Conduction and Radiation
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Module No # 01
Lecture No # 05
Relationship between "I" and "T" and candidate blackbody distribution functions

We will continue with the discussion on the quest for getting I b lambda I mean or the I of a black body, where I is the intensity. So, I told it different people are trying to work out. So, some of them use thermodynamic principles like they said that radiation has a pressure radiation can be treated like a gas which occupies a volume which exerts a pressure and so on. Therefore, they related the radiation pressure or they related the radiation pressure to the intensity that was the first part of the story. The second part was in the last class we look at the definition of radiation energy density u. And, we related the radiation energy density again to the intensity.

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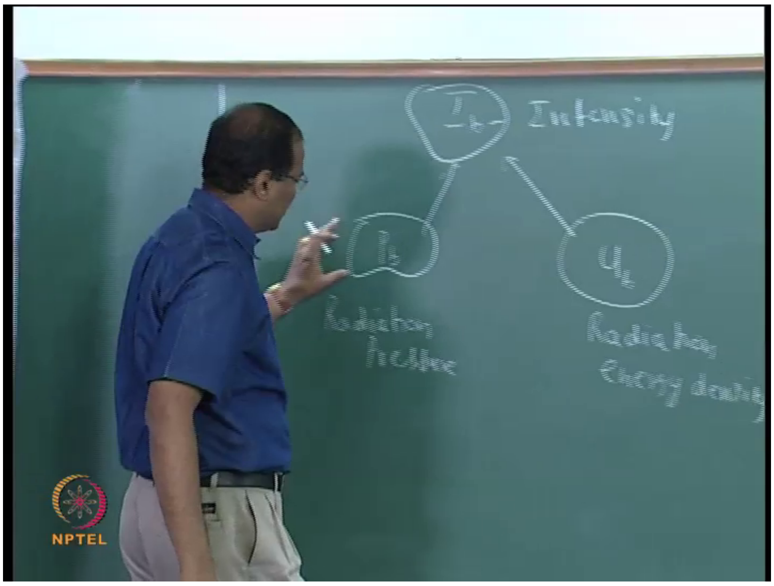

So, what do u seen as far is, there is intensity occupying occupying a volume v with pressure p, at a temperature t and all that. Now, we will start the story like this. So, u the total internal energy is a product of the specific internal energy multiplied by the volume the specific internal energy. I am free to define this specific internal energy as energy per volume or energy per mass. In this case I defined it as energy per volume. Energy per volume into volume will give you joules or kilojoules or whatever.

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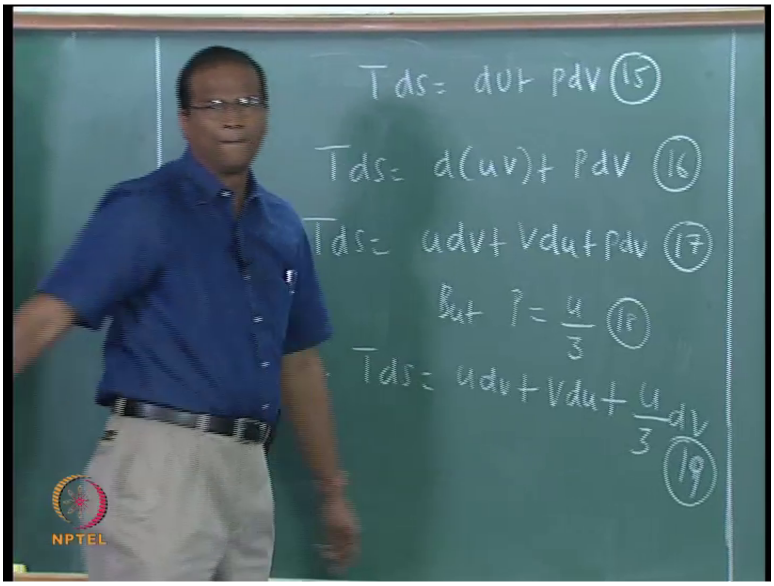

T d s is d u. Is it correct? or it should be other way? (( )) no u is a function only of t. I want it only as a function of T and I want it only as a function of v and d. What you want to do now? you can write that d is z equal to m d x plus n d y. left side dou by dou v of what you do? (( )). We will just say 1 by T, correct? Is equal to minus 4 u by 3 T square, correct? d by d T first term is 4 by 3 T d u by d T is that correct? Fine. Now, for the similar terms this fellow can be brought to this side and this fellow can be brought to this side therefore, 4 by 3 we call it as 23. 3 goes.

