Non-conventional Energy Resources
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Lecture - 10
Electromagnetic Radiation: The Solar Spectrum

In this class we are going to look at electromagnetic radiation in general and the solar spectrum in some detail.

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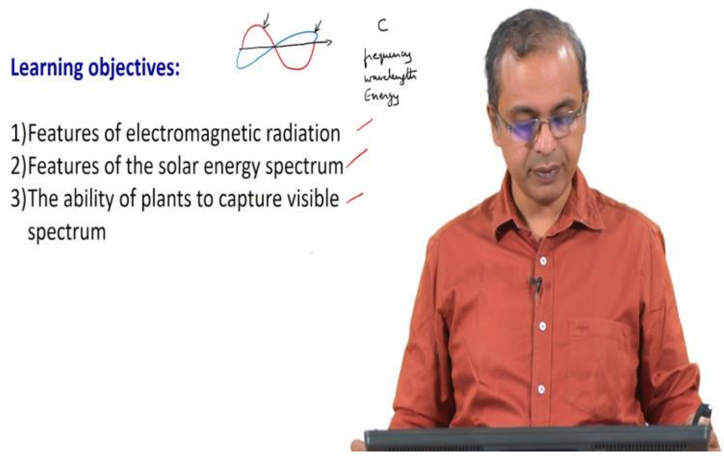

And our learning objectives for this class are we would like to look at some features of the electromagnetic radiation, and part of that is the visible spectrum, and in that context we would also look at the features of the solar energy spectrum and also we will look at the ability of plants to capture the visible spectrum. So, broadly in this context we will discuss the contents, that we will look at in this class electromagnetic spectrum in general it is the range of spectrum that we are used to.

In that where does the solar energy spectrum especially the visible spectrum where does it show up, and on top of it we will also get a better sense of the ability of plants to utilize this spectrum. So, we touch about the plants only in a very brief manner, just to tell get an sense of where how that is working out that you know we end up using how the plants seem to have a good ability to capture sunlight. So, that part we will look at very briefly, but the rest of it is where our focus will be. Well basically the electromagnetic spectrum consists of I mean it has been discussed quite extensively in physics over the years, and there is a wave nature to the electromagnetic spectrum there is also a particle nature to the electromagnetic spectrum.

So, in the wave kind of description of the electromagnetic radiation we see that it basically has a sinusoidal kind of wave and that would be the manner in which we get this electromagnetic radiation. And in fact, on a in a perpendicular plane we would also have a wave that goes like that, and this is therefore, if you look at this being the direction of propagation of the wave, then we basically have the electric field here and the magnetic field here, and that's how we get the electromagnetic spectrum. So, the electric field goes up and down, the magnetic field also goes in a sinusoidal way and they are mutually perpendicular to each other and that's how we get the electromagnetic spectrum. So, that's how the spectrum is, associated with the spectrum is a frequency and and of course, a wavelength and associated with this is energy.

So, these are the features that we are looking at we have electromagnetic radiation, it has energy associated with it, it has a frequency associated with it, it has wavelength associated with it. And basically we think of electromagnetic wave radiation as light, but light is actually what we think of as visible light is a part of the electromagnetic radiation, and all of it travels at the speed of light which is C. So, those are some of the features that we have to the electromagnetic radiation, and we will look at that in greater detail okay. So, that's what we will see as we proceed in this class ok.

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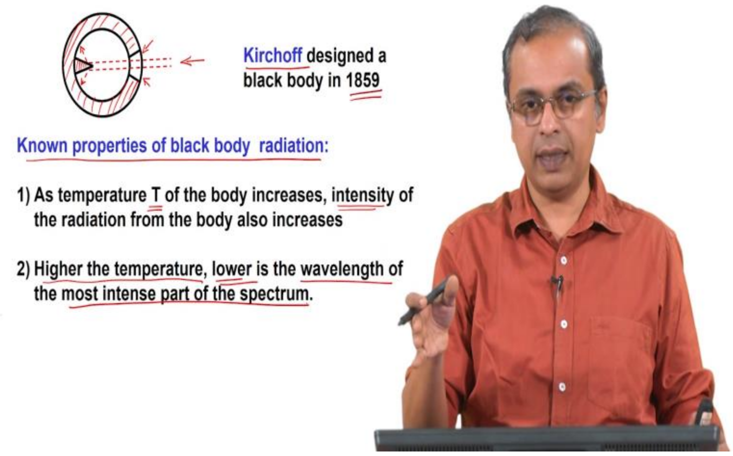

So, before we get into the details associated with the entire spectrum as such the; it is of interest to see how people studied the electromagnetic spectrum. So, for a while it was theorized there was a theory that you know that you could create something called a black body, which would absorb all radiation that falls on it.

If its if it's temperature is colder than the surrounding temperature, and if its temperature is higher than the surrounding temperature it will give out radiation across the entire spectrum of that is available in the electromagnetic region. So, this was mentioned and people discussed it and so on and people try to make a physical version of this object called the blackbody. Even though in theory they discussed that possibility of existence of such a body, it had been difficult for a while to make a body that gave this behavior.

