**Solid State Chemistry**
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**Lecture – 01**
**Solid State and Solid State Materials**

Today, we will start the first week and the first lecture of this course on Solid State Chemistry. So, in today's lecture I will be talking about the nature of the Solid State and Solid State Materials. So, we will start this lecture, today's lecture will be on solid state and solid state materials.

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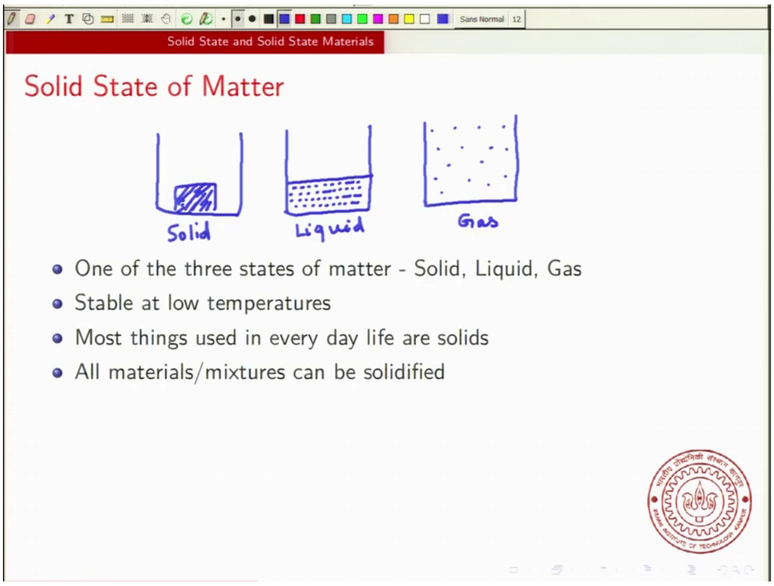


Now, what is the solid state of matter? So, solid state of matter intuitively you learnt that it is one of the three states of matter. So, matter exists in typically in three states – solids, liquids and gas.

And, we usually think that if you had a container and you had a solid, so, a solid will occupy some region of the container that it is put in. So, this will be a solid. A liquid on the other hand you expect it to take the shape of the container and it will occupy some region, I will just show it in this way that this is a region occupied by the liquid and I will show the liquid has lot of particles that are fairly close to each other, but not as close as in a solid. So, that is your liquid and it will take the shape of the container.

A gas on the other hand you say that it has very it has relatively few number of particles and so, it will typically you will find the gas particles all over the container and like a liquid it will also take the shape of the container, but you will find that there are very few particles in the gas. So, these are the typical three states of matter that you always learn and so, solid is one state of matter and it is stable at low temperatures as you increase the temperature you go from solid to liquid to gas.

And, most things in everyday life are solids. So, all around us we have solid materials that we deal with. In fact, our own body for large part of it is solid, ok; there is also liquid in our body, but a large part of it is solid and in any case most of the materials that we do that we use our solids. And, you can take almost all materials including mixtures you can take pure compounds and mixtures and you can solidify them. So, if you have something that is a liquid you cool it and it turns into solid. So, this is what we know about solids, ok.

But, there are some other characteristics of solids ok, which are quite interesting.

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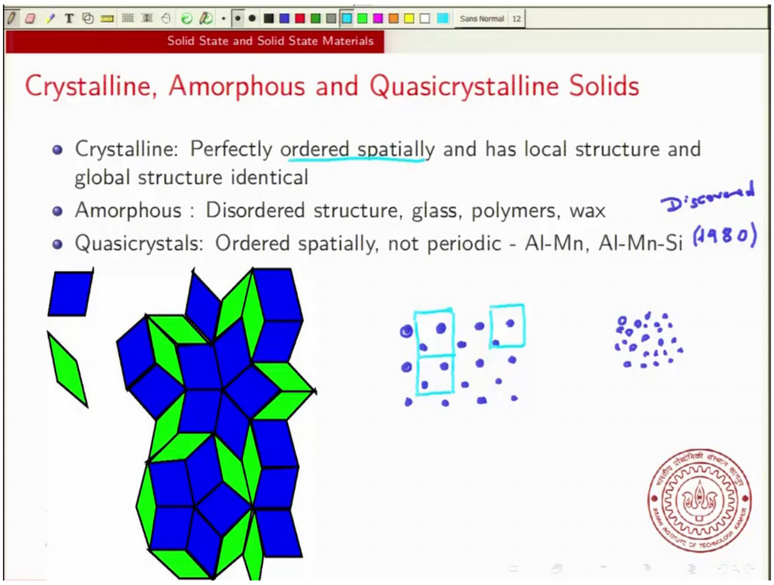


