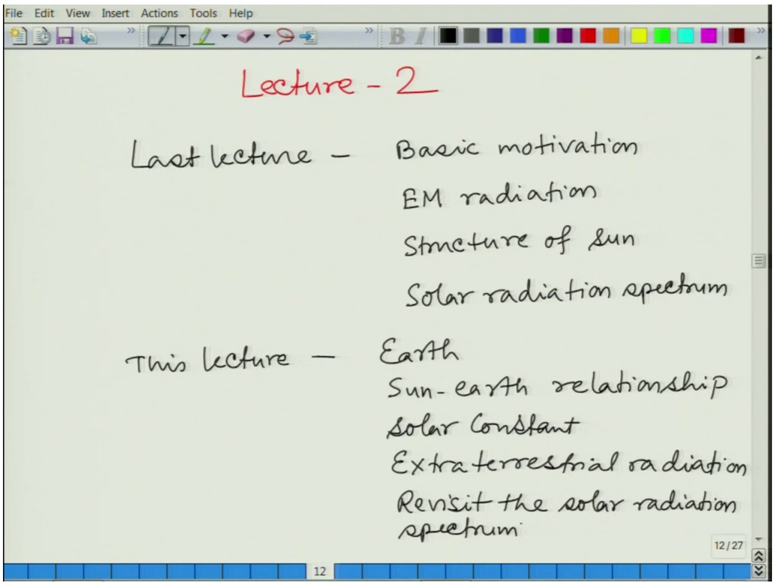
Elements of Solar Energy Conversion
Prof. Jishnu Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology, Kanpur

Lecture – 02

(Refer Slide Time: 00:16)

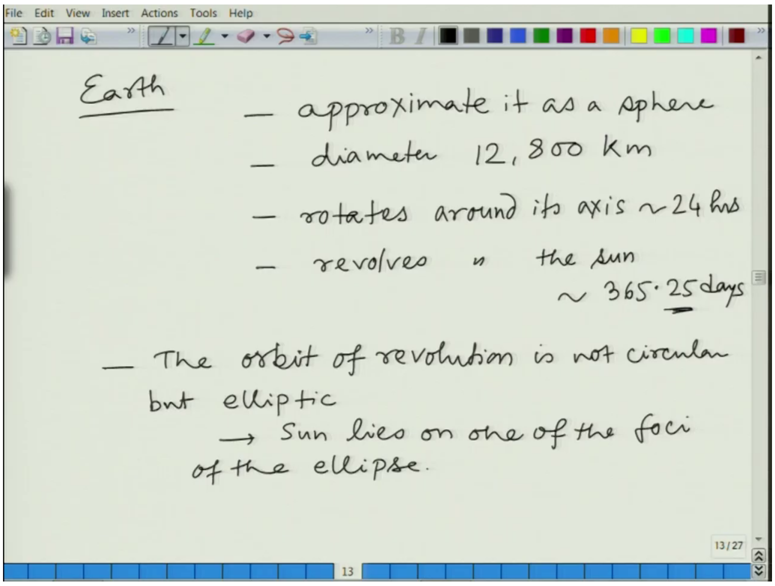


Welcome, this is the 2nd lecture for the course Element of Solar Energy and in the last lecture, what we have seen? We have introduced you to the course what is the basic motivation and then, we have talked about the electromagnetic radiation, the basics of it and then, the structure of sun ok. So, these are the major things we covered and we also talked about the solar radiation spectrum ok.

Now, this lecture what we are going to cover are the following ok. So, first we will we have looked at sun. So, we will need to look at earth now and then, the sun-earth relationship which actually only part of it we will see in this lecture and it will continue for few lectures from now onwards ok.

And then, we will talk about solar constant, what do we mean by that and we will also talk about the extraterrestrial radiation and how it varies and we will revisit the solar radiation spectrum with the new information that we learn in this class. And we will also if possible, if we can cover, we can also go to the sun-earth relationship revolution and other things ok. So, let us start.

(Refer Slide Time: 03:11)

