Solid State Physics
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Lecture – 53
Thermal Properties of Solid

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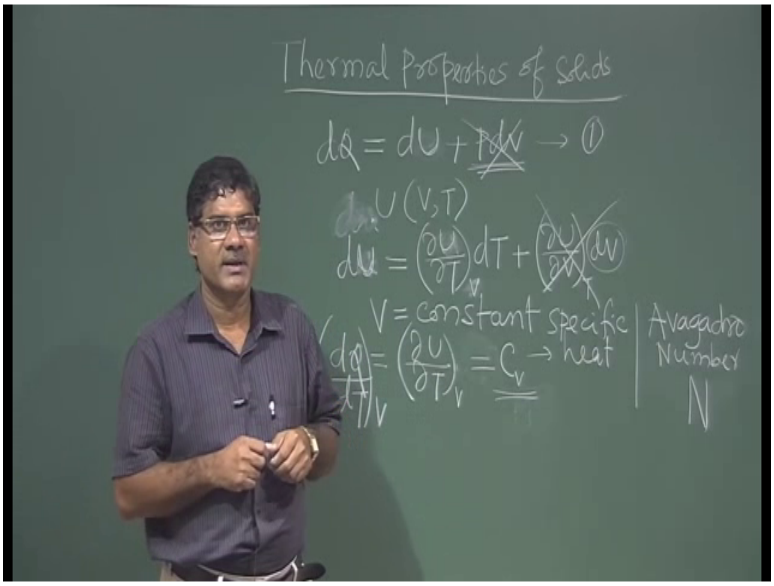

So, today we will study the thermal properties of solid. So, thermal properties means if you heat a system, if you heat solid, then what happens. So, any system have internal energy, if you supply dQ amount of heat to a system, so its internal energy changes, internal energy say U is internal energy; so its internal energy changes as well as it does some work. So, if increase volume by dV at pressure p, so this will be work done and that energy comes from this heat energy supplied to the system. So, this is the basically first law of thermodynamics.

Now, this internal energy is basically function of if you take function of V and T. So, change of internal energy it is del U by del T dT plus del U by del V at this is at constant V, and this is at constant T dv. So, this volume is constant volume.

So, if we consider that volume of the system remains constant, there is no change of volume. So, there will not be work done, all energy will be stored as a internal energy. And what is the internal energy, internal energy basically it is a potential energy and kinetic energy of the system. So, energy supplied to the system, it will change the internal energy of the system in terms of the change of kinetic energy and potential energy of the system.

So, at constant volume, if we keep this volume is constant, so then dU, so this term dV zero, this term will go, this term will go. So, then dQ will be equal to del U by del T, so that energy heat energy supplied to the system it will change the energy internal energy of the system or unit change of temperature if due to this heat if temperature of the system changes by dt. So, this dQ will be equal to this. So, due to change of this temperature dT, what is the change of internal energy, so that is the relation of external thermal energy to the internal energy of the system. So, this is at constant volume.

So, this we can write dQ by dT at constant volume, so this will go. So, what is this, this is defined by one parameter, it is called heat capacity, this seems at constant volume, so we write C v. So, dQ by dT at constant V that is basically change of internal energy, temperature. So, this is the definition of heat capacity. So, what is heat capacity? So, you have a system to change 1 degree temperature what amount of heat thermal heat you need or what amount of internal energy will change, so that is called heat capacity. So, this is the heat capacity of the system. So, this heat capacity depends on the volume of the of the system or mass of the system size of the system.

So, to make it independent of this size of the system, so if we define that for unit mass or for unit volume of the system what is the heat required to change 1-degree temperature. So, then that is basically it will divide by m, if it mass it will divided by m of this of the system. So, for unit mass if we define, so then it is called specific heat, it is called specific heat of the system. So, if we define the amount of material, so which should be the independent of the system size etcetera. So, it is all the time that is the either one gram or one mole of a system. So, here we will keep this as a molar specific heat means for 1 gram mole of that material to change the temperature by 1 degree, so this amount of heat is required at constant volume, so that is the molar specific heat. So, just we will call as a specific heat, so as long as we will not mention.

