CRYOGENIC ENGINEERING

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Lecture No - 40

Earlier Lecture

- In the earlier lecture, we have seen the importance of instrumentation in Cryogenic Engineering.
- Various properties like pressure, temperature, liquid level, etc are monitored for safe operation.
- We discussed about the thermocouples and the metallic RTDs in the previous lecture.
- **T**, **K**, **E** are the different types of thermocouples. **PT 100**, **PT 1000** are some of the commonly used RTDs in Cryogenics.

Outline of the Lecture

Topic : Instrumentation in Cryogenics

- Measurement of Thermo physical Properties
  - Temperature (continued)

- Measurement of Liquid level

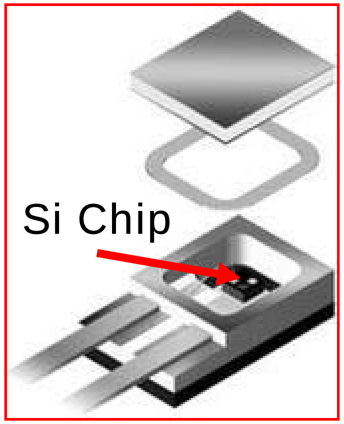
Introduction

- In the earlier lecture, we have seen a metallic RTD, in which, the resistance of a conductor changes with temperature.
- Similarly, non – metallic sensors like silicon diode, Cernox and Ruthenium Oxide exhibit this property.
- A diode is a two terminal electronic component, which is most commonly made of silicon.
- The **i – V** variation of a diode can be changed by adding impurities or dopants like germanium, arsenic etc.

Introduction

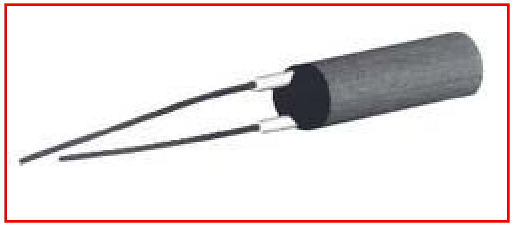
- In these sensors, a constant current supply, typically in micro amps, is fed across the sensor.
- With the decrease in temperature, the resistance of the device increases.
- It is important to note that, this property is in reverse to the characteristic of a metallic RTD.
- This resistance change is calibrated against the temperature change.

Non – metallic Sensors



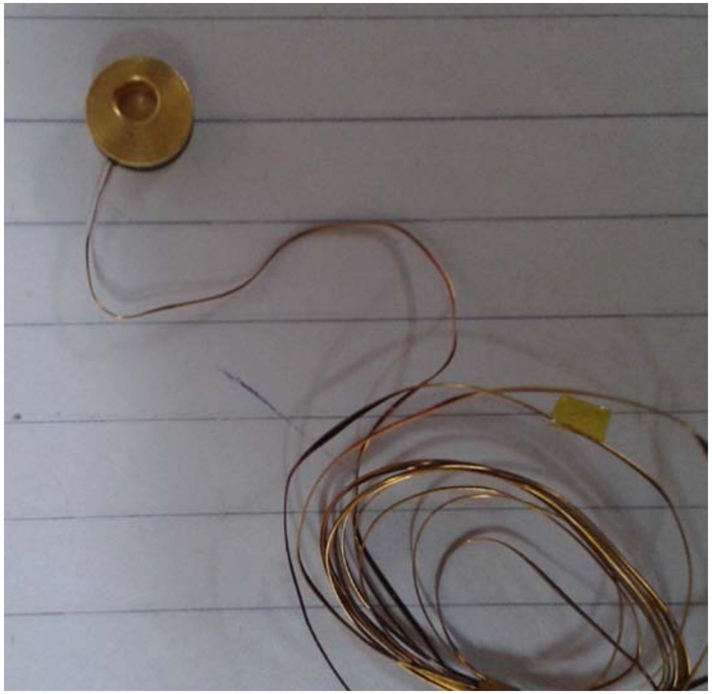
- Few of the commonly used non – metallic sensors are
  - Silicon Diodes – The sensor consists of a small silicon chip with a repeatable resistance – temperature property.
  - Cernox – Cernox is a sputter deposited thin film resistor. Cernox is the trade name for zirconium oxynitride, manufactured by Lake Shore, USA.