That you know as if the temperature of the surroundings is high, it will absorb all radiation falling on it; and if the temperature of the surrounding is less then its own temperature it will give out radiation to the surrounding. So, in 1859 Kirchoff managed to design this blackbody and that's what we have since then this design has stuck as the one of the best ways of creating this blackbody. So, he had this chamber which is what you see here. So, this entire chamber that you see here, this is the wall of the chamber that I am shading here, and inside that there is a conical structure which is sitting in here this conical structure that is sitting in here and so, any and this is the opening. This is the opening that you see out here.

So, any radiation that comes into the body, goes and strikes this conical structure that you see inside, and then distributes across gets reflected off that structure and heads off into other parts of this spherical structure that is otherwise enclosed. This structure only has an opening in the front. So, much of any radiation that goes in simply get's stuck within the walls of the structure, and then eventually I mean essentially gets absorbed by the structure.

And then if the temperature of this body is higher than its surroundings, the exact opposite happens the body starts giving out radiation, that radiation all comes out through this opening that you see here and you are able to measure this radiation. So, this was the blackbody concept and that had been created and designed by Kirchoff who demonstrated it in 1859. So, that's been a while you are looking at over 150 years since this blackbody has been demonstrated.

And some properties of the blackbody were known, and those properties where that as the temperature of the body increases; temperature T of the body increases, intensity of the radiation coming from the body also increases okay. So, in some ways that is kind of intuitive you raise the temperature of the body, the radiation coming off of it has higher intensity. So so, this was known intensity of the body of the radiation coming off of the body also increases. Additional feature that was noted was that higher the temperature of the body, then lower is the wavelength okay lower is the wavelength of the most intense part of the spectrum. So, what it means is that, the spectrum if you look at spectrum means the range of wavelengths a and you are looking at intensity across the range of wavelengths.

So, if you look at this spectrum it shows that first of all it's not uniform it is not that at all wavelengths you are not getting exactly the same intensity, that's not how it seems to demonstrate itself. On the other hand you actually see well defined variation in intensity as a function of as a function of the wavelength. So, you see wavelengths at specific wavelengths you see a specific intensity of this blackbody radiation, and it has certain shape associated with it.

Regardless of the temperature, the general shape looks the same the temperature simply decides how much at what frequency you are getting the maximum of that shape and also what is the sort of the area under that curve. So, this these are a few things that we get to see, but anyway. So, the point being as the temperature T of the body increases the intensity of the radiation coming from the body also increases, and as the temperature goes to a higher value the wavelength at which the highest intensity is seen is moves to a lower value. So, as the temperature goes up wavelength goes down at which you see the most intense part of the radiation.

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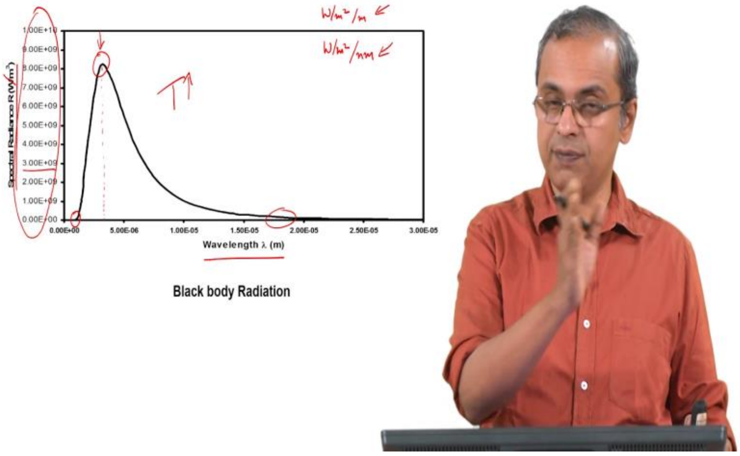

So, this was done and. So, you can see here one of the calculated you know blackbody radiation spectrum that you can see, and you can see here wavelength in meters, listed here in meters and something called spectral radiance, which is watts per meter square per meter okay. So, it’s the watts per meter square per meter, and so, it shows up here as watt per meter cube.

So, there is a per meter cube there, watt per meter cube. So, watt per meter square per meter which is watt per meter cube. So, that’s basically what you see here and so, it’s actually watts per meter square per wavelength, that’s per unit wavelength that’s basically what you are seeing and that’s why the per meter square per meter comes. So, it is actually watts per meter square, which is intensity and then this intensity at a specific wavelength.

So, per meter for every delta meter of wavelength what is that intensity that’s coming out. So, that is how you get this unit watt per meter square per meter, and we will see in some of our subsequent plots this it is convenient to stick to watts per meter square for the intensity, but the wavelength since many times they are presenting the wavelength in nanometers so you may see nanometer. So, you will therefore, see the values here look different based on which plot I am showing you, and in by or by several orders of magnitude. You can already see here its a 10 power 9 kind of value there. So, you can see that that those numbers are going to change significantly, and that's got to do with the fact that you may shift from a meter to a meter value here to a nanometer value here. So, that's the reason you will see some difference. In addition the values would themselves change based on the exact temperature T, at which this radiation is being recorded right.

So, these are all some of the features, and as you can see first all the shape of this curve is something that is not flat meaning, I am not seeing let's say let us take a value of 3 into 10 power 9, I am not basically seeing flat line at 3 into 10 power 9. I don't see for example, that at all wavelengths I will get 3 into 10 power 9 watts per meter cube that's not what you are seeing instead you see some variation you see that it starts of low here it goes to some high value here and it comes back to a low value here. So, that's sort of the variation that we see. And this is the region where you are getting the maximum intensity, so corresponding to that there is a wavelength. So, corresponding to that I can identify a wavelength or I can indicate a wavelength. So, this is what we meant.

