Conduction and Radiation

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Lecture - 2
Blackbody Definition

So today, we will look at a very important concept in radiative heat transfer namely blackbody. The definition of blackbody, its properties right and then this is central to the study of heat transfer; it is like the definition of God and looking at the properties of God, because it is essential to understanding spirituality. So, like that a blackbody is the benchmark; there is no perfect blackbody in the world. Do not extend the argument I am saying. So, we we define the properties of real surfaces based on some benchmark. That benchmark is the highest always getting CGP of ten and all this and this (( )). So, something like that is a blackbody.

So, we have to formulate, define the blackbody and look at some concepts underlying these definition and also some of the properties, and then we look at solid geometry and once we have definition of blackbody and then this solid geometry, then we will go on to the radiation laws namely Planks distribution before that the Rayleigh Jeans distribution which means displacement law The Stefan-Boltzmann's law and. So, on then it will be followed by properties and. so, on.

Now, blackbody. What do you think a blackbody is?

Absorbs radiation at all ways.

Does other bodies also absorbs radiation at all? Does not it also allow you to go through? Therefore, your definition is partially correct, but it is not fully correct.

Absorb and emit is a different story. Do not do not talk about emission already (( )).

Absorbs hundred percent of all radiation.

Absorbs hundred percent of all radiations incident on it and allows hundred percent of radiation incident on it onto itself and internally absorbs all of it. So there are two part of the definition. It allows all the radiation to enter it and it internally absorbs, but not even percent goes out. So, what does it imply technically? Reflection equal to? Zero transmittance equal to?

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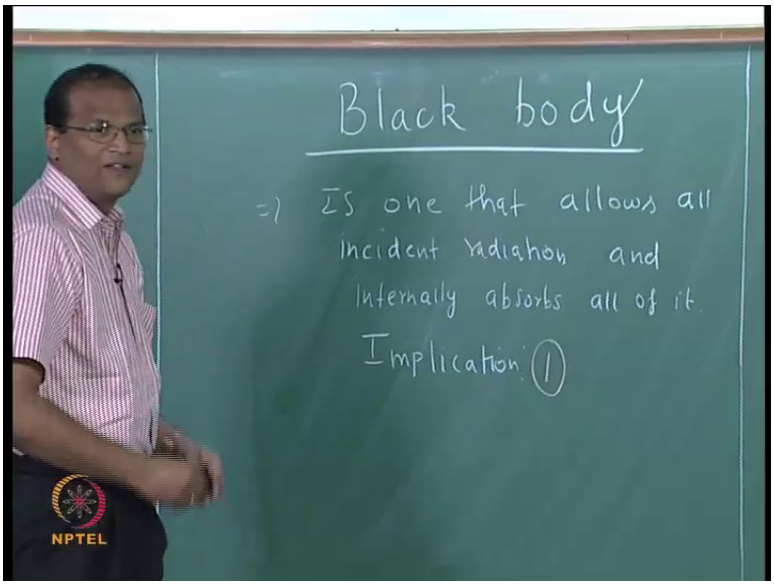

So, blackbody is one.. So, blackbody is one that allows all incident radiation internally and absorbs all of it. We will use some color. If it is too bad you tell me.

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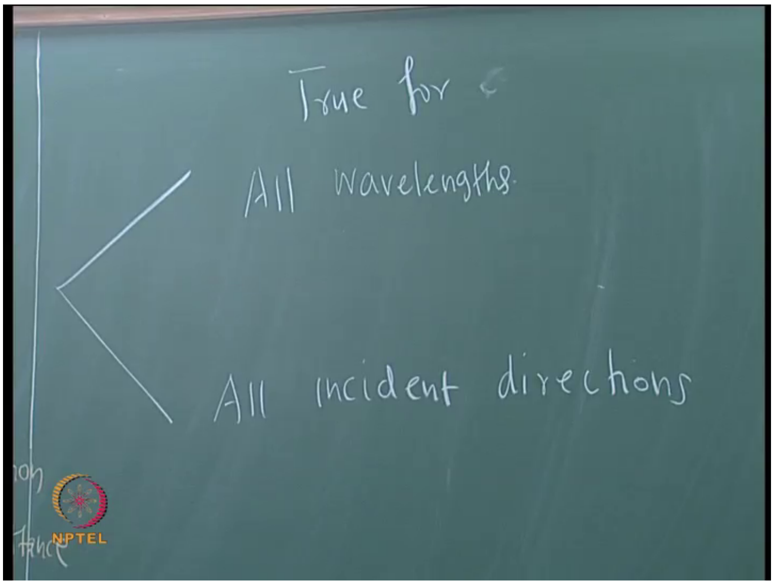

So, this definition requires further qualification because it allows all incident radiation internally absorbs all of it is true for all wavelengths and all incident direction. So, this is valid for all wavelengths and it valid for all incident directions.

So, therefore for a given wavelength and in a given incident direction there cannot be any body which absorbs more radiation than a blackbody.

Any real body has to absorb a radiation which is lower than that of the blackbody.

Now, if I ask a question how do I know what is the maximum absorbed that can be absorbed that comes from theory and is verified by experiment and all that. Now it is basically conceptual definition. We introduced something called a benchmark. So, this concept of maximum absorption regardless of the incident direction and regardless of the wavelength is central to the understanding of radiative heat transfer. So, the blackbody serves as a benchmark with which all the other real surfaces can be compared.

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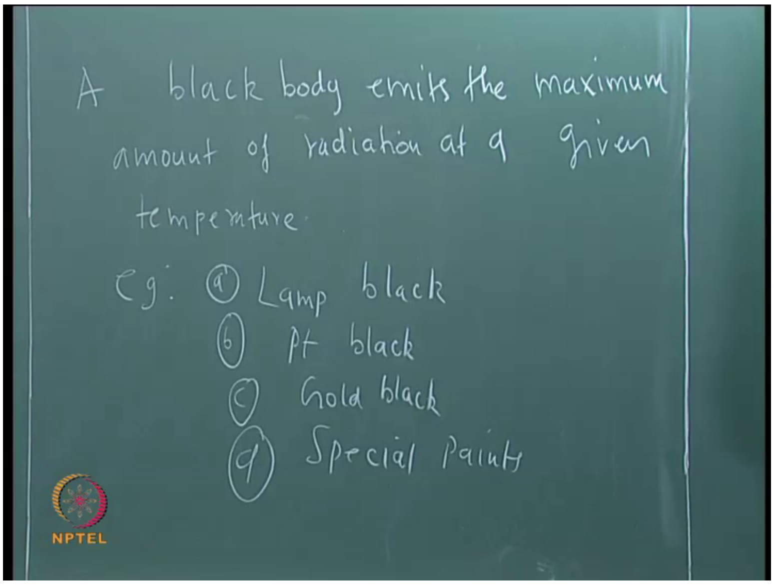

Now incidentally the blackbody also emits the maximum radiation for a given temperature. This is a consequence of this that can be proved. So, some people as Pradeep Kamath defined he said blackbody is one which emits a maximum amount of radiation. That is true, but that cannot be used for defining the blackbody. A blackbody is fundamentally defined on the basis of its ability to absorb fully that it is emitting maximum is a consequence of the first. It is a corollary.

