# Experimental Methods in Fluid Mechanics

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## Lecture 23 - Ideal Gas Thermometer, Temperature Measurement by Mechanical and Electrical Effects

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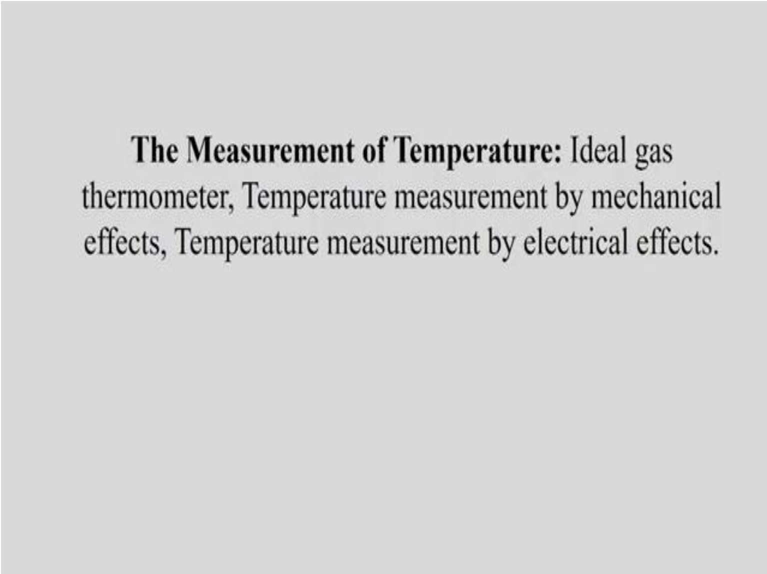


Good afternoon, I welcome you to this session of Experimental Methods in Fluid Mechanics. And today, we will discuss about the measurement of temperature, I mean different techniques by which we can measure temperature. And in this module, we will be discussing about the ideal gas thermometer and then the temperature measurement by mechanical effects and also by the electrical effects. So, we will start our discussion today with the ideal gas thermometer. We will see that the ideal gas thermometer is used for measuring temperature which is even less than 1 degree k, so, we will discuss about the ideal gas thermometer using a schematic depiction of that device, and then we will discuss that how we can measure a small temperature using this thermometer.

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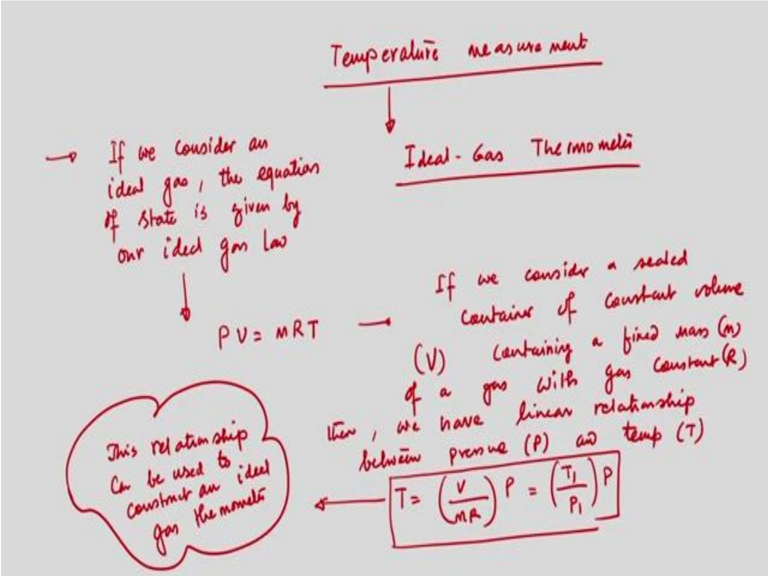


So, first I will discuss about the temperature measurement and that is the ideal gas thermometer. So, this ideal gas thermometer now, say if we consider an ideal gas, I am writing if we consider an ideal gas the equation of state is given by that we know in fact, we have studied this from our 10 plus 2 level course and also in our undergraduate thermodynamics course, that the equation of state is given by our ideal gas law and that is nothing but P V is equal to MRT.

Now, this is one part, second part, say if we consider a sealed container of constant volume V containing a fixed mass m of a gas with gas constant R then, so if we consider so we are considering ideal gas, the Navy's ideal gas thermometer we are considering ideal gas and the equation of state is given by our ideal gas law and furthermore, we are considering that we have a sealed container and the sealed container of constant volume V and the container is containing a fluid mass m of a gas with gas constant R, then we have no linear relationship between pressure and temperature. And that means if we fixed, if we consider a sealed container having constant volume and of course, gas constant is R then we have a linear relationship between pressure and temperature and we can write T is equal to V by MR into P.

So, see, this V by MR I have kept these 3 parameters within bracket, V is constant because we have considered a sealed container having constant volume of having fixed mass that is M and R is equal to constant. So, this is nothing but T1 by P1 into P. So, why I am writing like this? Now, question is this relationship which can be used to construct an ideal gas thermometer, so that means I can write this relationship can be used to construct an ideal gas thermometer. So, the theory is that ideal gas thermometer we need to know which is used to measure temperature rather I can say very small temperature which is even less than 1 degree K.

And while we are using ideal gas thermometer, we should know the operational principle rather when we are talking about ideal gas thermometer then the concept behind it that how we can measure that we need to know so, that means T is equal to constant and that constant is nothing but T1 by P1. Of course, that if we now closely look at this expression, we can say that rather I can say from this expression, this expression we can say that the thermometer can be calibrated by examining one point where temperature is T1 and pressure is P1, that means this relationship is used to construct a thermometer or by construct an ideal gas thermometer.

And if we see this expression, we can say that this thermometer can be calibrated by examining at least one point where temperature is P1 and T1 that means, if we know the temperature and pressure P1 and T1, we can calibrate and which is very convenient.