When I said that you know if the temperature of the body goes up, if the temperature increases then the area under this curve goes up and in addition this wavelength at which the highest most intense part of this radiation shows up shifts to a lower value okay. So, with these in mind I will just show you one more plot here.

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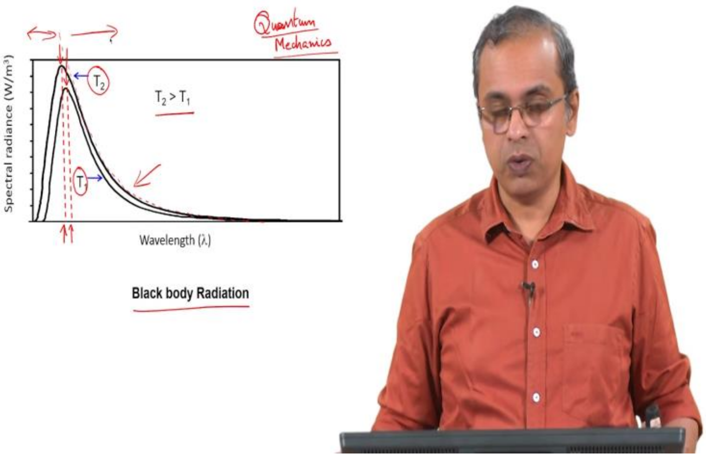

You can see here again watts per meter cube, and I have just shown that schematically. I am I am taking 2 temperatures here T 2 and T 1, and in this case T 2 is greater than T 1 and you can see that since T 2 is greater, the curve corresponding to T 2 which is this curve that you see here marked with this blue arrow corresponding to the value T 2, is actually a curve where the area under that curve is larger than the area under the curve corresponding to T 1 right. So, area of the curve corresponding to the value T 2 is larger than the area under the curve corresponding to the value T 1.

In addition the wavelength at which you see the maximum intensity wavelength at which you see the maximum intensity for the temperature T 2 is lower than the wavelength, where you see the maximum intensity for the value T 1 right. So, that is again consistent with the fact that T 2 is greater than T 1. Since T 2 is greater than T 1, the you are seeing that the temperature at which this is happening is different.

I mean the temperature is different and therefore, the wavelength at which this is happening is different. You are seeing the most intense part of the T 2 curve being at a lower value of the wavelength corresponding to the T 1 curve. So, these are the features and as I said this is the blackbody radiation. So, now, actually there are couple of comments I want to make about this radiation before I move on to looking at our own the solar distribution so, to speak.

This blackbody radiation that you just saw is a very important phenomenon, which has impacted greatly impacted the development of science and physics of the world. And the entire field of quantum mechanics entire field of quantum mechanics came from an analysis of this radiation. This exact curve that you are seeing on your screen, this basically this curve of it depends on which temperature it was looked at, but the analysis of this curve is what led to the creation of quantum mechanics or the discovery of quantum mechanics, the discovery of quantum mechanics as a field of science that existed within physics.

This happened around the year 1900 up until that point people were not aware of quantum mechanics and we or whatever physics, we knew up until then is today referred to as classical physics and quantum mechanics dramatically changed the way in which people looked at science, people looked at the you know interaction between matter and energy. That interaction was dramatically changed by the understanding of quantum mechanics.

An understanding of quantum mechanics comes directly by the analysis of this curve, for a long time people did not have any proper theory, which would give a good fit to this curve. So, normally they would come up with a theory and as per the theory you can you write some equations. Those equations then correspond to what that theory represents in a mathematical sense from the perspective of the physics of that theory. Now once you write those equations using those equations, you should be able to theoretically generate this curve that you are seeing on your screen.

You should be able to theoretically generate this curve. If you theoretically generate this curve across the entire set of wavelengths that you see here, you should be able to match this curve. Your theoretical curve should match this experimental curve across this entire set of wavelengths. Generally it was seen that it would match for certain set of wavelengths. So, you would see a match like this, but you would not see a match in this region okay. So, you would not see a match in this region, you would only see a match in this in the region this side. And for a long time people were stuck with those theories and used to think that with some minor modification, they would be able to get it to match the entire spectrum, but they were not able to do so.

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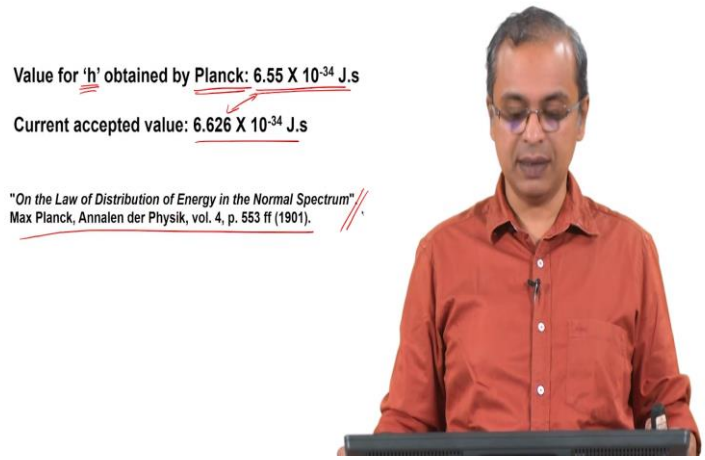

And the first person who managed to do it was Planck. So, he came up with another theory, where he needed to use a constant. So, he used a constant called which he named as h.