So, solids can be either crystalline amorphous or quasi crystalline, ok. So, a crystalline solid has perfectly ordered spatially and has a local structure and a global structure which are identical. So, in the sense in a crystalline solid if you would have let us say if these are the atoms of the solid they would be perfectly arranged in some structure, and this is

I am showing it in 2-dimensions, but you would have a perfect arrangement of constituent atoms or molecules in a crystal ok.

So, that is what crystalline solid will look. Everything is perfectly arranged. I am just showing one example here of a centered square lattice ok. This is in 2-dimensions, but we will see lot more about crystals later. In an amorphous solid the constituents of the solid are disordered, they form a disordered structure. So, you do not have a perfect ordering, you might have something like you have a solid like, but you have things that are not perfectly ordered, ok.

So, that would be an amorphous solid. So, things are very close to each other the components of the amorphous solid are very close to each other and so, and so, the atoms if this is made of atoms then those atoms are not able to move much, ok. However, it is not ordered, there is not much ordering of these atoms, ok. So, it is a solid, but it is not perfectly ordered and that is what you call amorphous solid. It is a disordered structure some examples of amorphous solids are glasses you can have polymeric solids, you can have for example, wax is an amorphous solid. You can have several different examples of amorphous solids. Typically these amorphous solids they collapse into powders and you cannot form big crystals with them.

A third relatively recent discovery is that of quasi crystals this was these were discovered around 1980, ok. So, they were discovered in 1980 and these are in quasi crystals there is a spatial ordering, but it is not periodic. So, in a crystalline solid the arrangement is periodic; that means, each atom sees exactly the same surroundings or each constituent, ok. It need not be an atom, but whatever unit of the crystal it sees exactly the same surroundings as any other constituent, ok. So, it is periodic, ok.

So, that means, if you move, if you change let us say you are looking in this region let us say you look at the crystal in this region and imagine that you just translate, and now, you start looking let us say in this region, the crystal will look exactly identical. Similarly, you translate into this region the crystal will look identical, ok. So, there is a translational invariance in a crystal. So, this is not there in a quasi crystal. So, you say it is audio ordered spatially, but it is not periodic and this is being observed in some alloys like aluminum-manganese alloy, aluminum-manganese-silicon alloy.

So, just to show you what would something that is ordered, but not periodic look like ok, this is a picture of a 2-dimensional quasi crystal it is called it is referred to as a tiling, ok. This is referred to as a tiling and it is in 2D, ok. So, it is a 2-dimensional tiling, and you can see that there is an order in the sense that you go around each point you see some sort of arrangement some sort of very regular arrangement. So, it is completely ordered, but it is not periodic. I mean you cannot you do not see you cannot translate this piece of the crystal for some somewhere and see the same ordering.

So, this is an example of a quasi crystal and this is a very special class of material. In most of this course I am going to be talking about crystalline solids. Almost the entire course we are going to be talking about crystalline solids. Though I should emphasize that there is a lot of interest in amorphous materials and by no means this is the entire spectrum of all solid materials, ok. So, but, for this course we will be mostly focusing on crystalline solids and we will be seeing how to understand this spatial ordering in the in the crystal ok.

