Solar Energy Engineering and Technology
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Lecture 3
Physics of propagation of solar radiation from the sun to earth

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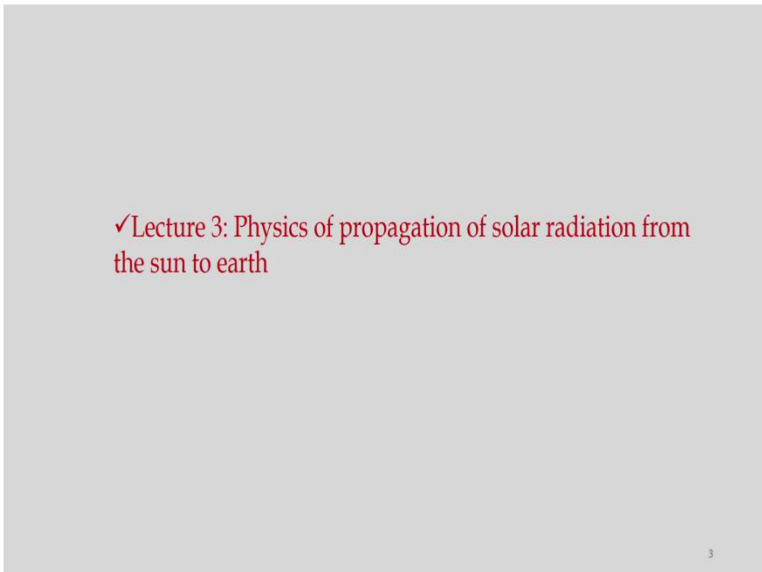

Dear students, today we will discuss the physics of propagation of solar radiation from the Sun to the Earth. So before I start to the physics, let us learn something about Sun.

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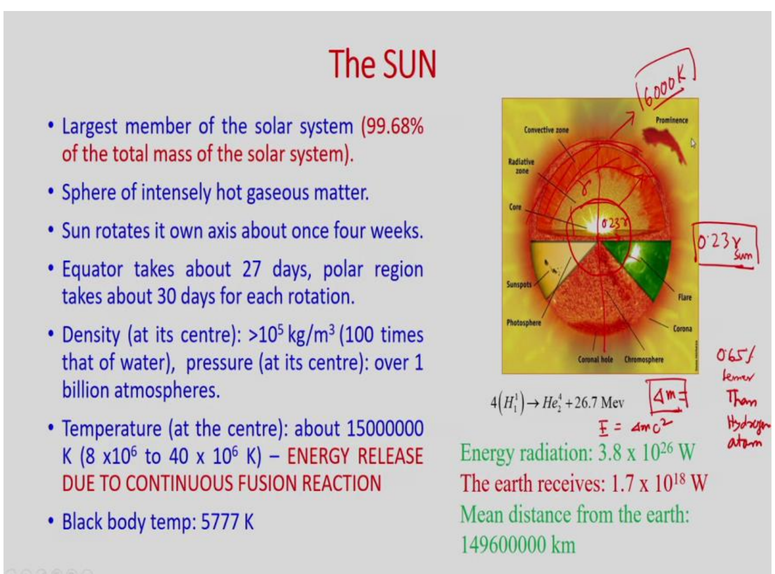

So, as all of us know about Sun, the Sun is the largest member of the solar system. It carries about 99 point 68 percent of the total mass of the Solar System. And it is a sphere of intensely hot gaseous matter. And the Sun rotates its own axis about once 4 weeks. This equator takes about 27 days. Polar region takes about 30 days for each rotation. If we talk about density and the pressure at the center, it is tremendously high.

So, density is about 10 to the power of 5 kg per cubic meter, which is about 100 times more denser than water. And pressure at the center is about more than 1 billion atmospheric pressure. So it is a very high pressure. And temperature at the center is estimated to be about 15000000 means it is 8×10^6 to 40×10^6 Kelvin. So, it is a very high temperature. And this energy release is due to continuous fusion reaction. So, as you know how this fusion reaction takes place.

So, if we consider this hydrogen atom and helium atom, if we know the mass difference, delta m Δm. So, this mass of helium atom is about 0.65 percent lesser than, lesser than hydrogen atom, hydrogen atom. So, once we know this Δm then we can use this Einstein's famous equation, which is nothing but $E=\Delta mc^2$. So, c is nothing but velocity of light which is equal to $3x10^8$ meter/second.

So, if we substitute this Δm and c then we can calculate the kind of energy which is generated in the Sun. So, it is found at about 0.23 times radius if we this radius of the Sun. So, in this location, that means, if we draw a line here, and if we take 0.23 times the radius if this is the radius and this is the (rad) r then 90 percent of the energy is generated here, at this core.

And then this energy generated here is radiated to the outer surfaces. And as you can see, this portion, this portion, this portion is a convective zone. As you can realize this core temperature is very very high and this our surface temperature is reported to be about 6000 Kelvin. So, there is a decrease in temperature from core to the surface of the Sun.

And because of these and from, from here it can be concluded that heat dissipation is taking place from the core to the surface of the Sun and then the amount of energy which is emitted from the surface of the Sun is distributed in the solar system and part of the energy is received by the Earth surface. And if we see this energy, radiation from the Sun is about 3.8×10^{26} watt. And this Earth receive energy about 1.7×10^{18} watt. And also we know the distance between the Sun and Earth, which is mean distance.

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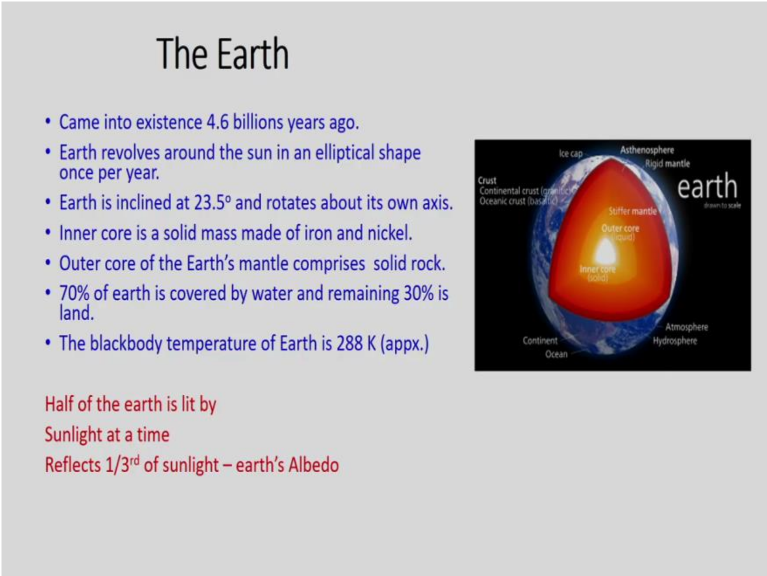

So, let us see what we can learn about Earth. So this Earth came into existence in about 4.6 billions years ago. Earth revolves around the Sun in an elliptic shape once per year. This Earth is inclined at 23.5^0 and rotates about its own axis. This inner core is a solid mass made of iron and nickel. And this outer core of the Earth mantle comprises solid rock. And also we know that 70 percent of Earth is covered by water, and remaining 30 percent is land. And this black body temperature of Earth is about 288 Kelvin. So, we will learn why it is called black body and what is the spectrum at this temperature.

