Illumination Engineering and Electric Utility Services
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Lecture No. # 02
Instructional Objectives

Good morning, welcome to this course on illumination engineering and electrical utility services. Today we take up lesson two of this course.

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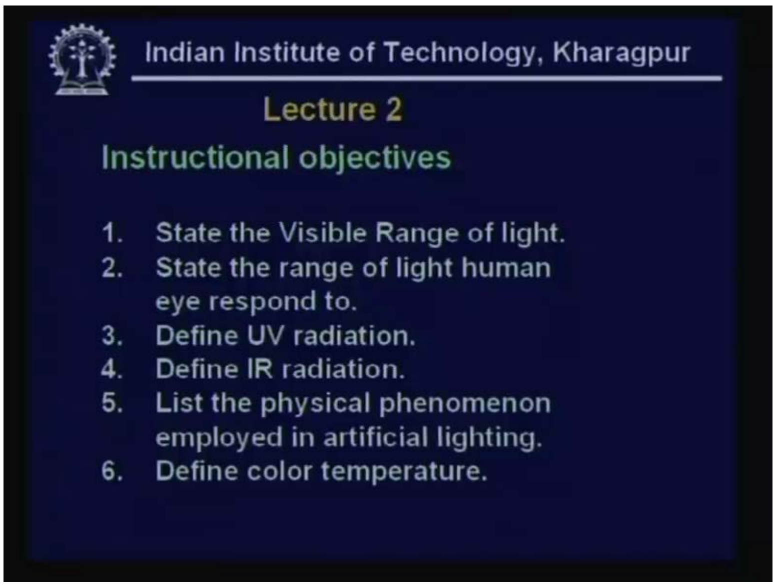

This lesson is to do with radiation and the instructional objectives for this particular lecture are ability to state the visible range of light. Two, state the range of light human eyes responds to and define what is a UV radiation, what is IR radiation and understand and able to list the physical phenomenon employed in artificial lighting and understand the concept of color temperature what it is. If we recall in the last lecture, we had already seen the need for the lighting and we did mention that the human life very much depends on light and more than 85 % of information is acquired through our eyes which requires light and sun is the most potent natural source of light and any efforts to make our environment lighted through artificial means is to make it as close to sun as far as possible using optimum resources at economic prices.

We have also seen in that lecture that most of the artificial sources employ some form of an electrical energy and therefore we had a look at the preliminaries of what constitutes an electrical power system and this has been with in complete details. We saw the various ways the power distributed and we realized that most of the power transmission system is ac in nature which could be balanced or unbalanced and three phase in nature which means there are two difference kinds of connections that are employed one delta, other star. We've understood what is meant by line and phase quantities and the use of overhead lines and underground cables for power transmission.

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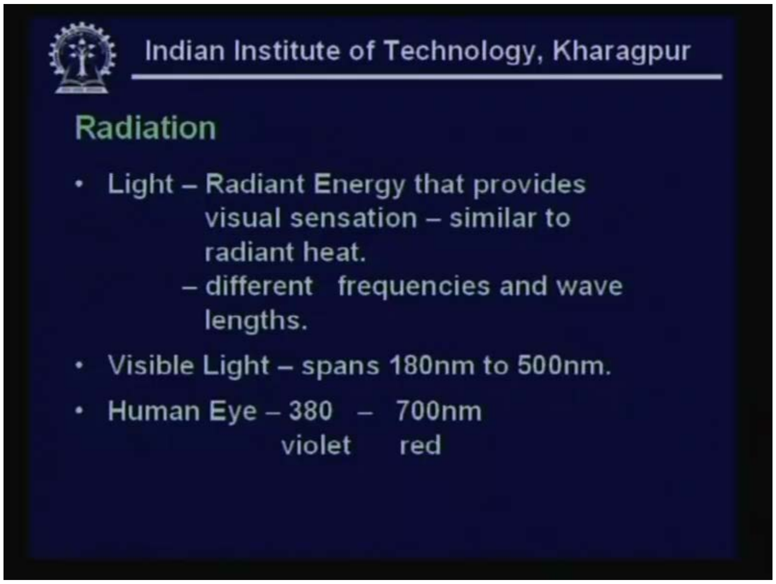

So, we begin today to look at a little more on to the phenomena of light or the physics of light, hence the chapter or the lesson is title radiation. By definition light is that radiant energy which provides visual sensation in eyes. Once again it should be reemphasized that the eyes are one sense of organs which require more than 85% of the information that a human being requires and therefore the visual sensation is provided by the light is in the form of a radiation and akin to radiant heat but the frequencies and wavelengths are different in that sense light is also form of a electromagnetic energy.

Now it must be mentioned here that the visual light or visible light spans over the wavelengths 180 nanometers to about 500 5000 nano, 1500 nanometers. There should be, there should be a small correction here, it has to be 1500 nanometers as against 500 what is mentioned in the slide. And we also look at how the human eye responds to the visible light, though visible light has a spectrum 180 to 1500 nanometers, the eye responds over the spectrum spreading over 380 to 700 nanometers. The 380 nanometers corresponds to the violet color light and 700 nanometers corresponds to the red. In fact if we pass the natural light obtained, we know that the natural source of light is sun light passed through a prism. We can see the beam splitting into various colors spanning from red to violet corresponding to various wavelengths. On one extreme one finds red color light of 700 nanometer wavelength and the other extreme is the violet color light 380 nanometers.

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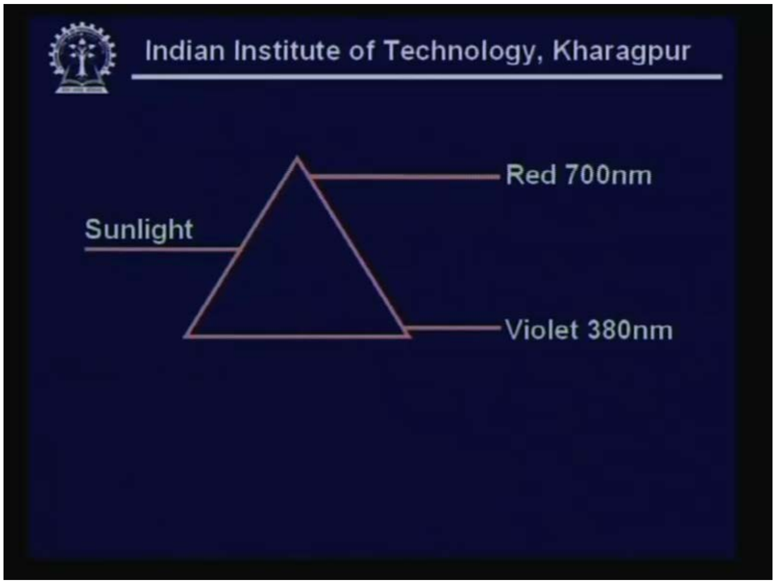

In fact this is a spectrum one finds in a rainbow and often times the children are taught that this consists of vibgyor meaning violet indigo blue green yellow orange red. In a subsequent lecture we will look at more ways of quantifying this colors and looking at them. So in this lecture what we do? We look at how the light has different colors, what are the energy contents and how the eye responds and these will be looked into and then look at some of the physical processes that can be used to produce similar effect from artificial sources.

