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Module No. # 02

Lecture No. # 14

History of Quantum Mechanics – 1

Hello, welcome to this fourteenth lecture in this physics of materials scores. And in the last class, we were looking at the difference between the classical particle and quantum particle so speak. And specifically, we said that classical particles are identical, but distinguishable which means, that if you have two particles at two different energy levels and (and) you maintain this situation that there is a particle at higher energy level and a particle at a lower energy level. In this situation, if you swap them that is counted as a different possibility because they are distinguishable. Our quantum mechanical particles are identical, but indistinguishable.

So, therefore, if you have two particles again occupying two different energy states if you swap them that is not countered as a different possibility because they are indistinguishable and you do not know if they have swap any way. So, I also said up front we do not know if a particle is a classical particle or quantum mechanical particle. So, what we do is we see if which of these two possibilities helps explain all the properties of a collection of those particles. And whichever works indicates to us that therefore, that particle behaves in the manner which is more consistent with quantum mechanical rules. So, this is the issue that we discussed in considerable detail last class. And the reason we came there is because we found that the classical way of counting particles and the microstates that those particles can occupy.

And therefore, the prediction that the classical approach gives us did not seem accurate, did not seem adequate for explaining the behavior that we were see for a collection of electrons in a solid. Even though, the same pretty good for a collection of atom in an ideal gas. So, given that we found that limitation, we considered other possibilities and we found that we had this other possibility which required these electrons to exhibit a behavior that they were identical, but also indistinguishable. So that brings as to this general topics of quantum mechanics. So, the (the) issue that we need to look at is to see how well we can employ quantum mechanical rules to a collection of electrons in a solid. And therefore, see if on based on the application of those rules or we able to explain the properties of the electrons that a collection of electrons display in a solid.

So, this is the direction we headed towards. So, as we proceed towards this and in our (in our) subsequent classes, we will actually get in to the mathematics involved in trying to put quantum mechanical rules, enforce quantum mechanical rules on electrons, in terms of trying to understand the behavior. What I would like to do now is to spend this class and the next class to take a step back and to look at the origins of quantum mechanics, the history of quantum mechanics and the major concepts in quantum mechanics. It is a very useful exercise for us to undertake because while we can just go ahead and use those rules it put things in prospective to understand, how it is that this subject came about, and what are the key concepts of the subject, and what is the extent to which we can understand the origin of this concepts, where the logic behind this concept and so on.

And also to see in (in) (in) (in) what degrees we are unable to actually come with very clear statement one by it is that the rule is what it is and accept it at what level we have to accept it on face value and so on. I would like you to look at the history of it to just see, what are the complications associated with how it has come about and so on. So that we can (we can) also understand and appreciate our own apprehensions as we try and utilize this too. That said I must say that there is a vast amount of scientific understanding out there, which is which should prove that definitively that we quantum mechanical rules actually do apply and they apply very well in a vast majority of the circumstances.

And so, therefore, we will accept it as it is, but we will also see, why is it that some of us when we first experience, when we first encounter quantum mechanics and when we first try to use it, we face some difficulties in trying to understand how it is that it is applicable. So, this (this) general issues is what we will examine in (in) greater detail through this the next couple of classes. So, I have title these classes as the history of quantum mechanics and on that bases we will look at the people who have done this, who has, who have opened up this door of quantum mechanics to us. And also, the circumstance under which they happen to lead us down this path. So, we will do thus in; do that in the subsequence class.

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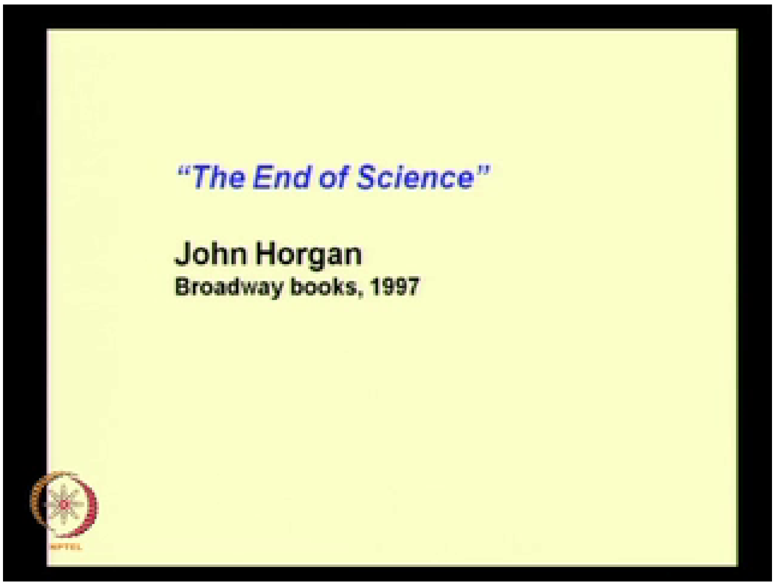

I do not know to what extent you do a general reading of other books associated, popular books associated with science. But in the year 1997, there was a book called The End of Science, published by John Horgan, he is the author of this book. And I am sure you can go and look it up in some book store or library and possibly you will find this book. I wish to highlight this book because actually this book explores this idea. That in this in the year 1997, or in the year 2000 have the arrived at a state where there is no further science that (that) can be discovered. So, this is the general idea that is explore.

In the book in it is own format, it is explore. And the basic thinking when we, when you talk of such a topic is that today people are aware of you know relativity, people are aware of quantum mechanics of course, people are also aware of the Newtonian mechanics. So, if you talk all these body of knowledge together, the argument that somebody might make is that that is all there is in science I mean; we have already reached the limits of science. And anything else that you can imagine, anything else let us say the kinds of imaginations that say a science fiction book or a movie (( )) the kind of imagination that you (( )) is going to remain pure imagination, none of it is going to happen to be true.

And what we have today is all that we are going to have. The general thinking then is that any further science that we see; from here on forward is only going to be incremental science. So, some minor detail here there which is not been fully trash out, is going to be explored in greater detail to going to have it examine. Some few additional constants, few addition corrective correction factors are going to come in to the picture, but that is about it. The basic science as is all there is the general thinking that some people have. And this is the general idea that is been explored in this kind of a book.

Well, this is the book as you can see was published in 1997. If you go back about 100 years hundred years earlier than this, so just before the year 1900, you will be surprise to find that in fact that thinking at that stage was also the same. That around the year 1900 they were lot of people who believe that all that was available to be discovered in science was already done. In fact, they were people who believe that and were stated perhaps that there was no further use in joining physics, there was no real future and getting into physics because that everything that needed to be discover had already been discovered. There was nothing of any great relevant had remain, there was no real future so to speak in the pure science so to speak because everything had been discovered only some minor detail remains to be find out.