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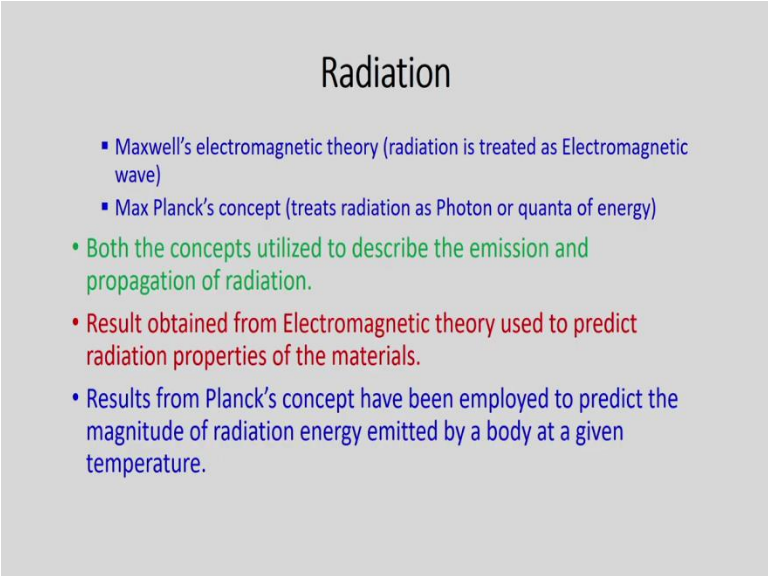

So now we will learn something about radiation. So, there are many theories available for understanding the radiation propagation, but no theories give accurate information about the radiation propagation. So, most important theories coined by two researchers, one is Maxwell's Electromagnetic Theory. This radiation in this theory, radiation is treated as electromagnetic wave and Max Planck's concept where radiation treats as Photon or quanta of energy.

Both the concepts utilized to describe the emission and propagation of radiation. The result obtained from electromagnetic theory used to predict radiation properties of the materials. And the results obtained from Planck's concept have been employed to predict the magnitude of radiation energy emitted by a body at a given temperature. So, these 2 theories are primarily utilized to understand the radiation propagation from Sun to the Earth surface.

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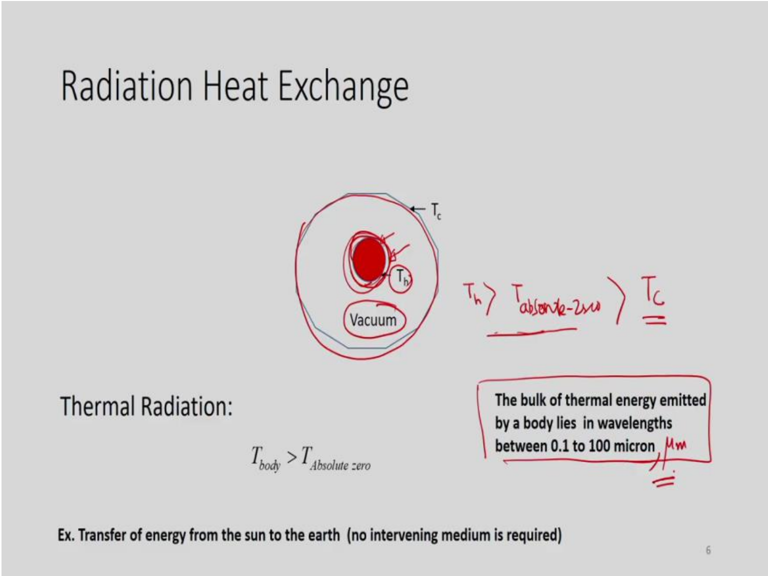

Let us take an example on radiation heat transfer. So, here what I meant to say how this thermal radiation is propagated? If your body temperature is more than absolute 0, then that body will start emitting thermal radiation. So, for example, if we consider an object having a temperature Th, which is more than absolute 0 temperature, absolute 0 and also greater than the cold surface Tc. So, this hot object is placed in a medium that is in the vacuum and will show how this hot object is cooled when a cold surface is surrounded by these hot objects.

So, what happens since these hot object temperature is more than the absolute 0 it will start emitting thermal radiation and because of this heat exchange, radiative heat exchange, so, this object temperature will reduce and only mode of heat transfer will be radiative heat transfer. Because no medium is present, this is kept in vacuum, no convective heat transfer will take place, only radiation exchange will be there. So, because of that this object will, will be cooled.

And same thing happens when radiation is propagated from Sun surface to the Earth surface. And from that what we understand, we do not need any intervening medium for transferring energy from Sun to the Earth. So, this Sun will emit thermal radiation at about 6000 Kelvin and this bulk thermal energy emitted by a body lies in wavelength between 0.1 to 100. So, most of the thermal radiation is emitted at this wavelength is 0.1 to 100 micron. So, this micron we can represent as μm also.

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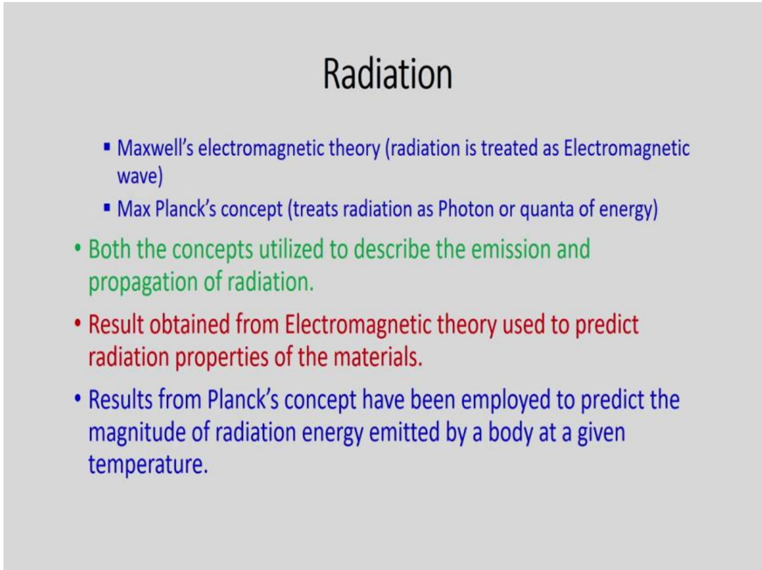

And if we have to learn about radiation, there are theories but no theories give clear information about radiation propagation. So two most important theories coined by Maxwell's and Max Planck's, are utilized to understand the radiation propagation. As per the Maxwell's Electromagnetic Theory, radiation is treated as electromagnetic wave. And as per the concept proposed by Maxwell's, this radiation treats as Photon or quanta of energy.

