Introduction to Solid State Physics

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Lecture – 01
Introduction to Drude's Theory of electrons in a metal – Part I

In this course we are going to study properties of solids. As they are subjected to different conditions like varying temperature, electric field, magnetic field, impinging of electromagnetic waves on the solid. You can apply or electric field or a voltage across the sample and look at the conductivity of the material, measure the conductivity or the resistivity as a function of temperature, see the behavior of the material in the presence of a magnetic field.

So, these are the different properties of solids that we will study in this course and you will learn about different sort of properties of the material as they are subjected to different conditions. However, before we study solids and try to understand properties like resistivity, conductivity specific heat, the thermal properties of the material or of the solid. Let us take a step back and let us look at the properties of a gas and how do we understand the behavior of a gas.

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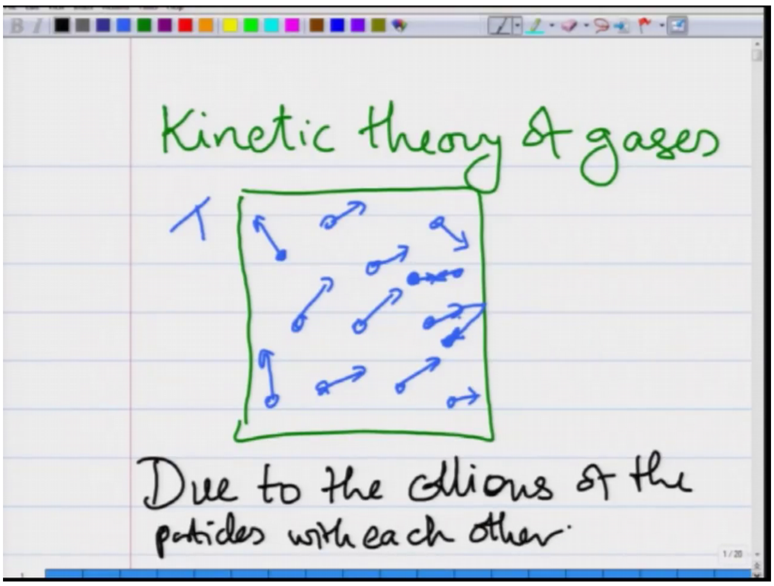

And for understanding the behavior of a gas you have already been exposed in your 12th standard to things like the Kinetic theory of gases. Now this theory describes the properties of the gas to a large extent quite well for ideal gases to a large extent and understanding the sort of recalling some of the properties of the gas by studying this kinetic theory.

We will also see some of it coming up again in our condensed matter in the solid state physics course, something similar to the kinetic theory of gases. So, using the kinetic theory of gases we will study, we will just recall some of the behavior of typical gases, what does the kinetic theory of gases say and we will use that, you will see that some of these theories and some of these ideas will get repeated when we study solids and some properties of the solid.

So, what is the kinetic theory of gases, let us recall some of the initial some of the ideas associated with the kinetic theory of gases. So, in the kinetic theory of gases you have a container inside which you have hard sphere like particles which are moving around randomly. The particles are moving around randomly this gas particle are enclosed in a chamber and all these gas particles are moving around the chamber is kept at a temperature T and all these gas particles are moving around randomly inside this temperature.

They undergo collisions with each other and they also undergo collisions with the walls of the container and in this kinetic theory of gases there are some assumptions which are made regarding this model.

So, one of the assumptions that is made is that these particles which constitute the gas which are these microscopic particles the atoms or the molecules which form the gas are like hard spheres non interacting, that they do not interact with each other there is no forces of attraction or repulsion between them, they are almost neutral and they are weakly interacting or non interacting. And so between when the particles are away from each other there is no interaction between the particles.

But as the particles move around they collide with each other as well as the particles collide with the walls of the container. So, you can have particles which go and strike each other, they can collide with each other as well as the particles can go strike and get reflected from the walls of the container and this phenomena keeps on happening.

