Elements of Solar Energy Conversion

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Lecture – 01

Hello, welcome to this course. This is the course on Elements of Solar Energy Conversion. So, I am Doctor Jishnu Bhattacharya from Mechanical Engineering Department, IIT Kanpur. And this course actually is a very targeted course for the solar energy technologies, whoever is going to use it or whoever is going to learn it how it is used; that is a course for this reason.

And there are few courses on this even online, but this particular course will target those people who are basically have some background already in terms of heat transfer analysis or the basic physics of sun earth relations and all those things. So, we will assume that this particular background is already there and we are going to focus from the next step.

But not only that, we are also going to look at some basics as well, because often these things are so common that we forget and forget to pay attention to that particularly they are taught in schools and after that, when we actually want to use these technologies or these information, then we fumble; because we did not pay that much attention when it was introduced to us ok.

And in this particular point i would like to share some my personal thoughts with you. When I teach in a classroom it is more like more interactive students can pause me and question me. Here also, of course, you can pause me by clicking a button. However, questions they have to wait ok, so that is a fundamental problem in this type of teaching.

This mode of teaching, but it has some advantage as well. What is the advantage? Advantage is you can take it at your own pace. If I am going too fast, you can pause me you can think what I said and then you can go ahead with the rest of the lecture, so that is the plus point.

Another thought I want to share you before I start anything, is that like this is the age of information abundance right. So, you have enough information around and you do not have to see through a class or watch this particular video to learn or basically to gather the information. So, when you are taking this course, please keep this in mind that the information collection is not the motto or goal of this course ok.

For any class or anything you want to learn and you want to gather knowledge; knowledge is rather intuition then the information you can search anywhere in the web and you will find so many information that I cannot even deliver in this course ok. So, keep that in mind.

What do I mean by intuition? Intuition is like when you go through the course and maybe a year or 2 after you have finished the course, then also you will carry some feeling or some intuition at some inner level, which you can use whenever you look at a problem.

An engineering problem related to this particular course or some decision you want to make I mean you are making a, I mean you are installing some air conditioner, where to put the external unit for split air conditioner. So, all these things are related, so you use your learning on solar energy so that you can utilize it in your life ok. So, let us start, this is the first lecture.

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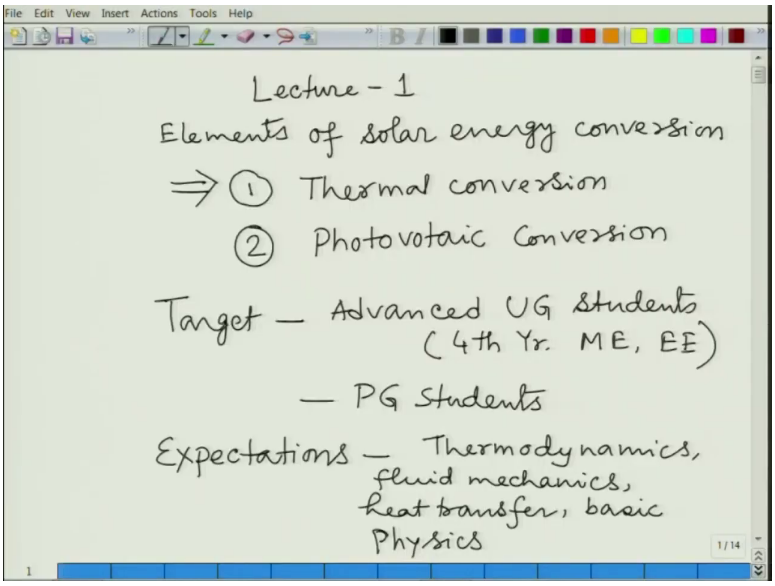

So this is lecture 1 and I should write the course name as well once; Elements of solar energy conversion ok. So, we are going to cover all kinds of conversion technologies. So, our main focus would be the thermal part, thermal conversion ok. Of course, we will cover the photovoltaic conversion, because, otherwise, the course will be incomplete right.

But our major focus would be here, particularly because there are plenty of information already available for plenty of courses as well are available on photovoltaic conversion ok. So, what we will do? We will focus more on thermal conversion and the photovoltaic part we will add for the sake of completeness ok.