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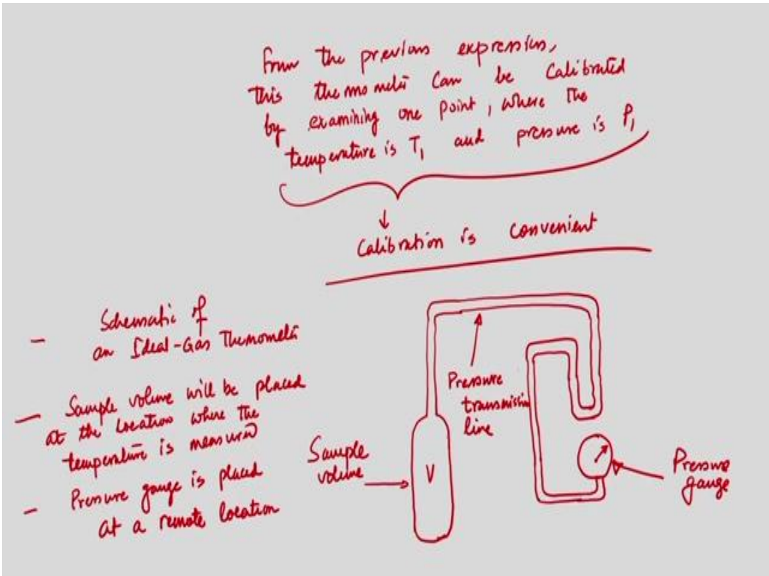

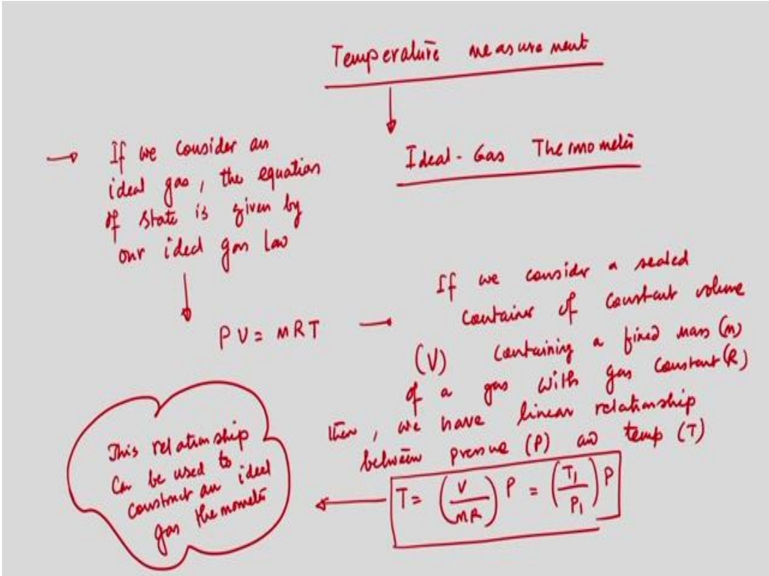


So, now I can write in next page that from the previous expression this thermometer can be calibrated by examining one point, where the temperature is T1, pressure is P1 and this calibration is convenient. So, this calibration is convenient. Now, if we try to now draw the schematic of an ideal gas thermometer, so from this expression, so, if we try to draw schematic of an ideal gas thermometers then so, we should now draw the schematic depiction of this ideal gas thermometer and which will help us to understand how we can measure temperature using this instrument. Now so, this is the pressured transmission line, this is pressure gauge and this is as I said, that sample volume V, so this is sample volume V.

So this is the schematic of an ideal gas thermometer. Now we will explain that how we can measure temperature so, what you can see from the schematic is that the sample volume is placed in one location where temperature of course will be measured. So this sample volume I can write now, this sample volume is or will be placed, I can write sample volume will be placed at the location where the temperature is measured. So this is the sample volume and we place sample volume over here where the temperature will be measured and pressure gauge is placed at a remote location so, these are important. Now, what do we do? We used the volume of the gas to measure the temperature. So, if we go back to my previous slide, so, we essentially used a volume of the gas to measure temperature and that volume of course that is we can see from the V.

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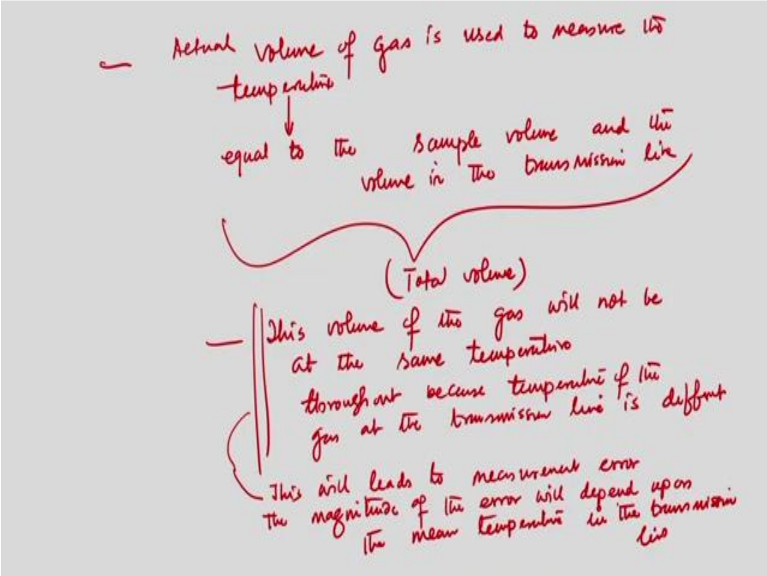


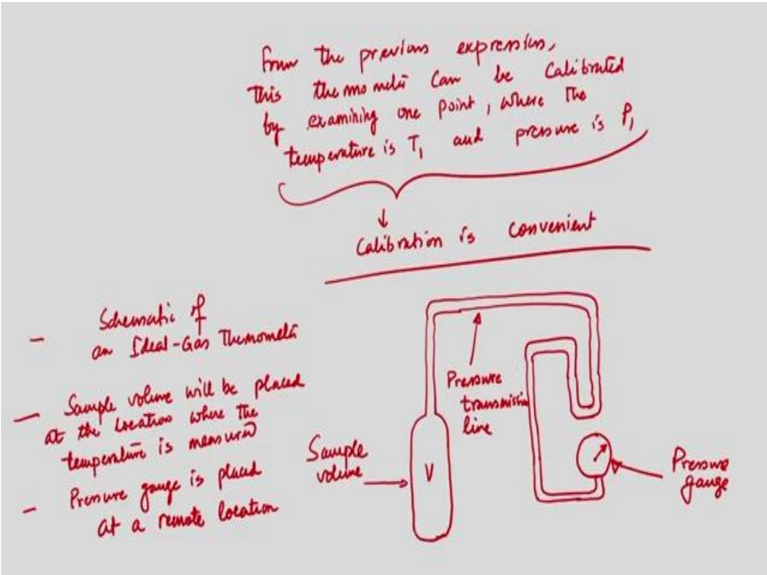


Now, so we can write that so, volume of the sample volume of gas is used to measure the temperature that is important, but, actual volume that is used to measure the temperature is the total volume of the sample volume. So, I cannot say, so, I can write the volume of the gas is used to measure the temperature or the actual volume of the gas which is used to measure the temperature is equal to the sample volume of the gas and the volume in the transmission line, I am writing because this is very important we should know.

