for the adjacent graph is

$$\frac{R_t}{R_o} = 1 + At + Bt^2 + Ct^3\left(t - 100\right)$$

- The constants **A**, **B**, **C** are found by calibration of RTD at any three standard temperatures.

Resistance Temp. Detectors



- The term Sensitivity is defined as the rate of change of electrical resistance with the change in temperature.
- Mathematically, it is expressed as

$$S = \frac{dR}{dT}$$

- The adjacent figure shows the sensitivity of a Platinum resistance thermometer.

Resistance Temp. Detectors

- The advantages of a RTD are
  - These sensors exhibit a very high repeatability and accuracy in their operating range.
  - Few typical values are
    - Repeatability : ±10 mK in **77 K** to **305 K**.
    - Accuracy : ±250 mK in **77 K** to **305 K**.
  - The effect of magnetic field is very low for the operating temperatures above **40 K**.

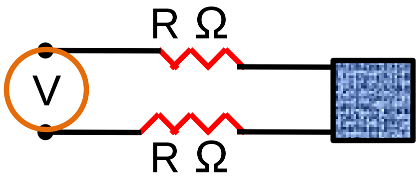
Resistance Temp. Detectors

- It is important to note that, proper care has to be taken while mounting a RTD.
- The unwanted mechanical and thermal strains causes a change in the electrical resistance.
- These changes induce error in the measurement.

Resistance Temp. Detectors

- The effect of lead wire resistance is very crucial in the accuracy of a RTD.
- In order to minimize this error, two different wiring arrangements are used.
- They are,
  - Two wire arrangement
  - Four wire arrangement

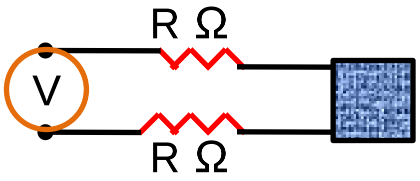
Resistance Temp. Detectors



- The schematic of a Two wire arrangement is as shown.
- Let the resistance of each of the lead wires be **R** ohms.
- The ohmmeter **V**, across the ends of lead wires, measures the combined resistance of RTD + leads.
- It is clear that this extra lead wire resistance is the direct error in measurement.

Resistance Temp. Detectors

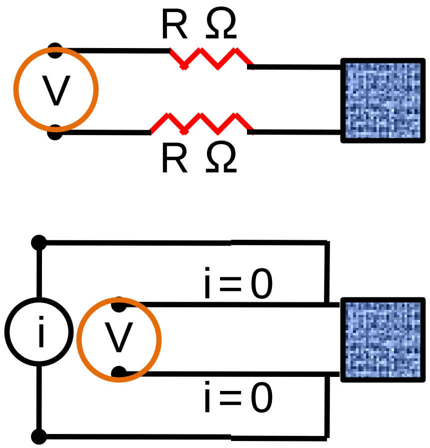
- Hence, the lead wire resistance should be as low as possible.



- In such arrangements, wires of short length are used to minimize the resistance.

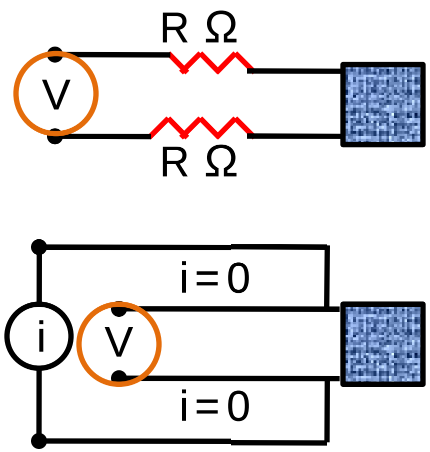
Resistance Temp. Detectors

- The schematic of a Four wire arrangement is as shown.



- An external constant current source (**i**), typically in mA, is used to power the RTD.
- The measurement leads are connected in parallel across the RTD.
- In this arrangement, the current flowing across the measuring leads is negligibly small.

Resistance Temp. Detectors



- The current being negligibly small, the voltage drop offered is also very small.
- The output of the sensor, either voltage drop or resistance is directly proportional to the RTD resistance.
- Therefore, the reading of the sensor is insensitive to lead resistance.

Resistance Temp. Detectors

- Some of the commonly used metallic RTDs are
  - PT 100
  - PT 1000
- PT 100 implies the sensor has 100 ohms resistance at 0^oC.

Summary

- In Cryogenics, there is a need to monitor various properties like pressure, temperature, liquid level, etc for safe operation.

- Thermocouple works on Seebeck effect.

- Different types of thermocouples are
  - **T type** : Cu and Cu – Ni alloy, 3 to 673 K.
  - **K type** : Ni – Cr and Ni – Al alloys, 3 to 1543 K.
  - **E type** : Ni – Cr and Cu – Ni alloys, 3 to 953 K.

Summary

- PT 100, PT 1000 are some of the commonly used RTDs in Cryogenics.

- In order to minimize errors due to lead resistance, Four wire arrangement is preferred over Two wire arrangement.

- A self assessment exercise is given after this slide.

- Kindly asses yourself for this lecture.

Self Assessment

1. Cryogenic Instrumentation should be capable of ____ operation from outside.
2. The heat release in sensors is due to ___ .
3. Measurement of temperature is based on ___ of thermodynamics.
4. Thermocouple works on _______ effect.
5. The Seebeck effect is highest for ______ type.
6. Resistance of a conductor ____ with a decrease in temperature.
7. RTDs are preferred upto ___, due to linear variation.
8. Errors are less in ____ arrangement, as compared to Two wire arrangement.

Answers

1. Remote
2. i^2R losses
3. Zeroth law
4. Seebeck
5. E
6. Decreases
7. 30 K
8. Four wire

Thank You!