First law of thermodynamics q minus w is equal to delta E. For a cyclic process q is equal to w. that that it is only a subset of the general law of q minus w is equal to delta E because, you do not know what happens when q is not equal to w. When q is not equal to w what is the story? It is equal to the change in energy of the. So, that is more general.

Therefore that the blackbody is capable of absorbing completely is the fundamental basis is the fundamental premise on which the concept of blackbody is has been proposed. right.

Now, example Ice is 0.98. Emissivity is ice. So we will list ice later.

Something called a platinum black lamp black lamp black Platinum black, some special paints which come very close to that.

So, suppose you want to do experiments in heat transfer lab not necessarily (( )) IIT Madras somewhere you are going to do experiment. You want to realize it is a blackbody; what you can do probably you take some aluminum plate or something you will coat Asian paints (( ))

and wipe on and take a brush and coat it and let it dry or if you are rich enough you can do the spray painting.

Now, you measure the emission it will give 0.8, 0.88, 0.99 all that, because there will be some places where you have not fully coated. After it dries second coat maybe it go to 0.92. After that it will asymptotically saturate. You cannot get that 1.00, but you will get something like 0.9495 for all practical purposes it is a blackbody, if you want to do experiments you can say high emissivity body.

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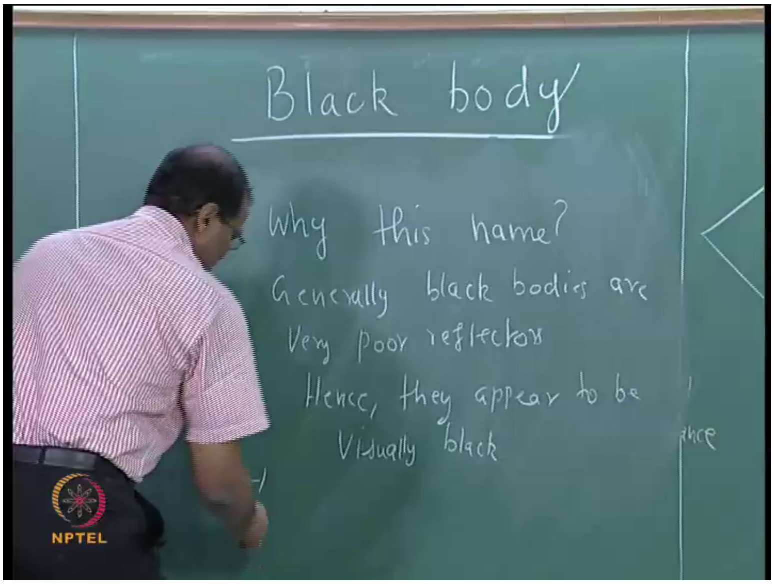

Now, why this name? Why cannot we call it white body? Black is after all a black color; generally a very poor reflector. Right? Hence, they appear to be black. Appear to be black from what point of view? They appear to be visually black. But the eye the eye is a very poor instrument to detect radiation because you can detect only a very narrow range of 0.4 to 0.7 micrometer. It takes maybe very black between 0.4 to 0.7 micrometer. But other parts of the spectrum what is the story? You are not in a position to you need sophisticated, an you need a spectrometer and this thing and to find out its behavior.

But, since the visible part of the spectrum is genuinely a part of the electromagnetic spectrum if, something is truly radioactively black between 0.4 to 0.7 also it will be black therefore, all radioactively blackbodies have to be visually black. However, all visually blackbodies need not to be radioactively black because we do not know.

Did I confuse or did I clarify?

If it appears black it is black in 0.4 to 0.7 micrometer portion of the spectrum. It may like, it may have a good emissivity, but I cannot say it perfect blackbody because the eye is a poor eye is a poor instrument to detect whether to find out whether something is blackbody or not beyond that 0.4 to 0.7. Aare you getting the point.?

But the radioactively black a radioactively blackbody has to be visually black, but a visually blackbody need not be radioactively black.

In fact, a radioactively blackbody like ice is actually white in color, because unfortunately for the certain portion of the spectrum alone it is doing some reflection. The other portion of the spectrum it just absorbs everything that is why people are trying (( )) this climate change and all that.

Is ice melts? Because there is a difference in the reflectivity between the ice and the water if there is a change if more melting takes place then it leads to what is called a runaway effect. Let us not get into climate science now I some of you have taken my atmospheric science course. So, you know this. So, therefore, is (( )) people there is a big deal about the reflectance of ice and water and all that what happens when melting takes place.

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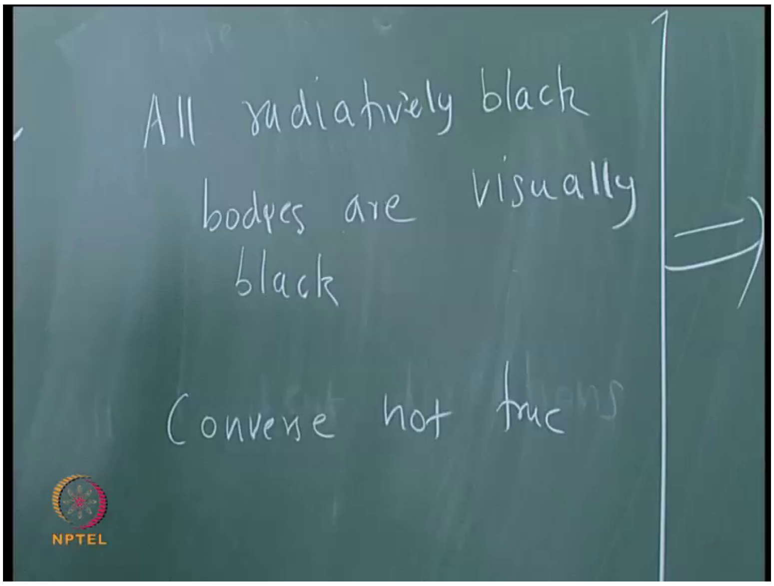

So let's conclude by saying this discussion by saying that, now one it not is true may or may not be. What are the properties? there other? How do you know there is there is something ideal concept called blackbody? Why it is necessary to figure out this concept? Why bringing the concept of blackbody at all for comparison purpose and also to describe radiative properties of various substances.