And you can imagine that clearly that you know that is been worlds of difference since then to now. So, you are aware that there should be in a big difference in the last 100 years in terms of everything that we have learned about our universe. In fact, even in the even though we say now that we (we) (we) have learnt everything about science now, as of now. Even at this time, we recognize that if (if) you do popular reading you find that for example, the universe. There is enough reason to believe that all our knowledge is able to explain only about 10 to 20 percent of the universe. There is a very large percentage of the universe which the which is generally been described as dark matter and dark energy for which there is no known explanation at this point in time. There is no clear understanding of this kind of phenomena.

Except that the overall behavior of the universe seems to indicate that there is a dark energy in a dark matter, but beyond that we do not seem to know much. So, you can understand that you know on the one hand we think we know about. When we know, when we say that you know you do not relativity or at least when we say we know at least there are some people in the world to know relativity and some people in the world who know quantum mechanics very well. If you say that that is the case even with that there is only so much that we understand of the universe. So, on the one hand it is tempting to think that we have learnt everything; on the other hand it is with humility that we need to recognize that there is a lot that remains to be found out about the universe around us.

So, this is as of today and 100 years ago the feeling was the same as I mentioned around the year 1900. The feeling was that there is nothing left to be discovered in science and everything had already been done.

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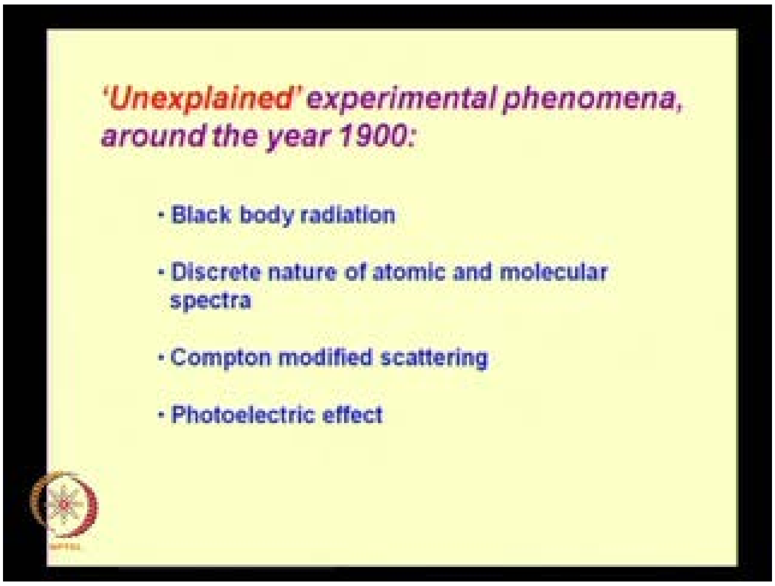

So, (so) this is the background that existed at that point in time. And again at that point in time also the feeling was that you know just a few minor details needed to be figured out. And those were also just some corrective factors at most some minor corrective factors which had to be in corporate in the general theory of whatever we (we) had for everything and then all the details for following place. So, this is the general idea that existed around the year 1900. Around that year if you look at the science at had evolved up until that point, there were specific experiments which gave data or therefore, and therefore, you call them experimental phenomena, which were not fully explained.

So, a few of them are listed here, one is black body radiation which we will talk about in (in) greater detail immediately in that during this class. The other is the discrete nature of atomic and molecular spectra. So, you (you) can see these atomic and molecular spectra. So, it turns out that you know when you have atoms and so on and you excite them, you give them energy and (and) you look at the spectrum of energy coming off of them. It the (it the) does not come out uniformly across all wave lengths. The so, an excited atom with enough energy when it starts releasing energy does not give out energy in all wave lengths uniformly. There are specific wave lengths which have high intensity and in many where there is no intensity.

That concept itself was not something that had any good explanation, in terms of the general understanding of how atoms where and how electrons where within the atoms and so on, that existed up until that one. So that was (that was) some data that people did not have an understanding one. Then there is something we call Compton modified scattering. So, this was this came along as a result of exploration that people exploration experiments that people did, in terms of how X rays interact with matter. So, I think around the year 1923, this was discovered. It was notice that you know X ray protons or X rays we would not call them protons at that (at that) stage we that was still in evolve in concept.

X rays which (which) interacted with matter and you examine the wavelength of the X ray after it came off of that interaction with mater. So, after it interacted to the sample, you look at the X ray that is coming off of the sample at you look at it is wave length. What is found was even though you sent in a specific wavelength, the in the wavelengths coming out of the sample so, you can see intensities at wavelengths that are longer than the wavelength of the ration that was sent in. Typically, it were only be a intensities at wavelengths longer, but there was some chance that you could also intensities at wavelengths lower than the inter, wavelength that was sent in. With this meant that the wavelength of the X ray being sent in was being changed in some manner and that point there was no clear explanation of how this could be explain.

This channel wave length was refer to as this modified scattering, this Compton modified scattering named of with the person who discovered it, he also got a Nobel Prize for it. So, there was no clear understanding on how this could happen, but it was shown that it was happening so, this are the very important term. Similarly, there was also an effect which was experimentally known which is the photo electric effect. Where it was known that you know if you take certain surfaces and then you have an incident radiation on it. Then at some under some conditions, electrons would come off of that surface.

What was generally known was that if you (if you) used certain up to if you change the frequency of the light incident on that surface up to a certain frequency, nothing no electron out come out of that surface. If you cross that frequency if you went, higher than that frequency electrons would start will start coming out of the sample. The intensity of the light falling on the sample effectively if the frequency was not high enough it (it) did not matter how (how) it does the radiation was you will not have any electrons coming out of the sample.

So, there was some issue associated with the frequency of that radiation and that sample and so on before you could see electrons coming out of the (( )). This was the photo electric effect, again there was no good explanation on how this could be explained and why intensity made did not seem to have any difference on the on whether or not an electron came off, if the frequency was not high enough. So, these were all specific experimental phenomena and there are also experiments associated with specific heat which also did not have specific heat of the solids at very low temperatures was again something that was not clearly explained in terms of whatever was low.

So, there was lot of such experiments, but mostly it was felt that these were experiments which were at one end of some extreme conditions that we were looking at. And then it was always felt that in some way the existing knowledge could be marginally extended and we would be able to explain these phenomena. Now, off this set of unexplained phenomena that existed around the year 1900 all of these were been explored by variety of scientist. And black body radiation was one of those unexplained phenomena which was also being examined. And it (it) was the this specific examination of black body phenomena that let to quantum mechanic, quantum mechanics being discovered so it is be.