So, the total volume that is used to measure, the actual volume of the gas which is used to measure the temperature is the total volume that is the volume of the sample plus the volume that is there in the transmission line. Now if this is the total volume, so this is the total volume and this total volume is not at the same temperature, that means that the volume of the gas, so this volume of the gas will not be at the same temperature throughout, why? Because temperature in the transmission line will be definitely different, that means what I would like to say, I would like to say the volume of the gas which is used to measure the temperature.

Now, the actual volume which is used to measure the temperature is the total volume that is the volume of the sample plus volume in the transmission line now, since the transmission line will be at a different temperature, so I mean the volume of the gas, the total volume of the gas will not be at the same temperature because temperature of the gas transmission line is different. That means, if we use this concept to measure the temperature of a sample volume and eventually, we are using the volume was used to measure the temperature and this is the total volume. So, we cannot ignore or we cannot trivially ignore the volume that is there in the transmission line.

Now, if I go back to the previous slide, then it can be seen, the sample volume that is placed over here that volume is of course will be used, this volume is nowhere responsible to measure the temperature, rather the total volume that is used total volume is responsible for the temperature measurement. Now, this is the place where I would like to measure the temperature, but that this temperature will not be the temperature of the total gas because the temperature of the gas in the transmission line will be different and because of this, this will lead to error.

So, this will lead to measurement error and the magnitude of this error will depend and the magnitude of the error will depend upon the mean temperature of the gas in the transmission line, mean temperature in the transmission line. That means the volume of the gas which is there in the transmission line will be responsible for the measurement error and the error, the degrees of, I mean the magnitude of error, the that will depend upon the mean temperature of the gas of the transmission line. Now question is and it is not only the mean temperature but also the relative volume of the gas which is sample volume in the pressure transmission line. So, this will leads to measurement error and the magnitude of error will depend upon the mean temperature in the transmission line.

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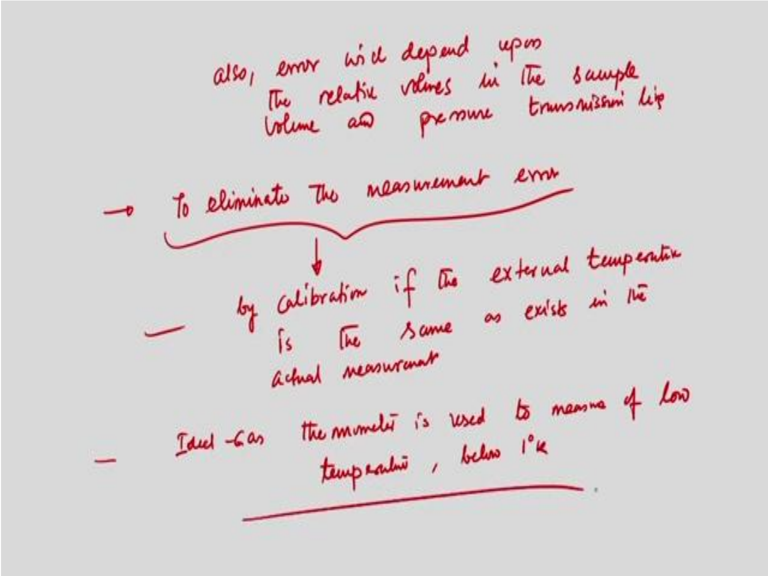


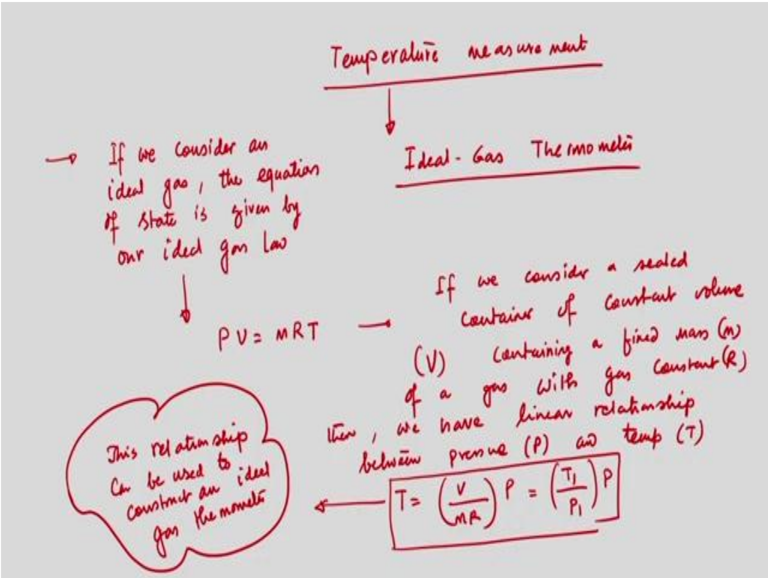


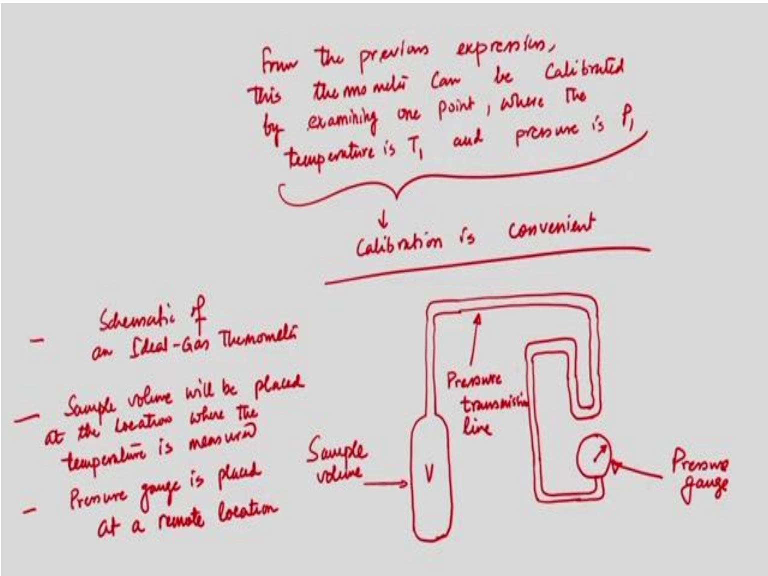

And also error will depend upon the relative volumes I can say of, relative volumes in the sample volume and pressure transmission line. So, these two are the possible sources of a rate through which we will get the measurement error. Now, so, since we have identified the possible sources of error, I mean, when you are using this ideal gas thermometer when you are using the gas volume to measure the temperature then we need to know how we can eliminate these errors.

