**Solar Photovoltaics: Fundamental Technology and Applications**
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**Lecture 38**
**Vacuum Technology in Solar Photovoltaics**

Welcome everyone to our solar photovoltaics course. Today we have 8th week, third module. So as you are learning from the last two classes about the different procedures for the vacuum technology and we have learnt about why we need the vacuum, especially in the context of the electronics devices and also we have learnt about how to make vacuum. So in our discussion, we have seen that there are three different types of vacuum is there.

One is the rough vacuum which is somewhere around 10 to the power -2 millibar and then high vacuum which is anything beyond 10 to the power -2 millibar to something like 10 to the power -7 million and anything below that like something like 10 to the power -8 millibar to 10 to the power -12 millibar, we call it as a ultra-high vacuum and we have seen that to make this kind of vacuum, we need vacuum pump and there are three different kinds of pump we have discussed in the last class.

One was a rotary pump which is a positive displacement pump and then there was this molecular diffusion pump, for example turbo molecular pump and the third class of pump was the entrapment pump, for example the ion palm or cold cathode pump. Now the rotary pump or sometime which is also called as a rough pump will usually bring the pressure from the atmospheric pressure to 10 to the power -2 millibar watt.

Whereas the molecular diffusion pump like turbo molecular pump, they makes high vacuum 10 to the power -7 millibar and this kind of vacuum is well enough for our deposition of any kind of metal electrode and but if we wanted to do some advanced imaging like SEM scanning electron microscopy or atomic force microscopy, then we need ultra-high vacuum, because there the electron beam comes and collide with the substrate surface so in that case we use entrapment pump.

Now the next thing is that once we know how to make the vacuum, now how can we measure the raccoon or to put it in other words like you know when we say it is a medium vacuum or it is a high vacuum, how do I know it is a medium vacuum or how do I know it is a high vacuum. So this is done by the instrument called gauge.

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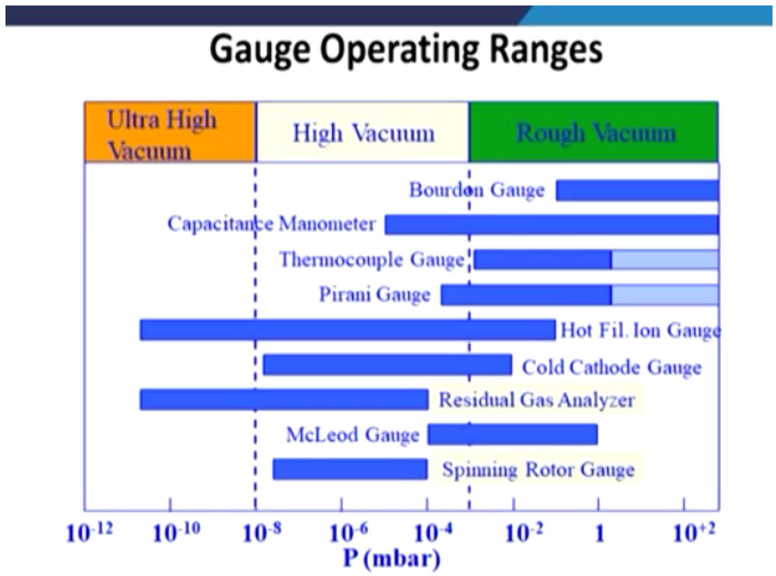


So there are some gauges, which work in the rough vacuum range. There are some gauges which work in the high vacuum range and there are some gauge, which works in the ultra high vacuum range. So here in this chart, we are showing the different kind of gauges, which are used for the different vacuum region. For example, you can see that the Bourden gauge or Bourden gauge that is used for the rough vacuum and this is one of the very oldest gauges.

Then in this capacitance manometer that is used from the rough vacuum to the high vacuum, thermocouple gauge is there. In Pirani gauge, Pirani gauge is from the rough vacuum to high vacuum. Hot fill iron gauge which can goes to high vacuum to the ultra high vacuum. Cold cathode gauge, residual gas analyzer, then McCleod gauge, spinning rotor gauge. Now these are different kind of gages which measures the pressure in different range.

Now today, although we will touch up on different kind of gauges, but in details we will discuss about two different gauges. One is the Penning gauge; another is the Pirani gauge. First we start with one of the oldest gauge called Bourdon gauge.

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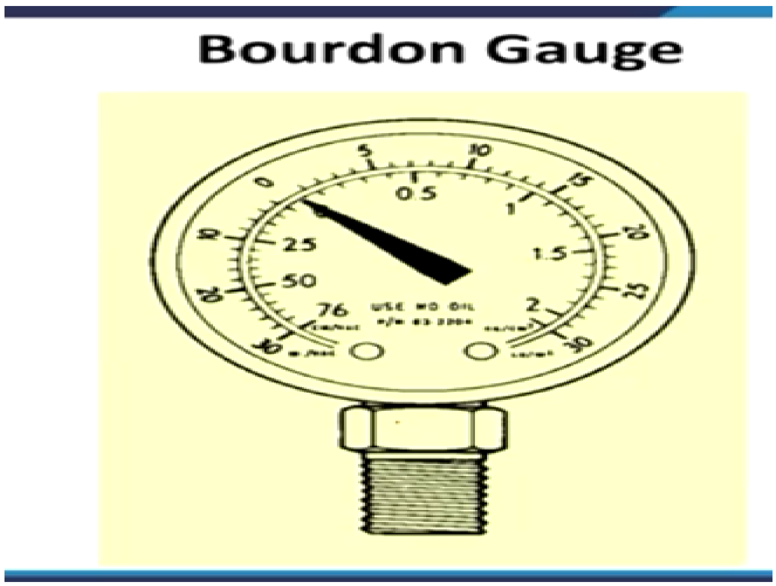


Now it looks like a table clock or it look looks like a watch where I can see that the reading, this 5, 10, 15, 20 this is calibrated the number. These are the pressure unit and the corresponding subunit is shown in the inner circle. Now you can see a cursor and the whole system is attached to a pump loaded spring. Now whatever the vacuum we wanted to measure we connect it to the Bourdon gauge.

For example, even like let us say once who rides the bicycle sometimes time to time we need to fill with the air right and so how much amount of air is there inside the tube of the bicycle, into the tire of the bicycle, that you can measure by using Bourden gauge. So it is as I said that it is very, very primitive and commonly used gauge which is used in mechanical engineering and for daily applications.

