Energy Conservation and Waste Heat Recovery
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Lecture – 41
Thermoelectric Generators – Functioning and Applications

Ok welcome back to the next lecture of Energy Conservation and Waste Heat Recovery. If you recall in the last class we are started with direct conversion devices and out of direct conversion devices the first such device that we were looking at was thermoelectric generators. So, thermoelectric generators if you recall is a means by which thermal energy if you have a lot of thermal energy let us say from your waste heat source you can use this device to directly get electrical energy as the output right and we were looking at how a thermoelectric generator works.

So, in the last class what we said was we talked about seebeck effect where seebeck found that if you have a metal and if you maintain a temperature difference, because of the movement of electrons we get an appreciable electric field or we get an electric electromotive force or voltage across the 2 ends, but; however, for metals that voltage is minuscule and we also saw that it is not possible to take you know a lot of these metal blocks and arrange them in series, because the voltages do not add up since the connecting wires actually oppose the voltage oppose the movement of electrons, that is required to you know for the additive action or for the addition of voltage in series.

So, therefore, what we ended up saying is we need to look at something else and that something else is what we call electron holes.

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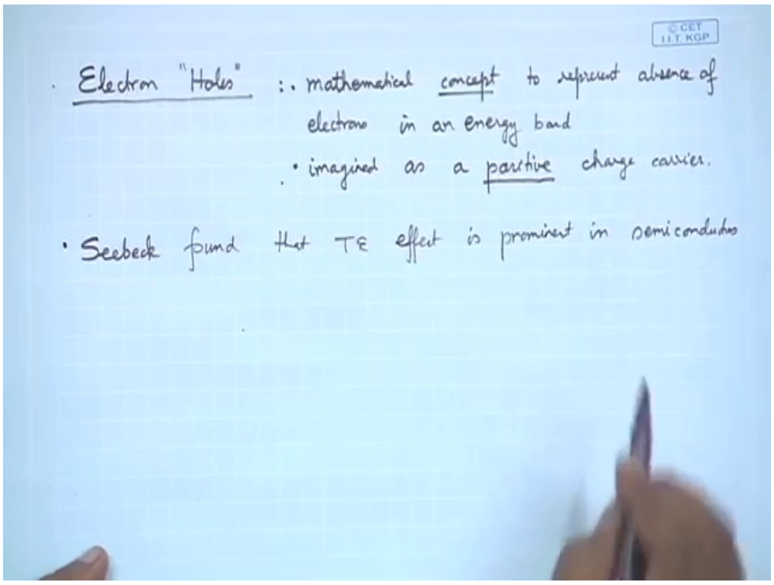

So, let us look at something called electron holes now recall Electron "Holes". However, let me would be very clear it is not a real or physical entity like an electron; electron hole is a mathematical concept, it means that if an electron does not exist in a space where it is supposed to exist we say that by not being present it has created a hole or if an electron migrates from a point to another it leaves behind a hole right.

So, let us I think most of us recall this when we studied our basic high school electric electricity, that this is a mathematical concept or just a concept I would say to represent absence of electrons in an energy band and we imagine this imagined as carrier electron is a negative charge carrier, this one is a positive charge carrier. Again let me repeat that hole is just a concept it does not actually exist, but it is it helps us in imagining that an electric current flows because of the flow of holes because we know that electric current the direction of an electric current is actually opposite to the direction of electrons clear.

So, therefore, with that concept let us think about what is the hole where do we get holes and so on clear. So, what seebeck found was seebeck found that thermoelectric effect is prominent in a class of materials called semiconductors. So, he said semiconductors are very ideal for thermoelectric effect they have high seebeck coefficient and so on. Now let us go back to semiconductors and think about what we know from our basic electronics knowledge right.

A semiconductor is typically a group 4 element silicon is the most common germanium is also another one and the good thing about semiconductor is you can also dope it with impurities right. So, when you dope a semiconductor with impurities you can give rise to either additional electrons or additional holes, depending on the impurity, again impurity here is an element which is typically a group 3 or a group 5 imagine again remember silicon for example, if we just go by silicon it is a group 4 element. So, 4 electrons in it is outer shell if you dope it with a group 3 element then we have less number of electrons right and so we have we give rise to additional holes.

