Solar Photovoltaics: Principles, Technologies and Materials

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Lecture – 02
Solar Radiation

So, welcome again to the second lecture of the course Solar Photovoltaics – Principles, Technologies and Materials.

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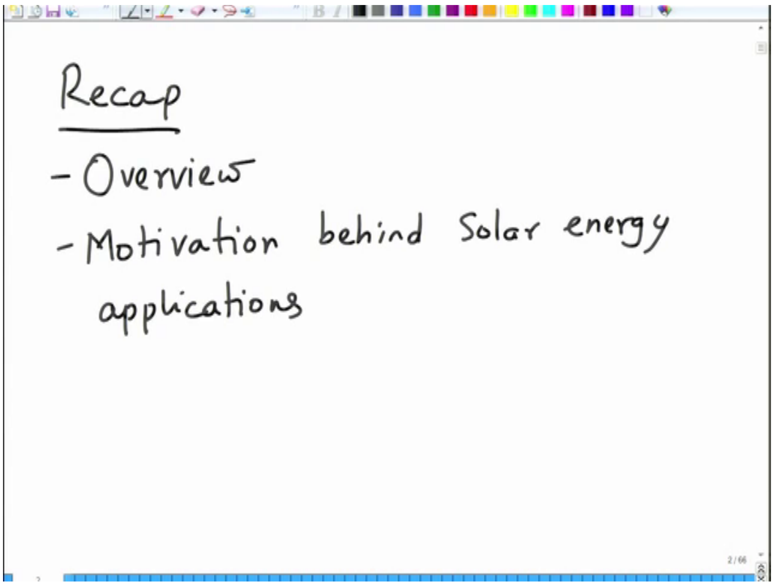

So, just recapping the last lecture we did not do anything significant in last lecture, but nevertheless. So, we just had a overview of the course that what we will do over the course of next 40 lectures and we also had a look at motivation for the use of motivation behind solar energy applications.

And, this is mainly because since we are all running out of fossil fuels in short in a relatively shorter course of time and given that we have a lot of pollution problems because of fossil fuel related energy, there is a strong need to develop nonpolluting solutions and from sources which are sort of in some sense permanent just like solar energy. So, there are many sources of energy, but solar energy out of all the sources is one of the most attractive ones because of near permanent nature and very high amount of energy that is available to the mankind especially in countries like India, which are hot and warm countries where sunlight is abundant throughout the year.

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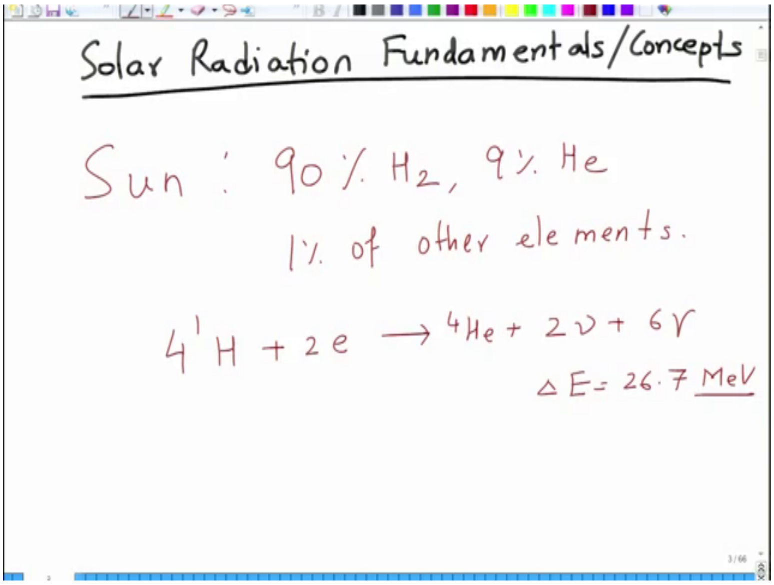

So, now we will move forward with our discussion on to begin with we will start with solar radiation fundamentals or you can say concepts,. So, this will be done primarily in the first week. So, if you look at the sun. So, the sun is about 90 percent of hydrogen and 9 percent of helium and about 1 percent of other elements. So, and the energy which is produced at sun is through this reaction 4 1 H plus 2 e giving rise to helium plus 2 mu 6 gamma and this reaction has energy of 26.7 MeV.