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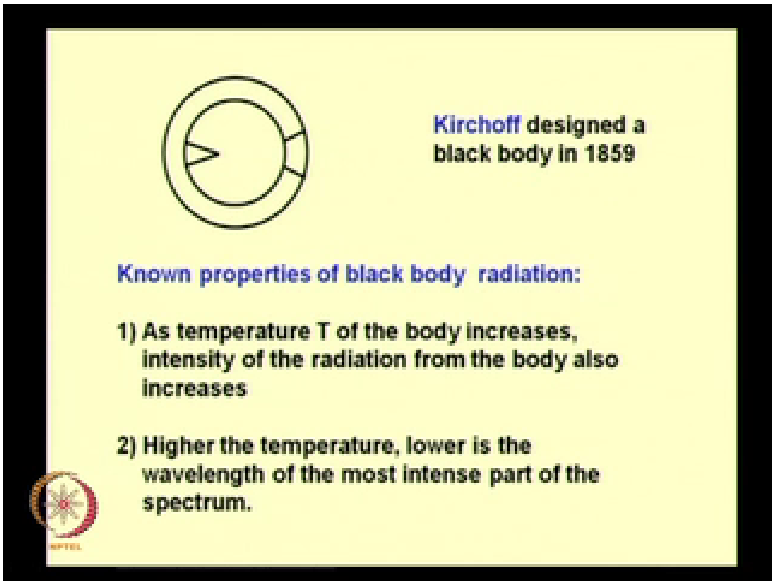

So, we will look now at how this happen. So, I am just see, what (what) is the process by which this is happen. So, what was known at that point in time was that if you actually take a body and you based on the temperature of the body, it would give out radiation. Anybody based on the temperature of the body would give out some radiation. So, for example, even we are giving out infrared radiation. So, that is why for example, them at our temperature, our body temperature we give out infrared radiation with most objects at room temperatures will (will) tend to give out infrared radiation. So, in fact, that is why if you go to the military, they have infrared goggles.

So, they if they are looking for people and it is dark you are not seeing visible light or not able to see the person, if you have infrared based goggles you can actually see the infrared radiation coming off of people. So, this is how this process is being used. At all temperatures you will have some radiations coming out which is characteristic of that temperature typically and for example, if you raise it several 100 degree C move towards 1000 degree C kind of range, then you start seeing visible light. So (so) that is why hot objects giving out visible light. And that is how you even see white light coming off of the sun. It is very hot it is of the order of about 6000 degree Cs the surface temperature of the sun.

So, this general idea was known that you can actually have radiation coming off of electromagnetic radiation coming off of a body, which is sort of related to the temperature at which that body is, and it should be a spectrum, you would actually get a spectrum coming off of it. Which means you would actually get a range of wave lengths coming off of that body and when (when) I say that it is mostly infrared or mostly visible. We mean much higher intensity is in that frequency range so that is what we will. But, across variety of frequencies you will you will still get some radiations coming off. So, in this context, an object was sort of imagine which was called the black body and then people attempted to create it where the as you can as you may be aware.

If you take light and you make it incident on (on) any object than you could have some of it reflected, some of it absorb, and some of it transmitted so, all these things could occur. So, hypothetical bodies was imagine which would actually then absorb all radiation so, if you put any radiation on it, it would absorb it. And then (if it) (if it were) if it were cold for example, so it will keep absorbing radiation till it is energy reaches the energy that is the ambient energy and then it would be not be able to then it will remain as it is. Then if you raise it is, if it is hotter than the surroundings, then it will give out radiation. So, and so, there is no transmission and there is no reflection associated with this body. So, this is considered as a black body and people try to design it.

And in a sense there is no perfect black body, but typically graphite surface is (is) a surface that would get very close to absorbing all the radiation that falls on it. So, in 1859 Kirchoff is credited with creating the black body so, which is what you see on your slide here. So, this is then the entrance of the black body so, radiation coming through this entrance and this are actually a sphere, a section of the sphere that is what I am showing you here, cross section of the sphere. So, radiation would come here, it would strike this conical section here and then the radiation would than reflect off into all the interior of this object.

And so, whatever light is entering this or any electromagnetic radiation that is entering here as an opportunity to get track with in it. And this ignore surface is all graphitic base surface so, it captures all the radiation. And then if (if) this is hotter than the surroundings, then by similar analog is process the radiation this comes out of this body. So, you can (you can) run controlled experiments where you can actually keep this black body at a very specific temperature. And at that temperature you can look at the radiation that is coming off of this body. And make a plot of how much radiation is coming out at what wavelength so, how much intensity is coming out at what wavelength. So, this is the basic information that you (you) can record.

Now, having done this what was known about the black body radiation are two facts. So, the first one is listed here, as temperature T of the body increases, the intensity of the radiation from the body also increases. So, basically, if you raise the temperature of the body, the intensity of radiation coming from the body increases so, this is something that was known. And the as I said you know there is a distribution of radiation across range of wavelengths. So, there is when you look at this distribution and I will show you a plot of this distribution, we will even draw it on the board at the movement.

When you look at this distribution, you find that there is a particular wavelength at which the intensities the maximum. So, in all other wave lengths it drops off, it decreases and then at some point there may be some limits to this diagrams have to speak, but basically you have this process occurring. You have some particular wavelength which at which you get the maximum intensity. And what was found is that the higher the temperature of the body, lower is the wave length of the most intense part of the spectrum. So, these are two things that are known about this where known about this radiation.

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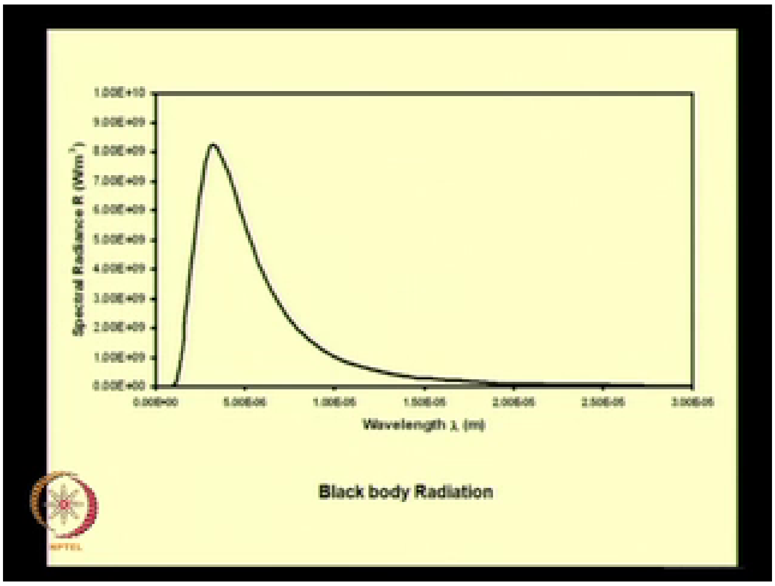

So, we will just see how this radiation looks and we will I mean we will examine this these two points little more carefully. So, what we have here on the x axis is wavelength so, wavelength is on the x axis. On the y axis we are plotting spectral radiation, radians. So, what spectral radians is? Is simply it is (it is) intensity per unit wavelength.