And the target audience, I should write what I expect the target audience is either advanced UG students, maybe my preferably 4th year mechanical engineering students or even electrical engineering students. So that is the another one is the PG students. That means;

either master degree or PhD students, who would like to pursue their research in the field of solar energy conversion ok. So, this will be an introductory course for them.

And for advanced UG students the background that they have in first 2-3 years of the engineering courses those will be used heavily in this course; so those are the target audience. And expectation from the students that I have is they will have some background in thermodynamics fluid mechanics, heat transfer and basic physics.

This kind of background I am looking for, so before you start you ensure that you have that background then only you will be able to follow and enjoy the course; that is the fundamental principle.

If you do not enjoy then you will not be able to build that intuition that I am talking about ok. Now, let us give a outline for the course, which you will be followed ok. So, we will diverge the whole outline as we go, but for the first couple of lectures let me put what we want to cover ok.

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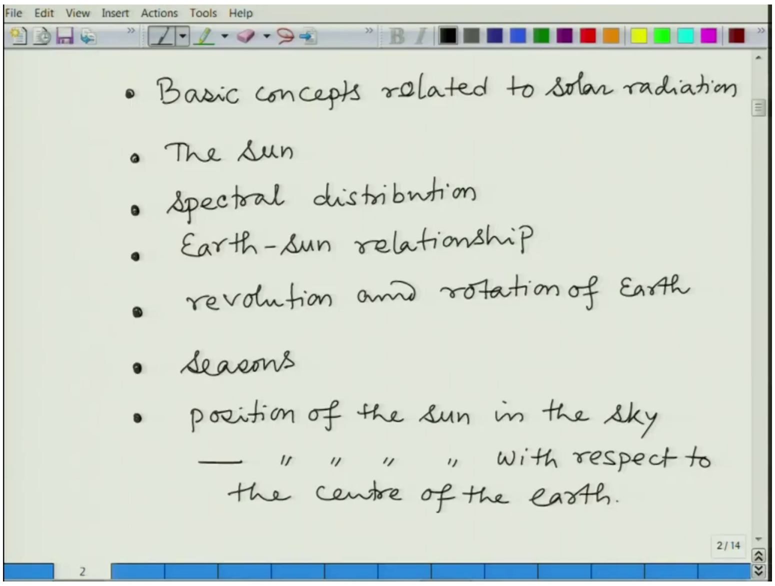

So, first one would be just to introduce the very basic concepts that are related to solar radiation ok. Then next thing we will talk about the sun ok because that is the most interesting body in the whole thing ok. So, we have to understand what it stands for. Now, we will talk about the spectral distribution of the sunshine.

And then the very important earth sun relationship. Because that will tell how much we are going to get on the earth and how we can enumerate them correctly ok. Then we will I mean for this whole thing what we will require is t he revolution and rotation of earth. Because that will come as a factor in this sun earth relationship, which is not a static thing it is a dynamic thing and we have to capture the dynamics ok.

Now, we will talk about the seasons and the position of the sun in the sky, if you look up what position you will see in the sky? And we will also need to put the same thing position of the sun with respect to the center of the earth. Because otherwise the position of the observer or wherever you are going to put your conversion technology there that that is going to change right.

You can do it in India, you can do it in some other country within India you can use different cities or rural areas. So, we have to have some fixed point with which you can generalize the principles of this sun of relationship and that reference point will be the center of that ok. So, that is what we are going to talk about in the first couple of lectures.

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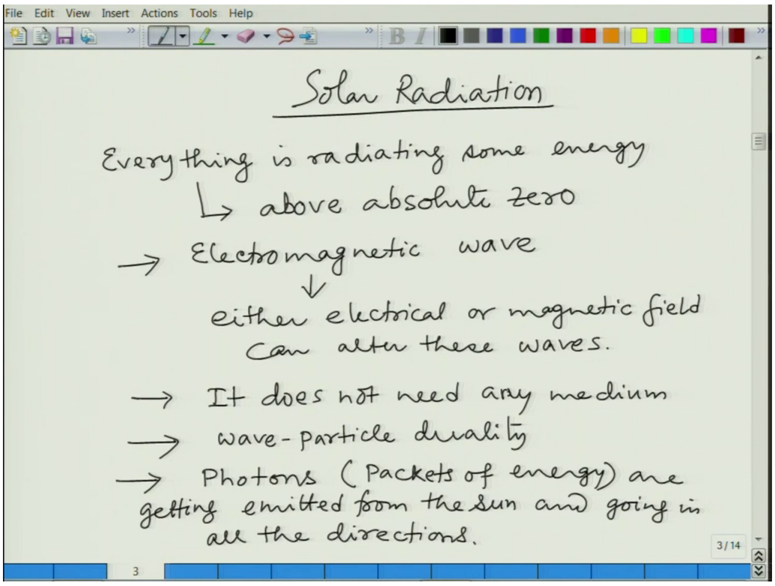

