Illumination Engineering and Electric Utility Services
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Lecture No. # 05
Laws of Illumination

Welcome to this lecturer 5, laws of illumination. In the previous lectures we had seen the need for illumination and subsequently we saw how the natural radiation is spread and based on that we look to have the artificial illumination systems as close to the natural illumination as far as possible. And why are we doing all these? We are doing all these because 80% of our information acquisition is through our eyes, the most important sense and depends on the illumination levels and therefore the next two lectures had concentrated on the functioning of the eye. As it goes, in any face sphere of science and engineering it is necessary that we are able to quantify the things which we study. And we also know that the physical processes follow certain observed relationships which we call them as laws and hence the title of this lecture has been titled as laws of illumination. Before we proceed further we look at the objectives of this lesson that is to say that at the end of this lesson, one should be able to define what is the standard of illumination.

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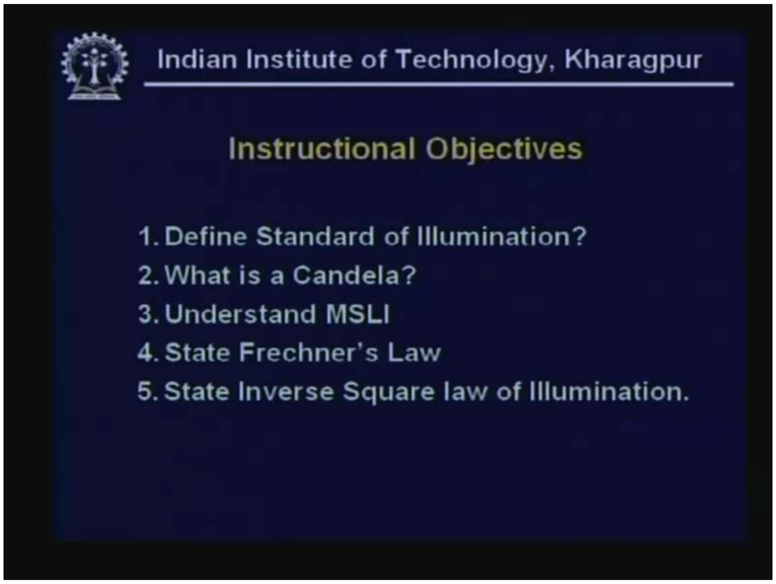

As already brought out to you quantification is a very important thing. It is not enough if I say that I have more light or less light, I should be able to give a value or hang a number to it to say that this is better than that and that's possible by way of standardization. And the way light is felt on the objects follows certain laws and that's what we going are to address. The second objective is listed as what is a candela. As we go along, we will know what is a candela. In fact incidentally candela is the standard way of assigning a light output and as may be understood, it is a variation of the term candle. All of us familiar with candle, whenever there is power cut these days of course we have emergency lamps but early days we used to use candles. And then there is a term called MSLI which stands for mean spherical luminous intensity and one needs to understand that. And as already told as title, the lecture title has laws, the one of the first laws that is associated with this luminous principle is Frechner's laws. So, one should be able to state the Frechner's law at the end of this lecture. And as has been with many physical phenomena, there is always an inverse square law associated. Recall the mechanics we have an inverse square law, recall electrostatic we have inverse square law. So it is interesting that most physical phenomena have the inverse square law governing the energy, delivery and utilization.

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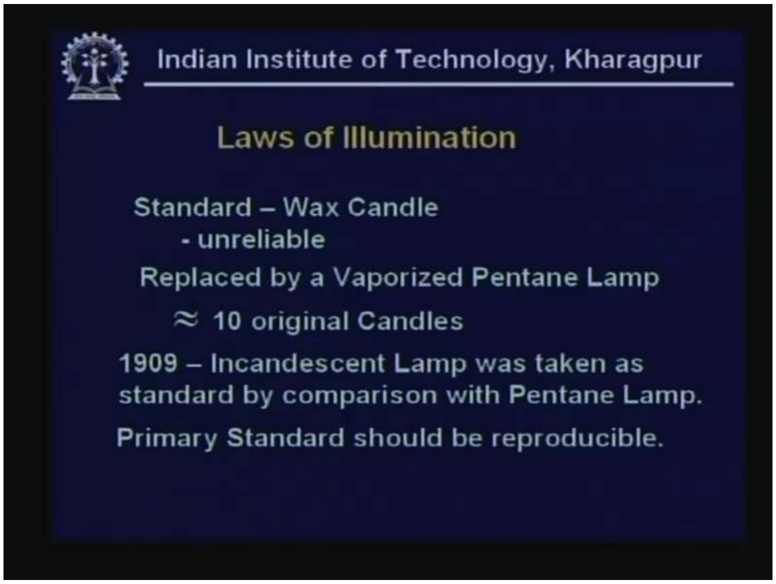

So, let's look at the laws of illumination and as I said before, we really going to laws of illumination, it becomes necessary for us to know how we are going to standardize the light output. And that is to say we are going to hang some numbers to the light and how do you do that? Because the first source of artificial light has been a candle. The first standard that has been adapted for light output has been a wax candle, however it is highly unreliable. Recall that in any meteorology or measurement technology, the standard adapted must be stable, must be reproducible from one laboratory to the other laboratory, hence it was considered to be very unreliable which was subsequently replaced by what's known as vaporized Pentane lamp.

A Pentane lamp running on the pentane vapor that is why it is called vaporized pentane lamp which emitted light approximately 10 times the original wax candle. This was subsequently taken which was subsequently in the year 1909, it was replaced by incandescent lamp and it is compared with a Pentane lamp. However this has not been used much because as already told, it should be reproducible which is not easily possible with the incandescent lamp, hence there was a move to look for a better standard.

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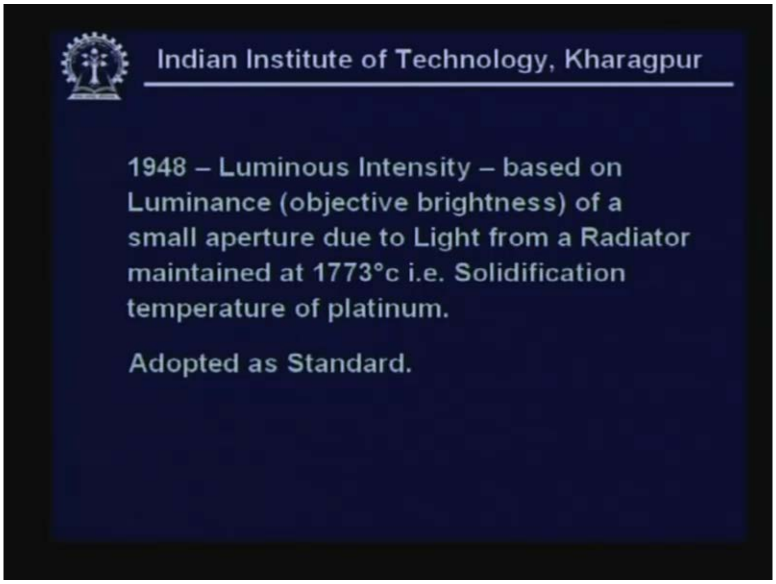

And probably in the year 1948, there was a better standard adapted and as written out here it was based on the light output from what is called as a radiator. Recall in an earlier class when we are talking about the physical processes involved in artificial light, we talked about various light output devices like black body, gray body, selective radiator, etc. So here we have standardized by considering a good radiator, radiating light through a small aperture and the platinum is been maintained at it's what do you call solidification temperature and that is being adapted as the standard.