So, basically now, if you would like to eliminate the errors, so, to eliminate in order to eliminate measurement error what are the things we need to know? That means, if we need to eliminate the measurement error that what we can do, that means, we can calibrate that means by calibrating by calibration if the external temperature that external temperature is the same as exists in the actual measurement. So, that means this error can be eliminated by calibration of course, if the external temperature is the same as exist in the actual measurement. So, this we can, we have seen that using this, by doing this calibration we can reduce the error.

Now, as I said this ideal gas thermometer is used to measure of low temperature below 1 degree K. So, that means if I go to the my first slide, we can say that this T1 and P1 this is very important that I can write T equal to T1 P1 into P. So, that means, if we somehow can measure the gas pressure and if we know the temperature T1 and P1 so, that means, if we calibrate from the previous expression, this thermometer can be calibrated, that is what I have written. It is examining 1 point, I know the temperature T, if I know the temperature T1 and then corresponding pressure is P1, from there we can now have the measurement but again you have identified that there will be possibilities of having measurement error. And we have also discussed that by doing calibration, we can reduce the error and this is suitable for the low temperature measurement and which is below 1 degree Kelvin.

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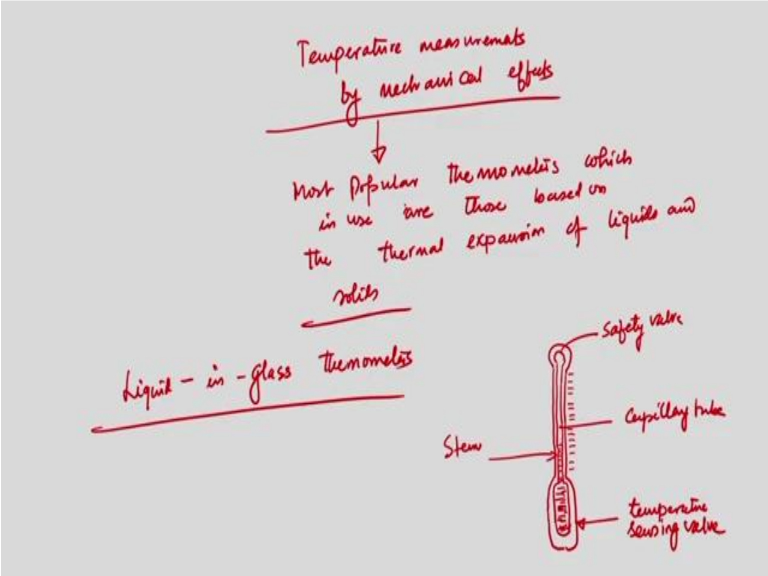


Now, that we need to know how we can measure temperature that is temperature measurement by mechanical effect. So, these two things we need to know. Basically, if we say that temperature measurement by the mechanical effect of course, we have discussed the thermometer so, most common type the most popular thermometers which are used to measure temperature are used, are those based on the thermal expansion of liquids and gas. That is what we have seen from our, we have studied from our 10 plus 2 level course and as well as the undergraduate physics course, that most common type thermometers or the most popular thermometers are which are in use, used the thermal expansion of the solids and liquids.

So, basically when you talk about thermal measurements by mechanical effect that is we are using thermometers. So, I mean most popular thermometers which are in use which in use I can say, which in use are those based on the thermal expansion of liquids and solids as well as solids. So, now, so we have to discuss about at least one or two cases where you will see that how we can again, I measure temperature using the expansion of the liquid and solids, of course, using the thermometer.

So, now we will discuss about liquid in Glass thermometer that is what we have seen and we have studied in class 10 plus 2 level. So, liquid in glass thermometer that is I have, I can now draw the schematic that now this is the liquid. So, this is liquid and we have scale that is what we have studied and this is safety valve, this is capillary tube, this is stem and temperature sensing valve. So, this is the temperature sensing valve, that is what we have studied. Now question is the volume of the liquid is known to be proportional to its temperature.

Now, the liquid that is used we know the volume of the liquid is known to be proportional to its temperature, thus the liquid in the temperature sensing valve that is there, that this liquid is there. So, this is the liquid, the liquid in the temperature sensing valve will expand. Now, if we place this temper in a thermometer, liquid in glass thermometer, in situation wherein or in our real experiments where you would like to measure temperature, now the temperature, liquid which is there in the temperature sensing valve will expand.

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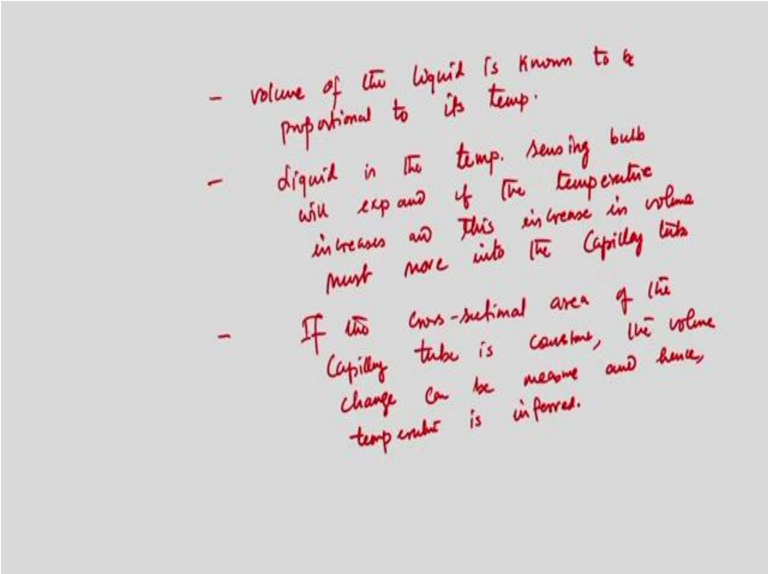


And as I said, so there are a few things that we need to know. First of all, one thing is that, first of all, volume of the liquid is known to be proportional to its temperatures. Now, liquid in the temperature sensing valve will expand, that is quite common. If the temperature increases as I can say temperature, the temperature increases and this increase in volume must move into the capillary tube. Now, question is that means, we know the volume of the liquid which is known to be proportional to its temperature.