And similarly if we dope it with a group 5 element we give rise to additional electrons. The first type is known as a P type semiconductor for positive holes are positive charge carriers remember and similarly the second one where it is doped with a group 5 element and therefore, have excess electrons is known as an N type semiconductor right N standing for negative because you have excess of electrons. So, a thermoelectric generator let us take a few steps ahead and a thermoelectric module in this case which we are going to use as a generator for generating electricity consists of 2 such semiconductors one is an N type the other is a P type clear.

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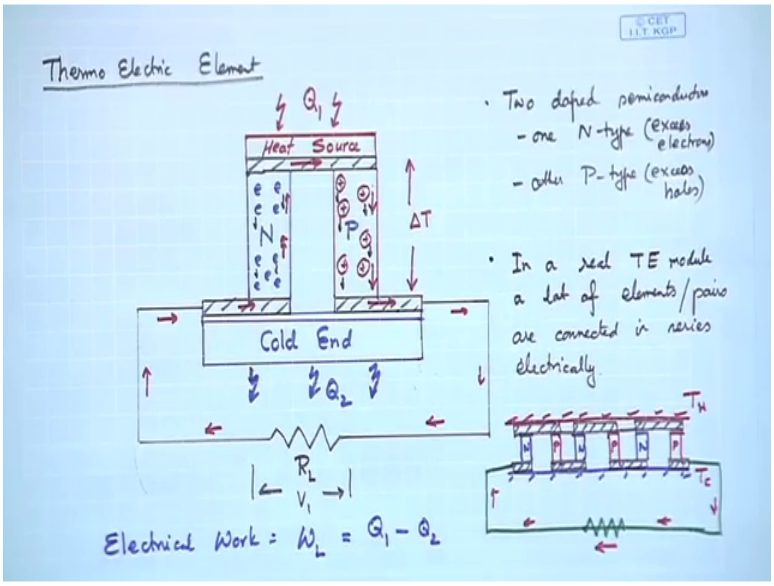

So, let me show that in this picture if you look at it now I have an N type semiconductor and I have a P type semiconductor, these are both doped semiconductors. So, this what I am showing here let me write it down is a Thermo Electric Element. What does it have it has 2 doped semiconductors right 1 N type which means excess electrons and the other is P type which is excess holes. So, now, let us talk about this in one case in the N type we have additional electrons. So, I will just write them as e and in the P type we have holes and I am going to denote them as with plus signs and so on.

Now, what happens is let us say now we have a situation where we have this N and P type the way they are arranged is the 2 components are arranged such that they are electrically in series what do I mean by that see there are these metal blocks which is denoted by this these are metallic sheets let us say denoted by this black shaded portions. So, on 1 end the 2 are connected in series electrically, now the other end again they have these small metallic sheets or pedestals both the elements this here it is not connected and that is how it is it is maintained.

Now, let us say that on 1 end I heat it through some heat source again that is the focus or the theme of this class is waste heat recovery. So, let us assume I have a lot of thermal energy which otherwise would be wasted and so I subject one end of this thermoelectric element to that thermal energy, that I have at my disposal and thereby this end heats up the other end is maintained at a colder temperature we can have a heat sink or we can just leave it at the room temperature. So, thereby we give rise to a temperature gradient across this ok.

So, we have a temperature gradient across the 2 junctions of each of these elements. So, this is also a thermoelectric element is or sometimes also called a thermoelectric pair, because this is a one pair of N and P. Now what happens when we heat up one end the charge carriers in that end gets energized right, just like we saw in metals the charge carriers there are electrons they get energized and they tend to flow from the hotter end to the colder end. So, here also it is going to be the same the charge carriers in both the N type and the P type are going to vibrate with more energy at the hotter end and the net effect is there will be a net migration from the hotter end of the migration of the charge carriers that is from the hotter end to the colder end.

Now, what are these charge carriers, these charge carriers are holes in the P type and electrons in the N type. So, therefore, what is happening let us look into this picture again. So, net what will happen is this electrons would like to flow from the hotter end to the colder end and similarly the holes would also like to migrate from the hotter end to the colder end clear. So, therefore, what happens now let us say if I join these 2 and close the loop then what happens is I will have a net flow of electric current from in this direction remember the electrons are flowing from the hot end to the colder end which means the current is flowing in the opposite direction.

