Experimental Physics I
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Lecture - 44
Determination of the calibration curve of a given (Type K chromel-alumel) thermocouple and hence determination of Seebeck coefficient

So, we are in 2nd year lab of Department of Physics of IIT, Kharagpur. Today, I will demonstrate the experiment on thermoelectricity and thermocouple.

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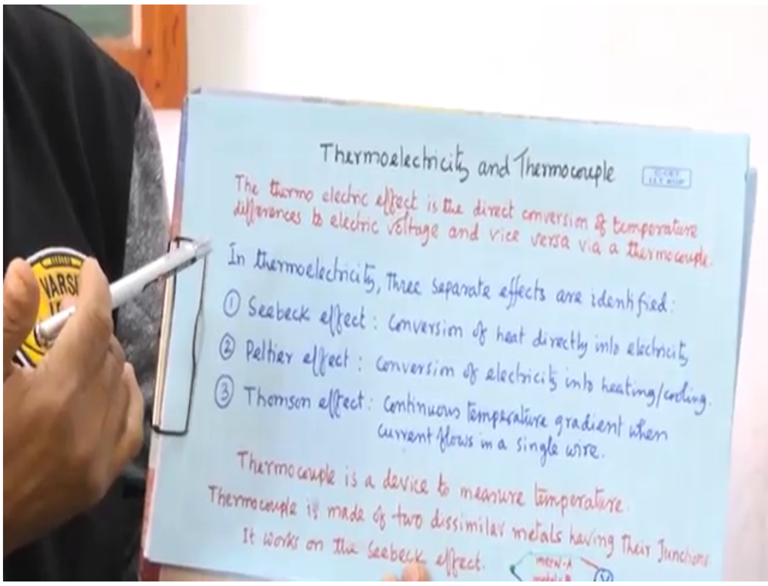

So, let us know about the theory of this experiment. So, this thermoelectricity you know this basically tell this thermoelectric effect. So, this thermoelectric effect is the direct conversion of temperature difference to electric voltage and vice versa by a thermocouple, right.

So, thermocouple, in a thermocouple you can convert, you can see the converge direct conversion of temperature into electric voltage. Also, you can see the conversion of electric current to the temperature ok. So, in thermo electricity you know there are 3 effects, one is Seebeck effect this basically conversion of heat directly into the electricity, then Peltier effect conversion of electricity into the heating or cooling, right and third one is Thomson effect this the basically continuous temperature gradient when current flows in a single wire ok. So, in thermocouple; in thermocouple basically is a it has junction of two types of wires, this two types of wire means is made up to two types of metal. So, thermocouple is a device to measure temperature and it is made of two dissimilar metals having their junctions.

So, it works on the principle on the effect; on the effect of Seebeck or Seebeck effect, right. So, if you take this one wire of metal A, this is another wire of metal B. So, if you have; if you have junction this the junction and you have here this is another junction this is another junction, but we just detach it to add this voltmeter using the third type of wire, but one can show that there will not be effect of this third wire. So, that effect will be nullified ok. So, basically two wires one junction is there then another junction is basically in between, so there is a bia.

So, now, this detached, this, its a detach because of including the because of including the voltmeter to measure the basically this electricity generated in this circuit. So, here basically one junction which will put a place where we want to; we want to know the temperature of that place and other one we consider that it is in a room temperatures; it is in a room temperature, reference is room temperature. So, then we do this way, other way one can do this if you want to keep this reference temperature is not room temperature in other temperature; so, generally what we do?

So, we just we make this also these two end also junction just connected it junction and in between in one of this wire just we just cut it and here using the third just this part using the third wire we connect the voltmeter ok. So, this the thermocouple and from this thermocouple in this thermocouple we have we should have arrangement for temperature difference in between the junctions and we should have option to measure the voltage that is basically whatever thermo emf is generated due to the temperature difference. So, that we have to measure. So, that option should be there also, right.