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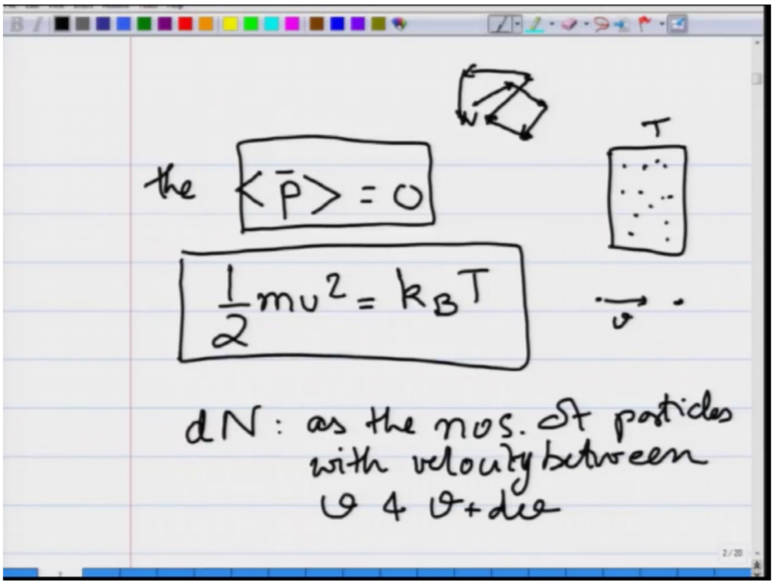

Now due to the collisions of the particles with each other the net average momentum of the particles is 0. The average momentum of the particles is 0 because, a particle which moves will get scattered and will get again collide and again collide and again collide and this process will continue. So, if you find the average momentum of the particle it will be 0 because it has randomly changed the orientation and so the net total momentum of the particle is 0. But between *2* successive collisions of these particles the average kinetic energy of the particle can be written as equal to k B times the temperature and T is the temperature of the gas.

The gas is the particles and the gas are enclosed and held at thermal equilibrium at a temperature T. So, between *2* successive collisions of the particles, if v is the velocity of the particle then the average kinetic energy of the particle can be written as equal to k B T and from here you can find out what is the average mean velocity of the particle using this expression, if you know the mass of the particles.

So, this gives you an idea of how to describe such a gas of particles which are sort of ideal particles non interacting, but they undergo collisions and they are at a thermal equilibrium at a temperature T and with each collision the momentum of the particle is randomized and as a result the total net momentum is equal to 0.

The average total momentum of the system or the particles is 0 because, the gas is not going anywhere the particles the gas remains where it is. So, this is the basic idea of kinetic theory of gases, it is based on these assumptions and one important aspect about these particles is that they have a velocity distribution. So, if you consider dN as the number of particles with velocity between v and v plus dv.

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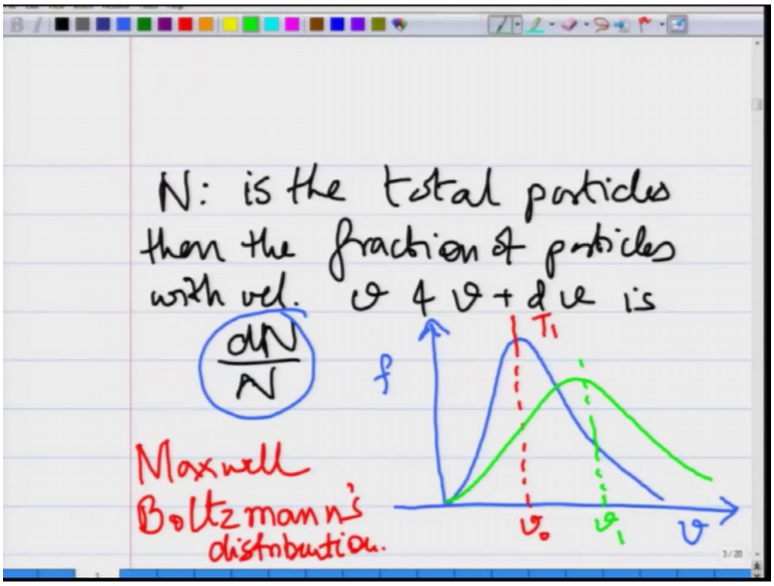

Let dN be the number of particles which have a velocity between v and v plus dv and if capital N is the total number of particles, then the fraction of particles with velocity between v and v plus dv is dN over N. Now this fraction or what is the number of particles which have a velocity between d v and v plus dv out of the total number of particles, this fraction has got a certain probability distribution, this has a distribution.

If I look at this fraction as a function of velocity or the speed, then you will find that it has a particular shape. At a given temperature T 1 the particles have a mean velocity average velocity v 0 and there is a certain spread there is a distribution of the velocities which the particles of the gas have and this sort of a distribution is called the Maxwell Boltzmann's distribution.

If you increase the temperature then say you go to a high then the distribution the average value will move to a higher value v 1 and the velocity distribution will spread. So therefore, in the kinetic theory of gases you have this Maxwell Boltzmann distribution of the velocity of the particles and I am sure you have been exposed to these concepts when you have studied statistical mechanics kinetic theory of gases. Now if I would like to calculate the average total energy of this gas having looked at the various parts of the kinetic theory of gases. Let us try and calculate the average total energy of this gas. So, to calculate the average total energy we take use of something called as the Equipartition theorem.