Both the concepts are utilized to describe the emission and propagation of radiation. The result obtained from electromagnetic theory used to predict radiation properties of the material. And the results obtained from Planck's concept have been employed to predict the magnitude of radiation, energy emitted by a body at a given temperature. So, what we have learned these 2 theories are primarily used for understanding the radiation propagation from Sun surface to the Earth surface.

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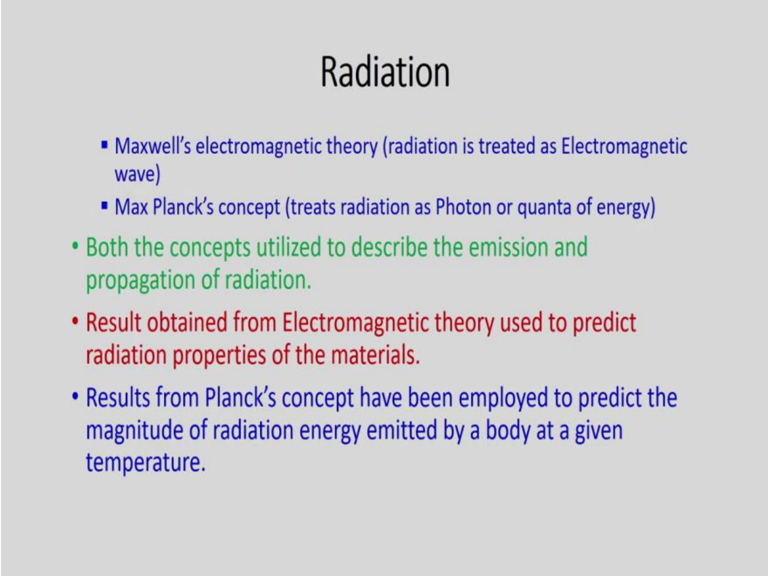

Let us learn something about the spectrum of electromagnetic radiation. So, when the radiation is treated as electromagnetic wave? The radiation from a body at temperature T is considered at all wavelength. So, that means lambda λ will vary from 0 to infinity. So, we learn black body and then how this radiation spectrum is important. We will learn in the later slides. Now, our concern is, if we consider this wavelength spectrum, here what we can see from 0.1 to 100 μm, this portion of the spectrum is known as the thermal radiation.

So, most of the radiations and most of the engineering applications this thermal radiation is applied and also solar radiation is fall under this thermal radiation. The Sun emits radiation at a temperature, which is black body temperature is about 5760 Kelvin or we can say it is close to 6000 Kelvin. So, at that temperature, we get solar radiation and that wave length fall in the range of point 0.1 to 3 μm. And under this solar radiation spectrum, we will have visible range which falls in the wavelength 0.4 to 0.7 μm.

And when we talk about infrared, so, its range is 0.7 to 1000 μm and in ultraviolet it is about 0.4 to 10^{-2} μm. So these informations are important because the kind of radiation with what is coming from the Sun and then what happens in the Earth atmosphere, and then the kind of radiation we received at the Earth surface and the radiation goes back reradiated from the Earth surface. So, this information is required.

So, short wave radiation is coming from the Sun surface and in something happens in the Earth atmosphere. And then this long wave radiation, which is reradiated from the Earth is like infrared radiation. So, that actually retains in the Earth atmosphere. We will discuss these issues in the coming slides. And also there are information like different kind of radiations can be applied in different applications. So, for example, X-Ray, as we know, this X-Ray machines are applied in many of the applications to take the image.

So, its wavelength ranges from 0.01 to 100 nanometer and of course, it is used in radiography. And for ultraviolet its range from 10 to 400 nanometer and it is mostly used in water purifications. And in visible range, its wavelength varies from 400 to 800 nanometers that means, 0.4 to about 0.8 μm and this is for daytime vision and photosynthesis applications. And near infrared ranges from 800 nanometer to 10 μm. So, it is used for nocturnal vision, at night visions to work at night.

In thermal infrared wavelength varies from 10 μm to 1 mm and it is mostly applied in heating and cooling applications and micro wave wavelength varies from 1 millimeter to 10 centimeter. And of course this is used in microwave ovens. Already we know what is microwave oven and most of the household this microwave oven is present. And radar waves, it is very long wave, 10 centimeter to 1 meter. And it is used for mobile, telephone and speed detectors. And for radio waves, where wavelength is more than 1 meter. So, the use of this wave is in radio, television and communications.

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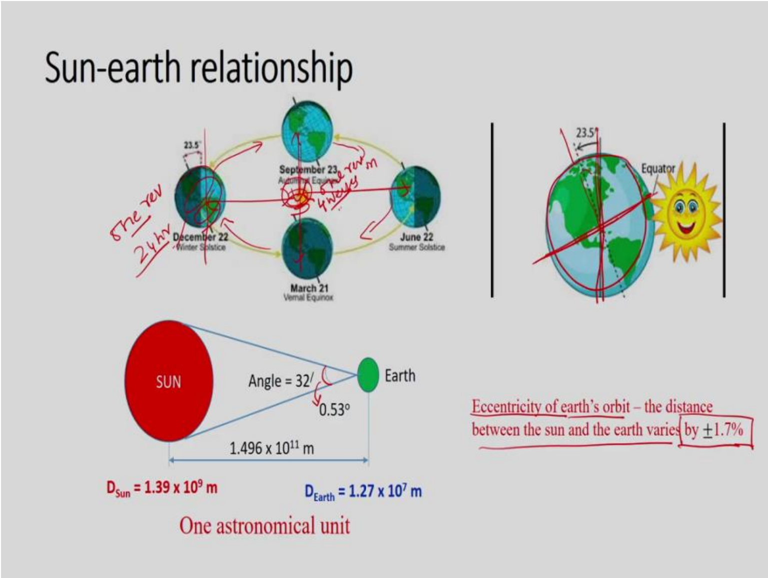

In this slide, we learn Sun-Earth relationship. So, Sun is here at the center and Earth is here. So Earth rotates along this path and also Earth rotates about its own axis. Sun is here, Sun also rotates about its own axis. So this is in 24 hours, 1 revolution, 1 revolution in 24 hours. And is about 4 weeks. 1 revolution in 4 weeks and distance between the center of the Earth and the center of the Sun is varying, because this is eccentric, this is not fixed. So when we have to tell the distance between the Sun and the Earth that is the average distance between the Sun and Earth.

Sometimes you know Sun-Earth distance is very long and sometimes it is short. So, we must know which day is very very close to the Earth and which day is very very far from the Earth. So, this information is always known to you and this will be more clear when we solve problems. And also Earth subtends an angle of 0.53 degree. Here this angle is 0.53 and the distance between the center of the Sun and center of the Earth, this is the average distance is about 4.96 x 10^{11} meter.