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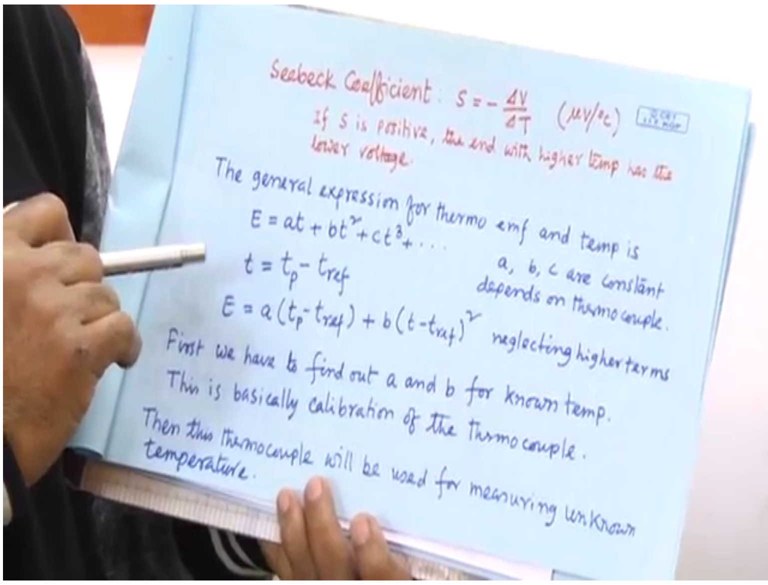

So, Seebeck effect, you know the Seebeck effect, as I told this if there is a temperature difference between the two junctions then there will be thermo emf, there will be voltage; there will be voltage in the generated in this circuit in the thermocouple. So, this Seebeck coefficient is defined as S equal to minus del V by del T ok. Del V is the voltage difference generated because of the temperature difference del T ok. So, this also this Seebeck coefficient also if it acts as a calibration.

So, for how for how much temperature difference what is the; what is the voltage generated? So, for unit for per degree centigrade or per degree Kelvin what is the voltage generated, so that one can use as a calibration factor. So, Seebeck effect coefficient is basically calibration factor. So, for measuring the unknown temperature, so basically you are measuring the voltage.

So, experimentally you will know the voltage ok. So, to convert it to the temperature, so this factors will act as a calibration factor. So, whatever voltage you are getting, so this if you divide it that voltage divide by this Seebeck coefficient that will give you the unknown temperature ok.

So, in this experiment whatever I will demonstrate our ours aim is to; our aim is to find out the Seebeck coefficient or aim is to find out the calibration factor. So, this also called calibration factor in this for this thermocouple ok. So, this negative sign is there. So, there then this thus this S is defined when it will be positive when it will be negative, so, that I have I have written here. So, S will be positive when the end of higher temperature will have the lower voltage ok.

So, actually in general expression for thermo emf and the temperature is E equal to a t plus b t square plus c t cube etcetera. So, neglecting higher term one can write; one can write E equal to a t plus b t square, because this a b c are the basically constants depends on the thermocouple wires ok.

So, now this t is basically this temperatures temperature of the place where you want to measure the temperature with respect to the; with respect to the reference temperature ok. So, this t is basically t p temperature of the point minus the t reference. So, this E then I can write a of t means t p minus t reference plus b t minus t reference. So, this also it should be t p it should be t p ok. So, t p minus t reference square ok.

Now, just, for the time being or this E t reference is 0 ice temperatures if this reference junction if we keep at ice temperature, so this is 0 degree centigrade, right. So, then this is 0, this is 0. So, then basically its a t p, a t p plus b t p square. So, its a equivalent to a t plus b t square ok. So, E equal to a t plus b t square so, this is your relation between the temperature and the thermo emf.

So, now a and b are unknown it depends on thermocouple either. So, we have to find out a and b ok. So, that will be the basically calibration of the thermocouple, calibration of the thermocouple. So, how we can do that? So, generally reference one you put at ice temperatures and this point other point other junction you keep at two unknown two known temperature, one can be; one can be boil temperature boiling temperature of water another can be other standard temperatures ok.

