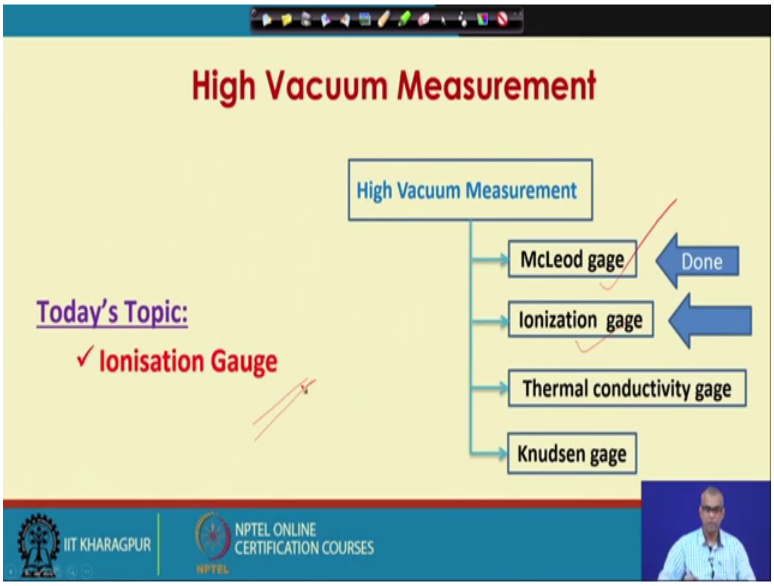
Chemical Process Instrumentation
Prof. Debasis Sarkar
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 27
High Vacuum Measurement (Contd.)

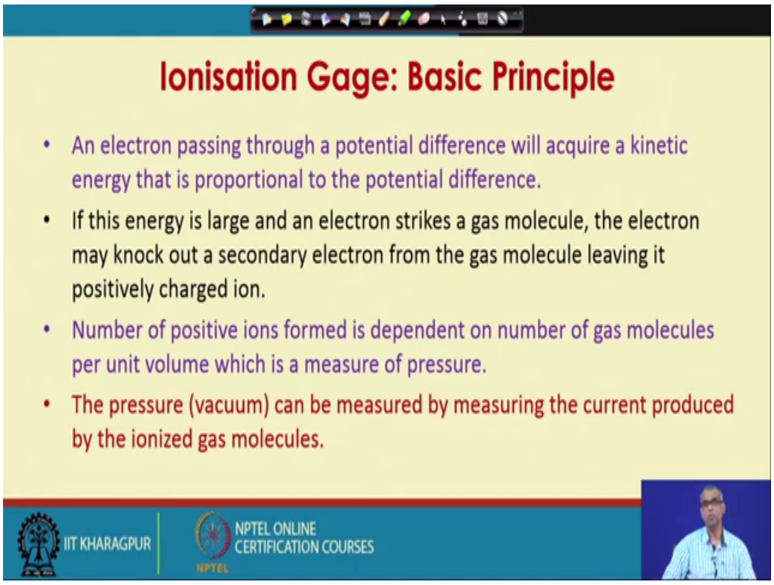
Welcome to lecture 27. In this week, we have started our discussion on measurement of high vacuum or very low pressures. In the previous lecture, we have talked about measurement of low pressures by McLeod gage. In this week, we will talk about another low pressure measuring instrument and that will be ionisation gauge.

(Refer Slide Time: 00:41)



So, we have talked about McLeod gage. And today we will talk about ionization gage. So, today's topic is ionization gage, which can be used to measure very very low pressures or very very high vacuum.