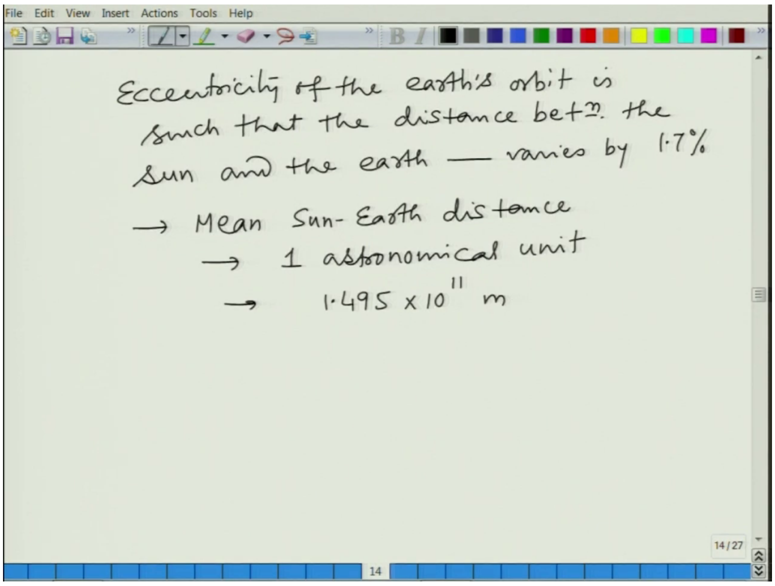


So, the first thing is we first need to know about earth because we live on it, we do not see how big or small it is, but we know about it ok. So, again we can approximate it as a sphere just like the sun and its diameter is approximately these many kilometers. So, about 13000 kilometers and again reminding you about building up this intuition of how big the sun is compared to earth, it is 110 times in diameter ok.

Now, if we talk about earth, so, it rotates around its axis approximately 24 hours that is what our day length is right. So, again that is approximate, and it revolves around the sun, it approximately 365.25 days ok. So, this one-fourth day that we are left with in counting every year what we adjust is in the leap year right, we add one extra day to adjust this one-fourth day, ok.

So, this is about earth and the interesting part of earth is that the orbit of revolution is not circular, but elliptic and that makes the things much more interesting than the circular one. So, sun lies on one of the foci of the ellipse and we know and we will again see how it gives rise to many interesting stuff.

(Refer Slide Time: 06:14)

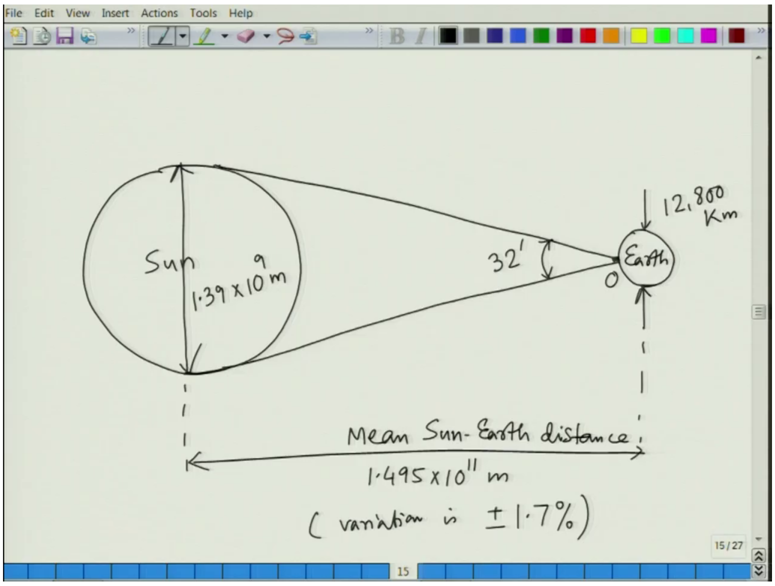


So, this eccentricity of this of the earth's orbit is such that the distance between the sun and the earth, it varies by 1.7 percent ok. So, the distance between the sun and the earth is not fixed, it varies by small amount, but that gives rise to again the variation in solar radiation that is reached from the sun to the earth.

So, when we have a variation, what we do? We need to find the mean ok. So, because whenever we have a change, I mean variation, if we do not have the mean, then it is difficult to enumerate that variation. So, the mean is or the mean sun-earth distance and it is also called 1 astronomical unit ok.

So, that is how we measure a very long distance. In cosmology, another the most commonly used one is the light year, but here this 1 astronomical unit we often use in terms of these smaller distances like sun-earth, sun-moon; I mean earth-moon and all these things ok. So, that distance is actually 1.495 into 10 to the power 11 meter that is the sun-earth distance mean.

(Refer Slide Time: 08:51)