And since we understand that because of this eccentricity of Earth's orbit the distance between the Sun-Earth is varies and this variation is about $\pm$ 1.7%. And also one more information we must know the angle this is, this is Earth and this part is equator, and this is the vertical line and this angle is 23.5, this always makes an angle of 23.5 and each rotates about its own axis.

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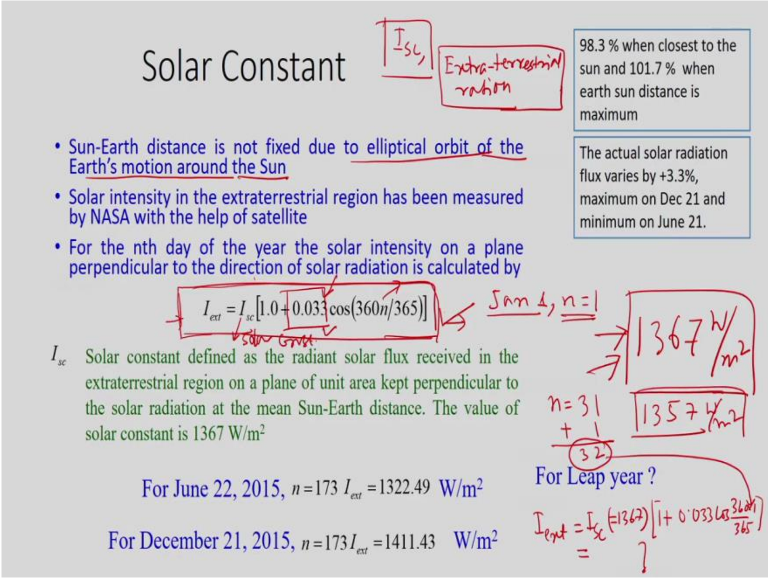

Now, we need to learn about solar constant, which is very, very important to understand why this is important in understanding solar radiation propagation. So, what is solar constant? This solar constant is defined as the radiant flux received in the extraterrestrial region of a plane of unit area kept perpendicular to the solar radiation at the mean Sun-Earth distance. So, this value is about 1367 watt/meter^2.

So, this is a solar constant value and this value will vary. Maybe if you consider in the month of June, this value will be about 1322 watt/meter^2 and in December 21, if we consider it will be about 1411 watt/meter^2. This is due to the variation in distance between Sun and Earth at different times. So, these variations can be considered. So, this variation is about 0.33%.

So, if we have to calculate the extraterrestrial region solar flux then we need to apply this equation, Iext = Isc (which is nothing but solar constant, solar constant and then this part) [1+0.033 cos (360n/365)]. So, this need to be considered. So, this variation is due to the elliptic orbit of the Sun's motion around the Sun. So, this need to be considered otherwise this value 1367 which is the recent time this constant is used.

Earlier people have made many calculations and there are variations like people sometimes claimed that this value is 1357, 1357 watt/meter^2. But in the recent times we use this value 1367. So, this is the precise value normally we use in our calculations. So, what my intention is in this slides, we need to consider this parameter, this parameter 0.033 cos (360n/365) in order to calculate the extraterrestrial region for any day.

So n represent the nth day of the year. Suppose if I am interested to calculate the extraterrestrial region or extraterrestrial solar flux received on January 1, then this value of n will be n is equal to 1, ok. So if we substitute the value of n is equal to 1 in this expression, then what we will have Iext will be Isc which is nothing but 1367x(1+0.033 cos 360 x 1/365).

Then we can do small calculations and we can calculate the amount of extraterrestrial region received on day 1 or January 1. So if I am interested to calculate this Iext for say February 1, then what would be the value of n? n will be your, because January will be 31 days plus 1 which will be your 32. So, if we substitute this value 32 in n here, then we can calculate what will be the radiation flux received on February 1. Of course, this radiation is extraterrestrial radiation which is above the Earth atmosphere.

So, let me summarize these slides, what we have learned. We have learned two very important parameters, one is solar constant and second one is extraterrestrial radiation. So extraterrestrial radiation, extraterrestrial radiation. So, we have not yet learned, what is terrestrial radiation. So, we will learn after 2-3 slides, what is terrestrial radiation, and what is the difference between extraterrestrial radiation and terrestrial radiation. So, this Isc will be required in many of our calculations. So, let us move to the next slides.

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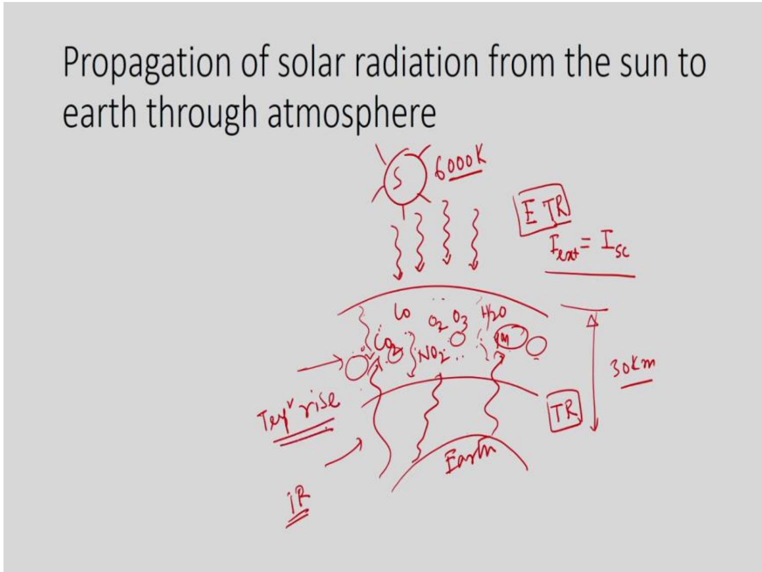

Now, we will study how radiation is propagated from Sun to the surface of the Earth. So, if we draw Sun here, this is Sun, and we will have Earth atmosphere here and Earth is here. So, this part already you know, I will write extraterrestrial region is ET, and terrestrial region is (E) TR, terrestrial region and extraterrestrial region I will write R here, ok. So, already you know the relationship, how this Isc and Iext is related, extraterrestrial region.

So this solar radiation, so Sun's surface temperature is about 6000 Kelvin and the short wave radiation is moving through the space. And we will have all the molecules here, like particulate matter and we will have oxygen, ozone, then you have H_2O, it is water vapor and maybe NO_2, maybe carbon dioxide, maybe CO. So, what happens when this solar radiation is coming from the Sun surface and it has to pass through this Earth atmosphere.

So, when this solar radiation is passing through this Earth atmosphere. So, the two things happen one is absorption of solar radiation and second one is scattering. These two phenomenons will be discussed in the later slides. So, these two phenomenons happens because of that we receive a low intense solar radiation at the Earth surface. So, here in this slides my concern is we need to know how this solar radiation is propagated from the Sun’s surface to the Earth's surface.

So, shortwave radiation is coming through the space and it has to travel through this Earth atmosphere. So, we go and already you know, this atmosphere is very thick about 30 kilometer and here what happens as soon as it strikes the Earth, so, it reradiates some kind of long wave radiation, long wave radiation. So, these long wave radiations are something called infrared, infrared radiations.

