Thermal Physics

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Lecture – 30
The Platinum Resistance Thermometer

Hello and welcome back to the last lecture of week 6 for this NPTEL course on thermal physics. Now in last class we have discussed about ideal gas temperature scale. And we have made a statement that this ideal gas temperature scale which is actually achievable using a gas thermometer is identical to the absolute scale temperature scale that is an outcome of the second law of thermodynamics which we will be discussing later.

But either way because the scales are identical we can use the units Kelvin for this ideal gas scale. And also we have discussed about the fixed point choice of fix point for centigrade scale or Celsius scale the fixed points are 0 degrees centigrade that is the melting point of ice at under what atmospheric pressure and 100 degrees centigrade which is the boiling point of water under 1 atmosphere pressure. And the gradation is between these two temperatures the gradation is uniform I mean there are uniform 100 divisions each having 1 degree centigrade or 1 degree Celsius mark.

Now and as we have discussed also that this gas thermometer is actually a very bulky hefty unit, it is big and it takes long time. So, we need to have an alternative which is portable which might not be that accurate gas thermometer is extremely accurate, we do not need that high accuracy but we can have something that is portable that gives a reasonable good measure of the temperature and which is cheap as well like the manufacturing cost is low.

So, in this regard we have the most common one is the liquid thermometer where the liquid level l is the measure of the this temperature and we have already discussed that you can also have a formula that you know t is equal to 273.16 l by l triple that means the length a triple point and you can use that. The other one which is more but then the again the liquid thermometer let it be the mercury thermometer, let it be the alcohol thermometer they are limited by the physical property of the system.

So, for example if we keep cooling any mercury thermometer if we keep cooling the working substance at some point the liquid will freeze. So, Mercury will freeze I do not remember what temperature but mercury freezes pretty fast actually. And you know for alcohol thermometer also it can go down to maybe minus 30, minus 40 degrees centigrade or Celsius not beyond that. So, we need something that is more wide range and that is where the platinum resisters have omitted comes in.

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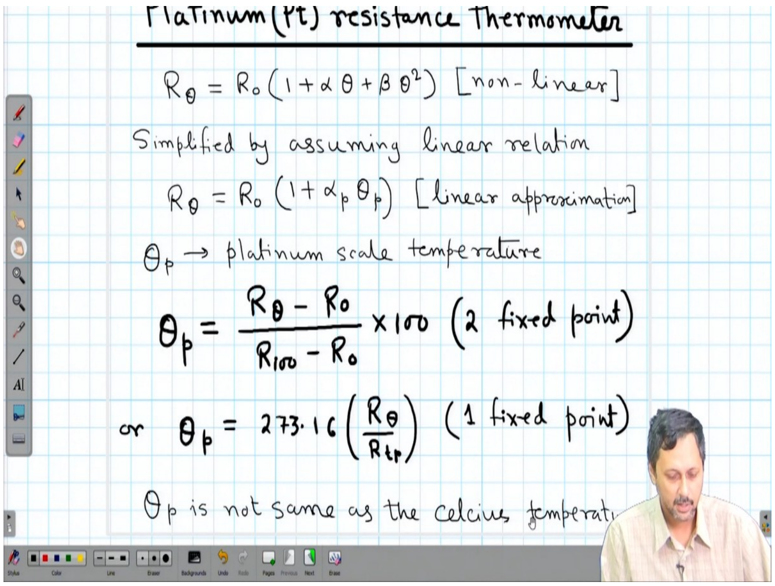

So, in the laboratory experiments especially the experiments where for example some temperature dependent properties measured platinum resistance thermometer is something that is widely used and also there is something called thermocouple. So, thermocouple is something that we are not going to discuss in this class. And if you are taking a basic electromagnetism course EM course then probably the thermocouple will be discussed in more details over there.

So what we are going to do is in today's lecture we are talking about we are going to have a brief discussion about platinum resistance thermometer the basic working principle and we will solve some problems So, what do we have here? We have R theta which is the resistance at a temperature theta given by R 0 1 plus alpha theta plus beta theta square. So, this is the typical behaviour of thermocouple and the values of alpha and beta can be determined from experiment.

Now this behavior as we can see is nonlinear now in case if the characteristics temperature dependence is nonlinear our previous construction will not work. So, what was done that was done by calendar actually that it was simplified using a linear relation that is R theta is equal to R 0 1 plus alpha p theta p where theta p is the platinum scale temporary. And of course when we are approximating a nonlinear relation with a linear relation there has to be some error, we will come back to that what is the magnitude of this error and all.

