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Lecture No. # 05
Free Electron Gas

Hello, this is our fifth class in this course on physics of materials and in today's class, we will begin our first attempt to create a model, for the electronic properties of material specifically, we will focus on conductivity. As we discussed in the last class, there is a good reason, why we are spending, why we will spend so much time on the electronic properties, especially conductivity simply because this lot of technological interest in this property, and there is also a lot of scientific interest because of the range of values that conductivity has.

As I mentioned last class between the best conductor, and the worst conductor of electricity that you can find, there is a range of values of about twenty seven orders of magnitude, which is more than any other property, more than the range of values, you will find for almost any other property, that you will you are likely to measure for a material. Therefore, there is a lot of scientific interest on the property that is conductivity. So, for this reason we will spend some time, trying to build a model for conductivity and build several models actually, for conductivity.

And try to see what is the insight that, we can gain into how various constituents of the materials, interact with each other and help as get a model and therefore a prediction, on what the conductivity of a material should be. I must also that in our discussion so far, we have specifically not included the special class of materials, which are referred to as superconductors that is something we will look at towards the end of this course.

So, when I talk of twenty seven orders of magnitude, it does not include superconductors it is what we would call so called normal conductors. So, standard conductors, that we are more familiar with a typical metal at room temperature and so on. The concept of superconductivity is very different, there are special aspects or special features that are prevalent, when we say that a material is demonstrating superconductivity. It is very different from the normal mode of the standard mode of conduction that we see in the typical materials at room temperature. So, therefore, we would like to treat that as a separate topic.

The kind of theory that explains a difference, from what we would use for conductivity at room temperature for most metallic systems. So, I am excluding that, I just wish to alert you to that we have excluded it for now, towards the end of the course, we will have a class more than one class perhaps, on just the aspects of superconductivity. So, for now we will focus on conductivity in the sense, that we are more commonly aware of and specifically, in the case of metal that there is a positive coefficient of thermal coefficient of resistivity.

So, that is the conductivity that we are interested in when, we raise the temperature of the metal the resistance of metal or the manner in which obstructs, the flow of electrons actually becomes more prevalent. So, this is what we would like to explain. So, we will do this, we will begin our first attempt to come up with a model by looking at something, that we have possibly you have been familiar with, from your high school days. Which is that we describe metals and as being a situation or state of a materials, where you have a free electron gas.

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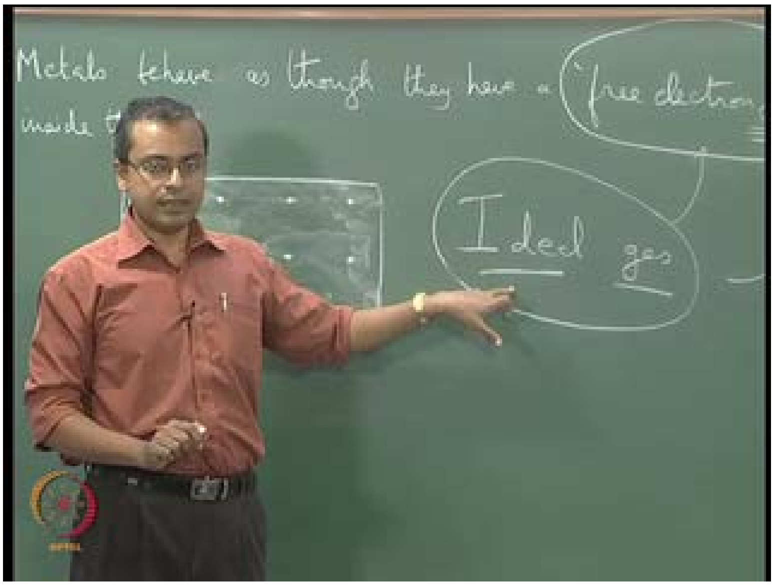

So, we hear this description so, we say that ((No audio 4:00 to 4:36)) this what we are often told that metals behave as though, there is a free electron gas inside the system and so, our attempt to describe metallic systems, our first attempt to describe metallic systems will take advantage of this description or will at least work around this description, this is the general framework within which we will operate.

So, what do we mean by a free electron gas. So, the way it is describe to us and which is the general format in which, we will continue to use this description is, that in a metal we have all the atoms that going to towards making a metal, those atoms actually have some valence state and to that extend they release an electron, which stays within that material, but is no longer belonging to a specific atom.

So, if there are thousand atoms present there and each of them has a valence 1 plus 1 or valence state of plus 1, then each of them releases one electron. So, the thousand atoms now together release one thousand electrons, these one thousand electrons are now free to run across, the entire extent of that. So, this general state we then referred to as a free electron gas state, where all those electrons, those thousand electrons which are now freely running across extend of that solid are together, referred to as a free electron gas.