Now, first thing is what we said is the solar radiation that is the first thing we would like to understand ok. So, you can see the sun is the source of all forms of energy that we see on the face of earth right. So, understanding solar radiation is very fundamental in under sending life in general.

And for this particular course it is very fundamental because that is the source that we are going to harness and use it for our purpose to you have to convert it to some usable form of energy, either heat or electricity ok. So, that we can transport it and we can use it.

Now, so, whenever we talk about radiation, if you have some background, very basic background in heat transfer, you know that any anything whatever you look at whatever you can see, maybe where you are sitting you have a fan on top of your head, you have a pen in your hand. So, all these things, whatever you are seeing everything is actually radiating some energy, so that is the first principle we have to understand ,everything is radiating some energy.

Now, here is a catch you must have heard about the absolute zero temperature absolute zero right. So here what I said everything I should specify that everything above absolute zero. Then only the statement will be fully correct. So, everything above absolute zero is radiating some form of energy ok.

And what is the form of that energy? That is we call electromagnetic or we should call electromagnetic wave ok. So, all these energy that is getting radiated those are in the form of electromagnetic wave. So, why do you call it electromagnetic? Because these waves are affected by electrical or magnetic field ok; so, either electrical or magnetic field can alter these waves that is why we call it electromagnetic wave ok.

And the very interesting feature of these electromagnetic waves is that, it does not need any medium to be carried ok. It does not need any medium right. And that is why the solar radiation that is getting radiated from the sun is actually being able to reach our earth because there is nothing in between right. If you say that in more stringent terms, there is ether, but that is also construction that is a theoretical construction right. So, physically there is nothing there and even then the radiation is being carried to the earth.

So, that is why we need electromagnetic wave to actually reach; it does not need any medium. And how this solar radiation is happening? Actually, we can call these waves, so we know of these wave particle duality, right that is also I am assuming you heard of. So, what we can say about this electromagnetic wave which is coming through the coming in the form of solar radiation.

That is our, so we can talk about the photons, which are basically packets of energy as if they act like particles. So, this photons which are packets of energy those photons as if it is getting distributed or getting emanated from the sun and going equally in all directions.

So, photons are getting emitted from the sun and going in all the direction. And of course, those photons they do not know where earth is, where mars is or whatever? So, what they do? They do not have any bias; they are going equally in all directions.

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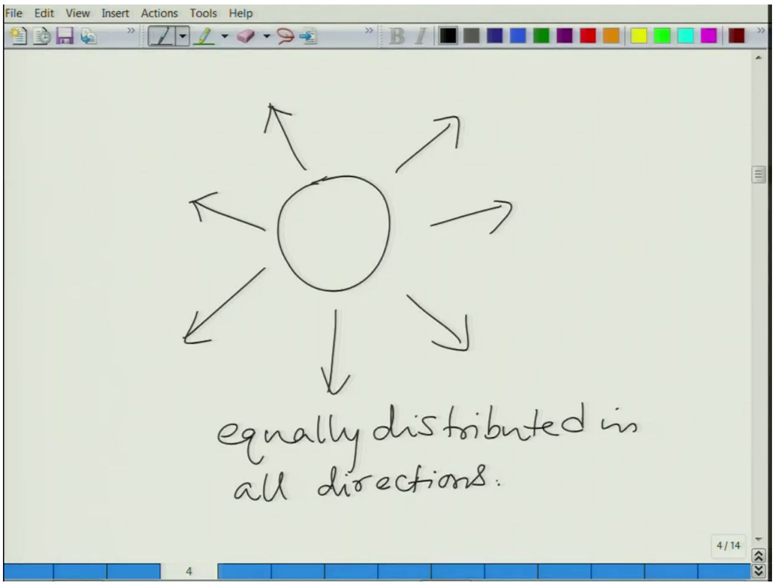

So, you can think of sun to be a sphere and these photons are going equally in all directions ok. So, basically what is happening? This is somewhat looks like a kids cartoon right when they first draw sun. And that is actually happening those are the you can think of you cannot see them, but you can think of the photons are going to be emanated just like this ok.

