Experimental Methods in Fluid Mechanics

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Lecture 12

Low Pressure Measurement

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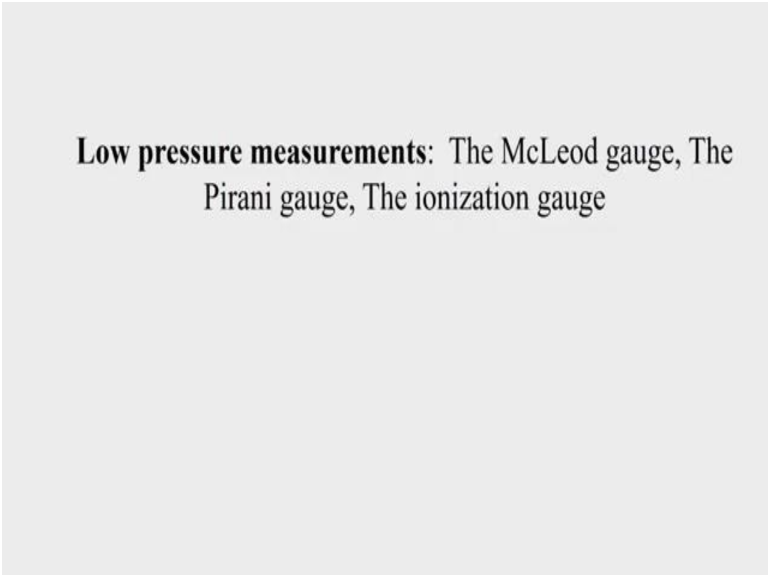

Good afternoon, I welcome you to the session of experimental methods in fluid mechanics today we will be discussing about low pressure measurement techniques and we will be discussing about McLeod gauge and Pirani gauge and their operational principle by how we can reserve low pressure which is very low and we have seen that rather we have discussed about U-Tube manometer, inclined well type manometer and different gauges.

And we have seen that using those gauges we can measure pressure, which is not very low, but quite low to very high pressure. So if you would like to measure very low pressure, and then there are a few instruments, we should know them, and we should know their operational principle. And to start with, today we will be discussing about the McLeod gauge. And we will see the principle upon which they operate, and how we can measure a very low pressure using this device.

So, one important point that I would like to mention here, that measurement of low pressure, I mean experimentalist will be using these kinds of devices instruments to measure low pressure, this would take a special care rather I can say, this measurement of low pressure needs rather, demands a considerable attention and a great deal of care, otherwise we cannot measure. So, now we will see that the McLeod gauge which is used to as a low pressure we will see the typical range of pressure, which we can measure using this gauge using this device. And of course, we will see how their operational principle.

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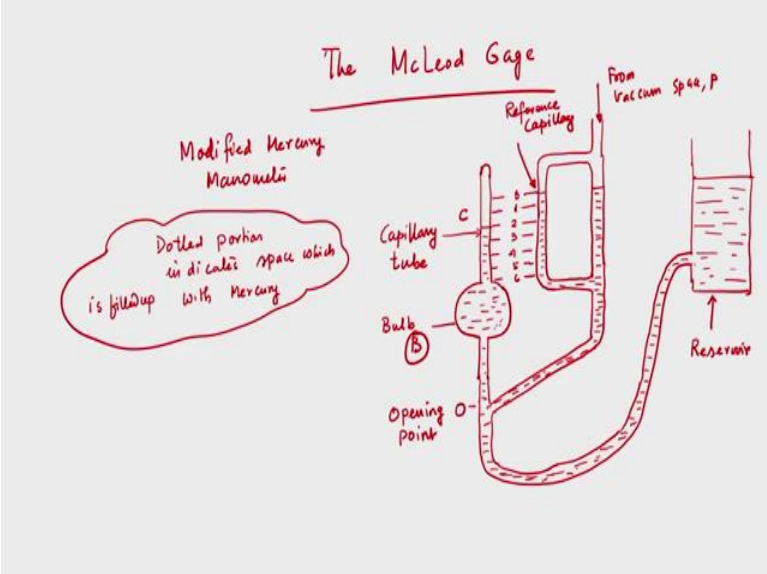

So we will now see the McLeod gauge the McLeod gauge. So, I will try to so the gauge schematically, then I will try to explain and it will it will help us to understand the operational principle of the McLeod gauge if we try to describe through schematic depiction. So, I am drawing the schematic depiction of the McLeod gauge. This gauges, I mean this gauge is having different parts.

So, this is a schematic of the McLeod gauge, this is schematic, this is not at per scale. Now, we can see from the schematic that the gauge is having 3 different parts, rather 4 different parts. One is this, this is known as Bulb B, this is known as Bulb B and this point O which is known as opening point and right hand side extreme this is reservoir and this person rather this tube is known as capillary tube, capillary tube C and this is you know from vacuum space and pressure is say P and this is a reference capillary, so this is a reference capillary.