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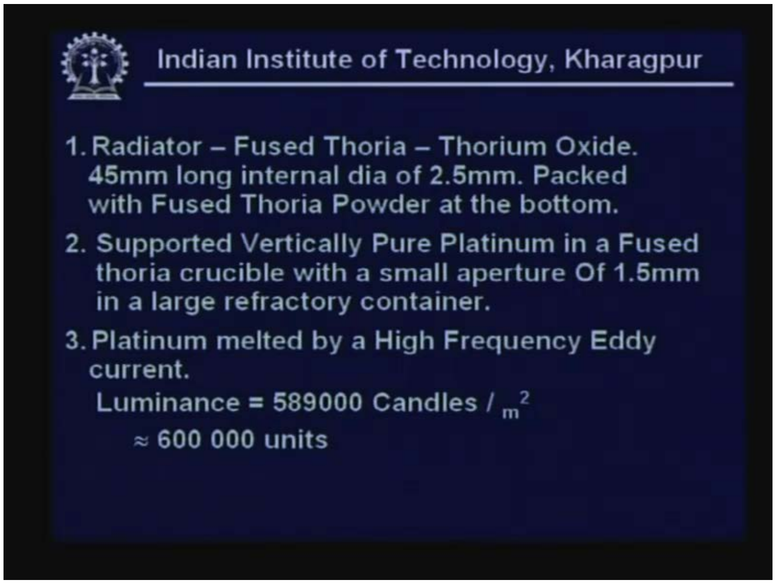

What are the components of this standard? These components of this standard are as can be seen, number one the radiator which is essentially fused thoria other words thorium oxide which is about 45 mm long with the internal diameter 2.5 mm. So this aperture is packed with fuse thoria at the bottom. This is supported obviously it is a powder packed, so it has to be put in a container. It was put in a container consisting of a fuse thoria crucible which had a 1.5 mm aperture and all these had to be kept in a good thermally insulted environment. And this is possible by keeping it in a large refractory container and the platinum, the pure platinum that is used is melted and it is to be maintained at what temperature? It is at the freezing or solidification temperature which is 1773 degree Kelvin. And to do that, the high frequency Eddy currents are adapted and it is observed that this gives rise to approximately 589000 candles output, light output spread over a units surface area. And therefore it was believed okay, though initially it was of this kind, it was later standardized as the light corresponding to 600000 units of original thing.

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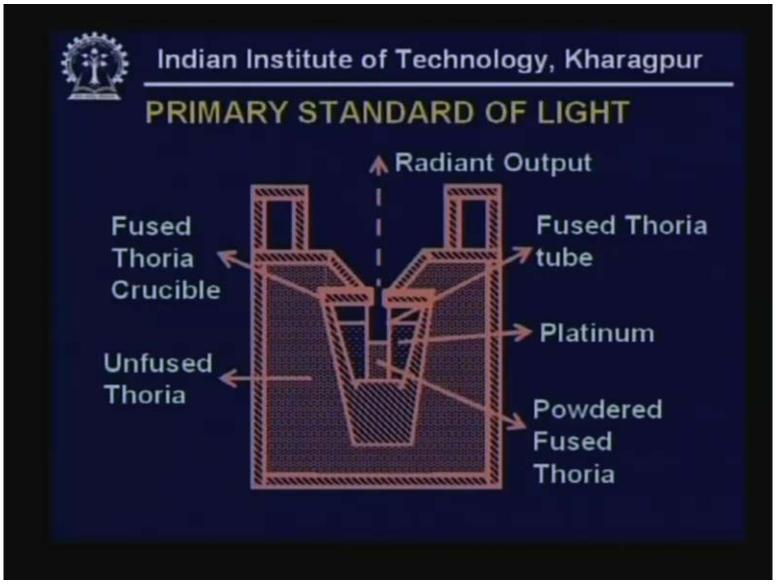

Let's have a look at the picture of the standard. As can be seen this is the primary standard of light. As you can see there is an opening from where the radiant output is brought out, this has got an opening of about 1.5 mm in diameter and there is a cubical which is fused thoria cubical kept in a highly refractory environment. As we said it has to be thermally insulated, so it's got an outer this thing consisting of unfused thoria in which in this cubical as already told, the radiator is pure platinum which is vertically supported. The crucible had a dimension of approximately 45 mm in length, vertical length and 2.5 mm diameter and this platinum is maintained in a molten state. That is at the solidification or freezing temperature of platinum that is 1773 degree Kelvin.

Now, this having been adapted, we said this gives out an output which was closed to 589000 candles per meter square which is been made equal to about 600000 units. So having said that the primary standard of light is this but today we adapt the light to be this and any light radiation output we compare has to be with respect to this. Having said this, we redefine our candela or what we said as the light output due to an original wax candle is the luminous intensity in the perpendicular direction.

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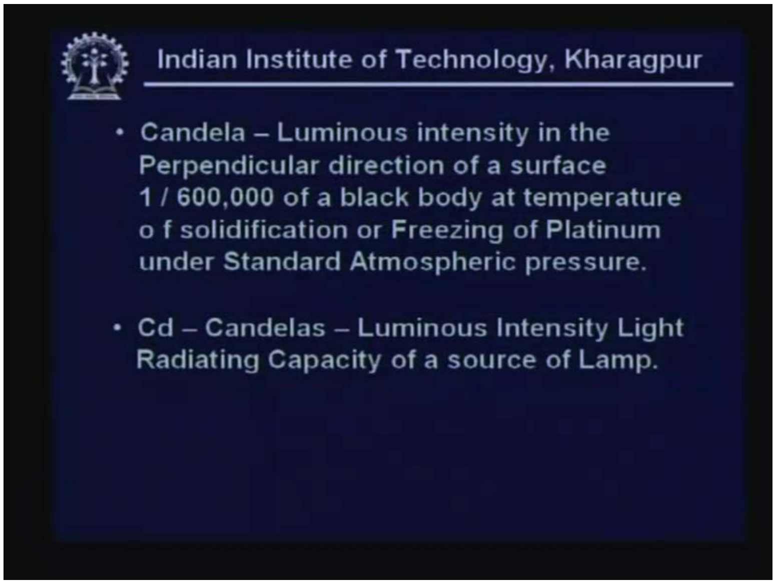

Obviously when we talk about the light output, we look at the ability of human eye to perceive the object when light falls in that. So we and this calls for the normal radiant, radiation to be considered, hence we talk in terms of luminous intensity in the perpendicular direction which is 1 by 600000. Recall we said the primary standard corresponds to about 600000 units of original candles, therefore candela has been defined as 1 over 600,000 of a black body which is nothing but here with platinum, pure platinum maintained at solidification or freezing temperature of platinum under what conditions. The standard atmospheric pressure. The candela is abbreviated as cd okay that means the candles or candela gives us an idea of luminous intensity or light flux radiating capacity of a source of lamp that is what it is.

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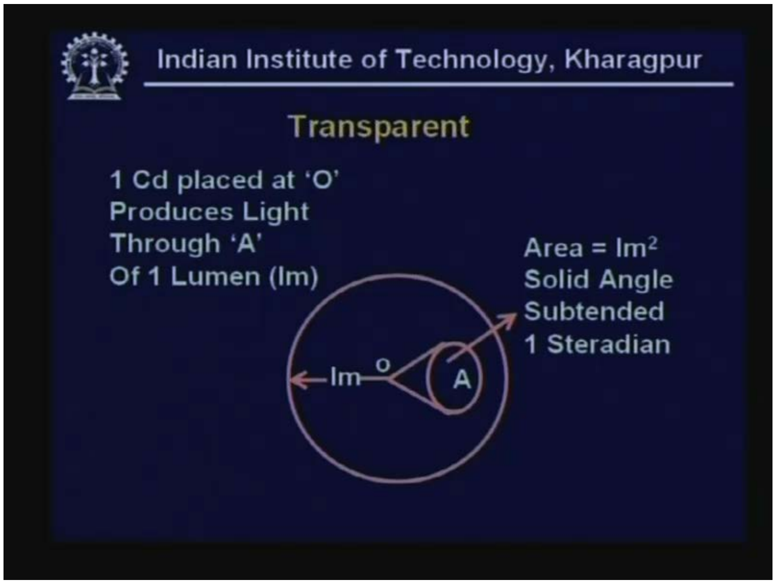

Now we go further try to express the effect of the light flux on the objects. Now how do we consider an electric system? We have a charge; we talk in terms of the field by talking at any point, the effect of this charge on a unit positive charge. The similar way one could define the light in luminous intensity at any surface. In order to understand this let us consider a transparent sphere at the center of which we place which is marked o, place a light source which produces one candela and consider on this transparent sphere which is, whose radius is one meter, consider a solid angle of 1 steradian. If we consider a solid angle of 1 steradian, it encompasses an area of 1 meter square only transparent surface. The normal light output during, due to this would be standardized as the basic unit of what we call luminous intensity and is defined or by definition we call it as one lumen.