So, for example we are just saying that, we have an ionic core here. So, we just have a schematic of two dimensional ionic core and let say all of these have released electrons. So, these electrons are actually running across this entire area, this is what the ionic core remains wherever they are and the electrons are running across the extent of the solid. So, this picture taken together is what we are referring to as the free electron gas picture. So, in this system originally when we think of a metallic system, we have those atoms sitting at regular lattice positions as we call them. So, these ions continued to sit those regular lattice positions, but they have released one electron, which stays within this solid.

So, to use the term the kind of terminologies use for it, the electrons are still localized within the extent of the solid. In other words they cannot ran away from that solid only, if only we extract the electrons somehow and remove it away from the solid and take it to infinity, where it no longer can interact with this, only then it is escaped. So, those electrons have not escaped, they are sort of stuck within the boundary of the solid. So, some boundary is there. So, the electrons now stay within this boundary. So, for our purposes they stay within this boundary, but at the same time, they are not attached to any particular ion, any particular ionic core.

So, an electron that might have been released from this ionic core no longer actually, specifically belongs to this ionic core, it runs across the entire solid. So, what happens now you have positively charged ionic cores, which in principle should repel each other and actually try to get away from each other. So, that is the general tendency because their like charge they are push each other away, the electron cloud as we describe it of this free so, called free electrons they provide the negatively charged atmosphere, within which these positively charged ions can now, sit stable at some equilibrium distance with respect to each other.

So, this is how the picture of the solid is, you can I mean loosely we can think of it you know some kind of a box within which we have contained a gas, something like that you think of. So, that description is not a very far from what we are attempting to use here. So, these electrons are free to run. So, this is the general idea that we use to wish to use.

So, what we like to do is to see if given that, this is the picture or to use the term, this is the model that we would like to that, we believe that the solid actually has, we would like to put some equations, numbers, relationships, to this model. Based on our best understanding of how these particles interact with each other and see if from all those equations, relations and numbers that we throw in to the system. We are able to get some prediction for how the conductivity of the solid given these, these general picture of the solid how will the conductivity be. So, what is the kind of conductivity that, we get from it.

So, what we are actually doing is, we are actually focusing on this word gas. So, free electron gas. So, gas is the word that we wish to focus on with respect to this particular description. Why I wish to highlight that, is that we are actually quite familiar with again from our high school days or even from our early college days. We are very familiar with this concept of an ideal gas.

So, we have this concept of an ideal gas, this we are very aware of we have a good sense of what it represents. We have a feel, we are very familiar with what equations go along with an ideal gas and so on. So, but we are at least quite conscious of what it is and how we can, what properties it may display, what can we extract from it, what predictions we can make about it? So, what we are going to do is actually take the rules or the behavior of an ideal gas, the general behavior of an ideal gas, all the rules that we associate with an ideal gas, all the behavioral trends that we associate with an ideal gas and impose that on this free electron gas.

So, we are going to take the ideas rules and the concepts that, we associate with an ideal gas impose it on this picture of a solid, metallic solid which contains a free electron gas using this idea, where this is independently developed and by imposing it on this system here we make a predictions. So, from based on this we are able to make some predictions so, predictions. So, we are that is our final goal that is what we intend to do, we would like to make predictions.

So, based on this combination, we would like to make predictions. So, of course, the minute we so, to step back and see what we are doing is, we are taking rules associated with a gas and enforcing it on a solid. So, we need to be very clear, on what we are attempting to do. We are taking rules associated with a gas and in fact not just any gas, rules associate with associated with the so called ideal gas and imposing it on something, that we have never imagine does a gas when a solid is given to you. When a solid piece of metal is given to you never, you never intuitively think of it as a gas.

So, in fact in our mind it is clearly etch that a solid is not a gas, that is the very definition of a solid as a state of matter, but we are going take the rules of an ideal gas, impose it on a free electron gas on a solid and then make some predictions. Where we are actually not stretching ourselves too far is because we are not actually imposing it on all of that solid.

We are actually imposing it on just the free electron gas, the free electrons the so called free electrons, which are now free to run across the entire extend of the solid, it is that set of electrons which are now freely running across the solid and therefore, having some characteristics similar to that of the of freely running molecules of a gas, which have some similarity. So, based we are taking that similarity taking advantage of that similarity to make this extra operation.

So, now given this we will add little more we will probe this idea, that we can put this ideal gas behavior on a free electron gas, a little more to see. How justified we in doing this, I have just tried to indicate that there is some similarity between this ideal gas and so, called free electron gas. So, we will try and put explore that idea little bit more to see, how justified we are in extending this idea of a ideal gas, to a free electron gas and we will also see, if there is any reason why we need to be cautious about this extra operation.