So, then if I speak about the specific heat that is molar specific heat means that system will contain Avogadro number of the atoms, so that is n. So, we will take a system of n number of atoms that is Avogadro number and for that to change the temperature by 1 degree, so we need the amount of heat, so that is C v. So, when we apply the heat to a system and we needs one parameter which express about the express the thermal property of the of the of the system. So, that is the parameter this C v is the parameter some people this other parameter C p is there, so that is at constant pressure, but in case of solid the C p and C v there is no much difference. So, we will treat as a this both are both are same similar, slight difference will be there, but it is not much, so that that is how we will just deal with this with the C v. So, what is the importance of this of this specific heat. So, let us discuss.

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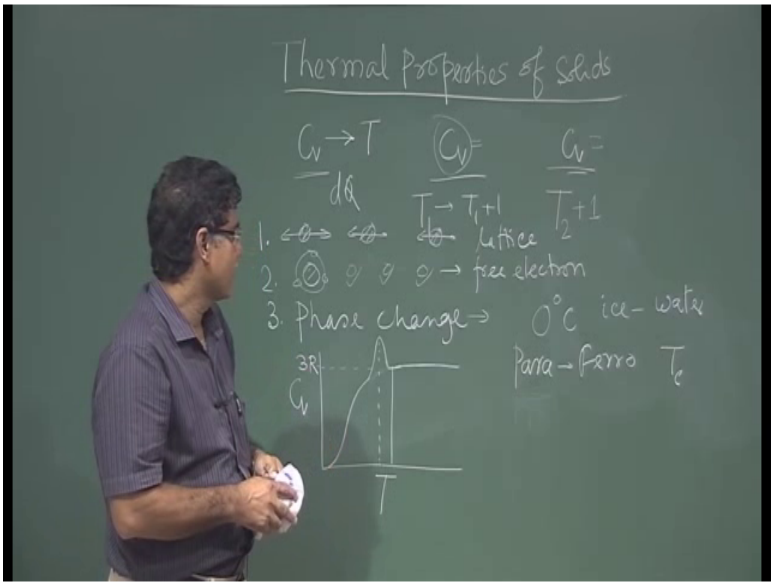

So, or what are the source which contribute to the specific heat. So, there are different source that C v changes with temperature or not. So, since it is related with the heat dQ amount of heat, we are supplying to the system and that system is having some change, what change its internal energy is changes. So, internal energy changes that is basically change of kinetic energy and potential energy of the system. So, whether that change is all the time it is same or it depends on temperature right means a system is at a temperature T 1 then to change T 1 plus 1 what is the amount of heat for 1 gram mole. So, that is c v. So, this is the amount, it is the some amount. Now, if my system is at T 2, if I change by 1 degree. So, again this for change of 1 degree, so what is the amount of heat required, so this again C v. So, C v amount of heat if we give the system systems temperature will change by 1 degree. So, whether these C v here and this C v here are same or different it is in fact, it is different, so this C v depends on temperature.

So, when we are giving C v amount of heat to a system to solid, so what may happen. So, solid is made of lattice, so or this atoms are arranged in the solid nicely. Now, when I will give this heat energy - C v amount of heat energy to the system, so what will happen it may happen that this atoms in a lattice, so this they will they will vibrate it, they will vibrate, they will vibrate, so its potential energy and kinetic energy will change. So, due to this heat this potential energy of this lattice and kinetic energy of the lattice point will change right, so that is why it is that absorbing heat and in terms of this vibration of the lattice points that means the changing of the kinetic energy and potential energy. This one may be the source of this source of contribution in C v. Or other way we can tell this when we supply heat to the system that systems having this lattice point. So, lattice points are vibrating, so its kinetic and potential energy is changing, so its internal energies changing. So, due to this internal challenge that is manifest as a this specific heat.

And the second contribution this atoms have electrons atoms have electrons right atoms have electrons right. So, in case of specially metal, so there are free electron, there are free electron, there are some free electron. So, from this electron, so electrons kinetic energy will change, when we supply heat energy, so its kinetic energy will change. So, it can contribute to the C v right. So, this lattice vibration and this is free electron can contribute to the to the system because of heat because they will change their energy by kinetic energy or potential energy in terms of kinetic energy or potential energy.

