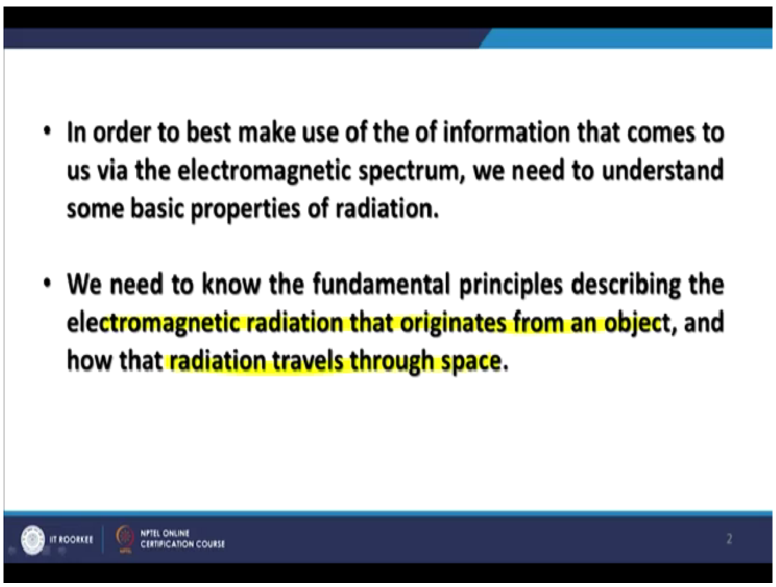
Remote Sensing Essentials
Prof. Arun K. Saraf
Department of Earth Sciences
Indian Institute of Technology-Roorkee

Lecture-06
Laws of Radiation and Their Relevance in Remote Sensing

Hello everyone and welcome to a new discussion which is own laws of radiation and their relevance in remote sensing. And as you know that every whatever the big propagation is there of EM waves which follows certain laws or this is how the understanding has been developed. So, whatever is you know in different parts of EM spectrum, whatever the waves are coming.

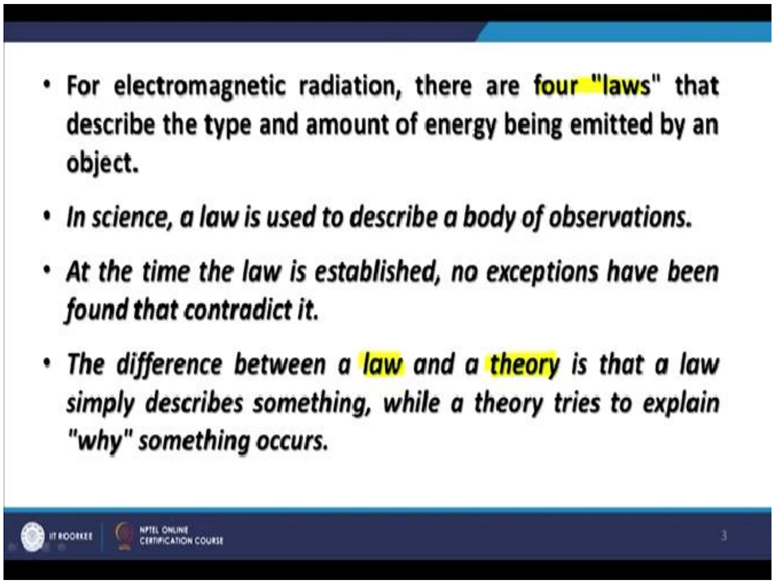
(Refer Slide Time: 00:56)



And they are having some basic properties of radiation and we need to know all these fundamental principles which governs this electromagnetic radiation basically that originated either from an object or from sun and how it travels through. So, the main focus here is like the EM spectrum or EM radiation that originate from an object because after interacting with the solar light or solar illumination, then the behavior of the object will depend of course, on different part of the EM spectrum.

But then how it originates one after the interaction and how it traveled through the space to reach that satellite based sensors. That is what is more important and this is what we are going to discuss.

(Refer Slide Time: 01:54)

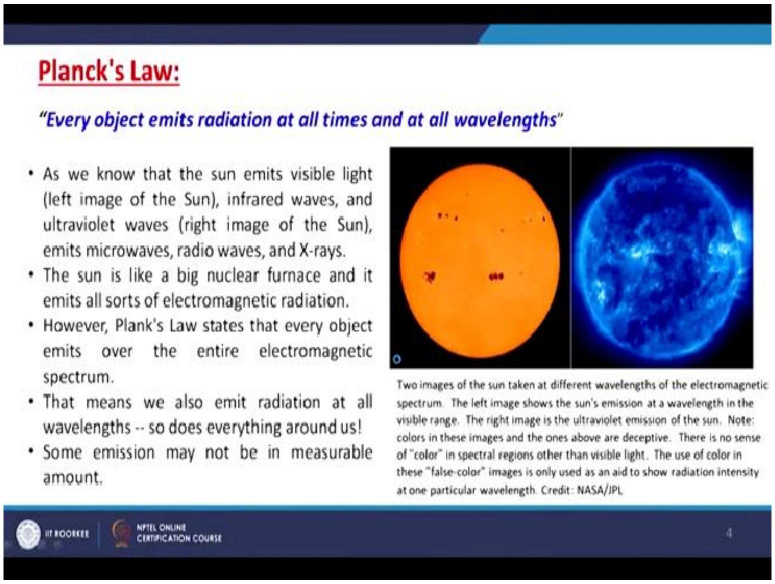


So for EM spectrum or EM radiation there are basically 4 laws which governs the type and amount of energy, which is being emitted by an object. And that as you know in science, whenever we use word law, and that means the law is used to describe a body of observations, and at the time and the law is established no exceptions have been found at that contradicted, but later on might be there are some exceptions.