So, what is the aspect of extra operation that we should be little bit concern about. So, that at least upfront we realize that we can anticipate some limitations, when we try and do this kind of an extra operation alright. So, we will first look at the good news in terms of these two of this extra operation.

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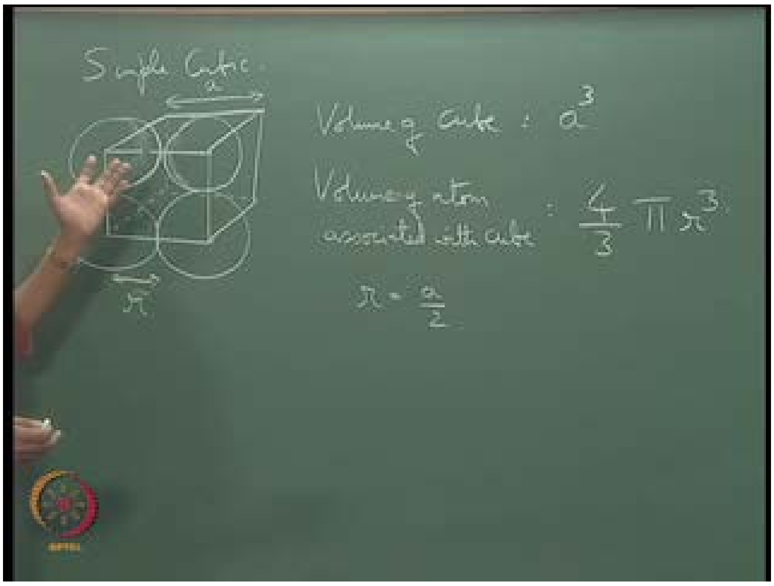

What is right about this extra operation. So, to speak we will now see in terms of a solid, what is said that we are trying to, how we can justify this alright? Now, let take a solid which has a simple cubic crystal structure. So, we will just draw that here right. Now, at the corners of the simple cube, there are atoms. So, the general picture that we have is that, we can put atoms which are roughly of this dimension, we just make those that atoms touch.

So, that is what I am trying to do here, for clarity I will just stick to the atoms with the front face of this cube, there are atoms on all of those corners also the other corners, which are there I have only put four here, there are four more behind. So, just for clarity we will just stick to these four atoms for now, and not worry about the other four atoms. So, the atoms have radius r and this crystal structure has a latish parameter a. Now, we are familiar with this idea of a packing fraction. So, this is something that we are familiar with so, we will just very briefly run through the calculation.

So, the volume of cube is simply a cube, when you have a simple cubic structure, you have eight atoms associated, I mean which are placed at the edges of this cube, but given that each of them is now shared by all of the neighbors. If you actually run through how many neighbors each of them is shared with, you will end up finding that on average per cube there is one atom, that is what you will end up finding on average, you will have one atom per cube because you have 1, 2, 3, 4 neighbors here and 4 neighbors on top.

So, 1 by 8th of this atom belongs to this cube similarly, 8 atoms are there. So, on average one atom so, the volume of an atom associated with this cube is simply. So, volume of atom associated with the cube. So, 4 by 3 pi r cube is the volume single sphere will assume spherical atoms are all spherical and then you will get 4 by 3 pi r cube. Given, that the dimensions of this cube, relate to the dimensions of this atom such that, the atom just about touch each other when they make this cube, we see that r is simply a by 2 therefore, r equals a by 2.

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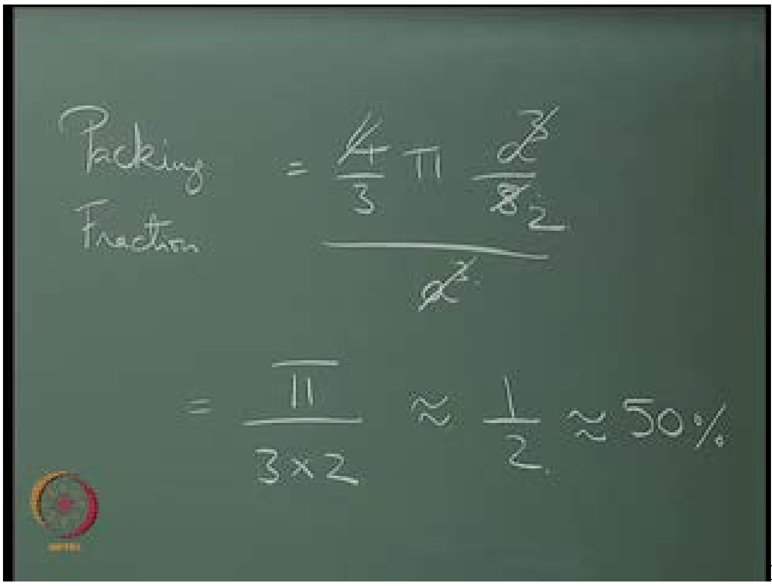

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So, if we look at packing fraction, what we have here is packing fraction is simply the percentage or the fraction of the volume of this cube, which is occupied by this atom. So, that is the packing fraction of this system. So, if you look at we have packing fraction so, I put it down here. So, a by 2 I have substituted for r. So, you have a cube by 8 and a cube is the volume of the, of the cube. So, if we simplify we actually have so, this is 2 so, this is actually pi by 3 into 2, pi is 3.14. So, we just want idea of the value we are not really interested with the exact precise value, but so approximately this is 1 by 2 because this is also about 3, this is also 3.