Now, this is the inner schematic of the McLeod gauge. Now, as I said that experimentalists who will be using this gauge to measure low pressure, here he should take special care, we should discuss what are those care, I mean an experimentalist should take. So now, rather I can say this is the modified you know Mercury manometers.

So this McLeod gauge is essentially a modified mercury manometer, and the reservoir, this dotted portion that means, this portions is filled up with the this dotted portion filled up is indicating so this dotted portion indicates mercury filled up, indicates space which is filled up with mercury, so this is what we should know.

Now, how we can measure low pressure using this McLeod gauge, so now I will write the steps one should follow to measure low pressure using this gauge, then we will explain why we need to follow those steps and why we are following the steps, then ultimately how we can measure low pressure using this gauge. So, now I will be writing this you know, the steps which you need to follow while measuring low pressure.

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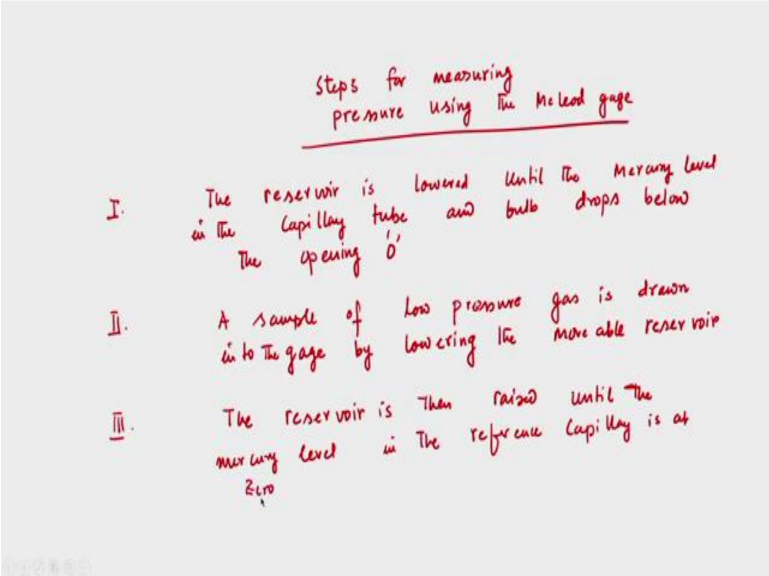

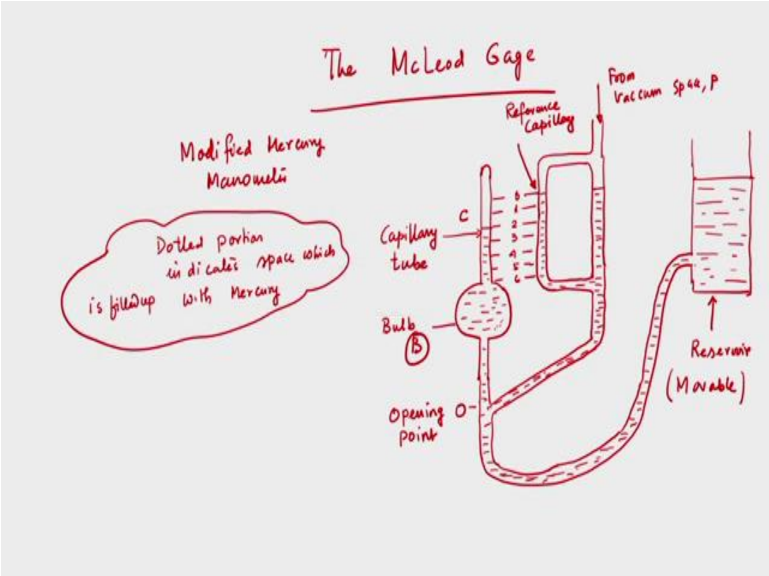

So, the steps for measuring pressure using the McLeod gauge. So, one, I am writing if I go to the my previous slide, so the reservoir which is movable. I am writing here this reservoir is movable that means this reservoir can be you know altered so that reservoir can be you know, lowered or it can be taken at a higher level so this is movable, reservoir is movable. So, as a first step, the first step is the reservoir level, the reservoir level is lowered until the mercury in the capillary tube and bulb drops the mercury level, I can say mercury level in the capillary tube and bulb you know drops below the opening O.

So, as a first step what we need to do, we need to lower the reservoir, while you are lowering the reservoir location, mercury in the capillary tube also in the reference capillary and from the bulb will mercury level will drop and the reservoir should, reservoir will be taking in a lower will be taken further down until the mercury level drops below the opening point O. So, this is the first step.

Now, while we are doing this. See, while we are lowering the reservoir location and because of this you know, movement of the reservoir further downwards, mercury level in the capillary, reference capillary and in the bulb will drop and at the same time, at the same time a sample of low pressure gas is drawn, you know, into the gauge by lowering the movable reservoir.