But the laws which we are going to discuss so far they do not have any exception. And sometimes we also use a word theory. So what is the difference between a law and theory is that the law simply describes something, while a theory tries to explain why something occurs. So, there is a slight difference between there is that the law simply described something while a theory tries to explain why something occurs.

That is based on the occurrence. Now in the first law that is the Planck's law and what it says that every object emit radiation.

(Refer Slide Time: 03:14)



At all time and all wavelength now and then when we says that every objects emit radiation and if there is one condition is that object has to have temperature above absolute 0 and that is a you know that is true for all objects which are present on the surface of that. So, that is why in short it is said that every object emits radiation and at all times and at all wavelengths.

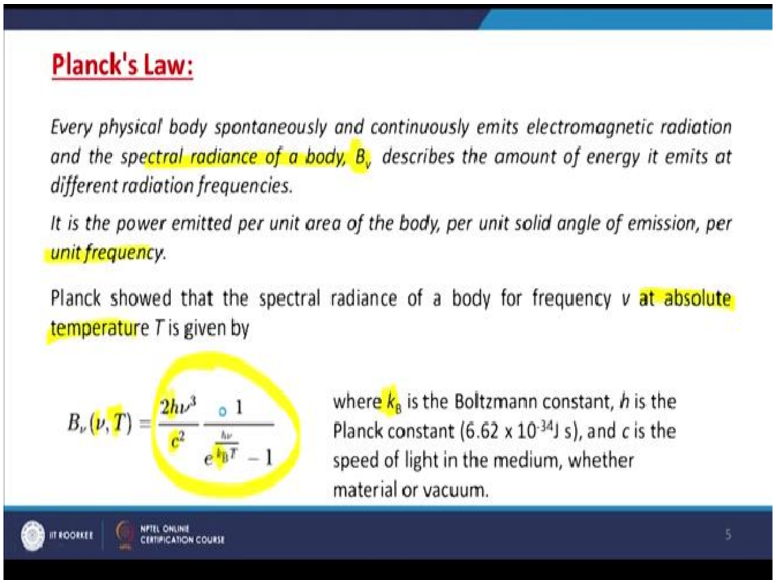
Now, whether our sensors are capable of detecting that emitance or radiation emit radiations at that distance that is very important for us, as also discuss in the earlier lectures of discussions that the thermal radiation definitely reaches which is the emitted by the objects or surface of the earth to the satellites, but others are from the reflected energy that is little different. So, as we know that sun also emits visible light.

And that is why we see sunlight and also it emits infrared waves and ultraviolet waves. And here, this left image of this is the sun and taking it 2 different wavelengths of EM spectrum, the left may shows the sun emission at the wavelength in the visible range. And this right image which is in blue color shows these images and there is no color in the spectrum vision or visible light and this is false color image is only used to aid so solar radiation intensity at one particular wavelength. And this is how it will look.

So, of course, in a different wavelengths, the same sun looks differently. So, sun as we know is a light a nuclear furnace and it emits all sorts of electromagnetic radiation and some of that is reaches to earth like visible light, infrared waves and of course ultraviolet lights also. So, that means that emit radiation at all wavelengths, so does everything around us and this is what I said that every object also emits radiation.

Because they are all about absolute 0 and some emission may not be miserable amount. Sometimes it is so small in quantity, that it cannot be measured. And sometimes it may be measured on the ground, but satellites which are around 850 kilometer, I am talking about remote sensing satellites, then it is for them to very difficult to detect or record such a mission. So, that makes only limited emitted radiation reaches to the satellite.

(Refer Slide Time: 06:22)

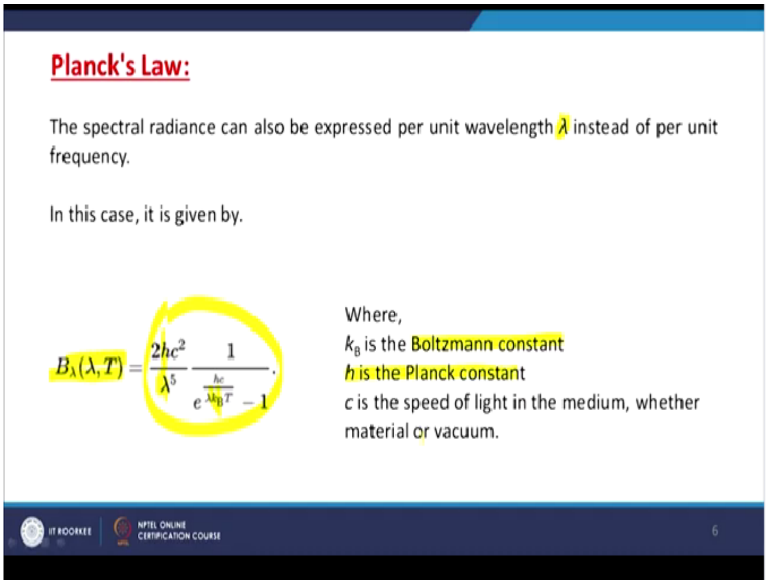


Now, further we look into this Planck's law that every physical body is spontaneously and continuously emits electromagnetic radiation. This is what the blanks law says and of the spectrum radians of VB describes the amount of energy it emits at different radiation frequencies. So, it is the power emitted per unit of the body and per unit solid angle information per unit frequency.