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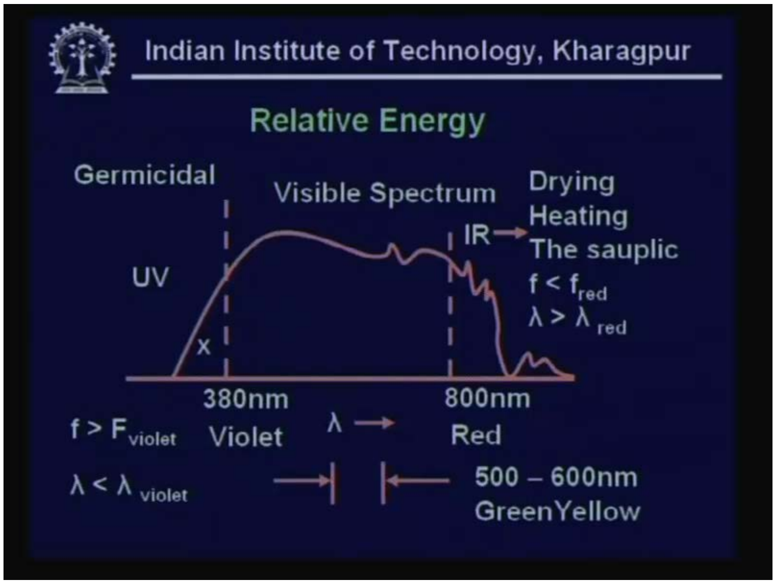

So, here we have a diagram which shows relative energy due to sun light in the visible spectrum. As may be seen the x axis is the wavelength of the electromagnetic spectrum or lambda. We find two vertical lines drawn one at 380 nanometers corresponding to violet and the other around 800 nanometers corresponding to red. The spectrum spreading over this region is what we call visible spectrum as may be seen in the mid region, the relative energy is a maximum and this spans over 500 to 600 nanometers falling in the green yellow region. We have a region whose wavelength is less then the wavelength corresponding to violet that is what we call as ultra violet and the frequency and the wavelength are inversely related.

It must be mentioned here that being an electromagnetic spectrum, it propagates the same velocity as the velocity of light in free space which is 300 meters per microsecond. Therefore lower the wavelength, higher is the frequency. Therefore we find ultra violet has a frequency of excitation or electromagnetic frequency, spectrum frequency higher than that corresponding to violet and this is referred to as ultra violet light. Therefore the light spectrum as can be seen is ultra violet visible spectrum then we have a third spectrum which is having wavelength more than that corresponding to red or lambda greater than lambda red which is marked in this diagram as IR meaning infra-red.

If you see carefully infra means smaller than, that means the spectrum radiation which has frequency less than that corresponding to red light is what is called as infra-red. All of us are aware of the usage of infra-red lamps for healing wounds and that's one of the thing. In fact in the slide it is mentioned the sauplic that should have been therapeutic that is the error in the slide spelling mistake, it must be therapeutic and there are applications in the area of drying, heating and therapeutic purposes using IR.

In fact certain discharge phenomena like lightning when needs to be photographed, infra-red cameras are employed. So what do we see? We see the energy content of sun light is a maximum in the green yellow region spreading between 500 to 600 nanometers and the whole spectrum of visible and the whole spectrum of light can be divided into three zones. One is UV having lambda less than lambda violet, visible spectrum spanning from 380 to 800 nano meters and IR or infra-red greater than 800 nanometers. Incidentally UV is used for germicidal applications and all of us are familiar, the aqua guard which is used for getting the pure water these days. So knowing about the relative energy is necessary for us energy to see how our eye responds and that is termed in terms of a relative luminosity.

The curve here as has been in the previous cure, we have drawn the wavelength along the x axis and the relative luminosity that is ability of eye to respond to the incident light that is what we mean by luminosity. And as can be seen from the previous figure, you can recall the maximum energy content was in the green yellow zone. In a similar way the response of the human eye is the maximum in the green yellow zone and therefore with respect to that how the eye responds to various light spectrums is what is seen in this particular curve.

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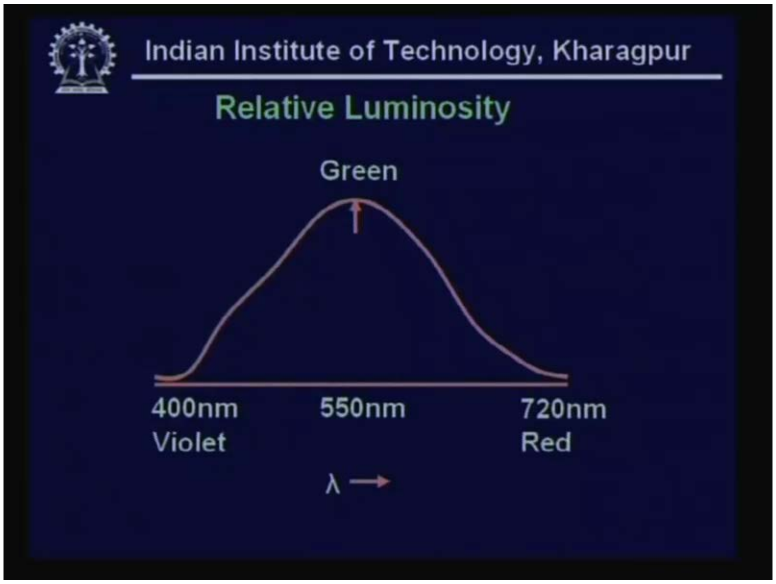

Let's see how we can use this to arrive at as various lighting sources. Now the artificial sources as we are all aware, all of us have been using one form of the sources or the other, remember unlike the prehistoric man our activities are not curtailed with sunset or do not begin with sunrise. We are in a zone I mean in the time period where we work 24 by 7 that is all the 24 hours around the week, round the week that is round the clock, round the week.

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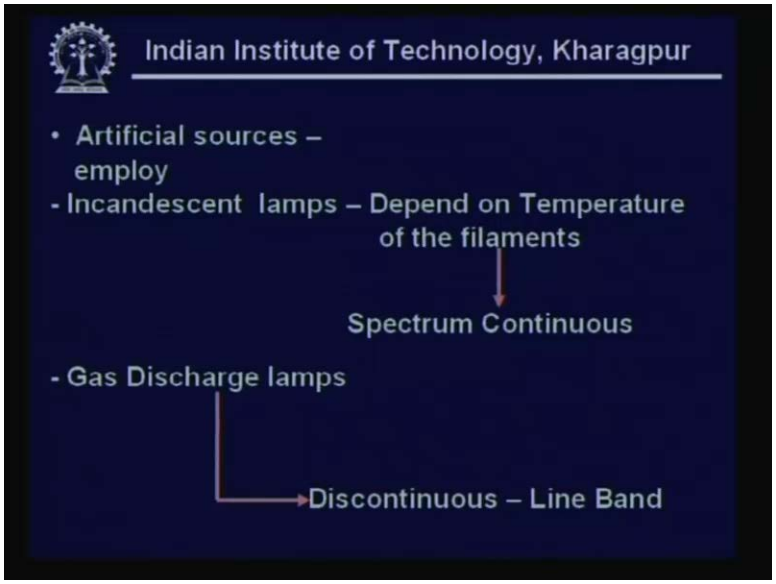

Incandescent lamps are one of the fore most sources that have been used, they depend on the temperature of the filaments and they are known to produce what is called as the continuous spectrum as we saw in the radiation due to light, sun light. Then you have gas discharge lamps which are known to produce a discontinuous or line band. They do not produce a continuous spectrum like the sun light that means they radiate light at specific frequencies and depending on the major, majority of the energy lying in a particular color we refer to discharge to be of that color.