Now, when we place the valve, temperature sensing valve in places where temperature is higher and that temperature we are interested to measure, now upon receiving heat the liquid will expand and that liquid when the liquid is expanding, that will move into the capillary tube. Now, question is if the cross-sectional area, I can write again I am writing if the cross-sectional area of the capillary tube is constant, the volume change can be measured and hence temperature can be inferred.

Now, so if we maintain the capillary tube cross-sectional is constant then volume change can be measured and we can measure, we can infer the temperature. Now question is, however, the length of the temperature K scale also will expand, change as the stem also will expand because with temperature, the stem will expand as well as the length rather I can say that length of the temperature scale also will expand or they will also change.

And this effect that means, with increasing temperature, valve rather stem will expand and because of this expansion of the stem, the scale, the length of the temperature scale also will increase also will change. I cannot say increase or decrease, that will depend on the temperature or on also the situation in which we are using this thermometer. But, because of this again there will be error, but this effect should be accounted for in the measurement.

So, this liquid in glass thermometer is easily set by the calibration and so, we do not require, we do not have any requirement to employ correction, if we have used the thermometer correctly. That means, if we have used the thermometer correctly, we need not to employ any kind of correction, because the temperature liquid and glass thermometer is usually set by the calibration and but one thing that is again I am telling that with a changing temperature the stem will increase, the stem will expand as well as the length of the temperature scale also will increase or decrease depending upon the temperature I mean where which we would like to measure, but this effect should be accounted for in the measurement.

So, this is the liquid and glass thermometer. I mean, now, this is the basic principle that is what we have discussed, where we can use the temperature using the mechanical effect and there are several types of, different types of liquid in glass thermometer, which are or that are in use.

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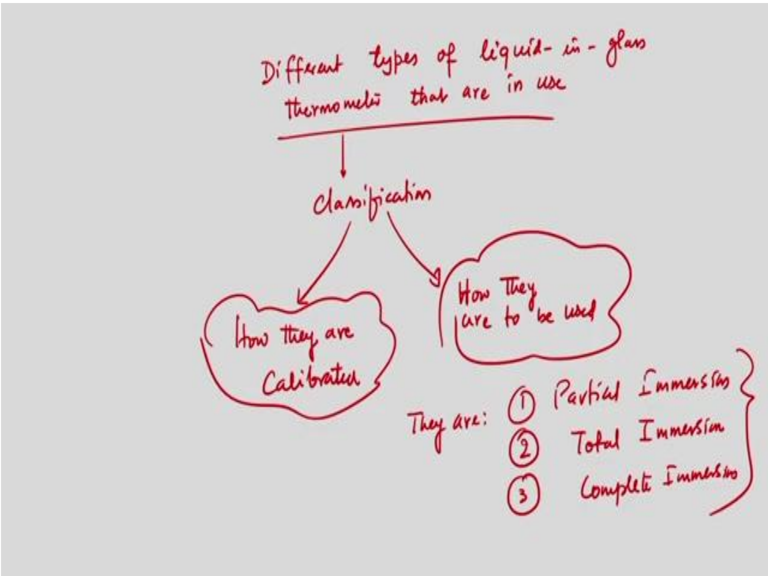

And so, I can say there are different types of liquid in glass thermometers that are in use. Now, where you try to classify, I mean knowing the fact that there are different types of liquid in glass thermometers, then we need to know how we can classify. So, classification is based on how they are calibrated and how they are to be used. So, basically, I can say the classification, this classification is basically how they are calibrated and how they are to be used. So, these two are the important, I can say basis by which we can classify liquid in glass thermometers into different two different categories, fine.

So, now I mean, if we try to know that what are the different types, so basically they are, so these are there, number one, partial immersion type; number two, total immersion type; number 3, complete immersion type. So, basically these two are the important basis by which we can classify the liquid in glass thermometer into different categories. But, and even if we can classify based on these two basis, the I mean different classes are the partial immersion, total immersion and number three is the complete immersion. So we should know a little bit about these 3 types and then we will go to see another mechanical type.

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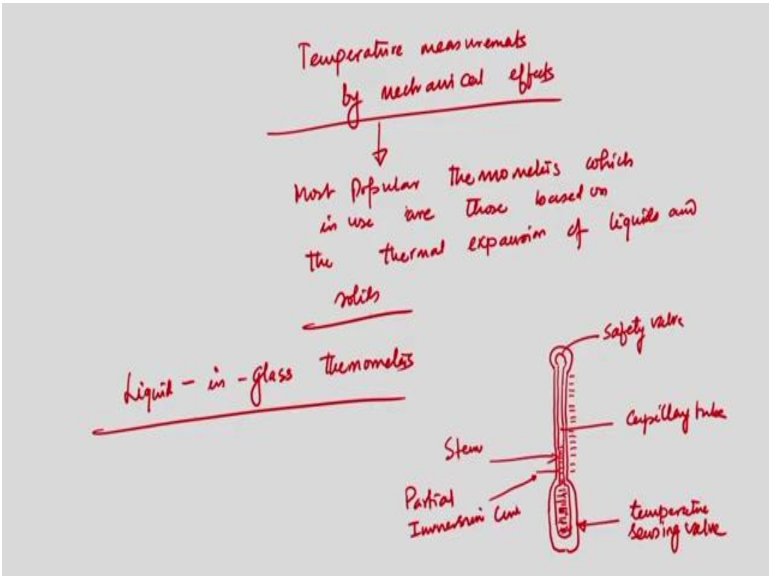