So, of course, it depends on the frequency that is why frequency per unit has also come. So Planck’s law shows that the spectral radiance of a body of frequency V at absolute temperature, this terms has now come here at absolute temperature t is given by B v, v and t equal to and this which has been given here. So, where k B is the Boltzmann constant H A here, H is the Planck's constant.

And C is the speed of light which has been used here in the medium, whether material or vacuum. So, this the B v that is the spectral radiance of a body B which is depending on the V and temperature t will have such a formulation.

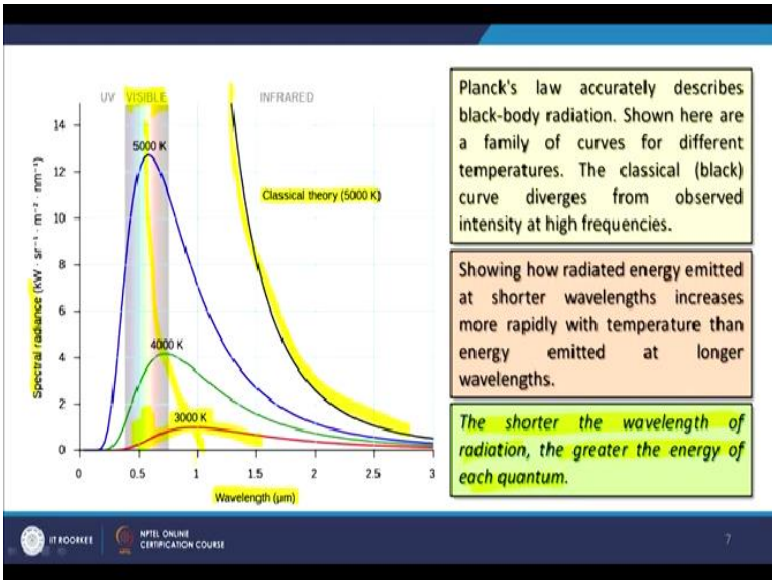
(Refer Slide Time: 07:59)



Now, further this spectral radiance can also be expressed or in this Planck’s law, per unit wavelength lambda instead of per unit frequency. So, we know that these are related inversely related rather that wavelength and frequency more wavelength less frequency, less wavelength more frequency. So, in case that is there, then we can write B lambda, lambda T instead of V and then we replace V with the lambda.

So, where k B again the same k B, k B is the Boltzmann constant, h is the Planck’s constant as well as in the previous formula and c is the speed of light in the medium whether material or vacuum. So, this is how the spectral radians is governed through this Planck's law.

(Refer Slide Time: 08:59)



And we want to go through now through these different spectral radius curves of at different temperatures along with the wavelength which we are having on the x axis spectral radians are here, then what we see that it temperature 5000 k that is about the temperature of the sun, then here we get the maximum light or this peak comes in the visible part of EM spectrum, which is what we are seeing.

Whereas if we go towards lower temperature like instead of 5000 if we come to the 4000 then there is a shift in the peak towards higher wavelength. Further when we go for 3000 Kelvin curve, again there is a shift. So, as you can see that there is a shift of these peaks towards the longer wavelength. This is of course is being governed by the Planck's law and what it says that, when you are having very high temperature, then visible light is also emitted.

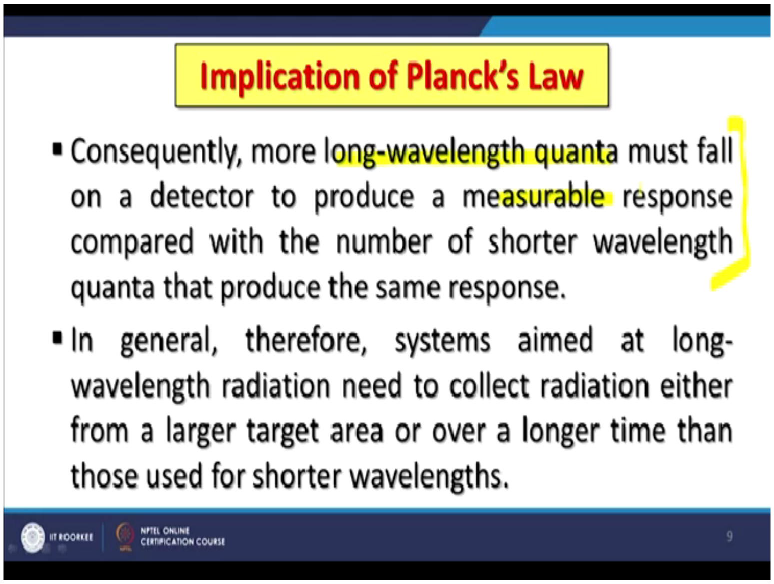
And then peak will come before that means it can be detected at shorter of wavelength. In this example, it is in the visible part, but when we go towards lower temperatures, then we can detect it longer wavelengths. So, the Planck's law accurately describes that is blackbody radiation. And soon here as a family of curves, as I have just discussed in the classic black curve, which is this one, the classic black curve.