And then over here it is simple because that current direction of current is same as that movement of the direction of movement of holes and then so we will have this electric current which is flowing through this clear. So, now, over here if you have a resistance, if you have a load then I am going to give rise to a voltage across this load because of the current that is flowing through this clear. So, that is how the thermoelectric module works let me summarize again a thermoelectric element or a pair consists of 1 P type and 1 N type semiconductor. They are arranged such that they are connected at one end in series and then what we do is thermally they are in parallel in the sense that one end is heated the other end is cold.

So, when we do this what happens is the charge carriers will tend to move from the hot end to the cold end? Now the charge carriers in this case is electrons for the N type and holes for the P type. So, therefore, electrons in the N type will migrate from the hot end to the cold end the holes in the P type will do the same. So, therefore, now if we close the loop or complete the circuit we will have a net current flow in the direction that is shown which is in the direction of the flow of holes and opposite to the direction of the flow of electrons.

And so now, if I put a load then I am going to get some useful energy out of it in the video that we saw in the beginning it was a fan that was arranged in this manner clear. So, this is how a thermoelectric element works, now keep in mind that the voltage that you are going to get out of a single pair like this is not going to be very high, but now what happens? Now in a real in a real case what we will do is we will connect a lot of them in series we can do that. So, how will it look I will draw it let me write it down in a real TE module a lot of elements or pairs are connected in series electrically of course, thermally they are always in parallel because one end is heated the other end is cold.

So, therefore, how will it look it will look like this. So, I am just showing small pair. So, this is n type let me draw the N types first I am sorry for the small picture here, but I hope we will understand what we are trying to do and then the other end is I am sorry I am sorry all right. So, this is how it looks. So, I have a series of N and P types the N is blue the P is red which is the color combination that we are using and if we do this what happens and again one end is heated. So, this end is heated at a temperature T 1 or T H let us say and the other end is cooled or maintained at a lower temperature which is T C then what is happening therefore, is if I connect these ends in series.

Let me do that by the green pen and I am I attach a load over here I am going to give rise to a current flow in this direction. So, then in reality this is how it works a thermoelectric module will have a bunch of these pairs or elements connected in series in this manner and thereby we will get an appreciable amount of current flow and voltage across it clear.

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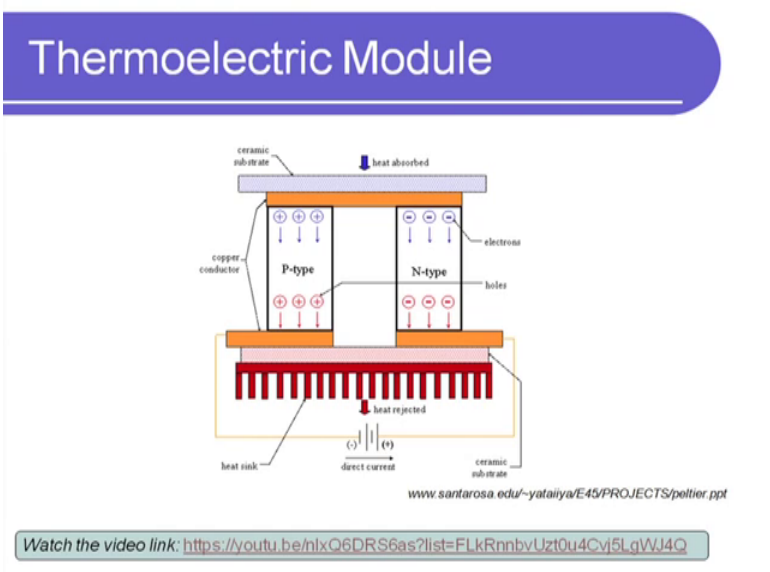

So, what we will do is. Let us look at it this is what is shown over here the same type that I tried to draw that picture is shown over here where you have the P type well the N type and P type the locations are reversed.