You can easily convert this into temperature and this is a huge amount of energy there is no reactor that has been made in the world can read this much amount of energy which is the order of 25 or 26 mega electronic volt. However, not all of this energy is available to us.

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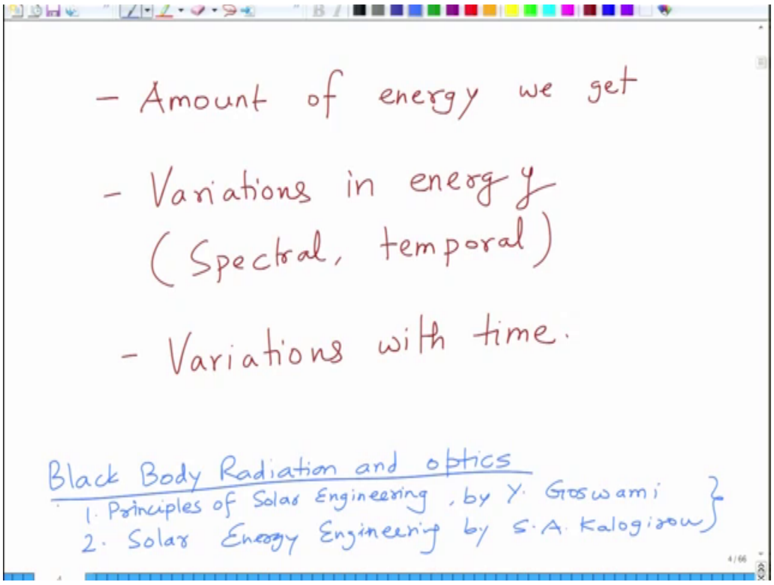

So, what we are interested in is working out what is the amount of energy we get and this energy is not available all the time. So, and it is not available at all the wavelength is not available for example, at night even during the day the intensity changes. So, what are the variations and these variations could be you know spectral as well as temporal. So, they could be time dependent, they could be wavelength dependent. And, then third is a season dependent and then variations with time for example.

So, there are various there are lot of works which have been done. We will not be able to cover all of them, but we will we will try to concise this information such a manner, so that you get a gist of what are the variation, what are the losses that happened the solar energy when it reaches the earth and how the variation take place over the period of time.

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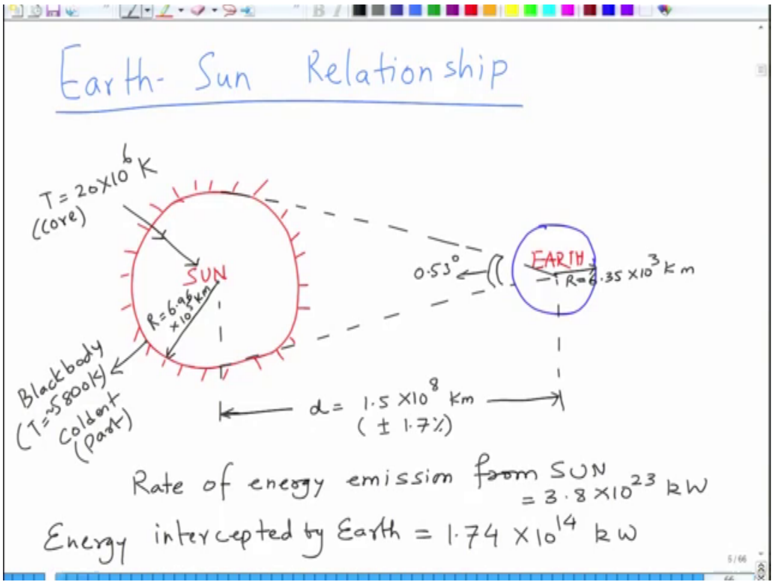

So, if you look at the sun-earth relationship of sun-earth some relation. So, this is where somewhere our sun is if I saw the sun red, so, this is where the sun is somewhere here and let us say if I draw the earth in blue, ok. So, this is sun and this is earth. So, sun would be something like a bright shining sun and this would be earth full of you know water and mountains and earth and land or whatever. And, the sun temperature is of the order of 20 into 10 to the power 6 Kelvin, and that so, it is a this temperature is at the you can say core and the outer surface is like a look in to a black body which is which is the coldest and the temperature here is about 5800 Kelvin, it is approximately 1500 800 Kelvin; this is the coldest part.