5 6 7 8, but put minus 8. You have to use minus 8 and T must be in Kelvin otherwise you will be violating provose law. Any Body at a temperature of 0 degrees centigrade it will not emit radiation that violates provose law. Therefore, this is called sigma. Sigma is called as Stefan Boltzmann constant. In honor of the two scientists or two physicists figured this out. This is Stefan Boltzmann's constant.

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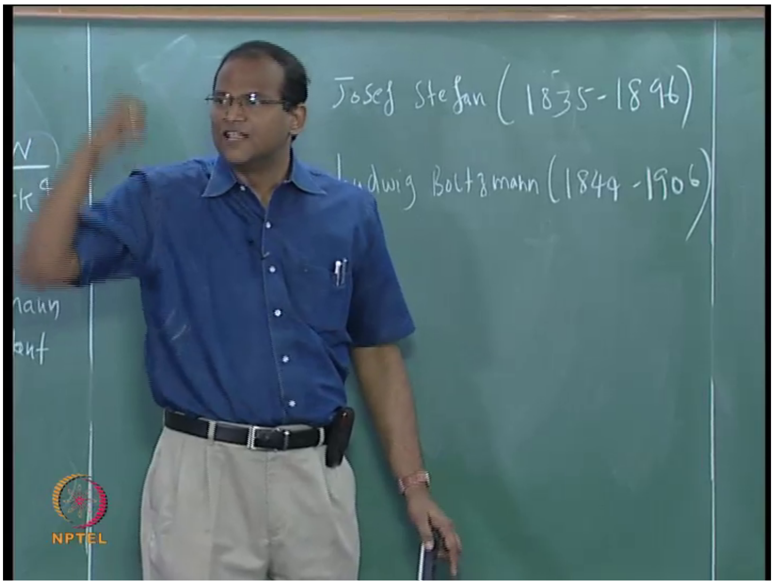

So, Joseph Stefan 1835 to 1896 I guess, then Hedwig Boltzmann. So, these are the two physicists. Joseph Stefan was Austrian, Boltzmann was German. Stefan was the PhD guide, Boltzmann was student. Boltzmann did PhD with Stefan, he got his PhD in the age of 22; he got his PhD in the age of 22. At the age of 25 he was appointed full professor of the mathematical physics in university of grates, at the age of 25 was appointed full professor. Boltzmann did so much effort. So, but Boltzmann was professor in Germany Stefan is basically Austrian, but Austria's people have been to Germany. You know that Austria is more or less, more or less Germany. So, they speak only German and all that. So, this is the story of this Stefan- Boltzmann's law.

But still we do not know what that I is? But we have achieved as certain kind of this thing have come, where you know that black body radiation power is proportional to t to the power of 4, fine. So, it is just from basic thermodynamics it is established T to the power of 4. They did experiments; they matched the experiment to the theory and got the sigma. So, PhD was so easy. But at those times imagine 150 years back, when people did not know anything at all. It is something radical is it not? They did not know something we raised to t to the power of 4. Because conduction is d t by d x convection, is ha delta t, radiation alone at some T to the power of 4.

So, Stefan is not there in Germany, Stefan it is always Stefan. Now so, many questions still unanswered. For a given temperature, how does this I b varies with lambda? For a given temperature, how does this I b varies with lambda? Does it hit the peak? Are there multiple peaks? And for a given wavelength, how does I b varies with temperature? And what happens when lambda tends to 0? What happens when lambda tends to infinity? What is that I b lambda which is satisfying all these, which we can which we are able to intuitively feel our guess? Are you getting the point? Therefore, people started working out this candidate black body distribution.