Curve that diverges from observed intensity at high frequency so, it is a completely different than what those 3 curves are there showing how radiated energy emitted at shorter wavelength as a blue been as increases more rapidly with temperature than energy emitted at wavelengths. So, when we move towards the longer wavelength, then these peaks and that this then these peaks are shifted towards the longer wavelengths.

The shorter the wavelength so, what we can conclude now, that the shorter of the wavelength of radiation, greater the energy of each quantum and this plays very important role in remote sensing. Because, here in previous lectures or earlier discussions we have seen or discussed that a lot of satellites are focusing in the visible part of EM spectrum. The reason is it is easy to design sensors.

Because at the shorter wavelength, the radiation that greater energy is available to be recorded by the sensors, but when we move towards the right in this case or a longer wavelength, then the energy available for the sensor to record reduces and this is all governed by the Planck's law.

(Refer Slide Time: 12:12)



So, how it is implemented or what are the implications of Planck's law, one part I have already discussed the other basic properties of radiation is its intensity equivalent to the brightness of visible light and this may be regarded as either the number of quanta or the amplitude of electric and magnetic fields. So, when you are having high magnetic, high amplitude, the more quanta at a particular wavelength, the greater the energy is transmitted.

So, that means a particular wavelength in the previous figure you have realized this one and the energy of a single long wavelength quantum is less than that one of the shorter wavelength, we have also seen that here in this one that the spectral radiance is a shorter wavelength, that it is very high whereas, it is very low when we go towards the longer wavelength.

So, further implications of Planck’s law is that consequently, more long wave, quanta must fall on a detector to produce a measurable response compared with a number of short wavelength quanta, that produce the same response. So, this means again, as I have been seen that in visible part of the spectrum, the sensors are very efficient and that is why most of these satellites remote sensing satellites are always having visible sensors.

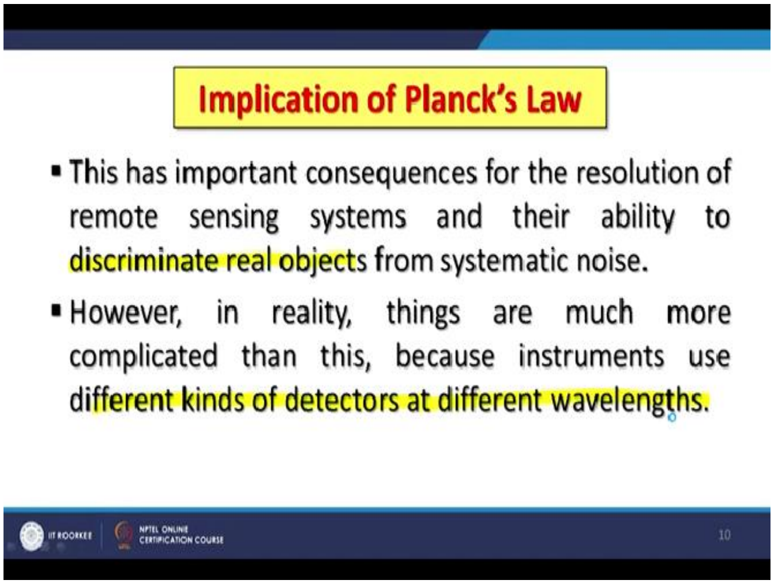
But when we move towards a longer wavelength, then more longer wavelength quantum must fall on a detector to produce measurable response that means, when we go for the thermal infrared, that is very long wavelength compared to what in the visible then the we get a very little energy available for measurable or available to measure by the sensor. So, that is why this also controls a less energy means also directly for lower spatial resolution.

So, all many remote sensing satellites then I will give you the best example from landsat it with the latest and OLI series landsat OLI series that at visible channels you may have a spatial resolution of 15 meter like in landsat-8 it is there. But when we move towards a longer wavelengths, like in thermal channel, then you end up with the 60 meter spatial resolution because in order to get sufficient energy registered via a sensor on board of a satellite from 15 meter resolution in thermal channel that much energy is not available to be registered on measurable response compared to the shorter wavelength.

And therefore in order to have that kind of energy available to the sensor, you need to cover a large ground area comparable or competitively large ground area and that means lower spatial resolution relatively lower spatial resolution. So, this is Planck's law also governs that means, it also governs the spatial resolution of the sensors. So, in general therefore the systems in that long wavelength radiation need to collect radiation either from a larger target area or over a longer time, then those us for shorter wavelength.

So, this last part is not possible for longer time because these are moving objects. So, we cannot stay on one location for very long time. So, the first one is they need to collect radiation from a large target and that means relatively lower spatial resolution. So, this is the biggest implication of Planck's law in the remote sensing.

