Sustainable Material and Green Buildings
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Lecture 40
Solar Energy and Solar Cells

So we looked into OTTV and energy codes in general. So we look into some of the potential solar energy options, before we look into things like ratings okay. So I think you know we just I might have have mentioned this sometime earlier.

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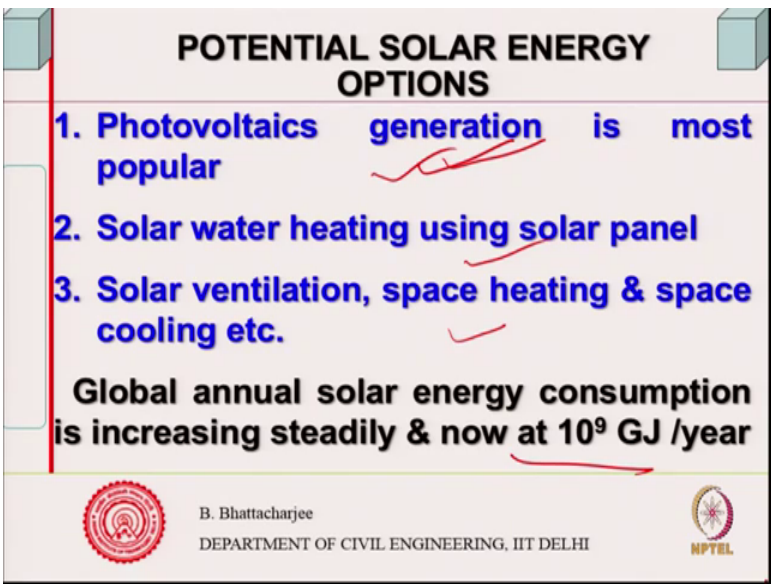

The options are photovoltaic generation is one of the major option, right and solar water heating using solar panel, so out of this, this is most popular. There are various options, for example, solar ventilations then similarly there are many others. Now we will look into this actually. Now what we know is generally it is currently of the order of 10 to the power 9 Giga joules per year. This is the data sort of the thing and it is increasing. So, solar energy utilization is gradually increasing. We know that people are getting conscious about it. And let us see what is look at photovoltaic scenario.

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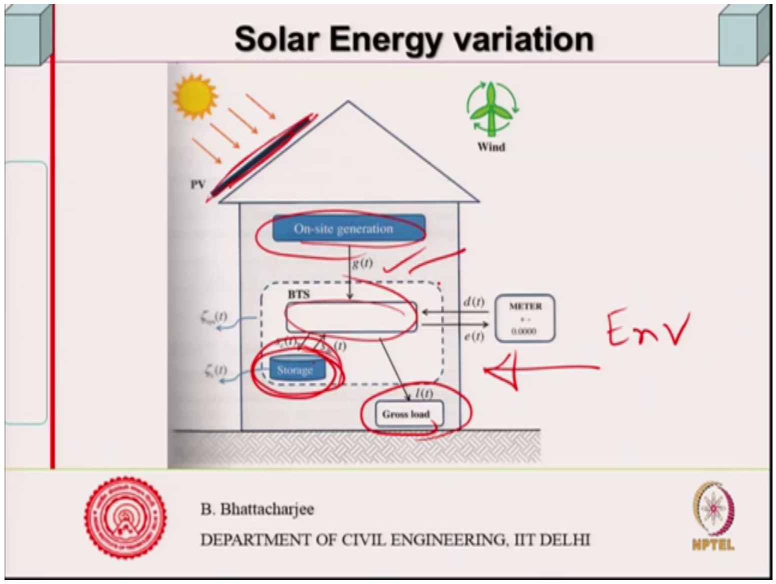

So before looking at that, you see this we have looked into the heat transfer in building some time or other or I might have mention to you. So there are certain amount of casual heat gain into building through fabric etc-etc. Now you can capture some the solar energy that comes into the building envelop using photovoltaic and any other on-site generation based on this you can have on-site generation, that is Gt, let us say. The load comes from the outside environment and appliances etc inside which is casual heat gain.

So on-site generation, if you can store that is good because it will not you know on-site generation, say through this or through other kind of sources such as local wind mill in the building, very tall building or something of that kind and this they will not match with the requirement. So you might need some storage sometime, right. And you might have a metering system as well.

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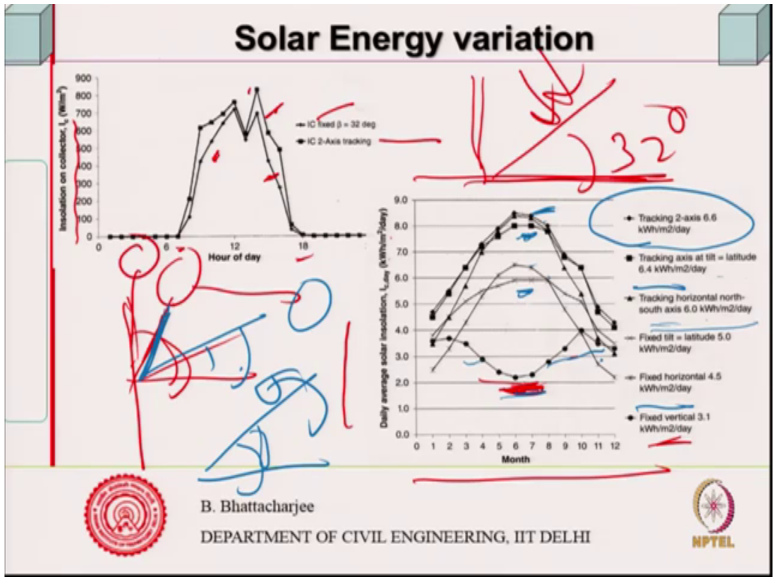

So if you look at variation of solar energy. Supposing, I have a fixed you know I have a fixed insulation collected on collector Ic stands for radiation on a collector. I keep it at a fixed angle of altitude, fixed angle for example tilt angle as we call it. So this tilt angle supposing if it is horizontal, it is 0. If I keep it at certain angle, beta equals to 32 degree, let us say. So this is 32 degree, solar radiation falling like this.

Then I get, if it is fixed, I get radiation received is somewhere here during the day hour, hour of the day, so around 8 am to 6 pm or something. Now this is fixed at a given angle while if I keep its angle change, track the sun then I get higher solar radiation. So you can make it you know automatic. So if you look at that, then supposing I have got, if you see this serigraph for various month, daily average solar radiation, direct radiation per day, kilowatt meter square per day let us say then this is fixed vertical. So vertical gets do not get, you know it gets much less, depending upon of course the month, right.

So say something like summer, vertical gets less radiation because altitude angle of the sun is very high, right. So this is the altitude angle of the sun, if the sun is here, it would not get any radiation. So supposing altitude angle is close to 90 degree, Cos 90 is 0 so I Cos (90), so it will get much less during the summer months. Winter months it gets because sun altitude is during winter months sun altitude angle is lower. So during winter months sun altitude angle is lower. Therefore during winter months vertical surfaces gets sunlight.

