Chemical Process Instrumentation
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Lecture – 28
High Vacuum Measurement (Contd.)

Welcome to lecture 28. We are talking about vacuum gages. So, we are talking about instruments that are used to measure very low pressure. So, we have already talked about McLeod gage, we have talked about ionisation gage. So, today we will talk about other vacuum gages.

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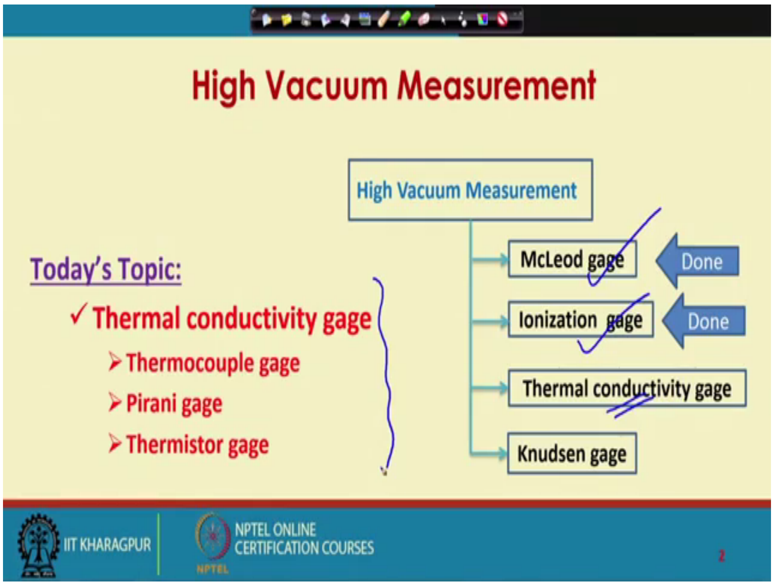

So, this is our today's topic. We have already talked about McLeod gage; we have talked about ionisation gage. And today we will talk about thermal conductivity gage. So, as the name suggests thermal conductivity gage depends on the variation of thermal conductivity of the gas with variation of pressure. Ordinarily at normal pressures, thermal conductivity is independent of gas pressure that is what conductivity tells us. Now, at very low pressures, thermal conductivity of the gas does depend on the pressure. So, we make use of this principle to design thermal conductivity gages. Under thermal conductivity gages, we will talk about three different variations. First, we will talk about thermocouple gage; next, we talk about Pirani gage; and finally, we talk about thermistor gage.

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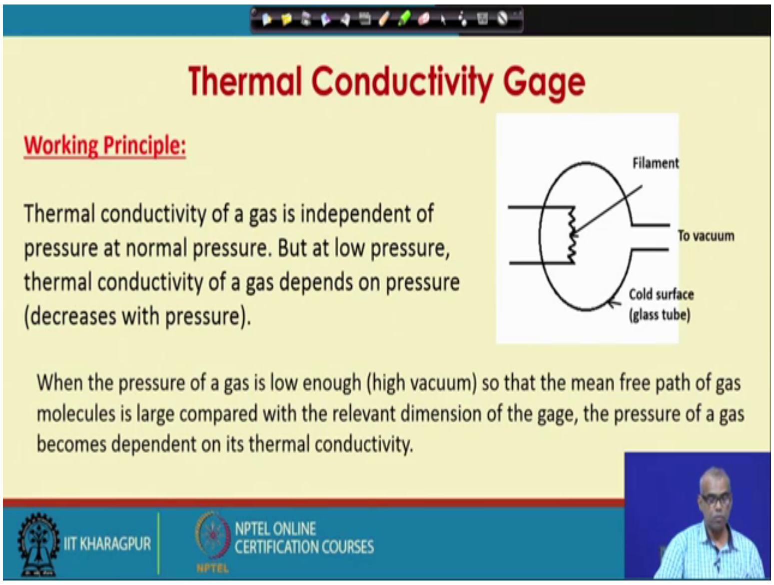

So, let us talk about working principal of thermal conductivity gage in some more detail now. Thermal conductivity of a gas is independent of pressure at normal pressures; but at low pressures, thermal conductivity of a gas depends on pressure in fact, it decreases with pressure.