But, please remember any candidate black body distribution has not only to satisfy whatever we considered so far. It should also satisfy, integral lambda is equal to 0 to infinity, integral theta is equal to pi by 2, integral p is equal to 0 to 2 pi I b lambda cos theta sine theta d theta d 5 d lambda equal to sigma T to the power of 4. So, it is actually an inverse problem, what is that I b lambda which is satisfying all this. So, people the best brains, the best brains in the last part of the 19th century the earlier part of the 20th century worked down this problem it was an unsolved problem in physics.

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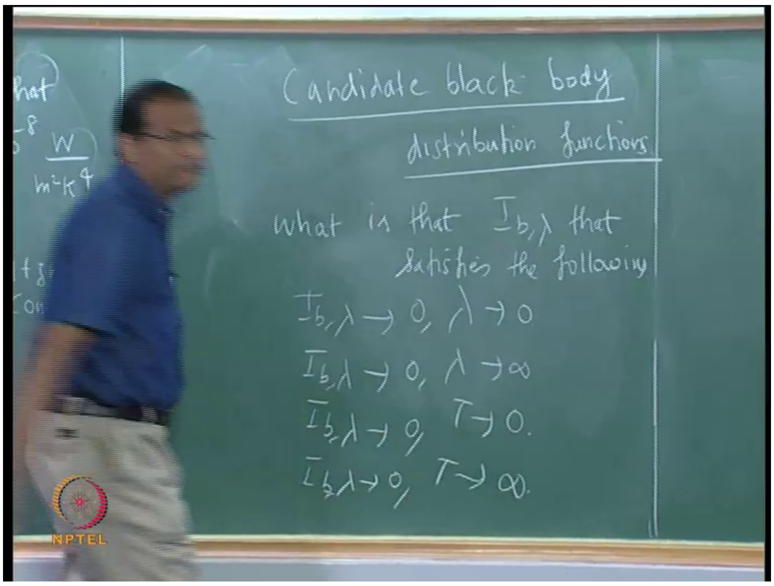

So, we can call it as candidate black body distribution functions. What are the various candidates? Flash of incite that alone is not enough. So, you have to be in right place at time. So, and then it requires years of hard work. So, though these people have done all these work in the twenties and thirties, Nobel Prize is not awarded for abstracts. At the age of 65 when you are 70 they will award the prize for what he did 30 years back. Now a days, those days they have won they got the Nobel Prize when they were very young even (( )) got when he was 47 or 48. But now it is becoming very difficult.

So, candidate black body distribution functions. What is that I b lambda, that satisfies the following? Wien was the first guy to come out with the distribution. So, William Carl Varner auto frisk France wily Wien. So, William Carl Varner auto frisk France wily Wien 1864 to 1928. What happened? Wien needless to say, he also a German. He is also a German the name is so crazy that automatically. See radiation fully everybody is all these characters are mostly Germans. Only after the Second World War this story changes. All of them are from central Europe, the continental Europe.

Some are there in outside the continental Europe, I mean that part of Europe that is not considered continental Europe, and it is United Kingdom. Normally, when it is continental Europe we do not include U K. He proposed in 1896. He proposed his I b lambda w, I b lambda w means I b lambda proposed by Wien. So, this is basically C 1 this is Wien's distribution. So, there C 1 and C 2 are two radiation constants. It is given by 1.19 into 10 to the power of 8 watts micrometer per 4 per meter square. C 2 is a second radiation constant, 1438 micrometer Kelvin. What happened? (( )) I am not telling you it is correct. We will examine it now he proposed he proposed it. If it satisfies everything, then plank there is no road for plank.

So, what is the problem with this fellow? T tends to infinity. Suppose, consider this it is ok for short wave lengths. See basically people did the experiments. They found out I b lambda versus lambda for various Ts and it is already there. Now, there must be a theory which satisfies this. That theory must satisfy all the asymptotes and also the integral must come to sigma T to the power of 4. So,all the physicists trying to work in their respective laboratories trying to figure out I b lambda. Each one of them each of these physicists claims that this I b lambda is a correct distribution for characterizing black body behavior.