Let us look at it once again, what did we do? We considered a transparent sphere of 1 meter in radius. We took a standard source whose light output is 1 candela placed at the center of this sphere O and then consider the light radiating out of this over a surface area or on the surface subtended by a 1 steradian solid angle. By the definition of solid angle, we know the radius is 1 meter and the solid angle is 1 steradian, the area and compassing surface which is marked here would be 1 meter square then the normal light output through this 1 meter square is termed as 1 lumen and this is the unit of a luminous intensity, just as the effect of electric charges is felt in terms of the force exerted by those charges on test charges at any point and the normal direction.

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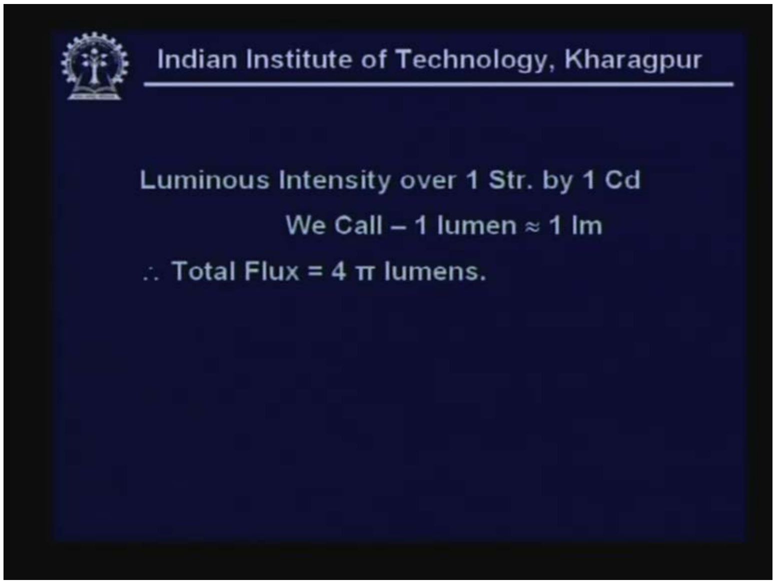

Similarly the light flux coming out of this source is felt in to the luminous intensity and it is standardized or its unit is by definition, the luminous intensity over 1 steradian by a 1 candela source on this surface of a 1 meter sphere is termed as 1 lumen. In that sense the total flux that's coming out of the source, considering a source placed in all directions about the source because if we consider all directions we can think of a spherical surface. And the total solid angle subtended would be 4 pi and recall we considered a sphere of 1 meter radius in that case total area would be 4 pi and therefore it is said that if we place a 1 candela at this center of sphere of 1 meter radius, we would get a flux of 4 pi lumens, that is the thing.

So how do we go about understanding this? We have defined the basic unit of luminous intensity which is nothing but 1 steradian, the flux coming out of 1 steradian by a 1 candle source placed at the center of 1 meter sphere is termed to be 1 lumen. And therefore total flux due to 1 candela placed at the center would be 4 pi lumens. As against this, if I take a source which has I candela, I is normally used to denote certain candle power of a source, this is also called candle power. See it is very simple recalling that the first and fore most artificial source has been wax candle that's how we have got. Let's see how we go about doing this.

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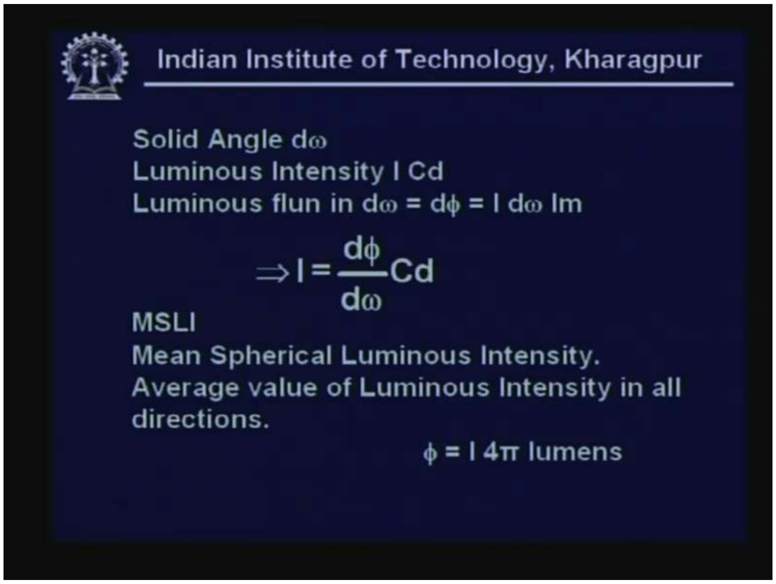

Let us consider the solid angle subtended over a certain area is D omega and then the total luminous intensity is I candela that is the source candela power is I candela, luminous flux in D omega, if we call it that is over the solid angle D omega is termed d phi then we have that as I into D omega lumens. Recall 1 candela over 1 steradian produced 1 lumen. If I have I candela over a range of D omega solid angle, it will be I D omega lumens. And therefore I say that D phi by D omega would be my I, the candle power.

Now there is another term which we often use with respect to these lamps because now recall after we started using electric lamps using thermo effect thermo luminance, it's been the incandescent lamps which are nothing but a filament maintained at a temperature placed at the center of a class envelope which means it had the ability of radiating light in all directions. So in a sense it could be viewed as a source of light, a point's source light, so it had the ability of radiating light in all 4 directions. It means the overall solid angle subtended by the light output is 4 pi and therefore the term means spherical luminous intensity is talked of, means spherical luminous intensity it means luminous intensity when considered in all directions. For a point source you will find that it is same equally distributed in all directions. When we go on to the control of gear, we can observe depending on the application one could orient the amount of light flux radiated in different regions to be varied and that's where it becomes somewhat important.

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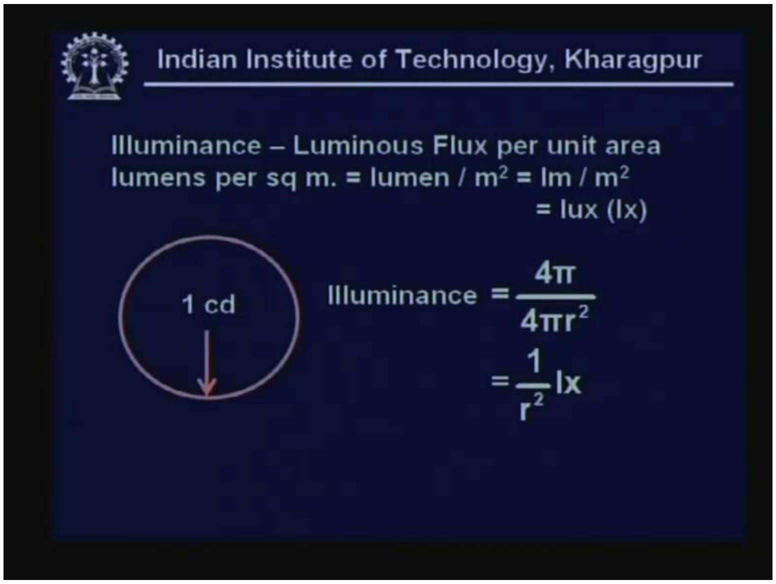

Now having said luminous intensity and the luminous flux, now how do we know how much light is really falling an object and we have to consider the area of the object into consideration. And this is defined by yet another term in fact that is what we call as illuminance. See we have not yet come to loss of illumination; we are in the process of standardizing the light output, we have learnt what is a primary standard. Now we have also learnt how luminous flux is defined and so we say the power, radiating power of lamp is expressed in terms of the primary standard and is talked in terms of candela and the amount of light that is coming in a particular zone is talked in terms of the luminous flux which is lumens and this luminous flux per unit area is what is termed as a illuminance.