So, or people also do this one can be this room temperatures and another can be the boil temperatures ok. So, at this two temperature you will get this two emf. So, now, basically E 1 equal to a t 1 plus b t 1 square. Another equation you will get E 2 equal to a t 2 plus b t 2 square ok. So, now, two unknown and you have two equation if you solve it then you will get value of a and b ok.

So, measuring two known measuring the emf at two known temperatures one is say at room temperature another is a boiled water temperature ok. So, one can find out this a and b, then when a and b is known then you can then basically you can measure using this thermocouple you can measure any unknown temperature. They just put there then what will be the that induced emf thermo emf you will measure and for this induced thermo emf what a b already known. So, what will be the temperature that you can find out? And this temperature with respect to basically is basically this ice temperature with respect to ice temperature. So, that is 0 degree centigrade. So, you will get this value that is unknown temperature that is in degree centigrade. So, you can convert it in Kelvin also. So, this is one way to do this experiment.

Another way one can do the experiment. So, one junction I will keep in ice, another junction I will keep in water, now I will heat the water and this water temperature will change; water temperature will change. Now, I have to use thermometer, standard thermometer or another thermocouple to know the temperature, to know the hot water temperature ok. So, now, what I will do? I will just at every 5 degree change of this hot water. So, what will be the emf thermo emf that I will take reading. So, I will take reading of induced emf at different temperature of hot water ok.

So, then basically T versus E, I will that data I will get. Now, if I plot; if I plot that E versus this temperature T then I will get the curve. Now, from the slope of the curve; from the slope of the curve I will be able to find out this del V del E or del V they are same thing, here I have written E, but here I have written V so but I should write here also E, right or here I should write V. So, I from the slope I will get I will get del V by I will get del V by del T ok. So, there is the; there is the Seebeck coefficient or that can be used as a calibration factor if that one thing we have to check whether it is curve is linear or not.

If curve is not linear then this coefficient we have to find at different points and we have to make chart; we have to make chart using this calibration factor we have to make chart this emf versus temperature. So, if you have the chart for a particular thermocouple then for any unknown temperature. So, you will get the thermo emf and for corresponding thermo emf; for corresponding thermo emf what is the temperature from that chart one can also find out ok. So, let me show the experiment and how to do that I will just show you here.

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So, here this is our experimental setup for this thermo electricity and thermocouple. So, you see this is a thermocouple. So, thermocouple means two dissimilar metals, so this is one type of metal and this is another type of metal ok. So, these two metal, dissimilar metal it has junction one junction here and it has another junction here ok.

So, now, just one wire just I cut it to just add this, to add this voltmeter because I have to measure the induced thermo emf; I have to measure thermo emf. So, this the voltmeter micro voltmeter. So, this reading is coming in micro voltmeter. So, this I have put no its I have put in 10 millivolt, so in millivolt range. So, it is basically it is a whatever reading its it is showing that is in millivolt ok.

So, basically here now is negative reading etcetera just forget it. So, now, these two both end are at room temperature, right. So, that is why this reading is almost 0, reading is almost 0. So, this is the thermocouple this copper constantan one wire is copper and another wire is constantan, I will tell you about I think I should tell slightly more about this different type of thermocouple we use people use in their lab, so, I have that chart; I have that chart I will tell you what are the types of thermocouple.