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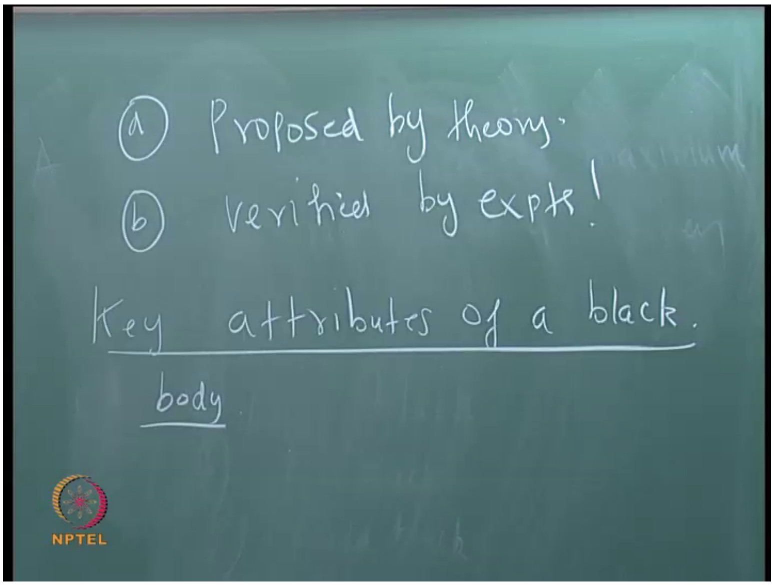

Therefore, the theory of blackbody and the properties are proposed by theory. What is that theory? (( )) What theory is it (( )) in physics? Quantum mechanics. k? It is proposed by quantum mechanics and it has been verified by experiments done by. so, many physicists. right.

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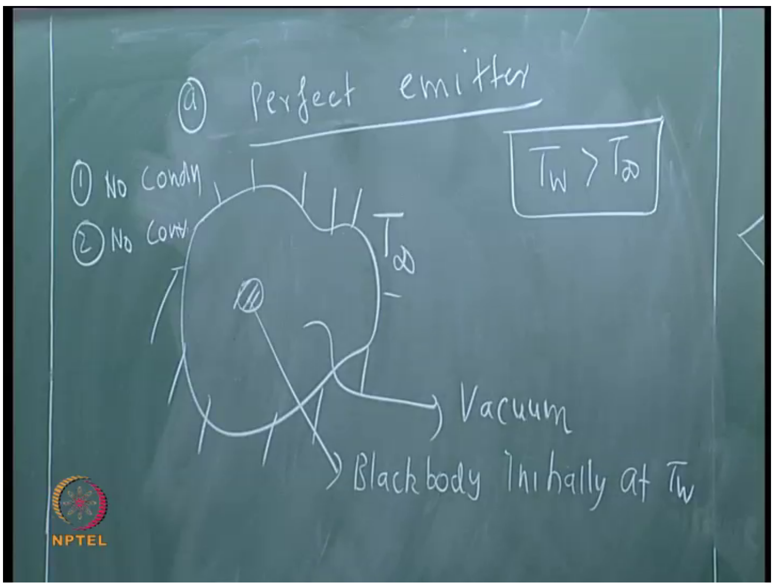

What is the basic key? The key attributes of a blackbody, a perfect emitter perfect absorber is already there in the definition?

Sir the blackbody is (( )) if you have the length...

No.

Now emission is if I looking at the reflection point; that definition of blackbodies from a emission anybody will continue emit radiation; so long as it at the temperature above 0 t. So, if you are looking at emission color what you are saying is correct. If you are looking at the reflection color my shirt is red in color not if it is emitting red I will die man. What is the temperature means? Displacement law I will tell you, I cannot survive. So, it is basically because this stupid shirt whatever if it takes it absorbs the entire color except this red (( )) yeah. So, that is that emission color the color based on emission. We use it in parametric. I will teach you little later. Any other question?

So, it is quite tricky discussion of blackbody and all that is quite philosophical, after that it will get numerical. Of course, then we will keep on solving equations and all that, but first part I will leave like that.

So, let us consider now you have to do some thought experiment let us consider an evacuated enclosure. Evacuated enclosure is at the temperature of T infinity. So, there is vacuum inside. Now I put a blackbody small blackbody blackbody initially at T w. So, I am saying that T w is greater than T infinity and the blackbody is not touching the walls of the enclosure; so which mode of heat transfer is prevented, no conduction. So, it is evacuated. So, there is a vacuum there is no medium. So, which other mode of heat transfer is prevented? Convection.

But T w let us say T infinity is thirty degrees centigrade and T w is 200 degrees centigrade. This is a small body in a large enclosure. After sufficient time has elapsed, what will happen? What temperature? (( )) I am saying that the enclosure is an infinite heat sink. For example, suppose I put for the argument that the heat received from this small body will not affect this enclosure, then eventually, equilibration will take place. The blackbody will achieve equilibrium with the surrounding eventually.

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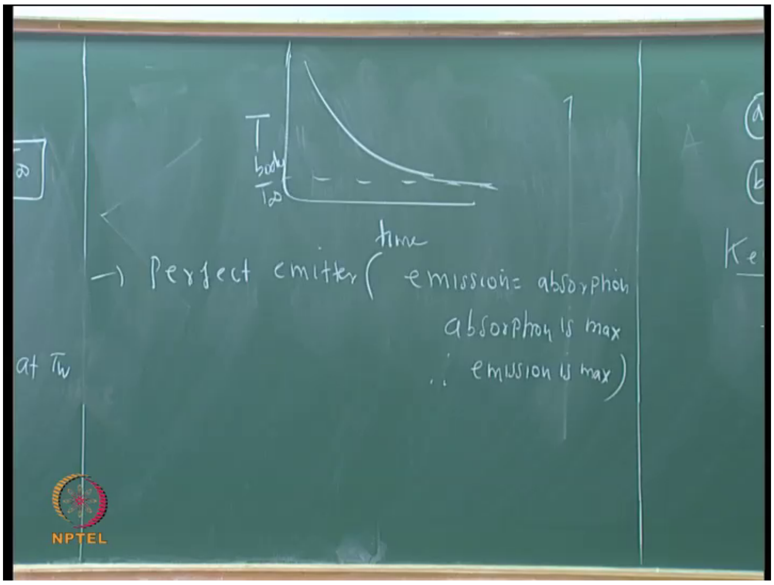

So, you have something like this. So, it reaches T infinity after sufficient length of time has elapsed.