So, that means, while we are lowering the reservoir, a sample of low pressure gas is drawn into the gauge and also the mercury level in the capillary tube reference capillary and the bulb drops and this, you know, lowering or the movement of the reservoir is continued until the mercury level drops the opening O. So, these are the first two steps. So, these are the first two steps we have seen and while we are executing these two steps, we can see that the mercury level will drop and at the same time the low pressure gas will be drawn into the gauge and these two you know steps, the experimentalists should follow with a special care.

Now steps three. So, the first two steps is important to know that we are bringing down, we are lowering, rather we are allowing the low-pressure gas will be drawn into the gauge and at the same time the mercury level will drop. Next what we need to do? Next step is, the reservoir is again raised, the reservoir is then raised until the mercury level crosses, sorry mercury level in the reference capillary, in the reference capillary, the reservoir is then raised until the mercury level in the reference capillary is at 0.

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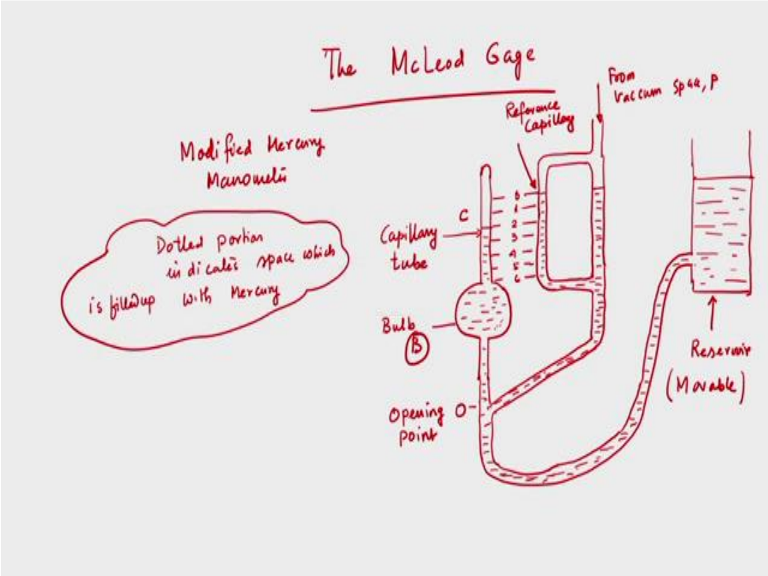

So, now, if I go back to the previous slide, then the third step is then since the reservoir is movable, now what we will do? We will you know, take the reservoir slowly you know in its original position rather we will have the movement of the reservoir half and while we are having this movement the mercury will now cross the point O, it will fill up the bulb, it will fill up I mean mercury will, you know now fill up the capillary and also it will fill up the reference capillary, but the condition is that we need to have a reservoir movement until rather we will have a continuous movement of the reservoir towards the towards its original location.

And this movement will be continued until the mercury level in the reference capillary that is shown by the 0 point. So, the marker level in the reference capillary is at the 0 location. So, maybe while the mercury is reaching at 0 location in the reference capillary, the mercury may not reach that level in the capillary tube, but our objective is to move the reservoir until the mercury level in the reference capillary reaches at the 0 location so this is the third step. Now, while we are executing these three steps, what is happening?

So, now, if we look at the second step then what we can see that during the, you know, movement of the reservoir your, I mean downward movement of the reservoir, we have seen that the low-pressure gas is drawn into the gauge. Now, the gas low-pressure gas now is getting compressed whenever the reservoir is now taken to the taken to its original position that means when the reserve is moving up.

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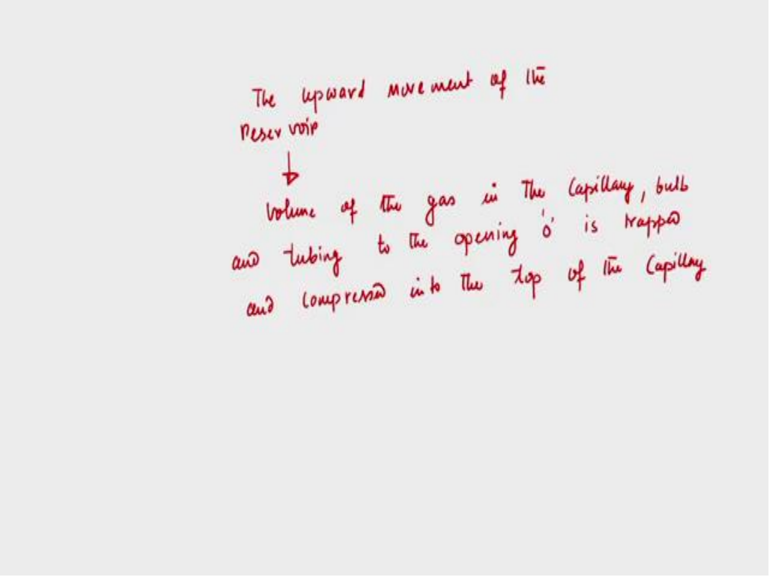

So, what will happen that the upward movement of the reservoir, the consequence of this movement is that volume of the gas in the capillary, volume of the gas in the capillary bulb and tubing to the opening O is trapped and compressed into the top of the capillary that is what, top of the capillary. So, this is the consequence of the upward movement of the reservoir. So now, volume of the gas in the capillary bulb and also the tubing to the opening O is trapped and compressed into the top of the capillary.