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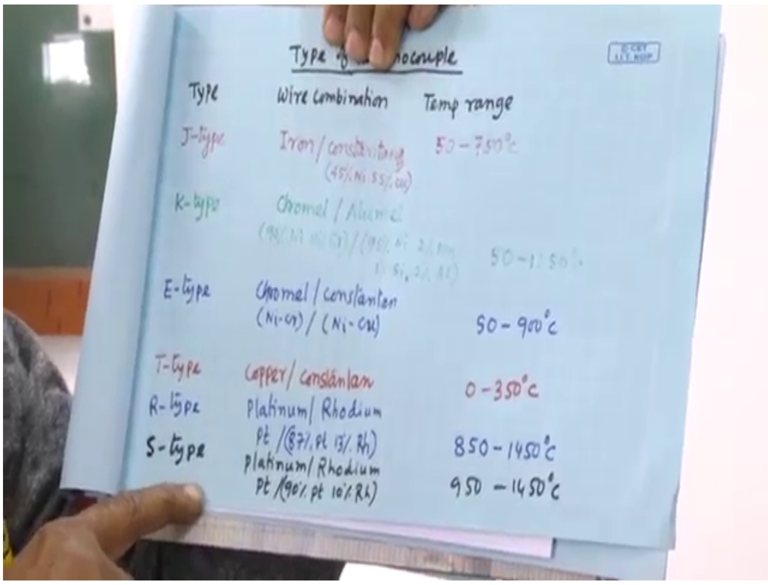

So, types of thermocouple here their different name is given you know J-type, K-type, E-type, T-type, R-type, S-type. So, this name are basically depending on the combination of the two types of wire. So, J-type thermocouple we tell when these two wires, one wire is iron and another wire is constantan ok. So, constantan means 45 percent nickel and 55 percent copper alloy ok, so constantan.

So, this is this can be one type of. So, people found the combination of the two types of wire they have chosen the metal in such a way so that the Seebeck coefficient should be high and also for different range of temperature this thermocouple different types of thermocouple is used ok. So, here also I have given. So, this type of thermocouple is used for this range of temperature for measuring 50 to 750 degree centigrade.

So, another type of thermocouple chromel alumel, very very popular thermocouple chromel alumel. So, chromel means 90 percent nickel at 10 percent chromium and alumel means 95 percent nickel, 2 percent manganese, 1 percent silicon, 2 percent aluminum these are alloy ok. So, this combination is used for measuring the temperature in this range 50 to 1250 degree centigrade ok. So, similarly chromel constantan, copper constantan, so whatever I told copper constantan. So, this thermocouple is our whatever I was showing that is copper constantan.

So, this tell this name is given this the T-type thermometer. So, R-type thermometer, S-type thermometer. So, R-type, S-type these thermometers are used for measuring higher temperature and these thermometer is used, basically these T-type thermometer this measuring for lower temperature ok. So, these are the different types of thermometer. So, copper constantan again constantan as I told this constantan means 45 percent nickel and 55 percent copper, so, that is the alloy. So, these thermometers we are using in our lab; so, I will.

So, I was showing you, so this the thermocouple of copper constantan. So, two junction, one is this junction another is the other one this one. So, and just here just we cut it here one of this wire of the thermocouple and we add this third type of wire to connect the voltmeter ok. So, this addition of this third type of metal in this thermocouple this one can show that this effect of this third type of wire or metal is nullify theoretically one show it will not affect this the theory of this thermocouple. So, it is the basically is nullify ok. So, but condition is that these two end has to be in the same temperature ok.

So, now, here I have you see ice bath, I have ice bath and here I have this arrangement for heating the water, for heating the water. So, now, I started heating the water and now, water is boiled. So, what we will do? We will which method we will follow? Method will follow just this one will we will change the temperature of this hot water and this one end basically will keep in one end will keep in ice one end of this junction, one junction will keep in the ice; one junction keep in ice, another junction will keep in you see just note here its a, now, it is showing this reading 0.73. So, because this reading is for the temperature difference, this junction is at room temperature.

Now, room temperature it is around 23, it is 0, so this temperature difference is 23. And for that what is the; what is the thermo emf voltage? That is 0.71 ok. So, interestingly you can I can show you that if I put this both end at the same temperature then what happens? If I put this two end at same temperature it should be 0; it should be 0, right, it should be 0, this reading should be 0, yes its almost 0 its almost 0, right ok. So, these two junction is at same temperatures. So, there should not be any thermal thermo emf, it should be 0 and that is what its a 0 its going towards negative and is slight fluctuation.