So, this long wave radiation reflected back from the earth surface and it retains in this Earth atmosphere and which leads to the contribution of heating up of the earth atmosphere. So, what I tried to explain here, we have Sun and Earth and then short wave radiation travels from the space and then that has to pass through this Earth atmosphere and it is received by the Earth surface.

So, some of the radiations are reflected back, these radiations, they are long wave radiations and that retains in the earth atmosphere. Because these are absorbed by the carbon dioxide and it retains and this leads to the greenhouse, or increase in earth atmosphere. Because internal energy of this Earth atmosphere is increasing and because of that, we are having temperature rise, temperature rise.

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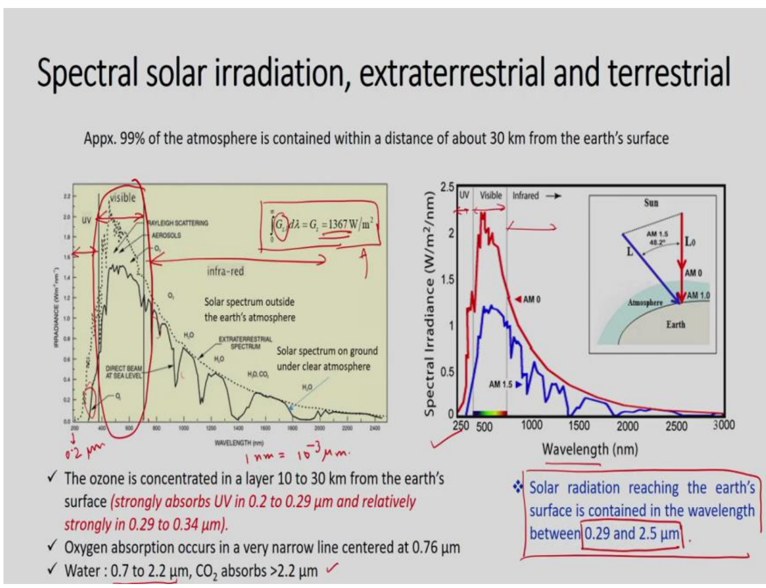

So, next slides we will learn about solar radiation, what is terrestrial radiations, and then what is, then in this slide we learn solar spectral irradiation, this is extraterrestrial and terrestrial radiation. So, it is known that approximately 99 percent of the Earth atmosphere is contained within a distance of about 30 kilometer from the Earth's surface, ok. And let us look into this figure. So, what it represents, it shows irradiance versus wavelength.

So, different wavelength, what is the spectrum for extraterrestrial region, and what is the spectrum for terrestrial region? So, this dotted line represents the solar spectrum outside the Earth atmosphere that is extraterrestrial region. And this solid line represents the solar spectrum on ground under clear atmosphere. As you can see, this region, this region is UV, this region is visible region and then this long region is infrared region.

So, this UV region is the most important for us, as far as solar PV conversion or portability conversion is concerned. So, what you can see from this figure is solar intensity is very high in case of extraterrestrial region and this is different or it is lower in case of terrestrial region. So, what happens, why this is so, because this radiation has to pass through this Earth atmosphere while radiation is traveling through this Earth atmosphere attenuation takes place.

So, radiation what we received that is in attenuation form and this attenuation is due to absorption and scattering. So, here this ozone is concentrated in a layer into 30 kilometer from the Earth's surface. And it is strongly absorbed UV ranges in the wavelength of 0.2 to 0.29 micron, and relatively strongly in 0.29 to 0.34 micron. So, here this scale is in nanometer, so, we can convert very easily. So, this 200 means about 0.2 micron. So, 200 nanometer means 0.2 microns.

So, because this is 1 nanometer is something like 10^{-3} micron. So that way we can understand the scale. And this oxygen absorption occur in a very narrow line centered at 0.76 micron, so it is about here. So, this oxygens are absorbed here and this part is ozone. And water absorption takes place in the wavelength range from 0.7 to 2.2 micron and carbon dioxide absorbed in the wavelength more than 2.2 micron. So, this information is very, very important and what we understand from this figure, the why this variation of radiation compared to extraterrestrial region.

The kind of radiation we received at the Earth atmosphere is different than kind of radiation which is available above the Earth atmosphere, because of this absorption and scattering in the Earth atmosphere. Also we will learn what is these things like emissive power. So this amount of radiation per unit wavelength if we integrate it for all the spectrums, then what we will get is it is called solar constant. So, this information will be more clear when we do some kind of numerical problems.

And this is also similar curve. It shows the spectral irradiance versus wavelength. So as you can see, wavelength, UV visible wavelength range, then visible wavelength range and infrared wavelength range. And we learn what is air mass in the, in a couple of slides later and which is also very very important. And the finally, what our concern is like solar radiation reaching the Earth surface is contained in the wavelength between 0.29 to 2.5 micron. So, this range is very important for us.

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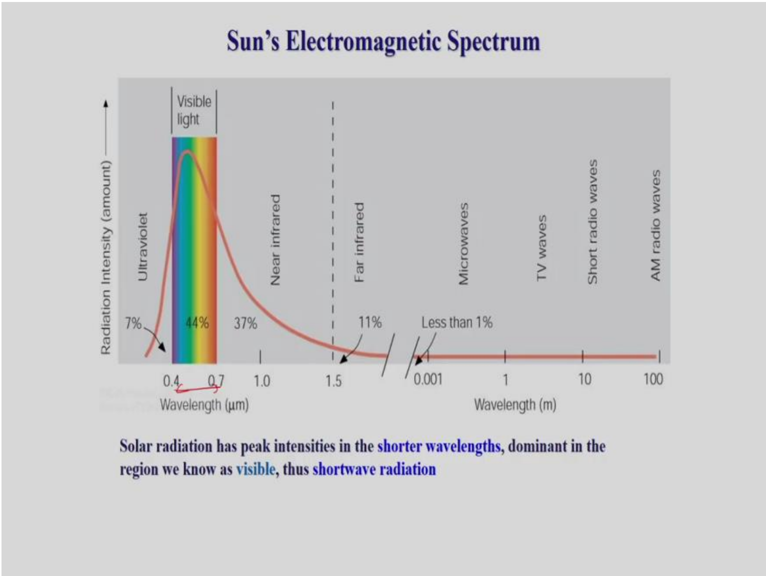

See the wavelength as we learn the solar irradiation has peak intensities in the shorter wavelength. So, when Sun ray is coming from the Sun surface, so, what we observe at this wavelength we will have peak and then it is decreasing. So, this visible range is very very important for us, and most of the solar PV is based on this visible light.