It's very important because as you go along designing the illumination systems, you will find that we talk in terms of recommended illuminance levels for various applications. That is a very important issue. We talk in terms of lumens per square meter and this is categorized or standardized as lux 1 lumen per meter square is a lux. So illuminance if you consider, again observe the diagram shows at the center of a sphere we trying to get illuminance at any point on the sphere. So assumption again here is that the source of light is a point source. Let's say it has the candle power of 1 cd then the total flux considering the radiant in all 4 directions or all directions in the spherically would be 4 pi. Remember the area of this sphere is 4 pi r square and hence the illuminance would be 4 pi by 4 pi r square or 1 by r square lux. So illuminance radially away due to a point source at a distance r can therefore be talked in terms of.

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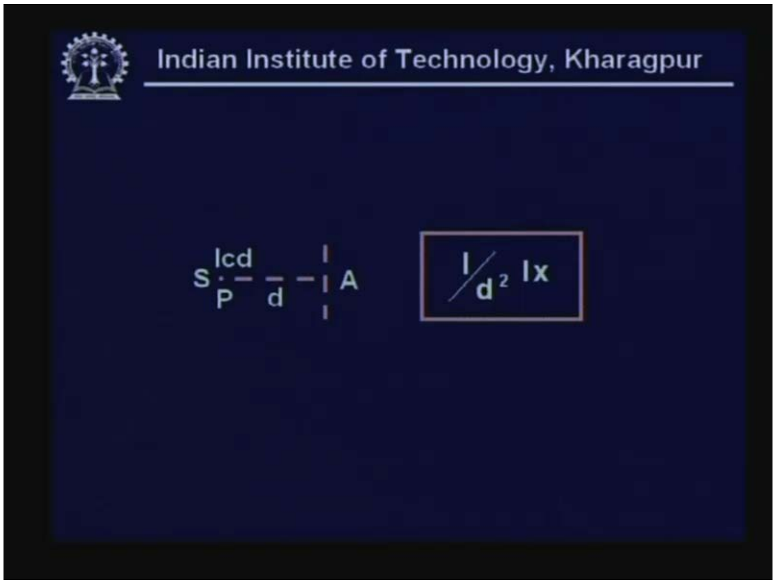

So observe the figure here we are looking at a particular source deemed to be a point source marked s placed at a point P and has the candle power or luminous intensity of I candela distant from a plane of observation at d units. Then on the illuminance in the surface by definition is I by D squared lux. Now in trying to find illuminance, we are looking at the normal, normal light flux incident. It is quite possible that there is every chance of light coming in an oblique direction. So some of these issues have to be addressed by way of considering how this is governed but it's time we took at the first of these Laws which we call Frechner's Law.

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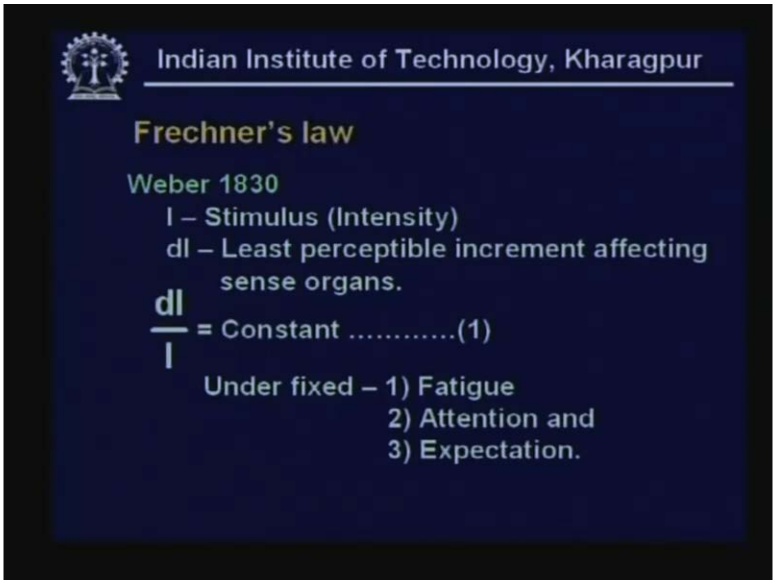

This is based on an observation made by Weber in 1830. This is about the way human sense organs respond. Consider a stimulus of intensity I and let it be having a least perceptible increment that can effect the sense organs as dI. The observation made by Weber says that ratio dI to I is a constant. This is under the situation, remember talking of the way I functions we said there are certain consideration the way I functions, fatigue is one important things. So this observation says that it holds good under fixed fatigue attention and expectation. See there are two things, the eye perceive is the physical device thorough which you allow the light or the information to get in to it but it is the brain that processes and you are able to see that means there is some amount of expectation. Often it is said you read what you want to read more than what is written unless it is properly written. So what is the Weber's observation say? It says if there is a certain stimulus I and it has a least perceptible increment dI that can affect the sense organ, the ratio of DI to I is a constant.

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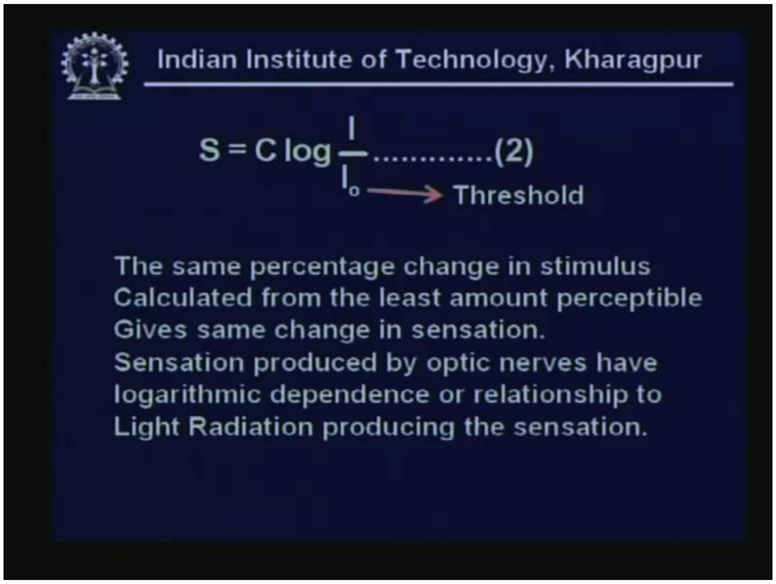

This is further examined by the Frechner's with respect to your illumination and he has found that there is a logarithmic dependence as far as optic nerves go and that is expressed as S sensation produced by optic nerve has. So what do you have, S equal C log I by I_0. What this I_0? I_0 is the threshold that is the minimum of luminance intensity that is able to produce any this thing on your eyes. So there are, this aspect has to be kept in mind that while designing light sources because any change how it is going to affect our human eye is depended on this Frechner's Law. The next thing as I said the inverse square law just as in any other physical system we have, this in fact is very apparent even from the varied definition of a illumination, illuminance.