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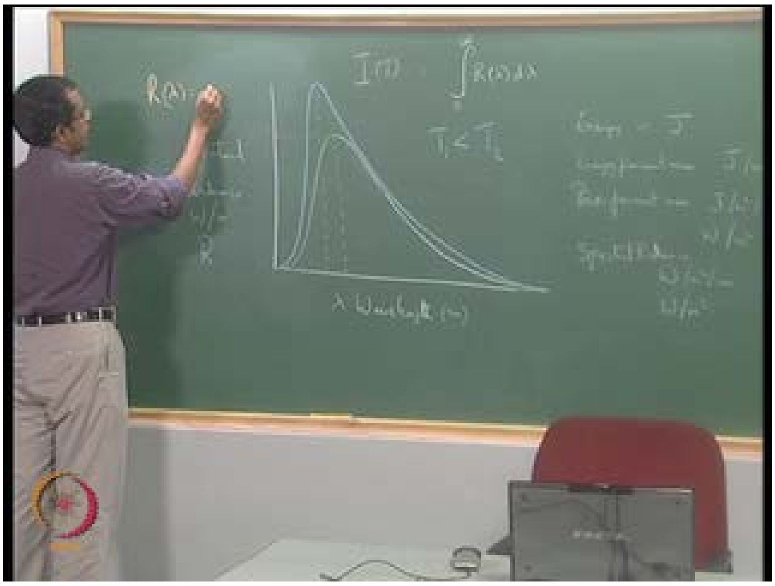

So, that is why so, intensity would be so, we will just plot this and we will just see what it looks like. (No audio from 21:26 to 21:38) So, this is wavelength and this is spectral radians. (No audio from 21:41 to 21:48) And we see that the units for this are watts per meter cube. So, if you see if you look at it this way, if you talk of energy at the units will be Joules we want energy per unit area, so that will be in Joules per meter square. If you want power per unit area (No audio from 22:20 to 22:27), that would be in Joules per meter square per second or effectively watts per meter square.

And is the spectral radians is power per unit area per unit wavelength so to speak. So, there therefore, spectral radians is in watts per meter square per wavelength we can write again in meters is sometimes it will be written in micro meters so whatever, but in principle could write it like this. So, therefore, this will be watts per meter cube. So, we can write it in watts per meter cube. So, this is spectral radians the we just leave at that for the movement and basically to look at our plot it look something like this. (No audio from 23:17 to 23:24) So, something like this is what we have in our plot. So, when we look at spectral radians, the intensity is simply the power per unit area.

So, the intensity so, when you look at a black body and you look at every wave length, you look at the radiations coming off of the black body and then you examine every wavelength. Every wave length you see what is the spectral radians that is coming and then you make a plot of all those points and then you come after this curve. The when you say when you talk of intensity what you are talking off is the area under this curve. So, the area under this curve so, whatever this is, this is R let say this is R. So, intensity I which is then the function of the actual temperature it is in. We will simply the so, across all wavelengths we can integrate the spectral radians and the with respect to lambda and then you will what you get is area under this curve which is the intensity. So, we said that so, we can do this.

So, in an experiment this is what is being done for the black body, this is the kind of data that is being obtained from a black body. Now, we can at every given temperature at a given temperature, you will get a given curve. So, at a specific temperature, you get this curve. So, when I draw this curve, this is for a specific temperature. As I mentioned at a given at any given temperature there is a specific wavelength this lamda here, this is wavelength lambda. So, this wave length lamda so, we can put this in meters or whatever (whatever) is the appropriate thing S I units will put meters there for the movement.

So, there is a particular wavelength which corresponds to the maximum spectral radians that you getting. So, this maximum wavelength and this maximum wavelength that you see is very characteristic of the temperature of that body. So, this is the important information related to the black body radiation. So, if you change the temperature so, let say we go to higher temperature. So, if you go to higher temperature, what is essentially been seen is that we just take a different color chalk here and make a plot of it. So, at a higher temperature, you will see (No audio from 25:42 to 25:52) something like this, and this is just a schematic that I am drawing for you here.

Basically, what (what) I wish to point out for you is that (No audio from 26:00 to 26:09) so, at higher temperature basically what I want to point out for you is that there are two things that we see at higher temperature. First is that the total area under this curve is now going up so, at the higher temperature which is the blue. So, we have T 1 and then we have T 2. So, T 2 is greater than T 1. So, at higher temperature what we see is that the total area under the curve has gone up. Which is consistent with the (with the) information that we are claiming that this data is given which is that the intensity associated with this object has gone up.

So, intensity has gone up and that is why the area under the curve is gone up. And the wavelength corresponding to the (wavelength corresponding to the) maximum point is our lower wavelength so, those are two things. So, (so) this is all the experimental data came out so, the data comes out like this it turns out that if you do the comparisons. The area under the curve at lower temperature is less than the area under the curve when the temperature is higher. The maximum point of the (of the) curve will be at a lower wave at a higher wavelength at lower temperature and at a lower wavelength at higher temperature so, these are the things that come out.

So, you can get this for a variety of different temperatures and so on. At some other temperature even (even) lower temperature it will move forward. So, this is the basic way which this curve develops. So, (so) this is black body radiation and this is the way it has come about. So, we will now look at the other analysis associated with this black body radiation. So, if you look again at this curve that I have put plotted here, the same what I have drawn on the board is exactly what we see here. This is spectral radians, this is the maximum wavelength corresponding to the maximum intensity, or maximum spectral radians and then this area under the curve we see the total intensity.

So, this is what we are dealing with move it of the black body radiation. So, the two points that we mention which is that the intensity goes up with temperature and that this maximum wavelength decreases with increase in temperature. These two are captured by two equations which fit the data so to speak.