Now, thermal thermal equilibrium is established in the enclosure in which an evacuator is enclosure in which a blackbody is present. But the small object is a blackbody. So, what is the story there? It is absorbing exactly the same amount as it is emitting, because if the emission is not equal to if the emission is not equal to the absorption then, there is a net rate of change of enthalpy, which has to take place inside the blackbody, as a consequence of which, its temperature has to go down or go up which is again forbidden because already equilibrium has been already established.

Therefore, therefore the amount of radiation which is emitted by the blackbody is exactly equal to the amount of radiation which is absorbed by the blackbody. Since, it is a blackbody it is absorbing the maximum amount of radiation. Therefore, it is also emitting the maximum amount of radiation.

How do you like it? A shady proof, but do not ask me sir what happens if we do not have the enclosure and all that. I know to prove it only with enclosure, but it is good enough. Do not ask me to repeat. I will I will distort it. So, to cut a long story short, it has achieved equilibrium with its surroundings.

Now, there is no convection no conduction. So, the amount of radiation falling on the body is equal to the amount of radiation which is going out in terms of emission. Emission is equal to absorption, since the absorption is maximum not because it is experimentally verified or whatever because, I have already declared it is a blackbody. So, since the absorption is a maximum emission is a maximum. So, it if it is a perfect absorber it goes without saying that it is a perfect emitter. So, all those stories you can write.

Now, we go to the next one.

Perfect emitter. So, I will write emission. Absorption is max therefore, emission is hushed here. It can be proved it can be proved for a non blackbody also, that is in the enclosure if it is only in enclosure.

So, if it if it is not blackbody.

No, even if it is not for a non blackbody also it is true. It does not automatically mean for a blackbody. It is not true. I am not saying it is true only for a blackbody. It is true for the blackbody.

What do you say?

The strategy now is before you will think about it I will go to the next one, but it is I will clarify what is your problem?

It is true for any bodies...

(( )) at steady state all the when both are in 10 10 (( )).

It would not be absorbing the maximum it will equal that is all, but I cannot I cannot put for the argument of maximum. The equilibrium anyway absorption is equal to emission there's no doubt about it. But the non blackbody is not absorbing the maximum that it holds good for a non blackbody. It does not prevent us from saying that it holds good for the blackbody. What is the problem?

Already it's (( )) I mean let it do whatever it wants, but what happens to that equilibrium? Let it do whatever it, we give it freedom. You can take (( )) study whatever hum you once again want to get 165 (( )).

We are already considered that the equilibrium (( )).

We have considered with the equilibrium because, I may be interested in the non equilibrium also, anyway you are doing an assignment right that is about non equilibrium, but here I want to prove something. We dint do the experiments only thought experiments. We do not have to spend. So, much time on this fine.

Yeah, I did not tell you because, I know that it is valid even for a non blackbody, but that is.

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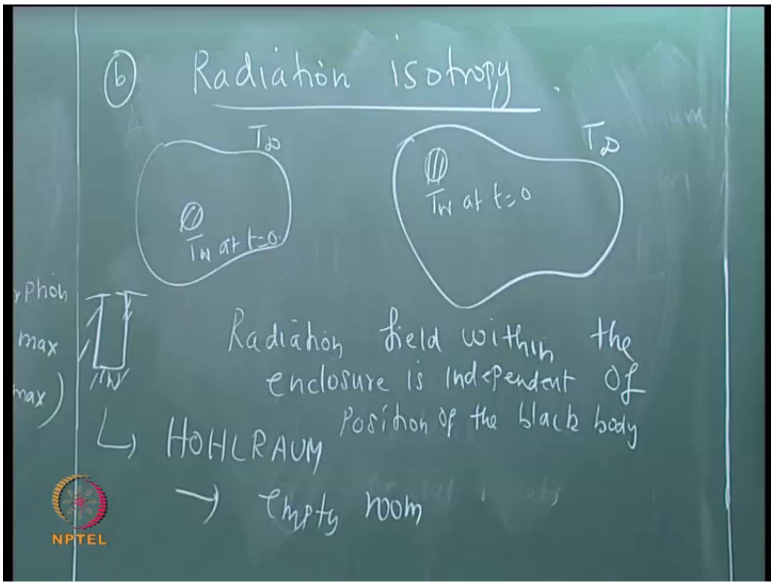

Radiation isotropy; if suppose the story is like this this T infinity T w or T equal to 0 right.

I have one more case, where it is the same enclosure in the same blackbody, but I am keeping the blackbody here. It is same T w or T equal to zero. Is there any change?

So, long as the enclosure temperature is at T infinity as it is a small body placed in large surroundings where the large surroundings have infinite capacity to take on the heat. Regardless of the position of the blackbody it will reach the same equilibrium temperature upon reaching equilibrium the emission will be equal to the absorption and that will be maximum corresponding to the temperature T infinity. Since, it is independent of position therefore, you can rotate you can keep it wherever you want it is independent of the position or the orientation of the body. Therefore, we say that there there is radiation isotropy within the enclosure; within the enclosure, a uniform radiation field has been established.

So, the radiation isotropy means the radiation field. This blackbody this blackbody is inconsequential. This blackbody is only a tool. Its only a prop for me to prove this. Even without a blackbody, I can have a cavity like this which is at T w which will be generating radiation. Because it is a (( )) greater than 0 kelvin consequent of the (( )) law it will continue to emit radiation.

So, if I have a cavity like this, I close I close the cavity on all sides, but only have a small hole and if I heat it. So, I evacuated cavity which is heated and which is maintained at vacuum it is a small hole, the radiation field emerge from emerging from mid could be isotropic; that means, it will not have a direction dependence. When the radiation is coming out, it will have a uniform intensity in all the directions. That is a radiation isotropy.