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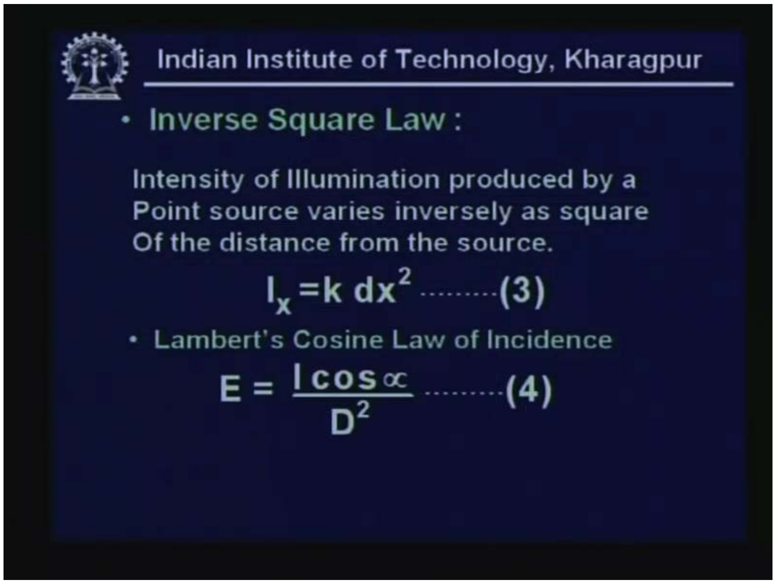

We said the illuminance at any point due to a point source turned out to be the ratio of luminous intensity to the square of distance between the point and the thing. So we find, so this is what is expressed in this equation. I am afraid that in this equation 3, it should be I_X is equal to K by dX square not K dX square, to that extent there should be a correction where dX square is the distance. Now talking of the illuminance, we consider these light coming in the normal direction from a point source when defining the illuminance or considering the inverse square law in it' basic form but we did mention that it is quite possible that the light from the source may not be radiant on the object, incident on the object in the normal direction, it could be obliquely designed.

How do we go about taking care of illuminance and those conditions? Illuminance however defined in terms of the normal light output and therefore this is by definition obtained from what we call Lambert's Cosine Law. So how many laws we have seen? We have seen there are three basic laws, the first law says that the ratio of luminous intensity, two the perceptible change in the luminous intensity is a constant and this sensation with respect to the human eyes is logarithmic in nature that is a very important issue. So you cannot keep on increasing the illuminance, light output luminous flux and at expect your eyes to up get better and better. So since its logarithmic the marginal increase may be enough beyond that unless you try to have more uniform flux radiant, you cannot get any improvement in the observational characteristics. Second one is actually direct corollary of the definition of illuminance which says illuminance is inversely propositional to the square of the distance. This becomes more clearer.

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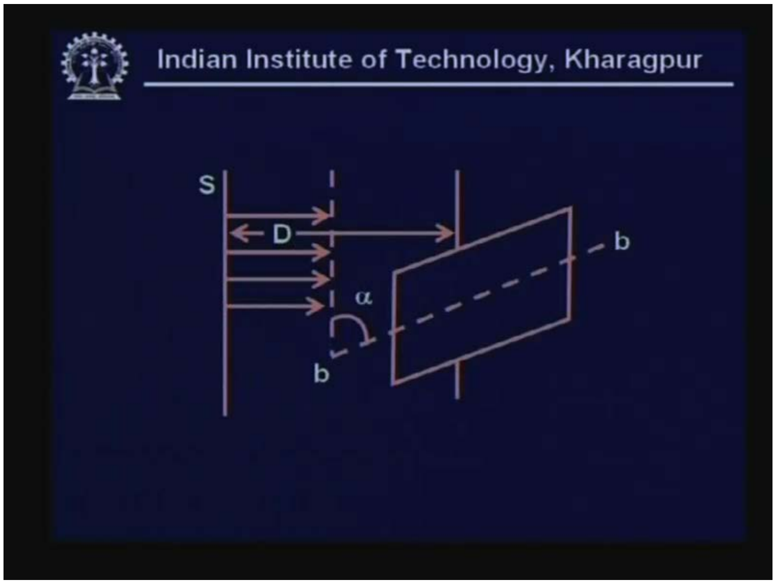

Now here in this picture what is it we are trying to see? You observe that there are 3 planes, 2 planes, one is source plane marked S, it could be an array of lamps which are radiating light in the normal direction shown by a thick arrows pointing from S towards right. The normal plane with the object plane, object plane is inclined at an angle alpha in fact we said mentioned about Lambert's cosine law, this alpha in the cosine law comes from this angle between the normal plane and the plane of the object. When we write I cos alpha, what is it we are doing? We are essentially taking the total light flux incident on the normal plane. So that is what it is, you can see that it is at an angle alpha, bb is the axis passing through the object plane on which the light is incident and you are trying to observe.

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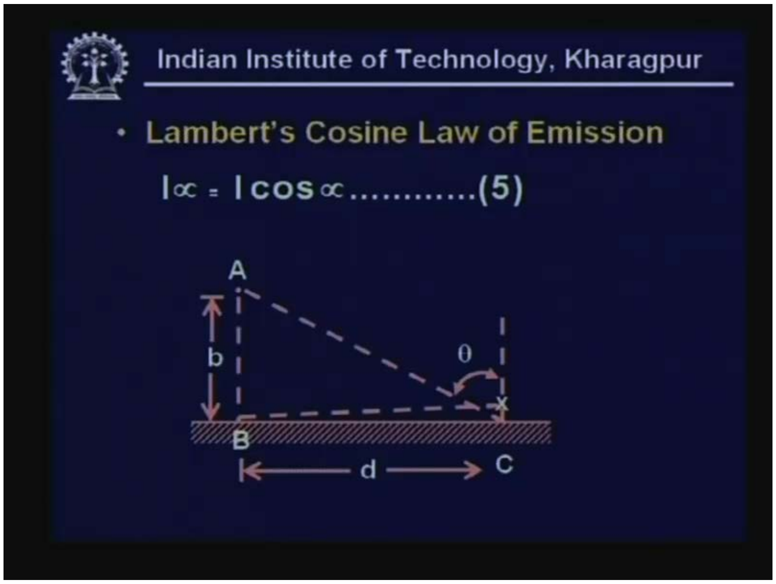

So it says I itself on that is proposal to I cos alpha that's obviously you can resolve the light into the normal component and the horizontal I mean the horizontal components. Now let us extend this and try to analyze for various situations in fact incidentally this law is also called as a law of emission. Now this picture out here shows this is a typically scenario, you find a lamp placed or a source placed at point A and the line bc is essentially a line on the floor let us say, this can be viewed as a the typical room with the light hanging from the ceiling suspended at a height b from the floor. So if you go by the definition of illuminance, one could work out illuminance at varying point on the floor and how it varies, okay. So this can be, this is in fact applying the definition of illuminance. The definition of illuminance is what? It says if the candle power of source is I then illuminance at the point of interest is I over the distance square.

Let's say we look at a point right below the lamp that's where you have I over b square which means it's got the maximum normal illuminance. Now observe when we move to the point C, the radially outward light rays are inclined to the normal axis and therefore normal light flux would no longer be I but it will be I cos theta, theta is the angle subtended by the radial output in the source and the normal axis to the point of the observation. And what is a distance? Distance is d. So we find that recall this angle can go from theta equal to 0 to 90 at the most. You recall if the point of observation is B right below the lamp what is theta? Theta is 0 in that case because the radial output light ray and the normal axis are co-incident theta is 0 where as when you go along away from the lamp farther and farther you are going to get theta higher and higher. And we know that when you move from 0 to 90 degrees, cos theta goes from 1 to 0, it reduces from 1 to 0 and that been the case you have a decrease in your eye normal light flux as you go away and luminance is depended on the distance between the source and the point of observation. As can be seen very clearly at the point B you have the minimum distance hence and you have the maximum light flux, normal light flux which means you have maximum illuminance right below the lamp. Going by this we can draw the illuminance as a function of your d by, it should have been d by b, it's not d by n and it is marked over a distance of what you call from 0 to 3.