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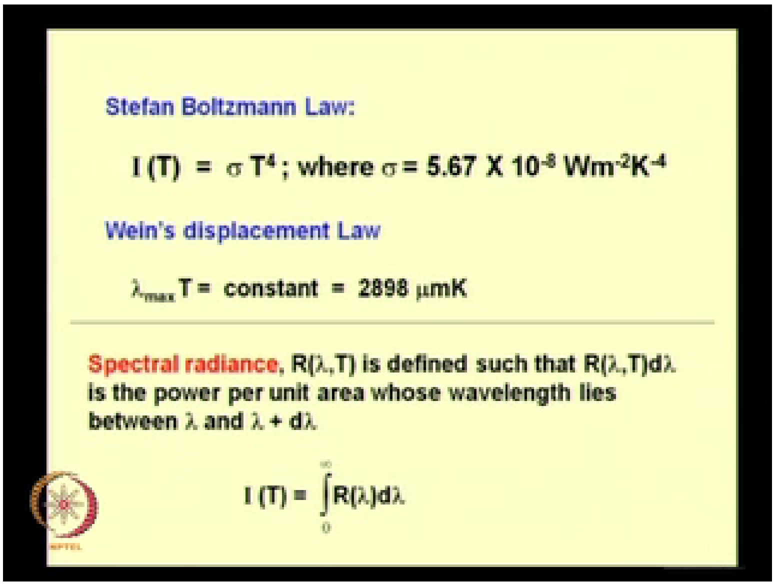

So, the first one is the Stefan Boltzmann's law (Stefan Boltzmann's law) which says that the total intensity associated with black body at a given temperature T equals sigma T power 4. So, this is something you would have probably seen in your high school. So, i sigma T power 4, where sigma is Stefan Boltzmann's constant and it has this value 5.67 10 power minus 8 watts per meter square per Kelvin power 4. So, if you know that, if you know the temperature, you can actually calculate the intensity. This constant happens to be there so, you are able to do this, you can match this with experimental data and this is what you will get.

Then there is something called the Wein's displacement law (Wein's displacement law) which (which) basically captures this information that as the temperature changes, the wavelength corresponding to the maximum of the, of that spectrum also changes. So that equation then works out to this lamda max T equals a constant. In other words, the product of the temperature and the wave length that gives you the maximum spectrum radians. So, that wave length gives you which gives you the maximum spectrum radians and the product of that with the temperature is a constant which works out to this number here. So, therefore, as the temperature goes up, the lambda max was to come down. That is what is because it is a constant.

So, these two have to be inversely related so, I said one goes up the other comes down. And as I put down there, the spectral radians R lamda T (( )) and T is defined such that the R lamda space d (d) lamda is the power per unit area, whose wavelength lies between lamda and d lamda. So, this is on per area the power on the within that wavelength region. So, when you do the integration from 0 to infinity of this spectral radius, then you get the total intensity. And this I is what is given by the Stefan Boltzmann's (Stefan Boltzmann) law.

So, now, the thing about the black body radiation is that the people once Stefan Boltzmann's law was put together this way, and this recognition was there. People had an explanation or at least understood how this came about or at least to understood that there is this relationship that sigma T power 4 was matching the intensity and this sigma was in universal constant. And similarly, which is Wein's displacement law told as about the maximum. The issue that was there that was (un) unresolved with respect to the black body radiation was the exact nature of this R lambda comma T or rather this spectral radians. The spectral radiance was then the information that told as or that encapsulated this information that at given wavelength, what is the intensity that is going to come out.

So, this is the information power per unit area so, the power per unit area at that wavelength. So, (a fundamental understanding of how electromagnetic radiation interacts with matter) a fundamental understanding of how electromagnetic radiation interacts with matter is necessary for us to give an equation which then tells as how this R lamda is, the form of R lamda. R lamda says, this is the amount of energy per unit area per unit time that is going to come out at this particular wavelength. That information will now have to be consistent with our understanding of how matter interacts with radiation.

Because only if you have consistent only if our understanding of interaction of matter with radiation is correct, we will be able to write an equation saying that therefore, at this temperature so much of energy will come out per unit area per unit time at this particular wavelength. So (so) therefore, it was necessary to see what is the form of R lamda. So, lot of work was done to see what is the form of R lamda, to see what is the equation that we can come up with for R lamda, which (which) would then have to be from first principles. Which would then have to be associated with our understanding of the exact nature of matter, the nature of light, how light interacts with matter and so on. So, a lot of work was done in this regard.

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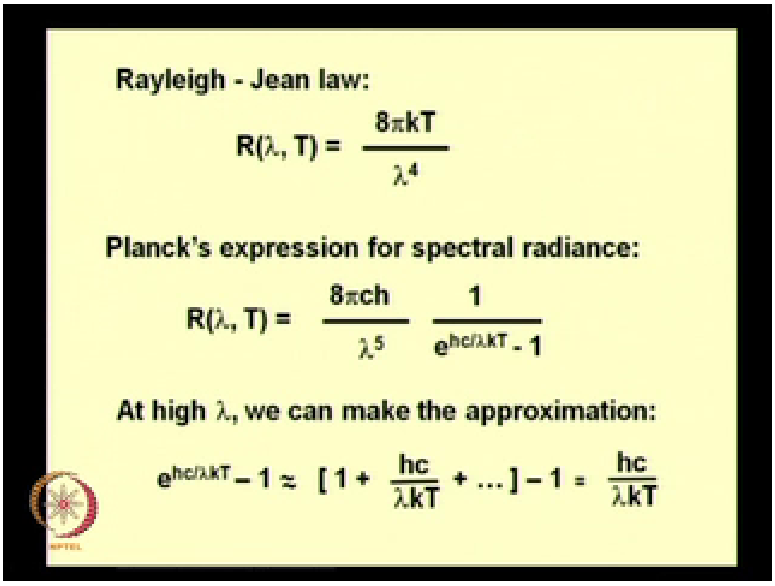

Now, the first attempt or one of the early attempt I want say the first attempt, one of the early attempts to do this process to come of with an explanation of what is the what is R lamda and what is the form of R lamda is credited to Rayleigh-Jean. And what they say what they did is they looked at in fact, the possibility that the entire interaction is occurring in a classical manner. And which means there is what is refer to as equipartition of energy. So, any energy being sent to a absorb by a body is absorb equally by all modes in which it can absorb the energy.

So, any translational mode, any rotational mode it is always equally absorbed by all the modes. And in that case (the value) the value of R lamda T works out to something like this, 8 by k T by lamda power 4. So, the issue here is that if you look at this equation 8 by k T by lamda power 4, the issue with this equation is that if you keep decreasing lamda, as lamda goes closer and closer to 0, R lambda T will keep on going up. So, (so) as lamda tends to 0, R lamda will tend to infinity. So, if you (if you) (if you) take this to be the value of R lamda and (and) say that this is the correct expression for R lamda, then what you will happen? What you will find is that you will find of the theoretical curve looking quite different from the experimental curve. What will the difference be? We will see that in the board.