And, the radius of sun is approximately; radius is about 6.96 into 10 to the power 5 kilometers. On the other hand earth has a radius of about 6.35 into 10 to the power 3 kilometers. So, you can see that there is a difference of nearly two orders of magnitude in the radius of sun and earth. So, earth is a lot smaller than sun. So, the angle which is subtended by sun at the center of earth is about this angle is nearly half a degree. So, to be precise it is about 0.53 degrees and the distance is, this distance is nearly if I take center to center distance it is. So, this distance d is about 1.5 into 10 to the power 8 kilometer and there is a variation of about 1.7 percent.

So, of course, this figure is not drawn up to that scale. So, it is just a schematic diagram. So, the rate of energy emission from sun is about 3.8 into 10 to the power 23 kilowatts, and the energy which is; so, you can see that since sun is large body it emits a large amount of energy, but earth being a small being at a large distance at a smaller angle which is subtended by earth, sun and earth the energy which is intercepted by earth is about 1.74 into 10 to the power 14 kilowatts. This is what we saw last time 174 peta watts, right. So, this is what the energy which is subtended by, now which is intercepted by earth that comes from the sun.

Now, not only we received the radiation from the earth, from the sun the amount of you know the amount of energy which reaches particular surface depends upon the time a temperature how much light is available outside and so on and so forth.

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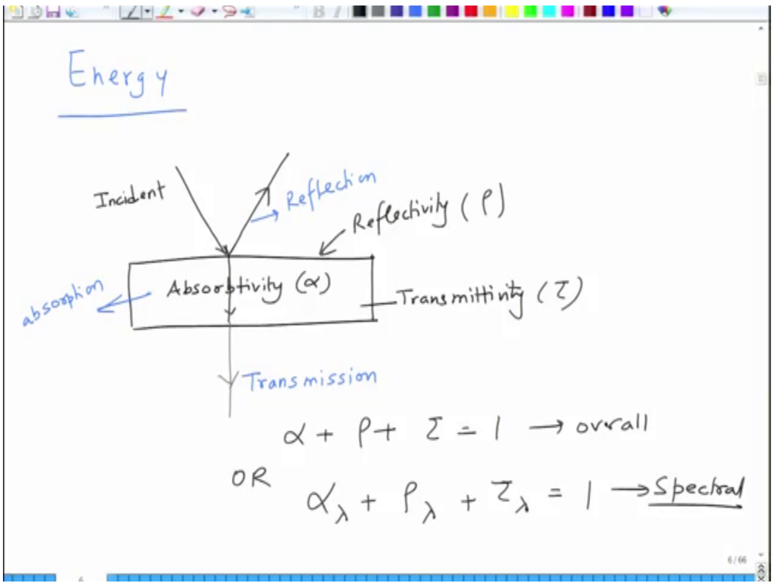

So, every surface so, if you want to make precise calculations of energy that is passing through a surface. So, let us say you have this surface this body let us say and this body has absorptivity of let us say alpha, ok. So, you have some incident radiation. Now, this incident radiation depending upon the absorptivity depending upon the reflectivity the surface will also have certain reflectivity and this will also have certain transmitivity, right which is typically determined as sorry tau and this is given as rho and alright. So, depending upon the reflection coefficient some may get reflected some may get absorbed inside and the remaining may go out, ok.

So, you will have you will have one component of reflection you will have some absorption and remaining will be transmission. So, all of these three components have to conserve, right because the energy is conserved as a result you can say that for a given material alpha plus rho plus tau is equal to 1 or you can also say for a given wavelength alpha lambda plus rho lambda plus tau lambda is equal to 1; this is spectral and this is you can say is overall. So, this condition is.