So, approximately 1 by 2 so this is approximately 50 percent, actual value comes to about 52 percent or something 51, 52 this is just order of magnitude, we got 50 percent fine. So, if you take a simple cubic structure and we run through this calculation, we get about 50 percent fine, this is one of the less structures. So, to speak so we will actually look at a more packed structure for a moment here. So, if you look at a so called close packed structure, which is like the face centered cubic structure F C C.

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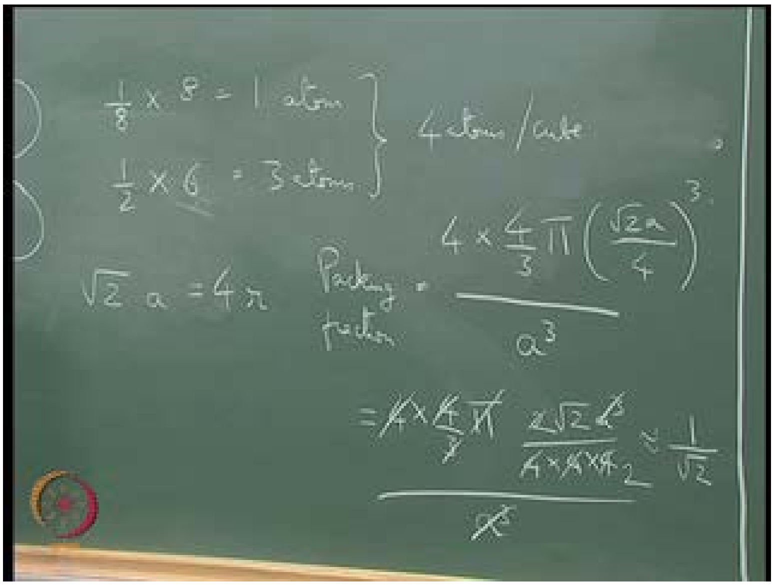

So, in face centered cubic structure, if you just look at the face of the cube, ((No audio)) for based on symmetric consideration it is enough, if we look at just one face of the cube for our purposes. So, face centered cubic structure looks something like this, if you look through the calculations of how many if you again see that, you know every corner atom is actually shared by 8 other cubes. So, 1 by 8th of every corner atom and there are 8 corner atoms, there are 4 here there are 4 in the other corners. So, into 8 so one atom.

And then the face centered atoms each of them is shared by the adjacent neighbor. So, half of this face centered atom belongs to this cube. So, there are 1, 2, 3, 4, 5 and 6 face centered atoms. So, 6 into half equals or half into 6 to speak to this convention, half into 6 equals 3 atoms. So, per cube there are 4 atoms now present alright and if you look at the relationship, this is root 2 times a this is so, this diagonal here is root 2 times a. So, root 2 times a because it is simply square root of a square plus a square. So, 2 a square root so, that is root 2 a that is equal to r plus 2 r plus r so equals 4 r.

So, again if you go through this packing fraction calculation, what we have is packing fraction here your denominator is a cube, still the volume of this cube that is a cube, there are 4 atoms times 4 by 3 pi r cube and r is related like this it is a by. So, this 4 will come down here so, 2 root 2 so, put it down here this is root 2 a by 4 whole cube. If you simplify this again we will just see here, I will just write it here. So, that we can cancel out, what we need to cancel out.

So, this is 2 root 2 a cube by 4 into 4 into 4 by a cube. So, we can just cancel these things out by a cube goes here this 4, this 4, this 4 and this 4 will go. So, we will have 2 here and once again we will just approximate and cancel out 3 and pi this is just an approximation just give us give ourselves, the order of magnitude so, we actually have this is approximately 1 by root 2.

So, this is what we will end up getting 1 by 1.4 1 4 is what you will end up getting as the packing fraction. So, this is 4 atoms their volume 4 by 3 pi r cube or you can even say you know root 2 by 2. So, 1.41 4 by 2 so this is roughly about 75 percent. So, this root 2 by 2, if you just look at it as root 2 by 2 root 2 is 1.414. So, you divide by 2, 70 to 75 percent, this is just an order of magnitude. So, we get of simple cubic you get about 50 percent packing fraction which means, about 50 percent of space is occupied by atoms so, to speak in much more packed system, you have 75 percent of the atoms occupying the space.