And third is a very important point, another point is a phase change. You are familiar of phase change means from one phase to going from one phase to another phase like this it can be structural phase, thermal phase change like ice and water. So, this is phase change that 0 degree centigrade right ice. So, its phase changes from ice to water. In this thing what happens normal time your give supplying energy to the system, and its temperature changes. So, to change 1-degree temperature how much energy I need to supply, so that is specific heat.

Now, when phase changes they are happens ice to water or water to ice that happens at 0 degree centigrade and at this temperature you are supplying heat, you are supplying heat, but there is no change of there is no change of temperature. So, it absorbs temperature, so that energy is spend for this phase change. So, in this case that how much amount of heat we require to change this phase change that is called latent heat, so that you know. But one thing is clear that when there is a phase change, it is that point at that temperature it is different from the other temperature. So, at that temperature, we need more heat to change 1 degree temperature right then the other point.

So, what happens this that phase change. So, their C v will be high, their C v will be high because to change 1 degree temperature, I need higher energy, so C v will be high when this phase change occurs. And this there are different kind of phases this is one example another example magnetic phase change, para magnet to para to ferro, so this that phase change occurs at curie temperature T c at the particular temperature T c. So, at this point this again this specific heat will be different than the other temperature other point. So, you will get basically smooth variation of as function of temperature, if you see the C v, so its variation is generally is like this for all the modalities like this for all the modalities like this. So, after a certain temperature after a certain temperature it is constant it is constant and this value is generally its 3R or R is 2 Kelvin per degree temperature per mole.

So, R is 2 Kelvin. So, it is 6 Kelvin, it is 6 Kelvin. So, up to above a certain temperature, it is constant C v is constant and this value is more or less 6 Kelvin per degree per mole for all solids, for all solids, even for gas molecules also. So, at higher temperature, it is constant, but at lower temperature it depends on temperature. So, how it depends on temperature, so that is our interest to study. So, these for normal metal material mole normal solids, if there is no phase change, so this type of C v T curve we get, but when phase change occurs. So, at that particular temperature the 0-degree or T c whatever at that particular similar this C v becomes high it is become high since become like this curve become like this.

So, then from this C v measurement as a function of temperature, one can identify the phase change of the system and at which temperature this one can find out. So that is why the C v measurement of a system as a function of temperature is very important to study the phase change of the system as it is may a magnetic phase change or structural phase change. So, order, disorder in alloy generally your atoms are arranged orderly. Now, if you change the temperature or decrease the temperature, it goes from order state to disorder state, so that is also another kind of phase change. So, these things one can study from this C v measurement, so that is the importance of this of this specific heat. So, or you can say that studying the thermal properties of solid, we can get many information about the solid and specifically one information about the phase change, this very unique method to identify to study or to identify the phase change in the system.

Now, here these typical curves these the typical not now forget this phase change. So, this does not occur for all system. So, these for particular system. So, will use when we need, but in general the specific heat curve is like this specific heat curve is like this. Now, so how the C v depends of temperatures, so that is now topics to explain and lot of effort was put to explain this temperature dependence of specific heat.

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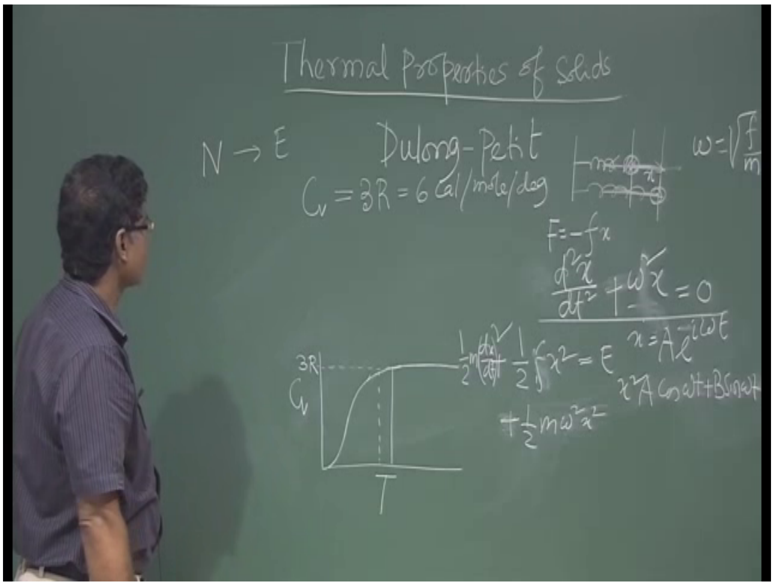