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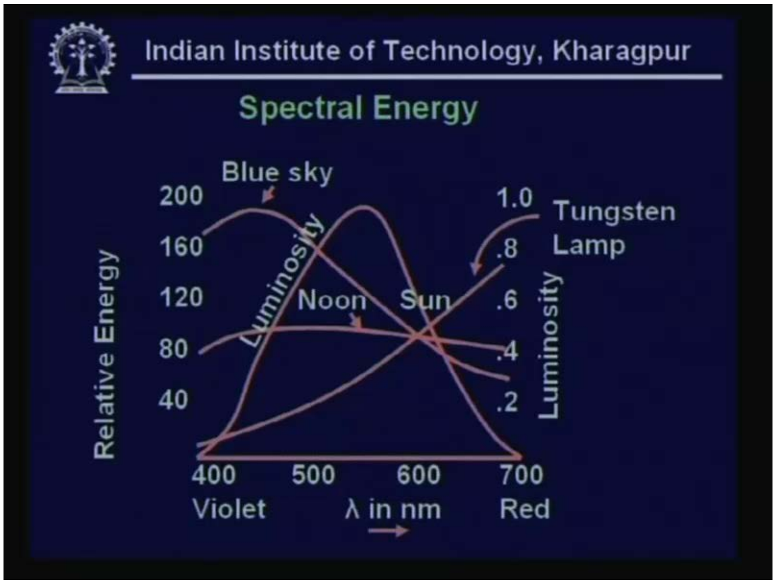

Then this is the two broad categories. So, one need to look at the spectral energy, what you can see in this figure is as been in all the figures we draw the wavelength of the radiant light along the x axis. There are about 4 curves, if you see the first curve is to do with the energy content due to noon sun, the second curve is due to the tungsten lamp and third one is due to blue sky. Now, one may look at with respect to, if you see the noon time's sun, if you consider that as a base you find that over the entire spectrum spanning from violet to red, it is more or less same throughout.

On the other hand that too to blue sky is peaking around somewhere between 400 to 500 nanometers where as that due to tungsten lamp peaks around the red, it is increasing from violet up to red. And in fact to have an idea of how this relative spectral energy can be utilized, the response curve of the eye is also drawn here which we said is the luminosity taking the maximum response which is the green light as the base, relative luminosity curve which is peaking around green corresponding to 550 nanometers is seen. So what does it mean? It means that though blue sky has a peak energy around 425 to 450 nanometers, the eye is unable to respond and therefore it is of no use. This is one thing which has to be kept in mind. If you see these diagram, there are three particular things have been considered. One, the all pervading sources sunlight, two blue sky essentially it's a sky when the sun is partially blocked could be clouded sky, third is an artificial source use employed a tungsten filament that is incandescent lamp. As already told it emits radiation based on the temperature of the filament based on the current flow through that.

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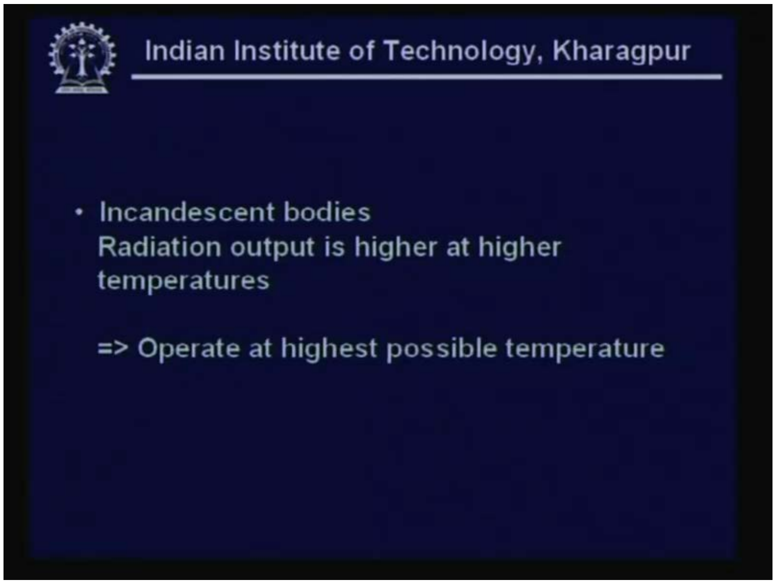

So, incandescent bodies are giving out a radiation which is dependent on the temperature which is maintained by them. The higher the temperature, you have the higher output. On the other hand, if you have any material therefore it means it needs to be operated at the highest possible temperature and at the same time, we don’t want any evaporation of the filament material. Yes, it must be operated at a high temperature without causing any evaporation of the filament material that is one important thing to be borne in mind.

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Having said so much, let us look little more deeper in to the physical processes that are enabling us to have various artificial sources. The first one as all of us are familiar in fact the naked lamps which are used by most of us are these incandescence source and the physical process that is responsible for radiation in this lamps is known as incandescence and is also termed thermo luminescence. This as already brought out depends on the radiation of the light at the elevated temperatures. The filament is being maintained at a higher temperature and in fact there is an associated heat. This has led to incandescence lamp which is normally used.

In the early days, it used to be in the form of a gas lamp or all of us are familiar that in our temples we light lamps using oil or when power goes, we use candles which are essentially depending on wax. Incidentally it must be mentioned, the standard of measure of light output is talked in terms of candle and luminosity is talked, luminous output is standardized as candela. Hence, this is all gives rise to what we call continuous spectrum. See the beauty of nature; it is continuous just as it has been continuous due to the natural sunlight so that's the thing. In fact all modern ways of looking at of alternate sources is to get a similar continuous spectrum at optimized energy consumption at an economic price.

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The second part is, the second physical process that may be used is luminescence and this is also called electro luminescence in the sense why it's called electro luminescence, because this is a form of a discharge update by the passage of electric current and that discharge is of a particular radiation. Put in other words, this is a chemical or electrical action on a gas or a vapor leading to light radiation. Now all these arch lamps which we have or the arch clamps used in projecting the motion picture they employ a carbon electrodes. There is an arch struck between two electrodes. The arch is essentially a combination of ionized particles which is a vapor which gives rise to radiation being at a high elevated temperature.

So, we find that unlike the incandescence this does not produce continuous spectrum, it produces color of a particular I mean light of a particular color. Now this color depends on the material employed and therefore on a spectrum, if you try drawing the wavelength vis-à-vis the radiation output, you find that it is not continuous over the entire visible zone but it is discontinuous or is known to produce what we call line spectrum or line bands. This is why it is called the line or a band spectrum. The next one is fluorescence. Who is not aware of the fluorescent lamps these days? We are using fluorescent lamps extensively in fact next to incandescent, fluorescence is most used source of light.