Non – metallic Sensors



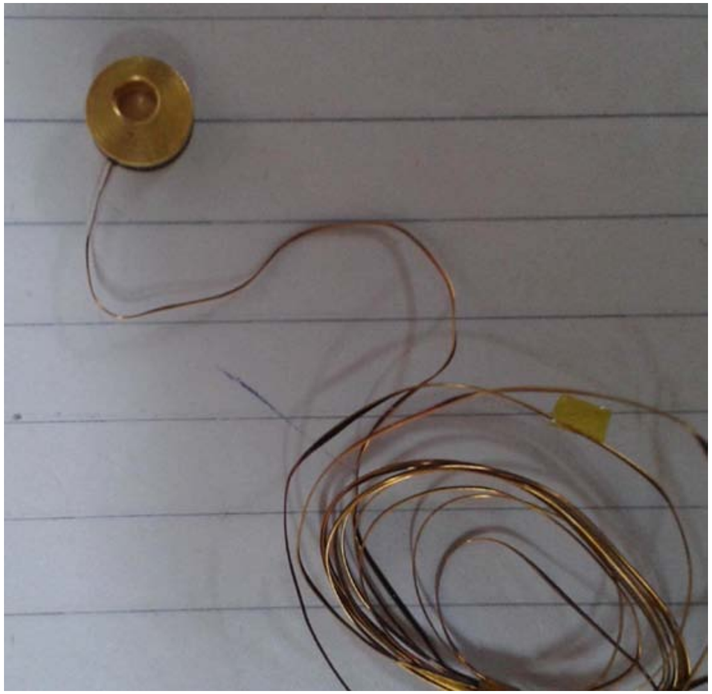
- Ruthenium Oxide – It is a thick film resistor which is widely used in magnetic field applications.

Silicon Diodes



- The adjacent photograph shows a casing which houses the silicon diode.
- The packing is a ceramic, hermetically sealed casing with the lowest self heating errors.
- The casing is designed to withstand the mechanical fatigue, occurring due to the temperature change.

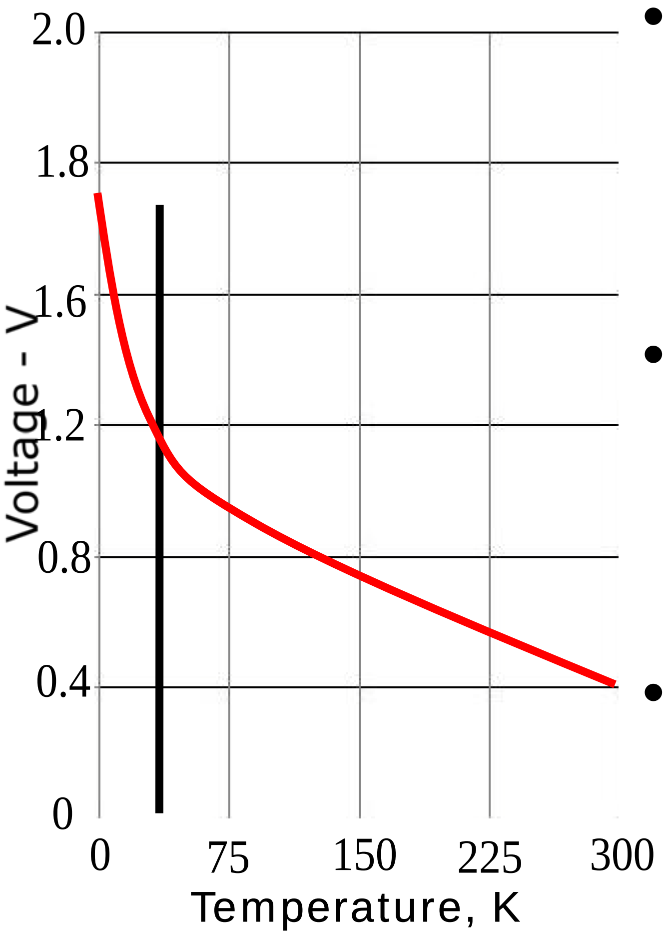
Silicon Diodes



- The four wire connection is recommended for accurate sensor readings.

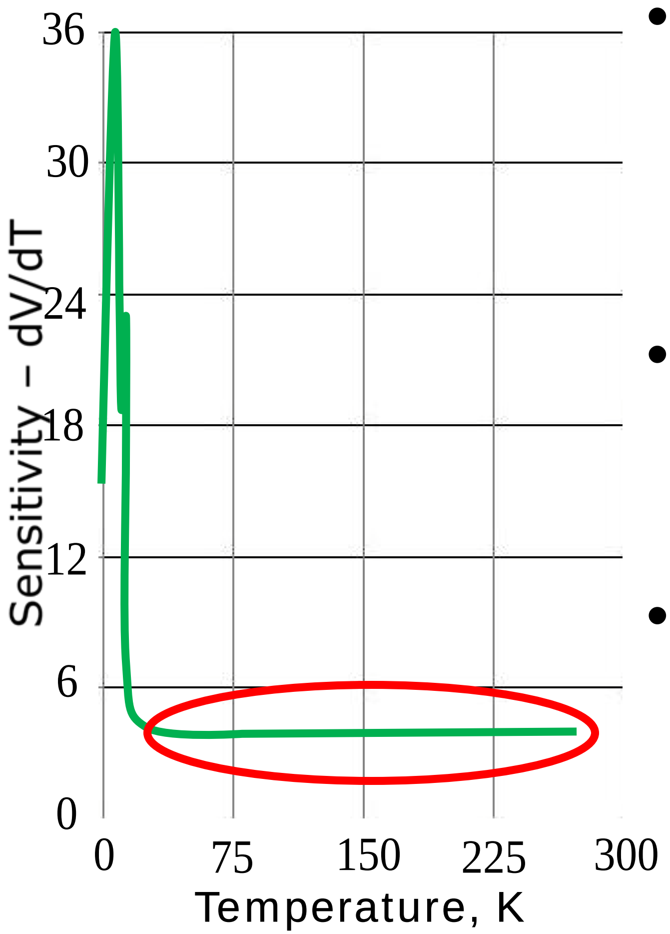
- Very often, these sensors are provided with signal conditioner and display/temperature controller.