And at that time he was trying to make it match he didn't know what the value of h was. He needed a constant, he used a value h I mean used a he represented it that constant with the value h with the indicator h and then he changed the value of h till he got his theory to match that curve. And when he did so, he found that for a value of 6.55 into 10 power minus 34 joule seconds, for that value of this constant h he got his theory to exactly match this blackbody radiation. And that match and the discovery of this constant h which is now referred to as the Planck constant is the origin of the field of quantum mechanics. It required that you know some behavior was expected of that body, and that behavior was being reflected by this constant h. The current value accepted value is 6.6 to 6 into 10 power minus 34 joule second it is only marginally different from what value he had come up with.

And this reference that I am showing you here is that original journal article in 1901 it is a very celebrated article, because an entire field of science started with this journal article that you see here, its considered of considered a phenomenal paper. Even today many aspects of the understanding of the universe, come down to this understanding of the quantum mechanical concepts and the application of quantum mechanical concepts under a wide range of conditions. So, therefore, this is considered a very phenomenal accomplishment very phenomenal discovery and it is of interest from that perspective.

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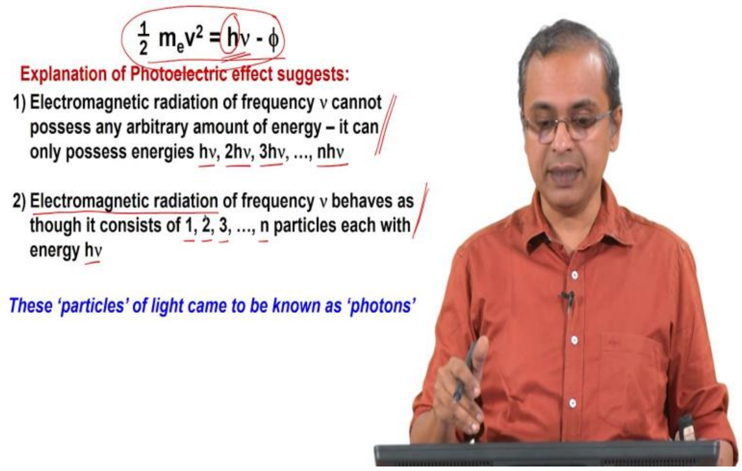

And incidentally that was also responsible for explaining the photoelectric effect, and it is of relevance to us because we are basically going to look at use electromagnetic radiation. For a variety of applications and those electro electromagnetic radiation waves that we are talking of have these properties.

So, we it does have this photoelectric effect, which is credited this discovery of this photoelectric effect or the explanation for the photoelectric effect is credited to Einstein, who basically used the quantum mechanical principle, where he uses this constant h, in this equation as h nu as the energy that corresponds to a photon which has a frequency nu.

So, he basically said that electromagnetic radiation of frequency nu cannot possess any arbitrary amount of energy it can only possess energy. So, in quantities that are h nu or 2 h nu or 3 h nu or n h nu. So, it behaves as though it consists of 1 2 or 3 etcetera or n particles each with energy h nu. So, that is why you get 1 h nu, 2 h nu, 3 h nu etcetera and n h nu. So, it looks like it consists of particles which are 1 2 3 4 any number of particles you can pick each particle has an energy h nu. So, if there are 25 particles it is 25 h nu.

So, this behavior was what was useful as an explanation for explaining the photoelectric effect. And this is credited to Einstein, and he is extended the idea that Planck had put forth as the you know through his Planck's constant, which he basically got from understanding the blackbody radiation. And this idea that electromagnetic radiation which I showed you as a wave, I showed you that an electric wave and a magnetic wave which are you know mutually perpendicular.

That the idea that such a wave concept could also be represented using particles is what this photoelectric effect is effectively demonstrated or was capable of ended up demonstrating to us, and these particles of light came to be known as photons. So, these particle behaviors of light even though we also think of it as waves, when it shows when there are experiments where it is showing you the particle behavior of the light or where the experiment is more easy to explain using the particle behavior, which we are attributing to light. Then there that particle like behavior of those of light and the particles that correspond to that light are being referred to as photons okay. So, that is the idea that was put together by Einstein.

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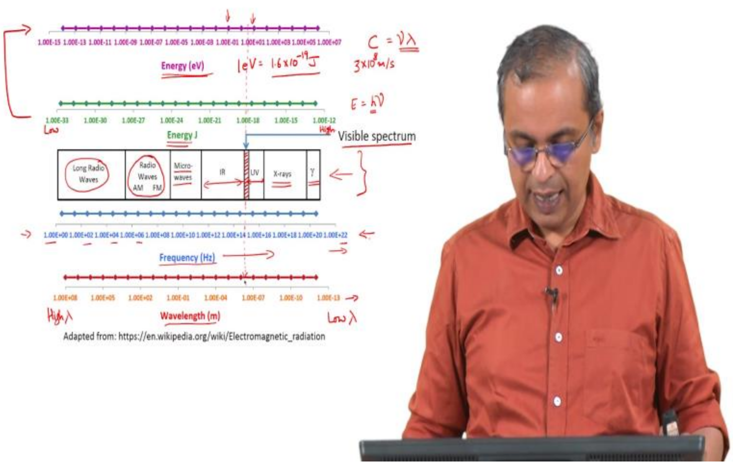

So, with that background we will now look at the overall electromagnetic spectrum, and get a sense of where is the solar energy and what is the visible spectrum etcetera. So, now, if you see here I have actually something in the middle here, which actually lists a bunch of names which you may be familiar with. And I have 4 different axis here marked; one is wavelength which I have got here, I have got frequency, I have got energy in joules, and I have got energy in electron volts okay.