So, this radiation isotropy is related to what is the called the Hohlraum. Hohlraum means empty room in. (( )) That is German. Hohlraum concept can be used to emit or simulate a blackbody under laboratory condition.

If you want to if you want to simulate a blackbody, instead of doing four or five coats of paint, you can build a cavity and close it on all side and have a small hole. Evacuate the cavity and heat it with a microbe wire or all that all over the place and then the pencil of rays which is coming out from the top hole or wherever it is, that is basically an isotropic radiation. It is equivalent to radiation from a blackbody corresponding with the temperature of the enclosure.

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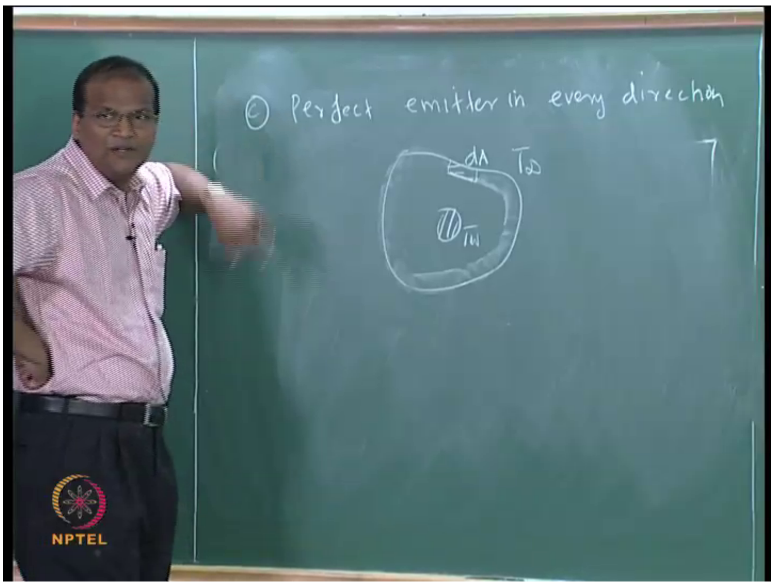

Perfect emitter in every direction; how do you prove this within the enclosure business? Suppose I ask T infinity. Now I have only one small area d A, which is active on the walls of the enclosure. The all the other areas are not radiating the radioactively active. Even then after sufficient time has elapsed equilibrium will be established and the body will also cool down to temperature equal to T infinity.

Now, the body will continue to absorb radiation and this radiation will be maximum because it is a blackbody, but all the radiation is coming in a particular direction because only one portion of the enclosure wall is active and it has to and it has to radiate back the same radiation because if it is not so, then equilibrium will not be established; therefore since it is absorbing the maximum in that particular direction by consequent upon v urging the blackbody by making. So, many portions of the enclosure wall invalid, It has to radiate the maximum in the same direction. Therefore in a particular direction also it will be the maximum emitter.

So, it is anyway is the same in all the direction it is maximum and equal in all the directions.

These are not required for solving the problems and all that, but this is the conceptual clarity is very difficult. No, I will not ask any question in the exam from this, but it is it is central to your understanding.

Well you can solve problems without understanding. I am putting forth one argument. I mean it can it can get radiation, you can design an experiment where you can receive radiation only in a particular direction it gets heated, but eventually it has to get cooled because that is, I mean from the second law of thermodynamic, but when it is radiating back the enclosure will not accept radiation from any other direction. So, it has to radiate in that direction. In that direction emission must be equal to the absorption.

Since, it is absorbing maximum consequent upon it being a blackbody, it is also emitting the maximum in that direction,. But as a consequence of radiation isotropy in the enclosure, it is not only maximum it is also the same in all the directions right.

Before you get further doubt we will move on to.

Perfect emitter in every wavelength

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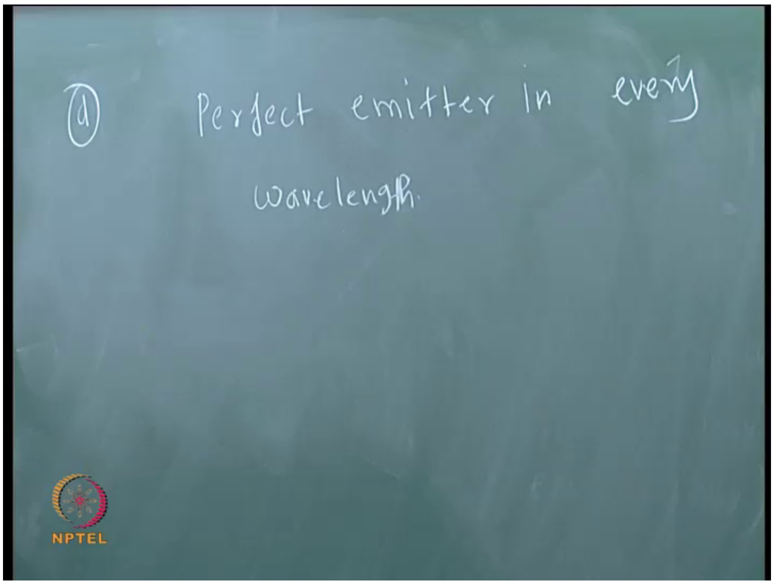

Now, I can design this, I do the same thought experiment, but now the walls of the enclosure are. so, designed that it will emit radiation or it will absorb radiation only in a very small wavelength interval of d lambda about lambda. When it is doing that this poor blackbody will also absorb radiation only in a small wavelength interval d lambda about lambda; while it can continue to emit radiation in any other direction in any other wavelength, but the walls of the enclosure are in a position to absorb radiation only in the same wavelength interval d lambda about lambda. Therefore, whatever is absorbed must be equal to whatever is emitted otherwise equilibration will not be established.

And this d lambda about lambda is purely under my control. I can change this d lambda about d lambda about the lambda at my will. This lambda can be in infrared ultraviolet whatever. Therefore it should be valid for any d lambda about lambda therefore, at every wavelength it will be the perfect emitter.