(Refer Slide Time: 01:01)

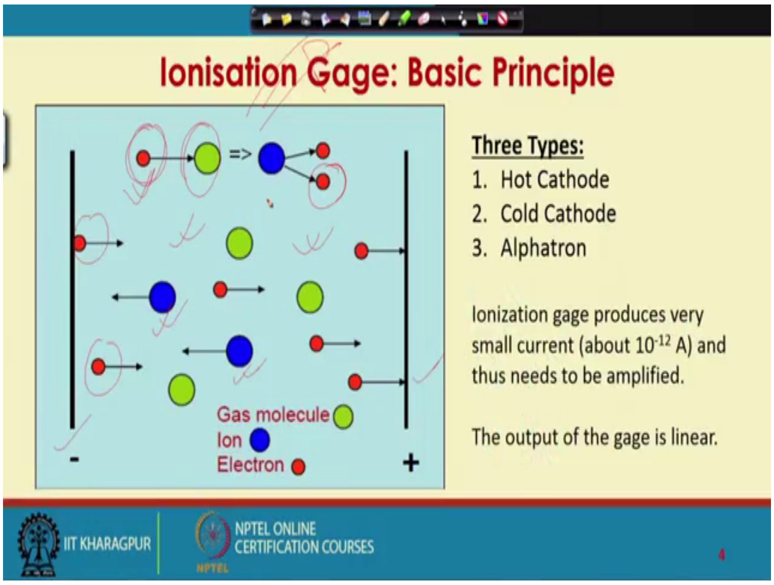


The basic principles of ionisation gage is as follows. An electron passing through a potential difference will acquire a kinetic energy that is proportional to the potential difference through which the electron is passing. If this energy is large, an electron strikes a gas molecule, there is a possibility that the electron may knock out a secondary electron from the gas molecule; and in that case, the gas molecule will be converted to a positively charged ion.

Number of positive ions formed is dependent on the number of gas molecules per unit volume and number of gas molecules per unit volume is a measure of pressure. Of course, the number of positive ions will also depend on number of collisions, so number of electrons that are passing through the potential difference. But if I can keep the number of electrons passing through constant, then the number of positive ions will depend on the number of gas molecules present in the chamber.

And number of gas molecules per unit volume is nothing but a measure of pressure. The pressure or vacuum can be measured by measuring the current produced by the ionized gas molecules. This current will be very small amount current, so amplification will be required for purpose of measurement.

(Refer Slide Time: 03:04)



So, let us look at the schematic. Electrons are passing through a potential difference. These are cathodes and anodes. Let us consider this is a close chamber; and to that chamber, the vacuum source is connected. So, we are measuring very very low pressure of say a gas stream. So, there will be gas molecules in this chamber. Now, when the electrons passes through this potential difference, they will acquire kinetic energy which is proportional to the potential difference that is being applied.

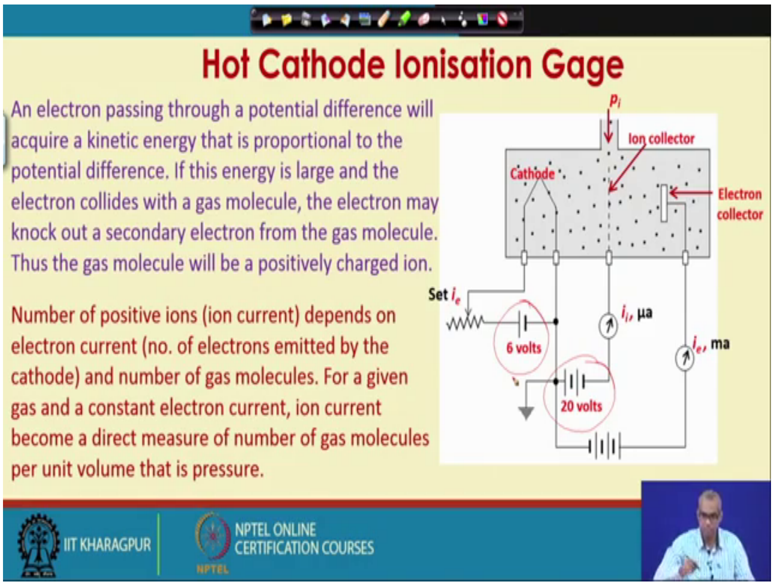
Now, if this kinetic energy is large, and if the electron collides with this gas molecules, the gas molecule will be converted to a positively charged ion. Because this electron when collides with the gas molecule and if this kinetic energy of the electron is very high, it can knock out a secondary electron and then the gas molecule will be converted to a positively charged ion.