And they are going and they are equally distributed in all direction ok. Now, how much of that total energy that is getting emanated will actually reach earth we will see in a minute ok. Now, if we look at this energy, it is not these all these photons their packets of energy, but they have a distribution. They are not all of equal energy or they are not all of equal characteristic.

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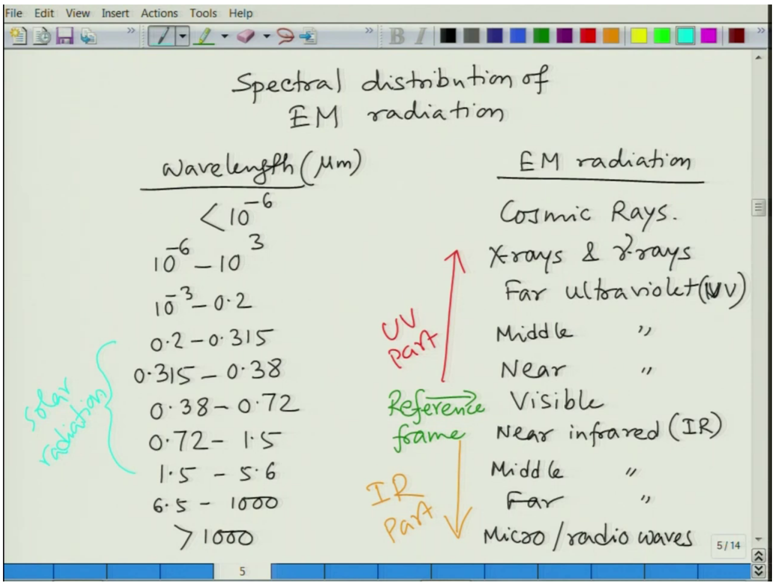

So, the characteristic of a wave is the wavelength right. So, we can find out or we can talk about the spectral distribution of this electromagnetic radiation. So, now I am taking a back step and I am taking talking about electromagnetic radiations in general term, not what is coming out of solar radiation we will talk about it in a while, but let us talk the whole spectrum of it in the most general term.

So, what we can see that we can write the wavelength in micrometer and we can write what kind of electromagnetic radiation it is. So, the most shortest wavelength electromagnetic radiations are called cosmic rays ok; which are coming from different cosmic bodies in space ok. Now, if we go to little higher range, then we will get x rays and gamma rays. These are also known to you from your basic physics knowledge.

Now, what we get in the next stage is the ultraviolet rays; an ultraviolet rays are also subdivided into few. So, first we get the far ultraviolet, then we get middle ultraviolet. And what is the range for that? This is the range for middle ultraviolet and what we call near these all names we have invented the humanity has invented it.

Because our reference frame is our eye right, whatever we can see as if that is the reference frame we fix and whatever is close to it we call near and then little far middle and all those things ok. But in nature, nature does not know which one is the reference frame. It does not have ok.

So in absolute scale, this naming convention does not mean much, but we can. Now, this is the most prominent electromagnetic radiation that we experience, everybody with eyesight they can see the visible light ok, but other than visible light all kinds of radiations are actually coming and going around you from different electronic gadgets from sun, even from stars, a nebula and everything and the visible light, that is what we see ok.

So, that ranges 0.38 to 0.72 micrometer. And beyond that what we have? 0.72 to 1.5 we call it near infrared. Infrared is often also called IR and this ultraviolets these are called UV ultraviolet. And beyond which we have middle infrared and far infrared and when the wavelength is very long we called it microwave or radio wave ok. Those also experience every day, but we do not see them.

So you can see here that this is our reference frame because we see that we experience that so vividly and I mean when the wavelength is smaller we cannot access them visually, but we get them ok. So, what we can see that the UV part that is the next to our reference frame and the when the wavelength goes above, we call it IR or infrared. Now, with this knowledge of spectrum, if we look at solar radiation where are we? Ok.