So, I have got 4 different axis here and I will briefly talk about them. It is of interest actually to step back and understand the fact that electromagnetic radiation has given us a lot of insight about when many things surround us. Not just on the planet not just in our sun, but basically in stars millions of light years away okay. So, simply today if you go and look in the internet or you look up some you know journal resources etcetera where they talk of say a composition of a star. They will talk about you know the composition of a star that is say 100 light year 100 million light years from here okay a million light years from here 10 million light years from 100 million light years from here something that is really far away, they will tell you what the composition is. How do you do this I mean how is it possible we where you no position to go pick up a sample from that sample from that star right.

So, that’s just not possible. It becomes possible simply by looking at the electromagnetic radiation coming from that star, that’s all you have to do you have to just it is already giving out the signal of what what is present inside it; we simply have to gather that signal analyze the signal and tell what is present inside it. So, in this context the rays refer to as x - rays become very useful to us at very high temperatures.

X rays can be generated in a variety of different ways at very high temperatures bodies will give out x rays. So, when you are looking at you know tens of thousands or hundreds of thousands of degrees centigrade or even millions of degrees centigrade, which is there in many of the stars at those temperatures the atoms present inside those stars are giving out their characteristic x-rays and so, simply by looking at the x - rays coming off of the star, it is possible to tell the composition of the star, even though it is like say 100 million light years from us okay.

So, such a phenomenal understanding of the universe around us is possible by understanding some basic concept of what is happening when the temperature is raised, and what is the radiation that’s coming of the body as the temperature is raised. So, then those are the kinds of insights that you get when you understand the spectrum, and that’s the reason why I would like to spend a little while explaining the spectrum to you, and then we will look at the more you know prominent aspects associated with the solar radiation. So, we have here on the axis here which is the frequency, a range of frequency. So, we have from about this is in hertz. So, we have 1 hertz here. So, then we have 100 hertz, this is you know 10 power 4, 10 power 6 and so on till 10 power 22. 10 power 22 hertz is the range of frequencies that you see here and corresponding to this. So, at all these frequencies you can have electromagnetic radiation okay.

So this is the range of frequencies you are starting at low frequencies at this end and high frequencies at this end. So, frequency is increasing in this direction okay. So, frequency is increasing in this direction, you have low frequency on your left and then it steadily increases to high frequency on your right. So, if you look at the range of frequencies that is represented in this scale here, you find at the lowest of the frequencies that I am mentioning in this image we have what we refer to as long radio waves. That’s what you see here, these are long radio waves, and then if you come to little higher frequencies you get the radio waves that we traditionally use, and there you have the AM and the FM and the FM is at a slightly higher frequency. So, you have AM and FM sort of showing up there then we have microwaves. So, this is what we are using in our ovens microwave ovens. So, that’s the frequency range of it.

Then comes Infrared. So, Infrared the range of speaker frequencies that are referred to as Infrared, and then a narrow band here, this narrow band of the electromagnetic spectrum is your visible spectrum, so this is a very narrow band of your electromagnetic spectrum and that is your visible spectrum, beyond that comes the ultraviolet and then comes the if you go to even higher frequencies you get x rays, and even higher frequencies you get gamma rays okay. So, this is the range of frequencies. So, essentially you see electromagnetic radiation that’s you know continuous series of frequencies, just by nature of the property of those radiation, what it does, how it interacts with matter, what in effects can you see from it, how are we responding to this radiation, keeping all this in mind you have all these names given to it and how we utilize those waves. We use it for radio waves.

So, we call it rate I mean. So, those waves are then then referred to as radio waves and so on and so, keeping certain attributes of the radiation as well as attributes of how we use the radiation together, we have given some names and that’s all these names that you see here long radio waves, a radio waves, microwaves, are infrared, visible, ultraviolet, x rays and gamma rays okay, and this is a range of frequency that is increasing from your left to right. Now if you look at the relationship given that this is all electromagnetic radiation, this is all traveling at the speed of light which is C okay. So, it is traveling at the speed of light c which is 3 into 10 power 8 meters per second.

So, the this is equal to nu lambda, where nu is the frequency and lambda is the a wavelength right. So, if you see here, you can see here this is wavelength in meters. So, this is wavelength in meters and this is frequency in in hertz right. So, if you multiply these 2, you should get this speed of light which is what you see here and basically this is what we see and that's how this axis that you see here marked as frequency, relates to the axis that's marked as the wavelength in meters. And as you can see here as the frequency since the product is a constant as the frequency increases the wavelength decreases right because the product is a constant and so, the wavelength at this end is low.