Silicon Diodes



- The adjacent figure shows the variation of voltage with temperature for a silicon diode.
- It is clear that the gradient of the curve is very steep for temperatures below **30 K**.
- Therefore, it is most preferred in this range for its good accuracy.

Silicon Diodes



- The figure shows the variation of sensitivity (**dV/dT**) with temperature for a silicon diode.
- The sensitivity remains constant up to **30 K**.
- It increases with the decrease in temperature, below **30 K**. Hence, it is most preferred for low temperatures.

Silicon Diodes

- The following table gives some of its properties.

Specifications	
Range	1.4 K to 475 K
Excitation Current	10μA ±0.1 %
Repeatability	10mK @ 4.2K 16mK @ 77K 75mK @ 273K
Accuracy	±50mK or better
Sensitivity	-33.6 mV/K @ 4.2 K -1.91 mV/K @ 77 K

Silicon Diodes

- The advantages of a silicon diode are
  - The activation current is in the order of **μA**. The **i^2R** losses are negligibly small.
  - It exhibits a linear response over the entire operating range with repeatability and accuracy.
- The disadvantages of a silicon diode are
  - Errors are induced in magnetic fields and these diodes are very costly.

Price (INR)	
Calibrated	39,000
Non – calibrated	20,000

Cernox

- As mentioned earlier, Cernox is a thin film RTD. It is manufactured by Lake Shore, USA.

- It exhibits a good temperature sensitivity over a wide range of operating temperatures.

- One of the most important characteristics of this sensor is its accuracy in magnetic fields. Also, these sensors exhibit a fast response time at low temperatures.

- Cernox are packaged in a robust, hermetically sealed casing similar to silicon diodes.

Cernox

- The following table gives some of its properties.

Specifications	
Range	0.3 K to 325 K
Excitation	10 µA
Accuracy	±5mK @ 10 K
Repeatability	±3 mK at 4.2 K

Cernox

- The advantages of a Cernox are
  - These RTDs offer excellent stability over the entire operating range.
  - Similar to silicon diodes, Cernox exhibits a linear response for temperatures.
  - Cernox diodes are not affected by the magnetic field.

Non – metallic Sensors

- The three important differences between a non – metal and a pure metal sensor are
  - **Sensitivity** : Sensitivity of a non – metal sensor is more than pure metal at any temperature.
  - **Temperature Coefficient** : The coefficient of temperature resistivity of a non – metal sensor is negative, whereas that of pure metal is positive.
  - **Resistivity** of a non – metal sensor is very high. As a result, a non – metal sensor has a small length and relatively a large area.

A Comparison

Silicon Diode	
Range	1.4 K to 475 K
Excitation	10μA ±0.1 %
Accuracy	±50mK or better
Repeatability	10mK @ 4.2K

Cernox	
Range	0.3 K to 325 K
Excitation	10 μA
Accuracy	±5mK @ 10 K
Repeatability	±3 mK at 4.2 K

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.

Liquid Level Measurement

- It is important to monitor the liquid level in a closed cryogenic container
  - To avoid the overflow of cryogen.
  - To know the amount of cryogen at any time.
- Various electronic measuring devices/techniques are available in order to monitor the liquid level.
- The level of liquid inside a container is often expressed as the percentage of the total volume.

Liquid Level Measurement

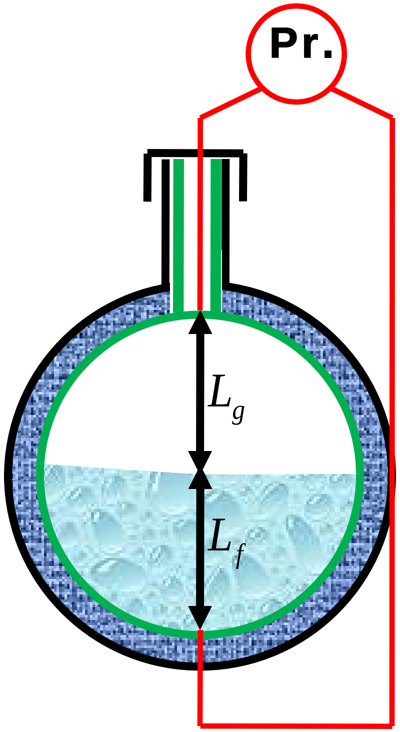
- The electronic measuring devices/techniques that are used in Cryogenics are