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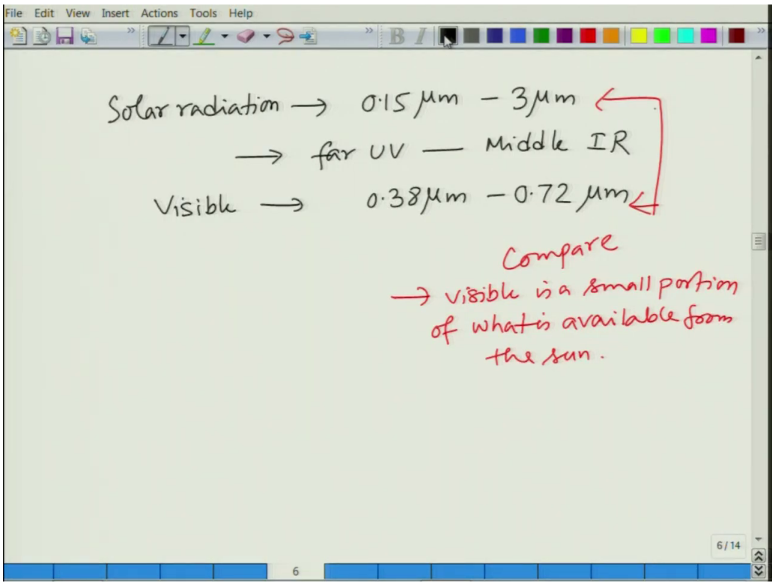

So, sorry so now if we look get solar radiation and look at the wavelength range of it that is 0.15 micrometer to 3 micrometer ok. So, if we go back and see 0.15 and 3, where are we? So, here, so we are in this range right, so we are in this range where solar radiation is obtained. So, a narrow range and centered around the visible light ok.

Now, so what we are? We are within far UV to middle IR ok. This is the solar radiation range that we are getting. And out of that, so, if you look at this range, then the visible range is 0.38

micrometer to 0.72 micrometer ok. So, if you compare these two range so if you compare these two, what we get is; that the visible is a small portion small portion of what is available from the sun; ok.

So, it seems that it is a very bright today that means lot of sun solar radiation is coming that is true, but there is more to that what we cannot see both in infrared range as well as in UV ultraviolet range, we cannot see the radiation which is beyond the visible light ok. So that is the whole point. Now, all these radiation let us go to the source now ok.

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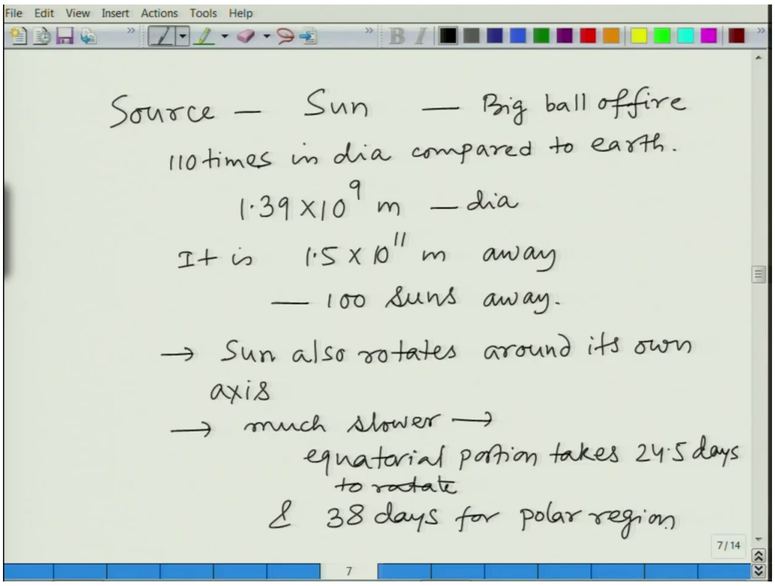

Now, source is sun ok; so we have understood somewhat about the range of solar radiation. Now, we will talk about the source of all these radiation. So, what is sun? It is a big ball of fire right that you know and it is about 110 times in dia compared to earth; ok.

So, yeah, it is a big ball of fire ok, so it is much much bigger. So, in terms of volume it will be cube of this 110 times only in the dia. So, what is the dia? The dia is 1.39 into 10 to the power 9 meter. That is the dia option and it is these many meters away 1.5 into 10 to the power 11 meter away from the earth. So, you can think of it as 100 suns away ok.

So, I mean I always stress on the intuition development. When you are learning you should focus on the intuition development because all these numbers, 1.39 into 10 to power 9 you are not going to remember after 2 years and you do not need to you can look whatever you can look up you do not need to remember that ok.