When the pressure of a gas is low enough that means, we are talking about high vacuum, the mean free path of the gas molecule is large compared with the relevant dimension of the gage, the pressure of a gas becomes independent on its thermal conductivity. So, when the pressure of a gas is low enough, so that the mean free path of gas molecules is large compared with the relevant dimension of the gage, the pressure of a gas becomes dependent on its thermal conductivity.

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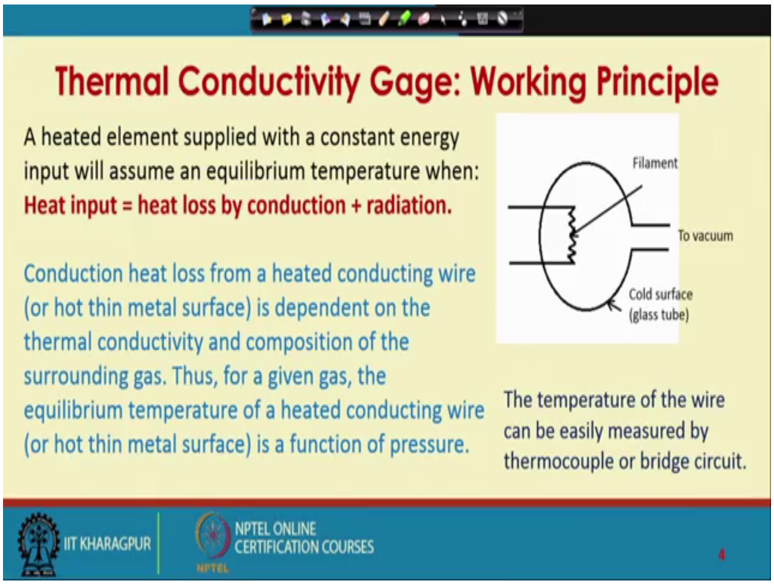

Let us look at this diagram. So, we have up filament which can be heated by supply of some energy. Now, this is kept as a within a glass chamber; and to that glass chamber, I apply the vacuum that means, this is connected to the gas source whose pressure I am going to measure. So, if this is the filament which is being heated by a supply of constant energy input, this is my hot surface. Now, the glass tube will work as a cold surface. So, there will be heat exchange between this hot filament and this cold surface.

So, a heated element supplied with a constant energy input will assume an equilibrium temperature when heat input equal to heat loss by conduction plus radiation. So, as I told you there is heat exchange between the filament and the cold surface of the tube; filament works as hot surface and the surface of the tube is the cold surface.

So, there is energy exchange between a hot body and a cold body. And after some time, a thermal equilibrium will be established. So, thermal equilibrium will be established when the heat input to the filament which is coming from the constant energy source is equal to the heat loss due to conduction, conviction and radiation. There are three different modes of heat transfer, conduction, conviction and radiation.

So, the filament will assume an equilibrium temperature when heat input to the filament is equal to the heat loss from the filament. Heat loss from the filament may occur by three different modes of heat transfer namely conduction, conviction and radiation, but convection is considered very negligible here. So, you can think that the heat loss is occurring mainly due to conduction and radiation. Among these two, the conductive heat loss will depend on the gas pressure, because we have just told in the previous slide that at low pressures, the thermal conductivity of a gas depends on the gas pressure. So, the heat conduction loss will depend on the thermal conductivity of the gas pressure. In other words, the temperature that the filament will assume when equilibrium is reached will have a relationship with the thermal conductivity of the gas.

So, conduction heat loss from a heated conducting wire or hot thin metal surface is dependent on the thermal conductivity and composition of the surrounding gas. Thus, for a given gas, the equilibrium temperature of a heated conducting wire or hot thin metal surface is a function of pressure. I can easily measure the temperature of the wire by say a thermocouple or by a bridge circuit. So, the basic principal in nutshell is as follows. In a gas chamber, if I heat a filament with some constant energy source, the temperature that the filament will assume at equilibrium will depend on the thermal conductivity of the gas.