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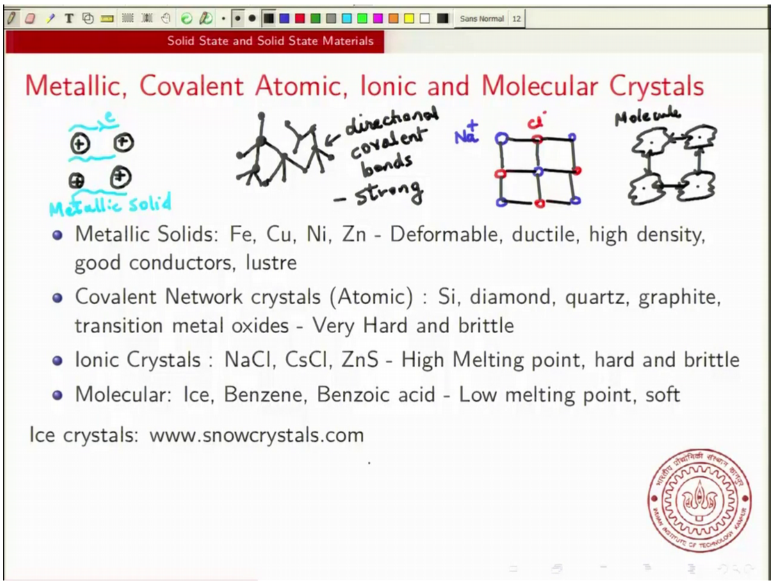


The other way to look at different types of solids is to think of them as based on the nature of the interactions between the constituent particles, ok. So, you can think of metallic solids, ok. This is example of all metals like iron, cobalt, nickel, zinc. These typically are deformable, you there ductile and they have high density they have good conductors. What I mean by deformable is that is that you can you can stretch them, you can make them into wires and so on.

They are typically good conductors of electricity and they typically have this lustrous look. And, in fact, in fact historically it is to explain the properties of metals. What makes metallic solids have these properties that are lot of science of solid state was developed,. One characteristic of metallic solids is that they in the if you look at a metallic solid, let say iron or let say copper; if you are looking at copper, ok. If you look at the structure of copper what you will find is that you will see all this the core of copper, ok.

When I say the core of copper it is a nucleus of copper and all the electrons except the valence electrons ok, they form some sort of lattice. They form this crystal structure, and in this you have the valence electrons are essentially the valence electrons are freely roaming around in this lattice formed by the core of each atom. So, this sort of bonding where you have the valence electrons, essentially going all around the entire crystal ok. This is sometimes referred to as metallic bonding and this is a characteristic of metallic solids. We will of course, discuss this in a lot more detail as we go on, but I just wanted to tell you the different kinds of crystals.

So, these metallic solids have this kind of picture ok. So, this is this would be a metallic solid or a metallic crystal, ok. So, the other kind of solids that we often deal with or what are called as covalent network crystals, and the best example is silicon or diamond, where essentially you have covalent bonds, ok. So, if you take diamond for example, you have a carbon atom, that is covalently that is tetrahedrally bonded to four other carbon atoms and now each of these is also tetrahedrally bonded to four others or. And, essentially you form a network structure of this whole solid, ok. So, so you form an extended covalent network that is shown this way, ok. Again I am not ok.

So, diamond is a good example also silicon forms a (Refer Time: 11:14) solid, ok. What is important the important difference between a covalent network crystal and metallic solid is that the bonds are covalent bonds. So, these are directional. So, covalent bonds have a preferred direction, and this is one very distinct feature of covalent network crystals, ok. So, and these are very strong, these are also very strong bonds. Typically covalent bonds are quite strong.

In addition to things like silicon or carbon or in diamond form you can also have oxides like silica; quartz is a form of silica which is also a network solid. You can have transition metal oxides. So, these are also covalent solids, ok. One feature of lot of these covalent networks solids is that they are very hard and I emphasize the word very because the whole structure is a network solid often some of the hardest materials are covalent network crystals, ok.