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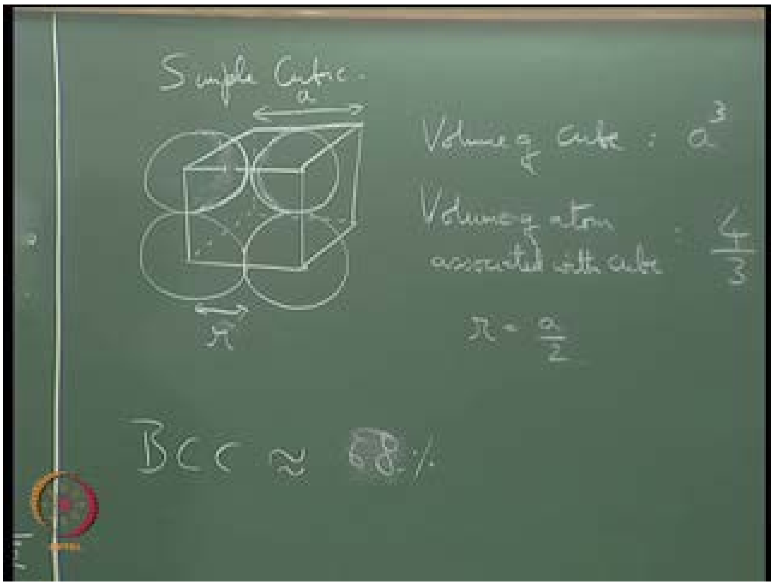

Now, if you look at it if you look at all the metallic systems, that you if you look at the other one the B C C, which we will not go in to the calculations, it comes out to about 62 percent, no actually 68percent, 68 percent is the packing fraction that you have for B C C, these are all approximate numbers. So, all I wish to point out is that you have numbers of this order 50 percent, 68 percent, 75 percent approximate numbers of the packing fraction. If you actually down through the correct calculations, you may get more precise numbers, but this is what you are looking at.

So, what you need to understand is that you know these are for example, solid objects that you find, solid objects like this. So, this is a metal metallic solid object that we have so, this is just a rod of a metal and this is a part of a gear, part of a gear it is a failed part. So, this is being actually some analysis is being going down on this part. So, this is a part of a gear and this is a spring, very strong powerful spring so, strong that is very difficult even press with your hand. So, this is the spring.

So, these are all solid metallic systems metallic objects that you can locate and you can find easily find. So, when you lift them when you hold them in your hand when you look at them, it is difficult to imagine that you know anything like 50 percent of it, 25 to 50 percent of it is actually open space it is vacant. So, when you say a packing fraction is 50 percent, when you say a packing fraction is 50 percent. It means 50 percent of the volume of that system is occupied by atoms, the other 50 percent is empty. So, this is not something that intuitively occurs to as, when you look at a solid object.

When you look at this solid object, if in case this had been simple cubic based structure, there are very few metallic systems that fall in the category, I believe polonium is one of them, but if this where such a structure 50 percent of this, half of this would be vacant empty space, that is not something that we intuitively imagine when you see it, even if you say quarter of it is empty again, it is not something that is intuitively known. So, but that is the fact when you actually do run through the calculations, you find there is that much of vacant empty space present within this solid object.

So, when you go back to our picture, that we say that you know there are ionic cores and then, the rest of the volume of that solid is actually being freely occupied by all those free electron gas. The electrons that have been released by those ionic cores and actually once the atom actually releases the electron, it is radius will actually slightly decrease.

So, we will actually have to use the ionic radius here. So, in fact in principle you can think of it as even more space has been available for the electrons.

So, even more than 50 percent may be available for those electrons to run across the entire volume of that solid. So, therefore, from the perspective of a packing fraction, when you recognized how much of that solid is actually vacant, and from that perspective it is not a very unreasonable thing to treat, the free electron gas as behaving in the manner that the ideal gas. So, where we actually look at the fact that an ideal gas, the atoms run across the volume of the container that and they have a lot of free volumes to run across. When you make that comparison to that solid even though in principle, we know upfront that solid is a different state of matter.

Even though we know that, when you realize that 50 percent of the solid is vacant or could be vacant depending on that crystal structure, 50 percent of it could be vacant and those electrons which are very, very tiny. Please remember an electron is extremely tiny relative to the molecule of a gas, when you take that in to account and it you assume that it is freely running across, that half the volume of that solid from that perspective alone, this link between an ideal gas behaviors does not seen very far. So, therefore, at least to start off with it is not an unreasonable thing to extend, the ideal gas ideas to a free electron gas, which happens to exist within a metallic system.