(Refer Slide Time: 16:31)

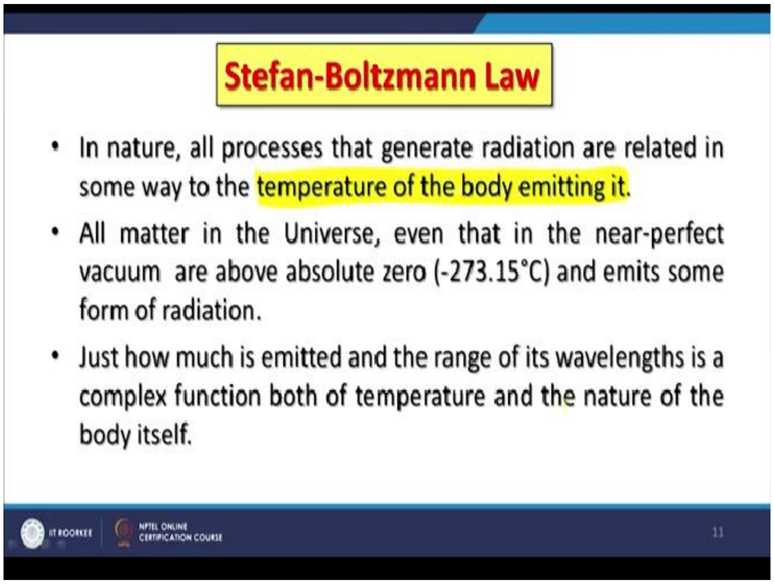


Further what we see that the important consequences for the resolution of remote sensing systems and their ability to discriminate real objects from systematic noise. So, if we go for higher spatial resolution, even in the longer wavelength, then we may have difficulties or discriminating different objects. So, in order to have as a kind of balance between discrimination and a spatial resolution.

And you know the thermal channels are generally having lower spatial resolution. And however in a reality things are much more complicated than this, because instruments use different kinds of detectors at different wavelengths. This is also true, because for visible channels, there are different detectors for infrared channels there are different and for of course, thermal infrared, they are different.

So, implications of Planck's law is that it controls the indirectly or directly controls the spatial resolution of the sensors. Now, the second law which is also equally important like Planck's law, and that is the Stephen Boltzmann law.

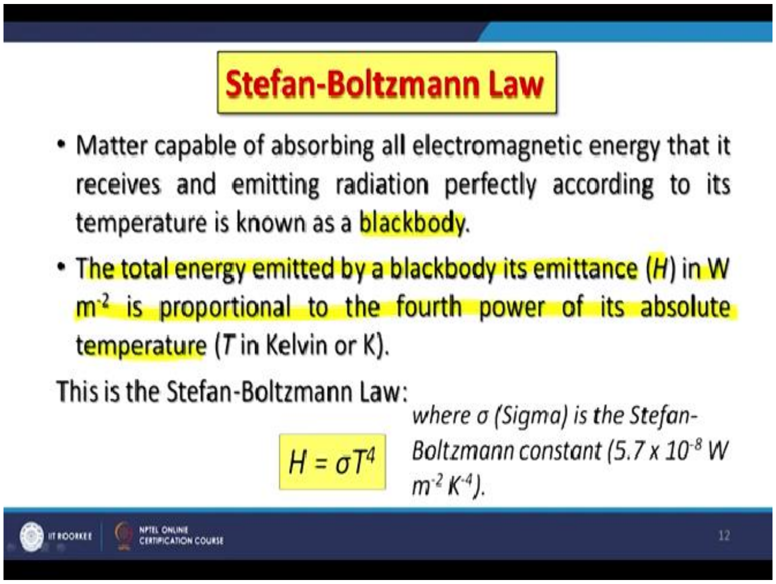
(Refer Slide Time: 17:44)



In nature as you know that all processes that generate radiations are related somewhere and how they related with the temperature of the body which is emitting it. So, more than temperature you may get the more emission, less the temperature, less emission. So all matters in the universe, including on the surface of the earth that even in the near perfect vacuum are above absolute zero, this point we have already discussed and emit some form of radiation.

No matter how small amount, but they will emit, because they are all about absolute temperature and just how much is emitted and the range of its wavelength is a complex function both the temperature and the nature of the body itself.

(Refer Slide Time: 18:37)

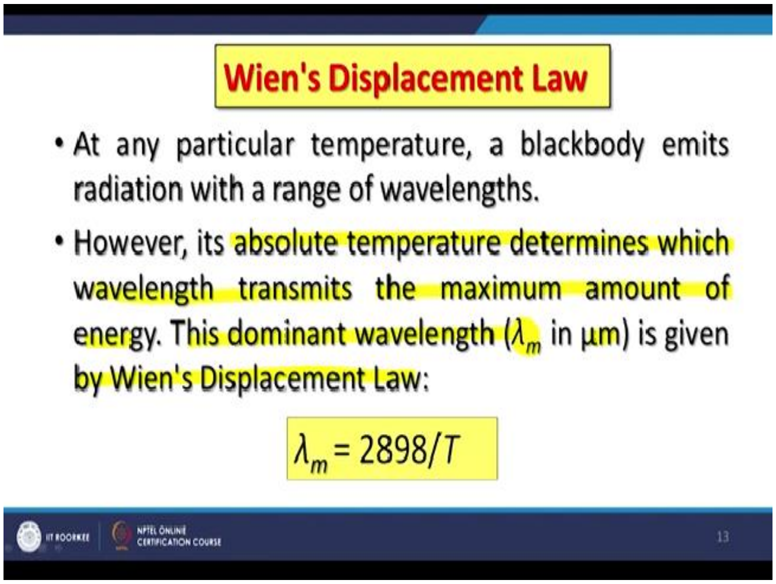


So, this materials capable of absorbing all electromagnetic energy that receives an emitting radiation perfectly according to its temperature is known as black body. And you know, this is theoretical and concept about the black body and no substance or material on the surface of the earth is behave like a black body, it can because whatever the radiation is receiving it may not emit all that radiation.