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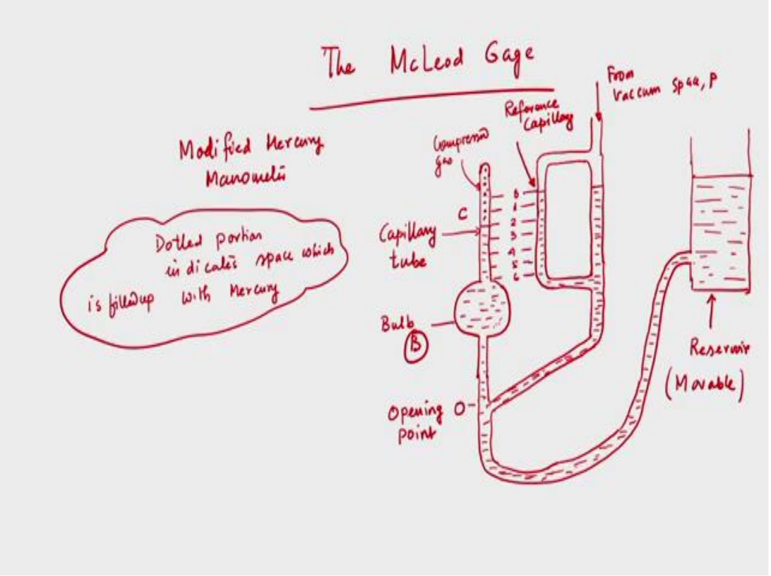

So, here we can see the drop of the capillary this is this portion is now having compressed gas, so this is the compressed gas. So, because the gas which is getting trapped due to the downward moment of the reservoir will be compressed as the mercury level goes up. So now, we will do, we will do small method vehicle analysis.

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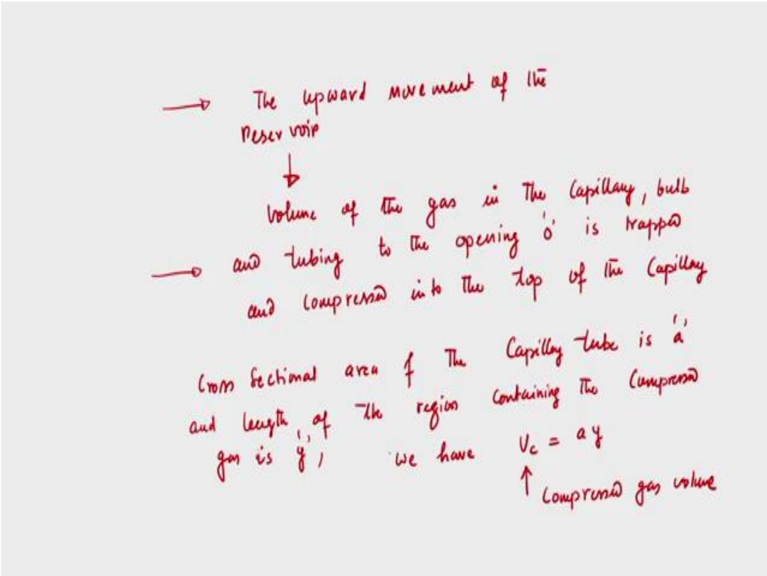

Say, the cross sectional cross sectional area, cross sectional area of the capillary tube, not the reference capillary is small a and length of the region containing the compressed gas is y, we have V c is equal to a into y where V c is the compressed gas volume so where V c is the compressed gas volume. So this is straightforward, very easy that if the cross sectional area of the capillary tube is a and the length of the region containing the compressed gas is y, then the compressed gas volume is a y.

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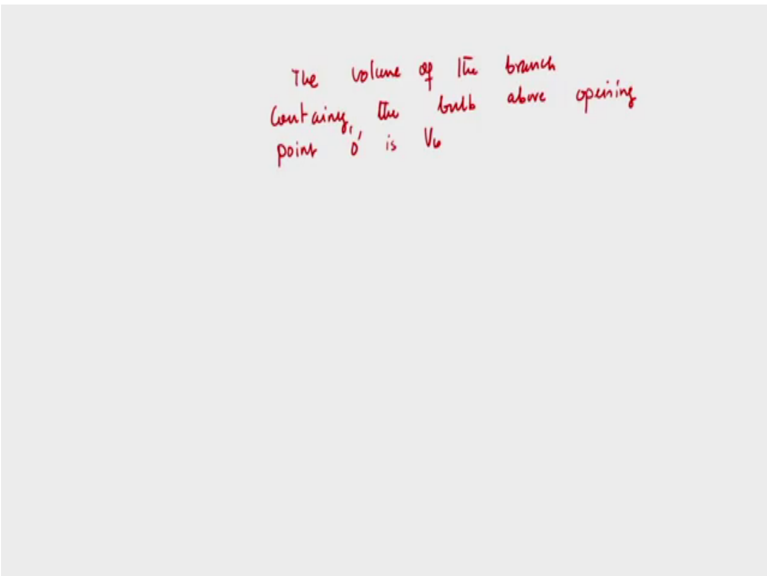