Now, if I measure the temperature of the filament I can relate the temperature measurement with the gas pressure. And the temperature measurement can be done very easily let us say I can measure the temperature of the hot filament by a thermocouple which may be welded to the hot filament or the metal surface which is being heated up or I can also make use of a Wheatstone bridge to find out the change in resistance due to change in temperature of the filament. So, either way I can relate the temperature of the filament upon heating with the gas pressure. So, this is the principal all the thermal conductivity gages uses.

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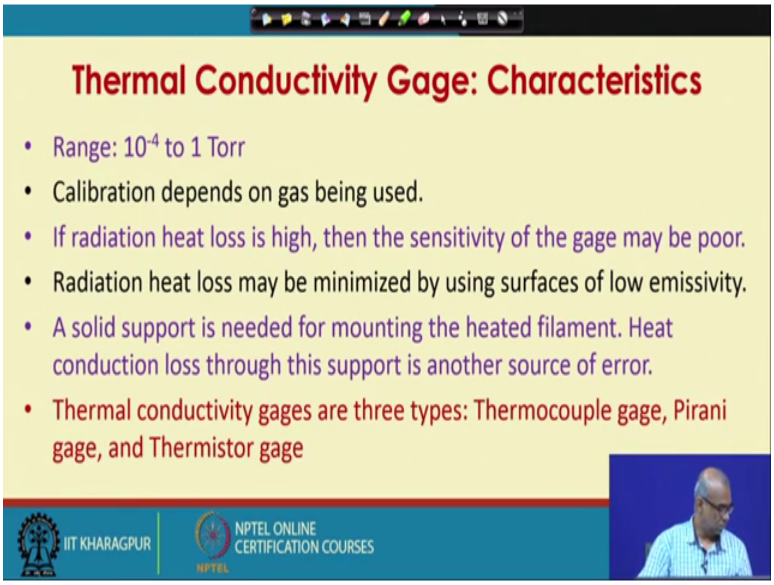

So, let us talk about some basic characteristics or features of thermal conductivity gages the range of such gages is 10 to the power minus 4 to 1 Torr. So, a pressure more than 1 Torr is not measured. Calibration depends on the gas being used, this is because the thermal conductivity is also property of the gas we are talking about. So, the calibration will depend on the gas whose pressure we are measuring.

If radiation heat loss is high then the sensitivity of the gage may be poor. So, what we want to mean is the radiation heat loss is a major part of the total loss then the sensitivity of the gage may be low. Radiation heat loss may be minimised by using surfaces of low emissivity. A solid support is needed for mounting the heated filament because you need to place the filament within let us say the glass tube or the enclosure to which the gas will be admitted whose pressure you are going to measure.

So, the filament needs to be mounted within the tube or within the enclosure. So, normally a solid support is required for mounting the heated filament. Heat conduction loss through the support is another source of error. Three different types of thermal conductivity gages we will talk about thermocouple gage, Pirani gage, and thermistor gage. The working principle is all same.

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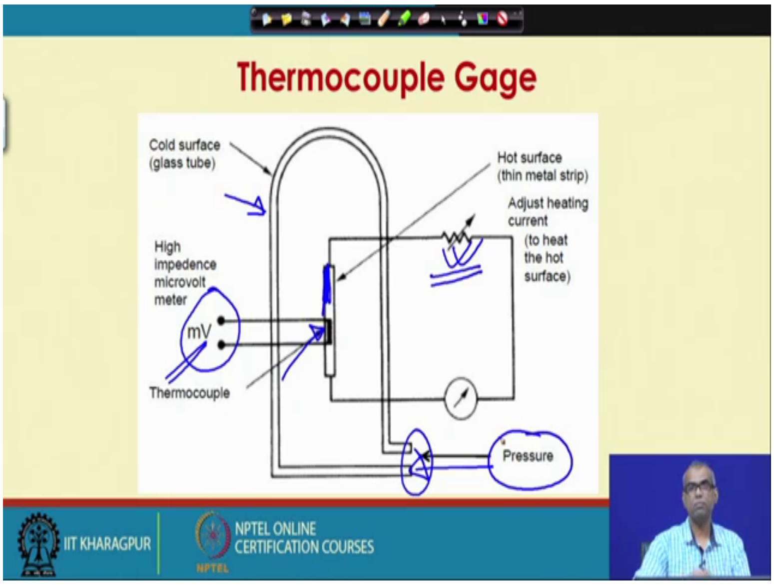