  - Dipstick (old technique)
  - Hydrostatic gauge
  - Electric Resistance gauge
  - Capacitance liquid gauge
  - Thermodynamic liquid level gauge
  - Superconducting LHe level gauge

Dip Stick Technique

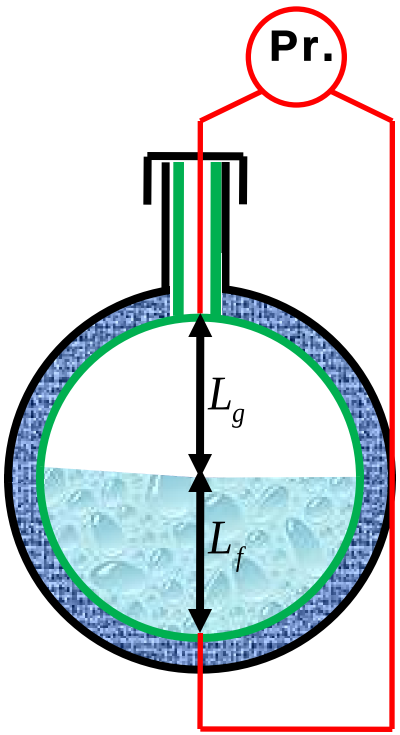
- It is one of the oldest and a simplest way to check the liquid level.
- A bubbling sound or a boil off is the indication, when a thin open tube is dipped into the liquid.
- The following video demonstrates this technique for liquid nitrogen.

Hydrostatic Gauge



- Consider a closed cryogenic vessel as shown in the figure.
- Let $\mathbf{L_f}$ and $\mathbf{L_g}$ be the heights of liquid and gas columns respectively. We have, $\mathbf{L = L_f + L_g}$.
- Pressure tapings are provided at top and bottom of the vessel as shown.
- The tapings are connected across a differential pressure measurement device.

Hydrostatic Gauge



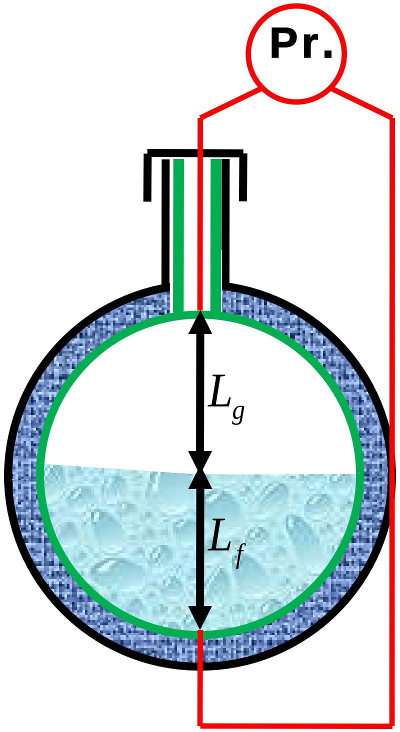
- As the name suggests, the hydrostatic differential pressure is calibrated in terms of the liquid level.
- Therefore, the pressure difference (**Δp**) can be written as

$$\Delta p = \rho_f L_f g + \rho_g \boxed{L_g} g$$

- Using $\mathbf{L = L_f + \boxed{L_g}}$, the above equation can be rearranged as

$$\Delta p = \left(\rho_f - \rho_g\right) L_f g + \rho_g L g$$

Hydrostatic Gauge



- The density of vapor is negligible as compared to that of liquid.

- Therefore, we have

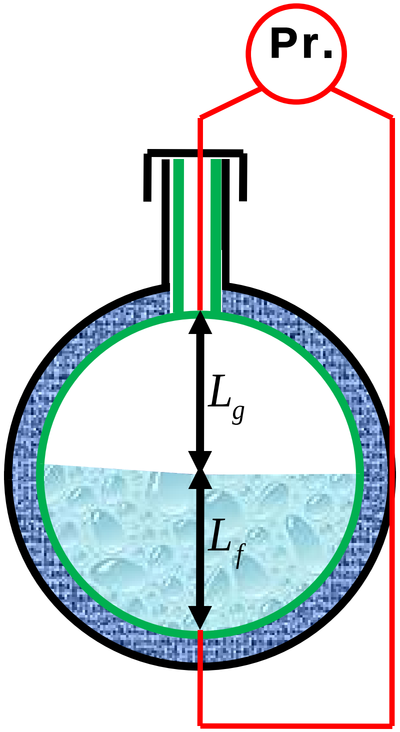
$$\Delta p = \left(\rho_f - \cancel{\rho_g}\right) L_f g + \cancel{\rho_g} L g$$

$$\Delta p = \rho_f L_f g$$

$$L_f = \frac{\Delta p}{\rho_f g} \qquad L_f \propto \Delta p$$

- The pressure gauge is directly calibrated in terms of height of liquid.