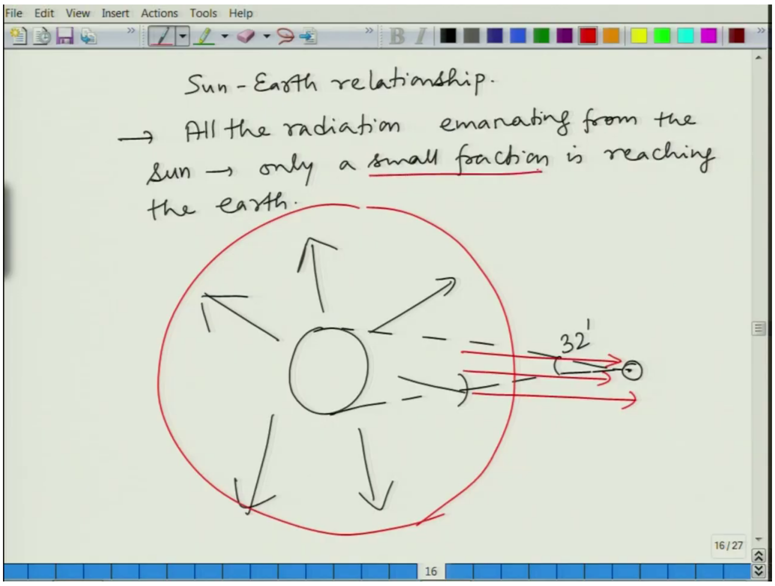


Now, if we draw the sun and earth, then let us say this is the big sphere which is the sun and the small sphere which is earth. So, this is sun, and this is earth. Now, if we have a an observer on earth ok, what we, will it see? It will see a sphere in the sky right; the sun will be a big sphere in the sky.

And what is the value; what is the value of this diameter? The sun diameter is about 1.39 into 10 to the power 9 meter and earth dia is these many kilometers ok. So, and the distance between these two centers that is the mean sun-earth distance that is 1.495 into 10 to the power 11 meter and that distance varies. Variation is plus minus 1.7 percent ok.

Now, I was talking about an observer on the earth, so, let us say O, what will it see? It will see a sphere in the sky that what you all see and the solid angle that sphere will subtend would be 32 minute. This is a very important number that will come again and again in the course, this 32 minute angle it will subtend the sphere sun ok.

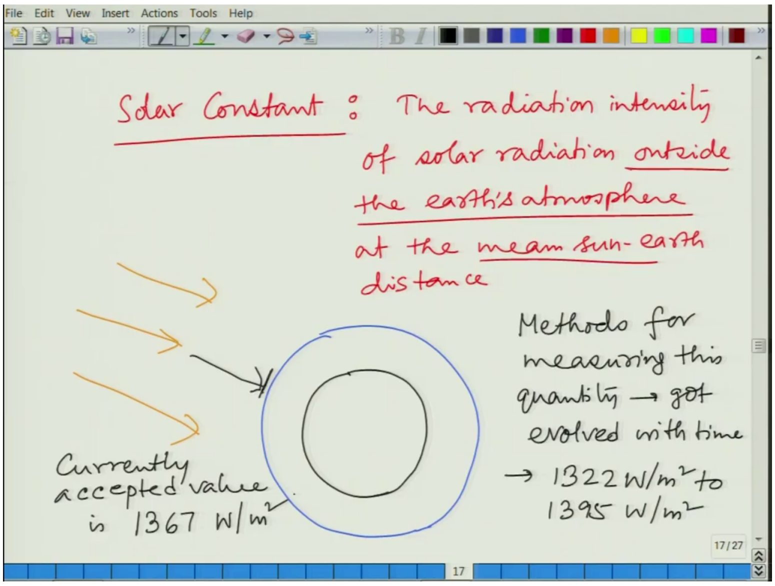
(Refer Slide Time: 11:30)



Now, what we need to know is the; I mean we are continuing with this sun-earth relationship and the all the radiation emanating from the sun only a small fraction is reaching the earth right that you can understand because you have a you have the sun here and all the radiation that are going around only if this is your earth.

And this 32 minute that is the solid angle it is making, that sun and the among everything, what is coming so, whatever is coming towards earth only a mole small fraction of this whole radiation sphere that it is making, only a small fraction is actually getting intercepted by the earth ok; so this is very important.

(Refer Slide Time: 13:17)



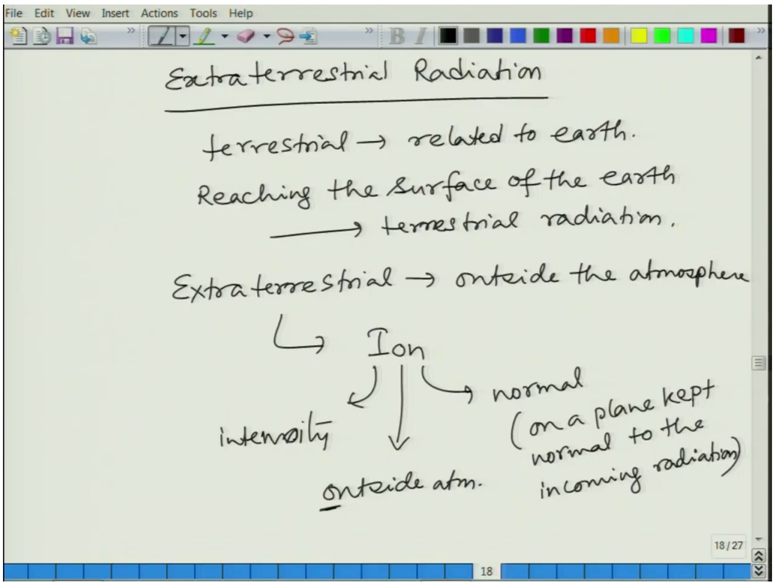
Now, next we will define the solar constant. What is the solar constant? It is the radiation intensity of solar radiation outside, this is very important; outside the earth's atmosphere because the atmosphere changes lot of things in the radiation. So, what we are trying to fix now is beyond the atmosphere.

