Introduction to Quantum Mechanics

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Lecture – 01
Black Body Radiation I- Relevant definitions and black body as a cavity

This is first lecture on Quantum Theory or Introduction to Quantum Theory, and any such course traditionally begins with Introduction to Black body Radiation.

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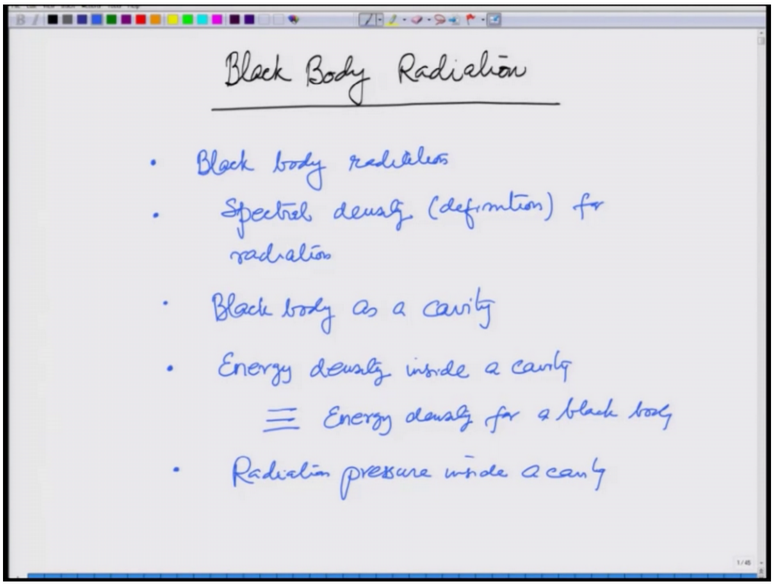

So, we are going to start this lecture with introduction to black body radiation. So, what the ideas that I am going to talk about is black body radiation, spectral density definition for radiation, then black body as a cavity, then energy density inside a cavity which would be equivalent to energy density for a black body, and finally radiation pressure inside a cavity.

These are ideas that will be used then to develop the concept of quantum; introduction of quantum hypothesis explaining the black body radiation as specifically density. So, question is; what is a black body?

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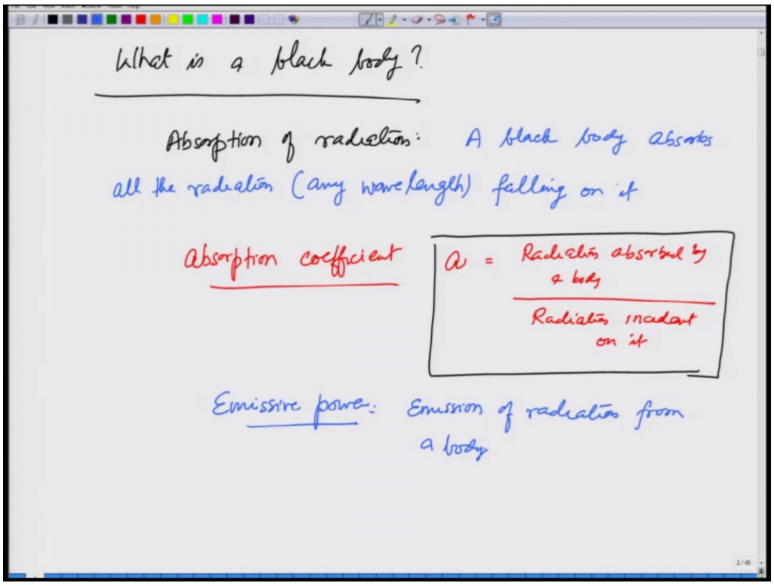

This is explained in terms of absorption of radiation which says that a black body absorbs all the radiation; and by that we mean any wavelength falling on it. There is no perfect material that forms a black body even the suit that you say does not absorb all the radiation may be 99 percent, but it does not absorb all the radiation falling on it or for all the wavelength.

So with this, we are going to define something called the absorption coefficient which is a; symbol is a, which is radiation absorbed by a body divided by radiation incident on it; that is the absorption coefficient. Simultaneously, I am going to define something called the emissive power and as you can well imagine, this is related to the emission of radiation from a body. So, what is emissive power?