Hydrostatic Gauge

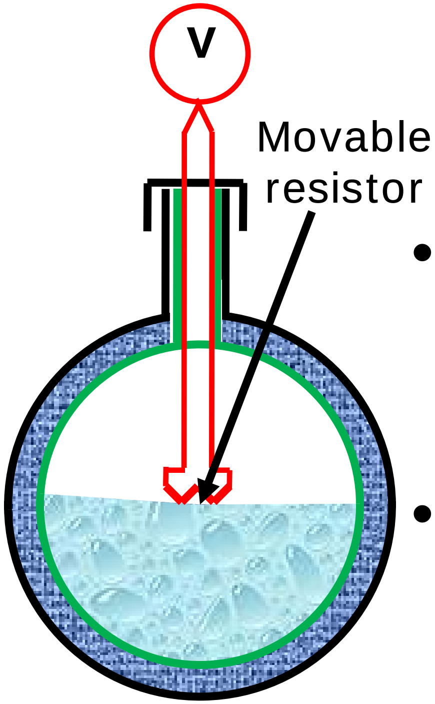


- The sensitivity of this gauge is directly proportional to the difference in liquid and vapor densities.

Densities (kg / m³)	
Nitrogen	$\rho_L = 808$, $\rho_g = 4.65$
Hydrogen	$\rho_L = 70.8$, $\rho_g = 1.33$
Helium	$\rho_L = 124.8$, $\rho_g = 16.7$

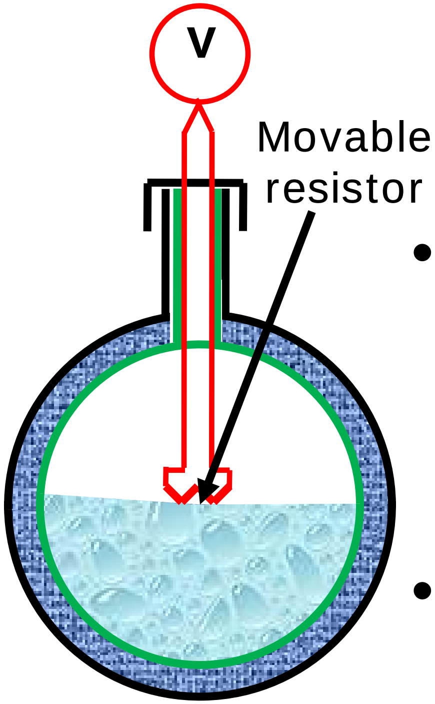
- In the case of $\mathbf{H_2}$ and **He**, $\boldsymbol{\rho_g}$ cannot be neglected in comparison to $\boldsymbol{\rho_L}$. Hence, these gauges cannot be used.

Elec. Rest. Gauge (Movable)



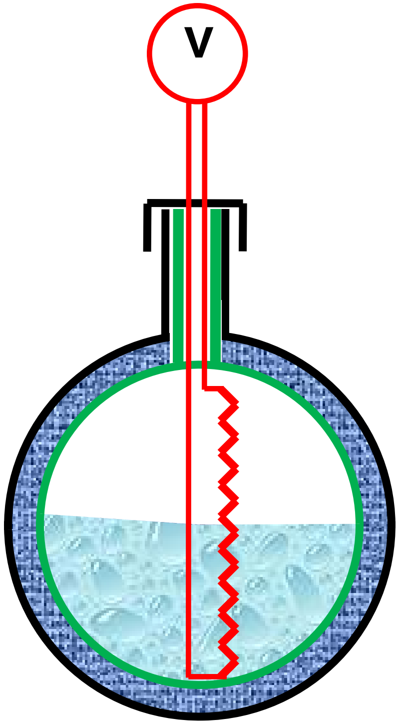
- The schematic of a movable electrical resistance gauge is as shown in figure.
- In this arrangement, a movable resistor is connected across a voltmeter.
- This movable resistance element is heated by using a very small current.
- It is clear that the wire temperature is high, when it is above the liquid level.