When there is no atmosphere, what is the radiation intensity there and it also depends on the sun-earth distance. So, we to fix it what we do, that at the mean sun-earth distance, this is also very important and that is called solar constant. So, what we can see that if this is our earth and we have a layer of atmosphere on top of this.

So, when solar radiation is coming, what we are measuring here is that we are placing a plane just outside the atmosphere and measuring the intensity on top of this plane ok. So, and again, when the sun and earth is at the mean distance ok. Now, there are lot of different methods.

So, methods for measuring this solar constant; it got evolved with time and it varies the value, the value varied from to 1395 watt per meter square ok. So, during the last century, there are lot of effort went into this measuring this solar constant which is important quantity and what is the value currently accepted? So, value is 1367 watt per meter square ok. So, that is the solar constant. So, we are first defining few things so that we can use them later ok.

(Refer Slide Time: 17:18)



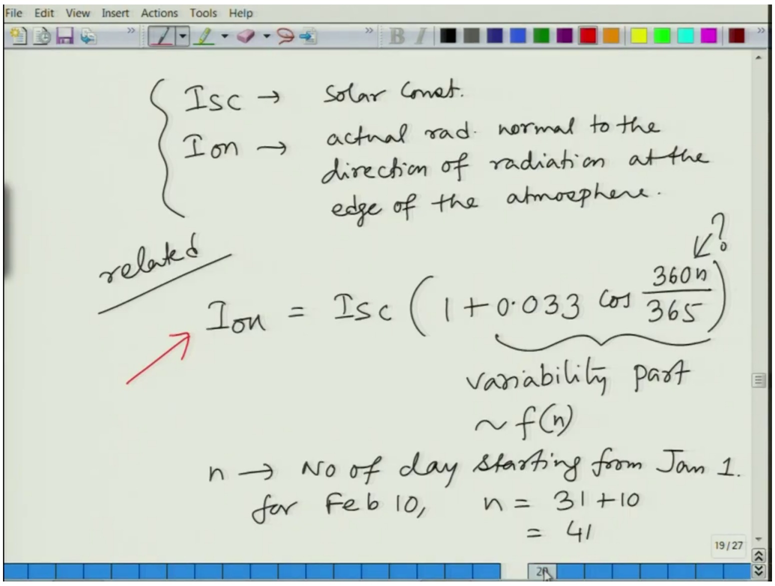
Now, we will talk about this extraterrestrial radiation ok. What do you mean by terrestrial? Terrestrial means related to earth; means, related to earth. So, basically in this case, whatever is reaching the surface of the earth that is what we called, terrestrial radiation.

Reaching the surface of the earth, we call terrestrial radiation and what is remaining outside, so, this extra terrestrial in this case, it means outside the atmosphere. As I said that atmosphere alters the solar radiation significantly and that is why it is important that we know what is coming at the boundary of the atmosphere and that is called extraterrestrial radiation and we designate it with Ion.

So, I stands for I mean why the name came? It talks about the intensity that is why I and this o is the outside atmosphere ok. So, this particular o is designated there and this n stands for normal that means; the measurement is done on a plane kept normal to the incoming radiation, clear.

So, we will talk about these different designations of intensities later as well. So, this is the first time, we are introducing it. So, Ion stands for the extraterrestrial radiation which is normal to the plane I mean on the plane which is normal to the radiation itself.

(Refer Slide Time: 20:24)



Now, of course, we have seen that Isc is the solar constant which is the intensity at mean distance outside the atmosphere and that has to be related to this Ion right. So, this is the actual radiation normal to the direction of radiation at the edge of the sorry edge of the atmosphere ok. So, this has to be, they have to be related right.