So, let us first talk about thermocouple gage what you see is a schematic of a thermocouple gage. So, this is the glass tube. And through this, the gas is admitted that means, this is connected to the gas source whose pressure I am going to measure. We have taken a thin metal strip, we have taken a thin metal strip, which will be heated up by adjusting the current flowing through it and this will work as a hot surface. So, inside the glass tube, I have taken a hot surface here which is the thin metal strip; and this thin metal strip is being heated up by sending appropriate current through it.

Now, as the hot surface gets heated up, it will exchange heat with the surrounding gas and the cold surface. Now, the heat conduction loss will depend on the thermal conductivity of the gas molecules, which depends on the gas pressure. So, the equilibrium temperature that the hot surface will assume will depend on the gas pressure. The temperature of the hot surface can be measured by attaching thermocouple on the hot surface. So, a thermocouple can be welded onto the thin metal strip hot surface and the temperature of the hot surface can be measured.

Later on when we talk about temperature measurement, we will see that the output of the thermocouple is millivolt. So, the thermocouple output is millivolt which is an indication of the or which is a measure of the temperature of the thin metal strip. So, finally, this millivolt output of the thermocouple which is a measure of the temperature of the thin metal surface indicates the pressure. So, this conception is very simple. It is simply consists of a glass tube to which the gas pressure will be admitted. And inside the tube we have mounted a thin metal strip, which will work as a hot surface. It will be heated up by sending current through it. And then we measure the temperature of the hot surface by taking help of say a thermocouple.

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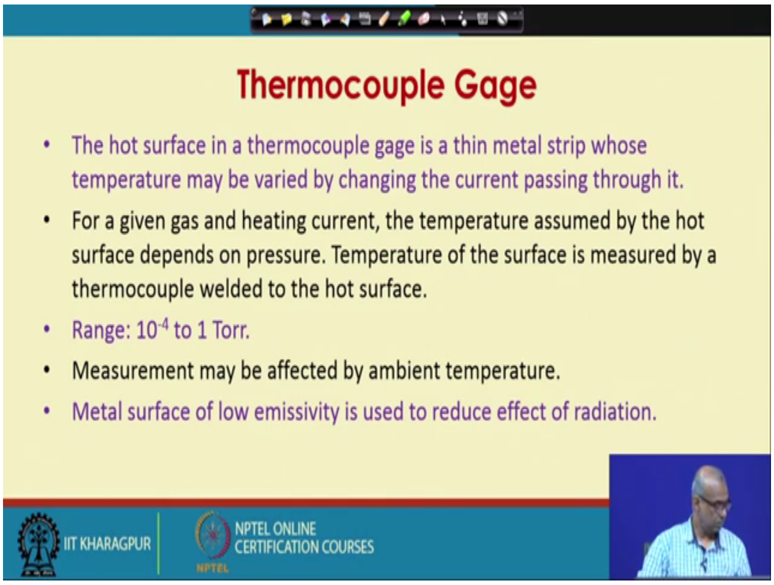

So, the hot surface in a thermocouple gage is a thin metal strip whose temperature may be varied by changing the current passing through it. For a given gas and heating current, the temperature assumed by the hot surface depends on pressure. Temperature of the surface is measured by a thermocouple welded to the hot surface. The range of a thermocouple gage is again 10 to the power minus 4 to 1 Torr. Measurement may be affected by ambient temperature this has to be taken care of. Metal surface of low emissivity is used to reduce the effect of radiation.