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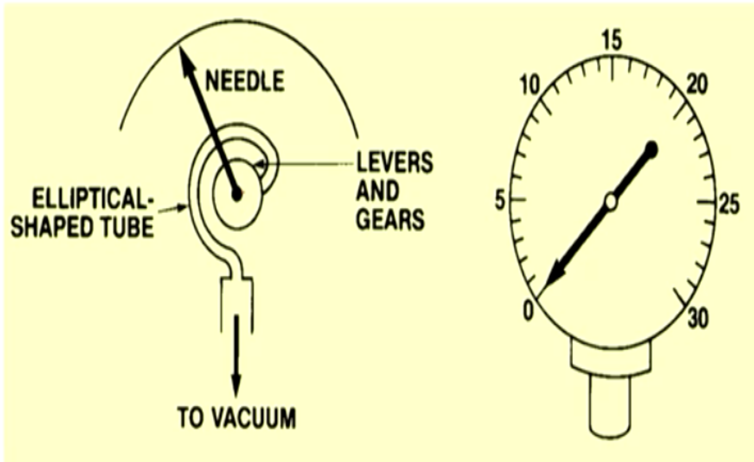


Now what happens here as a Bourdon gauge, you see this elliptical shaped tube and there is a needle which is attached to this elliptical shaped tube and the leaves and gears are also attached to the needle. Now this one of the part of this spherical tube or the elliptical tube that is attached with the outlet part or the inlet part whatever you define it as, as to the vacuum source. Now let us say this is a chamber okay and it has something like 10 to the power 6 molecules/unit meter cube okay.

So then I mean, this many number of molecules we can determine, if we attach this chamber to these gauge and what will happen, so the needle will deflect according to the tracer because of this gas molecule present inside the chamber and this deflection is read by the displacement of the needle, which is calibrated from an initial value of 0 to 5, 10, 15, 20, 25 and you can know what is the pressure inside the system okay.

So now when we talk about the gauge actually there are two common gauges, which is very, very popularly used, one is thermocouple gauge and another is Pirani gauge. Now these are the two gauges which is almost available with all vacuum systems whether it is a very ultra high vacuum systems like STM or SCM machines or even like you know for our solar cell devices, we use thermal deposition system, we use this kind of gauges.So that is why we will discuss about these two gauges here.

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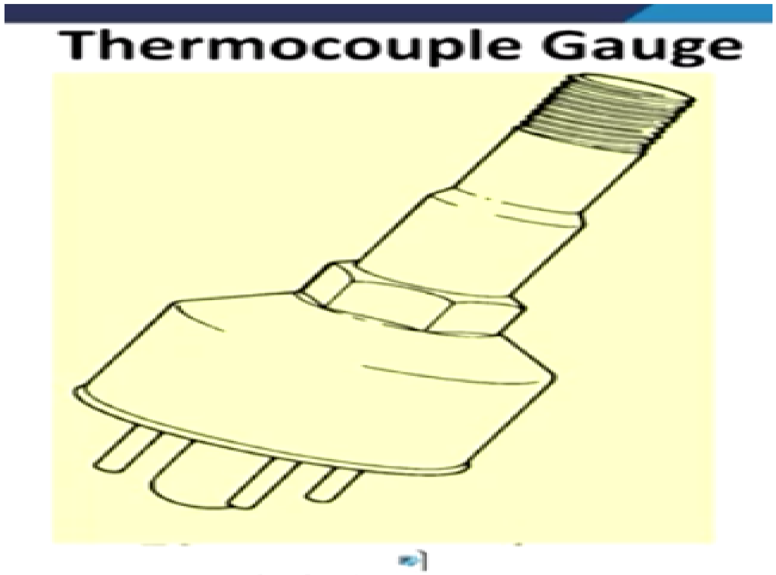


The first one is a thermocouple gauge. Now as the name suggests like you know a thermocouple stands for a metallic wear which generates the current based on the difference of the temperature. So this gauge, they sense or generates the current which finally eventually creates the voltage by the difference of the temperature in the system. Now the next video will show you how basically a thermocouple gauge works and you can understand the basic operating principle behind this gauge, which will also we will discuss later on in details.

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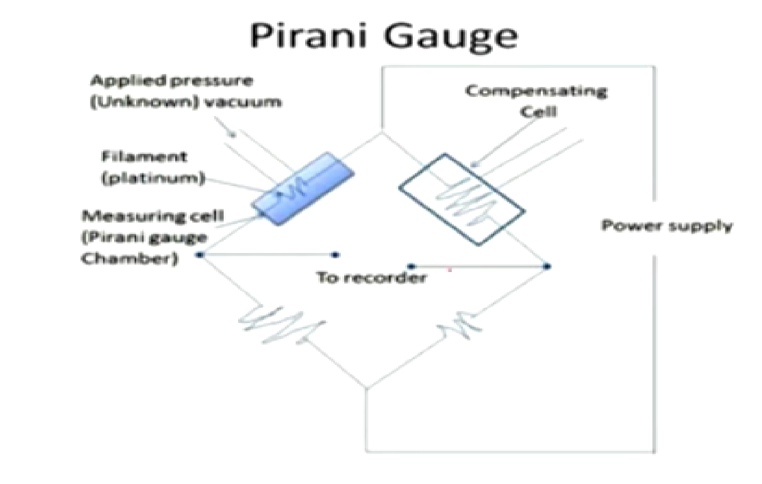


So the Pirani gauge here, this is which we reminds you this circuit is a Wheatstone bridge. So you know that for measuring unknown resistance in electrical engineering or in our undergraduate physics course, we always use this kind of Wheatstone bridge where there are four on resistance are there r1, r2, r3 and r4 and then the r4 let us say is an unknown resistance by taking the ratio of r1 to r2 and r3 to the r4 or unknown resistance we look for the null point or where there is no deflection.

So from that we can find out what is the value of unknown resistance so the similar kind of circuit we are using here with some changes, as here we are using a platinum filament which is like you know attached to the unknown pressure or the vacuum systems and then there is a measuring cell is there inside this chamber, which is called a Pirani gauge chamber and then on the other side just like a Wheatstone bridge diagram, you have a compensating cell and then there are two resistance on the two other side.

So this is connected to a recorder and everything is connected to a power supply. So what will happen like you know, so this compensating cell that basically balance the current which is coming out from the measuring cell okay and these two value is almost constant and we record the deflection from the recorder. The Pirani gauge consists of a metal filament usually platinum suspended in a tube which is connected to the system, whose vacuum is to be measured.