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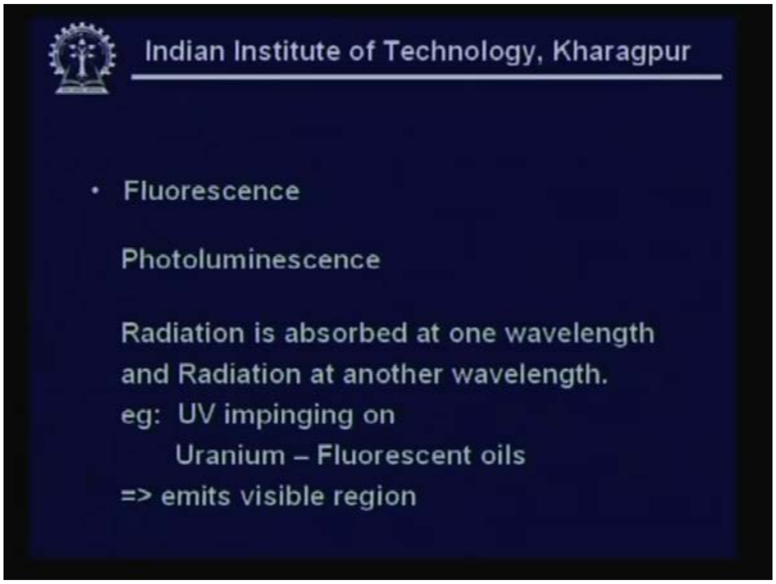

This is the state of art of light as far as the interior lighting goes, this is also termed as photoluminescence in the sense the concept is that there is a material that absorbs energy at one wavelength and radiates at another wavelength. Mind you, we said that the light can be categorized into three zones, one is ultra violet, second is visible and third is infra-red. Now if a material is able to absorb at one wavelength and radiate another wavelength, you remember the spectrum we showed, the blue sky has a peak around 420 nanometers but our eye cannot respond very well in those zone. Keeping that in mind, supposing that there is a material that can radiate energy may be in the UV spectrum and if there are materials available that can absorb the radiated energy and convert it and reradiate at another wavelength which is in the visible zone then we call this particular phenomena as fluorescence.

In fact the fluorescent lamps which we employ use this principle. They have what is known as phosphors which absorb the radiation, the UV radiation due to a discharge in a low pressured vapor which is reradiated as the visible spectrum. And in the process we are able to get what we call as a cool light. Remember when we use an incandescent lamp it is not just the radiation alone because the radiation is due to the filament being maintained at a high temperature. It tends to heat the environment, there is an associated heat. On the other hand the amount of heat radiated in a fluorescent lamp is much less and the efficiency is higher. Some of the examples could be the fluorescent oils, uranium is one such material, zinc is another material which is often used. And as already told to you it emits visible light in the visible spectrum.

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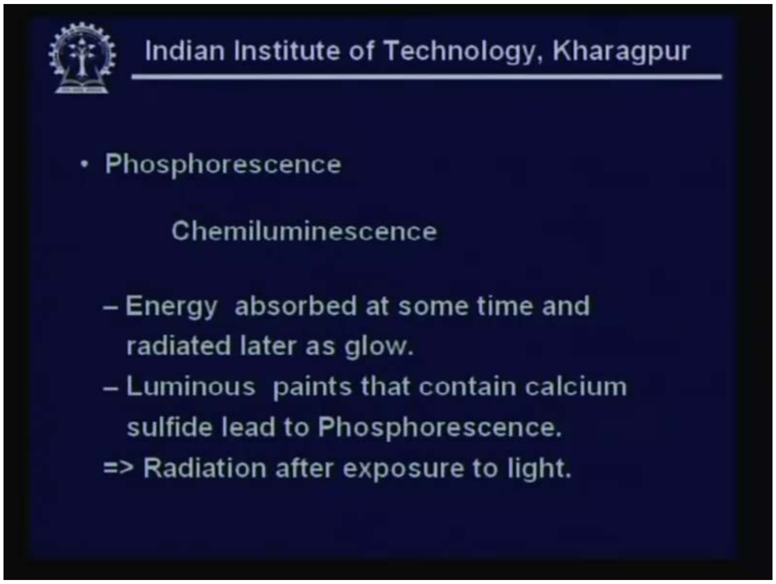

There is yet another physical process which is often used but may not be directly but this is what we called the phosphorescence. We talked about energy absorbed at the particular wavelength and reradiated in the visible zone but there is no time delay. On the other hand phosphorescence or chemiluminescence is what we call as a process by which the radiant energy is absorbed and having been absorbed is radiated. At a later point in time as a glow, one wonderful application is in the high way system where we use these kind of a materials and these luminous paints, they are useful for this particular purpose and the advantage is they radiate. The difference between fluorescence and phosphorescence is this. In case of fluorescence, the source of discharge is there only then visible spectrum comes out.

On the other hand a phosphorescent material does not require the original source of light to be available for radiation. Once exposed to light, it slowly radiates that is why when the roads unmanned I mean the roads where traffic density is low, they can be marked with such phosphorescent luminous paints, so you need not waste energy and they give the thing. In fact the high way engineering is one place where these physical process is extraordinarily employed. Therefore if you see in effect, most of our applications use a combination of luminescence and fluorescence.

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Luminescence as told to you is a form of a gas discharge which is a line spectrum. Fluorescence uses conversion of UV or the conversion of radiation at one wavelength to the visible wavelength. Fluorescent lamp - luminescent source low luminous valve activating fluorescent surfaces which lead to visible radiation. Intensity of course depends on the kind of gas that is used. Obviously fluorescent lamps use as I told you the kind of low pressure mercury vapor. So, the magnitude of radiated energy will depend on the gas vapor that's involved.

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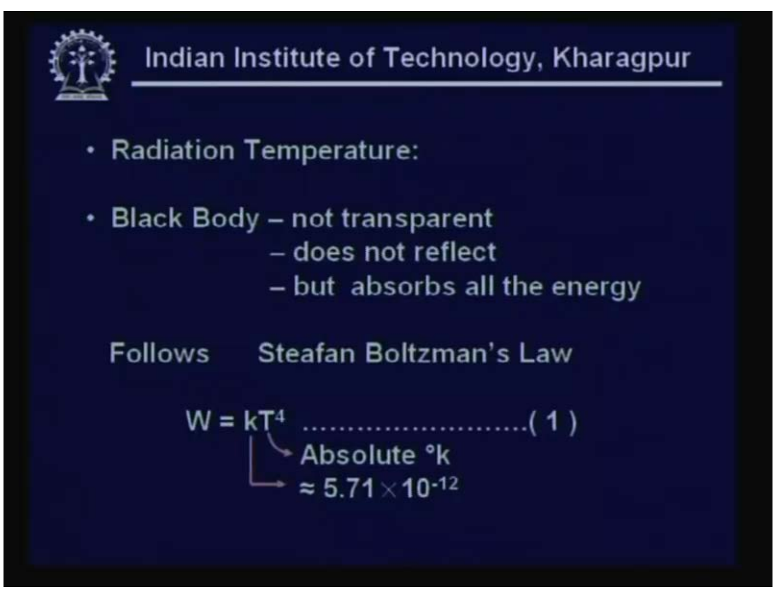

And how much of this UV light that is radiated gets into the visible spectrum is depended on the phosphor material that's employed. Central to the whole thing is that radiation temperature is a very important issue because that's been the primary this thing for the incandescent sources too. And even if you take the luminescent sources, you will have an electrode that's maintained at a temperature which creates the discharge and therefore the radiation temperature. In this sense, it is necessary to define what is a black body. A black body by definition is one which is not transparent which does not reflected but absorbs all the energy.

Mind you, we are talking about just light, all forms of energy that is light as well as heat and is known to follow what we call Stefan Boltzmann's law which is shown here. It shows the radiant energy is proportional to fourth power of absolute temperature. Absolute temperature is in degree Kelvin's. If the temperature of the material is in centigrade, you basically add 273 degree Kelvin corresponding to 0 degree centigrade, W stands for the energy radiated output then k is the Boltzmann's constant which is 5.71 into 10 power minus 12, that's how it follows.