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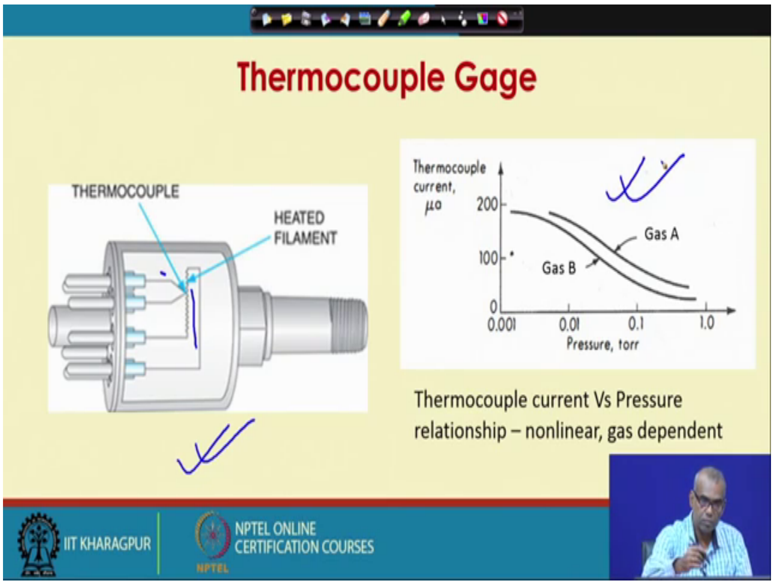

So, this is another diagram for thermocouple gage. You see this is the hot filament and this is the thermocouple, which is welded onto the heated filament. Thermocouple output which is millivolt or you can also take current verses output relationship is non-linear; and it is also gas dependent.

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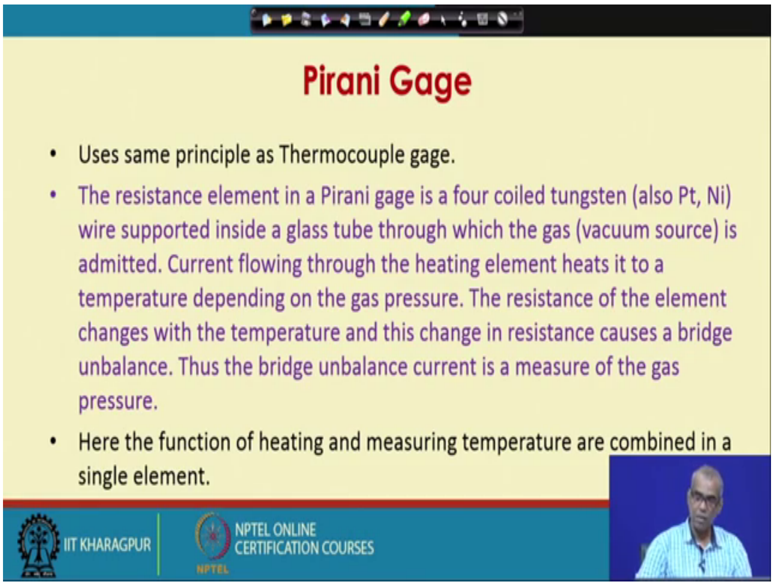

Let us talk about Pirani gage now; another thermal conductivity gage. Pirani gage uses the same principal as thermocouple gage. The resistance element in a Pirani gage is a four-coiled tungsten, you can also take platinum or nickel. So, the resistance element in a

Pirani gage is a four coiled tungsten wire or platinum wire or nickel wire supported inside a glass tube through which the gas is admitted. So, the gas admitted is the vacuum source.

Current flowing through the heating element heats it to a temperature depending on the gas pressure, because gas pressure will determine the thermal conductivity of the gas pressure. The resistance of the element changes with the temperature and this change in resistance causes a bridge unbalance. So, the change in resistance can be measured by Wheatstone bridge principle. Initially you establish the null point, and then due to change in temperature resistance of the filament changes, so that causes a bridge to go unbalanced. Thus, the bridge unbalance current is a measure of the gas pressure.