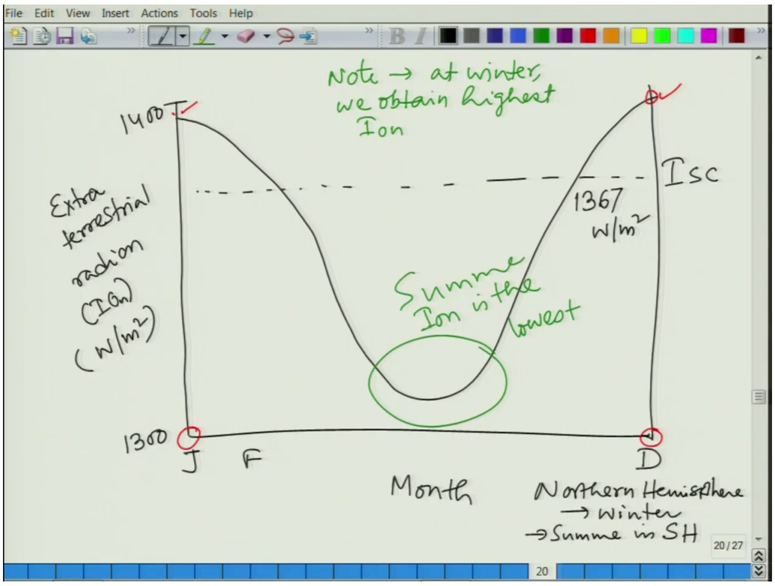
What is that relation? Again, lot of effort went into that and ultimately, what relation we got is the following. So, let me first write, then I will explain ok. So, this is the relationship we get for the Ion which is called the extraterrestrial radiation and Isc which is the solar constant ok.

So, you can see that this particular, so, this is the variability part right and it is a function of n right. So, what is this n? n is the number of day starting from January 1 ok. So, for February 10, you will have n equal to 31 plus 10 that means, 41 ok. So, for 365 days in a year, you can find a particular value of n and that n goes in this expression which will determine what would be the extraterrestrial radiation intensity on that particular day.

And here, you remember that we do not bring the complication that are coming for the leap year and other things ok. So, we assume that we have 365 days only and the amount of error that you incur by not considering the details of leap year is so minute that you do not care about it ok.

So, for engineering accuracy, you do not need to consider leap year, you just consider it to be a normal year with 365 days ok. So, that is the relationship that we get for the extraterrestrial radiation and the solar constant. Now, if you plot this particular relation, how will it look?

(Refer Slide Time: 24:14)



Again, I should emphasize that this is not to the scale; this is just for illustration ok. So, here let us plot month ok. So, like January, February and so on till December and on the other axis, we plot extraterrestrial radiation basically Ion and the unit will be watt per meter square ok.

Now, if you look at and these will be the, these are the values, let us say it varies between 1300 to 1400 ok. So, the values will be like this ok. So, here you notice that at the mean sun-earth distance you will have some value which is about this 1367 watt per meter square and that is the value we called Isc or solar constant.

And interesting thing that you note here is that so, if this is January; if this is January and this is December, and they have to be periodic right. So, for the next year also, it will start from here and these two points should match ok, this point and this point should match.

Now, and here you notice that this January, December, these are winter times right, at winter times we have the highest intensity that is available ok. So, this I should note here that at winter, we obtain highest Ion. Is not this counter intuitive? What do you think?

We expect that at winter, the amount of radiation, solar radiation that are coming will be less than the summer right that is our normal intuition goes by, but this is these are measured data, so, this particular plot is showing that at summer, Ion is the lowest. So, this is counter intuitive right.

But think in more general term like when we have winter, so, in Northern Hemisphere, we have winter, at the same time in the Southern Hemisphere it is summer right. So, summer in Southern Hemisphere. So, what we can see, and this is only outside the atmosphere and you have to Ion means what? You have to keep the measuring plane perpendicular to the direction of radiation and it is outside the atmosphere.

So, all the atmospheric change and as well as the angle of incidence are neglected in this Ion measurement right. So, that is why we are getting something which is counter intuitive and in the winter, we are getting the maximum extraterrestrial radiation and in the summer, we are getting the lowest ok.

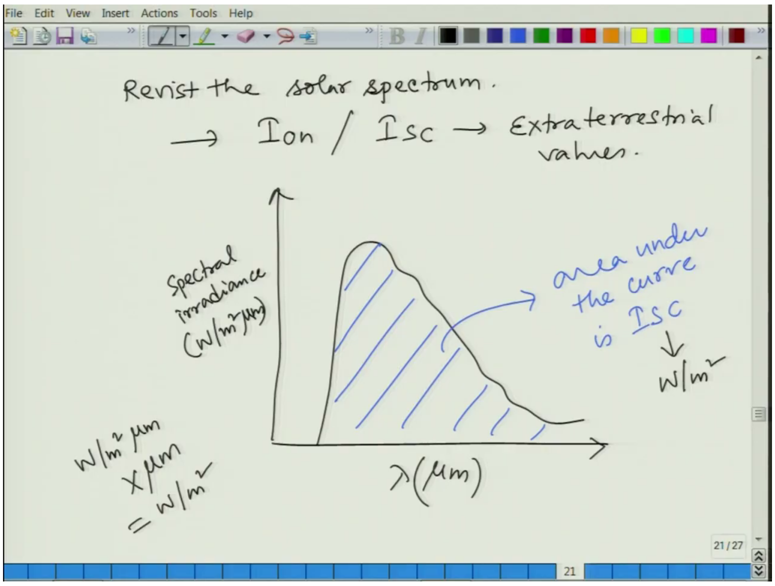
So, this point is an interesting point and again I should suggest that you should pause the video for now, and then, you think of it and get this internalized because intuitions only when let me give you an example of intuition. Like, if you tell a child to hold a glass, if a glass is made of steel or it is made of paper ok, we adults what we do?