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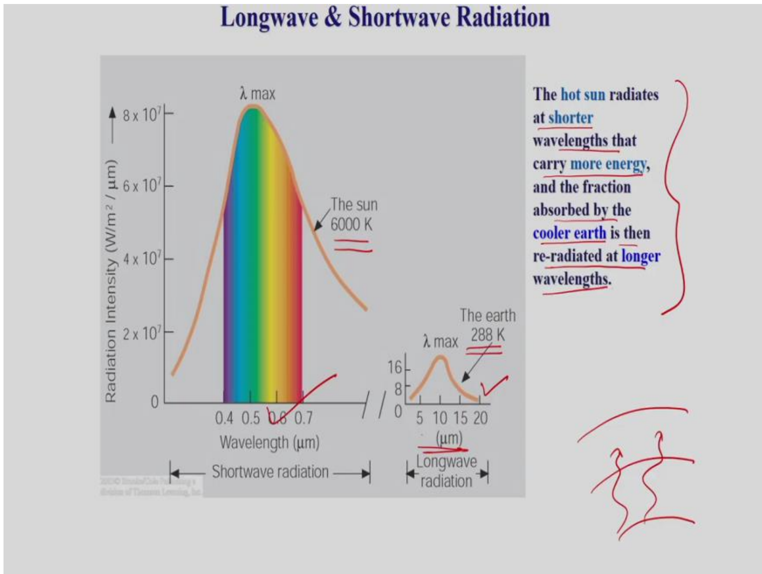

And here as we can say, when solar radiation is, so this is our atmosphere, this is Earth. So, this long wave radiation is going back. So, this long wave radiation is a long wavelength radiation. The peaks will be about at 10 microns and then is decreases. So, this is so about long wave radiation, this is about short wave radiation, ok. And this is at 600 Kelvin from the Sun surface and this is at Earth surface which is at 288 Kelvin. So, hot Sun radiates at shorter wavelengths that carry more energy and fraction absorbed by the polar surface is then reradiated at longer wavelength, which is shown in the figure.

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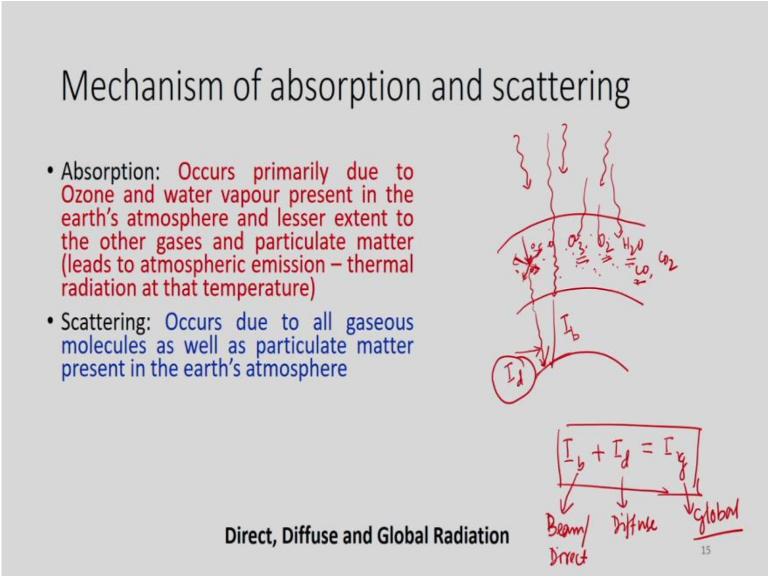

Now, we will discuss about the mechanism of absorption and scattering, which is very, very important for understanding what is diffused radiation and what is normal radiation. Because, after this lectures, what we are going to learn is different kind of instrument used for radiation measurement, and then how these two radiations are different, and what condition we can make, what kind of conversion devices?

That means, which radiation is important for say, concentrator and which kind of radiation is important for other applications. So, we will discuss the mechanism of absorption and scattering in the slides, which is very very important to understand the kind of radiation received by the Earth's surface and why this is so. That means, what is normal radiation and what is diffuse radiation. That idea we can generate by studying these two facts is absorption and scattering.

This absorption occurs primarily due to ozone and water vapor present in the Earth atmosphere and lesser extent to the other gases and particulate matters. But, scattering occurs due to all gaseous molecules, as well as particulate matter, present in the Earth atmosphere. I will draw the thing, same thing again here. So, this will be something like this. We will have aerosols, aerosols in particulate matters and all the gaseous molecules.

Like we have O_3, we have oxygen, we have H_2O, we have CO, we have CO_2, all the gases and this radiation is coming short wave radiation. So, what happens this radiation, some of the radiation is absorbed here, so UV is absorbed here then at different wavelength this will be absorbed at in the different molecules. And what happens there are some radiations which are unaffected, unaffected by these Earth atmosphere and it falls directly on the Earth surface.

And some radiations which is diffused and it travels in all the directions and its intensity is reduced. So, the kind of radiation which is unaffected by this Earth atmosphere is known as Ib, Ib is a beam radiation or direct radiation. And the kind of radiations which is received after scattering is known as Id, this is diffuse radiation. So, if we add these two, Ib plus Id is nothing but In or Ig. So, this is Ig is nothing but Global Radiation.

So Ib is beam radiation or direct radiation, beam or direct and this is diffuse, diffuse and this is global. So, here shortwave radiation is coming from the Sun surface and this travel through the space and then and it has to pass through this Earth atmosphere. So, while this radiation comes in contact to the Earth atmosphere, so, what happens, absorption of solar radiations takes place, also scattering takes place. So, based on the wavelength, so, different elements are present.

So, directly they are absorbed here, like UV is absorbed in ozone layer and then you have oxygen also absorbed in different wavelength and then water vapor then H2O. And some of the radiations which is no strike on the aerosols and its directions are sensed, it radiated in all the directions and some of the radiations is received under Earth surface. Sometimes what happens there is a parameter called release scattering. So, since air molecules are present, because of this air molecules this release scattering also takes place.

So, this scattered radiation, so, when it receives on the Earth surface its intensity is reduced and this reduced intensity is designated by I d, that is diffuse radiation. So, what we have learned here? We have learned the mechanism of absorption and scattering and then, we have learned a different kind of radiation that is beam radiation, diffuse radiation and global radiation. So, these radiations are very very important when we do calculations related to the radiation geometries.