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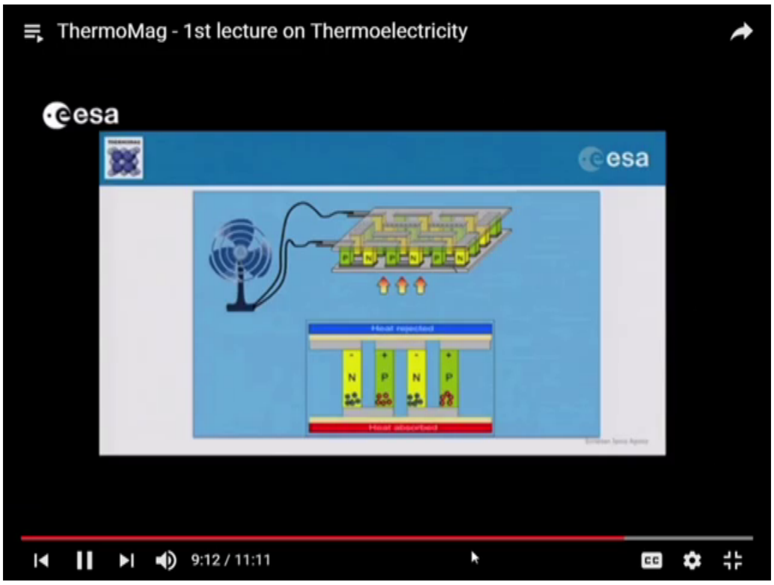

So, on one end heat is absorbed on the other end the heat is rejected and you also get some electrical work out of it. So, now, from our thermodynamic knowledge we know that the electrical work that we are going to get out of this is definitely going to be lower lower than that of the heat that is absorbed. So, we will come to this, but let us finish the video again now that we know how it works. So, remember we started by seeing a teaser video where the Thermoelectric Module was just a black box and we suddenly saw that if we maintain a temperature difference we are able to drive an electric current through the circuit. And this after this discussion of what is a thermoelectric element and what how a thermoelectric module consists of a lot of these thermoelectric elements connected in series. We can now look into the details of what was happening in the same video. So, I will play it again for a small short while.

Stimulation we replicate the video shown in the beginning of the lecture, just in this case we will apply heat to the bottom of thermoelectric model. We can see that with it is temperature gradient charge carriers migrate from the hot side to the cold.

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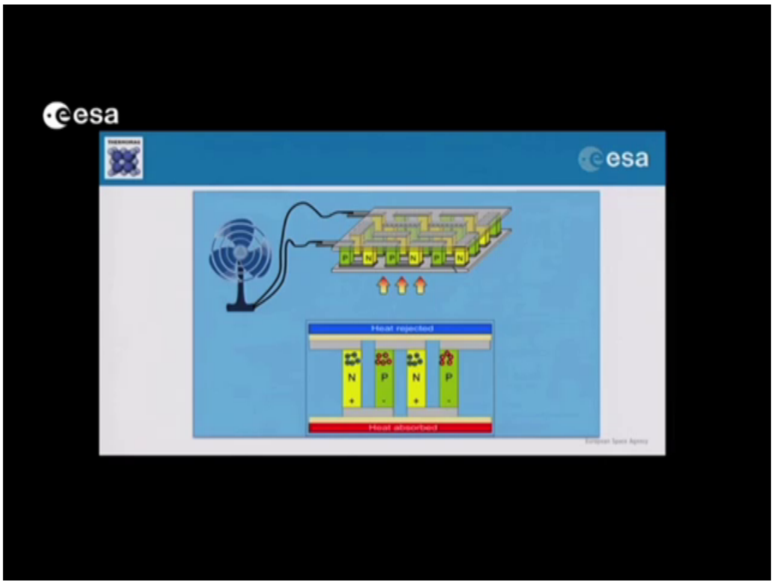

Rate in electric potential the fan is a closed in the loop. So, we get electricity in the circuit to summarize the seebeck effect is a production of an elect.

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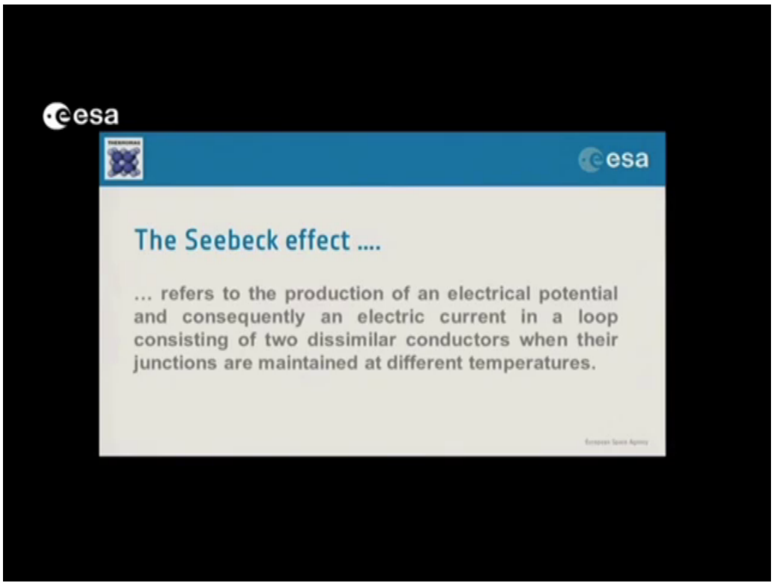