So, number of these positively charged ion will depend on the number of gas molecules present in the chamber. Number of gas molecules present in the chamber is nothing but a measure of pressure. More number of gas molecules in the chamber means more pressures; very few number of gas molecules in the chamber means very low pressures. So, the basic principles of ionisation gage is that we have to emit electrons which will acquire kinetic energy, and those electrons will collide with the gas molecules, whose pressure I am going to measure. After this collision, positively charged ions will be formed; I can measure the current due to projection of the positively charged ions; and that current will be a measure of the number of gas molecules or the pressure.

So, depending on how I ionised these gas molecules, I have different types of ionisation gage. I can heat up a cathode to draw electrons. I can impose a high magnetic field to draw out electrons. I can also use a alpha particle limiters making use of radioactive source to ionize gas molecules, so that way I will have different types of ionization gage. I can have hot cathode ionisation gage; I can have cold cathode ionization gage, and I can have I can have alphatron, which use alpha particles to emit electrons.

So, hot cathode ionisation gage will heat up a cathode to emit electrons. Cold cathode ionization gage does not heat up the cathode, there I make use of magnetic field high magnetic field. And then alphatron they are also you do not heat it up the cathode what you do is we make use of alpha particles radioactive source to emit alpha particles which will arise the gas molecule. Ionisation gage produces very small current which is about 10 to the power minus 12 ampere and thus needs to the amplifier. One good thing about ionization gage is that the output of the gage is generally linear.

(Refer Slide Time: 08:04)



Now, this is the schematic of an ionisation gage. This is the cathode, which is being heated up. So, an electron passing through a potential difference will acquire a kinetic energy that is proportional to the potential difference. If this energy is large and the electron collides with a gas molecule, the electron may knock out a secondary electron from the gas molecule, thus the gas molecule will be a positively charged ion.

So, I have cathode and I have anode which is electron collector now this cathode is heated up to emit electrons, so that electrons goes to the electron collector. While it is doing so, this chamber is connected to the vacuum which I am going to measure. So, thus this electron also collides with the gas molecules that are present within the chamber. When these electrons collide with the gas molecules that are present in the chamber, heat produces a positively charged ion. And I used ion collector, I use an ion collector, and get the ion current.

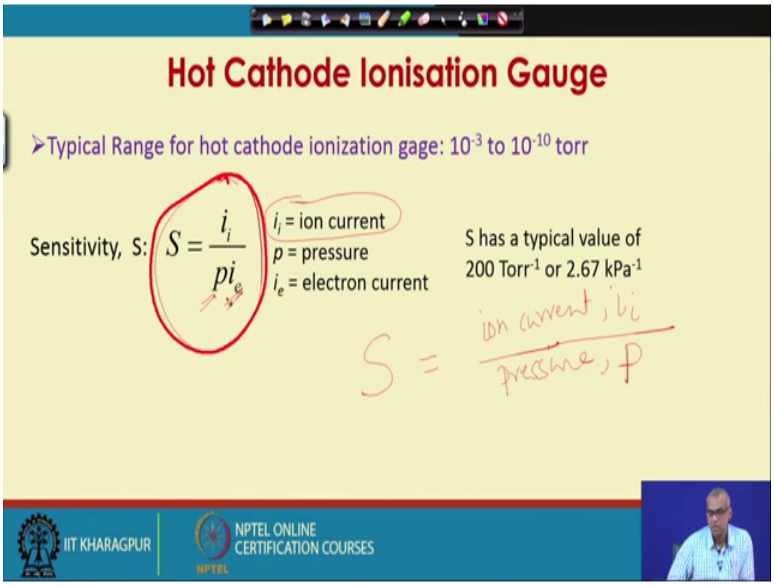
These ion current depends on the number of positively charged ions that is formed and number of positively charged ions that is formed will depend on the number of gas molecules as well as number of electrons present in the chamber, but I can say that an electron current which will control the number of electrons being emitted. So, ultimately these ion current for a given ionisation gage will be a measure of pressure.

So, number of positive ions or ion current depends on the electron current that is number of electrons emitted by the cathode and number of gas molecules. For a given gas and a constant electron current, ion current become a direct measure of number of gas molecules per unit volume which is nothing but pressure. So, typically this is around 6 volts and this is around 20 volts.