So, now one junction is at; one junction is at ice temperature, another junction I will put I will put in; I will put in hot water, I am putting in hot water. So, is really hot. Now, is temperature is I will tell you what is the temperature. So, if I put yes. So, I put in hot water. So, now, just you check this reading here. So, one junction is at ice another junction is at hot water. Now, I have to just wait for sometime to get this to stabilize it, to stabilize the temperature of this hot junction. Now, if seems is stabilized. So, I have to take this reading is varying 3.72 to 3.71 2 yes. So, I can take this in 3.71 ok.

So, if I wish then I can start to take reading at this temperature. So, what is the temperature of this hot water? Now, I can use; I can use this thermometer; I can use this thermometer; I can use this thermometer. So, this thermometer can measure up to 110, 110 degree centigrade. So, this I will put in hot water I put in hot water and then what is the temperature I can take reading from here.

But, I will not do that we have another arrangement more accurate arrangement. So, here you see we have used another thermocouple, we have used these are commercially available thermocouple. So, basically this here you can see this commercially available another thermocouple I have used and this end is in the hot water.

So, what is; so this meter, so this meter is basically calibrated one is calibration is done by the company. So, because of this because, so in this thermocouple reference is room temperature and one end is the temperature where you want to measure. So, at that place this another junction. So, this meter here it is showing the temperature reactive because this thermocouple is calibrated by the company and that Seebeck coefficient or this calibration factor is multiplied with the emf, so is the electronically inside. So, it gives the basically then display the temperatures, it displays the temperature.

Now, what we will do? So, now, at different temperature of this hot water I will take reading; I will take reading of this of this voltage. So, now, it is if I also already this a hot. So, basically, we should start say around 60 degree centigrade or 70 degree centigrade and then you vary the temperatures you heat will heat the water and there temperature of this water will change will increase. So, for each 5 degree temperature change what is this value that I will note down ok.

Now, it is 87, so for that 3.5 millivolt 87. So, this is the temperature. Now, if I think I can just the heater is on, heater is on now, right heater is on. Now, I will increase the temperatures or other way I can do I can just reduce the temperature just putting cold water, reduce the waters just if I put cold waters slightly cold water then I can reduce the temperatures I can reduce the temperature this changing the temperatures you know it is a ok.

So, if I start this what is happening? So, this is fluctuating or is heater is started to heat. You see heating very fast. So, slightly more water cold water I can give because I think I should start from 50 degree centigrade, I should start from 50 degree centigrade and then it may be around 50 ok.

So, slightly hot water I can take out and then you put you put more cold water, you put more cold water to reduce the ok. So, it is still it is a 63, 61, 59, 58 ok. So, you have to choose; you have to choose temperature of beginning temperature and then for that temperature, but is fluctuating yes temperature is reading is fluctuating. So, I have to take average reading or one can use this thermometer also. Anyway, so, it should stabilize, so, temperature is around 60 degree.

So, for 60 degree what is the voltage we have to take reading? Now, I will start heating, I will start heating and then I will take reading at 65, then 70 degree centigrade what is this value, then 75, 80, 85, 90, 95 as long as it goes I think around up to 90s also fine. So, each 5 degree step I will take reading ok.

So, within this range of temperature 60 to 90 that I will plot this voltage, this whatever reading here we are getting versus this temperature and then for this range of temperature I may get the straight line or may not get. If I get straight line then this Seebeck coefficient is constant, throughout this range of temperature. So, Seebeck coefficient it will depend on the range of the temperature, it may not; it may not valid for the full range of temperature.

So, that is why. So, in which range you want to calibrate this thermocouple. So, you have to do this experiment up to that temperature range and you have to see whether it is linear or not linear. Generally, it is not linear, but in the particular; so that depends on thermocouple also ok. So, in a particular range it maybe linear and then we tell that, this thermocouple will work up to in this range or it may happen that there are, so it is a changing its changing. So, there are different range and for difference range there will be different Seebeck coefficient means calibration factor that one has to take care. And if it is really non-linear then for each point; for each point you should have the you will have the different Seebeck coefficient and in that case calibration just one value one calibration factor is not enough. So, you need this curve either this graph method or this chart method.