So, depending upon the type of material through which on which the solar radiation is incident some of it is going to be reflected, some of it is going to be absorbed and some of it is going to be transmitted. So, if you have a solar panel solar panel will have various layers. So, depending upon what kind of surfaces on top some may get reflected, some will get absorbed and if it is opaque material it is very likely that none of it is going to be transmitted, most of it is going to be absorbed.

So, the idea behind making a solar cell is to minimize the deflection losses and minimize transmission losses. We would like to make a device in such a manner so that maximum amount of light is absorbed and this is where material design comes into picture. And, so and the amount of energy which is optically transmitted it is also dependent upon the angle of incidence.

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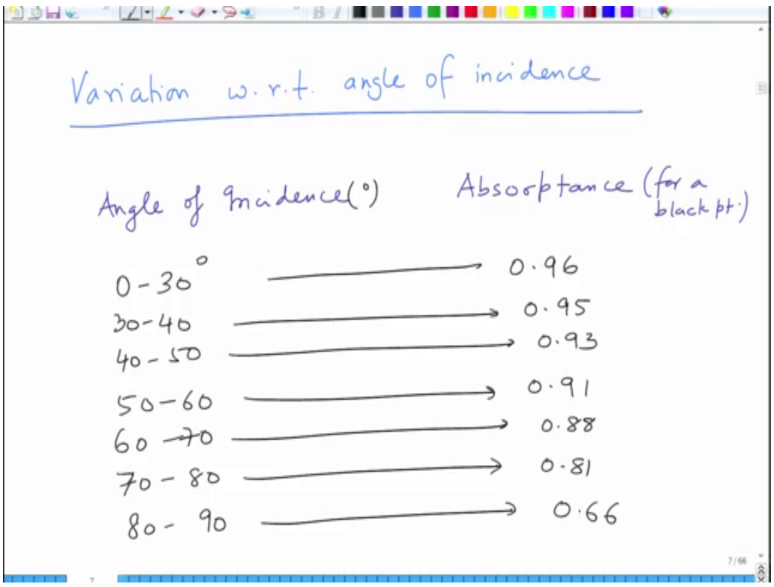

So, if you look at the variation. So, if you look at for instance angle of incidence and absorptance let us say for a black point. So, if I write various angles, let us say 0 to 30 degree, 30 to 40 degree, 40 to 50 degree. So, this is in degrees, 50 to 60, 60 to 70, 70 to 80 and 80 to 90. So, if I write the values here this would be about 0.96, this would be approximately 0.95 this would be approximately 0.93, this would be 0.91, this would be 0.88, this would be 0.81 and if you go to very very normal angle this value falls off about 0.66.

So, we can see that absorb absorptance for a black point changes from nearly 96 percent at angles from 0 to 30 degree to about 0.66 at normal nearly normal radiation. So, you can see that it is not beneficial to have sunlight coming directly into the solar cell. It is a good idea to have solar radiation coming at certain angle perhaps up to about 60 degrees where your absorptance is maximum. So, again these are all optical design factors which one has to keep in mind when the radiation is coming.

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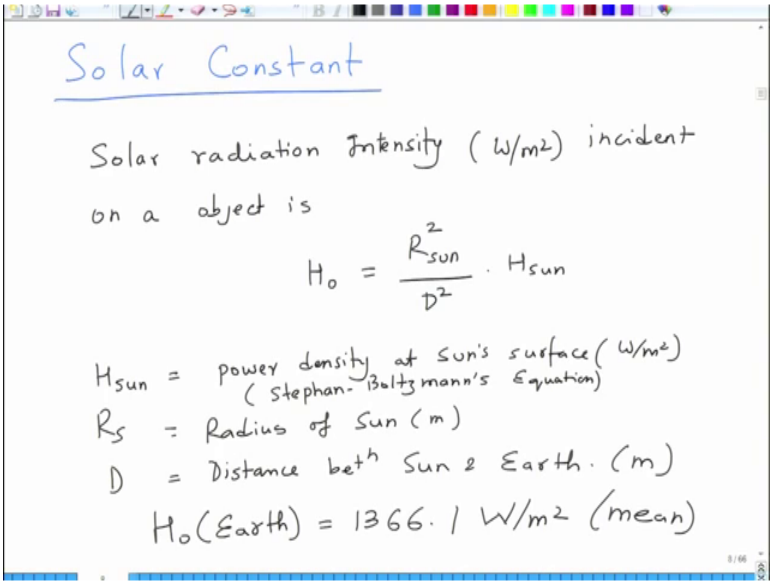