Elec. Rest. Gauge (Movable)



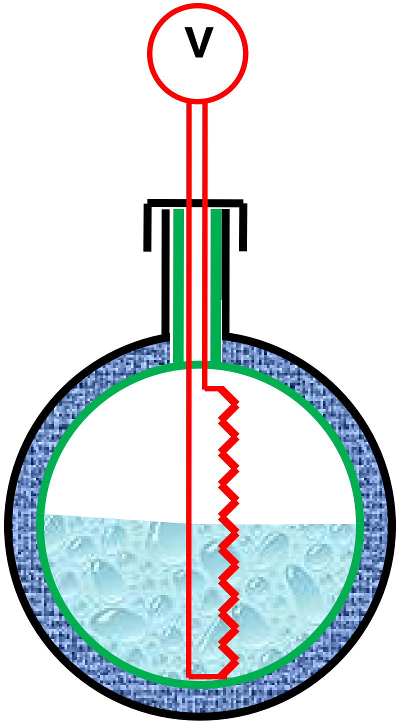
- The heat transfer coefficient of the liquid is nearly twice that of vapor.
- As a result, when the wire is dipped into the liquid, the temperature of the wire drops momentarily.
- The electrical resistance, thereby the voltmeter reading, undergoes a sudden change.
- This sudden change is the indication of the liquid vapor interface.

Elec. Rest. Gauge (Immovable)



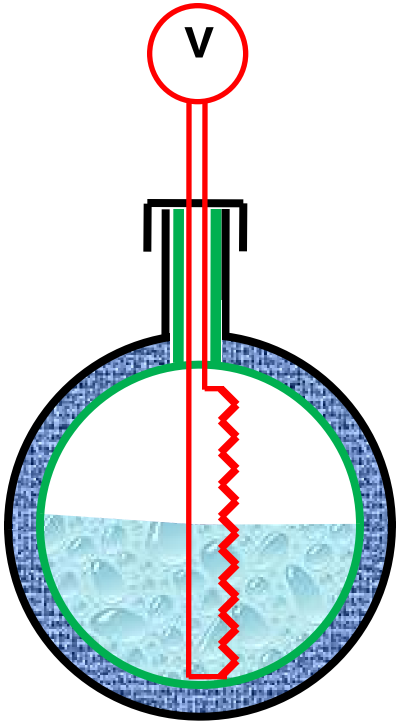
- This method was first devised by Wexler and Cox in the year 1956.
- Unlike in the earlier arrangement, this arrangement has a fixed resistor along the total height of the container.
- The resistor is connected across a voltmeter as shown in the figure.
- The resistance element is fed by a very small current.

Elec. Rest. Gauge (Immovable)



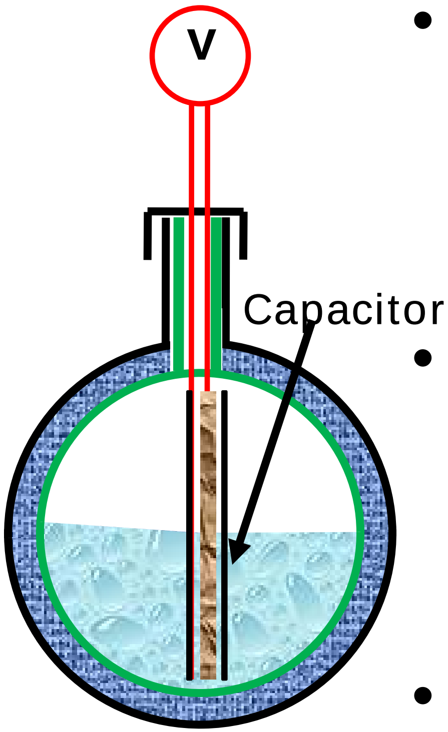
- With the change in the level of the liquid, the resistance of the wire changes.
- This change in resistance, thereby the change in voltmeter reading, is calibrated as a function of liquid level.

Elec. Rest. Gauge (Immovable)



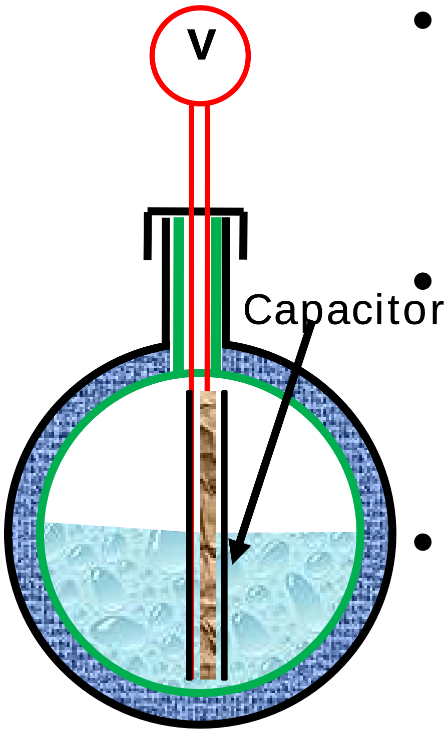
- The advantages are
  - The system does not involve any moving components.
  - The gauge has a continuous indication of liquid level.
- The disadvantage is
  - Continuous energy is dissipated leading to excess boil – off.