But I can tell you that this theta p is not the true temperature but it will be close enough because the value of beta is very small. We will see, we will look into some examples and we will see that the value of beta is very small as compared to the value of alpha. So, effectively the correction term will not be very large especially you know if we are staying close to these fixed points. So in this case in this expression also.

So, now we take this and we use this 2 fixed point method and we get theta p is equal to R theta minus R 0 divided by R 100 minus R 0 into 100. But once again this theta p is the temperature in platinum scale which is deviated from that of the actual centigrade scale or Celsius scale we will come back to that or we can use a single fixed point which is theta p is equal to 273.16 R theta by R triple point. So, once again theta p is not the same as Celsius temperature.

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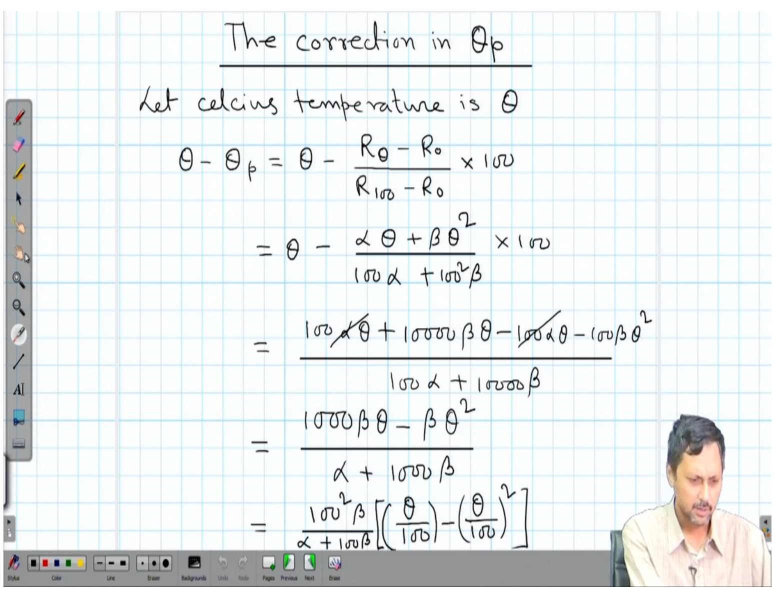

Now let us look at the correction in theta p. So, let us assume corresponding to theta p the actual temperature is theta. So, when the actual temperature is theta we have theta - theta p which is theta minus now what is theta p? Theta p is R theta - R 0 divided by R 100 / R 0 into 100 which is exactly this relation. So, we can substitute for this now remember R theta - R 0 what is the model relation the fundamental equation which is this one R theta is equal to R 0 1 plus alpha theta plus beta theta square.

So, R theta plus R 0 is R 0 alpha theta plus R 0 beta theta square. Similarly for R 100 If I put R theta is equal to 100 degree, R 100 is equal to minus R 0 is equal to R 0 alpha theta plus R 0 beta theta square R 0 and R 0 cancels from numerator and denominator leaving behind R theta plus beta theta square alpha theta plus beta theta square divided by 100 alpha plus 100 square beta into 100. Now we know compute this sum we do it in a rigorous manner.

And we see this; these 2 terms cancel out nicely. And finally whatever is left we can rearrange them in this particular form that is 100 square by 100 square beta divided by alpha plus 100 beta whole multiplied by theta by 100 minus theta square by 100, but now two things you see theta by 100, typically if unless and until it is a fraction, so it will be positive definite quantity which will be greater than theta by 100.

In case when theta by 100 is a fraction then it is a different issue but in general if not then this will be more as compared to this one. And in general beta is negative as experimentally determined beta will see that it is negative.