For the steel glass, we hold it more strongly and for the paper glass, we hold it much soft, in a much softer way that way what we do? We ensure that the paper glass does not crumble ok. Now, when we actually hold the glass, we do not think of it like purposefully right, it comes automatically for an adult, but for a child, it does not come automatically.

So, a child holds the glass with the same force and you often see that the glass crumbles, if it is a paper glass ok. So, that way, we build up intuition, we practice, practice and all and then, it get internalized, then we do not have to separately think of it ok.

Here also, you take a pause and think of this solar radiation and you get it in your intuition that in the winter or rather Northern Hemisphere winter, we are getting the maximum intensity possible outside the atmosphere because the distance between sun-earth is maximum at that point. Even if it is counter intuitive, you get it internalized, so that you can make sense of it ok.

(Refer Slide Time: 30:57)



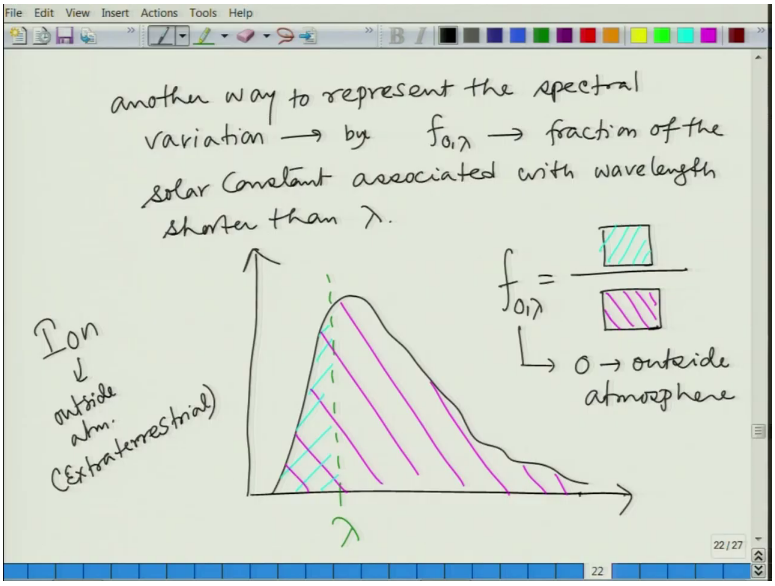
Now, we promise that we will revisit the solar spectrum because we want to emphasize that whatever solar spectrum, we have talked about in the last class that is only for this Ion or Isc all these extraterrestrial values not what we receive on the surface of the earth ok.

So, that is why we come back to it and we how the atmosphere changes it we will talk about later, but what we want to make point here is that whenever we talk about the spectrum, this is the wavelength in micrometer. Wavelength is usually designated with lambda and this is the you can say this is the spectral irradiance in watt per meter square micrometer ok. So, we have gotten something like this ok.

Now, what we want to emphasize here that the area under the curve is what? So, this area under the curve is Isc or if you plot it for Ion, you will get Ion. So, the intensity and this will be clear from the units as well. So, what is the unit of this particular spectral irradiance? It is the watt per meter square micrometer and for Isc the unit is watt per meter square right.

So, you can see that only when the micrometer is multiplied with this spectral irradiance unit, then only you will get watt per meter square ok. So, that is the point I want to mention here. This Isc or Ion that is the area under the curve, not the particular value ok.

(Refer Slide Time: 33:58)



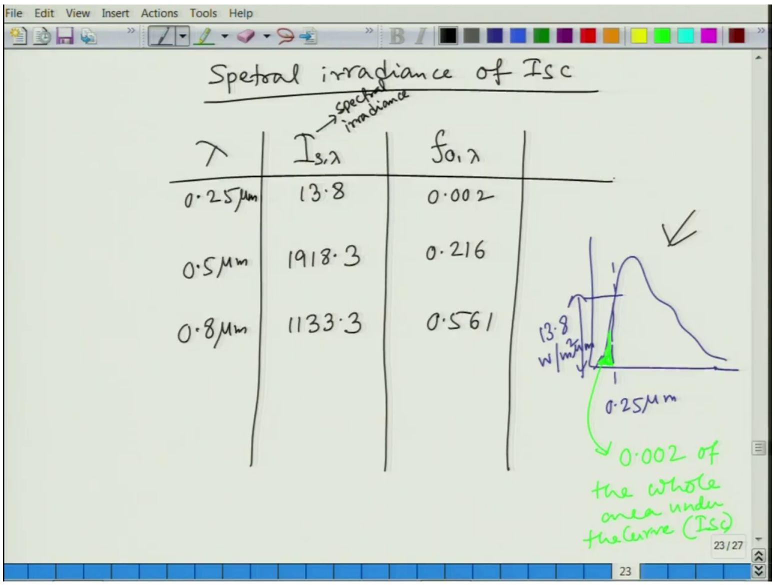
Now, another way to represent this is; another way to represent the spectral variation is by this quantity which we called f naught lambda ok. What is f naught lambda? It is the fraction of the solar constant associated with wavelength shorter than lambda; shorter than lambda ok.