So that is you already have seen in the last figure. You see that the Pirani gauge is connected of this platinum wire. This is the chamber, inside it there is a platinum wire is there and that is connected to the chamber for which we wanted to measure the vacuum.

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## Pirani Gauge

- The Pirani gauge consists of a metal filament (usually platinum) suspended in a tube which is connected to the system whose vacuum is to be measured.
- Connection is usually made either by a ground glass joint or a flanged o-ring. The filament is connected to an electrical circuit from which, after calibration, a pressure reading may be taken.
- Metal connector, sealed with a conducting wire (platinum filament) gets heated when electric current flows through it.
- This wire suspended in a gas will lose heat to the gas as its molecules collide with the wire and remove heat.

Connection is usually made either by ground glass joint or a flanged O-ring. Now this flanged O-ring ring, this is a terminology we used in the vacuum technology. So in vacuum technology like you know I mean when the pump is attached to any vacuum system like let us say, let me draw a block diagram. Let us say this is your pump and which is attached to a chamber okay. This is your chamber and this is your pump.

And we wanted to measure what is the pressure in the chamber by these gays okay. So in addition to this pump and addition to the gauge you can see there are a lot of pitting units are there. We have this tube so how effectively the pump will be able to ejaculate or evacuate this chamber that will also depend upon the properties of this tube and then there are lot of joints of this tube with the chamber and tube with these gauge also.

So these joints they are actually called flanged. Now this flanged, they can also come in different shape. Now this o-ring flanged that is a very, very commonly used structure for making this kind of connection here. The filament is connected to an electrical circuit from which after calibration a pressure reading may be taken. Metal connector sealed with a conducting wire usually a platinum filament gets heated when electric current flows through it.

Now so we use in the platinum wire in a Pirani gauge. Now once you heat this platinum wire so what will happen, the electron will be ejected because a platinum wire will get heated and the electron will eject from there. This wire suspended in a gas, so that will lose heat to the gas as it molecules collide with the wire and removes heat.

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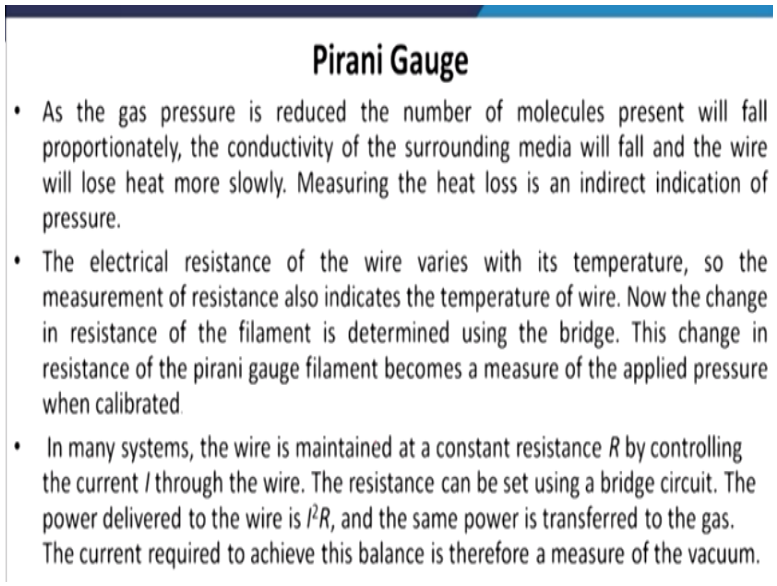


As the gas pressure is reduced, the number of molecules present will fall proportionately. The conductivity of the surrounding media will fall and the wire will lose heat more slowly. Measuring the heat loss is an indirect indication of the pressure. So basically again like comes back to the previous diagram, which we have drawn here, let us say this chamber is connected to this pump and which is also connected to this gauge system.

Now once you heat the filament what will happen like the gas molecule, let us say this gauge is connected to this chamber, now once I heat the filament here, so the hot filament they will like you know emits the electron and that electrons they will collide with the surrounding gas molecule. Now obviously in this process, there will be a heat transfer. Now this heat transfer that will change the surrounding conditions.

So the initial rate of the heat loss of the wire will gradually reduce over the time as the surroundings and temperature changes and this change of temperature is actually proportional to the number of the gas molecule in the system, because as more and more collision will happen more and more heat loss will be there. If there is less molecule inside the system, then there will be a less heat transfer or less heat loss.

So basically the heat loss is a measure of the number of gas molecule indirectly inside the system. Now we have learnt that the number of the gas molecule in a system is also is a measure of the pressure inside the system. So that means the heat loss inside the system is a measure of the pressure loss in the system. So by measuring the heat loss indirectly we can measure the pressure inside the chamber and that is the working principle behind this gauge.

The electrical resistance of the wire varies with this temperature. So the measurement of the resistance also indicates the temperature of wire. Now the change in resistance of the filament is determining using this bridge. Now obviously as we just have seen that any change of pressure, we can read it by the change of temperature, but we also know from the Joules law that any change of temperature is related to the resistance all right.

If you have a resistance R which is connected to an electric circuit and if the I amount of current flows through in it, so we know how much heat will be generated in it. So if we can measure the resistance inside the circuit which is also connected to the vacuum chamber. Now since the resistance is a measurement of the temperature, by measuring the resistance we can also find out an information about the pressure.

Now this resistance is connected to the bridge and that is why we have taken this Wheatstone bridge geometry to make a balance and every time a change of the resistance can be balanced by the corresponding change in the other arms of the Wheatstone bridge to get a null point. This change in the resistance of the planning experiments becomes a measure of the applied pressure when calibrated. In many systems the wire is maintained at a constant resistance R by controlling the current through the wire.

The resistance can be set using a bridge circuit with power delivered to the wire is I square R, if I is the current then R is the resistance and the same power is transferred to the gas. The current required to achieve this balance is therefore a measure of the vacuum. So since there is a resistance is there and there is a current flowing in the such system, there will be a power drop in the system and how much power it will consume, I square R.

And this much amount the power we are giving it to the platinum wire of the Pirani gauge. Now the same amount of power will also be delivered to the gas molecule so that is why if we adjust the bridge in such a way by changing only the temperature, which is like you know, you can consider as a independent variable here. So by changing or by measuring the current change to find out the null point or non-deflection point in the Wheatstone bridge, we can find out what is the corresponding change in the pressure.