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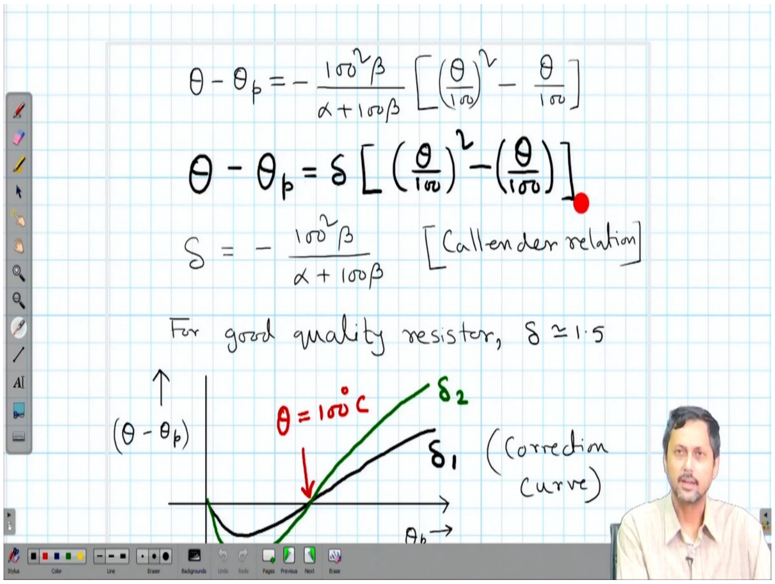

So, it is customary to write this in a reverse manner that theta minus theta p is equal to minus of 100 square beta divided by alpha plus 100 beta as beta is negative this quantity, this quantity times theta by 100 square minus theta by 100. Now simplified we write this as theta minus theta p is equal to delta whole multiplied by theta by 100 square by minus theta by 100. So, this is the correction term with delta is equal to 100 square beta by alpha plus 100 beta.

And this relation is called the Callendar relation. It was derived by the scientists Callendar and typically for a good quality resister we get gamma is equal to 1.5, gamma is a dimensionless number we see we have beta here, we have alpha here, we have beta here and it is a dimensionless number. Now if we look into this relation this is not actually exactly a linear relation in between theta and theta p.

So, if we plot the difference theta minus theta p as a function of theta p or we can do it as a function of theta also but generally theta p is something that we measure. So, this is our calibration so we want to have theta p. So, basically what we can do is we can you know take arbitrary values of theta and we can you know try to generate the difference theta minus theta p as a function of theta p. So, this will give you the calibration curves.

So, because for any given theta p you know what is the exact difference theta minus theta p from this type of relation and of course this relation will be depending on delta. Now look at this expression carefully for any value I mean for any value of delta irrespective of what is the value of delta if we take theta is equal to 100, then this is 1 minus 1. So that means this term will go to 0. So, irrespective of the value of delta we will have a 0 crossing of this relation at theta equal to 100.

Now for values of theta less than 100 we will have a negative value of theta minus theta p for above theta greater than 100 the values of theta greater than 100 we will have a positive value of this quantity. I mean you can you can do it yourself you can just try putting different values of theta and theta and see how this curves behaves. So, basically this is a quadratic in theta and it is a combination of a quadratic and a linear in theta so it should be have something like this.

So this is where we have theta is equal to 100 and we have positive theta greater than 100 and we have negative value of theta - theta p negative production for theta less than 100. So, this is more or less the theory of the platinum resistance thermometer. Now why platinum? Because platinum usually we can get into a pure form and it gives you a very wide range of detection.

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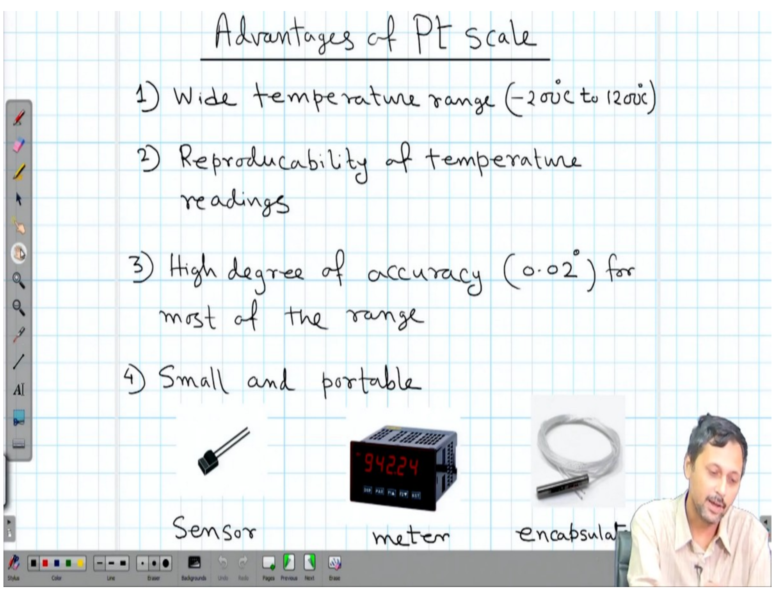

So, the advantages, this is the primary advantage is the wide temperature range of detection minus 200 degrees centigrade to 1200 degrees Centigrade is typically the working range of platinum resistance thermocouple. So, low temperature like moderately low temperature to moderately high temperature please remember minus 200 degrees centigrade is minus what is that 73 Kelvin which is not considered low.