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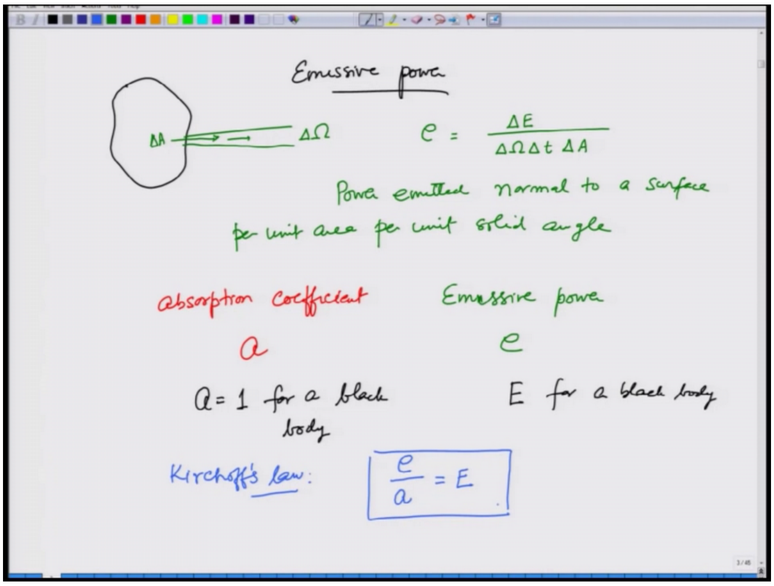

Suppose I am given a body, I am defining emissive power and from a surface I look at the radiation coming out perpendicular to the surface.

So, this is perpendicular direction, choose a solid angle delta omega, then emissive power which I will denote by e is defined as energy coming out in this small solid angle in per unit time. So, suppose delta e energy comes out in time delta t and suppose this area is small area is delta A then per unit area. So, emissive power is power emitted normal to a surface per unit area; per unit solid angle. So, we have defined 2 quantities; absorption coefficient and emissive power. This I am going to call a; this I am going to call e. This is something called; now I should write a is equal to 1 for a black body and let me call this E for a black body, and then there is something called Kirchhoff's rule.

Kirchhoff's law that says that emissive power of anybody divided by its absorption power is equal to E, I am not proving it, this can be argued very easily, but this is what it is.

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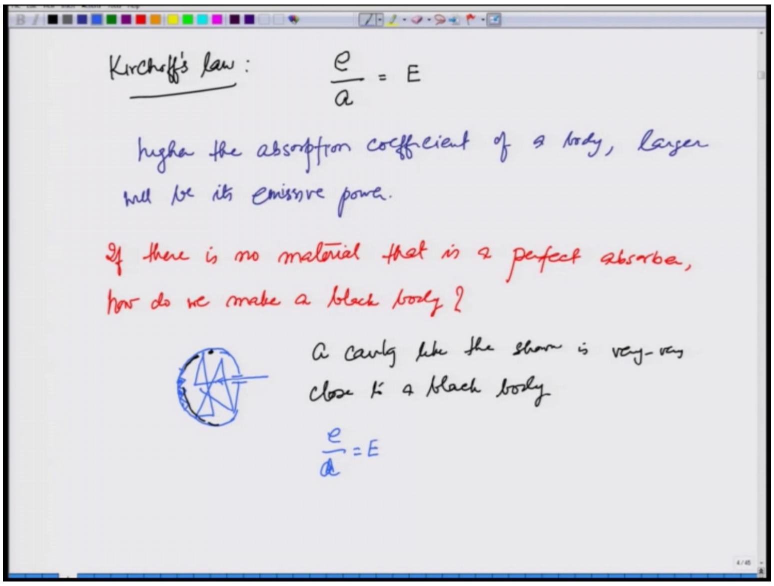

So, Kirchhoff's rule; law says that emissive power of any body divided by a is equal to E. So, higher the absorption coefficient of a body, larger will be its emissive power. So, something that absorbs more will also tend to radiate more. For example, suppose I take green piece of glass, it is green because it absorbs the red and other colors and reflects green. If I heat it up and put it in the dark, I am going to see red color coming out of it because it absorbs red much more.

So, emissive power for red color would be more or suppose you put a piece of wood and iron outside in the sun, the iron piece becomes hotter because it absorbs more, wood piece does not get that hot because absorption power is low; their emissive power will also be proportional to that a. So, iron when heated to a certain temperature would emit much more radiation than a piece of wood. So, that is kickoff's rule. Now next question is; if there is no material that is a perfect absorber; how do we make a black body?

By the way just talking on the perfect absorbing material, there is research going on into this because a perfect absorbing material would be very nice for solar panels because it will absorb all the radiation coming on to it. So, that to how do we make a block body. So, the trick is you make a cavity, make a small hole in it and let radiation go in from here on the back side of the cavity, you put zigzag wall. So, that the radiation that comes in, goes in arbitrary direction and you also put a little bit of black spot somewhere. So, that whenever radiation falls on that it gets absorbed plus I will put a black spot here.

Now, since it is going around many-many times, every time I can even make black inside, it gets absorbed; however, it does not come out of the hole. So, whatever radiation is going in it gets absorbed and therefore, a cavity like this; a cavity like the one shown is very very close to a black body whatever radiation is inside it, it is black body radiation.

Now, you may ask; why are we interested in black body radiation for that I will again go back to Kirchhoff's law which says that e over A is equal to capital E, therefore, this E on the right hand side is like universal quantity. So, if we study it, we can make statements about it in a universal way. So, a cavity like the one that I have shown is something which is very very close to black body or roughly a black body; now properties of radiation. So, we made a black body like this.