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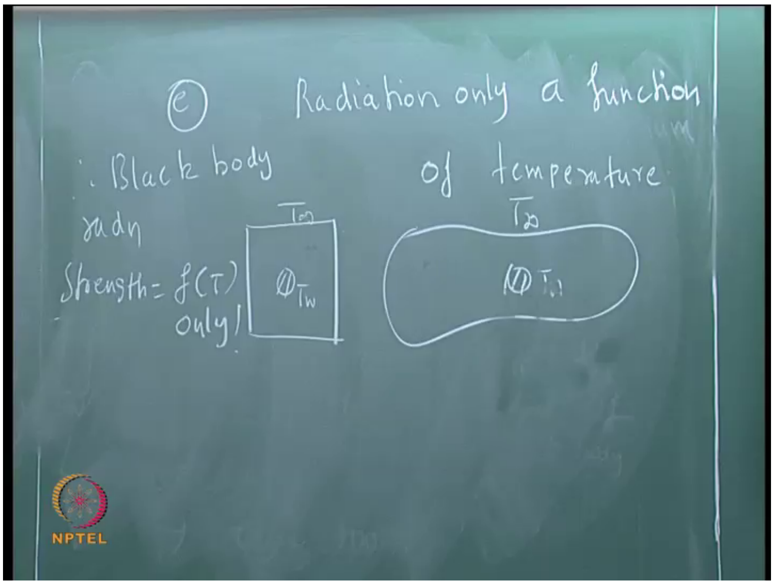

Now, E you can fill up. Suppose you have an enclosure like this T infinity and you have a blackbody T w. You start the experiment. Same thing vacuum no no no conduction no convection. What will be the eventual equilibrium temperature is here? T infinity. Here? T infinity. So the characteristics of the shape of the enclosure do not affect the eventual equilibrium temperature. Therefore the radiation field inside the blackbody does not care a damn about what is what is its shape size and all that. What all that has been evacuated and fully closed, it will continue to emit isotropic radiation corresponding to its temperature only.

Therefore, blackbody radiation whatever you want intensity whatever that we can see later. Blackbody radiation strength is a function of T only. So, we have covered lot of grounds, right? At least 5 attributes, right?

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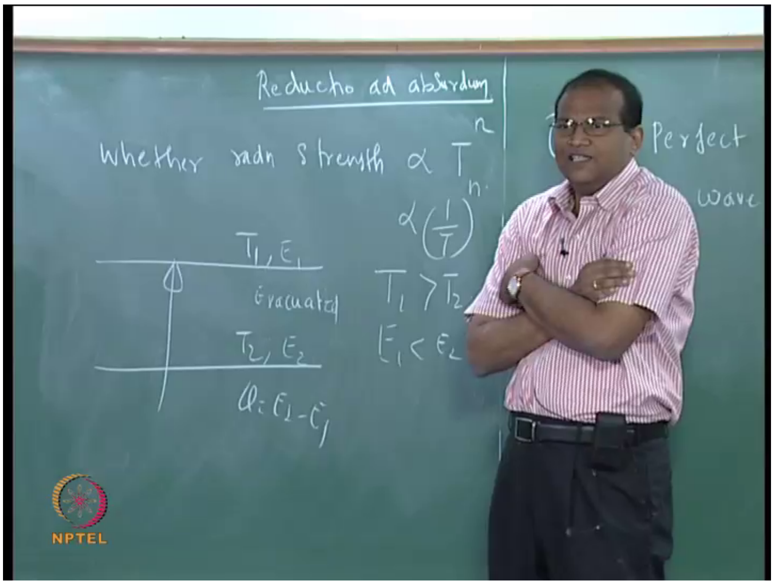

So, one more question you have to answer before we move on to solid geometry? Where m is greater than 1one for example, m is not negative. Whether the radiation strength increases with temperature or decreases with temperature? The answer is. so obvious, it increases it increases with temperature. This is what happens when you keep on arguing, so much about something. How do you prove it? How do you know that it is a monotonically increasing function of temperature the radiation strength? That is if there is a blackbody at 300 kelvin it is emitting some blackbody radiation. If there is some other blackbody at 500 kelvin it is emitting some other radiation strength intensity or flux whatever. How do you know that for 500 kelvin it will be more than 300 kelvin. No something tells no sir. It is 3 to the power of 4 whatever, but right now we assume that we do not know that it is proportional to the T to the power of 4.

Now, we can again do a thought experiment. So, we can consider two plates which are at temperatures T 1 and T 2 and the radiation strengths are E 1 and E 2. I will assume that T one is greater than T 2, but for a change I will assume that E 1 is less than assume if I divide by that no convection no conduction, only radiation is taking place evacuated.

Now if E is less than E 2, then what is the direction of flow of energy.? So, Q equal to E 2 minus E 1. So, it will flow from this. So, you have a positive transfer of energy from a body at a low temperature to a body at high temperature which is forbidden by the second law of thermodynamics unless you are able to transfer some work. Therefore, nothing in this argument is wrong except our original assumption that E is proportional to 1 by T. Therefore, the original assumption should to be wrong. Therefore, E has to be a monotonically increasing function of temperature.

So, such ways of proving something by proving the false to be observed it is called reductive ad absurdum. You have heard about it? Reducing the absurdity. I talk about it. (( )) How do you prove that that root root two is irrational? Assume that root two is rational and keep on getting something finally, you come to some conclusions and that conclusions are unsustainable. Then you go back and say that all the steps are correct except my original assumptions that root two is rational. Therefore, root two like many of us . So, now, let us these are the attributes of a blackbody.

Now, what is the story what is this E? We we do not know. How does it say? Is it T to the power of 1234 whatever? We do not know so, many minds. (( )) The best of brains hundred years back have been working on this problem. Right.

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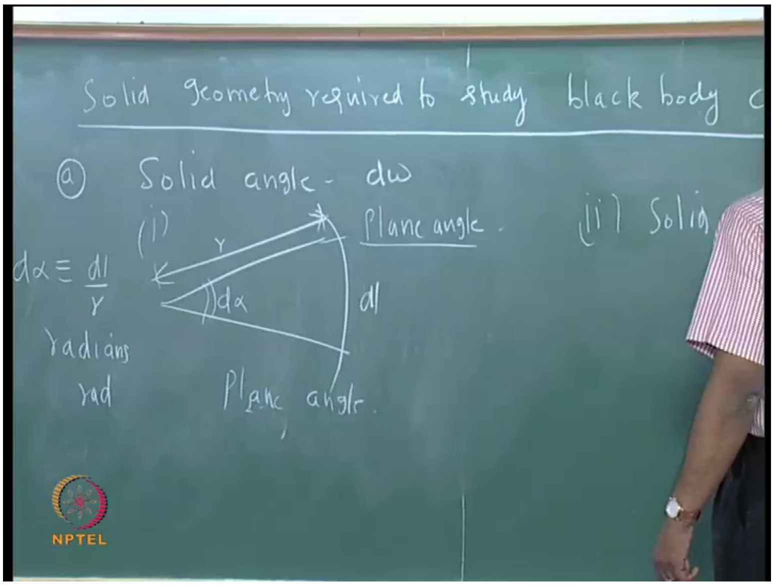

In order to derive this blackbody characteristics that is the quantitative aspects of the blackbody behavior, it is imperative that is study little bit of solid geometry. The solid geometry required to study blackbody characteristics.