(Refer Slide Time: 11:35)

This is a photograph of commercially available hot cathode ionisation gage.

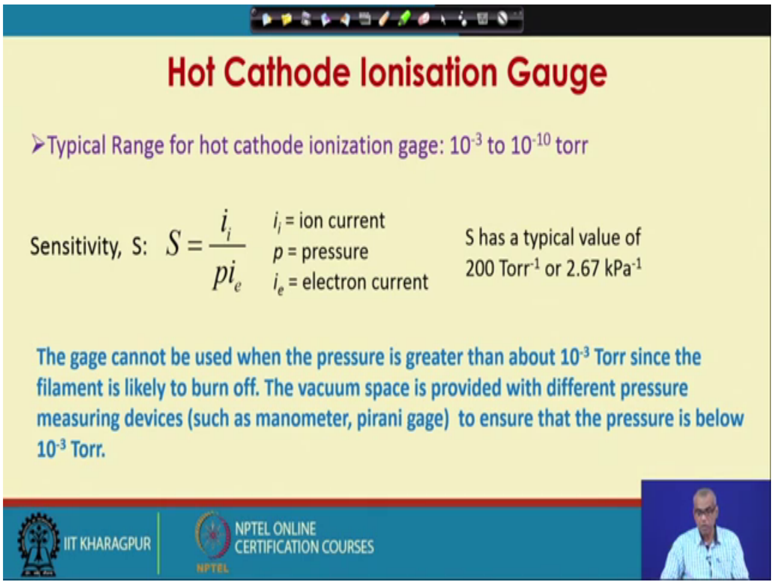
(Refer Slide Time: 11:46)



Typical range of hot cathode ionisation gage is 10 to the power minus 3 to 10 to the power minus Torr, 1 Torr is 1 millimetre of mercury. So, the hot cathode ionisation gage can measure a pressure as low as 10 to the power minus 10 millimetre of mercury. This is how I express the sensitivity of an ionisation gage. So, sensitivity in general will be output by input. So, my output is ion current which is i i that is how I am representing that figure also; input is the pressure p. But typically instead of expressing sensitivity of ionisation gage by i i by p that is ion current divided by pressure, we express the sensitivity of ionization gage as ion current divided by pressure into electron current, so that way the sensitivity becomes sensitivity value becomes independent of electron current. This is because different ionisation gage can use different electron current to emit electrons.

And if you have different electron current means different number of electrons are been emitted, so there will be different number of collisions between electrons and the gas molecules. So, there will be different ion currents. So, to make the sensitivity independent of electron current, so that I can compare the sensitivities of different ion gages that are using different electron currents, we express the sensitivity of the ionization gage as ion current divided by pressure into electron current. The sensitivity for ionisation gage has a typical value of 200 Torr inverse or 2.67 kilo pascal inverse.

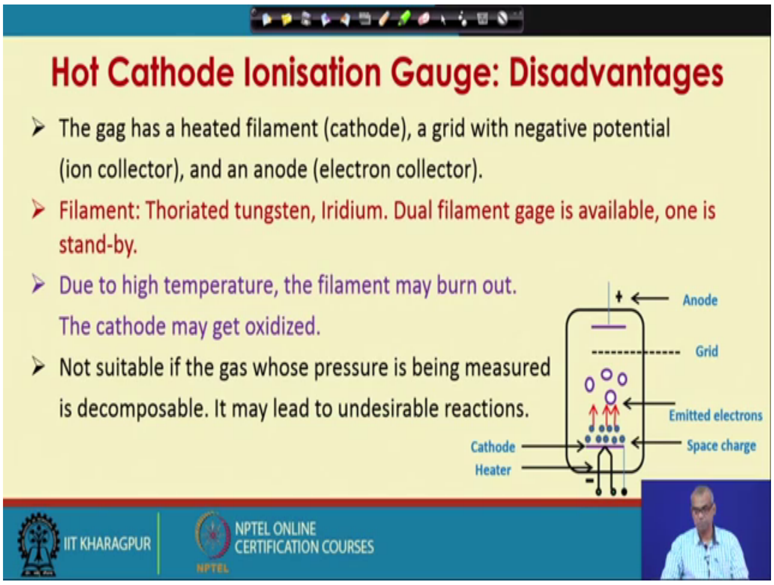
(Refer Slide Time: 14:47)



The gage cannot be used when the pressure is greater than about 10 to the power minus 3 Torr since the filament is likely to burn off. For the hot cathode ionisation gage, there is a possibility that the filament can burn off. So, you should never use the ionisation gage or hot cathode ionisation gage, when the pressure is more than 10 to the power minus 3 Torr. The vacuum space is provided with different pressure measuring devices such as manometer, Pirani gage etcetera to ensure that the pressure is below 10 to the power minus 3 Torr.