So if you keep the PV on vertical surface then summer months you are (like) unlikely to get but winter months you are likely to get some radiation. Now let us say some something, this tracking in both axes this will be maximum, which means that you keep on changing this angle of this panel, collector panel, you keep on changing both in horizontal as well as in vertical direction.

So when you keep on changing, you get maximum in summer months. Obviously, winter months it will be relatively less because radiation is high in summer months and tracking axis at tilt angle being latitude. So keep one angle but it is in horizontal plane say this one is horizontal plane it rotates but in the vertical tilt angle remaining fixed. That means this angle remaining fix but then it rotates in this plane, you know this angle remain in fix. In the vertical plane the angle is fixed, which is the tilt angle. But it is rotating in the horizontal plane, so following the sun that also you get fairly high.

And tracking horizontal right, tracking horizontal north-south axis, so similarly there are different angle if you keep it, you get different radiation. So vertical you get least in summer but winter you get just horizontal, fixed horizontal let us say is actually this, which you get high in summer but winter you do not get. But if you have tracking, obviously this is understood. So by doing tracking, you can actually trap more energy, you can trap more energy if you do tracking.

Okay, so this is one thing. So whatever device, whatever system you have whether it is a water heating system, a flat plate collector right, which will absorb heat and heat up the water in pipes or in blackened pipes, which we will discuss sometime later on or a photovoltaic devices which will actually generate electricity. If you do tracking, you always get more energy, right.

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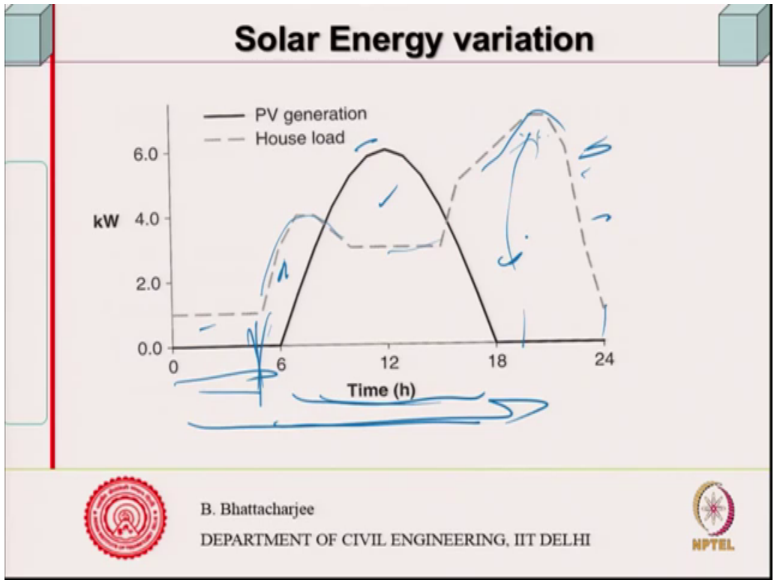

Okay, now you see the maximum load in the household is something like diurnal, daily 0 to 5 am or so, there is no load. But it picks up and maximum load is in the evening hours because both your lights and your cooling system or heating system because the space is maximum used residential spaces are mostly used also your commercial spaces will be used in the evening time.

So you have a peak somewhere there, household. house load if you see or even otherwise any loads generally will be seen somewhere there. But your PV generation is only between 6 to 18 because solar radiation you get from 6 to 18. So this is extra you are getting here. And these places you have to actually borrow from the grid.

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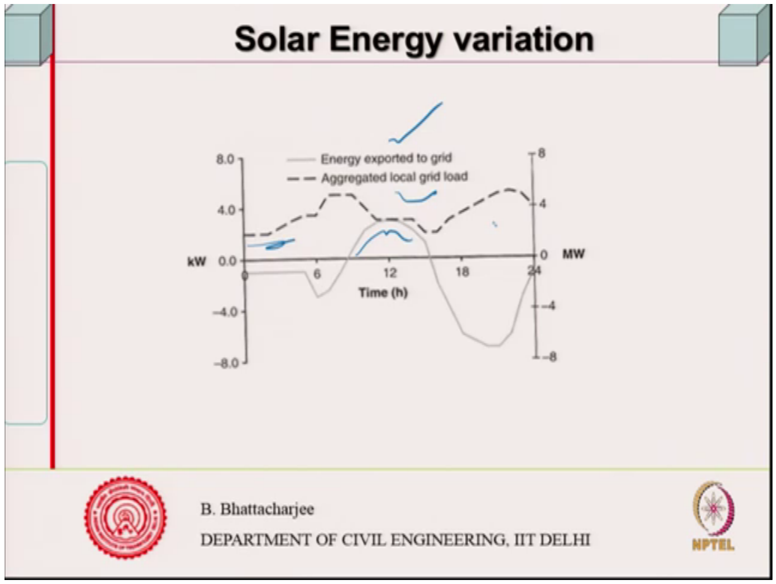

So we have this, something like this if I plot energy exported to the grid and local grid load because during the daytime, noon you can actually export some energy. But in the evening you have to get from the grid. So energy exported to the grid is this. It is peak at this point of time and aggregated local load, this is that. But this you know here it is. So basically there is a time during which you will have, you can get from the, you can get from the you have to I mean you can supply to the grid or store it for later on uses. So this we actually, when we calculate life cycle cost this becomes important.

So this is what we can see that at certain time of the day, energy exported to the grid is obviously negative because you are getting it at that point of time. Independently they are plotted. So minimal energy I actually take from the grid during the daytime. But I have to get it in the evening and so on.

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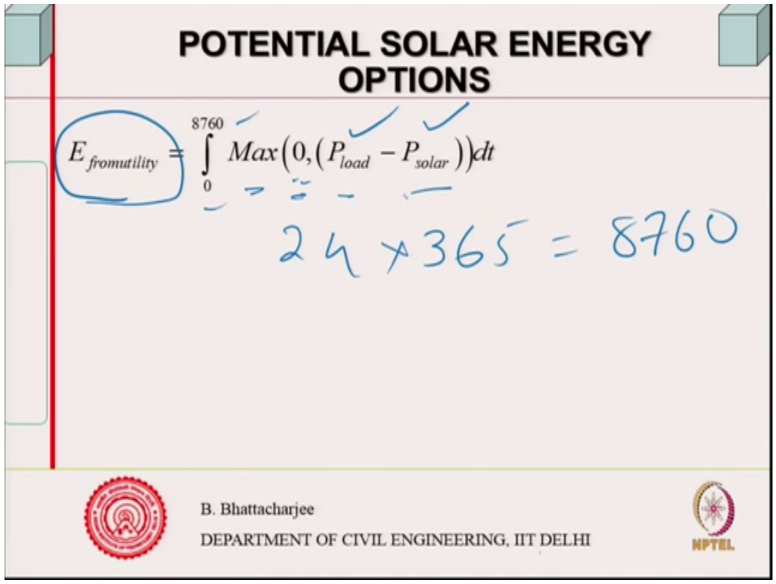