First, we will introduce solid angle d omega; so the plain angle that is d l right and the radius r; so d alpha equal to d l by r plain angle unit radiance one its plain angle; so two solid angle.

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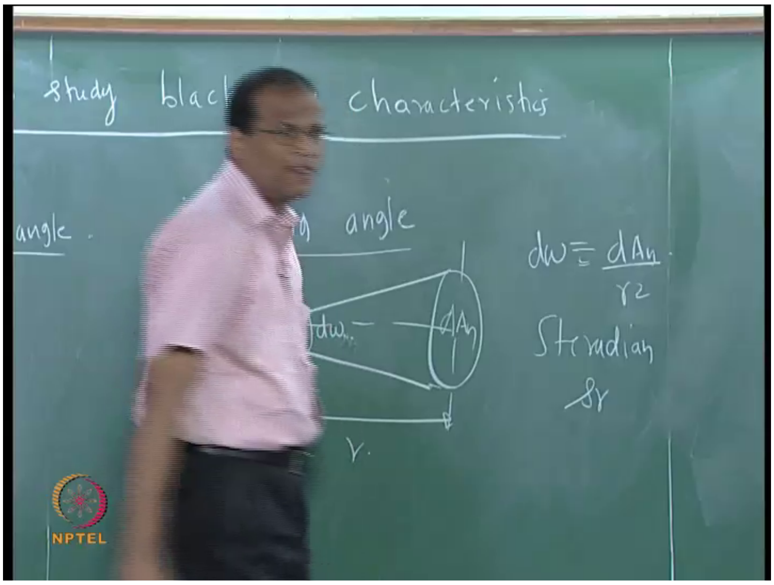

This is the area d A n that is area normal. This is the radius r. This is a small elemental solid angle subtended by the elemental area d a n at a point of this. So, d omega omega is a n the n subscript denotes normal area. What is the unit for this? Steroidal.

Don't put capital s r. Capital s small r is congium. The periodic table; what is the atomic number? Congium is congium 90. Congium 90 is used in cancer therapy radioactive. Do not put do not make it radioactive. Already there is a radiation so, lot of people use the capital k for thermal conductivity that is not correct capital k is reserved for Kelvin. Small k is thermal conductivity this solid angle.

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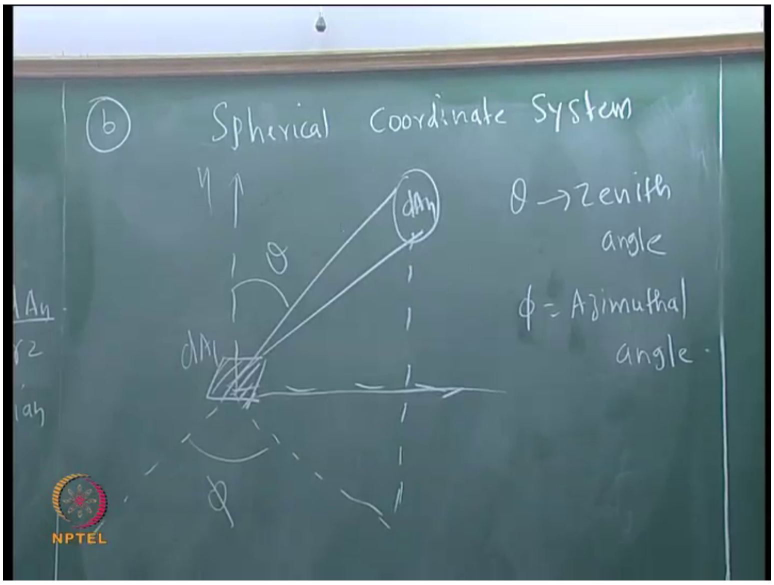

So, the first is solid angle. Next is we have to introduce a spherical coordinate system. So, what is a spherical coordinate system? So, let us consider, there is an elemental area d a one it is emitting radiation. It is going in all the directions. There is another elemental area d a n which is intercepting intercepting this radiation. So, this is the.

Now, you can you can have you can chain a torch light on this, then its shadow will fall on the x y plane, then this angle is called the pi and this is your n you need better when it is vertical and this d a is like this. So, this included angle this angle is called theta. So, theta is called the zenith angle and pi you call the Azimuthal angle.

Is there a stick here there used to be one stick it is there.

Let us start from this. This the x equal to 0 y equal to 0 z equal to 0 this point, but it is not clear. Is it ok you are able to see.? So, this is x equal to y equal to z equal to 0 that point. So, let us consider some d A n here we shine light on it. So, there will be a shadow. How it is? What is the deflection from the horizontal from one of the axis is basically a pi, that is the pi is this angle Azimuthal.

But with compared to the vertical how much it is deflected that is the theta. So, this theta pi is a very important rotation which is using in radiative transfer.

So, zenith angle.

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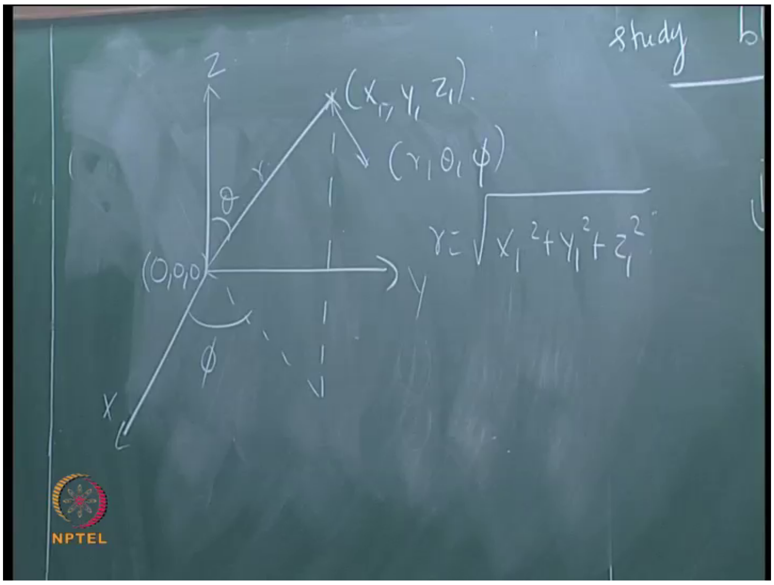

This you can on the coordinate system. You have now x y z some point which is given by x 1 y 1 z 1, this point can also be described the coordinates of this point as r theta pi, where r is basically of course, this is considered as 000.