So, before we actually connect the vacuum source with the hot cathode ionisation gage, we want to ensure that the pressure is less than 10 to the power minus 3 Torr. So, what you do is we first connect to the manometer that can measure low pressures or another vacuum measuring instrument known as Pirani gage which we will talk about later and make sure that the pressure is less than 10 to the power minus 3 Torr, then we make use of ionization gage to measure the vacuum.

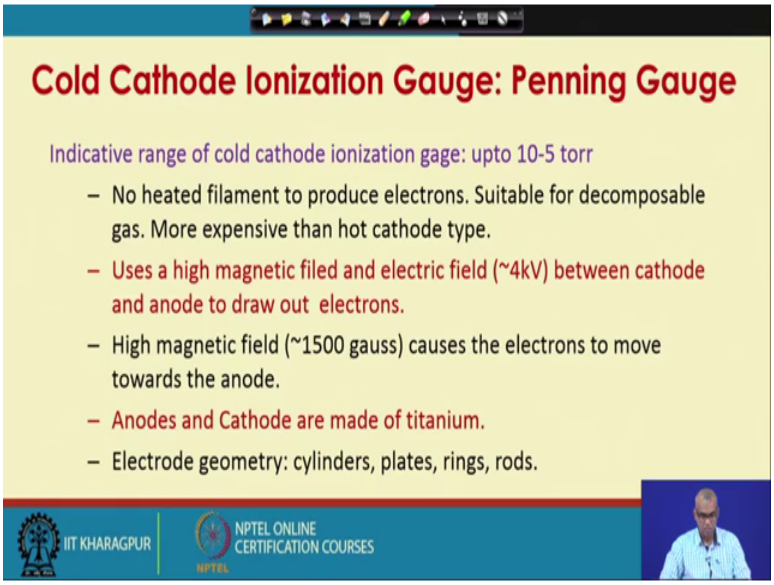
(Refer Slide Time: 16:16)



So, the hot cathode ionisation gage has a heated filament which is cathode. We have a grid with negative potential, which is ion current. And this was the cathode which is being heated up. This is the grid which captures ion, so it has a negative potential. And you have an anode which is positively charged and electron collector. The filament is typically made of thoriated tungsten or iridium. There are certain gages which has two filaments in that case one is usually (Refer Time: 17:20) stand-by. Thoriated tungsten means you have thorium in tungsten filaments made of tungsten.

Due to high temperature, the filament may burn out and the cathode may get oxidized. The hot cathode ionisation gage is not suitable if the gas whose pressure is being measured is decomposable. Since, we will be using high temperature to emit electrons from the cathode the gas whose pressure is being measured is decomposable, it is not suitable as it may lead to undesirable reactions.

(Refer Slide Time: 18:20)