But the intuition that you develop that is it replaceable. You cannot look up your intuition. Whenever you think of a problem if you just want to know how big sun is, you have to know that is 110 times in dia, that number is easier to remember right. And how far it is; it is you can place 100 of suns in between sun and the earth ok. So, that is how your intuition develops.

So, whenever you think that I am going too fast you please pause the video and then you develop you think of yourself and you develop these intuitions. And everybody has his own method to develop it so I do not want to tell you that you have to find it out ok.

So, now, coming back to our source, the sun, it is like this and one small bit of information that you do not know maybe or some of you may know that son also rotates, rotates around its own axis just like earth, earth rotates that is why we get day and night, but sun also rotates its own axis. Now, and it is much slower that is all much slower. How much slower it takes?

So, now there is an interesting twist as well. While the earth rotates, all the portions rotate simultaneously right because it is a solid body, but sun is plasma or you at west you can think of as some gas or fluid right. So when it rotates, not all of it rotates simultaneously it is the equatorial portion of the sun rotates faster and the polar portion of the sun they rotate slower ok.

Does it make sense? Yeah so much slower of course, and the equator portion or equatorial portion takes about 24.5 days day here means our earth day 24.5 days it takes to rotate and the polar portion it take 38 days ok; so that is about sun.

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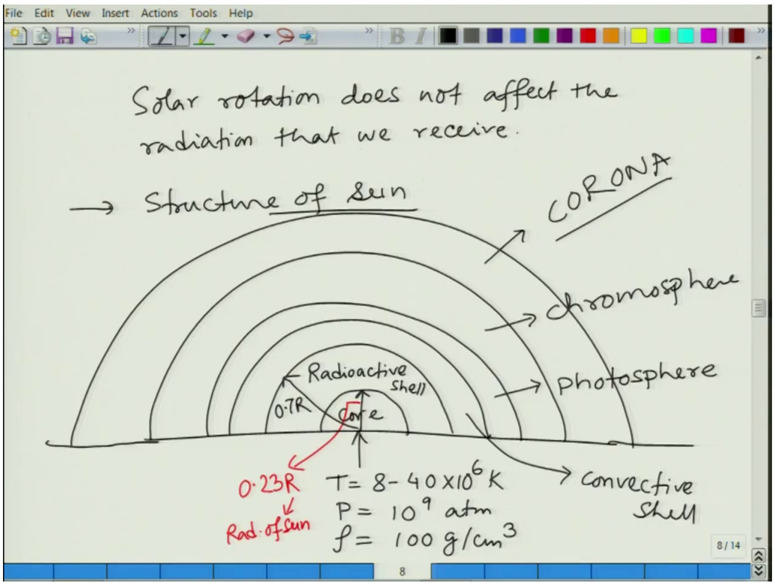

And this solar rotation we are not bothered much, because it does not affect the radiation that we receive ok. So, it does not affect the radiation and that is why we do not care about the solar rotation ok. Just a fact I wanted to share with you. Now, what matters is how that radiation is getting generated. Ok because that will tell us the spectrum of it and all other details so the structure of sun that matters.

So, if we look at the structure of the sun and let us not draw the whole circle, but we can draw it in a semicircle ok; so, the core of the sun is extremely high temperature, extremely high pressure right that you can just imagine and temperature here is about 8 to 40 into 10 to the power 6 Kelvin; very very high temperature and pressure here is 10 to the power 9 atmospheric ok again, extremely high pressure and densities also reasonably dense compared to any other portion of the sun ok.

So, that is the core of the sun and that core is defined to be about 0.23. So, this core we can talk 0.23 of R; R here is the radius of sun ok. So, 23 percent of the radius of sun is actually considered as core and beyond that all the interesting stuff that are happening we call it radioactive shell; we call it radioactive shell and that is about 0.7R.

So, up to 70 percent from 23 percent to 70 percent, we call radioactive shell. Then we have a convective shell and then we have photosphere, then we have chromosphere. I am not going to go into details ok, but it is good to have some idea of the source of the radiation that we are going to work with ok; and then at the outer boundary, which we actually see from the earth that is called corona ok.

And do not get scared by this name when I am recording this video it is still, the whole world is under lock down and other very severe restrictions people are scared of a virus name corona virus and I hope when we will when you look at this video the world got rid of this coronavirus, but the actual name comes from the sun ok.