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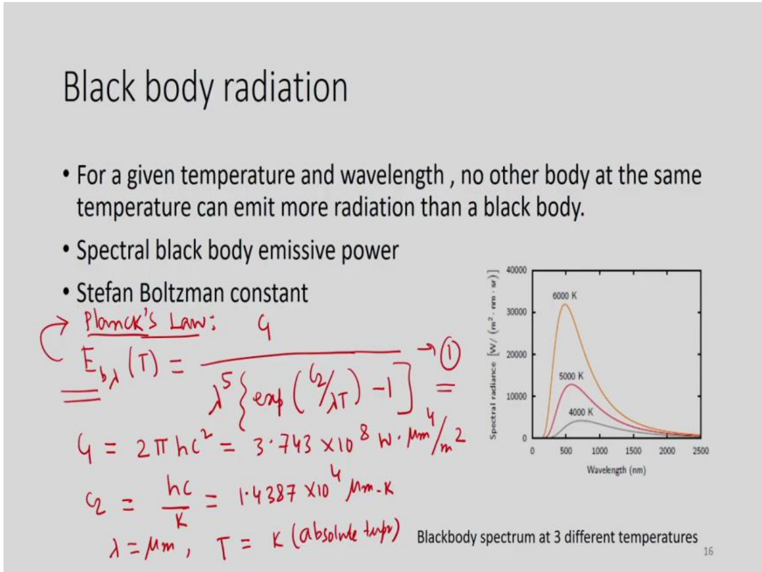

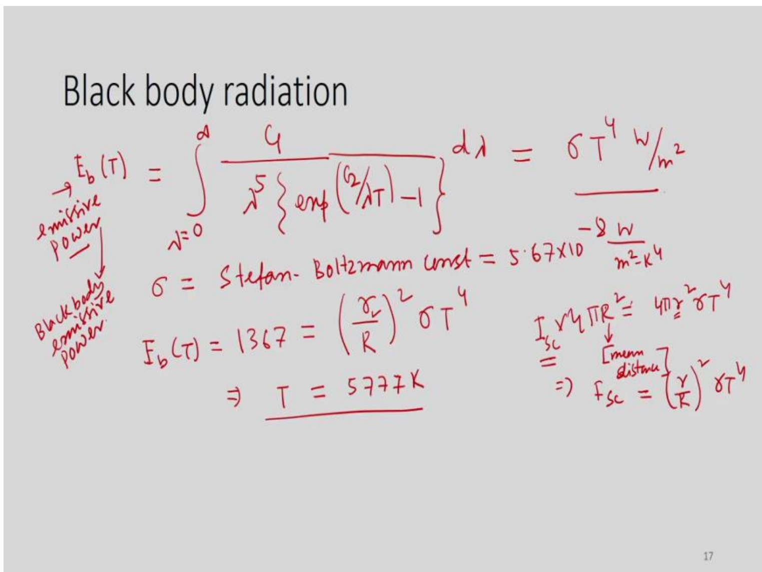

And we need to learn black body radiations. So, for a given temperature and wavelength, no other body at same temperature can emit more radiation than a black body. So, we need to understand what is a spectral black body emission or emissive power and a Stefan Boltzman constant. Because we can demonstrate it, Sun is a black body or Sun's surface temperature that is close to 6000 is a black body temperature. So, we can demonstrate it. Let us start as we know this Planck's law of spectral emissive power, how we define I,t E bw.

So, at certain temperature is expressed as $C1/\lambda^5\{\exp(C2/\ \lambda T)-1\}$ and then you have E, exponential of C2 by lambda T minus 1. This may be equation 1 and this C1 and C2 are constants and C1 is something like = $2\pi hc^2 = 3.7431 \times 10^8$ W.µm/m^2 which substitute the value of

Planck's constant and value of c which is something like 8 $W.\mu m^4$ / $meter^2$ and C2=hc/K, which is equal to 1.4387 x 10^4 μm K.

And T is the absolute temperature and λ is in, λ, λ is in μm and T is, this wavelength in μm and T is in Kelvin, this is absolute temperature, absolute temperature. So, this is the spectral emissive power and this is defined by Planck's, Planck's and also you know the Planck's law. So, this equation is 1. Now if I am interested to calculate the emissive power, what we will do? We will integrate this Planck's constant from wavelength 0 to infinity.

Let us see how we can do it. So if I am interested about emissive power, Eb(T), this is called emissive power. Earlier one it was a spectral emissive power. So if I am interested to find out this emissive power, what we will do, we will integrate this equation 1 from λ 0 to infinity. And this equation was something like this $C1/\lambda^5\{\exp(C2/\lambda T)-1\}$. And this is the lambda. So if we integrate, so I am not going to do the derivation.

So, what I will write, what you will get here finally σT^4 which is $W/meter^2$. So, what is λ? λ is Stefan Boltzman constant, Stefan Boltzman constant, Boltzman constant and its value is 5.67 x 10^{-8} $W/meter^2 Kelvin^4$. So, this is a black body emissive power so, also we can say this is a black body, black body emissive power, emissive, emissive power. So, it is the black body radiation flux emitted from a surface at an absolute temperature T.

So, in order to show the radiation emitted by the Sun, essentially black body radiation, we substitute the value of solar constant. So, if we have to show that radiation emitted by the Sun is essentially black body radiation. So, if then what we need to do, this is equal to $1367= (r/R)^2\sigma T^4$,. So, how I have calculated it because pi, 4 π R^2 square is equal to, we have this area and then we have, Isc x 4 π R^2 = 4 π $r^2\sigma T^4$ r is the radius of the Sun, R this is the distance between the Sun-Earth. So, of course this is a mean distance, so mean distance. So, that is how we can calculate.

So, if we substitute the value of 1367 here, and this Isc is equal to like small r by capital R square by sigma T to the power of 4. So, if we do this calculation, then we can calculate what is T, because these values are known to us, small r and capital R. And this T will be about 5777 Kelvin. So, if we use this T and if we go back here and if we substitute this value of T here, then we can calculate Eb that is spectral emissive power at different wavelength. And it is found that if we generate this Eb value at different lambda, it is quite close to a black body radiation. That is why you can say the solar radiation emitted from the Sun surface is a black body radiation.

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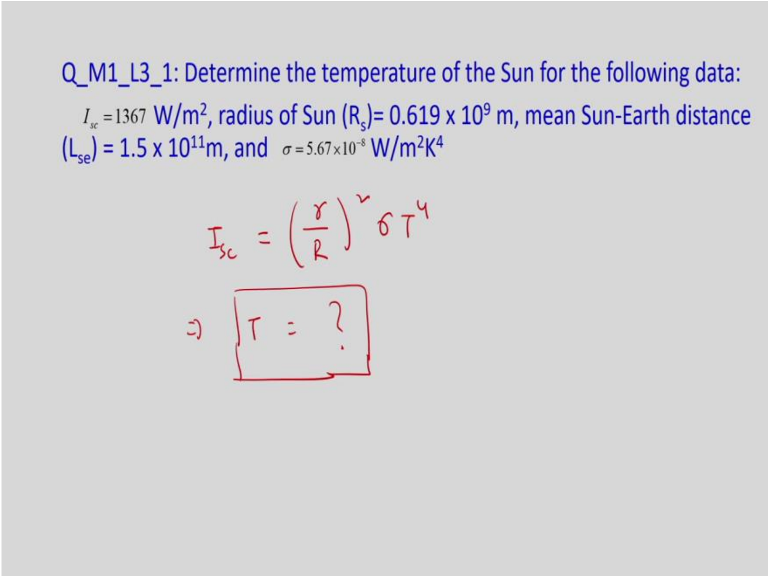

So, now, we can solve this problem, since already we have all the data, already we have given the hint how to solve this problem. So, temperature of the sun, straightaway we can calculate what is T or if we know solar constant Isc is something $(r/R)^2\sigma T^4$ and if we substitute these values we can calculate what is T. So, students I request you to complete this work, so that you involve how this kind of problems can be solved for better clarity.