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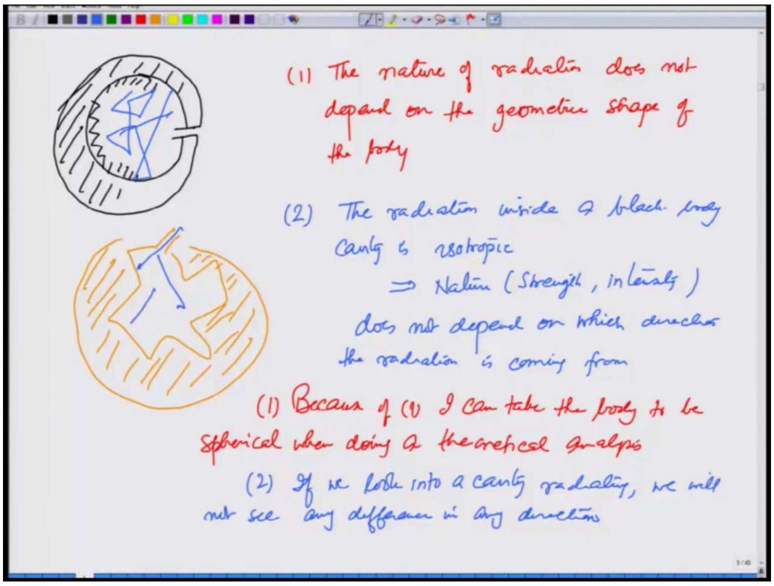

With a small hole here and zigzag wall here maybe painted with black inside. So, that it is a perfect black body and we can also make the walls very thick. So, that the radiation does not go out. So, this is a wall, all the radiation inside which I will show by blue is black body radiation. Now the properties of this radiation are number one the nature of radiation does not depend on the geometric shape of the body. So, I could have this cavity of this shape have a small hole here and even then it will be a black body. So, it does not depend radiation inside is that corresponding to a black body and its nature does not depend on the shape.

Number 2; the radiation inside a black body cavity is isotropic what; that means, is nature including strength; that means, intensity does not depend on which direction radiation is coming from. So, let us see the consequences because of one I can take the body to be spherical, when doing a theoretical analysis because the shape does not really matter and because of 2, if we look into a cavity radiating, we will not see any difference in any direction.

That means whether I look inside this cavity, whether I see here, whether I see here, whether I see here, I will not see any difference because there will be no contrast from any side coming, alright, a good example of this.

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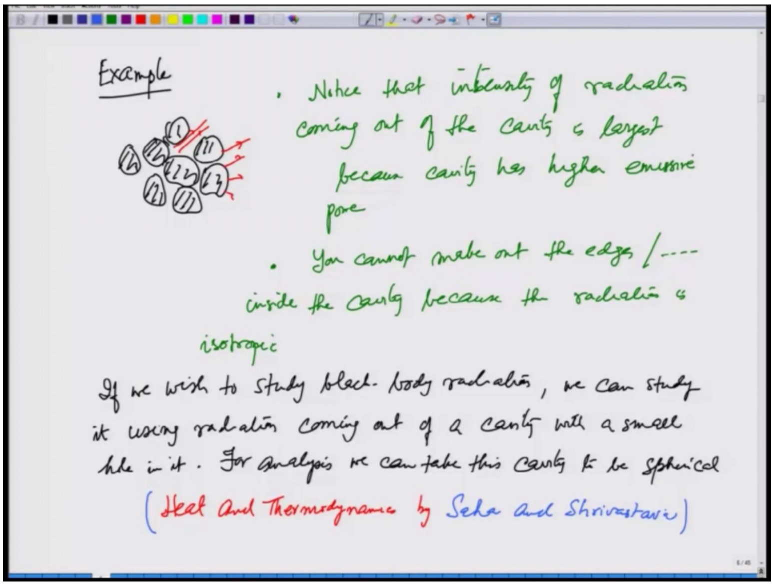

Whatever I said just now example is; when you have these coals which are burnt in a furnace and sometime these coals form a cavity and for example, here could be a cavity and radiation coming out of here, radiation also coming out of these burning coals, what you will notice that intensity of radiation coming out of the cavity is largest; why, because cavity has higher emissive power, it is closer to black body number 1; number 2; you cannot make out the edges, etcetera, inside the cavity because the radiation is isotropic.

So, let me summarize whatever we have learnt so far is that; if we wish to study black body radiation and as I said earlier; black body radiation, I want to study because it has a universal property. It is ratio of emissive power to absorption coefficient for all bodies, it has that universal property. So, if we wish to study black body radiation, we can study it using radiation coming out of a cavity which is closed, but has a small hole; with a small hole in it.

For analysis, we can take this cavity to be spherical. All this is very nicely described in book by book on heat and thermodynamics by Saha; this is our own Meghanath Saha and Srivastava. So, I have taken most of these materials from this book and this is really a very nice book, if you want to read the historical development and things like those, this is very nicely given in this book.