So any deflection due to the current change or the current meters change is actually correspond to the change in the pressure.

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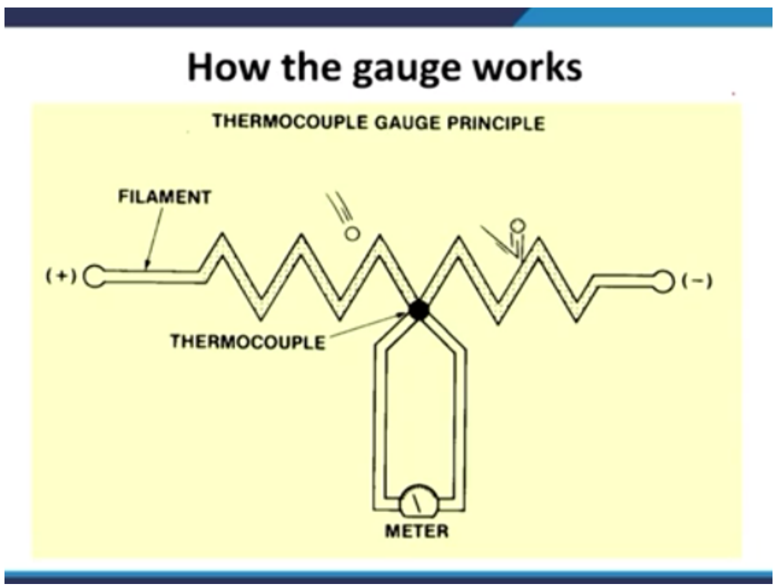


So thermocouple gauge principle as you have seen just like you know, I mean then there is a negative terminal, there is a positive terminal and we have a filament here and thermocouple is attached here and then there is a meter here.

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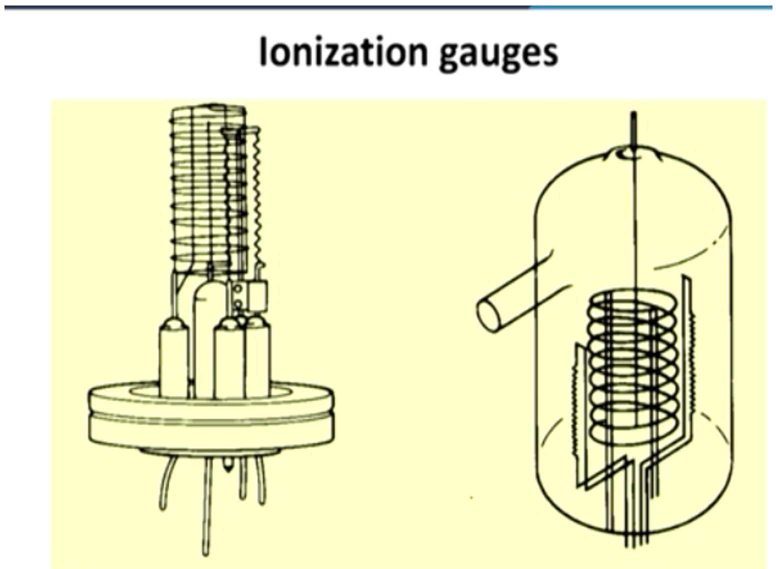


In addition to that, we have also ionization gauge now. As the name suggests, so ionization gauge works on the basis of the ionizations. Now to ionize, the gas molecule inside the chamber. Now to ionize the gas molecule inside the chamber, I need an electric current. So that is why inside these gauge, I need to have a system of generation of the electric current, which will eventually be able to ionize the gas molecule and the gauge will be able to measure that.

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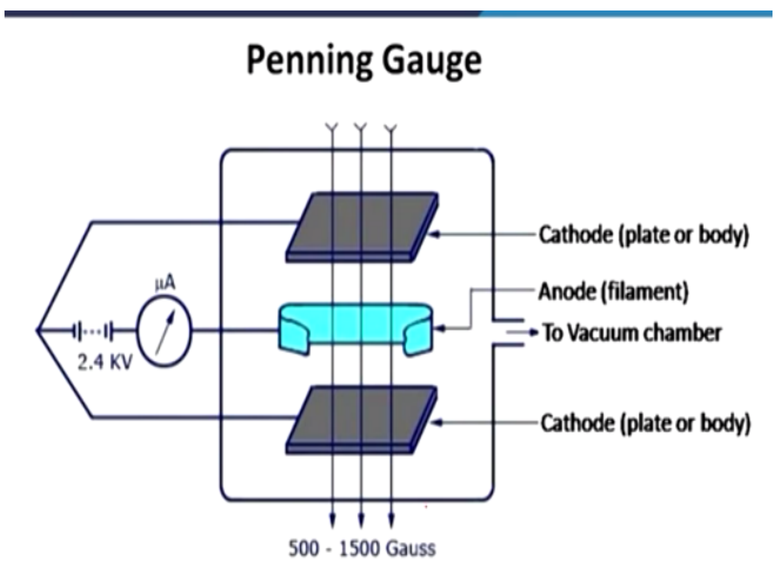


Okay so that the Penning gauge circuit in contrast to the Pirani gauge, like it consists of the two electrode, one is the cathode which is a plate or body and then there is an anode okay. So anode has a filament and then there is another cathode or the plate of the body is kept on the other side.

So that works like a grid and then this whole chamber is connected to the vacuum chamber, for which we wanted to measure the vacuum of the system.

And then this cathode is connected to the anode through an ammeter and there is an internal resistance and key is there and finally the circuit is complete by connecting it to the lower cathode. So any change in the cathode and anode bias or the current can be tuned by the second cathode also. Now what happens here, we apply a magnetic field in addition to an electric field in the system. Now in an electromagnetic field, we know how the charge carrier moves.

And we know like to balance the flow of electron in an electromagnetic field, we need a particular kind of force. So that kind of force will be counterbalanced by the corresponding change in the current, which is deflected in the connected ammeter, which is in an indirect measurement of the pressure in the Penning gauge okay.