And may not work as a perfect black body, nonetheless, that total energy emitted by a black body emitance that is H in W and watts per square meter is proportional to the fourth power of its absolute temperature and T in Kelvin T centigrade or Kelvin so this is the Stephen Boltzmann's law that the total energy emitted by a black body of its emitance H in watts per meter square is proportional to the fourth power of this absolute temperature.

And which we can write a very simple formula that emitance H black body emitance H = sigma T power 4 and because fourth power of its absolute temperature. So, this is how we can relate that emitance = sigma T power 4.

(Refer Slide Time: 20:15)

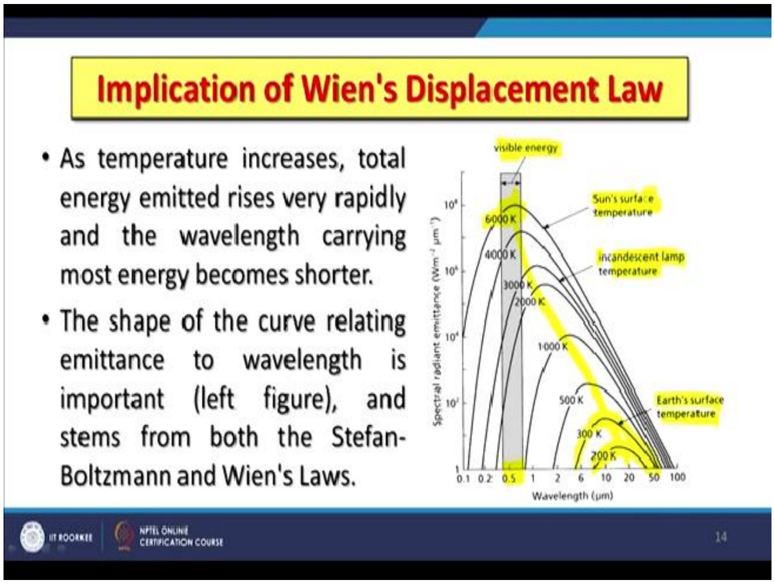


Now, there is a third law, which also important in field of remote sensing which governs controls about this emitance and of course, depending on the frequency, that is the means displacement law and this means displacement law is at any particular temperature, a black body emits radiation with a range of wavelength, because in earlier in this discussion today, in earlier part we have discussed that a material or objects on the surface of the earth are emitting energy all the time in all wavelength.

So, however this absolute temperature determines which wavelength transmits. So, higher the temperature that this might be at a different wavelength, lower the temperature, that emitance might be a different level and so it is a absolute temperature, which determines the wavelength, transmits the maximum amount of energy and this dominant wavelength that is lambda m in micrometer is given by Wien's displacement law which is lambda m = 2898 upon T.

So, this is how this Wien's displacement law, this part we have touched a little bit, but at that time, we did not mention deliberately about the Wien's displacement law that is coming.

(Refer Slide Time: 21:47)

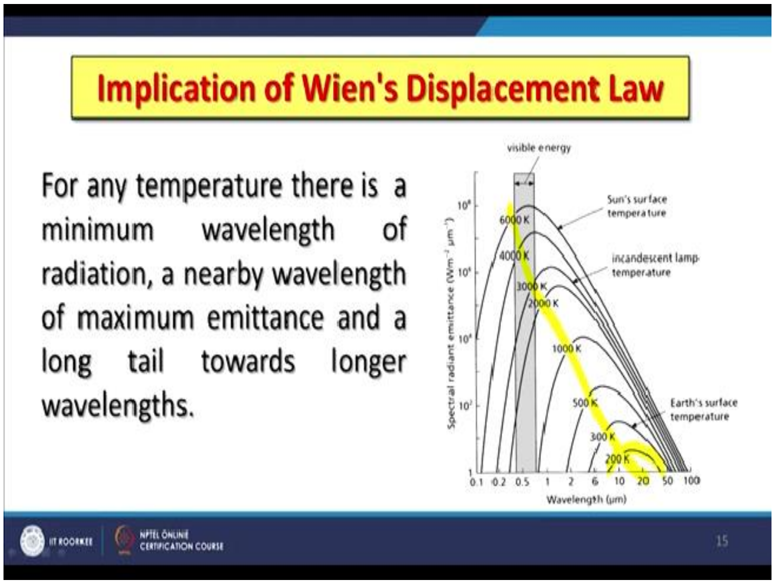


That when we move towards the shorter wavelength these curves, the peaks get smaller and shifted from lower ambivalent to higher wavelength. So, at temporary as temperature increases, the total energy emitted rises very rapidly and the wavelength carrying most energy become shorter. So, this is how the visible energy is having this is a 6000 Kelvin curve and it is having the maximum emitance at the time.

So, as temperature increases energy emitted rises very rapidly and wavelength carrying most energy becomes softer. So, it is a shorter wavelength, when we go for a lower temperatures, then things get shifted towards the longer wavelength. So, the shape of the curve relating emitance to wavelength is important as we can see on this finger right and it tends from both the Stefan-Boltzmann's and Wien's laws.