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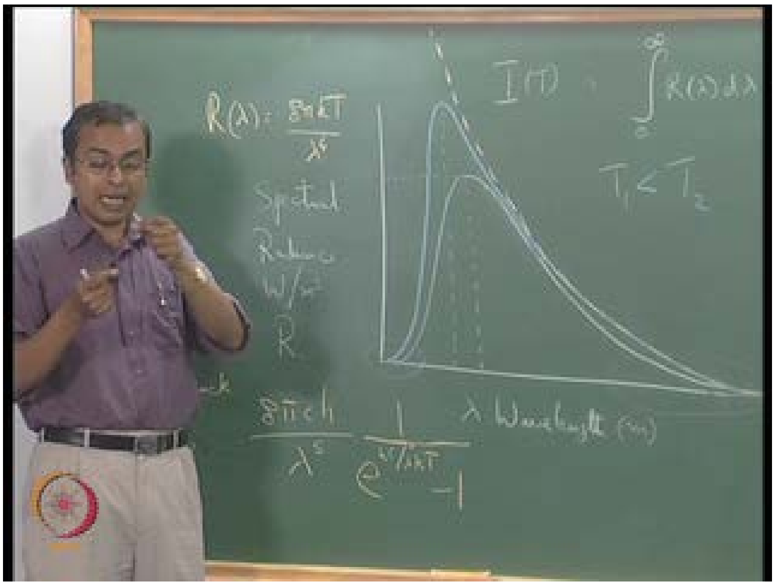

So, the Rayleigh-Jean expression we have R lamda is 8 pi k T by lambda power 4. So, this is what we have. So, if you see here if you take this expression and you make a plot of this. So, effectively this is the plot that is going to show up on this curve here so, what you will see is you should see a plot that look something like this. And let say we are doing it for this higher temperature T 2. So, you will see a plot that looks like this where, actually as the lamda goes to higher and higher values. So, it is going in this direction, the R lamda keeps decreasing and therefore, you see a curve that comes like this.

And in fact, it turns out that when you compare it with experimental data, the match of experimental data you can see that even on the board the match of the experimental data with this curve that is being predicted by the Rayleigh-Jean formula begins to match very well as you go to higher and higher wavelength. As you go to lower and lower wavelength, the lamda power 4 being the denominator simply means that this curve will go climb up to infinity indefinitely. So, it will go up and essentially go to infinity.

So, in fact, this law predicted that you would have what is called an ultra (ultra) violet catastrophe is the way it was described. So, ultra violet catastrophe simply captures this idea that at any given temperature you will have infinite radiation coming at lower and lower and lower frequencies I am sorry, lower and lower and lower and wavelengths or higher and higher and higher and higher frequencies. We know from (from) our daily experience that this is not the case. So, in daily experience, if you take a body it is not giving out any body, it is not giving you infinite radiation at higher and higher frequencies or lower and lower wavelengths. You know for a fact that the curve actually look like this.

So, if you go pester point it actually drops that to 0. So, the Raleigh-Jean law was unable to actually why this drop off comes. So, it goes up and eventually it stops dropping off. So, while the match is very good at higher wavelengths the match is not just poor, it is just completely unmatched with the data. There is no match between the data, the theoretical curve if you go to lower wavelengths. And this was based on classical formulation of this idea that you have equipartition of energy that you have at all at any given wavelength, any given frequency the body can absorb the frequency, can give out the frequency. And it will (it will) equally distribute across all the (all the) modes in which it can absorb or give out this energy. So, this is what the Raleigh-Jean formulation was.

So, then plant looked at this problem and he dealt with it differently and he came up with an which is put down here. Where he basically had 8 pi c h by lamda power 5 and 1 by e power h c by lamda k T minus 1. So, this is an expression that he came up with which is different and we will examine this in (in) just we just say that he came up with this expression. The basic idea that he had was that he basically said so that (when you) when you have, when you take a body and actually it let say it (it) is absorbing some radiation. What it means is that he consider the possibility that when you see a certain frequency coming from a body or a certain frequency being absorb by the body.

It means that an (an) oscillator of that particular frequency is now active, is the concept that is being used. And he consider the possibility that for an oscillator could be active, you would have to provide at least a certain minimum amount of energy. So, at that point in time he did not know exactly what that minimum energy would be. He just said that there is certain energy so, if you have a certain frequency you could have only energy only if it were as constant times that frequency, that amount of energy only would then would be required to excite that particular oscillator. If you had less than that energy you would not be able to excite the oscillator.

So, he just arbitrarily put this end. This was a process that he initiated arbitrarily and then he just wanted to see if this would help explain the data. So, he came up with an expression that looks like this. So, his basic argument was that if you go to lower and lower wavelengths so, the energy quantum required. So, the amount of energy because it is a lower wavelength if you write e equal h nu he did not know what this constant e was. So, for this so, this is so, if you write the Planck approach so, he is thing is and we have 1 by (No audio from 39:05 to 39:12) so, this is the expression that Planck's equation comes out with and his basic idea was as I mention that.

If you look at the possibility he consider the possibility that for a particular frequency to become active either in terms of absorbing it or in terms of releasing it you have to provide at least a certain minimum amount of energy h mu. So, some constant times this frequency and so, if you went to higher and higher frequency in other words went to when you go to lower and lower wavelength right then as a frequency goes up this h mu becomes a very large number right. So, if the energy available in the system is not that height this h mu may become larger than that amount of energy available therefore, you will not be able to excite this particular frequency right.

So, you have energy being supplied to the system so, you are providing some energy to the system now that energy has some value. So, as the and that can be shared across various frequencies, when the frequency is than very low it is able to the oscillators are actually active at that frequency, because the energy that you are supplying is much larger than the h mu corresponding to that particular frequency that mu is a very small number in that case. And therefore, the h mu corresponding to it is a small number this h he did not know what it was it was a constant that he was at that point in time not aware of he just assumed that there was a constant and so, if the frequency is a small number so, it is inversely related to wavelength.

So, the frequency is a small number; that means you are talking in this region higher wavelength lower frequency (frequency) is a small number h mu is a small number. So, therefore, you need only a tiny amount of energy to activate an oscillator that has this frequency. So, if you provide a certain amount of energy to the object there is a good chance that the lower frequencies can any becomes active, because they are in a position they are much smaller than the energy that you are providing. So, thousands of oscillators or millions of oscillators having this frequency can become active.

So, therefore, they are able to absorb that energy and similarly, later on even give out with energy, if you go to higher and higher frequencies which you come here this h mu that they were some constant, which you must still unaware of some h mu h times mu this value of h mu at (at) very high frequencies in other words low wavelengths high frequencies. The value of h mu becomes large because it becomes large; if the energy you are providing to the system is not large enough to be equal to that h mu you are not activating that particular oscillator right.

So, he just put in this rule to see if in (in) what way you can create a situation where certain frequencies are actually switched on so to speak and certain switch certain frequencies end up having to get switched of keeping in mind the fact that at higher frequencies it any way drops to zero. So, we find that there is by putting in this particular restriction that the energy that can be absorb can be given out by the system has something to do with that frequency and the and that comes as this constant times this frequency some unknown constant times this frequencies. We find that we are able to create a situation or he found at he was able create the situation, that at lower frequencies that step that step size h mu.