Now lower to that temperature we can use a thermocouple sensor we can use Cernox sensor there are different types of sensors we are not going into the details of that, then the second advantage is the reproducibility of the temperature reading it is reliable. So, if we measure the same temperature bath over and over again using the same order a different platinum resister resistance we should get the same temperature with good accuracy.

And this sorry we should get back the same temperature with good reproducibility also the accuracy for modern day platinum resisters thermometer is typically 0.02 might not be available for the entire scale. But we can get up to 0.1 or 0.05 plus minus 0.05 degree accuracy for the entire temperature length in general and in certain ranges the short range we can also have 0.02 plus minus 0.02 accuracy. And next the primary advantage of the most advantageous thing is this is small and portable.

Now if you are looking into some old school textbook for example maybe the same book older edition you will find the disadvantage is that platinum resistance is bulky and not easy more which is not the case anymore that used to be the case. Even in nowadays in certain colleges you will have platinum resistance or metered as a lab experiment then we will see that we have a big probe. You know at the bottom of this probe there is a fixed long platinum layer were connected.

And we have to carefully insert it inside the inside a cold path measured the temperature all these experiments are still there in some university labs and college labs. But let me tell you in modern day the sensors I have taken some pictures for you from the internet. Actually I myself in my lab used this type of sensors and they are tiny I mean we if I right now if I hold it in my hand you probably would not even see it from that distance there are a few millimeters 1 or 2 millimeters maximum maybe 2 where maybe 3 where depending on the configuration.

So, all we need is a sensor and small meter the meter is also small single din or double din meter. So, these are smaller units and not very expensive also like it is not only small and portable they are very cheap, it is like the cheap the this one for example it will cost around maybe I do not remember exactly but somewhere between 100 to 500 rupees and there are encapsulated sensors which will cost slightly higher but less than 1000 rupees for sure.

So, these are good quality ones and we also have the bit costly variety which will be like within 500 rupees and this meter is slightly on the expensive side but altogether below 10000 we can get very accurate portable temperature sensor sometimes even less sometimes within 5000 or 6000 we get very accurate portable meter with the RTD sensor. So, now a days due to modernization of electronics the things have been the actual platinum where is somewhere here inside this encapsulation we do not even see that.

Now one group of platinum resisters thermometer is that PT 100 why 100? Because the platinum resistance or platinum wires that is used that has a resistance of 100 ohms approximately around 0 degrees centigrade that means that the ice point. So this is why it is called a PT 100 and most of the sensors are these figures which I have given you that basically that is what you get commercially available the PT 100 sensor.

But in principle you can take any platinum piece of platinum where you know put it use it as a temperature sensor just by measuring the voltage. So, this device what we have here is essentially resistance measure measuring device and inside that there is an inbuilt calibration curve by which it will convert the resistance into temperature and show it into the display. So, these are typically there is not much of a difference between this device.

And small handheld multi meter except that there is an inbuilt calibration curve. So, it will pick up this resisters value or the voltage across the wire for a given current and converted into the temperature and show it to us. So, if you are interested you can you know look through the internet resources about PT 100 and PT 100 is widely used commercially, industrially as well as in the lab level, lab levels ones a little more expensive. But even the commercial ones which are available for as I said few 1000 rupees for a full set are pretty active.