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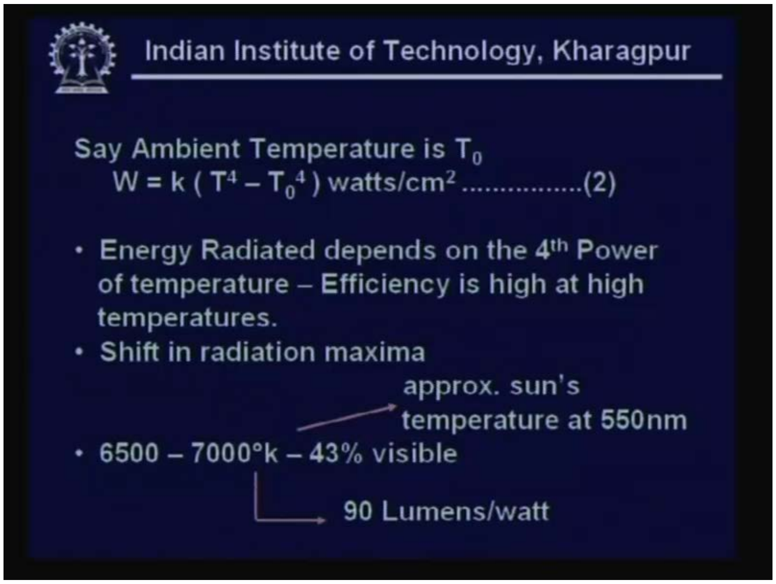

In case the ambient temperature is T subscript T_0 then the equations gets modified as shows here that is w equal to k multiplied by T raised to the power 4 minus T sub 0 raised to the power 4 watts per centimeter square. Now that means the radiated energy is proportional to the fourth power of temperature. Once again quantifying or re-emphasizing that the higher the temperature, higher is the radiation output and therefore efficiency is good at that time. Now there is certain shift in radiation maxima depending on certain issues, we look in to it. It must be mentioned, the 43% of the visible energy is around the black body temperature of 6500 to 7000 degree Kelvin and this is approximately the sun's temperature at 550 nanometers. That is corresponding to your relative energy maxima in the solar spectrum which we saw in the beginning and this would amount to an efficacy of light output of 90 lumens per watt. It must be mentioned that for most sources the light efficiency, the efficiency of a radiation of the sources is talked in terms of the lumens per watt of energy consumed. Lumens as we go along will learn that is the way we talk in terms of the light flux that is radiated.

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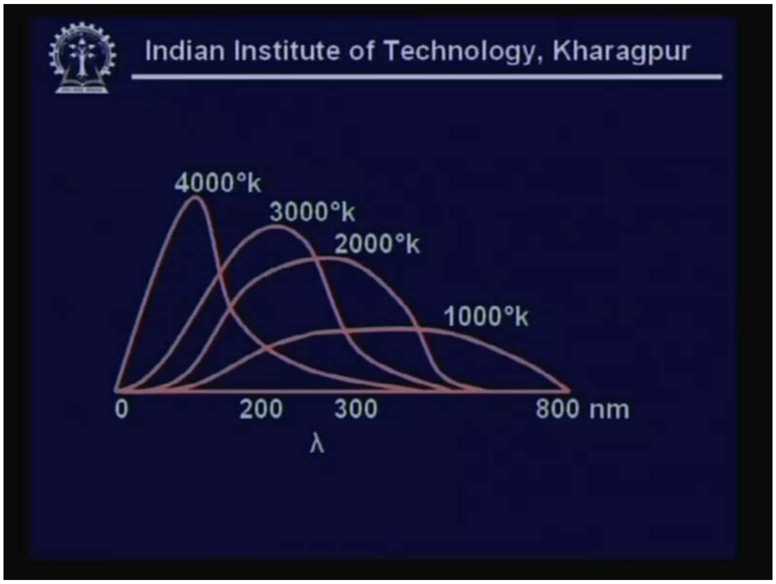

Here this diagram shows the radiation spectrum for black bodies placed at various temperatures. We can see the curve given for 1000 degree Kelvin, 2000 degree Kelvin, 3000 degree Kelvin and 4000 degree Kelvin. As may be seen for the curve corresponding to the body maintained at 4000 degree Kelvin, the spectral maxima is around 100 nanometers where as that for 3000 degree Kelvin is around 200 nanometers and that for 2000 Kelvin is around 275 nanometers and the 1000 degree Kelvin has around 400 to 500 nanometers. Another thing to be to observed, higher the temperature, the higher temperature is the relative maximum energy that is the two important issues.

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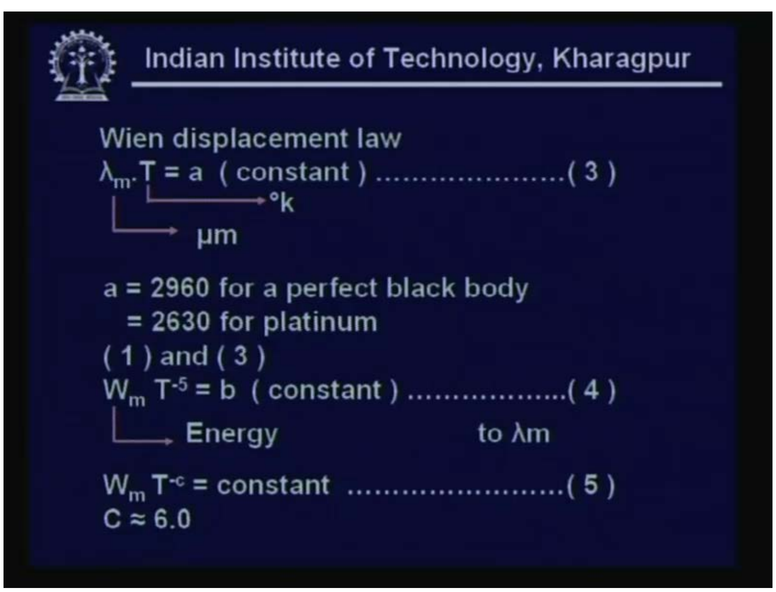

Therefore there is a certain displacement and this displacement of the maxima, we were talking about displacement, the displacement is the displacement of the relative maxima that is categorized or quantized in terms of Wien displacement law where $lambda_m$ the expression stands for the wavelength corresponding to the relative maxima and T is temperature and this product is known be a constant where T is the temperature of the black body in degree Kelvin. We saw if you recall we saw in this diagram, the black body maintained at various temperatures had different maxima. This occurrence of maxima at different points is what we call displacement and that is quantized by the Wien displacement law and it says it's a constant. This constant is known to be 2960 for a perfect black body and 2630 for a platinum body. So this is by combining, we had equation one which was essentially Stefan Boltzmann's law which showed how the radiated energy is proportional to the fourth power of temperature and the equation three which showed the Wien displacement law which says that the product of the wavelength corresponding to a maxima and a temperature are a constant. Combination, combining these two, one gets back W_m, W_m corresponds to the relative energy at the maximum lambda in to T to the power 5 minus is a constant b. Now this constant is known to be 6 for most of the things.