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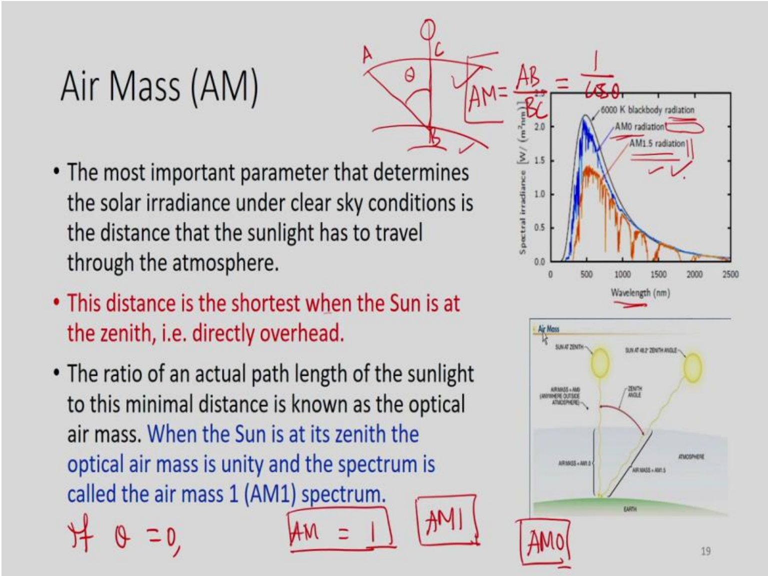

So, here we will introduce one concept called Air Mass. So, which is very, very important parameters in testing in a solar flatplate collectors, we, we need to understand very carefully. So most important parameters that determines the solar irradiance under clear sky condition is the distance that the sunlight has to travel through the atmosphere. Because we have atmosphere, we have atmosphere.

This is the atmosphere and then suppose if we, we are here, so, maybe Sun is at our overhead, then distance travel by the Sun ray is very very short, and if we take here then distance travelled by the solar ray is very very long. So, this angle is very very important for us. So, this is maybe A this is B, this is C. So, how we define, AM is something like = AB/ BC. So, this is something like 1/CosΘ. So, this distance is the shortest when the Sun is at the zenith and is directly overhead, as we understand from this figure.

And the ratio of an actual path travel or is a path length of the sunlight to the minimal distance is known as the optical mass, what we have defined here. When the Sun is at this zenith, the optical Air Mass is unity and the spectrum is called the Air Mass 1. So, so Θ, if Θ is 0, that is 1, that is called AM will be 1 if Θ is equal to 0, so m will be 1. So, this spectrum is known as AM1. In case of extraterrestrial radiation or extraterrestrial region, it is defined as AM0, AM0 because the radiation do not have to travel in the Earth atmosphere.

So, because of that it is AM0. And here this figure shows the spectral irradiance variation with respect to wavelength, as you can see, this radiation at the solid line is for 6000 Kelvin black body solar radiation and this is at AM0 in, in case of extraterrestrial region and this is at AM 1.5. Why this AM1.5 is so, important? Because all the experiments, all the testings are done at AM1.5, at an angle of 48.2 degree.

So, this is, this is very very important because solar testings are normally done at AM1.5. We can do very small numericals, so how to calculate this Θ if we know AM is 1.5. So, if we have to do any experiment, then we have to and that has to be validated, then we have to perform the experiments at AM1.5 and at the solar radiation of 1000 watt/meter^2. So, that is very very important as far as testing of solar collector is concerned.

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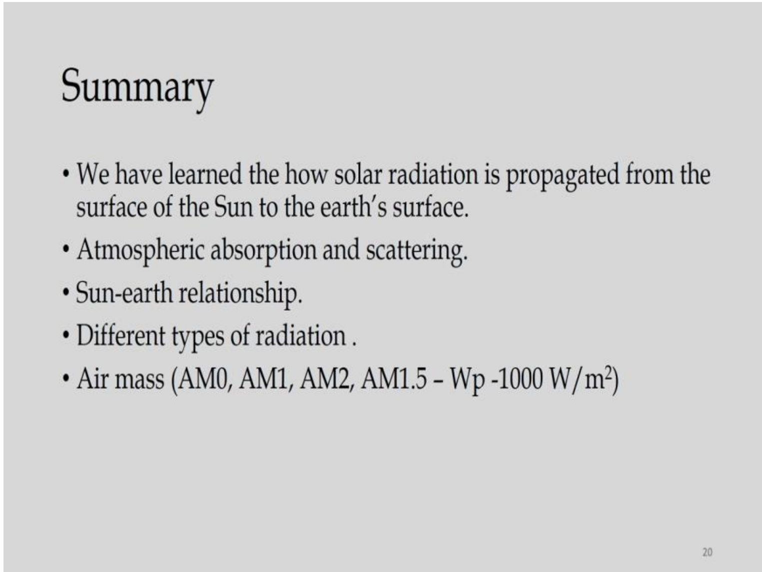

So, we will summarize what we have learned today. So, we have learned how solar radiation is propagated from the surface of the Sun to the surface of the Earth. And also we have learned what is atmospheric absorption and scattering, primarily the mechanisms, how does absorption takes place, absorption of solar radiation takes place, and at what wavelength that molecules are absorbed, solar radiations are absorbed by the molecules and how scattering takes place.

And because of the scattering how this radiation intensities decreases. Also we have understand the distinction between extraterrestrial region and territorial region. And also we have learned the relationship between Sun-Earth and how it travels, and what is the average distance between Sun and Earth. And how this distance is varying with respect to the particular day. And also we have learned the radiation variation with respect to the days and in case of extraterrestrial as well as terrestrial region.

And also we have understand the different kind of radiation, what is global radiation, what is diffused radiation, and what is normal radiations? So, when solar radiation is striking on the Earth surface without disturbing in the Earth atmosphere that is called normal radiation or direct radiation. And if it is scattered or scattered radiation is received by the Earth surface, so that is called diffused radiation. And if we add direct radiation or normal radiation plus diffused radiation then it becomes global radiation.

So, this is, these are very very primary or fundamental things we have studied today. And also finally, we have studied what is Air Mass. So, Air Mass 0, Air Mass 1, Air Mass 2, Air Mass 1.5. So, Air Mass 0 means that is radiation spectrum that is received above the Earth atmosphere. So, Air Mass 1 means, when solar radiation is at the zenith, that is our overhead and different situations may arise.

But, AM 1.5 is important because all the solar experiments are performed at Air Mass 1 point 5 and at a solar intensity of 1000 watt/meter^2 and also this is signifies in terms of watt peaks. If we have performed this experiments at this condition, so that is the rated test and we represent this as watt peak. So, what you can see in the modules that is watt peak, maybe 35 watt peak. So, that represents that is a standard test condition. So, thank you for watching this video.