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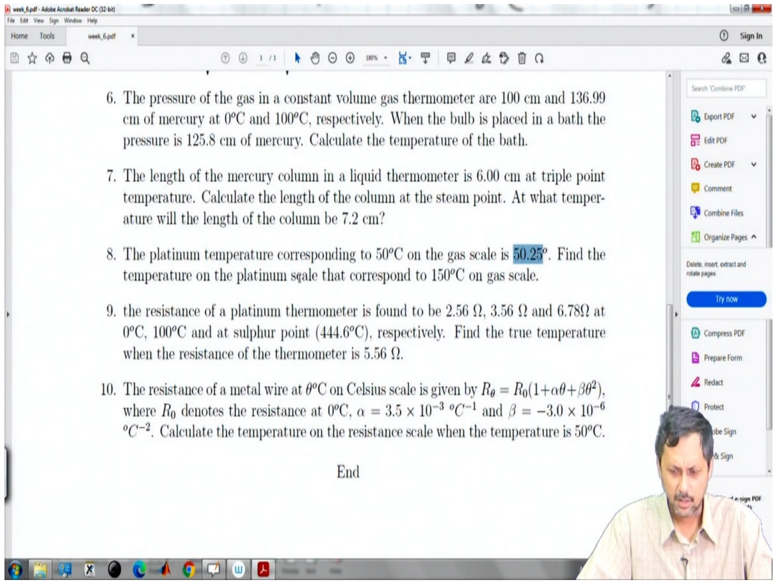

Next is we will finish this week's lecture by solving these 3 problems. The first problem is the platinum temperature corresponding to 50 degrees centigrade on the gas scale is 50.25 degrees, find the temperature on the platinum scale that corresponds to 150 degrees on gas scale. So, the platinum the temperature corresponding to the true temperature of 50 degrees centigrade is 50.25. So, we have to find the temperature on the platinum scale that corresponds to 150 degrees.

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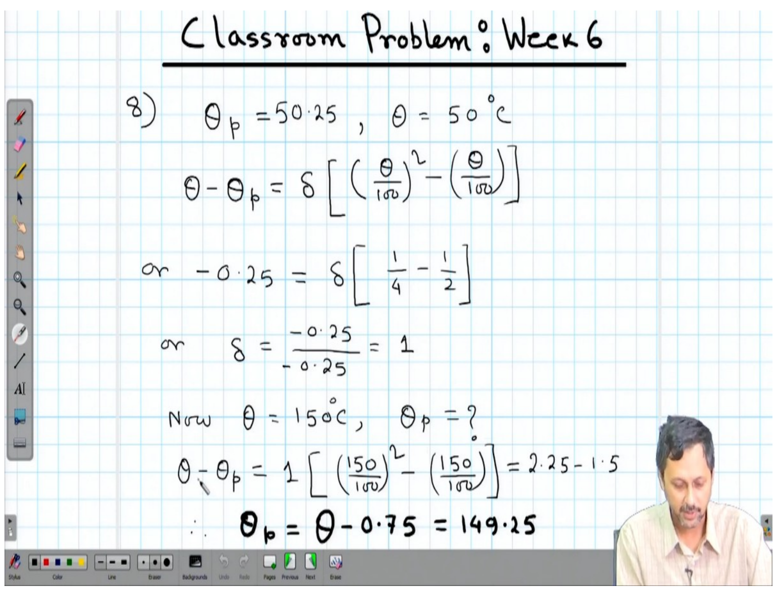

So, this is only one working formula here that is theta minus theta p is equal to delta theta by 100 square minus theta by 100 whole multiplied by delta. So, we put theta p is equal to 50.25 theta is equal to 50, we get minus 0.25 is equal to delta 1 by 4 minus half which is once again 0.25 minus 0.25 so we get delta is equal to 1. Now theta is equal to 150 degrees centigrade what is the value of theta p? Once again we have to use this relation now we put theta is equal to 150 degree and the value of delta is equal to 1 and we get 2.5 minus 1.5 which is 0.75.

So, theta p is equal to theta minus 0.75 which is 149.25, so this is a very straightforward calculation. One thing To be noted that in the first case this temperature over here, the true temperature is 50 and theta p is 50.25 that means theta p is leading the temperature and in the next case the true temperature is 150 and theta p is 149.25 that is theta p is lagging the true temperature which is expected because we are in one case we are on this side in other case we are on this side of this 0 crossing point.

So, theta minus theta p the quantity will change sign so that is expected. So, the next problem is actually what we can do is we can look at problem number 10 first and then we can come to problem number 9 because problem number 9 needs some consideration I mean some elaborate consideration. So the resistance of a metal wire at theta degrees centigrade term Celsius scale is given by R theta is equal to R 0 1 plus alpha theta plus beta theta square where R 0 denotes the resistance is 0 degrees centigrade, alpha is equal to 3.5 into 10 the power minus 3 and beta is equal to minus 3 into 10 to the power minus 6 of course the units are different.