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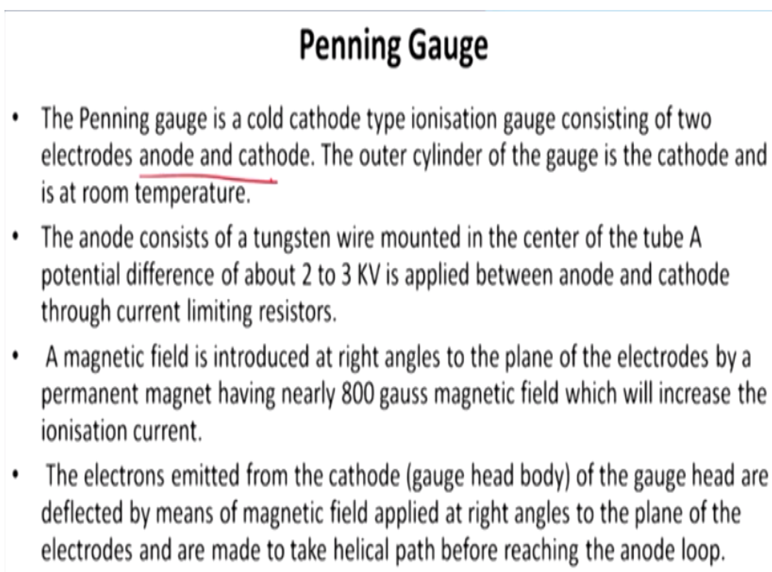


So the Penning gauge is a cold cathode type ionization gauge consists of two electrodes, anode and cathode. The outer cylinder of the gauge is the cathode and it is kept at room temperature. The anode consists of a tungsten wire mounted in the center of the tube A. A potential difference of 2-3 kilovolt is applied between anode and cathode through current limiting resistors. So again if you go back to our previous diagram here, there is a filament is there and then there is a cathode is there.

So we are applying a voltage of 2-3 kilovolt between this cathode and anode by this resistance right. A magnetic field is introduced at right angles to the plane of electrode by a permanent magnet having nearly 800 gauss magnetic field, which will increase the ionization current. Again go back to the previous picture. So you see that this arrow actually the direction of a magnetic field, which is applied perpendicular to the plane of the cathode and anode.

And the value can change from 500-1500 gauss and what is the reason behind putting the magnetic field, just to increase the ionization current okay. So what will happen to the electrons in the presence of the both electric and magnetic field? The electrons emitted from the cathode which is the gauge, head body of the gauge head are deflected by means of magnetic field applied at right angles to the plane of electrode and made to take helical path before reaching the anode loop.

So this is our basic electromagnetic theory. So you know that if there is an electron, it moves in an electric field, it moves in a constant velocity, but if I apply only magnetic field, it moves in a circular path, but if I apply both electric and magnetic field, then it will move in a helical path like this right. So that is why it is said here. So we are applying a magnetic field amount 800 gauss at a plane perpendicular to that between cathode and anode.

So then what will happen to the electron which is ejected from the cathode? So now they will follow a helical path, because now both the electric field and a perpendicular magnetic field is present there. So basically a Lorentz force is now working on the electron.

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## Penning Gauge

- Thus following very long path, the electrons ionize the gas by collision, even at low pressures. The secondary electrons produced by ionisation themselves perform similar oscillations and the rate of ionisation increases rapidly.
- Eventually, the electrons are captured by the anode and equilibrium is reached when the number of electrons produced per second by ionisation is the sum of positive ion current to the cathode and the electron current to the anode.
- This small current is calibrated to give a measure of the pressure of the gas and hence the chamber to which it is attached.
- The Cold Cathode Penning gauge can detect vacuum from 10-2 to 10-7 Torr or mbar.

Thus following very long paths the electrons ionize the gas by collision. So see there is a one more important factor of putting the magnetic field, not only to increase the ionization current, but if we put a magnetic field actually we get a helical path and once we have a helical path, then the time the electrons paint in the system is more in contrast to a straight line or a circular path. So what is the consequence?

Consequence if there is more time spent by the electron in the system, so the collision probability also increases, that means the electron can ionize more and more gas in the system. So even at low pressure the secondary electrons produced by ionization themselves part from similar oscillations and the rate of ionizations increased rapidly. So as the electron stays in the system more and more time, so what it will do, it will ionize the gas molecule. Once it ionizes the gas molecule, it will produce secondary electrons and these secondary electrons will also contribute to the ionization current. So the ionization current as a whole increases.

So that is what we said that putting the magnetic field we increase the ionization current right. Eventually the electrons are captured by the anode and equilibrium exists when the number of electron produced per second by ionization is sum of the positive ion current to the cathode and the electron current to the anode. Now an equilibrium will soon be released, because the total amount of current which is flowing from the cathode to anode that will be equal to the amount of current produced due to the ionizations.

So that both of them will be equal then will reach a equilibrium. This small current is calibrated to give a measure of the pressure of the gas and hence the chamber to which this attached. The cold cathode pinning gauge can detect vacuum from 10 to the power -2 to 10 to the power -7 Torr or millibar. So basically if you want to measure 10 to the power -2 to 10 to the power -7 millibar, which is a high vacuum, you can use Penning gauge.

So here the ionization current is a measure of the vacuum. As you can see in the diagram here:

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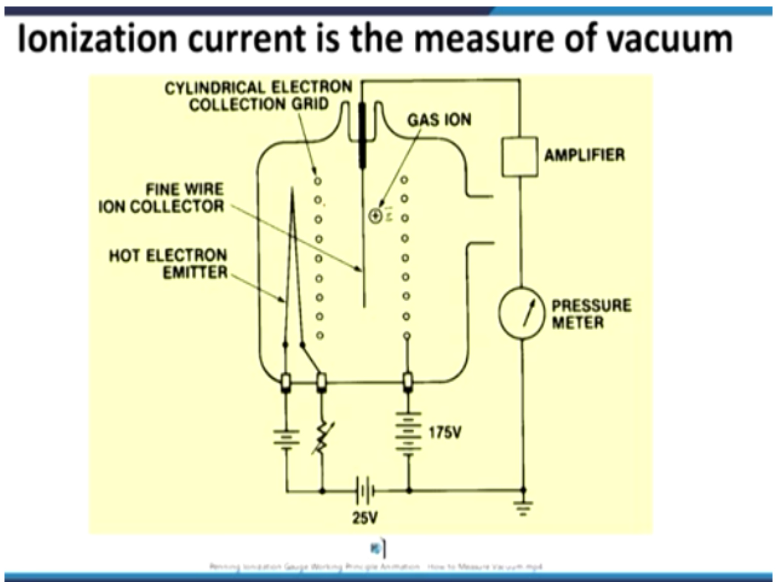


You see that there is a cylindrical ejection collision grid, it is here. There is a gas ion and then there is an amplifier, then there is a pressure meter, fine wire ion collector and then hot electron emitter. So whenever you ionize the gas molecule, there will be a balance between the current from the cathode to anode and the current due to the secondary ion produced. Now once there will be an equilibrium, we can amplify that and that the corresponding change of the current will be a measure of the pressure.