So, that is the first part of what we would to highlight at the same time, I think it is necessary to recognize the reasons why such an extra operation, should be taken with degree of quotient? Now, look at the reason, why we need to take this from an ideal gas behavior to a free electron gas behavior inside a solid with some degree of quotient. So, to do that what we need to consider is that, we get need to get a feel for is the number density of particles so, we will just see what we mean by that.

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So, let us take for example, an ideal gas what we are told of an ideal gas or what we are aware of an ideal gas is that at S T P. So, 0 degree c and one atmosphere pressure standard temperature and pressure 0 degree c and one atmosphere pressure. An ideal gas will occupy, one mole of an ideal gas occupies 22.4 liters. So, that is the volume occupied by one mole of an ideal gas. Now, we will run through some numbers one mole implies 6.02 3 Avogadro number into 10 power 23 atoms or gas molecules so whatever. So, one mole is 6.02 3 into 10 power 23 atoms, in this case let us assume an atomic gas.

So, we will have this some ideal gas we have. So, many atoms are present in one liter so, in 1 I am sorry in 22.4 liters at S T P. So, let us see the number density that we are looking at. So, we have 6.023 into 10 power 23 atoms in one liter and one liter is, 1000 liters is 1 meter cube. So, we will run these numbers on a perimeter cube basis. So, 1 into 10 power I am sorry 22.4 into 10 power minus 3 meter cube.

So, 22.4 liters 1 mole is contained in 22.4 liters 1 mole has so many atoms. So, so many atoms are contained in 22.4 into 10 power minus 3 meter cube fine. So, this is approximately, if you look at it we are looking at approximately 3 into 10 power 25 atoms per meter cube, 3 into 10 power. So, this is 2.24 into 10 power minus 2. So, that would make it 10 power 25 and 2 and 3, 2 and 6 would give a 3 there. So, this is approximate just because we are only interested in the order of magnitude really.

So, 10 power 25 atoms per meter cube is what we are looking at 3 times 10 power 25 atoms per meter cube so, this is for an ideal gas. Now, we will look at the other possibility, let us take a solid, in fact a metal for which we are to impose this kind of trying, where we this ideal gas behavior to the free electrons present within that system. So, an example that we will take of a solid system would be silver, we will just take silver it is density is approximately 10.5 grams per centimeter cube, normal it is atomic mass is approximately 107 atomic mass unit's. So, 107 AMU and normally valence, commonly demonstrated by it is plus 1. So, valence state is plus 1.

In other words, if you have a block of silver, it is reasonable to treat it as though, every atom in that silver in that block has released one electron for this so, called free electron gas. Now, given this information we will not worry, we will just use this density and atomic mass to give us an idea of the volume we are dealing with. And we will take use of the fact that again, one mole of this substance would have released per atom released one electron to this free electron gas. So, we will have an idea of the number of electrons, we will have an idea of the volume their contained it and therefore, we will get a number density.

So, since this is a solid all we are saying is that, we will just go this is some many grams per centimeter cube. So, we will convert this to grams per meter cube because we would like it in atoms per meter or particles per meter cube. In this case we will get it as electrons per meter cube. So, to do that we have 10.5 into so, this is centimeter cube 10 power minus 2 each centimeter is 10 power minus 2 meters. So, 10 power minus 6 meter cube. So, this is it will become 10 power 6 grams per meter cube that would be in the denominator so, it will go to the numerator so, many grams per meter cube we will have of silver.

And if you divide this by its atomic mass 107, that will give us the number of moles of silver per meter cube number of moles, of silver per meter cube and if you multiply this by Avogadro number this now, gives us 10 power 23, this now gives us the number of atoms of silver per meter. So, this is the density of silver, this is the atomic mass therefore, number of moles per meter cube and ten times the Avogadro number, gives you the number of atoms of silver per meter cube and assuming that every atom has released one electron effectively, the same number will be there, same number of electrons per meter cube will be available.

If we just run through this calculation, what we see here is again this is similar kind of number so, this is we can treat this as 10 power minus 1. So, this is 10 power 5. So, this is approximately 6 into 10 power 5 plus into 10 power 23. So, 10 power 28 electrons per meter cube. So, if you just run through these calculations we get 6., 6 something into 10 power 28 electrons per meter cube. So, if you do not worry about 6 and 3 essentially, we see that in an ideal gas, we have about 10 power 25, in this case atom per meter cube and in a solid, we have 6 power 10 power 28 electrons per meter cube. In other words that is the 3 orders of magnitude increase, in the number of particles per meter cube fine.

So, in a solid the electrons are one thousand times more densely packed, than the atoms in a gas. So, that is a difference of 3 orders of magnitude thousand times more densely packed electrons relative to the atoms in a gas. So, this is the reason why we need to be cautious, when we extend an ideal gas behavior to these so, called free electrons, which are present the free electron gas, that we believe exists inside a solid.