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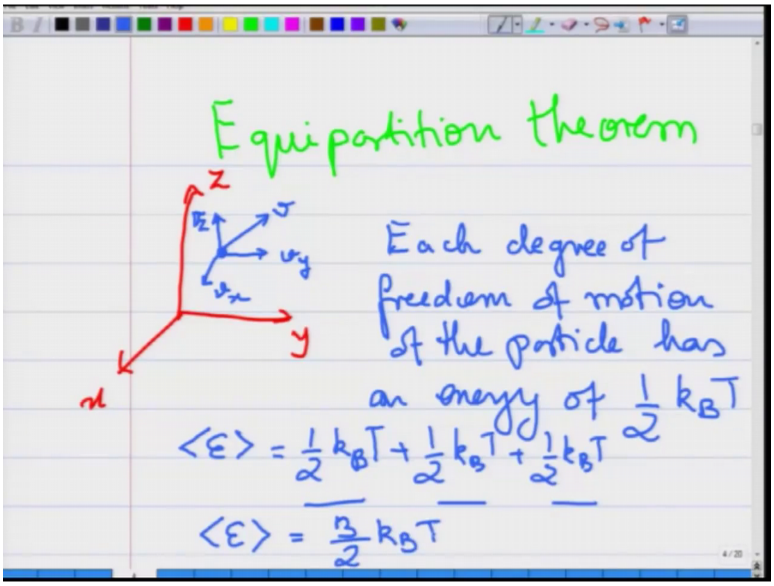

Where in you have your x y and z coordinates and you have a particle which is moving with a velocity v. Now this particle has 3 degrees of freedom, either it can move along the x direction it can move along the y direction or it can move along the z direction.

So, this Equipartition theorem says that each degree of freedom of motion of the particle an energy of half k B T, where T is the temperature of the gas k B is the Boltzmann's constant. So, each degree of freedom, here the particle has 3 degrees of freedom if the particle is in 3 dimensional space it has 3 degrees of freedom and each degree of freedom has half k T.

So, the average energy of this particle is half k B T plus half k B T plus half k B T, each of this half k B T is for each degree of freedom and therefore the average energy, total energy of this particle turns out to be 3 by 2 k B T.

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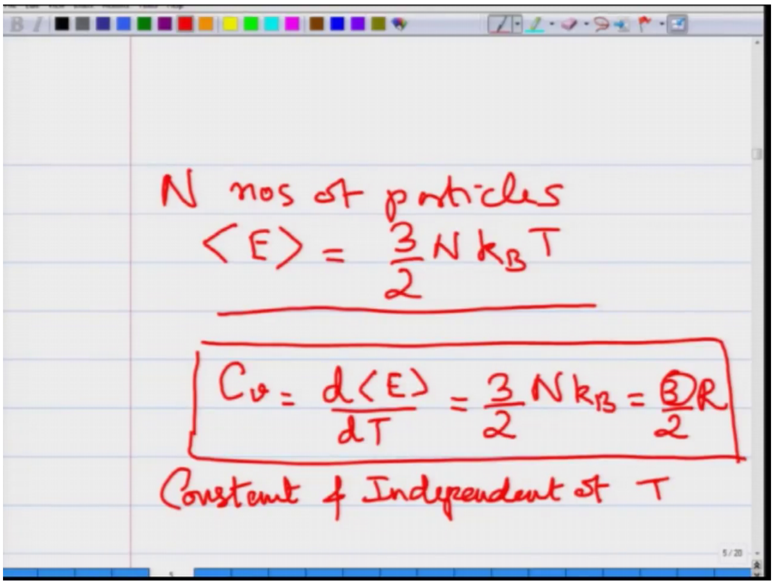

If we have N number of particles then the average total energy of this N number of particles of gas kept at temperature T is 3 by 2 N k B T. Now, recall that in the kinetic theory of gases we have considered no potential energy because, we have considered there is no interaction between the particles. So, this becomes the total energy of the gas of particles and now you can define a quantity call the specific heat which is the derivative of the total energy of the system of particles with respect to temperature and that will be 3 by 2 N k B or 3 by 2 R.

So, from the kinetic theory of gases you get a measure of the specific heat of the gas which is 3 by 2 R, it is constant and independent of temperature. So, this is one important property of the gas that you have the specific heat which turns out to be related to the degrees of freedom of the gas. This factor 3 is coming from the degrees of freedom and it is a constant which is independent of temperature, this is as far as gas is concerned. Where the particles are like hard spheres, far apart from each other they are not interacting with each other and kept at a temperature T.