So the unit of alpha is centimeter inverse unit of alpha centimeter square inverse calculate the temperature on the resistance scale when the temperature is 50 degrees centigrade. So, for a true temperature of 50 degrees centigrade we need to calculate what should be the value of R theta. Now this is pretty straightforward except for the fact that R 0 is not been specified alpha is given, beta is given we know the values of alpha and beta but we do not know the value of 50 degrees.

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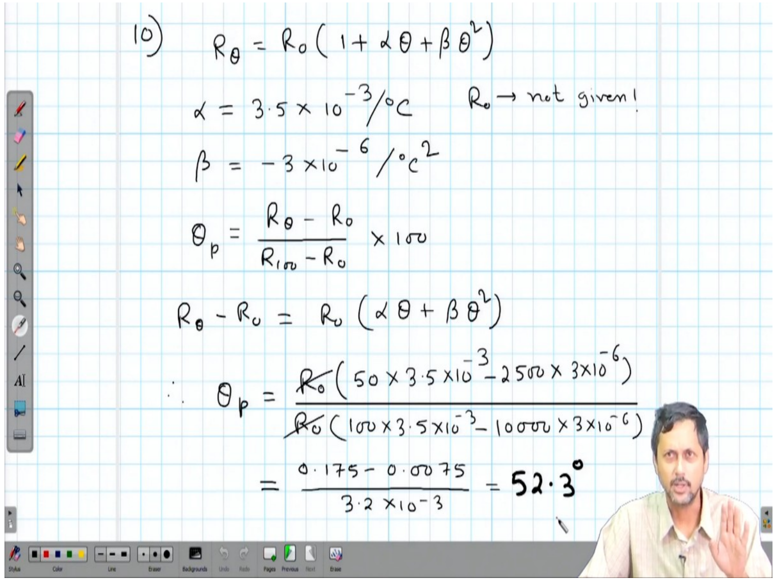

So, what we can do is we can problem number 10 we will, problem number 9 we will come back later, problem number 10 is this. So, what we can do is we can use this relation to start from this relation theta p is equal to R theta minus R 0 divided by R 100 minus R 0 into 100. Now R theta minus R is 0 going by this relation will be R 0 alpha theta plus beta theta square. Similarly R 100 minus R 0 will be R 0 100 alpha plus 10 to the power 4 beta.

So, exactly and then what happens R 0, R 0 cancels out exactly what is done here. And we finally get theta p and we can just have to use the values of alpha and beta and we finally get 52.3 degrees centigrade. So, for a true temperature of 50 degrees we get temperature value of 52.3 degrees centigrade 3 degrees from the platinum scale. Now also we can take it one step forward and we can compute the value of delta.

So, I will leave it to you to calculate the value of delta from this data. Now let us move to this last problem which is actually problem number 9 last but one, so the problem is this the resistance of a platinum thermometer is found to be 2.56 ohms, 3.56 ohms and 6.78 ohms at 0 degree, 100 degree and at sulphur point which is given us 444.60 degrees centigrade respectively, find the true temperature when the resisters of the thermometer is 5.56 ohms.

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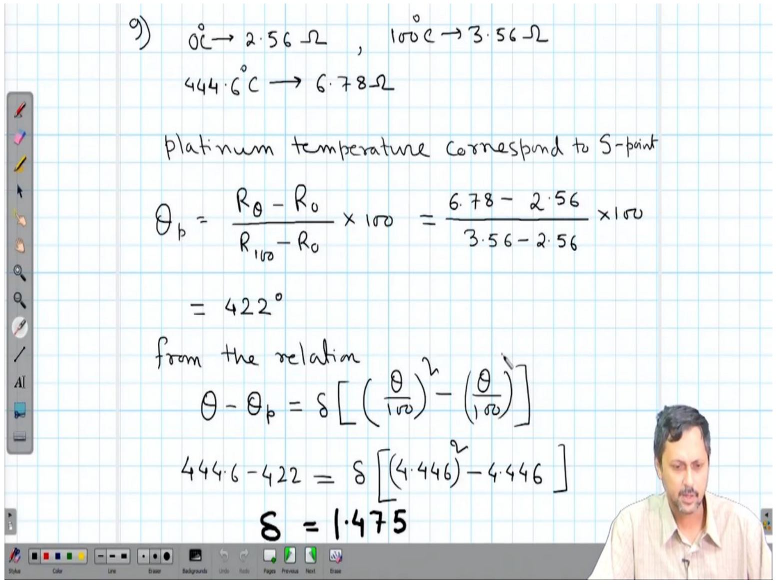

So, let us look at this problem so what is given is 0 degrees centigrade, the resistance is 2.56 ohms, 100 degrees centigrade is 3.56 ohms and 444.6 is 6.78 ohms. So, first thing is we compute the platinum temperature corresponding to 444.6 degrees centigrade. Now we put that theta p is equal to R theta minus R 0 divided by R 100 minus R 0 into 100 and we get 6.78 minus 2.56 divided by 3.56 minus 2.56 into 100 which is 422 degrees centigrade the deviation is considerably high.