This is wavelength lambda low lambda and this is high lambda okay. So, that is the way you see the wavelength axis marked. Similarly I have 2 other axes here both of which are energy, and energy is related to the frequency as E equals h nu, where h is the plancks constant that we just saw which is 6.626 into 10 power 30 minus 34 joules second. So, h nu. So, this is a constant. So, as the frequency increases the energy increases right because the h is a constant here. So, as frequency increases h increases I am sorry the energy increases as energy increases the frequency increases. So, you can see here, the with increasing frequencies that you see which goes from left to right of your screen the energy also starts off at low values of energy here as 10 power minus 33, and then goes up to 10 power minus 12 okay.

This is in joules in of energy going from 10 power minus 33 joules to 10 power minus 12 joules right. And an electron volt is a joule and the if you want it in an electron volt is 1.6 into 10 to power minus 19 joules. So, one electron volt is 1.6 into 10 to the power minus 19 joules okay. So, it's the charge of an electron 1.6 into 10 to power minus 19 coulombs. So, a coulomb volt is a joule. So, 1.6 into 10 to power minus 19 coulombs is the charge of an electron into 1 volt. So, that combination gives you 1.6 into 10 power minus 19 joules.

So, if you use that constant, you can convert this axis that you see here in which is in joules to this axis which you see here which is an electron volts. Using this relationship that one electron volt is 1.6 into 10 power minus 19 joules. So, with these kinds of relationships, you essentially have the same spectrum here. So, in the middle is the spectrum here, the spectrum that you see out here that is the spectrum that is their common across all of these axis, you simply have the same spectrum being explained to you as a range of frequencies or as a range of wavelengths as a range of energies in joules and as a range of energies in electron volts. So, this is what you see in this plot that you have got in front of you. Arrange of values across different different you know variables that you can look at to explain this spectrum. As I said a very small fraction of it is the visible spectrum and so, you can see that you know even though we see a rich range of colors you know violet, indigo, the entire VIBGYOR range of colors going all the way up to red from violet to red.

In the grand scheme of all the you know electromagnetic radiation that is out there that's a very small fraction of the spectrum. So, incidentally I mean we all give out as I mentioned in our discussion about blackbody radiation, at any temperature bodies are giving out radiation right. So, even we as human beings or any animal that is out there is also giving out radiation corresponding to its body temperature; for example, we are all giving out infrared radiation alright.

So, that's why if you look at the military applications they have these things called infrared goggles. So, they wear infrared goggles in the night, and that is what they also refer to as nighttime vision goggles. So, in that they have sensors which are sensitive to infrared radiation. So, in the night if there is some person that is walking, just because of the heat of their body they are giving out infrared radiation and there are sensors on this glass, which are sensitive to that infrared radiation they convert that to some visible color, that your eye is able to then see.

And that is how we were able to see that there is a person in front of you even though otherwise there is no no light in that area its pitch black you are still able to see this person standing in front of you at some distance. So, therefore, we all give out radiation. So, this blackbody radiation is not an you know an esoteric concept, it's not some theoretical concept, that you know you wonder why you are learning.

It's a real thing, were all giving out that radiation, the radiation that is coming off of us corresponds to blackbody radiation coming from stars corresponds to blackbody radiation, and interestingly radiation of the background of the universe people have found out the temperature of the background of the universe which means what? It is the temperature of the empty space, that is there all around us in the universe right that that we presently think of as the empty space that is there between the stars that is where there between the galaxies etcetera. That empty space has some temperature associated with it, it is not at 0 Kelvin it turns out that it is around 2 to 3 degrees Kelvin. Somewhere in that temperature range is what the background temperature of the universe is, which means that in under natural circumstances this is due to radiation that is there in the the space, due to the formation of the universe from the time of the formation of the universe.

So, the theory is that the universe has been cooling since then and some background radiation is still there, that gives you this background temperature. And it means that nowhere in the universe you can naturally get a temperature less than this. This is the minimum temperature that is there in the universe, at any place in the universe. So, naturally you will never see a temperature lower than this. If you ever see a temperature lower than this at any location, it means it has been artificially created, it means some intelligent life created it.

So, this is the way you know this is a very fascinating concept, you it does not seem like much it's just radiation it's a spectrum. But when you understand the significance of the spectrum you understand the features of the spectrum, and then you understand you know what would happen if you went to one extreme of the spectrum to the other extreme of the spectrum, what does the spectrum represent, and what can you infer from what the spectrum reference represents, then you find all these interesting concepts. You can learn about the universe, you can learn about stars, you can learn about the empty space between all the stars and galaxies, and you also know can have a you have the possibility of learning about intelligent life, if you ever discover something that is colder than this right.

So in fact, in the labs these days it is possible to reach temperatures lower than this 2.75 degree Kelvin or something else, much you can go much lower than that in labs. But the point is those are temperatures that are not naturally present anywhere in the universe. So, that is a phenomenal accomplishment, imagine that in your lab you have a small setup which does something, and you can say with confidence that this what you are just now seeing in this lab does not exist naturally anywhere in the universe okay.

Okay so, that is not even though you have never been to the rest of the universe. So, you can say that with confidence simply because of this understanding of the background temperature of the universe, which has got directly to do with the fact that background spectrum is consistent with blackbody radiation, and they are able to tell what is the temperature of the background, simply based on this blackbody radiation behavior okay.