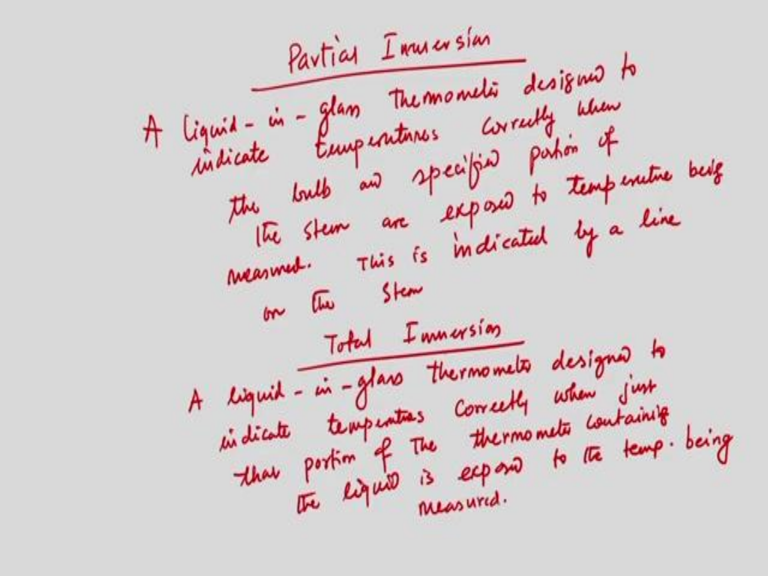


So if we talk about partial immersion, I will write in details and then so first one is partial immersion. So, basically liquid in glass thermometer of course. So this is liquid in glass thermometer design. If it is partial immersion type, liquid in glass thermometer is designed to indicate temperatures correctly when the bulb and a specified portion of the stem are exposed to temperature being measured. So, that means, this is a partial immersion type.

This is also a liquid in glass thermometer and this liquid in glass thermometer is designed in such a way that the temperature will be measured correctly when bulb or small portion or specified portion of the stem are exposed to the temperature which is being measured and this is indicated by a line on the thermometer stem and if we go back to my previous slide, so this is indicated by a line on the thermometer stem on the stem. So, basically this is partial immersion.

So, if I go to my previous slide where I have drawn the thermometer, so, this is the line, so this line is partial immersion line, so, I can write this is partial immersion line. So, this is partial immersion line. Next is the total immersion so, then we can see this is total, that means a liquid, this is also a liquid in glass thermometer total immersion type, which is designed to indicate temperature correctly of course, because our objective is to measure temperature correctly using this thermometer.

So, when we are defining different types of thermometer of course, liquid in glass thermometer then we have to say that this is also a liquid in glass thermometer which is designed to measure temperature correctly when just when just that portion of the temperature containing liquid is exposed to the temperature being measured. So I am writing so this is again, a liquid in glass thermometer which is designed to indicate temperatures correctly when just that portion, which portion?

That portion of the thermometer containing the liquid is exposed to the temperature being measured. So again, we have studied all these in our undergraduate text and also 10 plus 2 level, but just to recapitulate, so, this is total immersion type when a liquid in glass thermometer is designed to indicate the temperatures correctly when just that portion of the thermometer containing the liquid that is the, if I go back to the previous slide, where it will be clear or it can be seen clearly that this is the temperature sensing valve. So, that means what I can say that just that portion of the thermometer containing the liquid is exposed to the temperature being measured.

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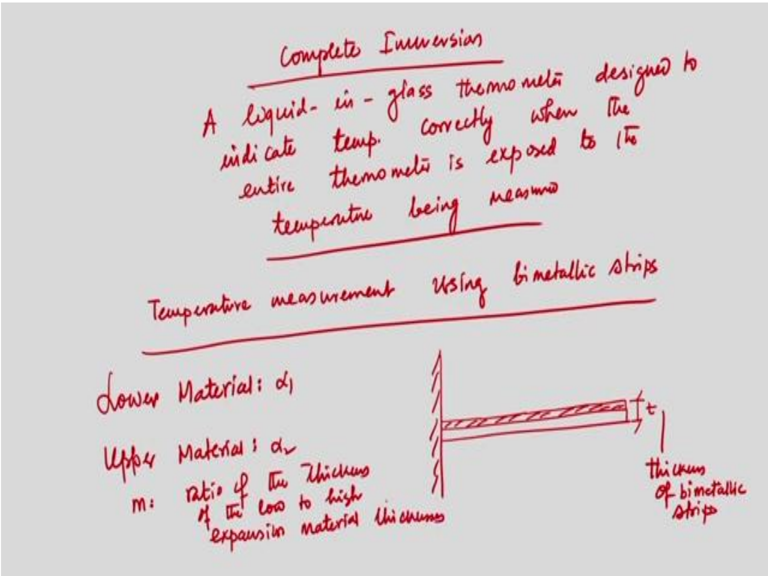


And now is the complete immersion, this is the final one. This is the complete immersion. So, this is also liquid in glass thermometer and this is also designed to indicate temperature correctly when the entire thermometer is exposed to the temperature being measured. So, this is the total that the entire thermometer will be exposed to the temperature being measured.

Now, the total and complete immersion liquid in glass thermometer can be used as the partial immersion thermometer because, if we go to my previous slide, then if we look at the partial immersion that is when the valve and the specified portion of the stem are exposed to the temperature being measured and this is indicated by line of the stem. Now, this total and complete immersion type liquid in glass thermometers can be used as the partial immersion type if a correction is employed. Now, so, these are the different issues.

Now, question is the temperature correction if we can employ correctly then only I can use this complete immersion and the total immersion thermometer as the partial immersion parameter. So, now, this is what we have seen and we have studied again I am telling in our undergraduate text as well as 10 plus 2 level physics. So, we are not going to discuss in details, just to recapitulate we have discussed, another thing we will discuss about that we have we can use, we can measure temperature using bimetallic strips.

So, temperature measurement using bimetallic strip so, this is another mechanical effect we can exploit to measure the temperature. Now, see consider if we consider two different I can say material with different thermal conductivity, different thermal expansion coefficients, and if we can bond them together say and I can show schematically. So, if I try to show schematically say if we have kind of two different material, say, I am trying to show the schematic of that, so, this is one material and we have another small material of that is what a different thermal, so this is and total thickness is T and then radius of curvature is infinite.

Now, these two different materials having different thermal expansion coefficients are bonded together. Now, lower and upper material have thermal expansion coefficients say lower material and upper material, I can write lower material and upper material. So, lower material say we have thermal expansion coefficient alpha 1 and this is alpha 2, total thickness of the bimetallic strip, this is bimetallic strip because two different materials are bonded together having different thermal expansion coefficient and we are considering the thickness of this bimetallic strip is T and ratio of the thickness of low to high thermal expansion material will be denoted by m.