And if we consider that the volume of the branch containing the bulb containing the bulb above opening point, above opening point, O is V b. So, we are considering the volume of the branch containing the bulb.

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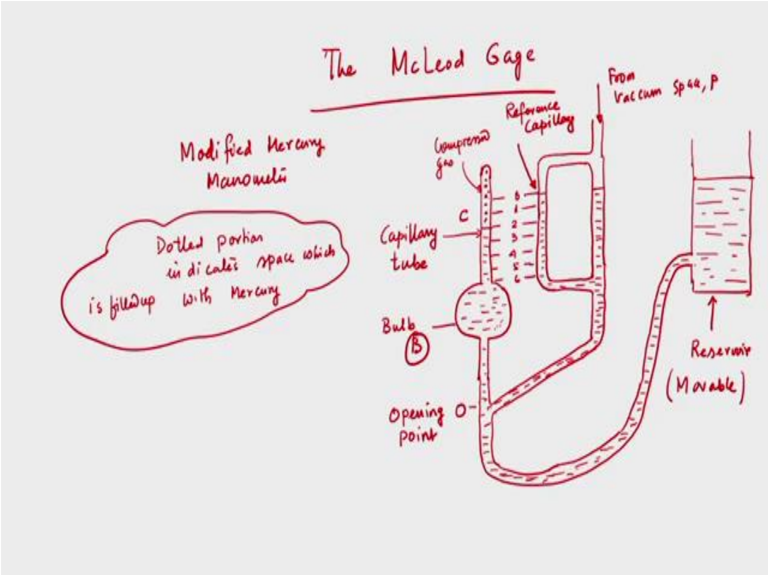

So if we again go back to the slide, where we have schematically depicted the McLeod gauge, so the gauge is having two parts, two branch, two different branches. One branch is having capillary tube and the bulb, other branch is having reference capillary. So, now the branch which is having above the opening point O, which is having bulb and the volume of that branch containing the bulb above opening point O is V b.

So, now, we have understood that essentially what we are doing, we are taking gas into the gauge by lowering the reservoir location and then whenever the gas is getting trapped in the branch which is having bulb and the capillary tube. So, now when we are allowing reservoir to go up, rather we are taking reservoir to up in its original position and the mercury level is going up.

And the movement of the mercury will now will try to compress the gas which is getting trapped in the capillary tube. So and this, the process is continued until the mercury level in the reference capillary is at the 0 location. So, the gas which is getting trapped will have further compression, if we consider that compressed process is isothermal.

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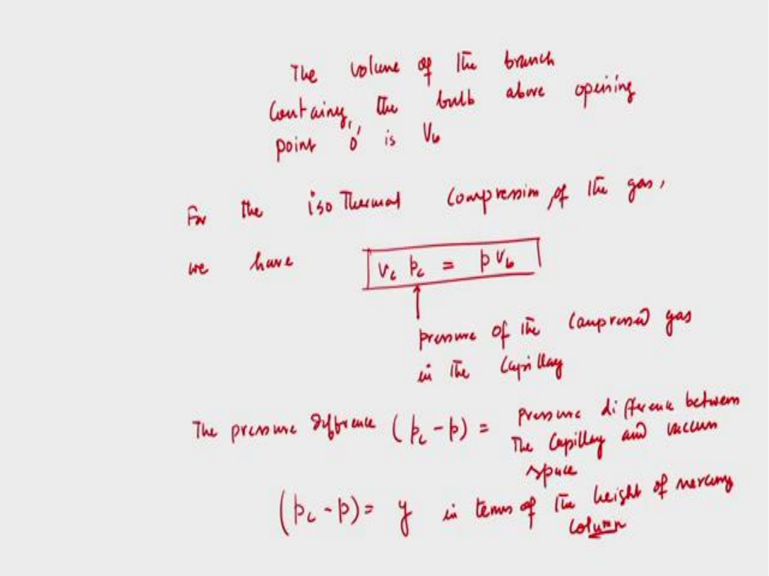

So, if the, rather I can write, for the isothermal compression, so for the isothermal compression of the gas we can write rather we have V c into P c is equal to P into V v. So, V c is the value of the compressed gas in the capillary, P c is the pressure and P c is the pressure of the compressed gas, so P c is the pressure of the compressed gas in the capillary. So, this is for the isothermal compression process.