But, they are brittle; you cannot deform them easily unlike in the case of metallic solids, ok. And, needless to say they are not typically they are not good conductors of electricity and they do not have the cluster that metals have, ok. And, they are typically much lower density than metallic solids.

A third class of crystals are ionic crystals, ok. So, these are basically the constituents are positive and negative ions, ok. So, for example, if you take sodium chloride; sodium chloride has a positive sodium ion and a negative chloride ion. So, if you see the sodium chloride crystal you have the sodium ions that I am denoting by blue sodium plus ions and you have chloride ions, and the whole structure is formed by repeating by an ordered arrangement of these two ions, ok. So, it looks. So, you have an order and I am just showing you 2-dimensions, but it is actually ordered in 3-dimensions.

And, so, now, what happens is that these bonds between sodium and chloride, ok. They are ionic bonds and they are very strong bonds, they are very strong bonds, ok. So, what happens is that it has a very these ionic solids typically have high melting points, ok. They can be hard, but they end up being very brittle. You cannot deform them easily like your metallic solids. So, actually the ductility of metallic solids comes from the nature of the metallic bond.

Then there is another class of crystals which are the molecular crystals, such as where the constituents are not atoms, ok. So, the constituents of the crystals are not atoms, but in fact, they are molecules you can have a water molecule ok, you can have ice which is a crystal of water molecules, you can have benzene molecules combined together to form a crystal, you can have one almost all organic molecules if you cool them enough they form solids and they end a crystallize. So, what is special is that I mean when you have molecule which I will denote by this shape, and you are essentially forming a crystal using this molecule. So, so, you have a whole you have lots of these molecules arranged in some regular order to form a crystal, ok.

Now, what you would expect is that if these are stable molecules then the interaction between these two the interactions between these stable molecules will actually be very weak, ok. There will be typically van der Waals interactions will be there if we if we if we have neutral molecules, if we have benzene molecules they will have either van der Waals or they will have pi-pi stacking interactions, but they are much weaker than the actual covalent or ionic bonds that are there in the covalent solids or the ionic solids.

So, therefore, they these will have very low melting point, because these they can easily be dissociated and they will be very soft, ok. So, what I want to say is that all these different kinds of crystals, they are very different in properties, but they still share certain features and the features that they share is that they all have some unit which is perfectly arranged on our lattice, and it is this feature of the crystal, that we will be studying over the next 12 weeks,.

Now, incidentally you know this I am may I mentioned ice has some molecular crystals. I should say that there is a lot of the structure of ice and the structure both the crystal structure and the crystal shape of ice is something that has attracted lot of interest and from several groups and it is a topic of both scientific and artistic interest, ok. So, I recommend all of you to visit this website snow crystals dot com just to see how you can get crystals ice crystals of many different shapes, ok.

And, I mean I mean we you could just take a look at it and appreciate the beauty that is there in all these crystal shapes, many of them are naturally occurring, ok.

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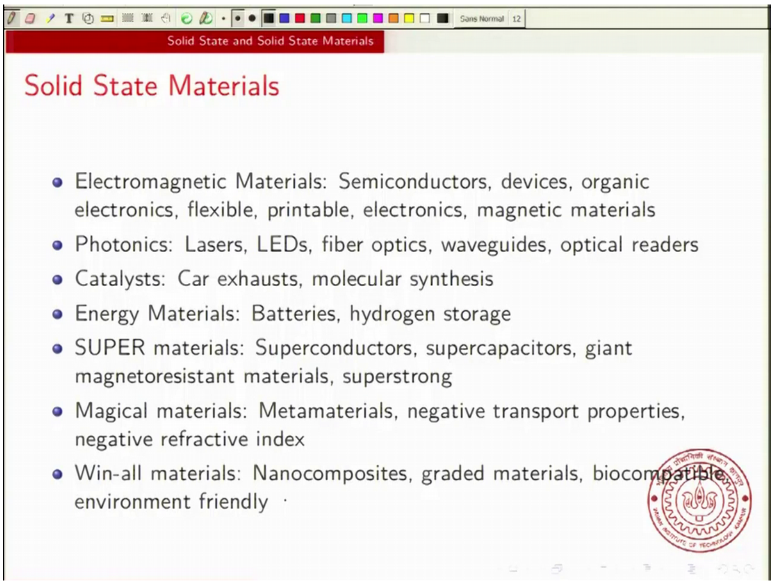