Now, from this gaseous phase let us start increasing the density of particles, let us try to bring the particles closer and closer together and we start reducing the temperature and we try to bring the particles very very close to each other and make it into a gaseous state where the particles were all far apart from each other. Now we want to bring the particles close to each other so that we can form a solid and we can bring in the parameter of temperature it can be at room temperature we can reduce the temperature.

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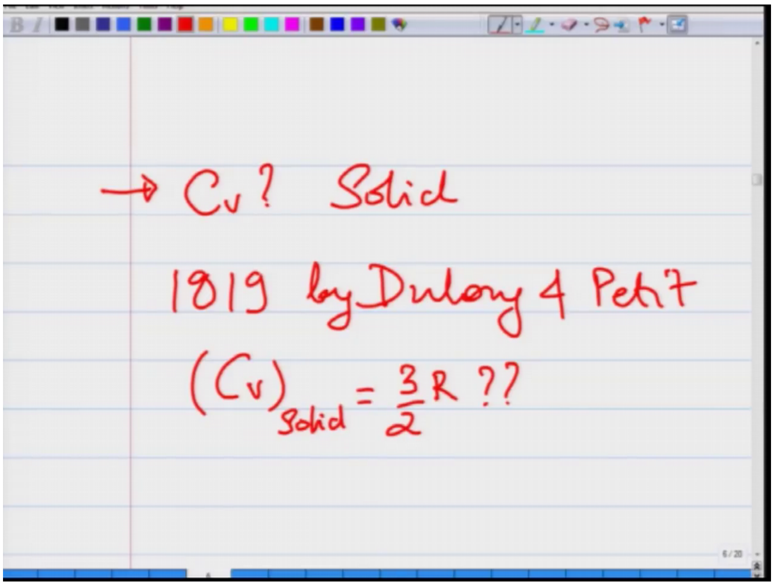

The idea is that as we go from the gaseous phase to the solid phase what happens to the specific heat? This is the question that as it becomes a solid, what is the behavior of the specific heat of the solid and this question was asked way back in 1819 by Dulong and Petit. That they wanted to measure the specific heat of the solid and is it does the specific heat turn out to be specific heat of the solid is it equal to 3 by 2 R, so they went about measuring the specific heat of the solid.

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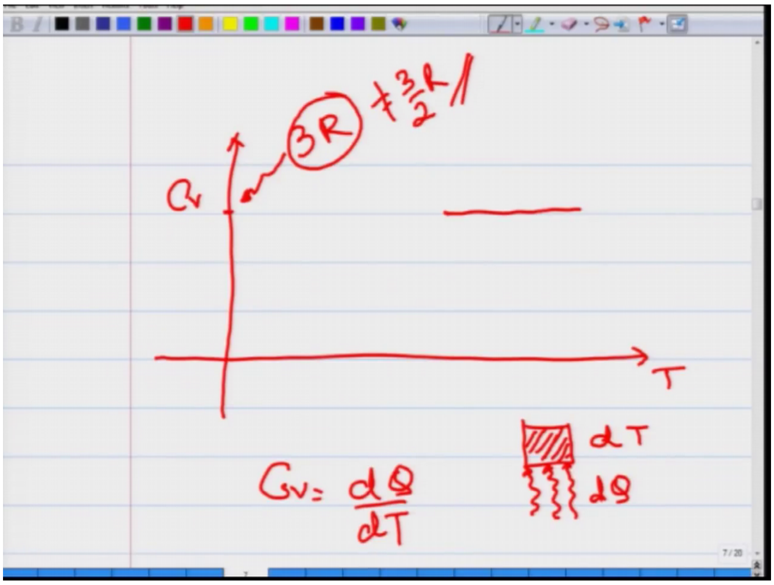

And what did they observe? So how do you measure specific heat the experiment is a little tricky, but you take a solid and you give a fixed amount of heat to the solid ensuring that all the heat. Say you are giving dQ amount of heat into the solid, you ensure that all the heat enters into the solid and does not go elsewhere, so that whatever heat you have supplied goes into changing the temperature of the solid.

So, you supply heat to the solid and the temperature changes by dT and then the specific heat of the solid is dQ by dT, the heat that you have supplied divided by the change in temperature that will give you the specific heat of the solid. So, they took a solid and measure the specific heat of that solid and they found of course that high temperatures they found a constant value.

The specific heat was constant as a function of temperature they measured it, till that time whatever was the variable temperature possible and the value they obtained was not 3 by 2 R, but the value they obtained here was 3R and not 3 by 2 R. Clearly this was a deviation from what is known for gases, it has jumped up by twice and this was the first sign that something else is happening in the solids Cv turns out to be 3 R and not 3 by 2 R and this is what we will explore in the coming few lectures this is just a hint of something different which is happening in the solids.