Now, the pressure difference this P c will be definitely higher than P because the gas is in the compressed state, we have compressed the gas by taking the reservoir in its original position rather towards its original position. So, it indicates that the pressure rather gas which is getting trapped in the capillary and the trapped volume is pressure of the trap volume is P c.

So, P c will be higher than the P and the pressure difference P c minus P that is nothing but so the pressure difference between the capillary and the vacuum space. So, this indicates the pressure difference between the capillary and vacuum space. And this P c minus P, I can consider this is y in terms of the height of mercury column.

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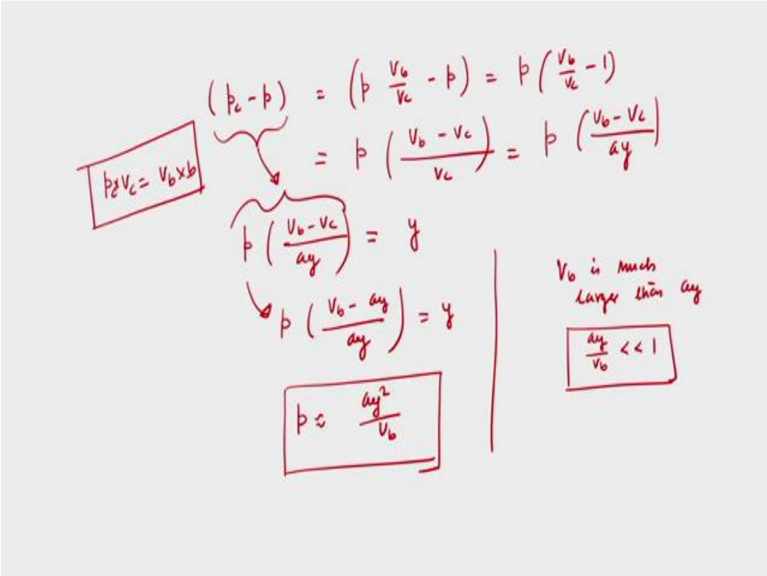

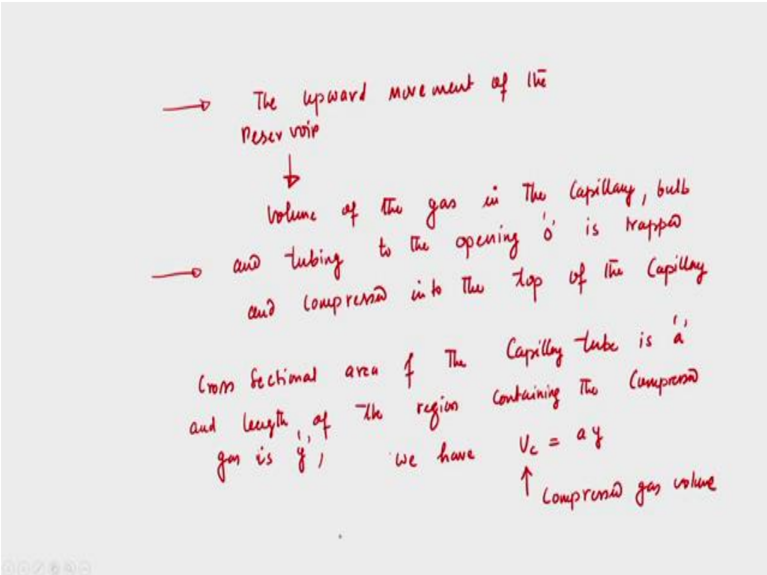

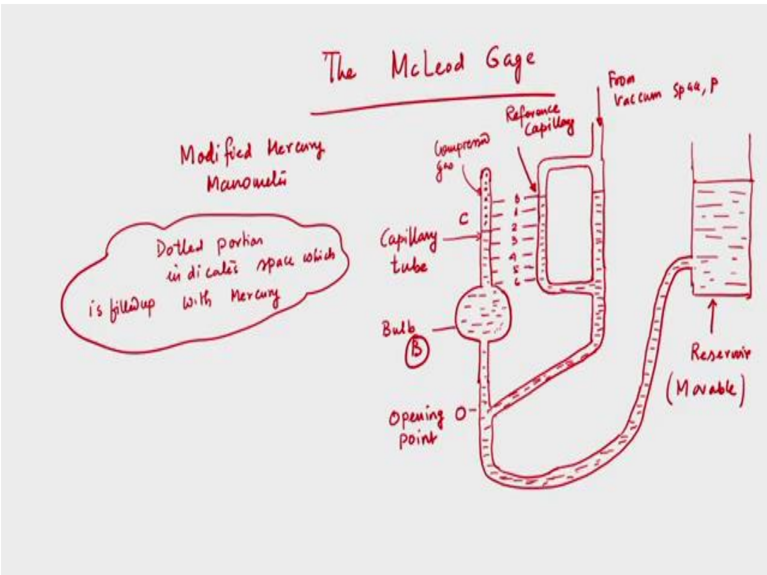

So now, if I go back to the, you know, this slide. Where we have written the cross sectional area of the capillary tube is a and length of the region containing the compressed gas is y? So, as if this P c minus P, which is the pressure difference between the capillary and the vacuum space and that we can write that is our length y in terms of the height of the mercury column. So, that is the height of the mercury column in the reference capillary, so that essentially indicates the pressure difference.