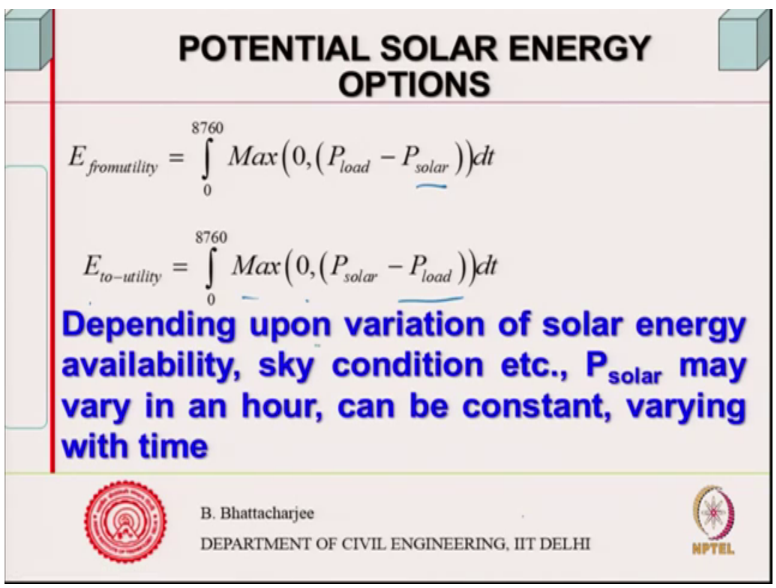

So options therefore, if I look at it for photovoltaic, sometime I have to get and sometime. So we define something called E energy from the utility that is the grid. That would be 0 to 8760 hours, that is 24 into 365 makes it 8760 all hours. Maximum between 0 and load minus whatever you are getting from. So this P stands for power. Power you get from the load or P from the solar.

Now maximum of this that means all negative values will be thrown out it will converted. So maximum of either 0, so it can be less than 0.So 0 P load. So that is the E from utility and E from solar to utility is maximum of 0, P solar minus P load, right and for the whole year, all hours. For all hours actually I calculate out. So this is alright. So depending upon the variation of solar energy availability, sky condition etc this may vary in an hour and can be constant or varying with time. So you might take hourly values, that itself is good enough, right.

So depending upon sky condition, everything put together, so this will vary and therefore one may you know integrate over the whole.

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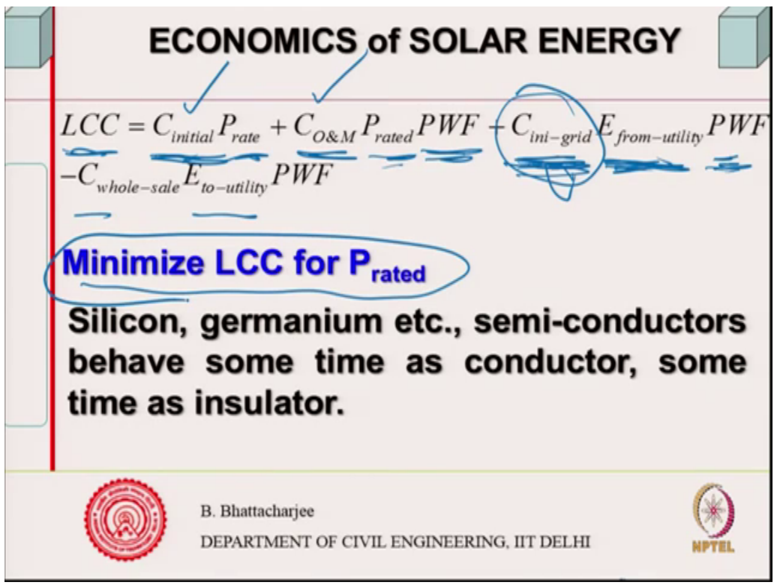

Now if I look at the economics part of it, life cycle cost I will have some initial cost of the system then rated power, P rated, how much it generates, P rated. There is an operation and maintenance cost. That is also multiplied per unit power. This will be per unit power. So for generation of unit power whatever is the cost that is the C initial and operation and maintenance cost per unit power that is known to me, multiplied by what is called present watt factor. Because these are all in different time and as we sometime might have discussed in engineering economics term right, this is present watt factor.

So this yearly expenditure, I must bring it to the current level and this is from initial cost from setting up the facility to get connected from the grid from the utility. And E from the utility power because this will be rated, power rated. So E is the power from the utility into present watt factor. So this is how it is, this is a cost sorry, this is the cost from the power you know if you getting from the grid what is the cost per unit power.

And E from the grid I am getting, from the utility I am getting or might be having my own generator. That is why the utility I am getting from the grid is fine. So this is the per unit cost multiplied by whatever we have calculated earlier, whatever we have seen earlier, whatever we have defined earlier

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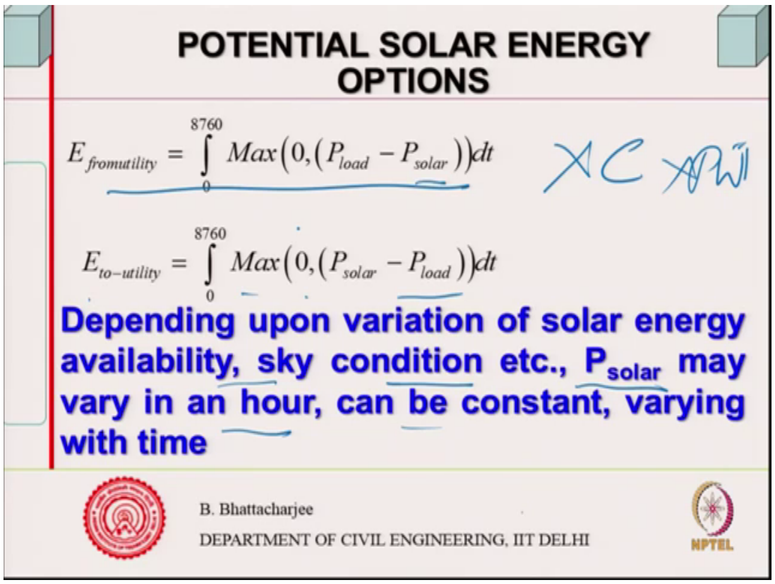

This is E, this multiplied by cost per unit multiplied by present watt factor. And this would be, the signs of these two will be opposite because this is what I am giving to the utility. So this is actually purchase rate. This will be the purchase rate ,this will be the selling rate. This will be the selling rate, this will be the selling rate right. So this is the selling rate. And so this is the purchase rate from utility and minus this is the wholesale selling rate to utility. So life cycle cost one can work onto this. And compare different systems if they like, right.

So you should minimize LCC. This life cycle cost should be minimized. If it is if the building envelop is designed properly then your load will be reduced. So when you talk like things like net zero building, we actually discussed that there are various factors or parameters we might have to choose like orientation, shape, envelop, etc-etc such that my load is minimal, load is minimal.