We can called it a step size or quantum that is that step size is small enough that when you provide energy to the system several thousand oscillators of that frequency can become active at high frequency the h mu is large. So, when you provide a certain amount of energy to the system it is less than h mu and therefore, the system is unable to absorb that energy at or rather unable to absorb it at that frequency it is not an (an) oscillator of that frequency is unable to switch on and pick up that energy right. So, so there you need to provide at least this much amount of energy before even one oscillator of this frequency will be able to become active, if you provide anything less than this (this) oscillator will not become active right.

So, this is the general idea that we put together when he did this he had no idea what this value of h would be, he simply assumed that as a attempt to this data an attempt to try to understand what is the how can you explain this kind of a data you assume that this a this was a possibility, and he enforce this possibility in his theoretical calculation. When he did this possibility he came out with a value of for R, that came out like this and when you do this if you found that by coming out with this kind of an expression he was actually getting a very good curve fit. In fact, what he did is he came up with this expression assuming that there is some constant h, which he did not know what it was.

And then with this information he change the value of h in this c is the speed of light so, that is fixed lambda we know from the data the temperature of that body is fixed k is Boltzmann constant so, all these things are fixed. So, only thing that is unknown is h right so, h is the constant that he thought might exist so, he just put it in and he came up with this expression. So, now, you can do a curve fit where you can try various values of h and see under what conditions the experimental data and the theoretical data match. So, this is what he did? And (and) what he found was that at a particular value of h the match was very good and incidentally, if you compare this expression with this expression what we will see is that when lambda becomes high this expression will reduce to this expression.

So, therefore, this Raleigh jean law as it is call is correct at higher wavelengths and the pluck law reduces to the Raleigh jean law at higher wavelengths so that. So, therefore, this expression becomes consistence to this expression only thing is at lower wavelengths I am sorry at lower wavelengths when the frequency is going up this law fails it makes no change for lower wave lengths, but clearly this is a different expression for lower wave lengths right so, that is the difference. So, what we see is that at high lambda we can make the approximation that this e power h c by lambda k T minus 1 works out this expression here.

So, e power h c by lambda k T will be 1 plus h c by lambda k T plus other terms minus 1 so, it becomes h c by lambda k T right. So, and what I have put here is in fact this denominator. So, this denominator is now this term here h c by lambda k t so, if you put h c by lambda k T here lambda k T will go the numerator that lambda and lambda power 5 lambda power 4 and if you do this, if you simplify it you will get exactly this expression the h c will again cancel out with this h c right. So, you will get 8 pi k T lambda power 4 so, this is.

So, it is very clear that from (from) a mathematical perspective the Planck's expression is exactly the Raleigh expression at higher at (at at) higher lambdas at higher wavelengths these two becomes consistent with each other at higher. So, what happen was a plank head actually looked at the black body radiation and try to see in what way he can explain what addition rules he can place on the system, which would help him get a good fit between the experimental data and the theory that here come out. And he found that he put in this rule where In the energy being absorb is in some way related to the frequency, and that there is certain step size associated with the energy which is related to the frequency.

And that you cannot just arbitrarily put in whatever energy at whatever wavelength at every given wavelength only, if you have a certain amount of energy the system very accept wavelength at that wavelength. So, it will be accepting energy the object still absorb absorbs energy the question is at what wavelength is it absorbing the energy or what set of wavelength its absorbing the energy? It turns out that at a given wavelength it will absorb only if there is a certain minimum energy available come and with that wavelength only then it will absorb, if it is if the step size is not equal to a certain value it cannot absorb at that wavelength it will have to absorb at some other wavelength.

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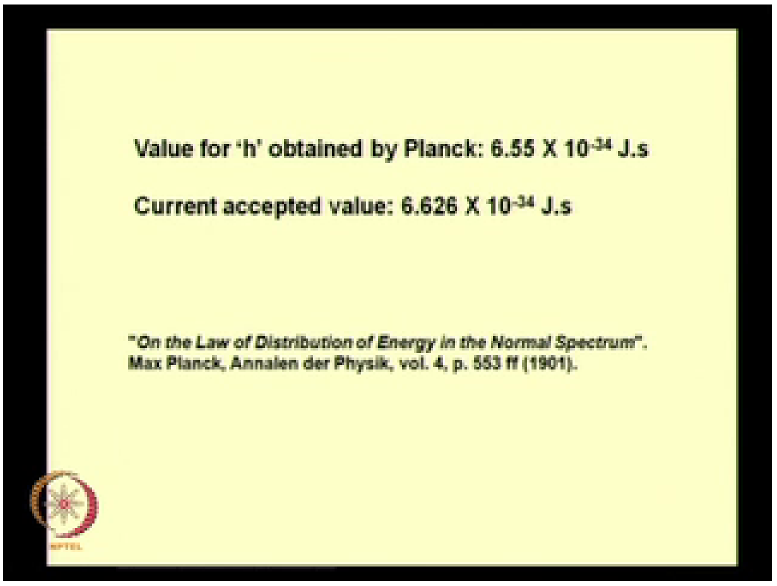

So, that is the basic idea that he got (got) together, and as I said he did have curve fit with experimental data and he obtained a value for h, that value on the day that he publish this paper which incidentally 1901 when he published his paper the value he came up with was 6.5510 power minus 34 Jules second was he had it in non s i units or that point in time. The current accepted value is 6.62610 power minus 34 Jules second so, you can see that you know in 19 naught one by doing a curve fit he came up with a value which is very close to the current accepted value right.

So, this is how he had come about this process gone about this process. So, what is actually happened is in this process he had in adherently stumbled upon this idea that energy as it relates to electromagnetic radiation has something of a step size associated with it. And that you have to the conventional thing that had been there up until that point that energy was at in the radiation in the manner in which matter and radiation exchange energy was continuous and smooth and everything, that concept had to be re examine. And he had stumbled upon this fact that the process by which energy is transferred between matter and radiation has some has some step size associated with and that you need at any every given wave length at least that much step size for that transaction to occur so, he had stumbled upon this idea.