So to understand in a better way we have put forward a video, which will show you how this Pirani gauge works or how it measures the vacuum of a system okay. So now we learnt about how to measure or how to know that how much amount of the vacuum in my systems. So what you have seen that if we use a Pirani gauge and if we use a Penning gauge almost we can cover from atmospheric pressure down to 10 to the power -7 millibar, which exactly we need it for our solar cell devices.

Now the another question is that as I mentioned while I was talking from the perovskite solar cell, that a very control environment is required. Now by control environment I mean that a very control humidity level and control oxygen level and there also you create a partial vacuum. When you deposit electrode, when you deposit a metal electrode on the solar cell you need a vacuum also there, but many often inside your chamber there can be a leak.

Now how you can detect the leak? So that is also a very important question as far as the vacuum technology is concerned okay. So for example like you know, I will give you a very common everyday example that is your bicycle leaks.

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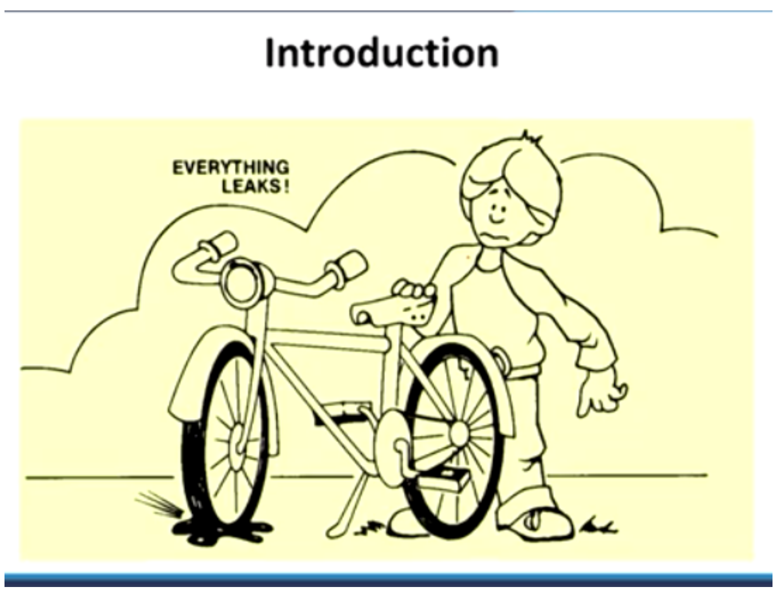


So everybody who rides a bicycle has an experience like you know if you ride the cycle to a very turbulent road, the tyre punctures and then how you measures that whether you have a tyre puncture or whether you have a leak in the tyre. So basically there is a no direct measurement what we see that as the pressure goes down the tyre, they deflates. So basically what it happens it sits down on the ground. So the effective pressure inside the tyre of the bicycle that get reduced.

But if you go to a bicycle shop, so they have a gauge which they can attach to these things and then they can find out like where is the exact leak, so that and in the earlier days usually there was no such gauge system. So the measurement of the leak detection was mostly based on the hearing the sound at the location where it is coming from and then they put is some kind of sealant there, but now they are this leak detection system are there.

So using that gauge you can find out where is that like leak is there, but the life is very easy here because we are not considering about very low pressure and even if a bicycle tyre leaks or even if a motorcycle tyre leaks, we can find out the leaks by the change of the sound or by looking at the tyre, because now it will deflates or it will like in an effective pressure change will be audible, but what will happen like let us say if there is a change of pressure from 10 to the power -2 millibar to 10 to the power -4 millibar.

So that is not audible or that is even not that you cannot visually detect it. So there should be an advance leak detection system to know that if there is any kind of leak inside my vacuum chamber. So there are several problems that can appear due to the leaks or problems that appears to be leaks and we should not be confused that this is a leak.

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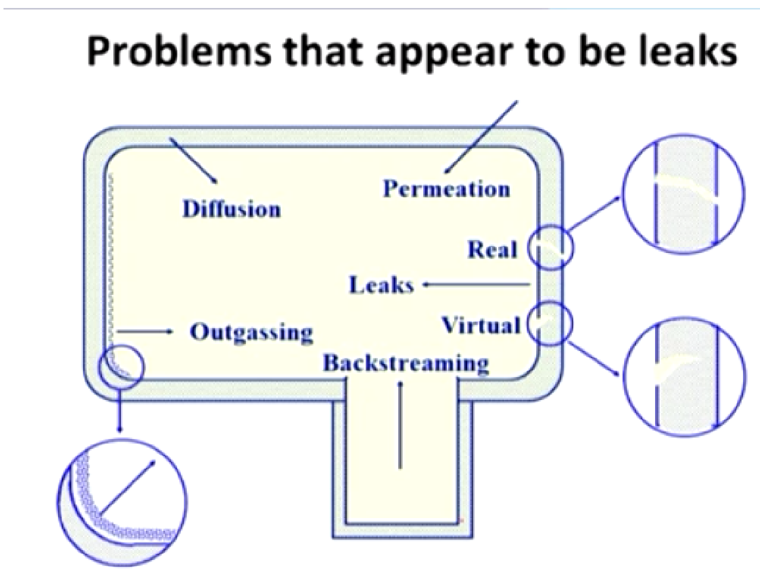


For example, there can be diffusion from the chair, from the inside or the outside wall of the chamber. There can be permeation that the gas molecule can permeate from outside to the inside of the chamber okay and then like you know after some time when the system degas or out gas it, so some of the residual gas molecule, which was stick to the wall of the chamber that can also come through here and then there can be also back streaming going back to the chamber inside.

And then the leak can be partial or virtual like it is extended to somewhat inside, but not the complete, but at the same time there can be real leak like that, where you can see that there is a real passage for the air flow or the flow of the gas molecule. So this is the real leak but the diffusion, permeation, outgassing and back streaming although this can lead to the reduction of the pressure of the change or the pressure.