So in that case, this would be relatively less. So my life cycle cost should be this should be plus actually. This is plus. This should be less and this then could be higher. So therefore life cycle cost will be lower, right. So we will discuss one, beside this photovoltaic, we will also discuss other systems. But first let us look at this. So what we know is silicon, germanium etc these are semiconductors and they are used in photovoltaic system.

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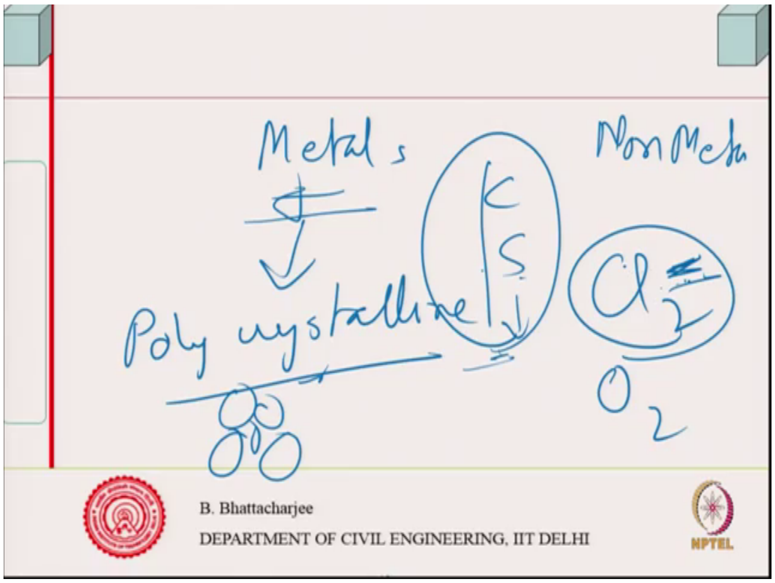

So if you look at periodic table, on the left hand side you have got metals and the right hand side you have got non-metals. In between you have like carbon, silicon etc they are somewhere in between and if you look at metals, they will have the number of electrons in the outer orbit which is far away from the nucleus. They can lose it very easily.

So if you look at the structure of metals, generally it is assumed to be polycrystalline. You know these are assumed to be polycrystalline although we are not talking the material right now, they are assumed be polycrystalline with all metal nucleus assumed to be spheres they are packed in a given manner. Like body centered cubic packing, face centered cubic packing, etc-etc so they are packed. So spherical nuclei they are actually packed in a given manner and packing density is sufficiently large. So that it is stable.

What happens is, the outer electron, they form a kind of a class cloud or which can move very easily. So in metals, nuclei which are assumed to be spherical, they are packed and outer electrons are relatively loosely connected to the system. So as soon as you give some energy electrical, potential these electrons can move that is why they are good conductors.

On other hand, non-metals they form actually covalent bonds, for example Cl2, O2 so two atoms combined together and share the electron of the outer periphery because where they have less. It is not stable. So they borrow from another bond and share it to become a, form a stable molecule. In between ones as such that they, they do so they are somewhere in between. So they do not lose electrons so easily and this one they do not lose. They can get from somebody or share. Now in this in between ones, this one is what is called is energy that the energy level is called Valency bond. Where in this one the electrons are what is called conduction band, so valency band and conduction band.

Here between this, in nonmetals supposing I give some energy, the electron will not move outside because the distance between valency bond and the conduction I mean valency band and conduction band the energy level is very high. To make it conductor, I have to give very large energy where if I give a small potential, electron moves. In this one, this is somewhat in between. So the difference between what called valence (bond) band and the conduction band is relatively less than this. Here it is infinite. So if you give some energy, it can get ionized at very high energy level, so some gases, of course. So that is it.

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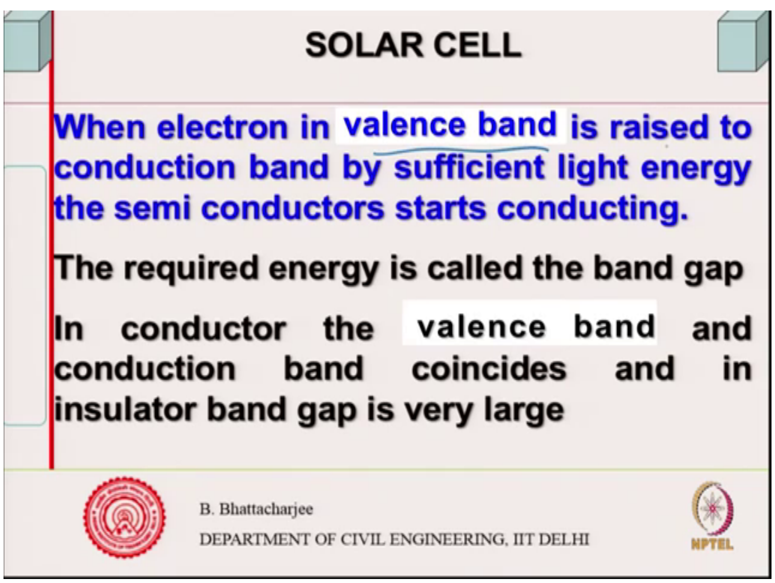

So if you look at this, let me erase this out. So when electron in valence band is raised to a conduction band by sufficient light energy, semiconductors starts conducting. So semiconductors are in between. Metals are conductors, non-metals are insulators. In the periodic table something in between, they are semiconductors. So when you supply sufficient light energy, they can start, they can actually starts conducting.

So this required energy is called band gap. So this is the valence band there is a band gap between the two energy levels. And in conductor, the valence band and the conduction band coincides and in insulator band gap is very large. So that is what it is, that is what I was just mentioning.

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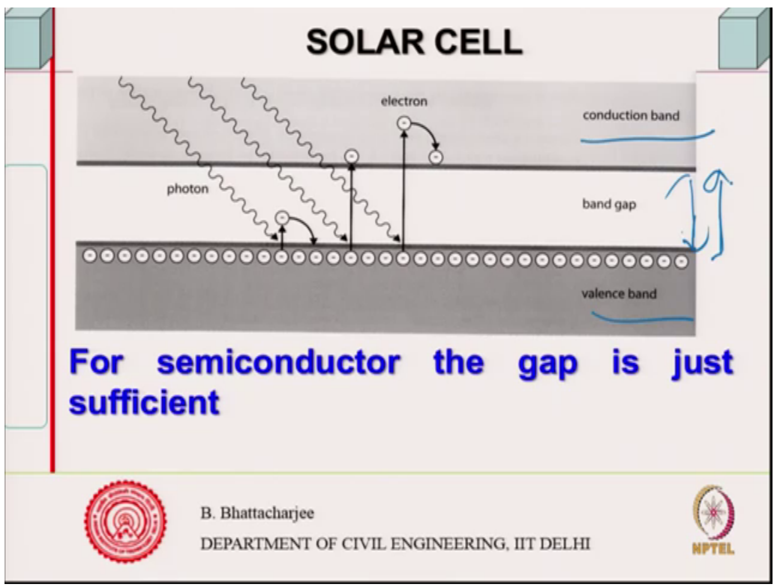

So what is done? What is done in this one is valence band, conduction band and this is the band gap. So this gap is very-very large in case of insulator. So you supply energy, electron will not move. In conduction they almost coincide, so the moment you supply they will move. So if you supply light, in semiconductor if you supply light. Since this gap is relatively less than the insulator with sufficient supply of energy they can jump into in this one. So that is idea and that is how electricity is generated out of solar cells.