So, let us look at it once more. The resistance element in a Pirani gage is a four coiled tungsten wire supported inside a glass tube through which the gas is admitted. Current flowing through the heating element heats it to a temperature depending on the gas pressure. The resistance of the element changes with the temperature and this change in resistance causes a bridge unbalance. Thus, the bridge unbalance current is a measure of the gas pressure.

So, here the function of heating and measuring temperature are combined in the single element. So, I am heating up the resistance, I am heating up the filament say tungsten filament or platinum filament or nickel filament by sending current through it, and also measuring the change in resistance by the Wheatstone bridge principle. So, in the Wheatstone bridge in one arm I can attach this tungsten or platinum or nickel wire which works as a Pirani gage. So, the function of heating and measuring temperature are combined in a single element.

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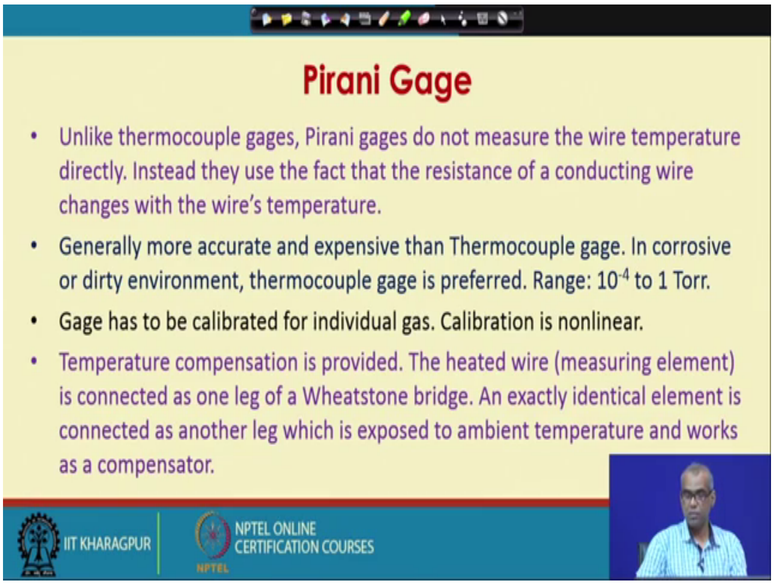

Unlike thermocouple gages, Pirani gages do not measure the wire temperature directly. Instead they use the fact that the resistance of a conducting wire changes with the wire's temperature. Pirani gages are generally more accurate than thermocouple gage, but it is also more expensive than thermocouple gage that is why in corrosive or dirty environment, thermocouple gage is preferred over Pirani gage. Again the range is 10 to the power minus 4 to 1 Torr. Gage has to be calibrated for individual gas, because thermal conductivity is a function of the gas we are talking about. So, different gases will have different thermal conductivity. Calibration is non-linear.

Temperature compensation is provided. The heated wire or the measuring element is connected as one leg of a Wheatstone bridge. An exactly identical element is connected as another leg which is exposed to ambient temperature and works as a compensator. Similar concept compensation of temperature we have also seen in case of stain gages.

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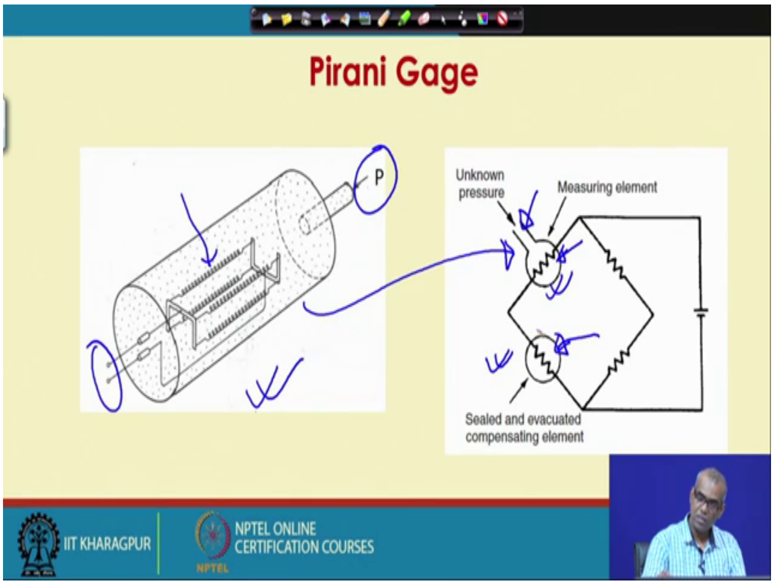