Capacitance Liquid Gauge



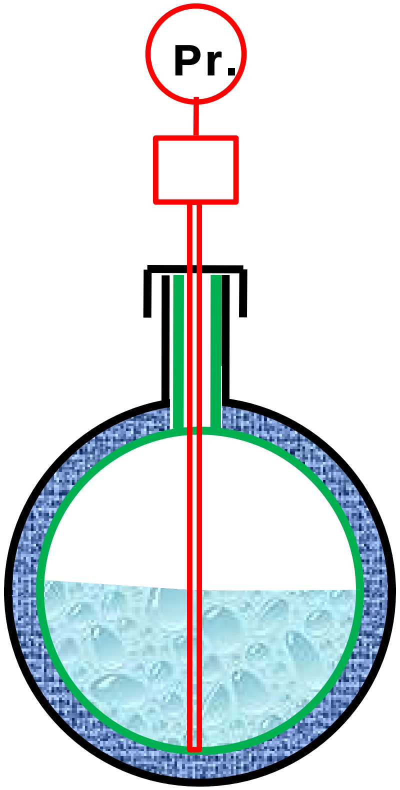
- In this arrangement, the level probe consists of two concentric cylindrical electrodes, placed vertically as shown.
- The dielectric constants of liquid and vapor are different. Let them be denoted by $\mathbf{C_f}$ and $\mathbf{C_g}$ respectively.
- The net capacitance ($\mathbf{C_{Net}}$) is a function of $\mathbf{C_f}$ and $\mathbf{C_g}$, which, in turn are functions of liquid and vapor heights.

Capacitance Liquid Gauge



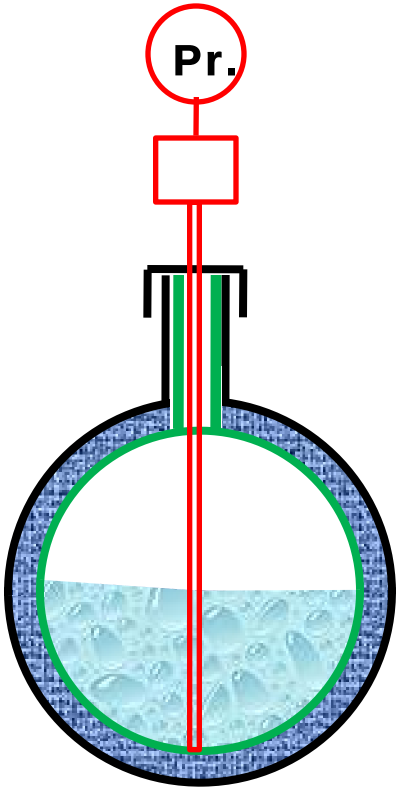
- With the change in liquid level, the net capacitance (C_{Net}) changes.
- This property is used to calibrate the liquid level inside the vessel.
- The advantages are
  - The system does not involve any moving components.
  - The gauge has a continuous indication of liquid level.

Thermodynamic Liquid Gauge



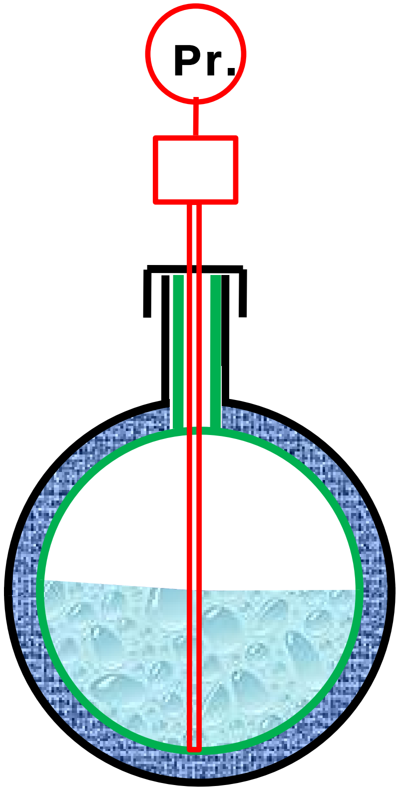
- The schematic of a thermodynamic level gauge is as shown in the figure.
- It works on a principle that liquid undergoes a large change in the volume, when it is evaporated.
- The probe consists of a thin capillary tube and a pressure gauge via a buffer volume.

Thermodynamic Liquid Gauge



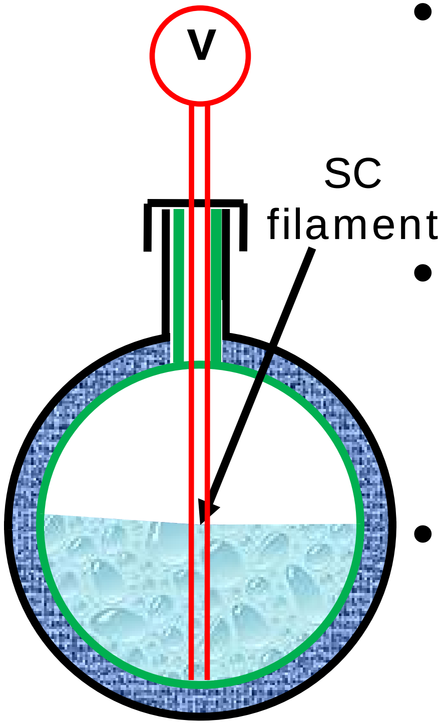
- The capillary is attached to a pressure gauge through a dead volume at an ambient temperature.
- The gauge is charged with a measured amount of gas of the same type, as that in the storage vessel.
- As the capillary tube is immersed into the liquid, the gas in the immersed portion of the tube is condensed.