So I think that video kind of that animation explains what we were also discussing through our drawings, it explained in nice manner that as to why that fan was rotating and so as you can see that this is a very nice niche way of converting electricity or converting thermal energy directly to electricity.

So, if you look at this picture that I had drawn on the on the sheet we were supplying electrical energy sorry thermal energy at one end and we were able to get electrical energy through this current flow and of course, what I did not show here was at the cold end there will be of course, rejection of thermal energy also and let us call that Q 2.

So, definitely the electrical work that we are getting. So, if we say w electrical work or energy W L is going to be Q 1 minus Q 2 from first law of thermodynamics. So, now, where do we use it and how good are these as conversion devices. Now let me tell you one thing that the efficiency of thermoelectric devices is very low, when we talk about what we mean by low is if you get efficiencies of the order of it is 10 percent or lower 10 percent is actually very high of course, it depends on the temperature difference that we have, but efficiencies are provide quite low.

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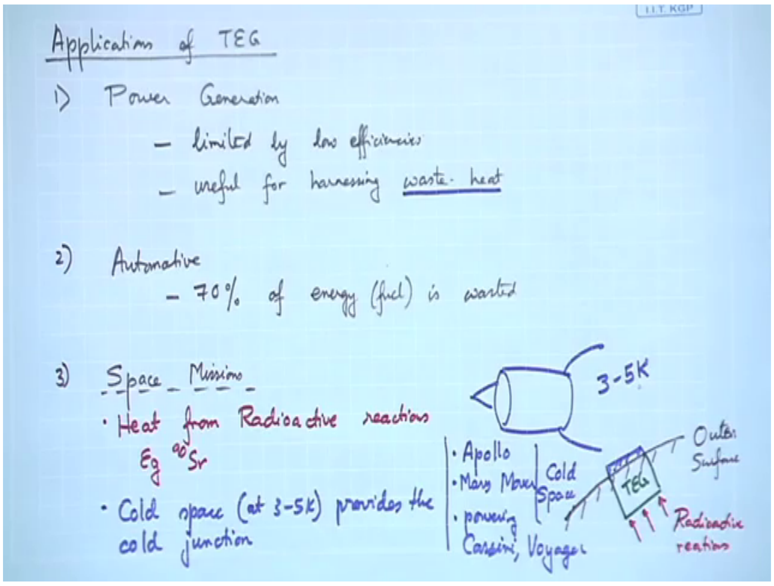

But still. So, therefore, if you talk about applications let us talk about Applications of Thermoelectrics; Thermoelectric Generators that is so one let me say power generation. Now you may ask that can we replace our power plants cold based power plants or gas based power plants completely by Thermoelectrics the answer is no, because the thermal power plants that we that we know today, just in a simple steam cycle the efficiency is around 30 percent in case of combined cycle where we have we have already crossed 60 and going towards 65 compare that to 10 percent for thermoelectrics.

So, therefore, replacing our existing power plants by thermoelectric generators is not possible it is it does not work because it is limited by the low efficiencies. So, I would say that it is limited by low efficiency, but; however, it is very useful for harnessing waste heat. So, this power if the power plant efficiency let us say single power plant not a combined cycle, if a standalone steam turbine cycle efficiency is around 30 to 35 percent the remaining that is wasted we can look at that as a potential heat source and convert it to electricity additional electricity using thermoelectric generators.

So, it is useful which can be looked at as a means for harnessing energy from waste heat, but not direct power generation by replacing existing power plants no. Similarly another application we can think of is in automotive because in automotive also if you look at a car almost 70 percent of energy from the fuel is wasted it is wasted from the exhaust pipe. So, therefore, can we use that energy can we harness that energy the trapped energy in that you know the hot exhaust gases from an automobile and convert it to some useful means.