So, we introduce a spherical coordinate system basically for the convenience (( )) are operationally convenient for us to understand concepts in radiation. Therefore, the spherical coordinate system becomes imperative, it becomes essential. Along with the spherical coordinate system, we have to include the solid angle because, the radiation is spreading in a three dimensional fashion.

Now, can we revisit that d A n. Can you write d A n in the r theta coordinates? That is d A n and then take d A n by r squared. Can you get an expression for the elemental solid angle? For a differential area d A 1, put the differential area d a n in terms of r theta and pi. Maybe I can draw a figure and that will help you.

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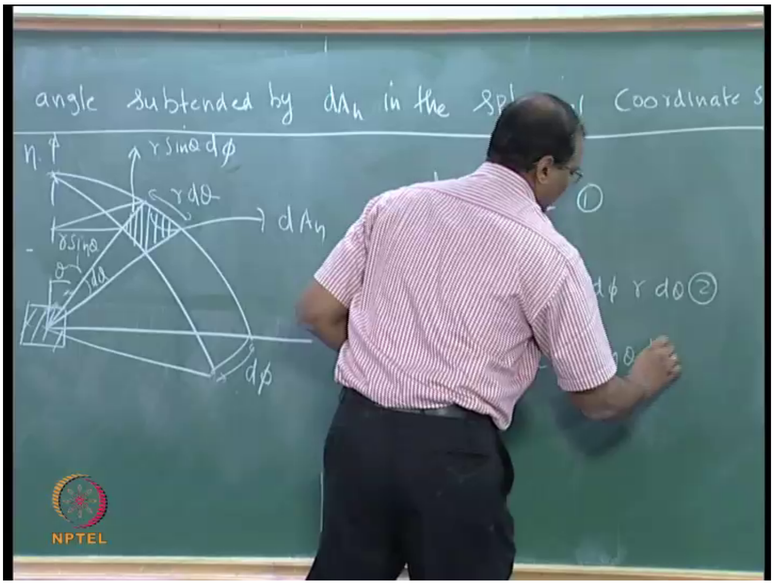

Let’s look at the solid angle subtended by the same d A n. So, this is my d a 1. So, now, instead of putting the area like this, I can make it clearer. I take a point here. This must be p right put r with d theta this is theta. So, you get vector

Now, what is this? r.

Student: (( ))

Good r pi theta.

So, what about this fellow? So, this area under consideration; so this is my d a n. Please note, solid angle subtended by an elemental area d a n at a point on d a 1 where d a 1 is that area which is emitting the radiation and d a n is that elemental area which is receiving the radiation. So, you need a (( )) undertaker; d a 1 is emitting surface. From there, radiation is spreading in all the directions. Among all the directions we are taking, 1 d a n a small elemental area and find out how much it is capturing. I am writing it in terms of fundamental coordinates. As r keeps on increasing the fraction, it captures will keep decreasing. Is it not?

For the same area, so this water bottle is generating radiation. I am capturing the radiation with this chalk piece. This area is fixed this area is fixed; if this chalk piece is moved away and away? What will happen? The amount of radiation which is falling on the surface less and even at the same radius depending on the direction it can be it can change. Are you getting the point? So, if you put it like this it cannot do much; if it is vertical it.

Now, what is this? So, what is this now tell me? Very good already you are (( )). So, r sin theta. So, this fellow is r sin theta d pi. Therefore omega equal to d a n by r square d a n is r sin theta d pi r d theta 2 therefore, omega is equal to sin theta d theta. (( )).

So, what will be the total solid angle associated with the elemental area d a 1? That is radiation is falling on to a hypothetical hemisphere above it what should be the solid angle.

I will just close in two minutes.

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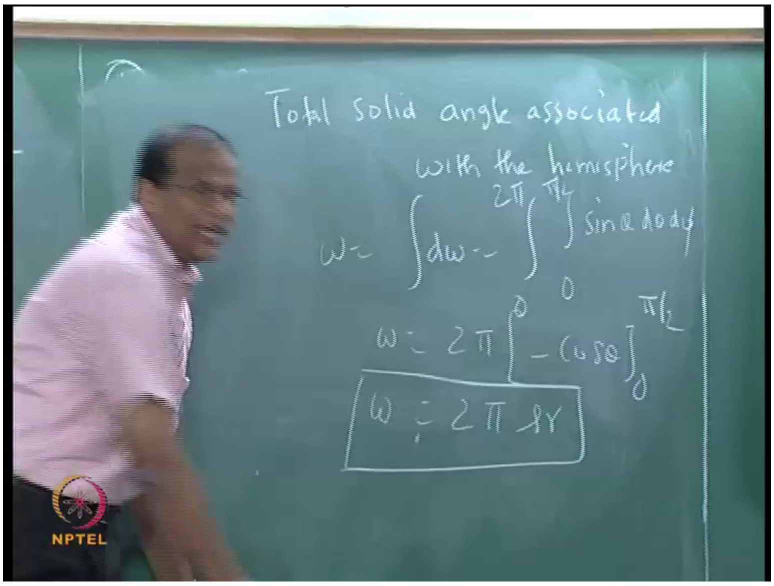

Total solid angle; so the pi will vary from 0 to 2 pi and theta will vary from 0 to pi by 2 sorry hemisphere is pi by 2 sin theta d theta d pi. So, therefore, the total solid angle associated with the hemisphere is 2 pi is the radian. The total solid angle associated with the sphere will be 4 pi steradian. So, total angle associated with the circle was 2 pi. The total plain angle associated with semicircle is.

Pi.

Hemisphere is.

2 pi double of

Solid angle.

Hemisphere is.

2 pi.

Full sphere is.

4 pi.

(( )) we will close. Tomorrow we will find out we will introduce an important concept called radiation intensity. I will work with solid angles and see how intensity. Once you have intensity how you can calculate flux. From finally, we are interested in the flux, but solid geometry is inevitable without solid geometry. We cannot proceed. You can work with x y z also, but it is very tedious. It is better to work with r theta pi.