So, these controls, this is the temperature of the earth here, which is the 300 Kelvin and these are the lamps incandescent lamps temperature which is around 3000 K and the sun's temperature is around 6000 or 5000 6000 k here. So, because that is the maximum emitance is coming and that is why it is getting detected at shorter wavelength and this is all governed by the sifting or displacement of peaks is govern by Wien's displacement law.

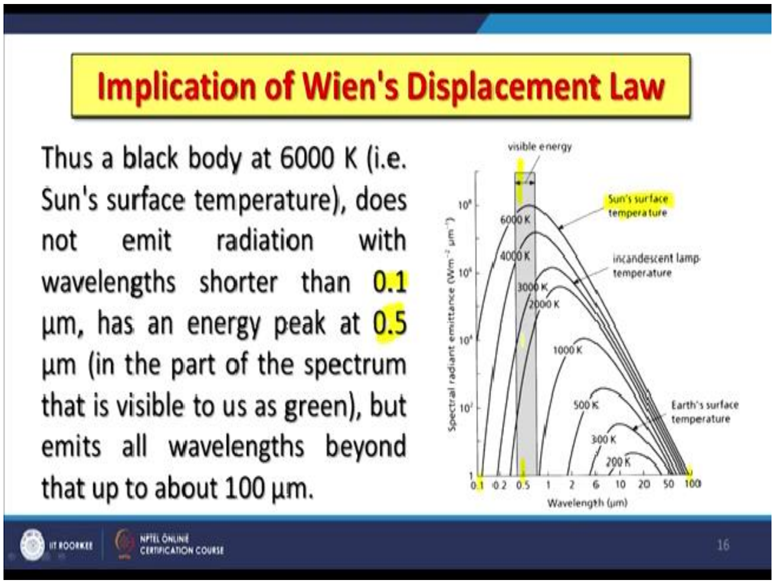
(Refer Slide Time: 23:28)



What are the implications that for any given temperature, there is a minimum wavelength of radiation because all objects are emitting all the time depending on the wavelength. So, minimum wavelength of radiation a nearby wavelength of maximum emitance and the long tail towards longer wavelength. This is what we are seeing in case of 6000 or 4000. That tail is becoming longer, but this peak reaches earlier. So far any temperature there are different temperatures marked here as you can see here.

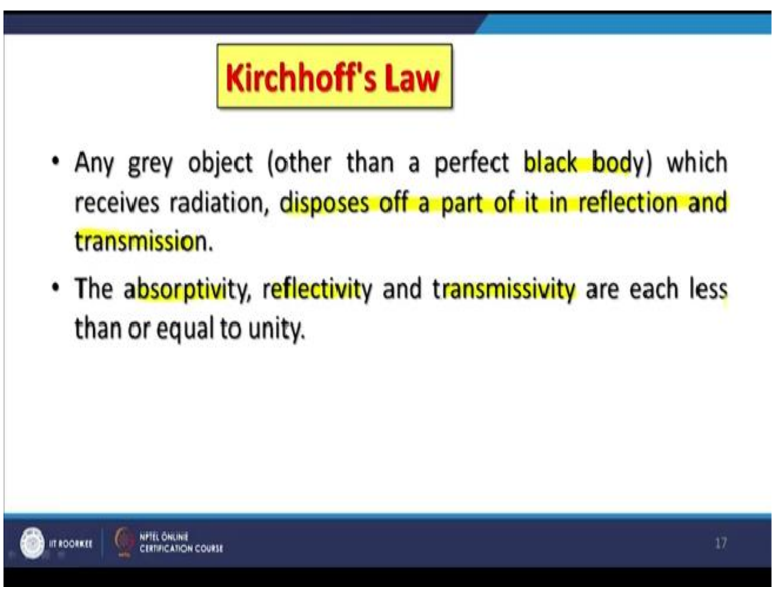
There is a minimum wavelength, minimum wavelength of radiation and the nearby wavelength of maximum emitance and a long tail towards that longer wavelength, this is what we see. So, the bodies which are emitting less, having less temperature emitted longer wavelength.

(Refer Slide Time: 24:25)



Thus a what we can see it this is state that a black body at 6000 Kelvin, that is the sensor temperature does not emit radiation with wavelength shorter than 0.1 micrometer. So, it does not emit here and has energy peak at 0.5 micrometer as you can see here, so, this is having maximum and in that part of the EM spectrum, which is the visible especially is as green. But emits all w wavelength beyond that up to 100 micron. So, the curve ends here. So, the emitance is there, the peak is in the visible part by the sun.