So, if we write a few I mean a few steps further, then we can write this P c minus P is equal to you know P into V b by V c minus P that is P into V b by V c minus 1 because P c into V c is equal to V b into P from the previous expression we have seen for the isothermal compression of the gas we have this relation. And just if we have plugged in the middle of P c, I have written P c in terms of P and we are getting this, so I can write this is V b minus V c by V c. So, this is again P into V b minus V c divided by V c.

If I go to the previous slide, where I have written the length rather the volume of the compressed gases a time y, where y is the length of the region containing the compressed gas. And this y is again indicates that the pressure difference between the capillary and the vacuum space.

So, now, V c I can write in terms of a into y, and that V c minus p so that means p into V b minus V c by a y this is the P c minus p. So, that is the pressure difference and that is what we have seen we can write that in terms of y that is the, you know height of the mercury column. Now, we can see that P is equal to so P into V b minus a y by a y that equal to y, and P into V b by a y.

And so, now if we go to the previous slide here we can see that the you know, V b is much larger than a y because volume of the bulb is rather much much larger than the volume of the compressed gas. So, if we write this that V b is much larger than a y so then we can write that P is equal to a y square V b so P is equal to a y square by V b. So, rather I can write that a y V b is much much less.

So, that is we have written that the pressure which is nothing but a y square by V b, note that. So, the pressure vacuum pressure very small pressure that is why we have used the terminology you know vacuum space very small pressure which can be retained in terms of a y square by V b, where we know a, we know V b, but what we need to measure that is the y, length of the, you know, height of the mercury column.

So, if we can measure y and for that we need to have very accurate measurements, we need to have we need to take special care and from there we can get rather we can measure the pressure because all the values are known. Now, one important thing is that we can measure very low pressure of course, and the typical value we can measure using this McLeod gauge is I mean gauge pressure of course.

So, the gauge pressure from about, sorry, we can measure low pressure very low rather very low pressure even less than 1 torr or 133 Pascal you know, we can measure it. But, of course, the measurement of this low pressure we can have using this McLeod gas. But using this McLeod gauge if you would like to measure low pressure, we will rather the experimentalist will encounter considerable difficulties and he or she requires a good deal of care, otherwise he or she cannot measure, he or she will come up with a wrong measurements.

Now, see, if you would like to measure very low pressure which is even less than 1 torr or 133 Pascal, then of course, it is quite straightforward that someone who will be using this gauge a special care should be taken. We have seen that there are many other conventional gauges like you know, U-Tube manometer then, other Bellow gauges, diaphragm gauges, those are there, we can measure with a low pressure I mean quite low to very high, we can measure even low pressure using those gauges with you know high resolution manometer or the diaphragm Bellow gauges. but we cannot go beyond a particular value.

So, if you need to measure up, I mean if you need to measure which is extremely low that we cannot measure using conventional pressure gauges, that is what I said just now that diaphragm gauges, Bellow gauges and also the high resolution manometer, we need to rely on this kind of McLeod gauge and other type is also there. But one thing is the experimental should take special care about it.

Now, when you are talking about this McLeod gauge to measure low pressure, we have seen that basically the moveable reservoir, the movement of the reservoir towards the down, towards its further down will allow the low pressure gas to be taken in the into the gauge and in the next step, whenever we when we are taking the reservoir in its high position then the movement of the mercury will try to compress the gas which is getting trapped. Now, the moment of the reservoir which is continued until the mercury level in the reference capillary is at 0.

So, the gas which is getting trapped in the capillary, which will have further compression. So, there is a possibility that the compression of the gas. So, if the vapour is there in the gas which is getting trapped and when we further compress the gas, the vapour might condense. So, that issue is only the important point we need to consider and there is a possibility of having error if we do not take a special care on this aspect.