And this is obvious because as we see as we go away from this 0 degree centigrade is the deviation becomes more and more significant that is why we need to use the recalibration procedure. So, the first thing is we need to compute the value of delta from this delta so we have theta minus theta p is equal to delta theta by 100 square minus theta by 100 theta is 444.6. So, it is 444.6 minus 422 is equal to delta 4.446 square minus 4.446 simplifying we get a value of delta which is 1.475. Now what is the problem statement?

Problem statement is; find the temperature when the resistance of the thermometer is 5.56 true temperature when the resistance of the thermometer is 5.56 ohms.

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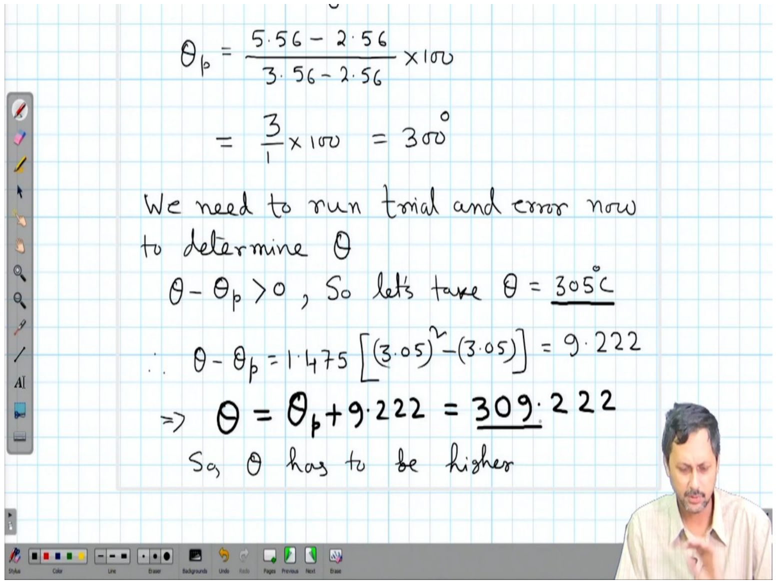

So, next is what do we do corresponding to unknown temperature the value of theta p is 5.56 minus 2.56 divided by 3.56 minus 2.56 into 100 which is exactly 300 degrees. Now this 300 degree now where the problem is the problem is the following we have so on this scale we are somewhere here? We are somewhere here we know the value of delta. So all we have to do is we have to find out the truth the difference which corresponds to theta minus the difference theta - theta p which corresponds to this particular temperature theta p.

Now in order to do that so we basically need to run a trial and error to determine theta because this curve which is already there you know in here this curve is not known to us. So, basically we do not want to plot the entire curve and then find it we all we want is let us have this one is our 300 degrees centigrade we want to trail around this value and see which gives you a good estimate for theta minus theta p.

So, let us do it think of it I mean it is not so easy unless and until you have the whole calibration trial curve we cannot really do the full computation or we have we cannot do it at one go we have to do trial and error. So, for theta - theta p greater than 0 so we take, so here theta minus theta p is greater than 0. So, when theta p is 300 degrees so we have to assume that theta is we have to understand that the actual temperature has to be greater than theta p.

Because we are on the positive side of the theta minus theta p value rather we are on the higher side of 100 degrees centigrade. So, let us start with 305 degrees centigrade. Now corresponding to so that means what we have to do is we have to compute the difference theta minus theta P using this relation for 305 degrees centigrade. Once we do that what do we get? We get 9.22 the difference between the actual temperature and the measure temperature as 9.222.

So, from here what we get theta will be equal to theta p theta plus 9.222 which will give you 309.222, so we start with a value of 305 and we end up with a value of 309 so which is not correct. So theta has to be we have to start with slightly higher value.