So, first the Dulong-Petit they tried to explain, but so t they explained that that this specific heat is constant it is independent of temperature, it is independent temperature and they found this C v value is 3 R. If it is approximately 6 Kelvin per mole per degree. So, what they did, so it is known that the solid is made of let atoms, atoms are arranged in the solid. So, they consider that this atom they considered that this atom in solids. So, they oscillate, so they oscillate so is like a spring mass system you know, this harmonic oscillator spring mass system. So, they oscillate with respect to this, so they just go here. So, it go here so; that means, it is expand come here and then it is be. So, it oscillate it respect to this it oscillate. So, spring is extended and spring is compressed.

So, if spring strength is it is called spin constant if it is f. So, this force per unit length, so for unit expansion or compression if this force is the current amount of force is required. So, when it is extended up to this say x just extended and then if you leave it just you do your force. So, if you hold it here, so you will feel restoring force acting in this negative direction. If it is the positive direction of x, so how much force restoring force no proper unit this is f and then f x will be for x extension. So, f x will be force. So, there is the force restoring force, and it is towards negative direction.

So, Newton's second law f equal to this. So, if this mass is m say m d 2 x by dt square that will be minus fx. So, f by m, m I can take this other side. So, this I can put this side, so this will be equal to 0. So, now, f by m if I define omega equal to square root of f by m, so this I can put as a omega square. So, this is the equation of simple harmonic motion. So, one can find out the due to this motion what is the kinetic energy what is the potential energy one can find out. So, potential energy will be half fx square half x square and kinetic energy will be square half m v square . So, b you can write dx by dt hole square, so that will be the energy of this oscillator kinetic energy plus potential energy.

So, one can find out the form from here. So, solution of this kind of harmonic oscillation this one can write A e to the power i omega t i omega t or one can write A cos omega t plus b sin omega t, so A cos omega t plus B sin omega t. So, these are standard. So, one can find out the kinetic energy and potential energy. So, your potential energy will be half m omega square x square. So, from here, if it is so, these are basically x equal to this, x equal to this. So, twice if you differentiate omega square comes. So, half omega square f is there half n omega square what will be the so twice if I integrate. So, omega square will come out omega square will come out right half k x square half. So, half f omega square, so omega square is basically your half x square no f say I am not differentiating it, so kinetic energy half k x square x values here. So, one can use this. So, f one can be replaced by m omega square omega square equal to f by m. So, f equal to so that is why I was writing. So, this part half m omega square x square right like this is happen v square.

So, here just my intention is that that energy is having one part is kinetic energy and another part is potential energy right. So, there is the energy of each harmonic oscillator. So, how many I have such oscillate oscillator. So, n oscillator are there. So, its energy are E, energy are E. So, now this now energy is E. So, E can vary to 0 to infinity because oscillators are oscillating like, so it can oscillate with any energy 0 to infinity. So, how this energy, so energy of all particles are not all oscillators are not same it can have any value between 0 to infinity.

So, among the n number of particles, so n 1 number of particle have some energy one particle energy. So, say N 1 E 1 and N 2 number of particle have energy E 2 etcetera, etcetera. So, energy are distributed among this N number of particle. How it is distributed, so there is the Maxwell-Boltzmann the statistics. So, energy is distributed among the particles. So, with this is controlled by this factor if E by K B T these the Boltzmann factor. So, I can write this.