So, the amount of energy which is reaching us is defined by a quantity called a solar constant. So, am not going to physics of solar radiation like Planck's Law and black body radiation, I am sure all of you know that. If you really want to know about black body radiation I would suggest you to and optics then I would suggest you to read the Solar Thermal Engineering book by Y. Goswami and another book you can consider is by yeah so, you can consider this another book solar Solar Energy Engineering by S. A. Kalogirow.

So, these two books give you a good idea about. So, for this book is the first ones name is different, first ones name is Principles of Solar Engineering by Yogi Goswami he is an expert on solar thermal devices and then Solar Energy Engineering by solar test solar is

Kalogirow and that is again a good book. These two books give you fair details about blackbody radiation, the optical principles the how the you know what is the relation of transmission with respect to index of reflection and reflection and so on and so forth.

So, these two books would be able to give you a brief account of those things. So, unfortunately we do not have sufficient time to and get together into those details, but what I wanted to point out was if you have certain amount of radiation coming on the surface the amount of radiation that is going to be so, you will have some reflection losses you will have some absorptance and some transmission. From the perspective of a solar cell it is important to maximize the absorption and minimize the reflection and transmission and this is where your material design and solar cell design comes into picture and not only that the angle of incidence also plays a important role in how much energy are going to receive inside the how much energy to absorb within the solar cell.

So, for instance you can see here, that if your angle of incidence is near normal you have nearly 65 percent of absorption for a blackbody considering it is a black body whereas, most of the surfaces of grey in nature as a result this figure is going to be even lower and for a incidence angle of less than let us say 60 degrees you have more than 90 percent absorption, and these figures will change when you change the type of surface that is to convert from black to grey.

So, solar constant is so, let us now look at solar constant. So, solar radiation intensity in watt per meter square that is incident on object is given as H naught is equal to R sun square divided by D square into H sun and what is H sun here? H sun is power density at sun’s surface in watt per meter square and this is basically from Stephen Boltzmann equation, ok. Stephen Boltzmann equation for a for a black body can give you this power density and this R sun, so, let me just right here from Stephen equation.

This you can see in the books which I have just told you and R sun is basically the radius of sun in meters and D is the distance between sun and earth again in meters. This is what is the solar radiation density that is incident upon a object.

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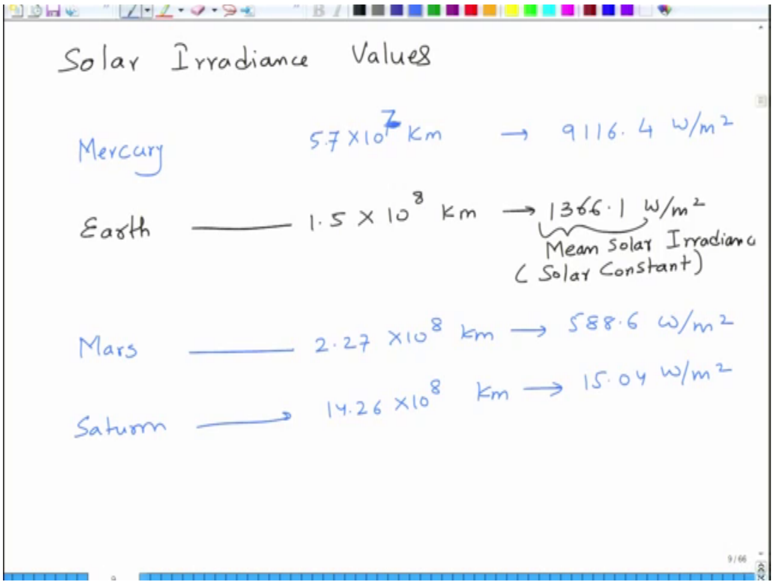

So, if you now look at the values of solar irradiance. So, for earth we have it is such a distance so, corresponding to a distance that earth has it is about if you remember it is about 1.5 into 10 to power 8 kilometers and let me see if this was the right figure. So, yeah, it is about 1.5 or 8 kilometers and this gives a value of about 1366.1 watt per meter square. So, this what is the mean solar irradiance, mean solar irradiance and this is called as solar constant, ok.