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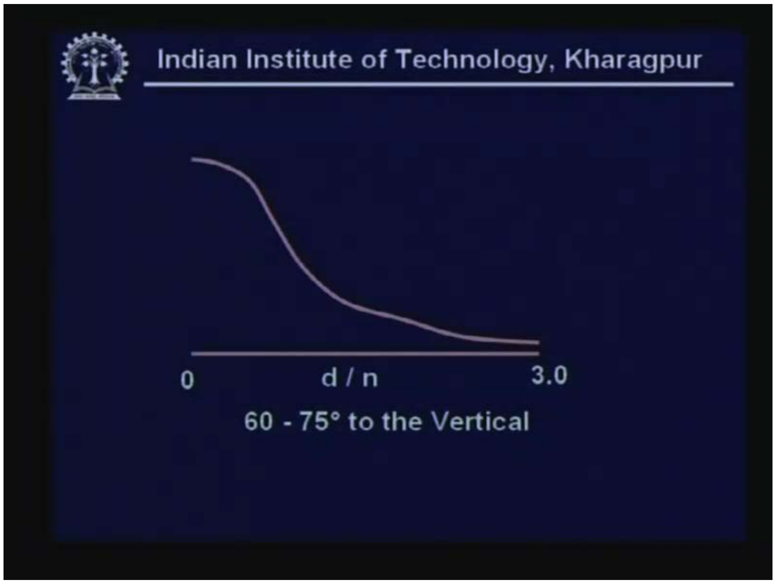

If you observe carefully, initially for some small distance it is near about the maximum, this can be the curve pertaining to your luminous intensity or illuminance. And as can be seen it's nearly same as under the lamp only for short distance that is you can allow or have nearly same amount of illuminance or light flux only over an angle of 60 to 75 degrees from the vertical. That is this theta which you are observing beyond that it would give very large depreciation, it could be ineffective and this aspect has to be borne in mind in trying to have uniform illuminations. It is obvious supposing I am working on a cable which is typically 1 meter by half a meter, I would like to have as nearly as possible same illumination level all through and that is the issue. And the single lamp may not serve to have completely uniform illuminations and therefore you one may have to go in for more than one lamp.

We will also see that as against the points source a line source, line source recall the florescent lamps or tube lights which we use are nothing but line sources of light and just as we found that light flux is inversely proportion to the square of distance for a point source. We can see a similar direction that due to the line source would be inversely proportional to the distance as against square here and if you are able to have a large sheet of light, it could be independent of that distance. So these are some of the things we will revisit as we go long. So now going back to the thing. We take this example, we try to express illuminance along the distance away from the point below the lamp. As can be seen this is how the illuminance is going to vary that is very important we said this source that in our trying to have the systems, we should keep in mind this angle theta between the radial light ray and the normal to the plane should not be more than 60 degrees to the vertical.

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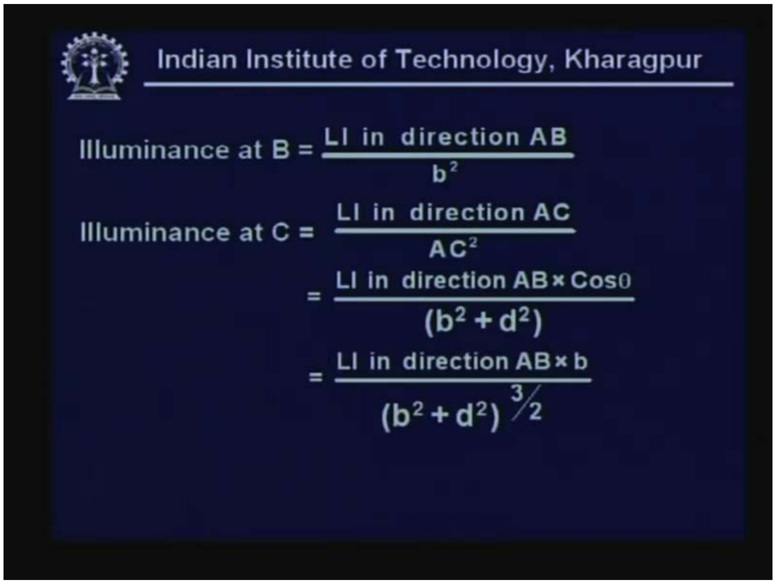

Illuminance at the B therefore is luminous intensity or the candle power or candela in direction AB. Recall the diagram, we had a lamp located at the point A and right below we are talking about the point b is right below the lamp and the height between this point and the height of this source above the floor is B units and therefore it is luminous intensity direction AB by B square. Whereas, what should be the illuminance at C? It should be luminous intensity in direction AC by AC square and which is luminous intensity in direction AB into cos theta by what is AC square is b square plus d square. And you find that the luminous intensity at, in terms of your AB one could… So you find this is how it can be expressed and this rate, this is how one has been able to draw this curve with respect to distance observed that in this relationship you could, you can bring this b and this is how one does.

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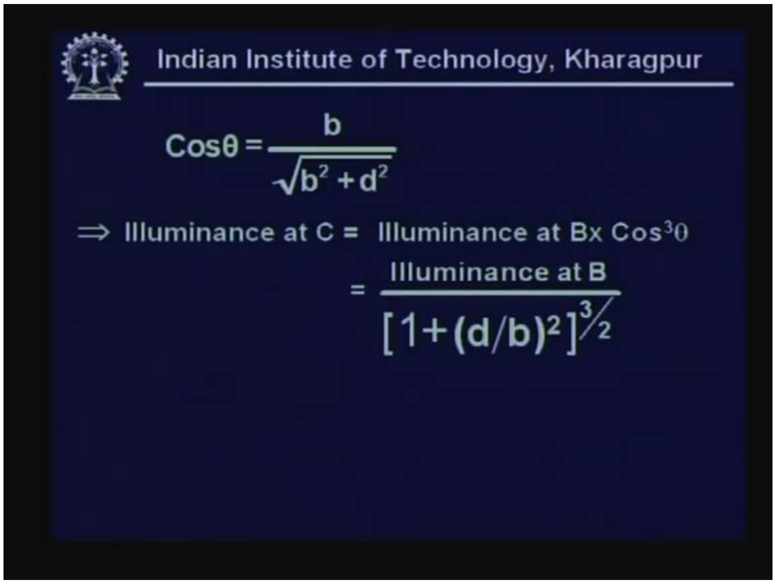

Remembering cos theta is B by, so what do we get? We get that illuminance at C is nothing but illuminance at B into cos q theta or expressed in other words is 1 plus d by b square cubed. So this is how and all this says that illuminance is a maximum right under the lamp and it keeps on decreasing and the variations is going to be this nature and should be, it is best used only when it is kept that the theta within 60 to 75 degrees. Now having said so much about the way to standardize the light output, we said it is in terms of luminous intensity which is unit of which is a candela which is based on the wax candle later adapted as the platinum or a radiator maintained at melting or freezing point of the platinum in a thoria crucible which has adapted as a standard primary standard which is equal to how much? 600000 candelas, light output due to that is 600000.

Now if that be the luminous intensity then we define the luminous flux as categorized in terms of lumens and for a point source, we say it emits light in all directions uniformly. And therefore we talking in terms of a what we call mean spherical luminous intensity and total light flux is in all directions, therefore subtends over 4 pi steradians of solid angle and hence is termed in terms of 4 pi I and it is where I is the candle power and is termed in terms of the lumens. Now once you have the luminous intensity and luminance, the effect of this on the plane of the observation is talked in terms of a illuminance which is luminous flux per unit area is talked in terms of lumens per meter square or lux.

Now all these is governed by set of laws which we call them laws of illuminance, illumination. First law is that due to Freshener which tells the behavior of I based on the least perceptible stimulus that affects our sense organs and which was initially observed by Weber or in biological systems later they can observed by Freshener for optical systems. The sensation of the optic nerves is logarithmically depended that means increase in light beyond certain level would not really make much a difference put in other words. The second law, the law, inverse square law which is a direct outcome of definition illuminance which says it is 1 over x square where x is the distance i over x square and this applied to any arbitrary plane is taken care by Lambert's cosine law of emission. So having said this, the immediate requirement would be to access any of the systems that we have and the measurements or assessments test methods are in fact called as photometry.