So, it is basically you are trying to find ok, again if we have this particular form of the spectral irradiance and then, let us say we want to know f lambda at this particular lambda ok. So, what is that? So, this is the area under the curve which is shorter than the wavelength lambda and what is Isc? Isc is the whole area under the curve ok.

So, basically we can write f o lambda, o I am coming next, so, let us talk about this first. So, what we get? It is area under two areas. So, here on the numerator, you have this particular area and on the denominator, we have this particular area ok. I think this is clear.

Now, let me come to the o part, which is you already guessed I guess that this o stands for outside atmosphere right just like Ion. This Ion, o stand for outside atmosphere or it is called extraterrestrial right, here also it means extraterrestrial and lambda is for this particular lambda ok.

(Refer Slide Time: 37:29)



So, now if we want to specify this spectral irradiance of Isc because too many variables we cannot handle so that is why, we have taken the solar constant only which is outside atmosphere and we will now see what is the spectral variation for the same. So, the same thing we can instead of graph, what we can write?

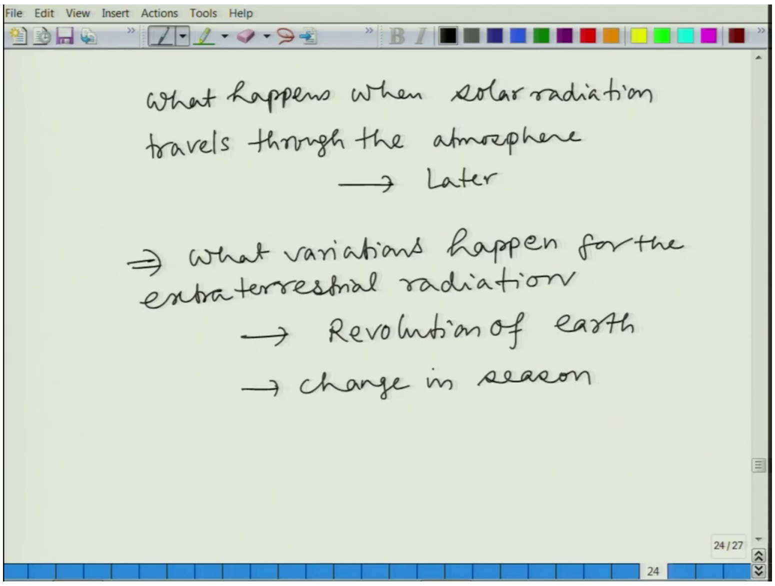
We can write the numbers which is lambda for a particular wavelength. So, basically, this I we cannot use multiple times. So, what we can do? This I spectral let us say s and lambda. This is basically the spectral irradiance and here, we can write the f o lambda ok. So, basically if you take few values, you can list lot of these values but let us take few of them.

So, if we take lambda to be 0.25 micrometer, then this I s lambda that will be 13.8 and this will be 0.002. So, basically if we draw this figure again, so, what it means is that at 0.25 micrometer, this height would be 13.8 watt per meter square micrometer ok. And this particular area sorry here, this particular area will be 0.2 percent.

So, this will be 002 that means 0.2 percent of the whole area under the curve. Whole area under the curve is nothing but Isc ok. So, that is how we designate the solar spectrum and let us look at few other values may be at 0.5; 0.5 micrometer, we have the intensity 19.18; 1918.3 and the f o lambda would be 0.216 ok. Similarly, just like this figure, you can find out what it means ok.

Another one value let us take at 0.8; 0.8 micrometer, we have 1133.3 and this is 561. So, you can see that by 0.8 micrometer, we have covered more than 50 percent of the total energy that is coming in, total Isc ok. So, that is how we often measure the spectral irradiance outside the atmosphere.