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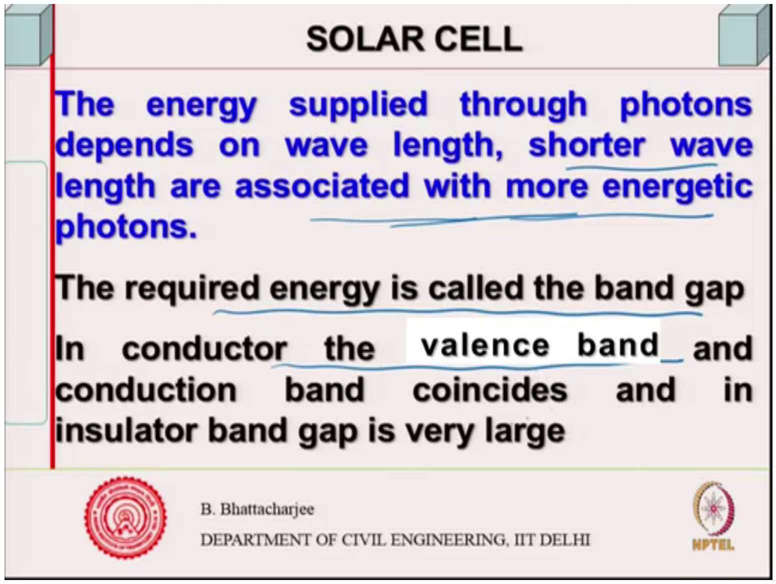

So the energy supplied through photons depends on obviously wavelength and as you know shorter wavelengths travel, the shorter wavelength have high energy, so they can travel over, they carry actually high energy. So sun's energy is short wave which can actually travel through glass. But while we know that a long wave it does not. The terrestrial radiation from terrestrial that is what we talked about.

So shorter wavelengths are associated with more energetic photon. The required energy is called band gap. So in conductor, the valence you know as I said, this is already I have mentioned.

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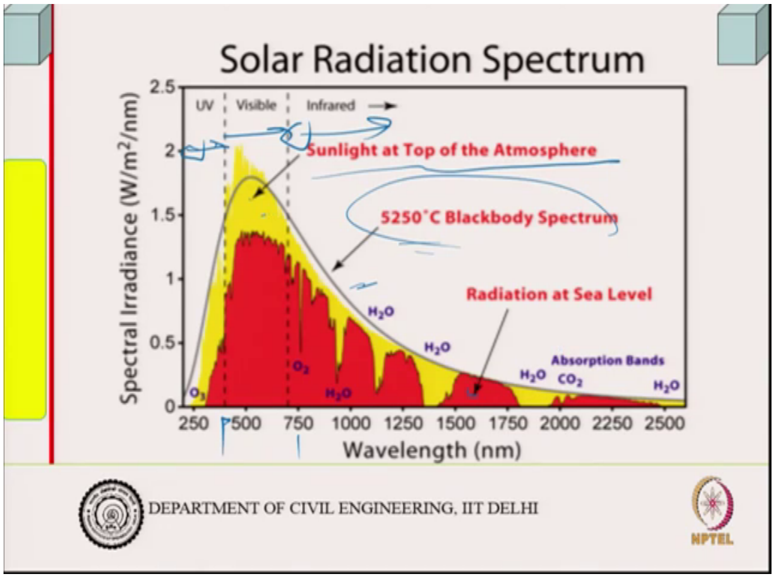

And if you look at sun's radiation, this is ultraviolet, this zone is visible, this range and this is infrared. This is you know this is so this is average at 5250 black body spectrum. So sunlight at top of atmosphere is something like this and this is at the sea level because there will be lot of absorption in the atmosphere. So there is some absorption that takes place, alright. So that is the sun's energy, so peak is around the visible range. Because peak is around the visible, that is why you see it.

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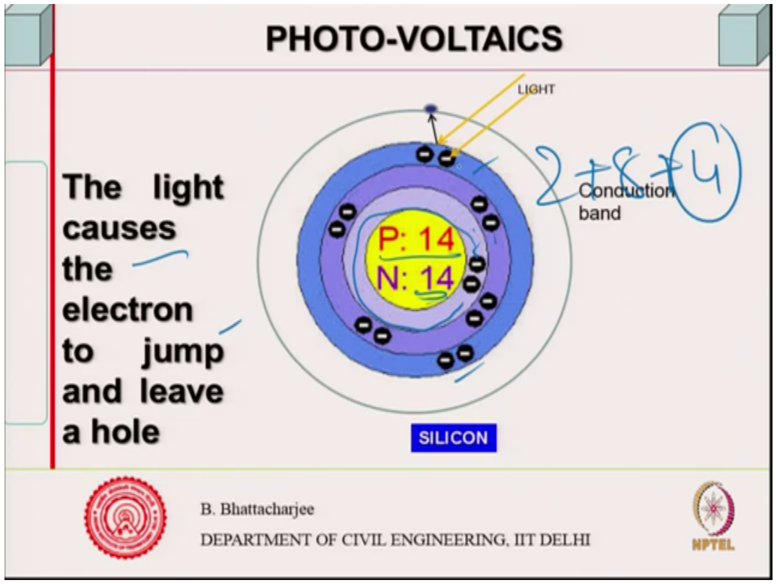

And in semiconductors, something like as I said, in the middle of the periodic table we have silicon or carbon. Let us say silicon you take. Its atomic number is 14. It has got ofcourse 14 protons as well, so atomic weight is 28 but we are not bothered about this. So if you look at this 14 we know that is s, p, d, f etc-etc you remember? So these are 2 electrons, then 8, 2 plus 8 plus outer shell will have 4. So these are the 4, right.

Now this is the silicon atom what looks like and if I give energy there then this can jump out. This can jump out because these 4, if I give energy, the gap between the valence band and the conduction band is relatively less compare to that of the insulator, right or non-metal on the right hand side. So this can actually jump. But what is, so light causes the electron to jump and leave the hole there as you call it. So, now net effect is a positive charge.