So, this is the spectrum, you can see here as I said this is the visible part of the spectrum. So, just for you to get an idea of you know what values you are looking at here, if I extend this up here. So, you are looking at less than 10 electron volts right. So, this is 10 electron volts, this point here is 10 electron volts, this point here is 0.1 electron volts right. So, if you look at this you are somewhere below 10 electron volts is the energy corresponding to this, and in terms of wavelength if you just go down here, you are looking at a value that is around there. So, it is little higher than 10 power minus 7 in meters.

So, it’s more like 10 power minus 6 or in that range between 10 power minus 7, 10 power minus 6 and. In fact, that’s what it is. It is less than a micron 0.4 to 0.7 microns is what you are looking at as the wavelength of visible light. So, wavelength of visible right is somewhere in the 0.4 to 0.7 microns or 400 to 700 nanometers, and its energy is around less than 10 electron volts is what you are looking at.

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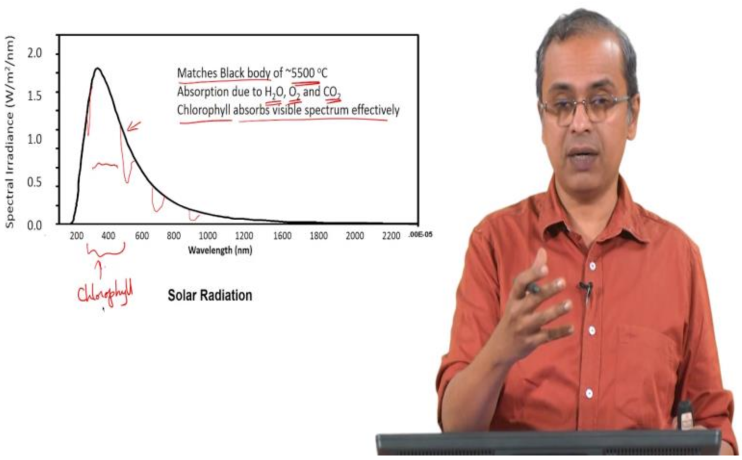

And more specifically you will see that we will look at those 2 values in just a moment, but what I wanted to also highlight is the fact that the solar radiation, the radiation that's coming from the sun which has this you know range of spectrum, but the visible spectrum is what we tend to see the most. Has a set of features for its you know spectral distribution, which matches that of a black body of temperature roughly about 5500 degrees C that is the temperature of the surface of the sun.

So, what you see as the surface of the sun has a temperature of about 5500 degrees C and so, corresponding to that you have the blackbody radiation that I am just showing you here this curve that you see here and so, the radiation from the sun that reaches the outer reaches of the atmosphere. So, if you come to the earth's atmosphere and then you cross that earth's atmosphere, let's say you are more than I say 12 kilometers above the surface of the something like 20 kilometers above the surface of the earth.

So, there were about 80-90 percent of the atmosphere is now below, you are very little of the atmosphere is above you. At that point the radiation that's reaching the earth has the spectrum that you are seeing on your screen okay. So, so that is the spectrum you see and that is blackbody radiation spectrum corresponding to a temperature of that body sitting at a temperature of 5500 degrees centigrade. So, that's. So, therefore, this is a very beautiful aspect of the science than physics that people have discovered, that you can say so much about the sun by just looking at the spectrum right.

So, now that is at the outer part of our atmosphere. From there the radiation has to penetrate through the atmosphere and reach the surface of the earth. Now as it penetrates through, you have various gases in the atmosphere you have water, water vapor, in the form of you know water vapor, moisture, clouds and everything that is there, we have oxygen and we have CO_2 and so, the range of gases that are present, these are some prominent gases that are present. So, these will absorb radiation.

So, they have some natural frequencies at which they absorb radiation, corresponding to various vibrational frequencies of the molecules that are present. So, they absorb this radiation. So, what reaches the surface of the earth is a slightly modified version of the curve that that you see on your screen, because this is what reaches the upper surface of the atmosphere, and as it comes through at specific wavelengths you have absorption.

So, at specific wavelengths you will see a drop in intensity, this is just a schematic that I am showing you here. So, corresponding to this you will have some drops in frequency and these correspond to I am sorry a drop in intensity. So, these correspond to absorption that is occurring at those frequencies, due to the gases that are present. Due to the various gases that are present in the atmosphere, you see absorption occurring at specific frequencies. So, when you are at the surface of the earth, at those frequencies you don’t have enough intensity.

Those frequencies have been taken away by the absorption phenomena that are occurring between the surface of the earth and the upper surface of our atmosphere okay. So, that is how this happens, and we also find that interestingly chlorophyll which is there in our plants has an absorption spectrum which sort of has a you know some features in this region. So, it is able to actually able to absorb very well in this region of frequency. So, chlorophyll absorbs very well, absorbs very well in this frequency range and so, it’s something that has evolved in nature in the plants, in the leaves of our plants, that has a very good absorption spectrum in the range of the visible light.

And since it has evolved that way it is able to do a great job of capturing the sunlight that is coming in, and carrying out the photosynthesis process right. So, that is how the plants are interacting with the sunlight that is coming in. Because they have this pigment in them which has an absorption in occurring in the right set of frequencies, which correspond very nicely with the spectrum coming from the sun okay. So, you can see therefore, a fair bit of the solar spectrum is in the visible range, but you actually have quite a bit in the infrared and the ultraviolet range also so in fact, you will see later that a fair bit is available in the infrared.