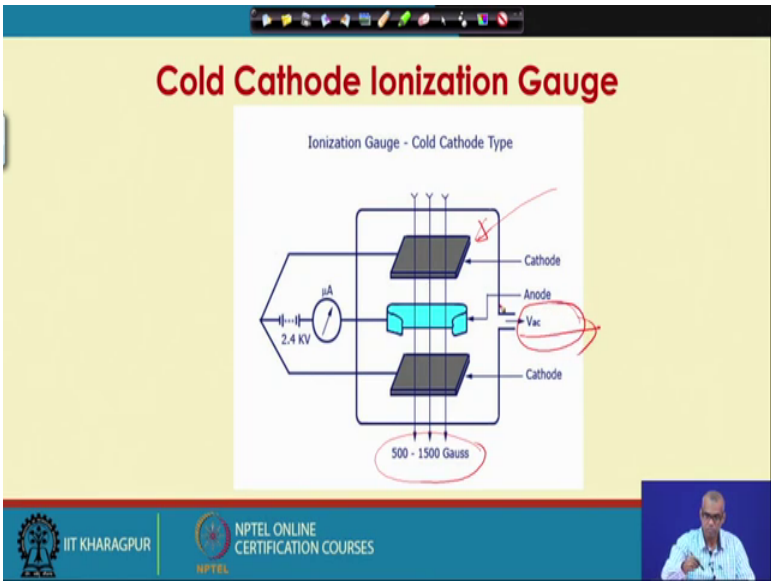


Next, let us talk about cold cathode ionisation gage. This is also known as Penning gauge. Penning was the inventor of cold cathode ionisation gauge. As the name suggests in case of cold cathode ionisation gage, there is no heated cathode. So, we do not heat up the cathode to draw out electrons. Here we will make use of high magnetic field. So, the indicative range of cold cathode ionisation gage is about 10 to the power minus 5 Torr. This is 10 to the power minus 5. There is no heated filament to produce electrons, so this is suitable for decomposable gas, but it is more expensive than hot cathode type.

Cold cathode ionization gage uses a high magnetic field as well as high electric field about 4 kV between cathode and anode to draw out electrons. High magnetic field around 1500 gauss causes the electrons to move towards the anode. In case of hot cathode ionization gage, we heat up the cathode to draw out the electrons and it passes through high potential difference. In case of cold cathode ionization gage, I have the high potential difference, but I super impose a high magnetic field. The electric potential is about 4 kV, and the magnetic field that is super imposed has a strength of 1500 gauss.

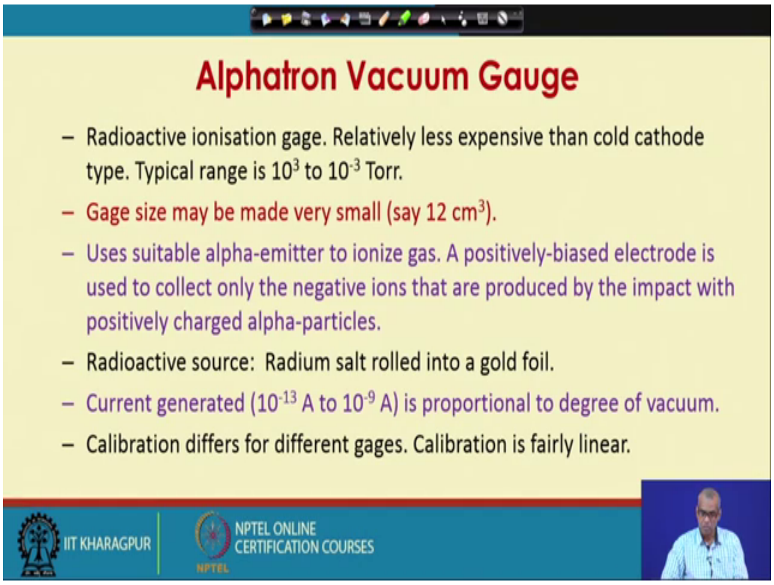
So, high magnetic field causes the electrons to move towards the anode. So, as it moves towards anode, this will collide with the gas molecules that is present in the chamber, chamber will be connected to the vacuum source, which we are going to measure. So, as it collides with electrons, as it collides with the gas molecules, the gas molecules will be ionised, you measure the ion current, and then it becomes same as measurement with ionization hot cathode ionization gage. Only difference is the electrons are emitted not by heating up the cathode, but I am super imposing a high magnetic field in a high electric rate. Once electrons are produced, the measurement principle with hot cathode ionization gage and cold cathode ionization gage are similar. Anodes and cathodes are generally made of titanium. We can have different types of electro geometry such as cylinders, plates, rings, rods.

(Refer Slide Time: 21:52)



So, this is an image of this is a schematic of cold cathode ionisation gage. So, you have the cathode and you have the anode. So, you super impose the magnetic field which is as high as 1500 gauss. This chamber is connected to the vacuum source. So, this connected to the gas whose pressure you are measuring is very, very low pressure or high vacuum. So, this magnetic super imposed magnetic field will draw out the electrons and then those electrons will collide with the gas molecules positively charged ions to be formed you measure the ion current, the ion current is a measure of this vacuum.