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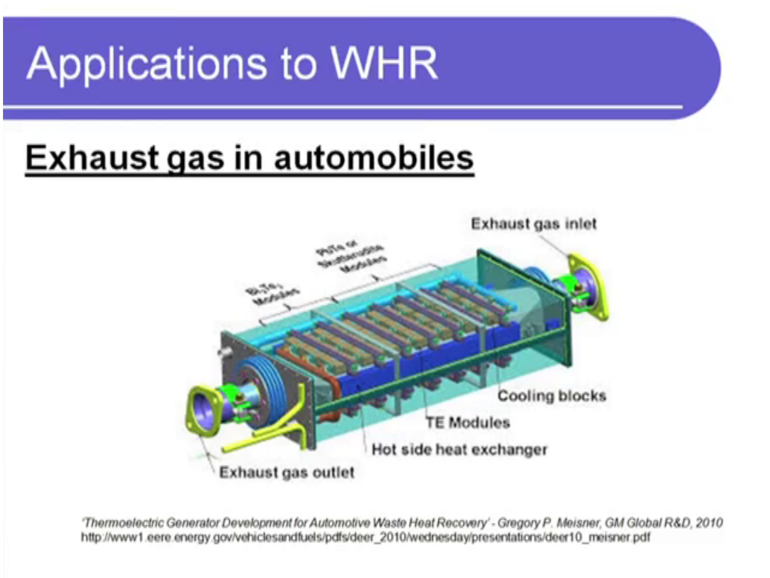

So, that is actually happening exhaust gas in automobiles there are several companies that are looking into it you can harness that energy and use it through thermoelectric modules and probably use it to dry something useful for example, the music player inside or maybe the ac unit may be directly not the compressor. So, much, but or maybe for charging the batteries if you think of hybrid vehicles the internal lighting maybe the blower of the fan in the ac in the HVAC system. So, you have some additional electrical energy available to you which can be used right.

So, this actually is a hot topic of research a gm Toyota everybody was looking at it and it was forecast that in 2017 we will finally, see an actual a car a car in the market with this thermoelectric module implemented. I do not know what is the latest on that, but all I can say is we probably the we are going to see this in the very near future actually applied all right, but one application where thermoelectrics have been in use is in space. So, actually in space missions thermoelectrics have been used for quite some time now why is this because think about it.

Let us say in a let me draw a very simple picture of a spaceship like this a very childish cartoon let us say. So, where is this is in the outer space away from the sun the ambient over here is around 3 to 5 Kelvin. So, very low all right. So, therefore, if I consider that this is my outer surface of the spaceship. So, this is my outer surface then what happens this part is cold space at temperature of 3 to 5 Kelvin. So, therefore, the cold end is taken care of now let us say I put a thermoelectric generator over here.

So, the cold end is already taken care of this is cold space on the hot end what is done is the heat source is given over here and this comes from the radioisotopes the heat from radioactive emissions. So, I would say heat from radioactive reactions for example, strontium 90 example. So, this is how it works so on one end the and let me write down here also the cold space at 3 to 5 Kelvin provides the cold junction. So, this actually is in use all right. So, this has been in use let me write down a few names it has (Refer Time: 26:19) used in Apollo, it has been used in mass movers and then it has also been currently it is powering Cassini and voyager.

I am sorry for the crowded writing over here, but let me repeat again that then the space missions the thermoelectrics have been used for quite some time for more than 30 years now because Apollo if you think about it. It was used in Apollo because the way it was used is the way it is used is the outer space is at a very low temperature so the cold junction is taken care of and the heat is being supplied from radioisotopes from Radioactive reactions and therefore, this thermoelectric generator has been generating electric power and powering these Cassini Voyager also which are now currently in space.

So, those were a few words about the applications of thermoelectric generators and some of them potential for example, automotive is very close some of them in practice like in spaceships and some of them being research for example, looking at the waste energy that comes out of our power plants. So, with that we will end this lecture and in the next class what we will do is we will do some analysis on getting what is or analysis on the thermoelectric properties the efficiencies the work that you can get and so on.

So, thank you very much and we will continue with thermoelectric generators in the next class.