So, this is a schematic of Pirani gage. You can see the four coiled tungsten wire or platinum wire or nickel wire supported within the tube. So, this goes to electrical circuit for heating up the coil, and the gas is admitted or the vacuum source is connected. Now, this is connected to one leg of the Wheatstone bridge.

Now, initially to balance the circuit, so there is no unbalance current in the bridge. Now, when the gas pressure is admitted or when the gas is admitted to the Pirani gage, the temperature of the measuring element will change that will cause a change in the resistance, so that will cause an unbalanced current in the circuit and that will be measure of the unknown pressure or vacuum.

Look at this one. So, to the adjacent arm, we have put exactly identical element that means another Pirani gage which is exactly identical, but it is sealed and evacuated. So, both the Pirani gages experiences the same effect of ambient temperature, but this one the measuring element experiences the change in resistance for the pressure of the gas also. So, the effect of ambient temperature on this measuring element gets cancelled by the effect of ambient temperature on an identical Pirani gage connected to the adjacent arm.

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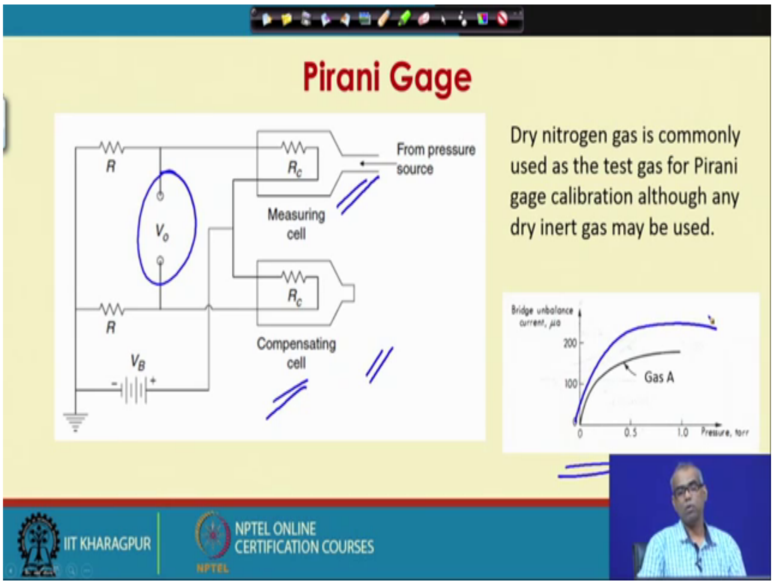

So, this is just another diagram for Pirani gage how will you measure the change in resistance using Wheatstone bridge principle. So, this is the measuring element or the measuring cell to which the vacuum source is connected and this is the compensating cell. So, they are in the adjacent arms. So, this is the output voltage which gives you indication of the pressure of the gas. Dry nitrogen gas is commonly used as the test gas for Pirani gage calibration although any dry inert gas may be used.

So, this is a plot of bridge unbalance current verses pressure. So, what is the bridge unbalance current, when you apply different pressures to the Pirani gage for a particular gas. You see that the relationship is non-linear. This is shown for a typical gas A let us say this is for air; for some other gas B, it may be something like this. So, this depends on the particular gas we are talking about. So, the calibration is non-linear as well as gas dependent.