So, there is a different in thousand, 3 orders of magnitude or thousand times more densely packed electrons are present within this solid, relative to what is present here. The reason why this is something that we need to be about is because in an ideal gas, we make statements and which we will do even now, that the particles do not interact with each other. So, they are isolated enough from each other, even though I mean they do interact with each other, but they do not each other. There is a we basically say that they colloid with each other, but after that collisions there is no further interaction between the particles.

So, they do not influence each other between those collisions. Now, the more densely you packed those particles, the less reasonable that statement becomes. So, the more closely the particles are packed, there is a greater chance that they will actually interact with each other, even between the collisions therefore, the kinds of things that we say for an ideal gas. Now, slowly becomes less and less reasonable to say about system where you have electrons, which are much more closely packed thousand times more closely packed.

So, we have actually two pieces of information, one is that most of the there is a lot of vacant space present within the solid. And therefore, on that basis it is reasonable and interesting to extend ideal gas behavior to study electrons in a solid, at the same time even though there is that much space available. The electrons present within the solid are about thousand times more densely packed than, the atoms present in an ideal gas therefore, that provides us with a reason to be about such an extra operation.

So, both these things are there, we need to keep both of them in mind. So, it is not unreasonable, but at the same time we need to be cautious about this whole process. So, with these ideas in mind, we will just put down now the kinds of rules, that we will expect our free electron gas to obey and based on those rules, we will then develop our theory for a free electron gas and therefore, predict the conductivity of the material. Especially, a metal based on our of ideal gas behavior to a free electron gas. So, we will just put down the rules today, we will then have to take some tangential deviation to develop few of the ideal gas concepts, that are of interest to us and then impose them on the free electron gas.

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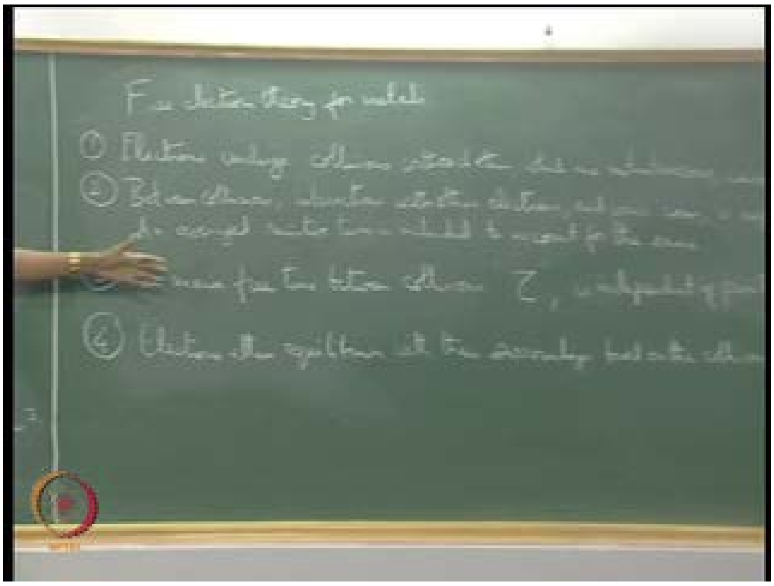

So, we will go into our ideal gas behavior a little bit into in the next class, and then we will come back again in the class after that and impose that on the rules, that we are now going to put down and see how the equation step for metals, is based on some assumptions. So, the first assumption that we put down is that undergo, electrons undergo collisions with each other. So, electrons undergo collisions with each other, which are instantaneous and these lead to scattering. So, the first thing that we say about electrons, as they behave as a part of free electron gas is that, they undergo collisions with each other and as a result of these collisions the electrons scatter.

So, these scatter they go all around the place before they bounce of other electron. So, this is one thing, these rules that we are going to put down, you will see that many of these rules are very similar to what is being stated, when you develop the ideal gas behavior. So, to the equation for the ideal gas behavior and that is the reason, why I highlighted that upfront between scattering, between collisions, Interactions with other electrons and ionic cores is neglected.

So, between collisions interactions with other electrons and interactions with ionic cores is neglected, in it is details, in the details. And I think this needs to be explained a little bit, what we are saying is between once an electron is collided with another electron and bounces off, till it makes the next collision with some other electrons, which is randomly moving through the solid, in between there is a certain amount of time that it is travelling between two collisions in that time, we are not specifically writing any detailed equations on how it is being influenced by other electrons around it, being influenced by the ions around it.