Now, one of the reasons why solid state chemistry is of lot of interest in especially in recent times is that many of the materials especially the modern materials that we use are materials that are solid state materials. And, one of the things about solid state materials is that you can really if you understand the solid state you can actually understand the origin of the properties and you can make better materials with better properties this is this has been the driving force for a lot of the research in solid state in solid state chemistry, ok.

So, I will just show some examples these are by no means all the types of solid state materials, but these are some example of solid state materials that are actually used in day to day life and many of them you use them without even realizing that they are being used, ok. So, there are a whole range of solid state materials which have put is basically electronic and magnetic materials, ok. So, right from semiconductor devices there is nowadays there is a lot of interest in organic electronics, ok. So, I mean you might have seen some advertisements where they say that your TV screen is organic LEDs and there is interest in flexible electronics where you have electronic materials, but they are flexible and, these have several applications.

There is also interesting printable electronics and then there is also a huge range of materials which are magnetic materials, all kinds of magnetic materials are of interest. Then there is a whole class of materials which I would classify as photonic materials, ok.

So, these are various they have various interesting optical properties for example, the materials that are used for lasers for LEDs fiber optics wave guides optical readers etcetera. Then there is a whole class of materials which are used as catalysts which are used as catalysts for various reactions.

So, for example, the car exhaust, ok. So, that that has a catalyst which consists of lead, and again, again there is lot of research on developing better catalysts, but in fact, in fact industrially almost every chemical reaction is carried out in the presence of catalysts and many of these catalysts are actually solid state materials, ok. So, the whole field of molecular synthesis involves catalysts and which are which are solid state materials.

Then, there is a class of materials which are again recently there is a lot of interest in these energy materials and here here here I am particularly referring to batteries like lithium ion batteries, again this is another solid state material. Then there are material for hydrogen storage, ok. So, there are because if you can store hydrogen you can use hydrogen as a fuel to do various activities like running cars or something and so, you need to store the hydrogen and there are some solid state materials that are used for hydrogen storage.

Another class of materials which people are discovering more and more is what are called these super materials; I am calling them super materials because they have extraordinary properties, ok. For example, a superconductor has extremely low resistance. So, again again this is a solid state material, a super capacitor you can have a super capacitor you can have a giant magnetoresistant resistant materials the GMR materials which are used in lot of storage devices. You can have materials that are super strong, and again again these are solid state materials where for some reason or the other the properties are unexpectedly good,.

Then, there are these almost magical materials that are there again again these are solid state materials. These are just to give an example there is this whole class of materials called meta materials, which have negative transport properties. So, for example, they can have negative temperature coefficient of resistance or they can have negative refractive index. So, there is a whole and these are not these are not single compounds, but these are actually materials where you where you do various things I mean you put one layer of one material another layer of a different material and you and by you know manipulating the entire material, you make these almost magical materials.

And, another example again again this is in the same class as meta materials, I am calling it a win all material which typically has more than one property that is very good. For example, you can imagine that you have something that is both super strong and super light, ok. So, that would be a material that is both super strong and super light which is not typically found.

So, so, these are typically nanocomposites are used to really tune multiple properties. There are again graded materials where you have different materials in different proportions. Many of these phenon materials are biocompatible they are environmental friendly. So, usually when you take a solid state material you say that oh it is not going to be biocompatible, but by manipulating them you can generate these exceptional materials which are both biocompatible and environment friendly.

So, I will conclude this lecture here for today. So, what I have tried to show in this lecture is the basic properties of the solid state of matter and what are the general framework in which we try to understand and study the solid state of matter.

Thank you.