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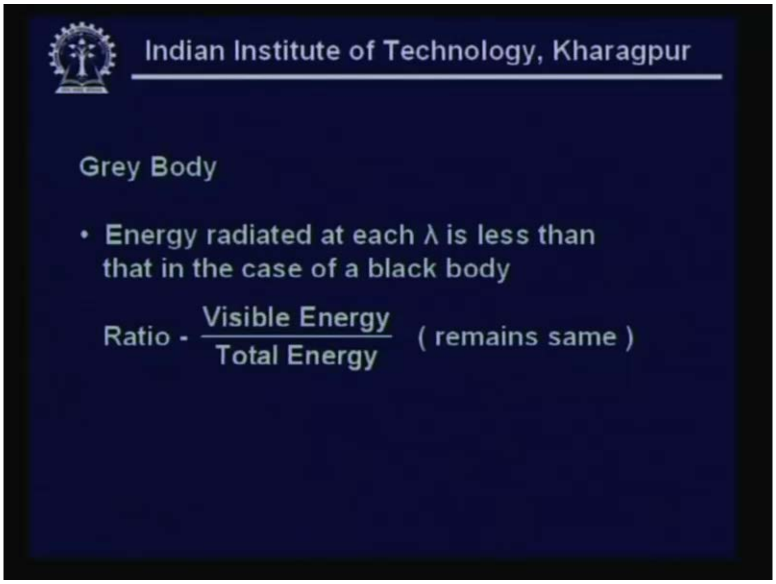

Now is the time we define what is a gray body? Having defined a black body, we define the other end what is a gray body. A gray body is one which radiates lesser energy than that in the case of black body. However one should bear in mind the ratio of the visible energy to the total energy is kept constant or remain same. That means a gray body is one which reflects a certain percentage of energy at each of these wavelengths or lambda. One good example of a gray body is a carbon filament lamp. When we study the incandescent lambs, it will become clear that the first of the incandescent lambs had carbon filaments.

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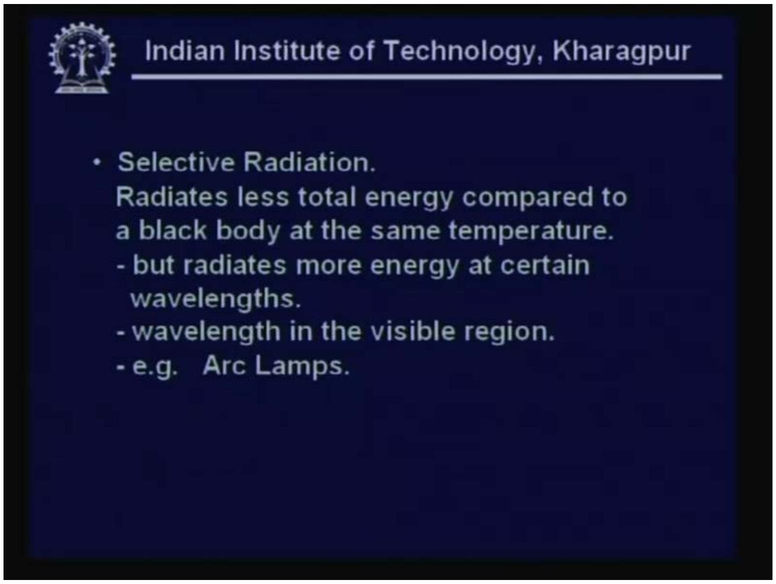

So as opposed to black body and gray body, we have what are called selective radiators. So selective radiation means radiates less total energy compared to a black body at the same temperature but it does radiates more energy at certain wavelengths. See a gray body reflects a certain percentage of light at all lambdas, on the other hand the selective radiator radiates more energy at certain wavelengths not all. And if supposing the lambda or the wavelength at which it radiates more energy is in the visible region, it will be useful for us as a source of light, artificial source of light and one such example are arch lamps.

Now having said this much, it becomes necessary to know how we categorize sources in terms of what we call color temperature. So we have seen that a material being maintained at a certain temperature is central to all kinds of sources. The four processes we saw were what thermo luminescence or incandescence, eletro luminescence or basically a discharge lamps, fluorescence absorption of energy at a particular I mean radiation of energy at a particular wavelength is converted into visible spectrum. The other hand the phosphorescence absorb radiation at one particular time is reradiated at a later point in time. And this can be compared in terms of a black body radiation and therefore we define what we call the color temperature. This is that temperature at which a complete radiator, we said that a black body must be operated to match the color of luminous source.

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So whatever source we have, when we say it has a certain temperature 1000 degree Kelvin as color temperature, it does not mean that it is going to be operated at 1000 degree Kelvin. It means that if a perfect black body is taken, it needs to be operated at that temperature to get the same radiation output. For instance the blue sky which is all pervading can be thought of having a temperature of 25,000 degree Kelvin where as a florescent lamp typically what we normally employ has a temperature of 4500 degree Kelvin. The day light what we have, 500 watt day light lamp has a 4000 degree Kelvin and similarly the candle flame which we are very familiar has a temperature of 2000 degree Kelvin.

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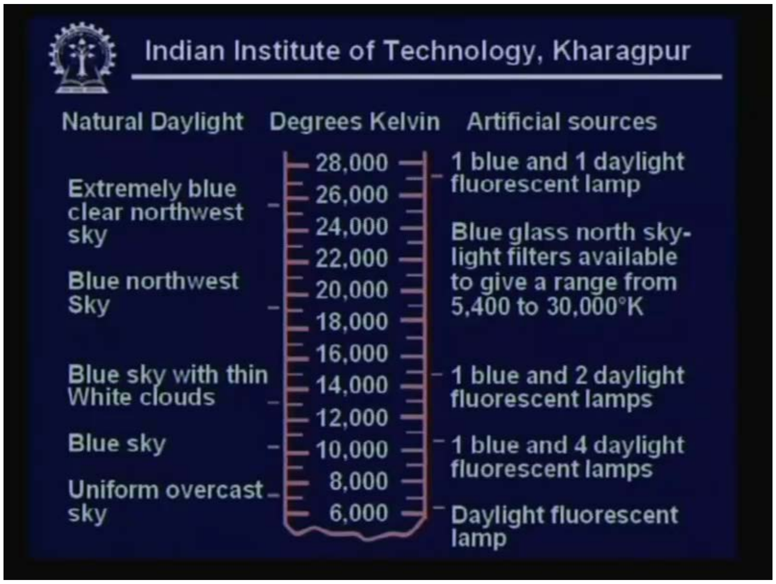

Now this picture in fact shows on one side you have three columns, in the center we have the temperature scale in terms of a color temperature. On the left hand side it talks about the natural sources and on the right hand side we have artificial sources. We said artificial sources could be using any of the physical process such as incandescence, electro luminescence, fluorescence and phosphorescence. As may be seen between 24,000 to 28,000, we have on left hand side is extremely blue clear sky whereas in the right hand side we have what are called as daylight fluorescent lamp. And likewise if you go down, you have blue northwest sky between 18,000 to 22,000 degree Kelvin and with thin clouds the temperature comes down 12 to 16000.

Now here on the right hand side you should observe that a single source is not mentioned, the combinations of sources are shown. As may be seen in order to get radiation in the zone 22,000 to 28 degrees Kelvin color temperature, we have to combine more than one source or use certain filters. As can be seen completely overcast sky, uniformly overcast sky can be compared to the day light fluorescent lamp which may be having around the 5000 degree Kelvin.