The basic problem with all these expressions is, all of these fellows tried to explain these with thermodynamics or classical physics or kinetic theory of gases. But they did not know that using classical physics black body behavior can be explained because it will come. So, Planck introduced that E is equal to H nu and it has to be in multiples of 1 H nu, 2 H nu, 3 H nu that nobody thought of. It was too futuristic at that point in time. So, they were all trying to, they felt from physics and classical physics and thermodynamics which has been developed, enough knowledge is available to explain black body behavior. So, they faced that water loop because of this approach.

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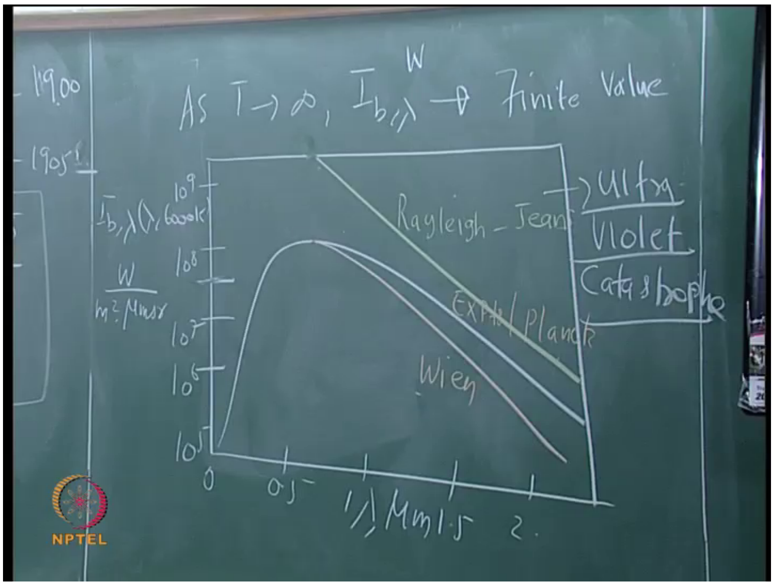

Now, what is the problem with this? As T tends to infinity I b lambda V, when T tends to infinity this becomes 0, denominator becomes T the power of 0. Therefore, it tends to a finite value. I b lambda tends to a finite value which is not correct. Because you know that as a temperature increases molecular agitation will increase so much. The body will radiate more and more and experiments do not suggest this. Therefore, the Wien's distribution is valid only for certain part of the spectrum. So for an example we can write like this. You can draw. So, I b lambda, lambda and 6000 Kelvin, 10 to the power of 5, 6, 7, I b lambda watts per meter square, micrometer steredian.

What will be this? I am looking at a spectral distribution. X axis must be lambda in micrometer. We are always looking at the micrometer. So, let us say 0.51, 1.52. So, it is not very clear. Which will be the better color? So, this experiments or plank I can say. Right now we do not know because we have not seen the plank distribution, this is Wien. So, there is a significant departure from the experimental values at higher values of the wavelength. So, this is for a representative temperature at 6000 Kelvin. Why are we hung up on 6000 Kelvin? 6000 Kelvin is an important temperature for engineering because sun.

It is an important thing for us. Therefore, if you take the spectral distribution of I b lambda versus lambda corresponding at a black body at 6000 Kelvin, the Wien's distribution significantly departs beyond the peak corresponding to the 6000 Kelvin. Left side of the spectrum the story is fine. So, it is agreeing with the experiment. So, and it is semi empirical and is based on thermodynamics. And, he did not look at the experimental results available in literature he did not see. That is why in his papers he has not bothered to rationalize or explain what the reason? What are the reasons for the departure from observed experimental?

He proposed on his own independently without looking at other people's papers or other people publish experiments. Because this Stefan and Boltzmann already have done some experiments and they did that entire then other people also measured I b lambda. So, this is the first distribution.