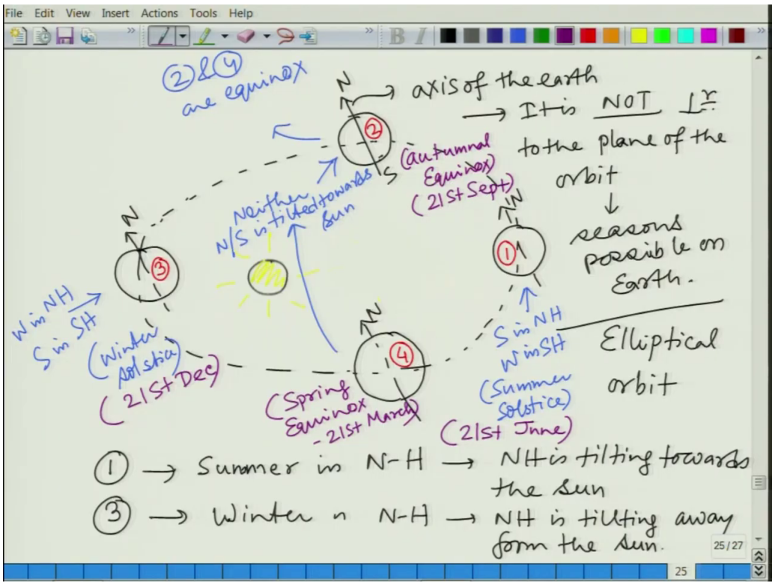
(Refer Slide Time: 41:44)



Now, what we can talk next? Now, what happens when solar radiation travels through the atmosphere? This particular thing we will talk about later ok, but there are lot more interesting thing that things that happen in the extraterrestrial radiation only. So, what variations happen for the extraterrestrial radiation, that is what we are going to see now ok.

So, now we need to invoke the revolution of earth and the change in season, then only we will be able to understand how this variation happens, what are the major factors as well as it will help you develop your intuition ok.

(Refer Slide Time: 43:38)



So, let us say that we have sun here at the center and we have an orbit. So, it is elliptical somewhat I could make it elliptic and earth is moving around the sun on this elliptical orbital ok; so this elliptical orbit ok. Now, one interesting thing happens because the earth is not revolving around the sun with its axis normal to the orbit plane or orbital plane ok.

So, if we call this is the axis of the earth ok, it is not perpendicular to the plane of the orbit and that is the most interesting feature of the revolution of earth around the sun and that is what makes the seasons possible on earth ok. So, that makes the seasons possible on earth ok.

So, before we go into that, go into the detail, let us say that we have four seminally important positions of the earth on this orbit ok. So, everywhere the rotational axis is or the north-south axis, let me just write north in every case and in one case we have written south as well ok.

Now, if we look at this seminal position, can you guess what; let us say this is the position 1, this is position 2, position 3 and position 4 and this is sun ok.

Now, this position 1, what position I mean what would be the corresponding date can you guess? This would be the summer, summer in Northern Hemisphere right and because the North Pole or the Northern Hemisphere is tilting towards the sun. So, North Hemisphere is tilting towards the sun that you can see and this is because the orbital is the axis of the rotation is not perpendicular to the orbital plane ok.

And the exactly opposite position which is position 3 that will be the winter, winter in North Hemisphere right because for position 3, you can see that the Northern Hemisphere is tilting away from the sun.

So, Northern Hemisphere is tilting away from the sun and what we can say that at the same position, it will be for position 3; we have summer in Northern Hemisphere sorry winter in Northern Hemisphere and summer in Southern Hemisphere right. Here, we have summer in Northern Hemisphere and winter in Southern Hemisphere right.

And for position 2 and 4, we see that neither north nor south is tilted towards the sun ok. So, these positions, we can see neither, north or south is tilted towards sun. So, what we can expect? It will be neither summer nor winter and these are called equinoxes. So, both position 2 and 4 are called equinox position because nox stands for the night and when the day and night are equal in length that is what we called equinox ok.

And these extreme positions this is called summer solstice and this one called winter solstice and here, we have this bias, we all name it in terms of Northern Hemisphere. Summer solstice means, summer in Northern Hemisphere that condition we are talking about and for winter solstice, again winter in Northern Hemisphere.

So, those who are watching this video from Southern Hemisphere, you have to reverse the intuition completely for the whole course because that is how the nomenclature goes ok.

Now, if we look at this earth revolution around the sun, what we understand is that there will be two extreme positions which are called solstices and what would be the summer solstice?

The date will be 21st of June that will be the longest day for the Northern Hemisphere and the shortest day for the Southern Hemisphere and the other direction for the winter solstice; we will have 21st December, when we have the shortest day in Northern Hemisphere and longest day in the Southern Hemisphere.

And for the equinoxes, again the position 2 is called the autumnal equinox and the date is 21st September and the other equinox that we have that we call spring equinox which is 21st March, again these equinoxes are named with respect to the Northern Hemisphere, so, fine.

So, we have come to the end of this class where we have looked at the extraterrestrial radiation, how it varies and what is solar constant, and we also looked back at the solar spectrum in the extraterrestrial radiation and we have started the sun-earth relationship in terms of the revolution around the sun and how it varies the season and what are the different nomenclature for the solstices and equinoxes.

So, in the next class, we will start from here and we will define the tropics, what it means, and we will take up from there.

And thank you very much for your attention.