(Refer Slide Time: 23:08)

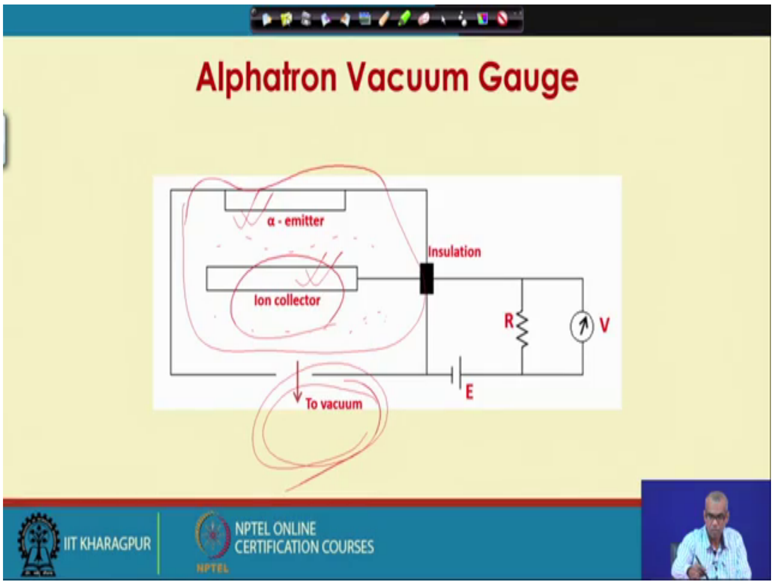


Next, we will talk about alphatron vacuum gauge. This is a radioactive ionisation gage. This is relatively less expensive than cold cathode type, but this is also not hot cathode type, meaning this is a version of cold cathode type, but you do not use super impose magnetic field to draw out electrons. What you do is make use of radioactive material to generate alpha particles which will ionise the gas molecules. The typical range of alphatron is 10 to the power 3 to the 10 to the power minus 3 Torr. The gage size may be made very small it may be as small as 12-centimetre cube, 12 cc. So, alphatron vacuum gage uses suitable alpha-emitter to ionise gas.

A positively-biased electrode is used to collect only the negative ions that are produced by the impact with positively charged alpha-particles. So, we use a suitable alpha emitter to emit alpha-particles which will collide to the gas molecules and will produce negative ions. So, a positively-biased electrode is used to collect the negative ions which are produced by the impact of positively charged alpha-particles, and this current will be a measure of the vacuum.

Typically, as radioactive source we use radium salt rolled in the gold foil for cold cathode for alphatron. Current generated is proportional to the degree of vacuum, and it is very small of the order of 10 to the power minus 3 ampere to 10 to the power minus 9 ampere. Calibration differs for different gases. However, the calibration is fairly linear which is an advantage, that the calibration is linear is true for all ionization gages.

(Refer Slide Time: 26:04)



So, this is the schematic for alphatron vacuum gauge. This is the chamber which is connected to the vacuum source. You have the alpha emitted here. So, this is radioactive source material. So, it produces alpha-particles. These alpha-particles collides with the gas molecules that are present and the negative ions are collected using this ion collector. So, the current due to this is a measure of the number of ions formed which is dependent on the number of gas molecules present in this chamber because that decides the number of collisions and number of collisions decides by number of ions formed. So, ultimately the current due to this negative ions is a measure of this vacuum.

So, we talked about three different types of ionisation gages. All these ionisation gages have fairly linear output which is an advantage. We talked about hot cathode type, we talked about cold cathode type, we talked about alphatron. All these can be used for measurement of high vacuum.

Here should be taken for hot cathode type which has a disadvantage of filament also possibility of filament burn out or gas decompositions which have overcome in case of cold cathode or alphatron. But cold cathode is more expensive, it uses high magnetic field super imposed on high potential difference; and in case of alphatron, it makes use of a radioactive source. So, we stop our lecture 27 here.