Or if you have a palm down curve so if you know how much time you need to get a particular kind of pressure and if you do not get that pressure in that particular time, you might be suspicious that there is a leak in the system, but before coming to that conclusion one has to make sure about or one has to exclude all other possibilities like diffusion, permeations, right and degassing or outgassing and then back streaming.

Then only we can know about the leaks. Now leaks can be a real leak or a virtual link. A virtual leak does not extend to the whole wall, but a real leak can extend towards the whole wall. So that there is a really a channel has been created, so that the gas molecule can come outside and that change the pressure reasonably okay. Our problem is to find out the real leak. How can we find out where is the leak in the chamber?

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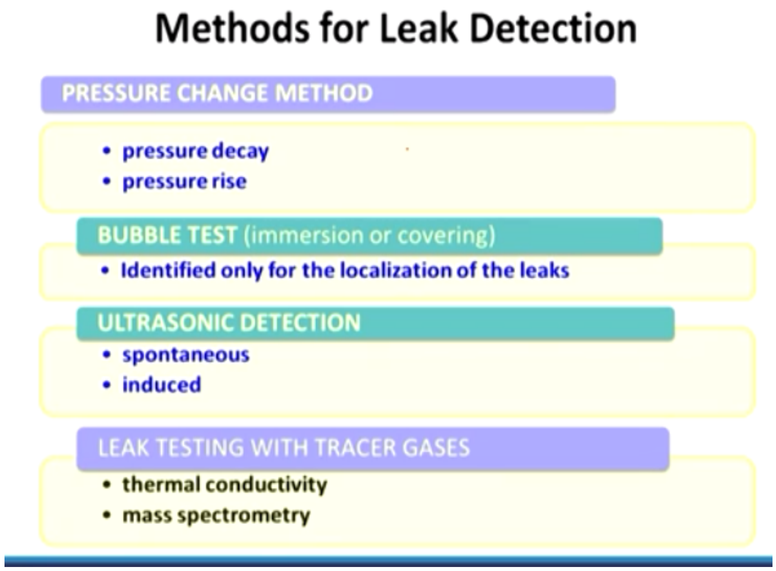


Now the methods of the leak detections, there are several methods for the leak detection, one very popularly used common technique is the pressure change method. Here you look for the pressure decay or you look for the pressure rise. The two things can happen either the pressure can be reduced or pressure can be increased. A common test which we use like you know is bubble test, which is an immersion or covering test identified only for the localization of the leaks.

So the bubble test can tell you where the leaks are there. Then there are ultrasonic, sound based detection system like spontaneous or induced and then the leak detection testing system with tracer gaseous, thermal conductivity and mass spectrometry.

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## Tracer Gases:Thermal Conductivity

These devices are mostly portable types as probes. The different gases are detected according to their different thermal conductivity.

These characteristics varies with dependence from molecular size and speed. They can be used with different gas or gas mixtures, since each of them produces a different thermal conductivity respect to the air.

Tracer gas like thermal conductivity as this instrument is showing here, these devices are mostly portable types as probes. The different gases are detected according to their different thermal conductivity. Well like let us say you have a leak in the system, so if you have a leak in the system, initially I have a vacuum chamber which is filled only with the nitrogen gas okay. Now there is a leak in the system. So what will happen?

All other gas from the environment will also enter inside the chamber. So now in addition to the nitrogen gas, you will also see hydrogen gas, you will also see oxygen gas inside your chamber. Now as we know that each and every gas has different thermal conductivity. So if I insert my thermal conductivity based meter or the tracer gas meter inside the chamber and if I get a signal of the thermal conductivity due to the hydrogen, oxygen in apart from nitrogen.

So I know that in addition to the nitrogen, I have also hydrogen, oxygen and all sorts of gas inside my chamber. That means there is a leak inside the chamber. So these characteristics varies with dependence from molecular size and speed. They can be used with different gas or gas mixtures, since each of them produce a different thermal conductivity respect to the air.

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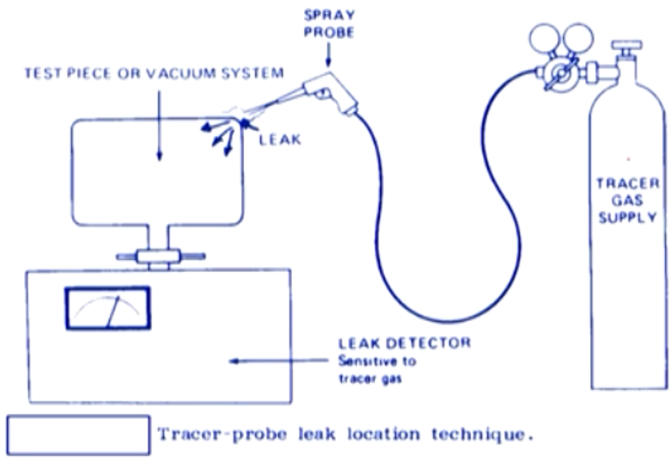
# Tracer probe leak detection technique




Tracer-probe leak location technique.

Tracer probe leak detection techniques, here there is a tracer gas supply which is connected like you know let us say you have a helium gas or nitrogen gas cylinder, which is connected to a tracer probe. Now this is the chamber, right. This is the chamber and on which we wanted to measure whether there is a leak or not and let us say there is a leakage here. So what will happen, this probe so that is this chamber that is connected to a leak detection, which is sensitive to a tracer gas and it.

Tracer probe leak detection techniques, here if I bring my probe to here, now the probe contains a particular kind of gas. Now due to the thermal conductivity change, so I will only see the signal corresponding to the particular gas, which I am using as a probe. Now that usually that probe I use whatever the gas is there inside the chamber. If there are some other gas in addition to the probe gas is there, then that signal will also be shown here.

So by looking at that system, we can see that exactly where there is a leak is there or let us say, I have a nitrogen, I mean this chamber is full of nitrogen gas and here I am using an oxygen gas cylinder okay. So this chamber is connected to this leak detection unit. So since it works on the thermal conductivity, so I will see a deflection which is based on the nitrogen gas thermal conductivity. Now I have this probe and I am rotating this probe throughout this chamber.

While I am rotating, there is no deflection, no deflection, no deflection. When I am coming to this point, there is a leak is there. So if there is a leak is there, then oxygen is like diffusing inside. So in addition to the nitrogen gas, now I have oxygen gas in the system. So suddenly I will see a change or a shift in the needle. So that will tell me, now in addition to the nitrogen gas I have also oxygen gas in the system that means this is the position where I have the leak.