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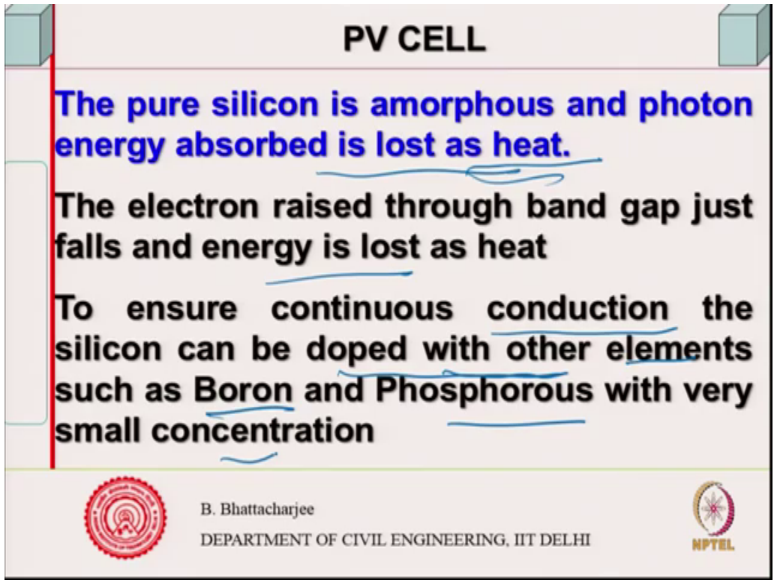

So the pure silicon is amorphous and even if it jumps. Even if it jumps actually, the energy is absorbed and lost. It will move actually it will jump and maybe energy is lost and then it comes back again. So this energy is absorbed and it is as heat converted into it and it might come back to it. So just falls and energy is lost as heat, so if I have just you know I supply, it jumps out. But it will generate heat and come back.

So in order to ensure that there is a continuous flow, I must see in some manner, the electron that has come out must be able to move to another atom and so on and so forth. So to ensure continuous conduction the silicon can doped with other elements like boron, phosphorous with very small concentration. So supposing I have boron or phosphors as we shall see. Boron has got 3 electrons in the outer shell because it is in the same group as aluminum, group 3. This was in the left hand side, on the metallic side. And phosphorus is on the right hand side. It has got 5 electrons in the outer periphery.

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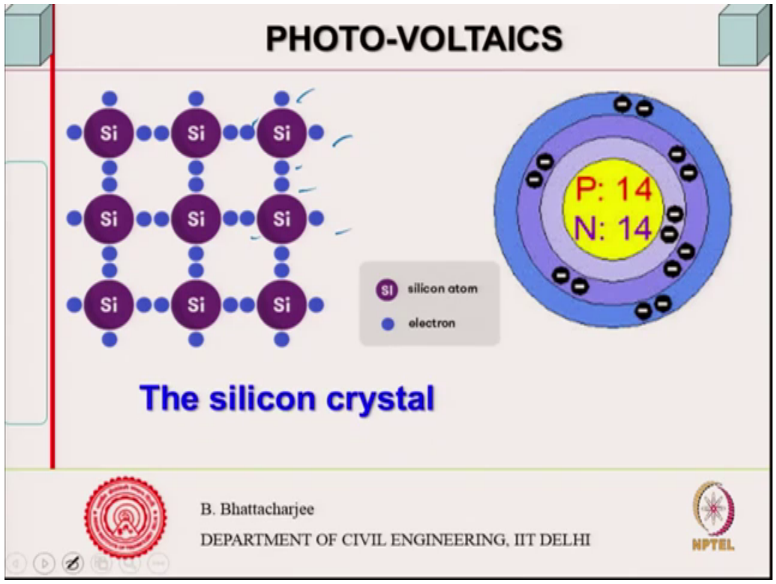

So let us see. This is the silicon atom. There are 4 outer electrons with each silicon atom we are showing right, outer electron that what it is. So that is how the silicon looks like, silicon crystal supposing I mean silicon atom.

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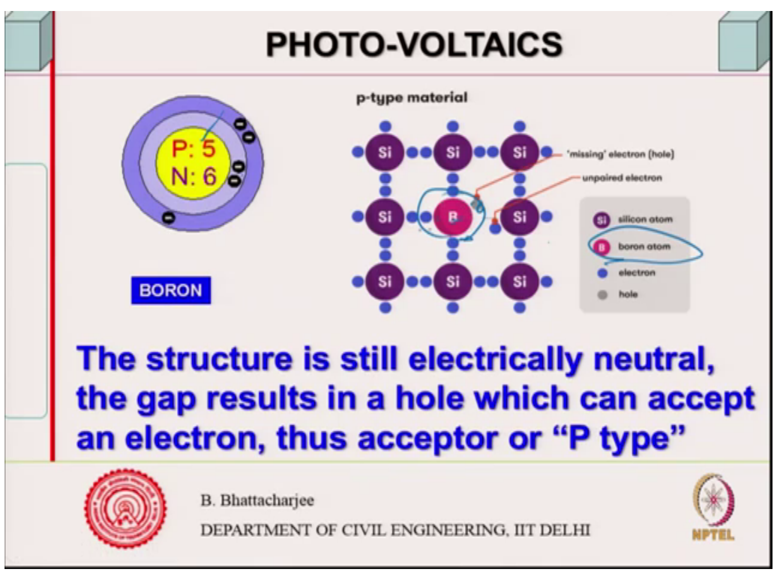

Now supposing instead I put boron, instead of silicon there is 1 boron. So I mixed it up, doped it. So this is the boron atom. Now it has got 3 instead of 4. Silicon was having 4 it has got 3 electrons in the outer shell 1, 2, 3 instead. So it has got this is missing. This is missing because boron has got 3 electrons in outer shell. So then there is a gap here, right. The system is electron neutral because the number of protons here and the number of electron, they all matched they are same. So it is electron neutral there is no problem, right. So this is what boron is.

It has got atomic number 5 right, so 1, 2 and 3 there alright. So I mix this up sometimes, still is. And the gap results in hole that means there is a gap here. So 1 electron possibly can come here, right there is a gap because otherwise it was all 4, 4, 4 here suddenly there is 1, 3.

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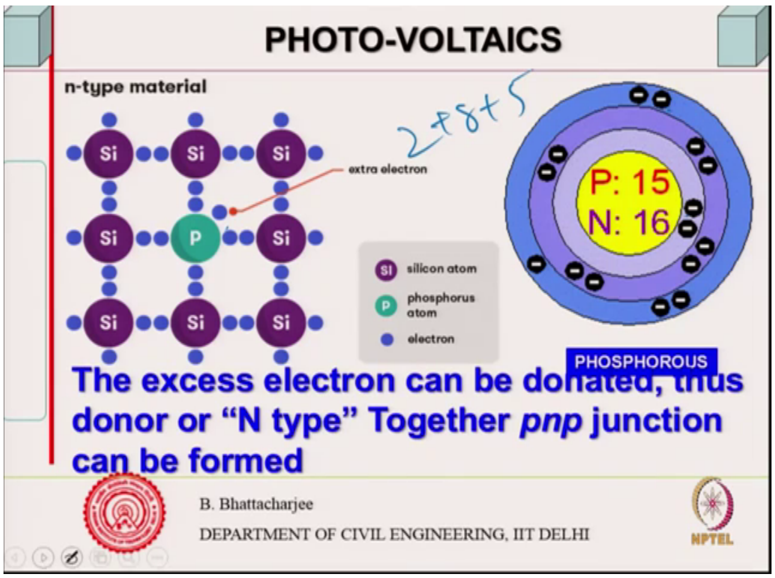