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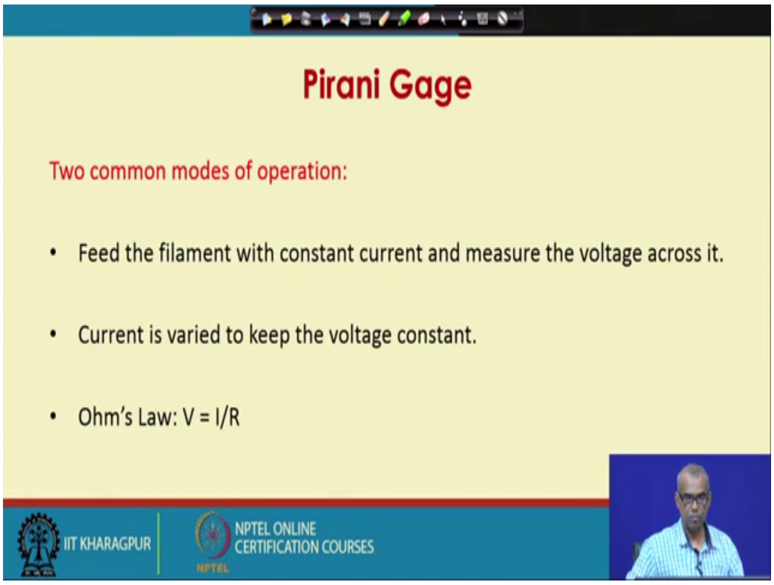

There are two common modes of operation for a Pirani gage. We can feed the filament with constant current and measure the voltage across it or we can vary the current to keep the voltage constant, both comes from principles of ohm law which says voltage equal to current divided by resistance. So, one mode of operation is that you supply a constant current to the filament and measure the voltage across it; other one will be you vary the current to keep the voltage constant. So, these are two common modes of operation of Pirani gage.

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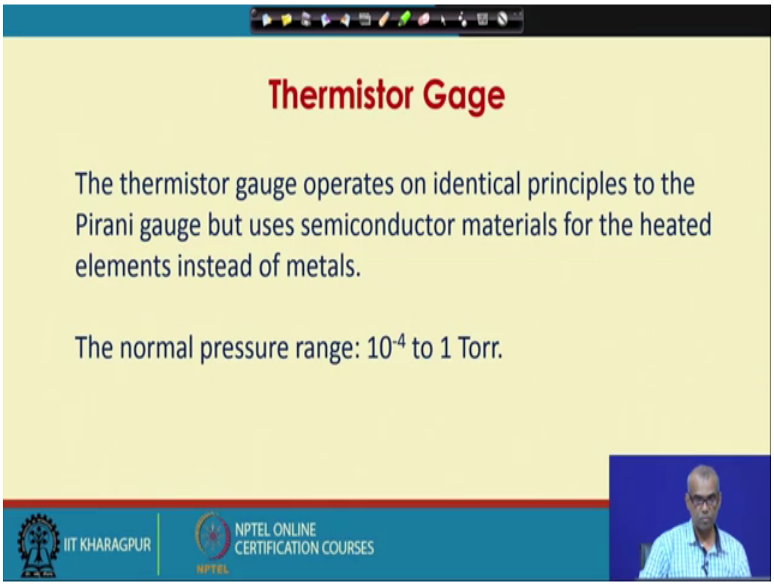

Finally, let us briefly talk about thermistor gage the thermistor gage operates on identical principles to the Pirani gage. So, the working principle is same as Pirani gage. The only difference is that a thermistor gage uses semiconductor materials for the heated elements instead of metals. A Pirani gage uses hot filaments made of tungsten wire or platinum wire or nickel wire; whereas, thermistor gage uses semiconductor material instead of these metals that is the only difference.

So, the difference lies in the material of construction of the filament or hot surface. In case of Pirani gage, it is a metal which is either platinum, nickel or tungsten; in case of thermistor gage, it is a semiconductor material; everything else is similar. Again the normal pressure range is 10 to the power minus 4 to 1 Torr.

So, we stop our discussion on thermal conductivity gage here. So, we learned about three different thermal conductivity gages, thermocouple gage, Pirani gage and thermistor gage.