So, for that thermocouple we have to prepare a chart for different temperature what will be the emf or for different emf what is the value of the temperature or it can be if you plot it, so from graph also one can find out what will be the temperature for a particular thermo emf ok. So, it depends on thermocouple. So, here say you are trying to find out the Seebeck coefficient for a particular range of temperature.

Here I started from 60, I started from 60 ok. So, 60 to up to 90 I will do the experiment say and then I can find out the Seebeck coefficient only for this range and I cannot claim this Seebeck coefficient will remain same above 90 degree centigrade or below 60 degree centigrade. So, it depends on your experiment and your claim also. So, these things one should write in discussion ok. So, here now it is 65 degree centigrade. So, this voltage I have to note down this 2.6 ok, it is 2.6. Now, I will gain wait and when this temperature will be 70 then I will note down this one this thermo emf.

So, this way you should make table this temperature of hot bath versus the thermo emf and reference temperature is basically ice temperature that is 0. So, this is the experiment and from that from the plotting of the graph one can find out the one can find out the Seebeck coefficient. So, del V by the del T. So, now, if it is non linear so, then we tell dv by dt, dv by dt means the differential form. So, it will vary at each and every temperature or each and every voltage. So, here, so its not 70 yet. So, its increasing from 2.6 to it is going to 2.7 to ok.

So, this way just you have to continue the reading and do the rest of the things, including the error calculation and you have to write this write the answers ok. So, of if you find out; so after finding out this Seebeck coefficient or calibration factor if you, so generally we tell to measure the unknown temperature. So, then you hot junction you have to put in unknown temperature and but this reference junction has to be in has to be in ice. So, then find out this value of this its 70. So, it is a 2.8, you have to note down 2.8 ok. So, for unknown temperature, so hot junction, now you have to put in that unknown place where you want to measure the temperature and then just you have to note down this one and then from graph or from chart or from if it is linear from calibration factor or that is called Seebeck coefficient you can just convert to the temperature ok.

So, this is very simple experiment, but its technologically very important experiment because this thermo couple is you see this mercury thermometer is used in very few places. It can measure the temperature from ice temperature to say boiled water temperature ok. So, 0 to 100 in this range you can use mercury temperature this mercury thermometer.

But when you want to measure say above 100 degree centigrade, so, 400, 500, 600, 1200, 1500, 2000 degree centigrade, 3000 degree centigrade what you will use. So, this thermocouple is used for the broader range of the temperature ok; so that is why different types of thermo couples are there means different combinations of wires as I showed you J-type, K-type, T-type ok.

So, itsa very this very useful thermometer for the lab, for the industry and advantage of this one is that this directly you are converting temperature into the electrical signal. And for interfacing; for interfacing of any instrument, so depending on the temperature ok, so this thermo couple is very very useful because mercury thermometer when you will use then it is not you are just observing the reading, right you are not converting to the electrical signal ok; so, this is the non-electrical; non-electrical.

And for interfacing you need always you need to either temperature or pressure or force always you need to convert into the electrical signal. So, that what this basically sensor transducer ok. So, that has come up how to convert the; convert the non-electrical parameter into electrical parameter in terms of electrical parameter. So, here thermocouple is directly it is coupled with the this conversion of the non-electrical temperature to the electrical thermo emf ok. So, that is why this thermo couple is very useful for industry for lab and for and also another advantage is that is this thermo couple is used for the broader range of the temperature. So, it seems is a very versatile thermometer.

And so thus this principle of this thermo couple for measuring temperature today we demonstrated and this is very you should understand it clearly and this is very useful for the common use in the laboratory or in our industries ok. So, it is a temperature increasing and this also increasing one should take that reading. And important is that how the arrangements is made and what is the significance of each and every tools, that one has to understand. And you should not forget to note down the least count of each instrument whatever you are reading because you will need to calculate the error on this measurement ok. So, I think I will stop here.

Thank you.