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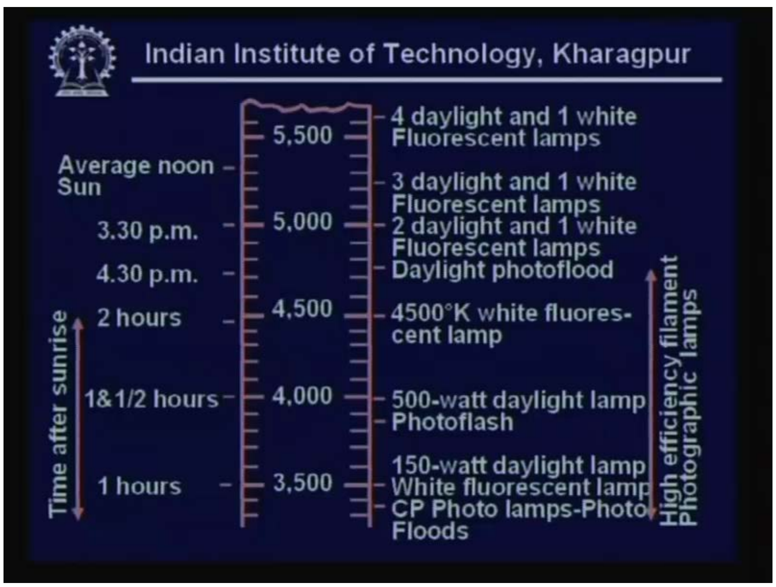

Continuing further, the average noon sun can be seen to see have around 5500 degree Kelvin which can be obtained with a one fluorescent lamp may be. Okay? This is how as we go along we see the difference kinds of a lamps 500 watt daylight photoflash lamp, 150 watt lamp all lamps as we go further down we find this thing and how the day’s natural light and artificial light color temperatures are going around.

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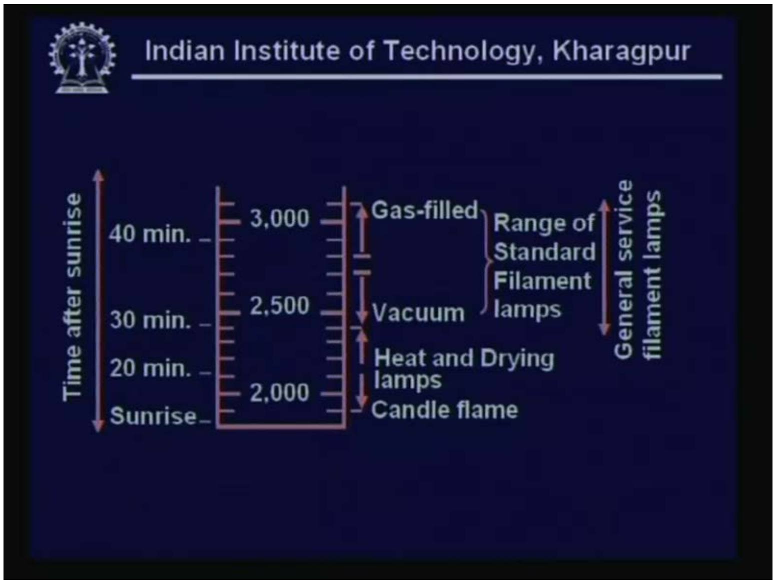

You can also see the range of gas filled and vacuum, as go we will see that the incandescent lamps which are put in a bulb or envelope, the glass envelope could be evacuated or could be gas filled. The gas filled lamps come in the range of 3000 degree Kelvin where as the vacuum lamps come around 2500 degree Kelvin. So you the, around the sun radiation is known to be around 2000 degree Kelvin.

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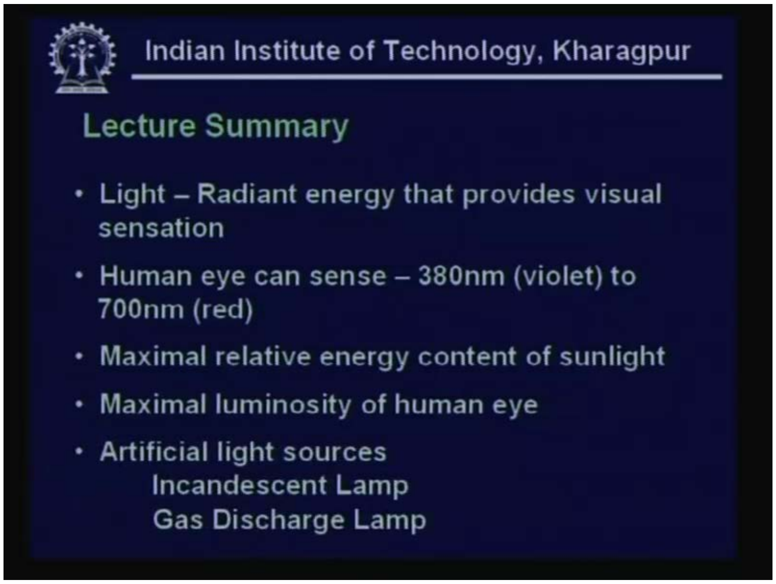

So having seen this, what have we learnt in this lecture? We have learnt that light is the radiant energy that provides visual sensation. We've seen how the spectral energy is radiated and it has a maximum around green yellow zone. And the entire light output can be categorized into three regions one ultra violet, two visible zones and three is the infra-red. And we've also seen that human eye responds to between 380 nanometers corresponding to violet to 700 nanometer corresponding to red with a maxima around 550 nanometers, coincident with the maximal radiant energy due to sun. Maximal relative energy content of sunlight and maximal luminosity of human eye as I already told to you both are around 550 nanometers. The artificial light sources as we know are incandescent lamps and gas discharge lamps.

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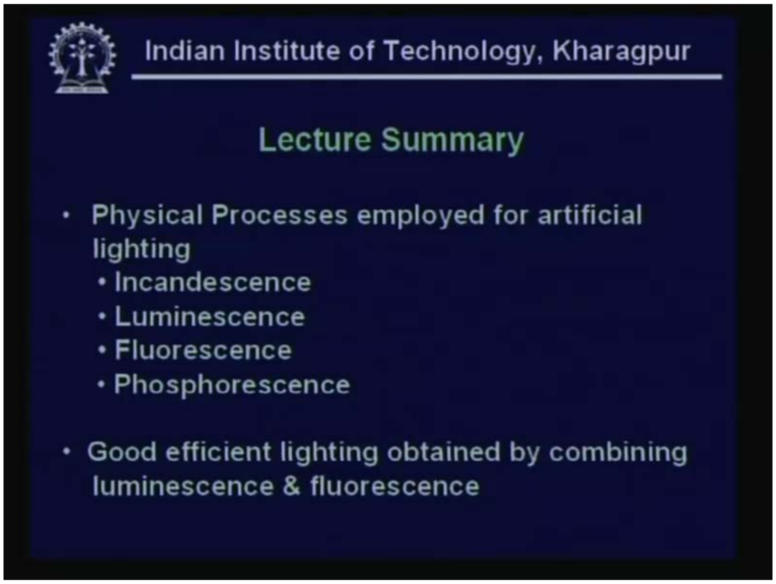

And continuing with this summarization, we have seen that the processes could be employed in the artificial lighting are incandescence, luminescence, fluorescence and phosphorescence. As told to you incandescent lamps are commonly employed, luminescence is all the discharge lamp which we come across, the sodium vapor, mercury vapor which we see in our street lighting. Fluorescent lamps commonly known as tube lights and phosphorescence is employed in luminous signs that are employed on highways. And now how does one obtain a good or efficient lighting, it is obtained by a suitable combination of incandescence, luminescence and fluorescence. Incandescence though produces a continuous spectrum has low efficiency, the efficiency of a light sources talked in terms of the light output per watt of energy consumed the light output as will be seen later is talked in terms of the lumens, light flux is talked in terms of the lumens, therefore a source efficiency is talked in terms of lumens per watt.

And the Stefan's Boltzmann law and Wiens law, Wien's is displacement law, for thermo luminescence are very important, they state that the radiation output is proportional to the fourth power of the temperature. And therefore in categorizing any light source we talk of a color temperature, the temperature at which complete radiator must be operated to match the radiation of the luminous source.