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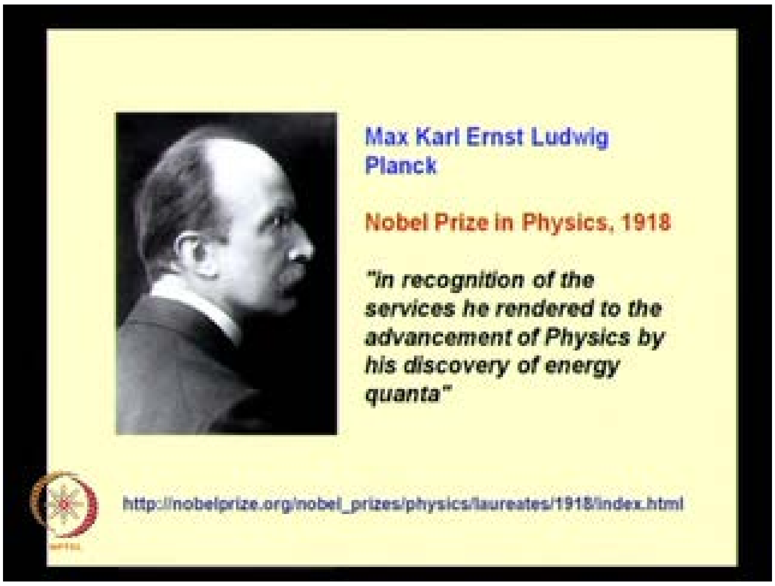

So, for doing this (this) step size or quantum as it became came to became refer to is the starting point for the entire field of quantum mechanics. So, what started as a curve fit what started as an attempt to clear up those small pieces of experimental data which apparently people did not understand than the starting point for an entire field of science. So, he is attempt to do this the single paper that he published on nineteen naught one is considered as the starting point for quantum mechanics, and we consider that as a very significant contribution today there is a lot of science that we do, which fundamentally ovals its origin so, to speak to this discovery of this and then its subsequent development and use.

In fact, even at a time that he did this he (he) himself was not completely convinced or completely sure of what exactly here done he just had done something that he himself felt was you know a kind of curve fit, that help explain the data. He was not so, the general belief is that he himself was not so, convinced that nature in fact, behave like this it (it) was a very difficult thing to accept that nature had some step size associated with how it went about things and then that if he did not have this quantum process involve certain things would not occur.

So, this was something that was very difficult to accept and very difficult to understand and so, it was taken on state value, that in fact, if you do this the system seems to explain the data so, (so) on that basis this process was accepted. However, we have come a long ways in see he has actually he stumbled upon this discovery of quantum mechanics and he initiated this entire science of quantum mechanics and of course, he won an Nobel prize for this in 1918. Even very recently this is something that has linked on there are lot of famous scientist you have who have come about since then and who have done a lot of work, which is which is sort of related to quantum mechanics and therefore, there are several noble prizes which are sort of associated with this general area.

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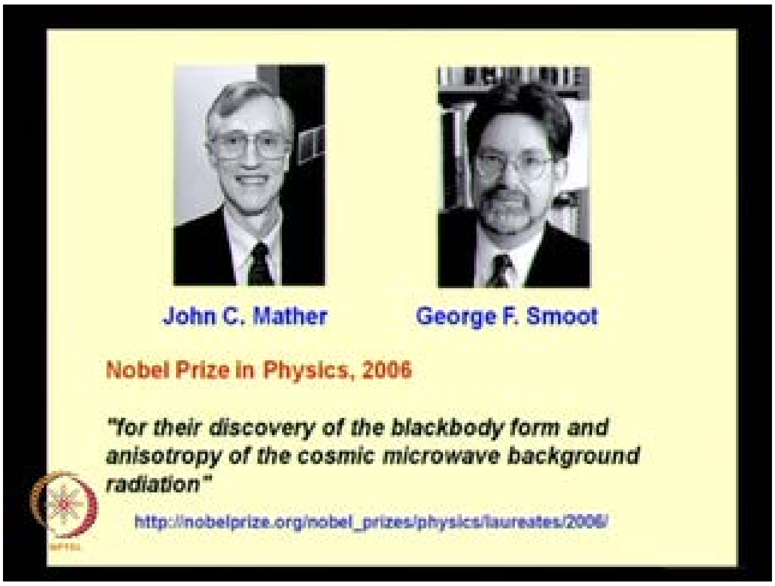

In fact, if you see even recently relatively recently in the year 2006 the Nobel prize for physics. So, the was given to Mather and smoot were here for the discovery of black body form of cosmic microwave radiation. So, they basically sent out a satellite which looked at the background radiation in the universe and they made a plot of the data, that was obtained from the radiation available in the universe just coming (coming) towards. When you make a plot of this data it terms out that it is a plot that it exactly the same form that we (we) have drawn on the board of that of a black body in other words the universe is giving out radiation.

Which (which) actually has the same kind of form that at some wavelength at very high wave length it drops to zero at very low wavelength it drops to zero and somewhere in the middle you actually have a peak. And based on this peak they have even have been and so, the general form fit the black body radiation data that we have drawn and it also exactly fit the black distribution law. And therefore, we were able to actually able tell as the background temperature of the universe and it is based on their calculations the temperature of the universe the background temperature is about two point seven Kelvin two point seven five Kelvin is the background temperature they have for the universe.

So, in other words naturally it is it is generally believed at naturally speaking you will not have a temperature lower than this anywhere in this universe. So, that is the natural lower temperature that exist in the universe it is slowly cooling it has from the time the universe was came into existence came in the manner that we (we) currently understand that he did, if the temperature of the universe has been sturdily coming down average temperature and this is the current temperature of the background of the universe.

So, this is something that the discovered by sending out a satellite it is called the cosmic background experiment or C O B E you can look it up in any of the source that you may have accessed to and they will show you that actual data that they obtain from this experiment and the temperature that (that) corresponds to that particular data. So, you can see that this is a this data this black body radiation is not simply matter of some esoteric curiosity of a few people it is not something that you can say it is it is some experiment, which exist in some very particular conditions in a lab and it is of no real relevant to day to day life.

And it is in fact, it captures a very fundamental aspect of how energy exists in our universe and how it behaves and how matter interacts with energy. A very fundamental aspect this aspect of this entire process of interaction of the matter and the energy and how it exist in our universe is captured very elegantly this simple experiment of this black body. And therefore, even though in the year nineteen hundred or just in the year preceding nineteen hundred it look like one of those few small experimental phenomena that were still needed a little more explanation, but soon would be hint out. It entered up that it was the, it had hidden in it a very fundamental aspect of science, that we that thanks to we had stumbled upon and we have discovered.

So, this is the origin of quantum mechanics as an exploration of this black body radiation which has which seems to have such profound consequence and of is of significant, that we even know things about the universe were able to tell the temperature of the sun we are able to tell the temperature of stars and so on. Which have which had millions of kilometers away from as millions of lighter away from as we are able to do all that thanks to our understanding of this black body radiation and how the theory behind it is.

So, it is a very phenomenal discovery and science behind it and it is the origin of quantum mechanics and (and) what we will do in the rest of our course is to take some of these principles of quantum mechanics and apply it to our subject of study, which is electrons in a solid and see how well it explains the theories that exist in the data that, we get from the solid. In the next class we will continue a discussion on the history of quantum mechanics, because there are few other specific relationships, which are considered very important aspects of quantum mechanical behavior.

And we will at least become familiar with those relationships and see how the inter integrate with respect to each other, because it is that body of relationship that together we will take and utilize when we examine the electrons and solid. So, we will have one more class which looks at the history of quantum mechanics and then we will get back to utilizing those concepts to study the material behavior. Thank you.