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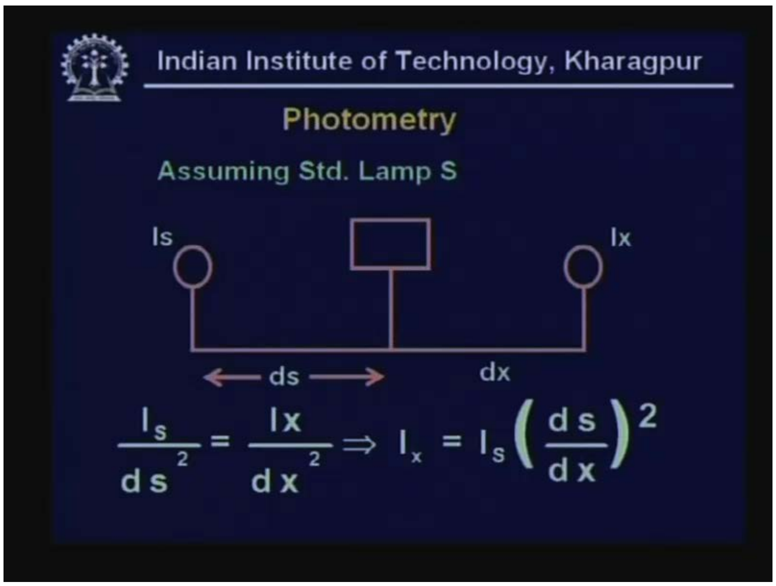

And this invariably would have a employing, what is called as photometric bench on which the on one side the standard lamp is placed I s of I candela. This could be an incandescent lamp which is compared with the primary standard which is nothing but a perfect radiator maintained at the temperature of freezing or solidification of platinum and Ix corresponds to the, what you call the test lamp. What we find is the square screen, this is the dark screen placed at the center and which can be made to move and it is essentially balanced obtain same level of illumination on either side from this lamp or that lamp, normally incident on the screen from the balanced this distances one could obtain the value of I.

So this we will look at in detail. That means what we're trying to do? We move this central screen till such time the illuminance on either side is same. Illuminance recall is nothing but luminous intensity by the distance square, so you have I_s by d s square is equal to I_x by dx square. So this becomes the important and in fact more details of these photometric methods could be covered in a subsequent lecture.

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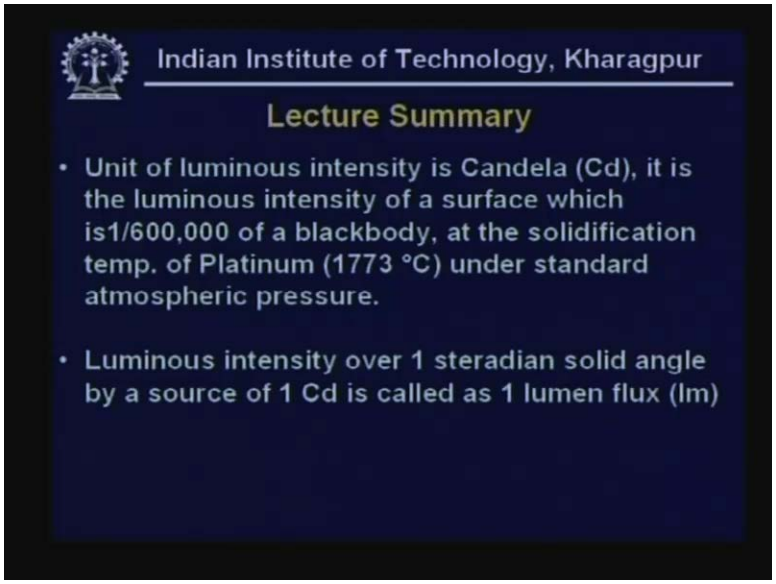

Coming to the summary of the lecture, we have defined the basic unit of light flux as luminous intensity is a candela which is the intensity of a surface which is 1 by 600000th of a black body at the freezing temperature of the platinum which is 1773 degree Centigrade under standard atmospheric pressure.

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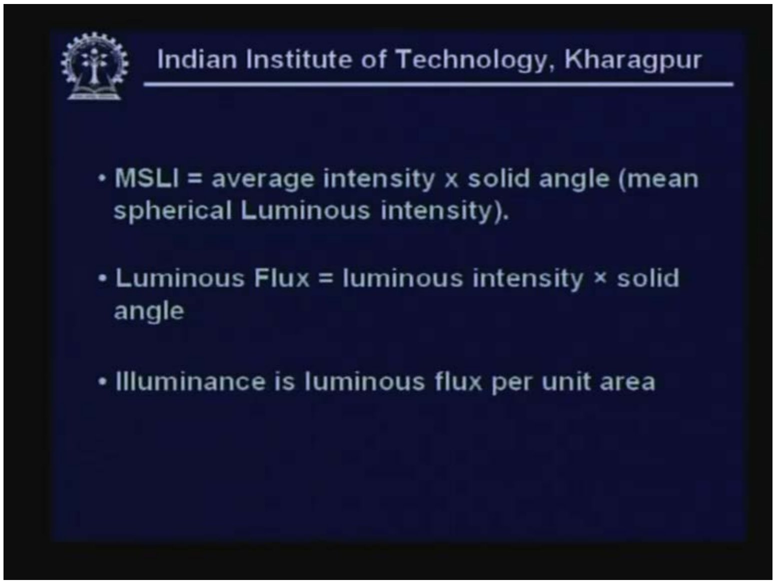

The luminous intensity over one steradian solid angle by a source of one candela has been termed as the unit of flux which is one lumen means MSLI is used with all points sources is the average intensity into solid angle which is mean spherical luminous intensity in all directions.

Luminous flux is luminous intensity in to the solid angle, illuminance is the luminous flux per unit area.

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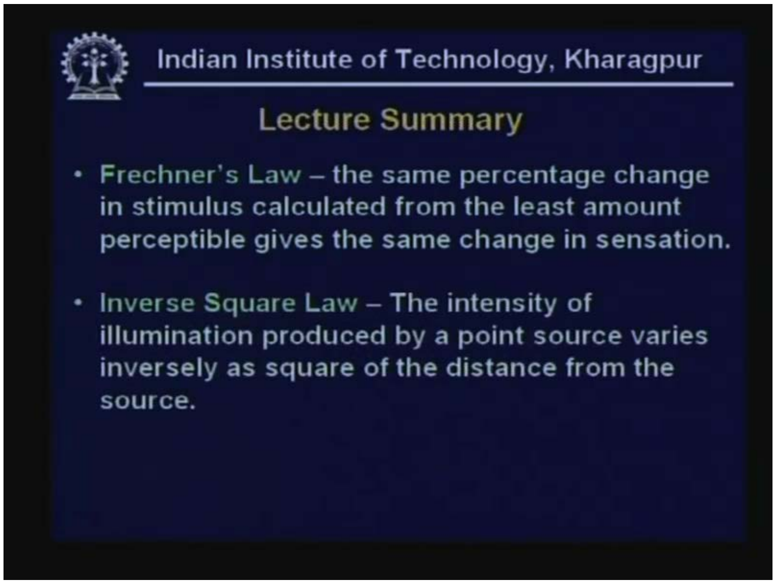

And the Frechner's law gives us the idea of the response of the eyes which says same percentage in stimulus from the least amount perceptible gives the same change in sensation. Inverse square law is nothing but the definition of illuminance which says illumination varies as a square of the distance inversely.