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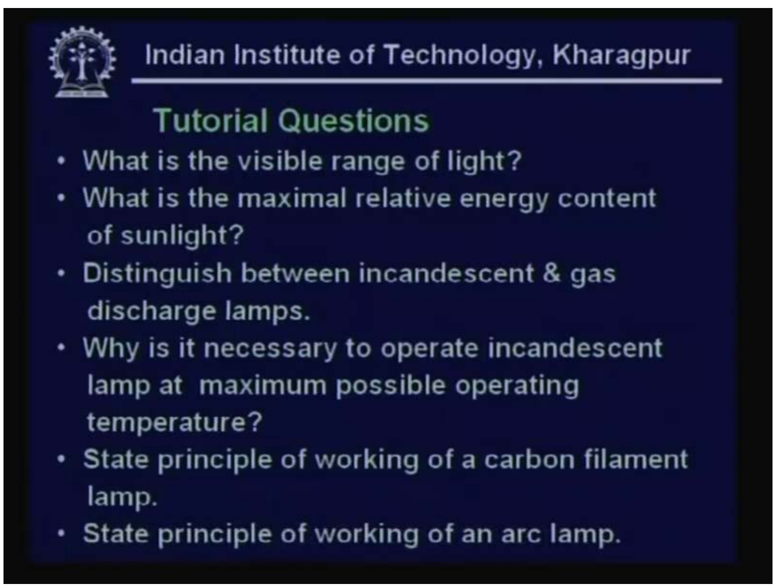

So with this there can be few questions that could be addressed to complete the lecture. The first question could be what is the range of light, the visible range of light, what is maximal relative energy content of sunlight or where is the maximal relative energy content of sunlight, distinguish between incandescent and gas discharge lamps. Why is it necessary to operate an incandescent lamp at maximum possible operating temperature, state principle of working of a carbon filament lamp, state principle of working of an arc lamp?

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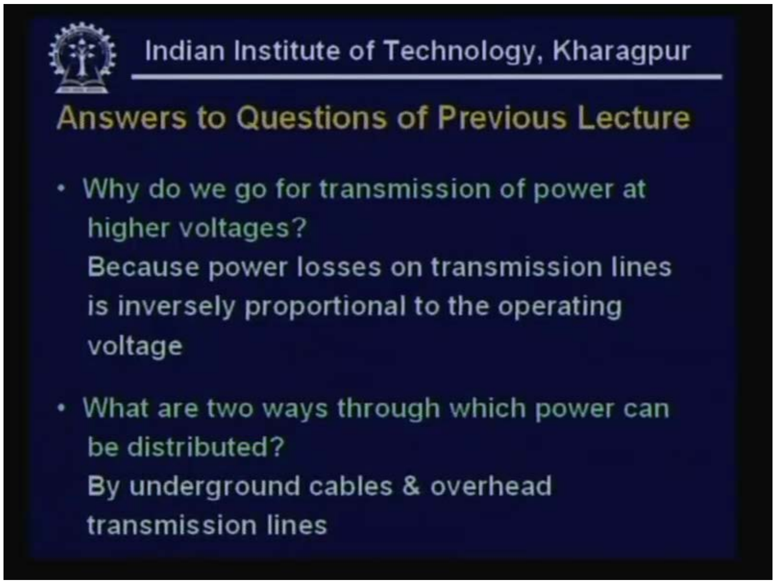

Now some of the questions proposed in the previous lecture let's try to answer them. The first question was why do we go for transmission of power at higher voltages because power losses on transmission lines are inversely proportional to the operating voltage. Two, what are two ways through which power can be distributed? As already brought out it could through underground cables or overhead transmission lines as told to you in the previous lecture in thickly populated metros, we tend to distribute through underground cables is sparsely populated rural areas through the overhead transmission lines.

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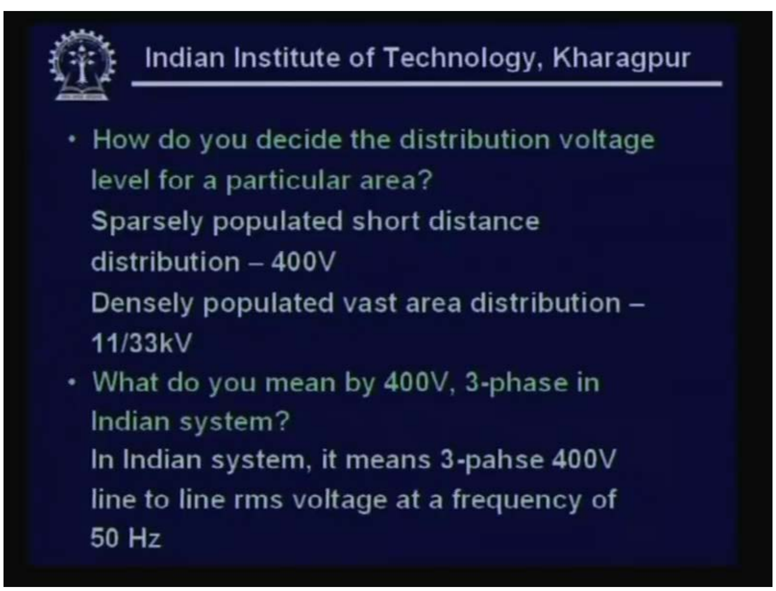

How do you decide the distribution voltage level for a particular area? As already told sparsely populated short distances, you can distribute at a low voltage that is 400 volts three phase whereas densely populated vast areas it should be at a higher voltage that is 11 or 33 kv. What do you mean by 400 volts three phase in an Indian system? As mentioned in Indian system, it means the supply is three phase, the voltage is 400 volts line to line RMS and the frequency is 50 hertz. Thank you.

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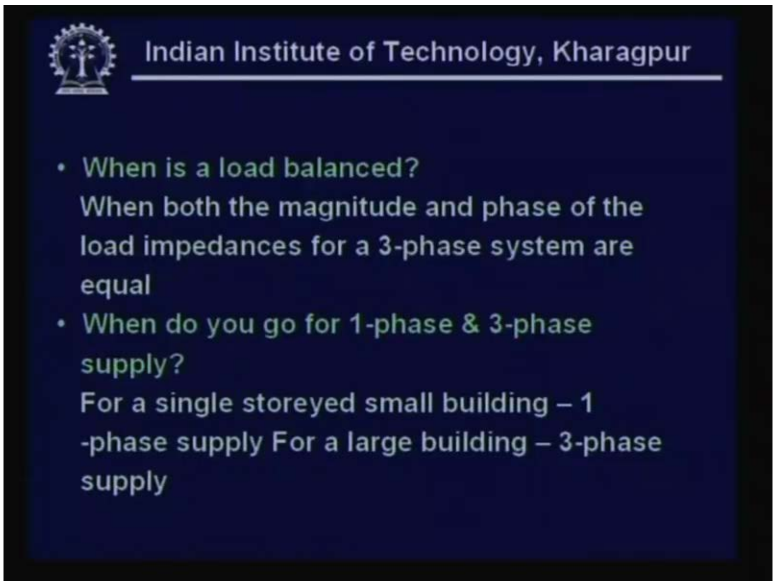

When is a load balanced, I am sorry. When is the load balanced? When both the magnitude and phase of the load impedances for a 3- phase system are equal, the load is said to be balanced. As opposed to this if either of them are different then the load is said to be unbalanced. When do you go for single phase and three phase supply? For a single storeyed small building, one could have a single phase supply, for a large buildings three phase supply. That means when you have large loads, you need to distribute, you go in for 3- phase supply. Thank you.