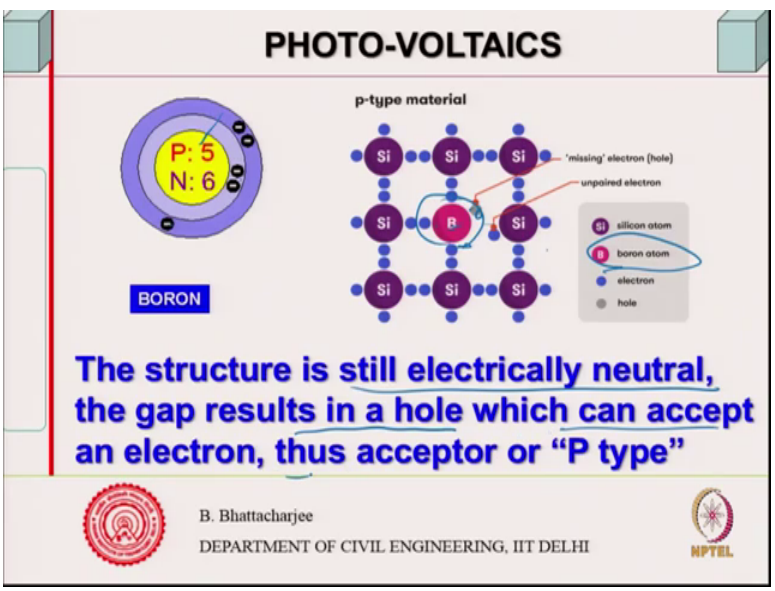

Similarly, if I have phosphorus which is 15, so 2, 8 plus 5, 2 plus 8 plus 5 so in outer shell it has got 5 electrons. And I just put phosphorous one I have got extra electron there and again this is also electrically neutral. So earlier case, I had 1 less electron, here I have got 1 more electron, right. So if I now if the electron then jumps you know the boron 1 where there is boron there is a gap there. So that gap can be filled up by if an electron jumps out from silicon. It can go to the, right go to boron.

And in case of phosphorus it is other way around. It has got an excess electron which it can lose easily. So excess electron can be donated, this is called donor or n-type. And previous one is called p-type. So the structure is electrically neutral, the gap results in a hole which can accept an electron by an acceptor. So you have p-n-p junctions, you can form. And if you now pass the light, the electron can move from one to the other because there is a gap available and there are some excess that they like to shed off.

And this system can be built together to form what is known as a semiconductor and they form a photovoltaic device that can be formed in a photovoltaic device.

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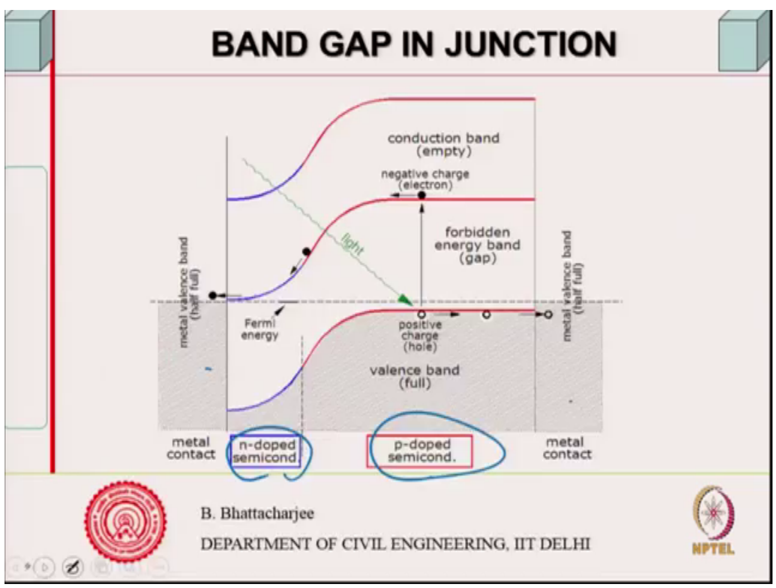

So these junctions are used right. If something like you have p doped semiconductor, you have n doped semiconductor and you have metal on both the sides. So when light falls onto it, right, P was the one which would actually accept, that is what we said, P was, what was P? The excess, so N is the one which can give away. So P is the one which can accept actually. So this when light falls onto it from the silicon it will accept, right. But then it becomes electrically negative.

So if there is a metal conductor, it will move to the metal and since this is actually lost 1 electron, this will supply that electron. So this process can continue. So when you have a PNP junction, light falls onto it. The movement of electron can take place because one of them is an acceptor other the donor. And acceptor can accept the electron that will move out of silicon. And as it becomes electrically negative, the electron will tend to move. And the other one, which is the donor also like to reject an electron and the process can continue. So that is how actually photoelectric devices work.

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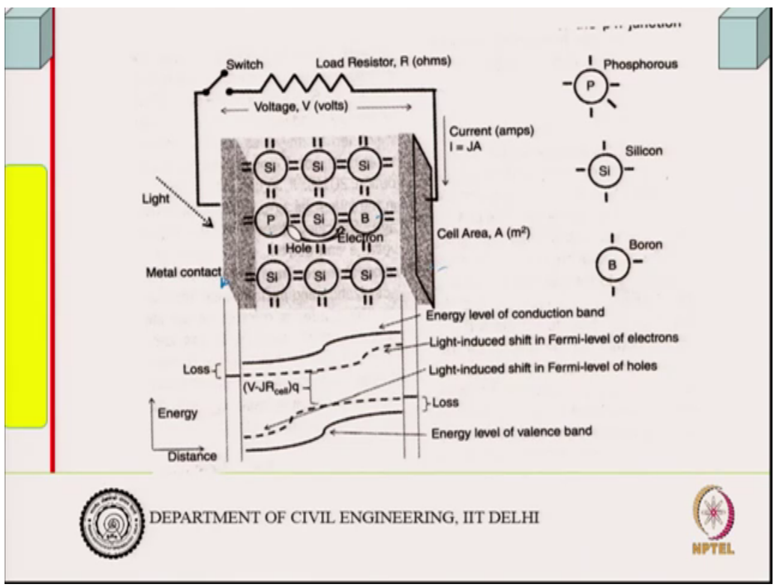

So there is the diagram, now essentially I will have boron, silicon, phosphorus you know you can see this something like this structure. Then you have got metal, metal contacts some are there, right and as the light falls onto it, actual construction looks something like this. I will come back to this later on.