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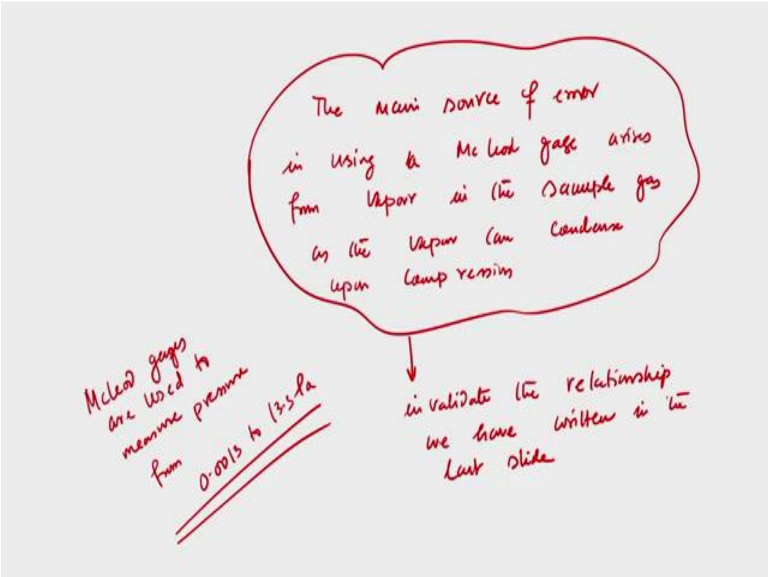

So, again I am writing that if the gas low pressure gas. So the main source of error, I am writing the main source of error in using our McLeod gauge arises from vapour in the sample gas, as the vapour can condense upon compression. And this if you do not take care and it may invalidate the relationship we have written in the last slide, in the last slide.

So, if the gas, sample gas is having even small amount of vapour and if the vapour will start condensing as it compressed further, so that is the main source of error a McLeod gauge have. So, but this issue should be taken into consideration, otherwise the measurement using the relationship we have discussed may not be valid. So, and as I said you that the measurement disk, disk y that is very important that we need to measure otherwise we will come up with the wrong results.

And using this pressure gauge, we can have a very low pressure that is what I said in the last slide and only the one source of error I mean we have identified that if the sample gas contained the vapour otherwise, there is no other major sources of error which experimentalist will face or will experience while measuring pressure using this low pressure gauge.

So now again I am writing, this McLeod gauge are used, rather gauges are used to measure pressure from 0.0013 to 13.3 Pascal. So, we can see the range of pressure this gauge can measure, I mean the range is from 10 power minus 3 to 10 square so basically, I mean of the order of 10.

So, huge range this McLeod gauge can measure and so, it is so, measurement is so accurate and so difficult, I mean measurement is so difficult that we need to take special care otherwise, we will come up with the wrong results. So, the McLeod gauge is one of the gauges used to measure low pressure, we have seen and we have discussed about the operational principle upon which this instrument works.

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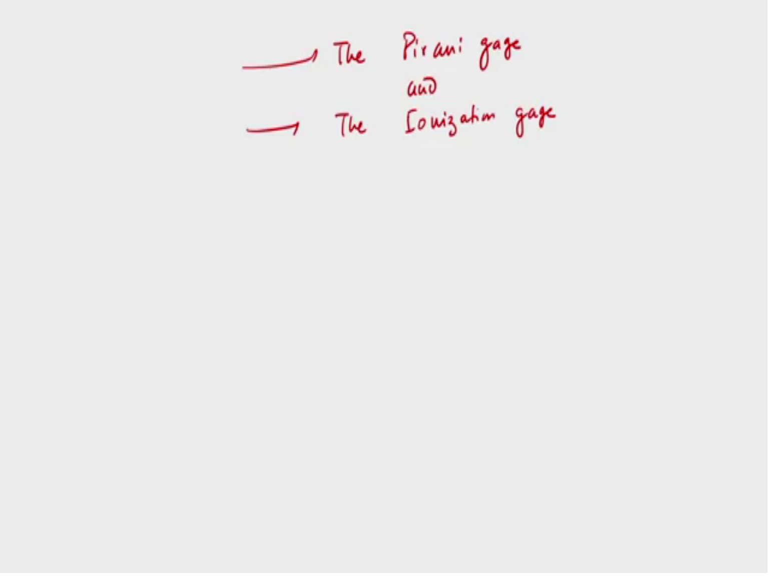

Now, other important gauge is there which is known as the Pirani gauge and the ionisation gauge. So, apart from the McLeod gauge there are other two different gauges available, which are also used to measure a low pressure; one is the Pirani gauge, other is the ionisation gauge. And this the Pirani gauge which is you know which exploits the reduction in effective thermal conductivity of gas with pressure in the region of low pressure.

So, that means again we are using the one property of the gas that is the reduction in the effective thermal conductivity of the gas in the region of low process. And this is used to measure I mean in order to measure the pressure which is near vacuum pressure. So, we can see that by measuring the change in effective thermal conductivity of the gas of course, in the low pressure region, we can say that we can measure we can calculate the what is a low pressure which is close to the vacuum pressure.

And we will discuss the working principle of the Pirani gauge and also we will be able to discuss about the ionization gauge and of course, through their schematic depiction, how they are working and the typical range of pressure they can measure. And of course, several issues we need to consider while measuring pressure using these two gauges, and those aspects we will discuss in the next class. So, with this, I stop my discussion today and we will continue my discussion in the next class. Thank you.