Thermodynamic Liquid Gauge



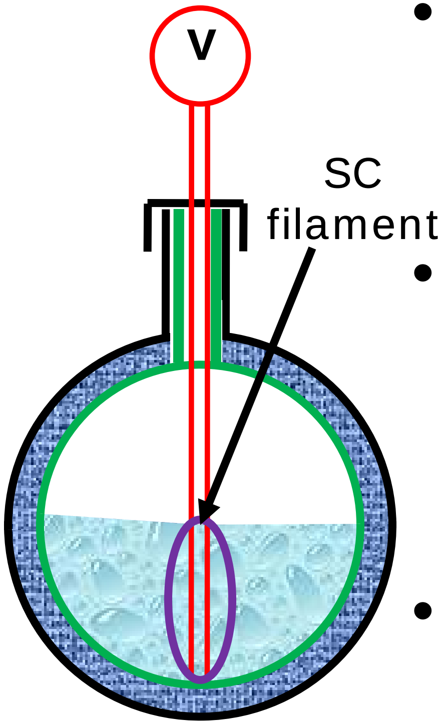
- The change in the volume of the gas during condensation reduces the gas pressure within the capillary and the dead volume.
- This drop in pressure is used as an indication of the liquid level inside the container.

SC LHe level gauge



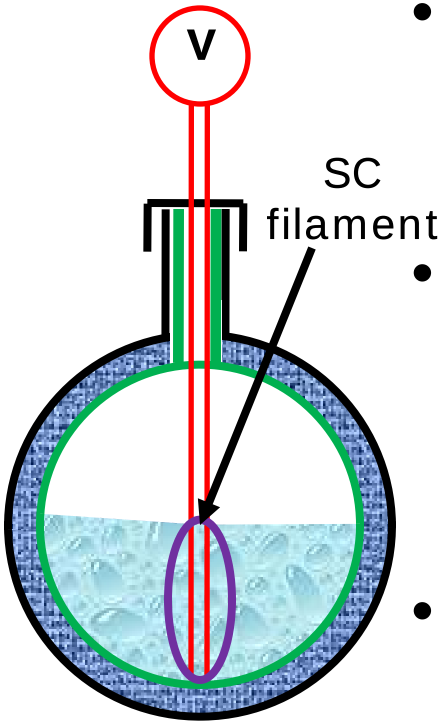
- The schematic of a SC LHe level gauge is as shown in figure.
- In this arrangement, an immovable SC element is dipped into the LHe.
- The sensor is connected to a voltmeter and is fed with a small current.
- These sensors measure the liquid level by measuring the resistance of the measuring filament.

SC LHe level gauge



- This superconducting filament is housed inside a Teflon protective tube.
- The portion of filament in liquid remains in the superconducting state and exhibits zero resistance.
- Therefore, the resulting voltage along the sensor filament is proportional to the length of filament above the liquid helium.

SC LHe level gauge



- This sensor provides a continuous measure of the helium depth.
- Four wire technique is used to eliminate the errors resulting in variations in the length of the leads.
- The small amount of heat generated in the probe is dissipated primarily in the helium gas rather than in the liquid helium.

Summary

- Some of the commonly used non – metallic sensors are Silicon diode, Cernox and Ruthenium Oxide.

- Silicon diodes have negligible i^2R losses, exhibit a linear response, good repeatability and accuracy.

- Cernox RTDs offer high response time and have low magnetic field induced errors.

- Sensors used to monitor liquid level are Dipstick, Hydrostatic gauge, Electric Resistance/Capacitance level gauge, Thermodynamic level gauge and Superconducting LHe level gauge.

- A self assessment exercise is given after this slide.

- Kindly asses yourself for this lecture.

Self Assessment

1. In a silicon diode, sensor consists of a ____ with resistance – temperature property.
2. Voltage in silicon diode ___ with decrease in temperature.
3. For a silicon diode, the sensitivity ____ 30 K.
4. ____ diodes are accurate in magnetic fields.
5. In hydrostatic gauge, pressure gauge is directly calibrated in terms of _____.
6. In hydrostatic gauge, sensitivity is dependent on ______ densities.
7. The heat transfer coefficient of liquid is ____ that of vapor.
8. SC LHe level gauge has an immovable ______.

Answers

1. Silicon chip
2. Decreases
3. Increases
4. Cernox
5. Height
6. Liquid and vapor
7. Twice
8. SC element

Thank You!