(Refer Slide Time: 25:14)

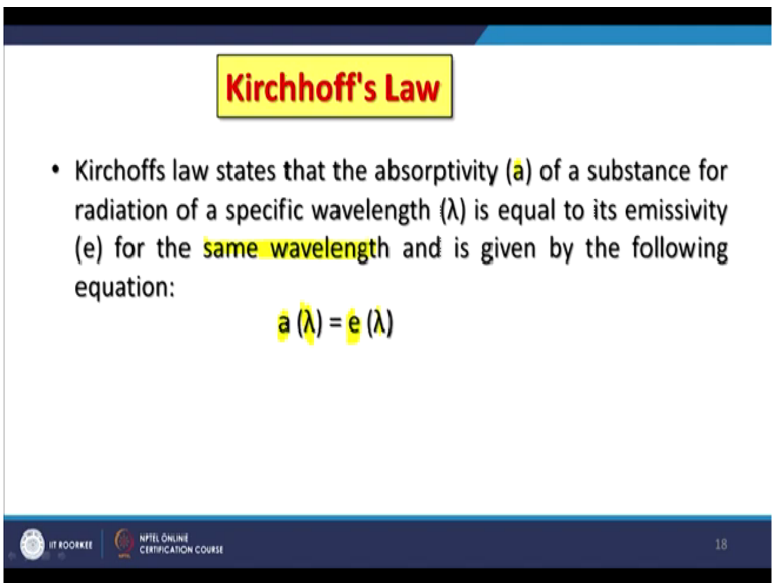


Now, the third law or sorry the fourth law that is last law which we discuss in this lecture is the Kirchhoff's law and which says that any gray object other than a perfect black body, because the natural objects are generally gray in not by color, but why because of black body reference in that reference. So, which receives radiation disposes of a part of its reflection and transmission.

And this absorbability, reflectivity and transmissivity and these are all each less than or equal to unity. So, this is how that because we do not have any perfect black body available, this is only theoretical part. So which receives radiation grey objects they disposes of a part of it in reflection and transmission. So, this further absorptivity, reflectivity and transmissivity are each less than or equal to unity.

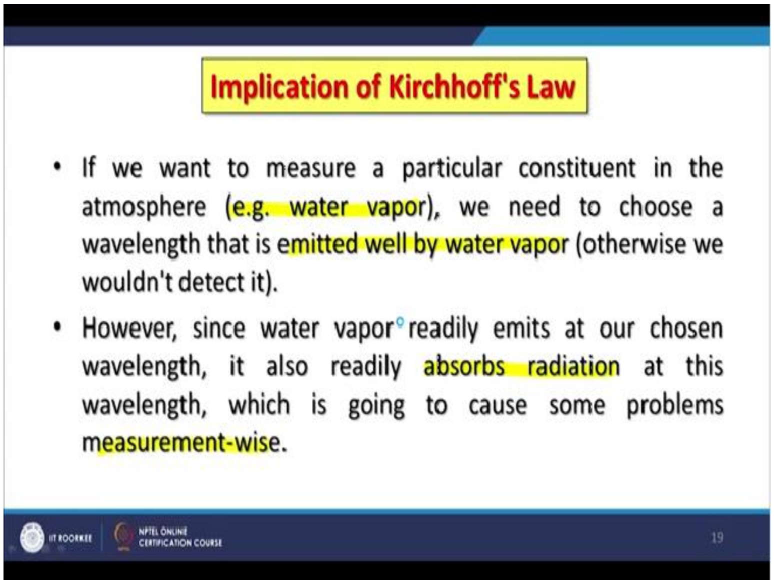
So, you may get 100% absorptivity but, generally, it is not the otherwise it would be a perfect black body or 100% reflectivity that is also not there. So, that is why less than or equal to unity.

(Refer Slide Time: 26:37)



Now, how it can we can define this Kirchhoff's law that absorptivity a of a substance for release and have a specific wavelength lambda is equal to its emissivity that is e. So, a lambda = e lambda. So, the absorptivity at particular wavelength is equal to emissivity at that particular wavelength. So, for the same wavelength we are talking here. As a given by this formula very simple one **that** that absorptivity lambda = emissivity lambda.

(Refer Slide Time: 27:19)



Now, what are the implications of Kirchhoff's law, that if we want to measure a particular constituent in the atmosphere for example, maybe water vapour we need to choose a wavelength that is emitted well by water body, otherwise, we would not detect it. Recall a discussion held in earlier lectures especially when I have been discussing about the you know, these spectral curves responses there it matters.

So, different objects will give you a peak at different locations. So, wherever they are giving the peak in this spectral curve that is the best band for channel to choose, if you want to study that particular thing. So, here, if I take the example of vegetation, then vegetation in infrared discussed earlier that will have the maximum reflectance. So, that means infrared channel are generally suitable for a study vegetation.

The same way if I want to study the water vapor which is available in that atmosphere, then I need to choose going through those spectrum curves I need to choose that channel which is having that water will put having maximum emitance by the water vapor. And here we are talking about thermal channel vegetation is a infrared example. However since water vapour readily emits at all chosen wavelengths.

So, it is also readily absorbs radiation at this wavelength which is going to cause some problems, measurement wise. If it is a you know absorbing radiation and also it is you know absorbing radiation and also emitting radiation at the same wavelength then there might be some problems. So, the choosing the correct band for a particular study is very, very important and this can be understood easily by using Kirchhoff’s law as we have discussed that a that is the absorptivity lambda = to lambda.

And this lambda has to either the same wavelength if I am seeing absorptivity at a visible channel, then I am looking the emissivity in visible channel, but emissivity in visible channel will not be there. So, the thermal channel then both has to be at the same wavelength then only this, will fall true.

So, this brings to end of this discussion about laws which governs the emitance, how it reaches to the sensor, how it is recorded in the sensor, and how different objects starting from a black body to gray body or a natural objects, how they behave. All this can be understood very well by using these 4 laws. Thank you very much.