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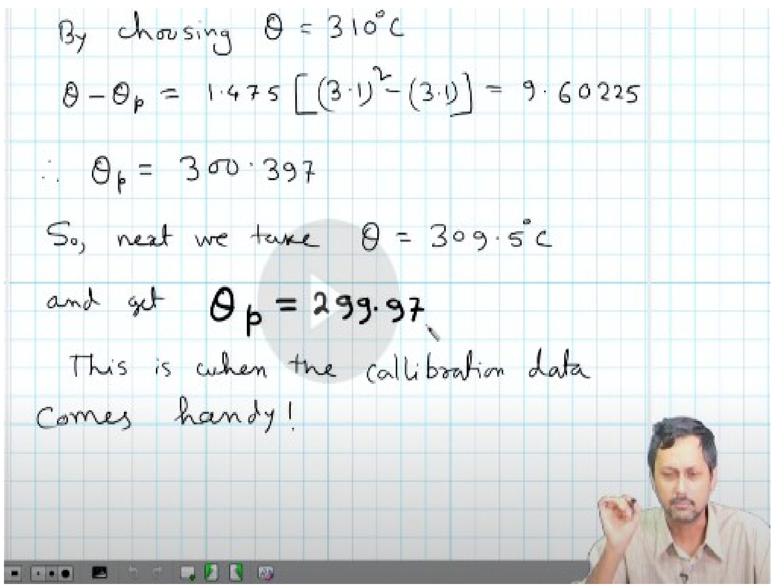

So, we take 310 degrees centigrade next and what do we get theta minus theta p is 9 point, so what we are trying to do here is minus 3. So we are actually starting with a value of theta p we are starting with the value of theta assuming this value is this and we are reproducing the value of theta p. So theta p will be theta minus 9.222 which is 305 minus 9 will be whatever it was I mean I do not remember exactly but it will be like 888.297 degree not centigrade.

I hope this is correct, whatever I mean, you can understand what I am trying to tell you. So, just check this value once again I do not have a calculator. So, theta p will be this, but our theta p is 300 degree which is more than what we have predicted using this starting value of theta. So, next is we take 310 degrees centigrade and theta minus theta p once again if we just put the value of delta which is 147, we get 9.60225. So, theta p will be theta minus that is 310 minus 9.60225 which is 300.397. So, we are going close. So, previously, we got 297.88.

Now, we are getting 300.34 almost, so we take slightly less value of compared to the previous one. So, we take 309.5 so, we are half by 0.4, so, we just take 309.5. And we get once again a theta p value of 299.97 which is almost equal to 300. So, let us say this one is our correct value of course, we can take more values like we can take 309.45 and 309.5 and see if we can exactly produce 300, but there is no other way primarily because this relation you see this relation on the right hand side we have only theta and not theta p.

So, we have to have the correct theta p, we have to start with the trial with the value of theta and see if we are getting the correct theta p and we have to keep repeating this trial unless and until you have this calibration, if you have this calibration curve handy in your hands. So, exactly the same procedure, we know take any arbitrary value of the you know arbitrary value of theta and see what value of theta p we are getting and then we can produce a calibration curve that will give you.

So, basically this is theta minus theta p also we can have a calibration curve for theta versus theta p that will give you a more direct measure for a given theta p what is the value actual theta? So, unless and until you have this calibration curve, we need to have such trial and error process anyway. So, this fortunately in this modern day instruments for example, this one this calibration curve is pre-fitted.

So, you do not have to go through this rigorous procedure every time we measure the value of temperature, the temperature what is displayed on this unit, they are already precalibrated, but typically one unit is calibrated with one sensor. So, that is why it is very important that you know before we put in a new sensor that you can start measuring with a new sensor, the recalibration of this unit is done properly.

So, this is one thing that we have to keep in mind at the lab level experiment. Otherwise, you know, even without calibration if we do not have this unit, we can measure the resisters across the sensor and we can use the simple relation this one the calendar relation and we can get back our decide numbers, dessert temperature value. So, that is where we stop and we have in this week we have discussed about zeroeth law of thermodynamics which is well, although it has been derived after the first and the second law of thermodynamics.

This is also considered one of the fundamental laws. Now, next week onwards what we will start with? We will start with the so called classical thermodynamics. So we will start with the basics of thermodynamic processes, what is the some basic definitions related to thermodynamics? And then we will talk about the basic thermodynamic first law sorry the basic laws that is the first and the second of the thermodynamics. Thank you.