So, now, question is, as I said that these two materials have different thermal coefficient, expansion coefficient and that is what alpha 1 and alpha 2 and this t is the thickness of 2 or I can also write bimetallic strips. So, one metal strip is taken over other metal strip now, and m this is very important that is nothing but I can say ratio of thickness of low to high expansion material thickness although the thickness of the bimetallic strip is a combination or a summation of the thickness of two different material, but the ratio of the thickness of low to high expansion material thickness will be denoted by m. So, this is nothing but a ratio of the thickness of the low to high expansion material thicknesses, so, this is m. Now question is and then also we need to define our ratio that is nothing but n.

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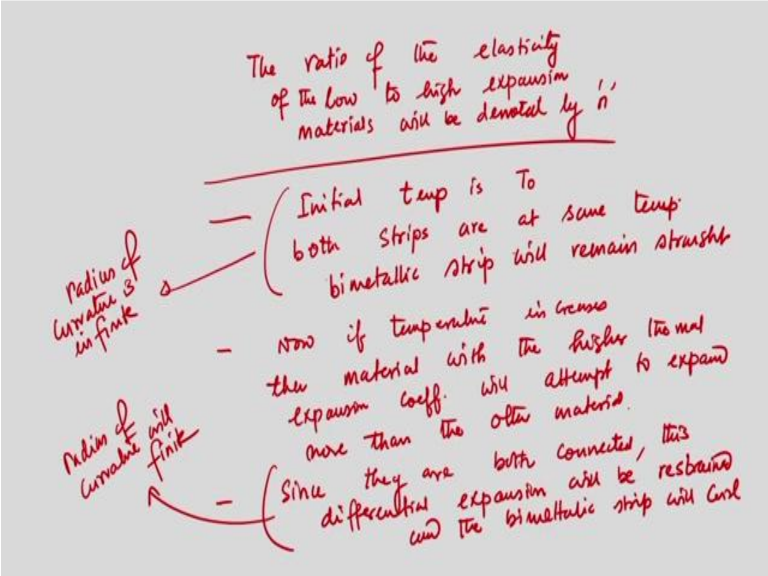


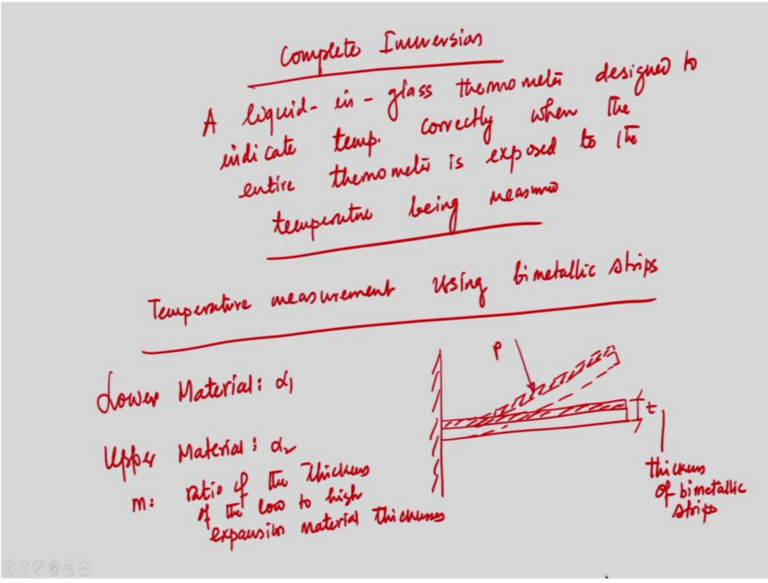


So the ratio of elasticity also will be different elasticity of low to high expansion materials will be denoted by small n. So, these are that parameters you have defined; number one, that is elasticity of low to high expansion material is n and similarly, thickness that is ratio of thickness of low high expansion materials, thicknesses is denoted by m.

Now, what will happen if the originally when we have bonded these two material together if the original temperature is T naught and temperature has not changed, the bimetallic still remains same. That means, when if that initial temperature of both the materials are, both the metallic strips are kind of like and say any constant T naught then they will remain straight but now, if there is a kind of change in temperature, that means, they will remain straight and the radius of curvature will be infinite. But now, what will happen if temperature increases, then the material with higher thermal expansion coefficient will attempt to expand. Of course, that is quite obvious, and that expansion will be more than the other material.

Since they are both connected, they are bonded together, what will happen? This differential expansion will be restrained and the bimetallic strip will be called. So, what will happen, say initially, initial temperature is T naught, both strips are at same temperature, bimetallic strip will remain straight. Now if temperature increases, then material with the higher thermal expansion coefficient will attempt to expand and expand more than the other, more than the other material.

Now, this will happen. Now since they are both connected, this differential expansion will be restrained and the bimetallic strip will call. So, (())(55:43) straight and I can write, so that means radius of curvature is infinite. Now for this particular case, radius of curvature will finite. Now, that means, if we go back to my previous slide, then I can write that what will be the radius of curvature. Now, I mean, if we go to my previous slide, so that means, the new shape will be like this. Similarly, so, this will be the new position of the bimetallic strips and this radius of curvature R will have the finite value. Now, what is important? This radius of curvature will have the finite value.

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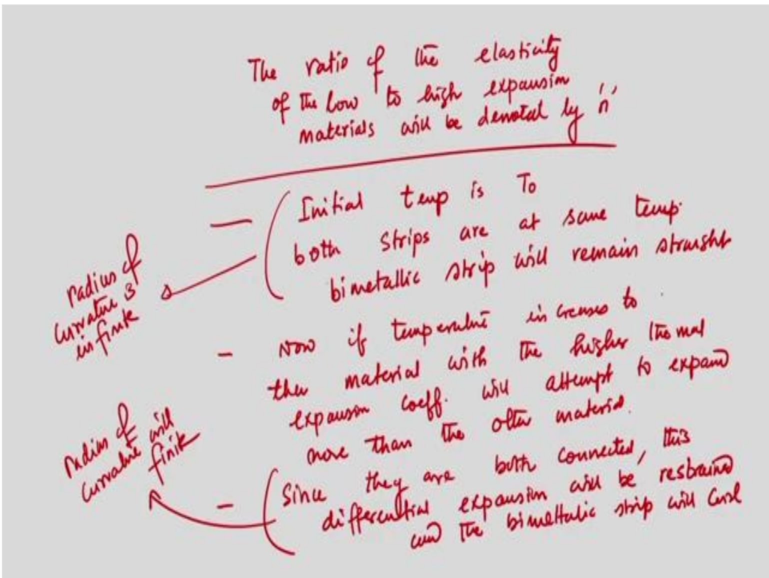