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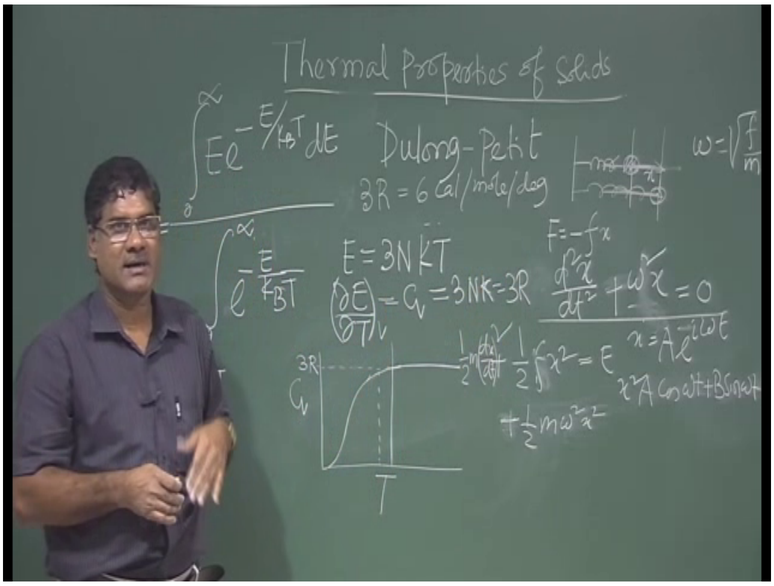

So, what is the total energy of your system if total energy of our system, so energy of particle of one particle E, it is multiplied with this factor E by K B T.

Now, if I integrate this energy can vary 0 to infinity and over dE over integrate over dE. So, if I integrate 0 to infinity in that range, so I will get total energy of my system of my system. So, system contains N number of particles, so or harmonic oscillator. So, I will get total energy of N number of particles. So, now, I have to divide by this, I have to divide by the total number of particle. So, it is N, so that one can get integrating just this factor 0 to infinity. So, it has to give n because there is the restriction for our system. So, total energy has to be this.

So, then I will get average energy of each oscillator, I will get average energy of each oscillator, so that is the way one find out the average energy of the oscillator. So, from here, if you do this, so you have two part kinetic energy and potential energy. And if you put this replace this E by kinetic energy and potential energy of the harmonic oscillator, I think and if you do this integration, so simply you will get this equal to K T. So, that is basically equal partition law comes from here. So, each particle have potential energy and kinetic energy. So, particle each particle can vibrate in any direction of this three material particle direction. So, it has three degrees of freedom. So, for each degrees of freedom, this energy is half K T.

So, for three degrees of freedom this energy is 3 by 2 K T that is for kinetic energy and that is also for potential energy. So, total for a one particle you will guest you will get the energy 3 K T because it has three degrees of freedom. So, kinetic energy half K T and potential energy half K T, so total is K T. So, for each degrees of freedom it is K T, but remember half of it is for kinetic and half of it for potential. So, three degrees of your freedom, so 3 K T energy will get.

So, average energy. So, here n number of particle you have con considered. So, it will give K T. If we do integration, you will get K T. So, now, K T now I have three number of particle N number of particle each particle have three degrees of freedom. So, total energy of the system will be E equal to 3 N and each for each degrees of freedom this energy is K T. So, whatever here average energy we are getting, so that is basically for each degrees of freedom that is the energy.

Now, if you integrate, so I am writing E here. So, earlier I have is U internal energy or Q. So, instead of U, I am writing E now. So, your del E by del T at constant v of the your system, so that is C v that is basically C v and that you will get 3 N K. And N K is nothing but R, it is 3R. So, we are getting this C v for one gram mole of solid is 3 R. So, that is basically is Dulong-Petit law and it tells that kinetic energy a specific heat is independent of temperature, but that is not true experimentally found it should be like this. So, Dulong-Petit law only can explain the specific heat at higher temperature; at lower temperature, it cannot explain. So, then Einstein came forward and try to find out what is the difficulties what is the drawbacks of this model, and he gives then again another model to explain the specific heat and lower temperature, so that we will discuss in next class. So, I will stop here.

Thank you.