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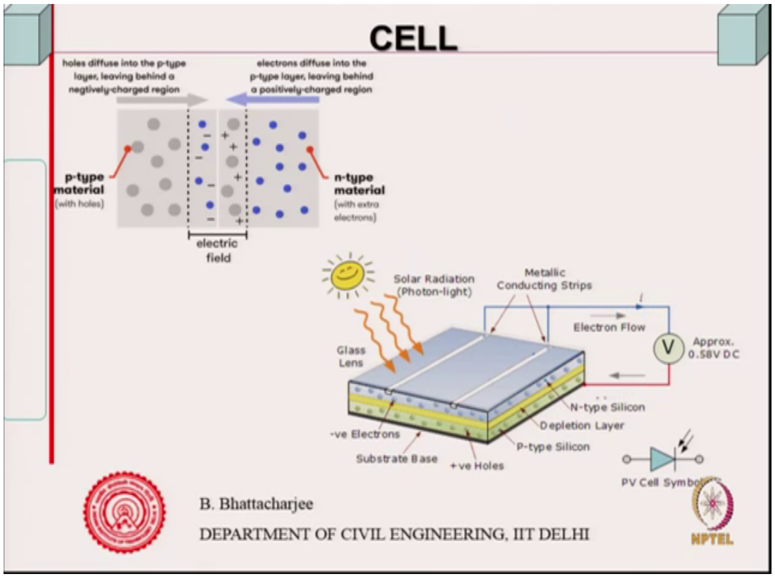

Actual construction looks something like this, not even this. This is a better look. So you have transparent surface, there is a metal, there is a metal here. So light falls onto this. Now this is actually n-type, this is a some depletion layer. There is a p-type and the metal here. So electron moves flow takes place from this one, from n-type to the (you know) p-type, n-type to the p-type as the radiation falls on, lights falls onto this. And there are metal connectors through which the electricity will flow. So we will be back here again in a moment but just let, yeah so that is what it is.

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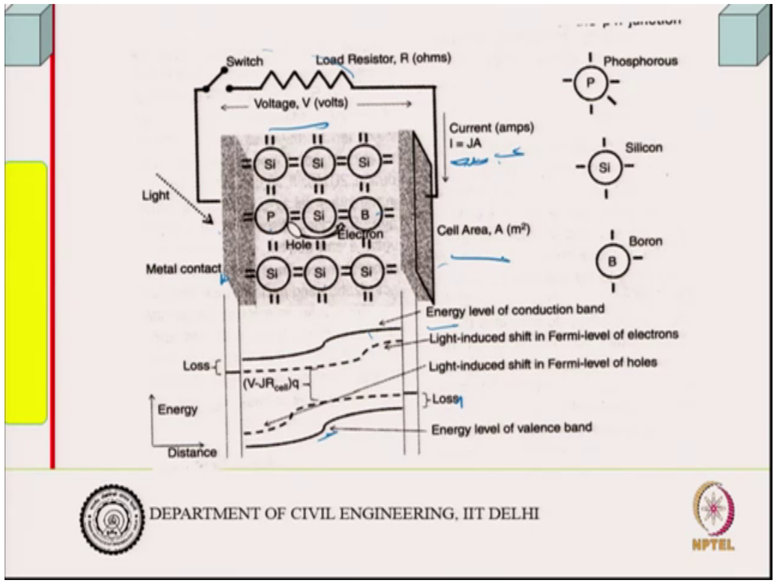

So this is how but then this will have some. So therefore it will generate some voltage and you can have some load. Then the current will flow through this. So this is what it looks like, energy levels. Now there will be losses in the system, so there will be some losses in the system ofcourse and that has to be taken care of. So, I would be treated as some flux multiplied by A. In this case, okay we will see that what it is. So will look into this, current in amperes is given by JA. We will define all this. Cell area is A.

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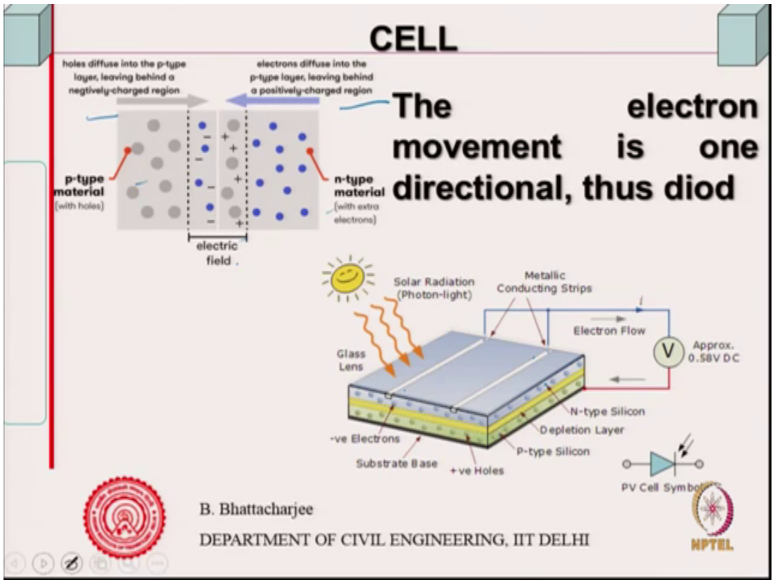

And we will look into this actually, the algebra part of it. So that it looks like the p-type, the n type and electric field is generated. So holes diffuse into p-type. They are leaving behind a negatively charged region and electron diffuse into the p-type layer leaving behind a positively charged region and so on. So there is the voltage difference created. So that is the idea. The lights fall into and so on.

So anyway, how it is important for us. I mean we are going too much into the details of this construction. The electron movement is thus one directional. We will be interested in the efficiency of the system. Look into efficiency of the system, power usage, how much efficient the system is, this is some background, little bit of background this because this is the subject by themselves.

So the electron movement is one direction in this one. So it is a direct current system, DC. So whatever light passes, causes you know positive basically. So it is somewhat it is all DC actually. So this is all direct current system, right and it is one directional.

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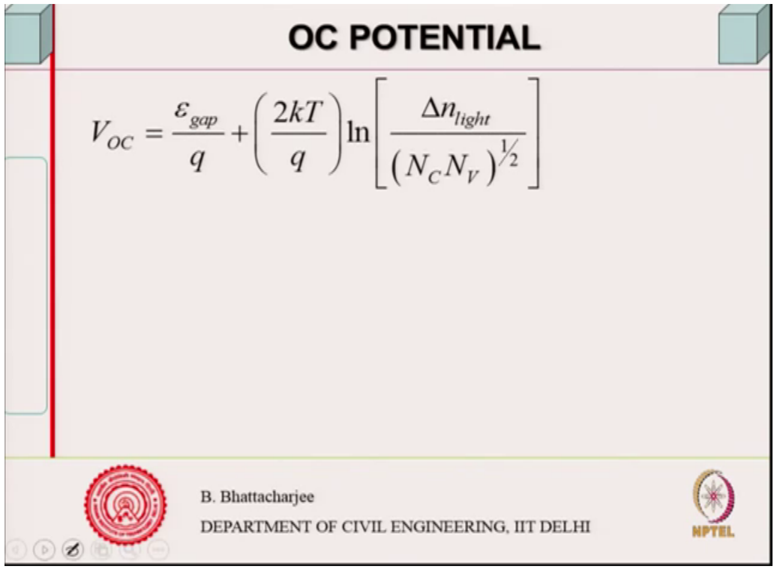

So people denote it by, okay this we will come later on. So people denoted it by a specific symbol which we will look into.