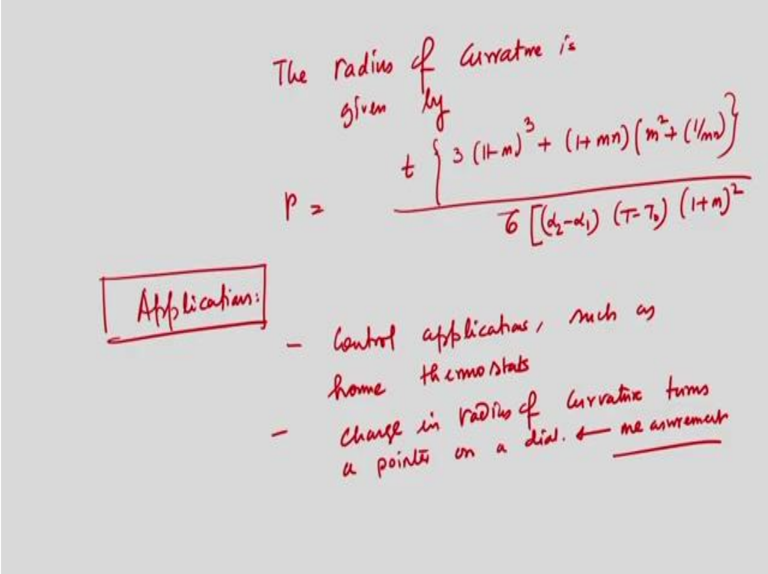


Now, if we try to find out this radius of curvature that means, the radius of curvature is given by that means, if the temperature increases of course, the material is having higher thermal expansion coefficient, will expand more than the other and the bimetallic strip will call and we will have a final radius of curvature and the radius of curvature R will be given and I am going to drive this, but it will be given 3 into t into 3 into 1 plus m cube plus 1 plus m n into m square plus 1 upon m n divided by 6 alpha 2 minus alpha 1, T minus T naught into 1 plus m square.

So, this is the expression where we have defined every parameters, only if I go to my previous slide, that if the temperature increases, temperature increases to t. So, initially temperature is T naught, now temperature increases to t then of course, we have seen this is quite obvious, we have seen from our undergraduate 10 plus 2 level physics, now, this radius of curvature will be given by R. Now, this is the formula, this formula is most useful as a design guide, as we will never know the material properties to sufficient accurate and so, it can be, I can say this can be used to directly measure temperature.

Now, however, we can use this formula, otherwise, I can say that we can use this problem as a mathematical structure for the calibration. Now, as I said that, as you will never know the material properties to sufficient accuracy so it can be used directly to measure temperature without any calibration, as I said because material properties we will never know. So, we can directly use this formula to measure the temperature now by knowing the radius of curvature, but the bimetallic strips, as I said that bimetallic strip thermometers can produce sufficient forces force to trip switches as such are often found in so, the application I can say.

So applications of bimetallic strips so, these are the few applications and what I said that material properties we will never know, the material properties to sufficient accuracy. So, it can be used directly, this formula can be used directly to measure the temperature, but again I can say this formula can be used as the mathematical structure for the calibration and what are the applications? So, the bimetallic strip we will call now, the bimetallic strip thermometer can produce sufficient force to trip switches such as which are often used for the control applications.

So, which are often used for the control applications such as home thermostats, also I can say the change in radius of curvature turns a pointer on a dial. So, this is essentially, so this control application and this application is essentially for the measurement. So, the accuracy I can say the accuracy of this type of thermometer is entirely dependent upon the care with which it was constructed and calibrated and commercial I mean, I cannot say that accuracy will be, I cannot predict, basically the accuracy that will depend upon the care which was taken while this bimetallic strip is produced or constructed and also the calibrated.

Now, I can say that accuracy is 1 percent of the full scale and these applications as I have mentioned that this is used for the control application such as home thermostats, also it is used in other measurement applications in fact, important other bimetallic strips I know are important. Rather they can play important role for the measurement, measurement as the strip can be coiled such that the change in radius of curvature can turns up on the dial. So, these are the different applications which are used and this is again, so this bimetallic strip is again a mechanical effect which is used to measure the temperature.

So, by knowing the radius of curvature, we know the m and n other things, so, by knowing radius of curvature from there we can calculate what will be the initial temperature I know and by knowing the radius of curvature if I know the, I know alpha 2, alpha 1, m, n all those things, from there we can calculate what is the temperature T and which can be easily seen from the expression that I have written over here and also I have discussed about the applications.

So, now, to summarize today's discussion, what we have discussed today, that is we have started our discussion with the ideal gas thermometer, we have seen that how we can measure temperature and the concept that we have discussed, also we have discussed about the possible sources of error and how we can eliminate this and then we have discussed about the measurement of temperature using mechanical effect. For that we have used, we have discussed about the liquid in glass thermometer and of course, different types and the basis which there are two important basis by which we can classify and also we have discussed about those.

In fact, these parts are we have in fact studied in our 10 plus 2 level also in our undergraduate texts. But, we have discussed again and finally, we have seen another important instrument which is used to measure temperature exploiting mechanical effect that is the bimetallic strip and we have seen that how we can measure temperature using the bimetallic strip. So bimetallic strips are nothing but the strips of two different material which are bonded together having different thermal coefficient of expansion, different other properties.

So, by measuring the radius of curvature, we can directly measure the temperature and since, as I said that we will never know the material properties, so I can say with sufficient accuracy, so, this can be used directly to measure the temperature. However, if someone would like to calibrate this mathematical, this formula can be used as a mathematical structure for the calibration and from the application point of view, we have discussed that this is used for the control application such as home thermostats, also it is it can be that biometric strips play an important role for the measurement that is such as the strip can be coiled and change in radius of curvature turns a pointer on the dial which is having an important applications.

And then we will discuss about the measurement of temperature using electrical effect, we will see that how electrical effects can be explored to measure the temperature in different applications and perhaps these important aspects will be very much helpful to use those who are doing experimental fluid mechanics research. So, and that part we will discuss in the next class. So with this, I stop my discussion today and we will continue in the next class. Thank you.