So, this value is so, if I go to previous slide so, H naught on earth is 1366.1 watt per meter square this is the mean value, alright. Then we show some fluctuation in this value if you have some fluctuation in the distance. So, distance is the error of about 1.5 percent which means this value will also have that much error, but we take it as log on 1366.

Comparing with other planets such as, for example, if you look at Mercury; Mercury is at a distance of you know 57 into 10 to the power 6 kilometer or you can say 5.7 into 10 to the power 7 kilometer. This has a solar constant of about 9116.4 watt per meter square. So, nearly you know 6 times or increase in the 6-7 times increase in the value whereas, if you look for something like Mars; Mars has a distance of about 2.27 into 10 to the power 8 kilometer and this is the value of about 588.6 watt per meter square. And, if you look at something like I do not know Saturn or which is very far Saturn has a distance of 14.26 into 10 to the power 8 kilometer this has a value of about 15.04 watt per meter square.

So, mercury being closer to sun has much higher value of solar radiance are sitting somewhere in between as a value of about 1366 watt per meter square whereas, the values for Mars and as you go farther and farther they drop significantly in fact, at Pluto it would be even smaller, it is less than a watt per meter square. So, it is not a good idea to have a solar cell on Pluto.

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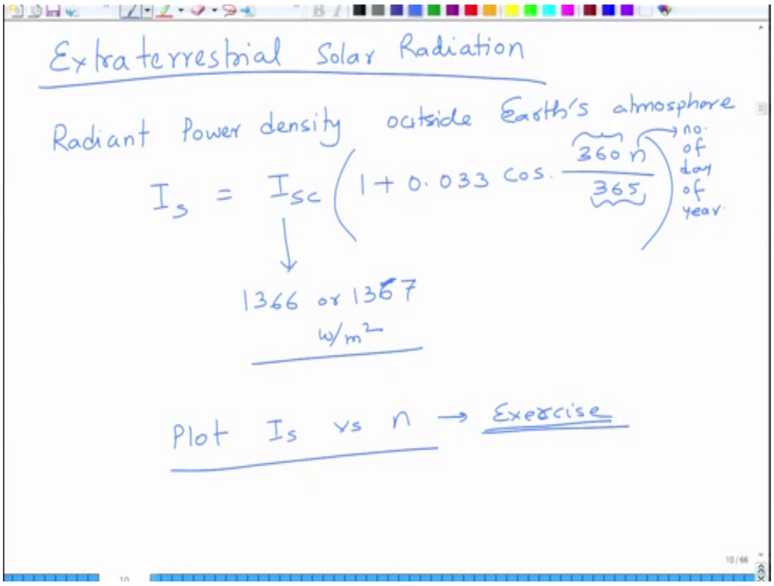

So, there is something now called as extraterrestrial solar radiation, right. So, we defined various things. So, the radiant so, the previous value was the solar constant which was a mean value of solar radiation that is incident on the earth's surface, ok.

Now, the radiant power and power density outside earth's atmosphere is given through, let us say this is I S, this is given through I SC which is a solar constant. Now, this is dependent upon the number of the day of the year. So, this has given us 1 plus 0.033 into cos of 360 n divided by 365 year. So, this 365 is the number of days in the year, 360 degree is the angle around the circle and this n is the number of day of year. So, this I SC has a value as I said as were 1366 or some people also say 1367 watt per meter square and n is the day of the year. So, we can see that this value will change. So, this value of and the power density outside earth's atmosphere will change depending upon the which day of the year you calculate it.

So, this goes as solar constant multiplied by 1 plus 0.033 into cos of 360 into n divided by 365 and this n is the number of day of the year. So, you can see that if your n is equal to 365, alright so, this will be cos of 360 and cos of 360 is 1, right, cos of 2 pi is equal to 1. So, this will be approximately equal to the solar constant. So, you can calculate on which days it is going to be equal to the solar constant, on which days it is very minimum and so on and so forth.