So, however we do put in an averaged term.((No audio)) So, we do put in some kind of an average resistive term to account for this general interaction, but we are not specifying anything in any grade detail. So, therefore, some aspect of this ideal gas kind of behavior, we are still maintaining. So, the detail of the interaction is neglected, but some averaged interaction is being accepted or accounted for. So, that is what is important there is something that, we call the mean free time between collisions, the mean free time between collisions is represented by tau.((No audio)) So, this is the average time between collisions. So, an electron as I mentioned bounces of one electron of another electron, then travels for some time, then hits the third electron.

So, this is going on for all the electrons within the system at any given time, the duration between two collisions will vary from for all the electrons. So, we may travel a longer distance before they hit the next electron, some may immediately hit the next electron, and some may immediately hit the next electron and so on. So, this happens so, we cannot actually since, there are so many electrons within a solid, we cannot actually individually note down the numbers for every single electron or attempt to put numbers down for this.

So, what we do is there is something called the mean free time on average, this is the time that an electron travels between two collisions, it will have a collision on average, it travel this time before it has the next collision that average time is tau and that is independent of the position and velocity of the electron. So, in other words and this is reasonable, because by definition this is mean free time this is just a mean average. So, clearly velocity is higher the chances that it another electron may be higher, but that is that is all accounted for the fact, based on the fact that we using the mean free time, this is the third assumption((No audio)) electrons attain equilibrium with their surroundings, using these collisions with other electrons.

So, therefore, the collisions are important, you cannot just completely neglect the collision. So, the collision is so, that is the reason why we are putting these rules down. We wish to highlight that they are the electrons are free to run across the extent of that solid there is a lot of vacant space within, the solid and the electrons are free to run through the solid and as they do so, they colloid with other electrons.

So, those collisions are instantaneous in other words there is no time that we are associated we are not saying that, you know when the electrons hit each other for one, second their next to each other, we just say instantly they hit bounce off. So, that is instantaneous and this causes scattering. So, the electrons run all around the place, because of those collisions, between the collisions the interaction between those electrons is being neglected the interaction.

So, there will be some repulsive interaction between the electrons, that is being neglected there will be some attractive force between the ions present in the solid and the electrons that is also being neglected and that is not unreasonable because as we mentioned. You know even between the ions there is a force of repulsion, but the electron cloud effectively which has the same amount of charge as those ionic cores.

The total charge of all those ionic cores is the same as the total charge of that electronic cloud. So, these sort of cancel each other which is true even for the electrons. So, even for a single electron that is running around, there is a large ionic core that is present within the system, large set of ionic cores and there is also a large electronic cloud. The total negative charge and the total positive charge more or less, cancel each other out expect for this one electron charge. So, largely it is running in a more or less neutral system surrounding.

So, therefore, the interaction is being neglected in these details, but an average resistive term is being included, which we will see when we actually put it is value down, and there is a certain mean free time between collisions, which is independent of position and velocity of the electrons because it is the mean free time, as we describe and finally the reason we need to focus on the collision because that is the manner, when the two electrons colloids they exchange energy. So, there is an exchange of energy. So, one is gaining energy losing energy, overall energy is concerned, but there is an exchange of energy and that is how the electrons attain equilibrium with their surroundings.

So, when you take a block of metal and place it in a room, that has a certain temperature, let say this block of metal was cold, you take it out and keep it in room, which has a higher temperature, it is only because of these collisions with various electrons and so on, that slowly the heat begins to permit into the system. The electron which very close to the surface of the metal, sense the temperature first they gain energy. We just deflected by their velocities, how they move and so on and they go on colloid with other electrons, the ionic cores also participate in the process.

So, which we are not addressing at the movement, but for our purposes we will focus on the electrons at the movement. Later we will see what the ions do, but we will focus right now at the electrons because the properties we are going to focus on depend on those electrons, the specific property that looking. So, they attain equilibrium with their surroundings, because of the collisions and therefore, it is important to keep track of the collision, we cannot completely neglect those collisions.

So, that is the basic idea and so, these are the broad rules, that we will take they have lot of similarity with the rules that ideal gas, ideal gases have and that we impose on an ideal gas or we expect an ideal gas to demonstrate and the very same rules. Now, we will now impose on the solid and on the electrons in the solid and see what kind of behavior, those electrons demonstrate and based on this, based on this model we will now be able to predict specifically, the electronic conductivity. We will also predict the thermal conductivity, these are two major properties that we predict and we will see some interesting relationships between them.

So, it is with is background that we will halt here. In our next class since, we are going to use some ideal gas behavior and specifically, we will use specific quantities or relationship from an ideal gas behavior, which will be relevant here, we will develop those specific quantities briefly, then we will come back to these assumptions impose those quantities on these assumptions, I am on that basis we will develop the electronic conductivity, that will be two classes from now and 3 classes from now, we will look at thermal conductivity. So, that is how it looks going forward from here. Thank you. .

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