So I can exactly find out where is the leak is there.

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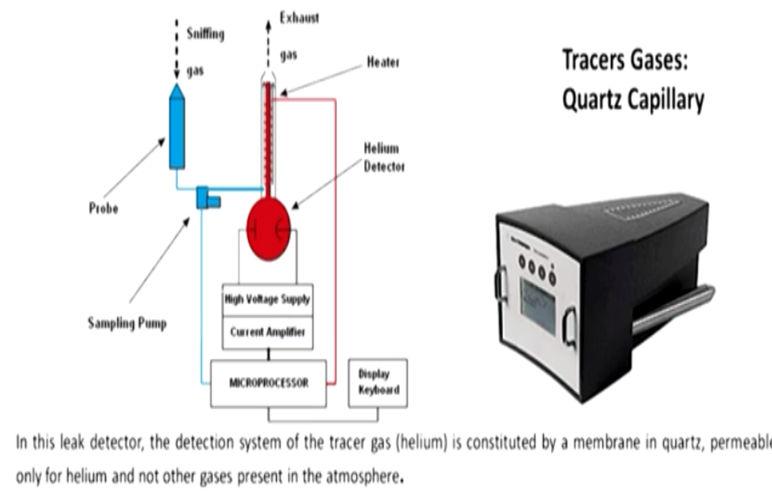


Now this tracer gas system can also be based on the quartz capillary like this instrument shown here is a quartz capillary based systems. So here the sniffing gas enters through this inlet which acts like a probe and this probe is connected to a high voltage supply and a current amplifier and finally this is connected to a microprocessors and the microprocessor actually display the change of the current and then there is a helium detector is there.

There is a heater here inside this system and whatever the gas is emitted from here that exhausts through there. In this leak detector, the detector system of the tracer gas helium is constituted by a membrane in quartz permeable only for helium and not for other gases present in the atmosphere. So in this leak detector, the detector system of the tracer gas helium is constituted by a membrane in quartz permeable only for helium and not for other gas present in the atmosphere.

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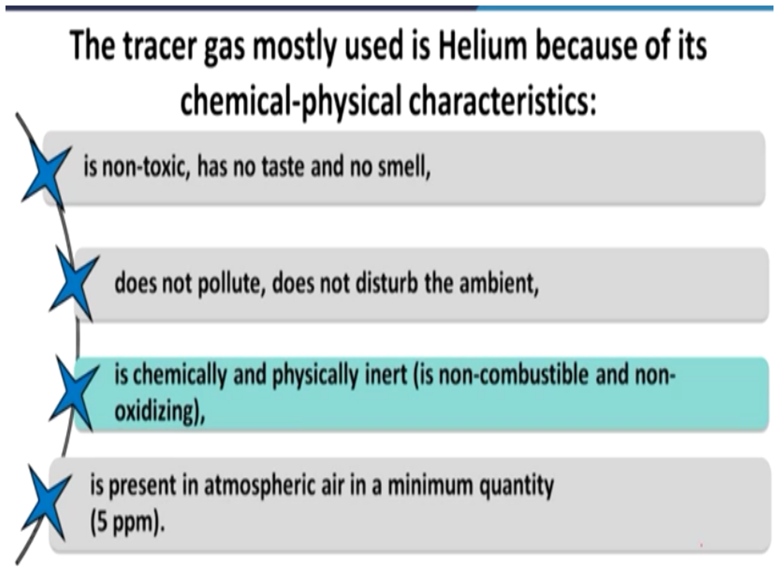


The tracer gas mostly used helium gas because of its chemico-physical properties. Well you all know that helium is a noble gas. It is an inert gas all right. So it is a non-toxic and it has no taste and no smell. It does not pollute, does not disturb the ambience. It is chemically and physically inert a very important properties. It is non combustible and non oxidizing. It is also non reactive. It presents in the atmosphere in a minimum quantity, 5 parts per million.

So because of all of this properties helium is mainly used as a tracer gas. Well like you know I told you when I was talking about the first two lectures that in the context of the vacuum technology, we use a particular jargons or particular words to define the connection parameters or to define the rings. So some useful fitting parameters we will discuss it here.

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And I will show you and solve this picture, so the next time you can see it, you can identify. Here we are showing some pictures of the flanges. So these are all flanges okay. Now flanges they can be standard quick reach. There are different commercial name for them like QF, KF, NW or DN. So whenever you see this kind of code, basically they are standard quick release flanges. So named based on the internal diameter. So for example if I have a DN16KF that is actually a 16 millimeter diameter of the flanges.

Large quick release they have name like LF, LFB, MF or ISO. So now if you see something like LF16F, so you know that there is a large quick release flanges, which is a diameter of 16 millimeter and then there are these clamps or bolts 63-500 millimeters and then the conflat used in ultra-high vacuum settings usually metal to metal seals. Let us say I wanted to make an STM machine or I want to make an SCM machine.

So there we need to maintain a very, very high vacuum 10 to the power -11, let us say. There we use the flat. So the sizing odd, Europe inner diameter in millimeter, but not applicable any outer diameter in inches. So from country to country also some of the nomenclatures and some of this parameters of terminology also changes. So today in this lecture, we have discussed about the different gauge systems.

So we have seen that there are two main gauge, which is used in the vacuum technology one is the Penning gauge and another is the Pirani gauge and these two gauges can almost cover all pressure regions. Now another important things we have learnt that not only the gauge, but you also know if there is a leak in the systems and we have seen that the trace detection system which is based on the helium gas.

And helium is a popularly used gas because it is not only the non-toxic, but it is also non reactive and we have seen that how positionally or how we can find out the location of a leak in a chamber by using this helium leak detector systems and we have also seen that some of the common terminology like flanges conflat which is used in the vacuum technology. So in the next lecture, we will discuss about once we make a solar cell or once we make thin films, now how will look the morphology of the thin films.

So if I use an optical microscope, then there because of the resolution issues will we not be able to see the all features of the film. So there we use an electron microscope. One of the very popularly used electron microscope is a scanning electron microscope. So very often when we make the device, we have to use the scanning electron microscope.

So in the next lecture, we will talk about what is the working principle behind a scanning electron microscope or how it works okay. So this is for so far for today. Thank you very much for your attention.