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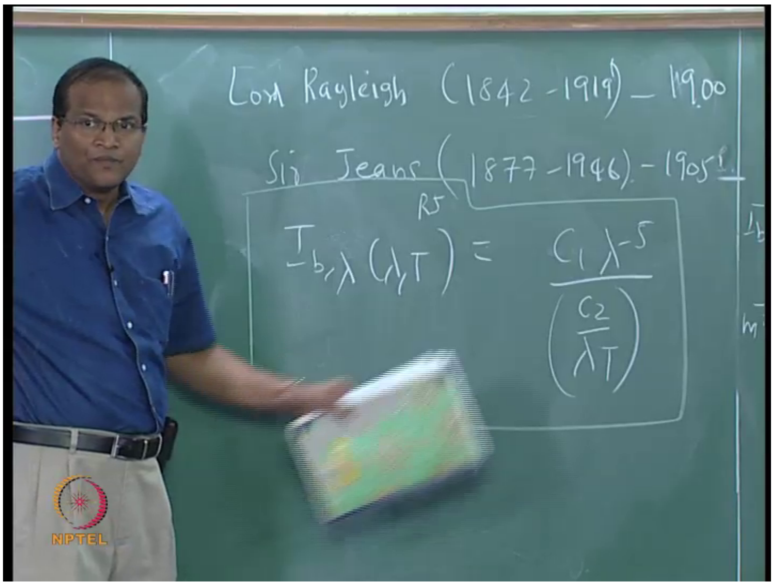

Now, come two other scientists Rayleigh and jeans he just added one minus 1 and it this is shear agree this is absolute agree. He just added one minus 1 and then his distribution agreed beautifully well. It was so excellent agreement with I b lambda distribution. So, whether you consider any temperature, for any temperature at all wave lengths, it gave very good agreement. Then he started seriously thinking, why is he giving agreement? How do you put minus 1? What is the, so first he only did curve fitting.

Sometimes you do reverse engineering, first you draw the curve and then you put the points. He did not do that, but essentially he did curve fitting. So, see the both fellows are very close. Wien use C to the power of C 2 by lambda d, this fellow just put minus 1. Now it gave an excellent agreement. Now, max plank gave in 1901, but is fellow in 1905 gave the in-correct distribution. Both were publish in the same journal called philosophy magazine. So, either the editor or reviewer was not seen, this fellow has not seen his paper. As far as Planck is concerned, he got an excellent agreement with this. Therefore, this fellow should know that I am not getting agreement, I am having ultraviolet catastrophe.

Because the editors were much closed to these 2 guys, so, they just allowed these papers. So, you can see that they troubled birth of quantum mechanics. Because they are respected scientists it should be correct. So, they four years after that, correct result was published sir jeans published the in-correct results. So this is the. So, some in order to understand the science perfectly, you have to understand his history. That is what (( )) has said. That is why I put the history in perspective. Now we have known that the controversies surrounding this.

In tomorrow's class first we will derive the in-correct distribution, I b lambda of Rayleigh jeans. How you, from where the equation he figured that the in-correct distribution? And how Planck proposed the quantum hypothesis? So, I hope to finish it in the next two classes or max three classes. Then once you have this I b lambda you can do all you can whatever you want. Differentiate I b lambda with respect to lambda and then find out where it is hitting maximum. You can integrate, it will become sigma T to the power of 4 or all those things are possible. But right now there is no quantum, there is no quantum mechanics. First it is started with curve fitting, he put minus 1, it is agreeing.

Now, how it is possible to make it minus 1? Minus 1 will never come if you use classical physics. Therefore, Planck figured out that unless he uses E is equal to H nu, he will not get the result. Therefore, E is equal to H nu must be correct. If E is equal to H nu then the continuous transfer of energy is not possible. Energy is transferred only in steps of H nu. Therefore, there is a quantum jump 1 H nu 2 H nu. Therefore, H cannot be infinitively, small H cannot be a 0 and H has to be a finite constant. That constant is 6.627 into 10 to the power of minus 34 joules second and it is now called as a Planck constant.

His major contributions are first curve fitting then second proving. Then second proving that H is not a 0 not 0 means it cannot be infinity or small. It has a finite value and you can have 1 H nu, 2 H nu, 3 H nu. You cannot have 1.5346 H nu to 1.3467 H nu, energy transfer cannot take place. As of today it is a correct distribution because it satisfies all asymptotic relationships. It also agrees well with experiments. You do not know what will happen in the future. Fine, we will stop here.