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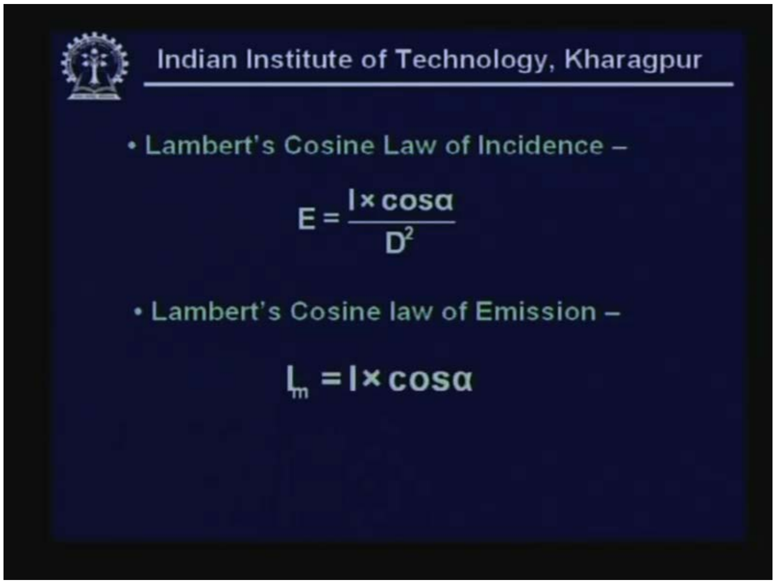

Lamberts Cosine law of incidence is useful in estimating. Here E is the luminous intensity at arbitrary point in arbitrary direction which is I cos alpha by D square. This is cosine Law of emission talks about candle power, incidence talks about the luminous intensity illuminance that is the lux.

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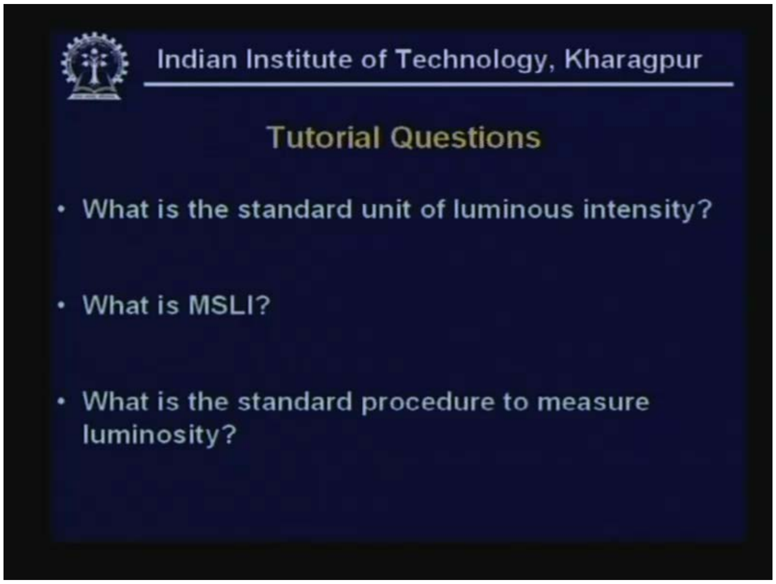

Some of the questions that can be addressed from this lecture are what is the standard unit of luminous intensity, what is MSLI, what is the standard procedure to measure luminosity.

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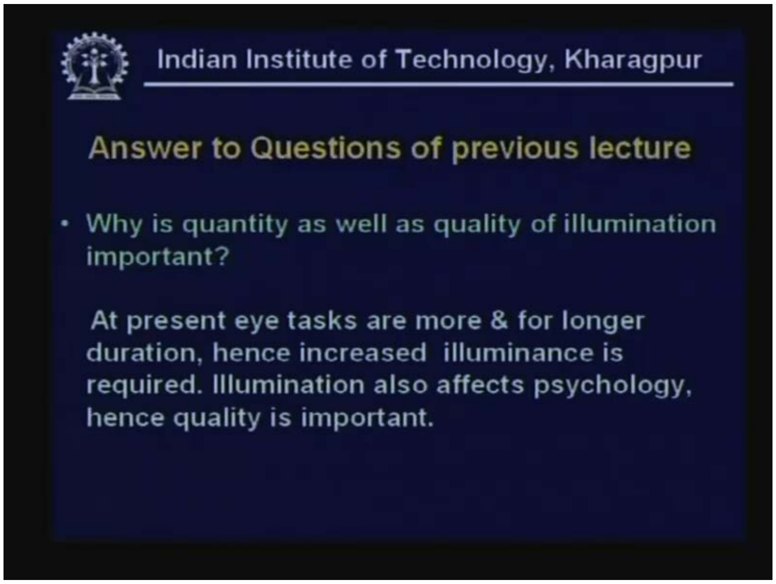

Some answers to the previous lectures questions: Quantity as quality of illumination are important, why? At present eye tasks are more and for longer duration and hence increase illumination, illuminance is required. So illumination also affects psychology hence quality is important.

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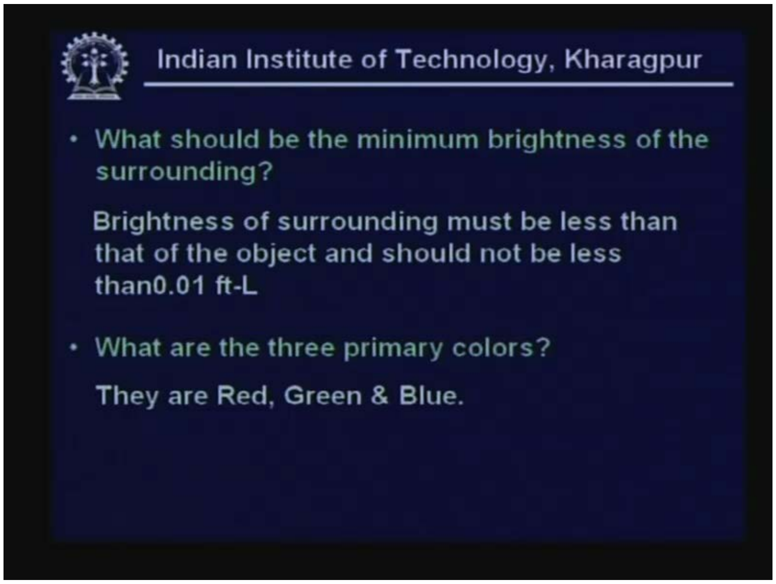

What should be the minimum brightness of the surrounding? Brightness of surrounding must be less than that of the object and should not be less than 0.01 foot lamberts. What are the three primary colors? As already known they are red, green and blue.

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How does aging leads to loss of vision? As can be said aging leads to decrease in adjustment capability of the focal length of the eye thus higher illumination is required for older people.

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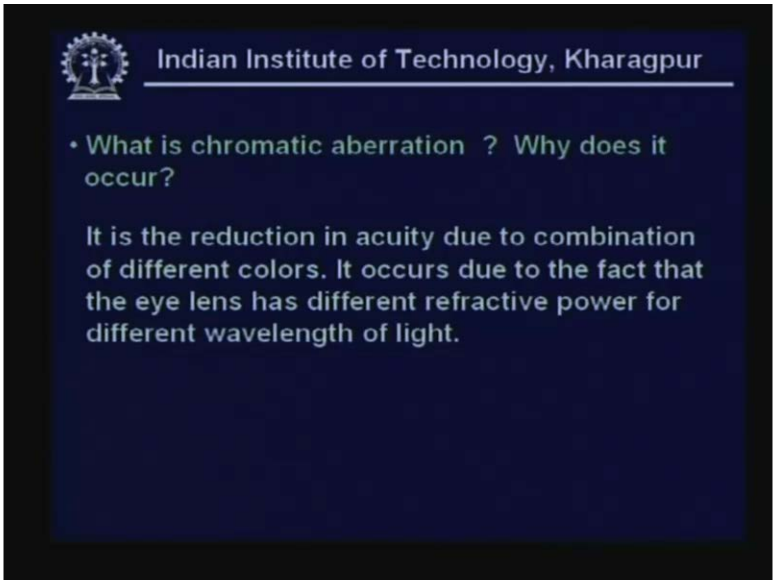

What is chromatic aberration and why it occurs? It is the reduction in acuity due to combination of different colors. It occurs due to the fact that the eye lens has different refractive power for different wavelength of light. Thank you.