So, actually the virus, if you look under the microscope it looks like something is radiating from a center and that is why it is called a coronavirus. But the name comes from the sun, which is the outer layer of sun is called corona ok. But all the structure of the sun is very interesting.

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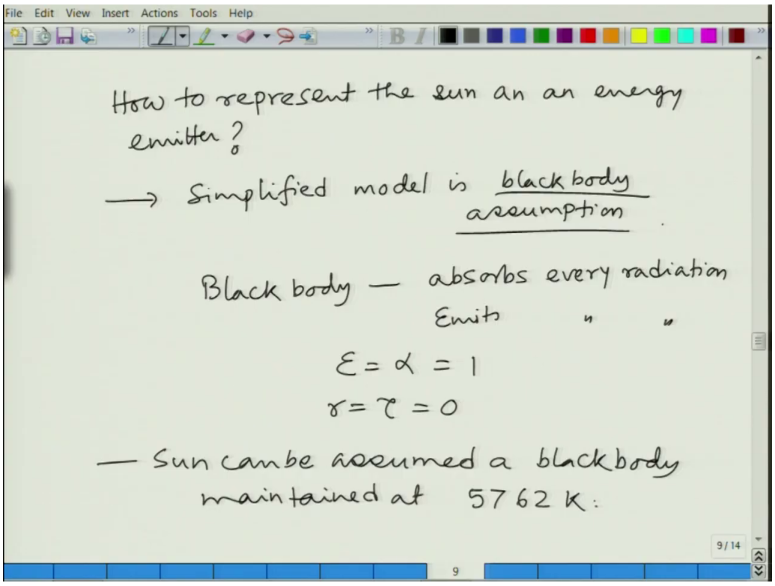

However, what it boils down to is how we are going to represent the sun as a source of energy. So, how to represent the sun as an energy emitter? Ok we cannot consider all these core, chromosphere, corona all these things we just simply cannot. We have to have very simplified model of sun and that simplified model is black body assumption ok. Again I am assuming that you have some basic understanding of radiative heat transfer. You are familiar with what a black body is.

So, black body is nothing but a idealistic assumption of any energy meter which does not have; so a black body it absorbs everything for every radiation and it emits every radiation that is what it calls I mean that is what it means what a black body is. So, basically, if you talk in terms of radiative heat transfer, the emissivity or absorptivity both of them is equal to 1 ok.

And the reflectivity or transmissivity all of them are 0. That is what a black body means, so this complicated structure of sun what we can do?

We can assume it to be a black body, so sun can be assumed a black body maintained at 5762 Kelvin ok. So, at this temperature, if you just replace the sun, you place a black body there at this particular temperature 5762 Kelvin then you will get the similar kind of radiation that we receive as solar radiation on earth ok. So, that is what it means.

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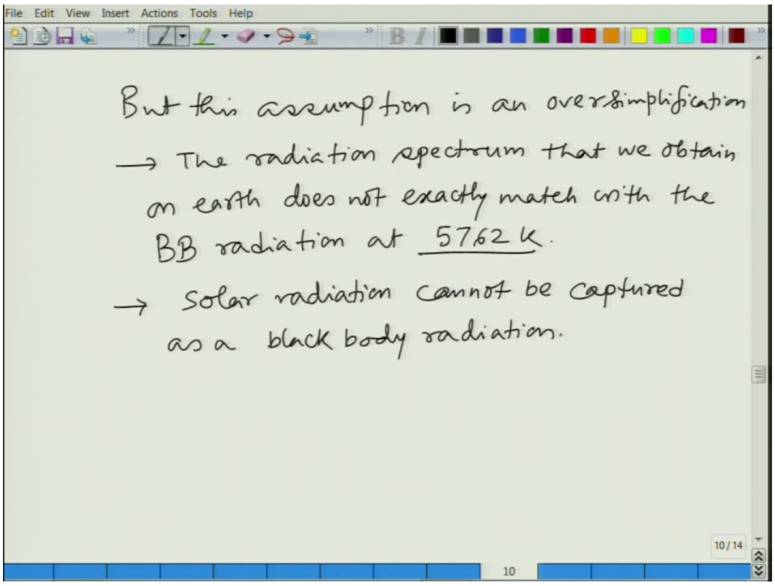

But again any assumption is but this assumption like any is and over simplification ok. Why I call it over simplification? Because the radiation spectrum that we obtain that we obtain on earth does not exactly match with the blackbody; I am just abbreviating that with BB black body radiation at 5762 Kelvin that does not exactly match, but it is a reasonably close assumption.