So, if you only capture the visible spectrum, we are not doing enough justice to the solar spectrum, significant part is available in the infrared and the chlorophyll that exists naturally in plants is doing a good job of capturing this sunlight because of the absorption spectrum and how it relates to the spectrum coming from the sun okay. So, that’s that’s the reason why it was of interest and that’s the reason why I have spent this you know some time in this class, looking at the solar spectrum looking at electromagnetic radiation in general and solar spectrum in particular. Because it tells us a lot about what is happening in our nature, what is possible from our perspective when we try to make devices that are trying to take advantage of the solar spectrum?

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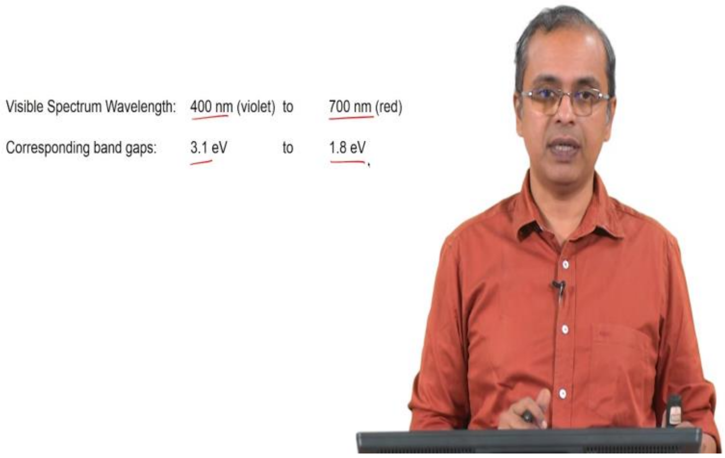

So in fact, as I just pointed out when we looked at that spectrum our visible spectrum ranges from 400 nanometers to 700 nanometers, which is what you saw in that plot that I just showed you, and the corresponding band gaps are about 3.8 3.1 to 1.8 electron volts. So, these are some you know parameters that we should be aware of. Again when we utilize these parameters I will again draw your attention to these values. So, that there is continuity and we did make that discussion, but this is the sort of range of values that we are looking at for the spectrum and so when we try to capture it, we have to be aware that our ability to capture should be good in this range, and that's the point that we need to bear in mind.

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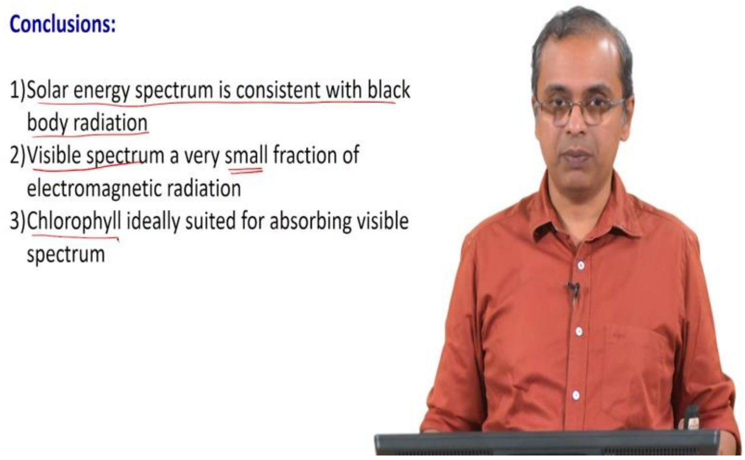

So, in conclusion we have seen looked at the solar energy spectrum, and we see that it is consistent with blackbody radiation kind of behavior; we have looked at electromagnetic spectrum in general. The solar spectrum in particular, we also see that the visible spectrum, it's a very small fraction of the electromagnetic spectrum.

So, you have very large electromagnetic spectrum, wide range of things are happening in that electromagnetic spectrum, and we utilize various parts of this electromagnetic spectrum fairly routinely, for various you know activities that we do have, for various technologies that we use we are using this electromagnetic spectrum. The visible spectrum is a very small fraction of this overall electromagnetic spectrum. In fact, in the entire diagram that I drew is a very thin region was the visible spectrum.

There is so much in other parts of the spectrum, and we also found that you know it so happens that the chlorophyll that is there in the plants is ideally suited for absorbing the visible spectrum and therefore, does a great job of capturing solar energy doing photosynthesis and creating you know the food that we are able to utilize okay. So, with these comments I would like to conclude this class, where we have looked at the electromagnetic spectrum in general, and the solar energy spectrum in particular.

Thank you.

KEYWORDS:

Electromagnetic Radiation; Solar Spectrum; Black Body; Spectral Radiance; Wavelength; Black body Radiation; Planck Constant; Photoelectric Effect; Photons; Particle nature of light; Wave nature of light; Solar Energy; Visible Spectrum; Wavelength; Frequency; Composition of Stars; X – Rays; Long Radio Waves; AM; FM; Microwaves; Infrared; Ultraviolet; Gamma Rays; Radio Waves; Speed of Light; VIBYOR; Infrared Goggles; Chlorophyll; Photosynthesis

LECTURE:

This lecture illustrates the Electromagnetic spectrum in general and in particular about Solar Spectrum & visible spectrum. The Electromagnetic spectrum is explained as a range of frequencies, as a range of wavelengths, as a range of energies in joules and as a range of energies in electron volts. The Solar spectrum is equated to and is consistent with blackbody radiation kind of behavior. The relation between Temperature and wavelength is explained in this context.