There is going be some variation and it would be nice exercise to plot I s versus n, ok. So, this is an exercise that you can carry out for a better understanding of results.

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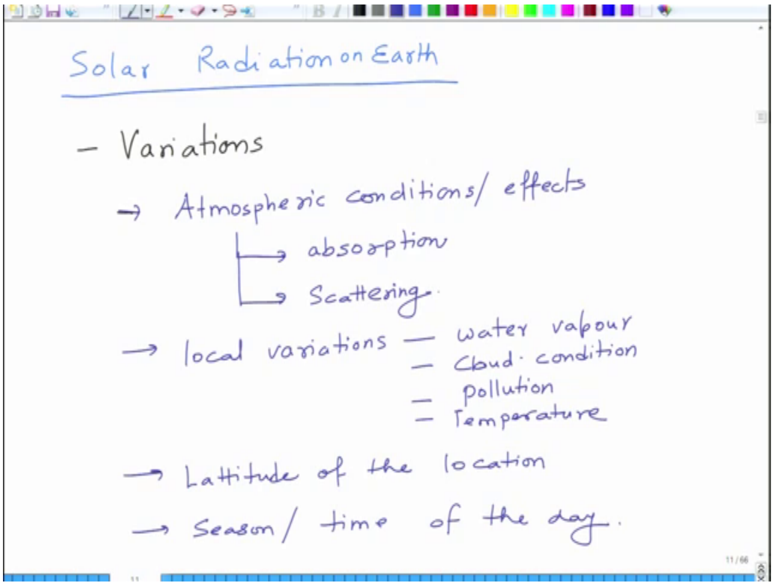

So, the solar radiation that comes on the earth. So, the there are variations of why you get a constant value on the outer atmosphere nearly constant value, there are variations with respect to the values which reach on the surface and these variations occur because of things such as atmospheric conditions and or conditions or effects and this is mainly to do with the things like absorption and then you have a scattering, ok.

So, absorption could be because of more presence of a variety of molecules which can absorb that already radiation and scattering could be because the presence of molecules as well as dust particles and so on and so forth. So, they lead to absorption is scattering. Then you have local variations; local variations could be because of things like water vapor, how much moisture you have in that atmosphere it depends upon the cloud condition and it also depends upon the pollution, how much pollution you have in the atmosphere.

So, for example, if you look at that difference between clear day and the day when you have a smoke in the air so for example, even in winter suppose it rains today tomorrow the cloud tomorrow the sky may be very clear, right and as against to what it is today when it has not rained and a lot of moist in the atmosphere a lot of dust particles in the atmosphere which entrapped by humidity, and very low velocity conditions as a result they stay still and lot of scattering of sunlight takes place we can see you can see the effect that sunlight does not reach you with that intensity as it would reach you on the clear day.

So, this is because of pollution, cloud condition, water vapor, temperature and so on and so forth and then it would also depend upon the latitude. Latitude of the location and then of course, it is going to be affected by season and time of the day. These things affect the amount of energy that reaches us. So, on one hand we are saying that we have a solar constant of 1366 or 67 watts per meter square which is essentially the energy that is incident on the earth, but earth is not just a surface that is the atmosphere around it and this atmosphere around it affects the amount of energy that reaches us.

So, extraterrestrial radiation is basically solar constant multiplied by 1 plus 0.033 into cos of 360 n divided by 365. You can see that the value of this cos factor will vary between 0 and 1, right. So, this is not really going to so you can see that this factor is only 0.033. So, value here is not going to change significantly, it is going to remain somewhere in the vicinity of 1366. It has some variation as a function of n, it is not going to hugely different.

However, what makes it really variable are these conditions. The atmospheric conditions such as the absorption, scattering, local variations because of water vapor, cloud condition, climate, pollution, temperature where you are whether you are in England or whether you are in India, whether you are in Sri Lanka or in Malaysia and the season and time of the year. So, we will further delve into these topics in the next lecture.

Thank you.