So, in science, what we do; we give start with a model and then slowly introduce complexities on that model. If we start to model the whole thing at a time, then we will never be able to do it. That is why we start with the closest model and then slowly introduce the complexities in it.

And actually any it is not about this temperature 5762 Kelvin is not the culprit. It is that the solar radiation cannot be captured as a black body radiation. Why all these things you have to go in much detail about solar physics, solar chemistry, how it is transferred and all those things which is beyond the scope of this course. So, let us stick to what do you observe rather than explaining it.

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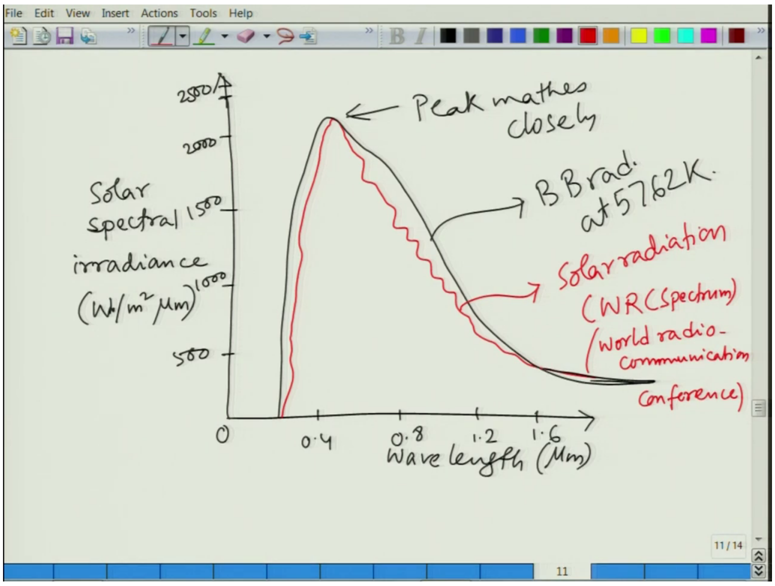

So, ultimately, what we get? What we get is; I will I mean this is not the figure is not to the scale just I want to give you some idea, where these lies. So, what we are plotting here? Here we are plotting wavelength in micrometer in the x axis and in the y axis we are plotting solar spectrum whether spectral irradiance and that is in watt per meter square micrometer.

So, basically what we get let me draw some numbers as well here it is 0.4, 0.8, 1.2, 1.6 and so on ok. So, the sorry I need to demarcate the 500, 1000, 1500 and then 2000 maybe 2500 here. So, let me draw the solar spectrum with the red one and it goes up to and you have lot of vehicles here and it comes down where the wavelength goes up for the infrared region ok.

Now, if we compare the solar spectrum with black body radiation at that 56 5762 it closely matches, you can say or it goes off. So again, at the infrared range it closely matches and in the other range it does not close, does not match exactly but it closely matches, particularly the peak value.

Peak matches closely for this is the black body radiation at 5762 Kelvin and this is the solar radiation and this is called this particular radiation we call it WRC spectrum; WRC stands for World Radio Communication conference.

So, it is a global body which designate that this is the standard solar spectrum because we will see that solar spectrum is also not a universal like invariant thing. It changes with many parameters where you measure, when you measure and all those things. So, we have to fix that this is the standard value so will take it from this particular monitoring body, world radio communication conference ok.

So, now, yeah, so this is the difference and also we will see that this particular solar radiation is not that what we get on the crus I mean crust of the earth. This is what we get beyond the atmosphere when the from the sun towards to the atmosphere at the end of the atmosphere, the radiation quality does not change ok.

And when we talk about the earth crust, where we actually see the solar radiation and we can actually harvest energy and all there is a significant difference. And that is what we are going to see in the next class. So, this is the basic the first class introduces you with the basics of the structure of the sun, basic of the solar radiation, how we can conveniently model it with some black body assumption and where it differs.

In the next class what we are going to see is the extraterrestrial radiation with respect to the on the crust or terrestrial radiation ok. With that I would like to thank you for your attention and see you in the next class.