Nanostructures and Nonmaterials: Characterization and Properties

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Lecture - 26

Atomic Bonding

In this lecture, we will learn about atomic bonding, before we learn about the structure of a material, it is very important that we learn about what is happening at the atomistic because the atomic structure will affect the property.

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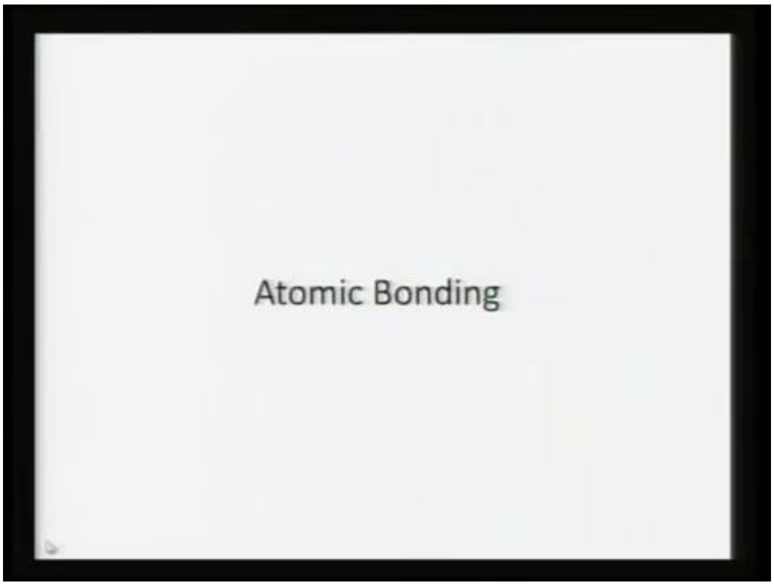

Atomic Bonding

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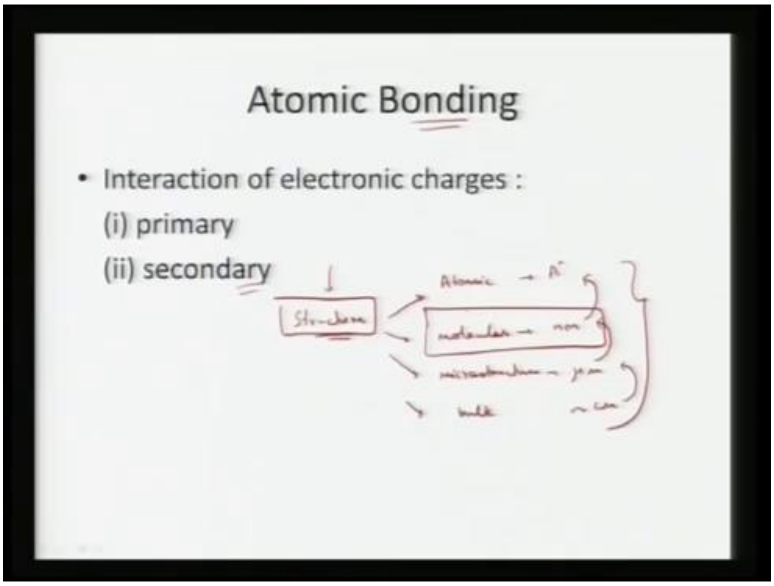

Atomic Bonding

- Interaction of electronic charges :

  (i) primary

  (ii) secondary

The behavior in which engineering material can be applied any particular application for it is nothing but bonding holds the materials together and the interaction of the electronic charges can occur by a either via a primary bonding or a secondary bonding. In primary bonding, we have very strong interaction of either ions or atoms and secondary bonding we have very lighter or we have very feeble interaction between all those electronic charges. Once we learn about the electronic bonding, to define the structure of a material the structure of a material it is become essential to know lens scale at which we are talking about structure of a material.

If we are talking about atomic scale, then the atomic interaction become highly critical, so we are looking more at the angstrom scale. If we are more worried about molecular structure then it become very essential to see what is happening at the molecular scale and in this case, we are talking about the regime of couple of nano meters. Then, let us see what is happening at the more bulk level say at micro structure of a material, so in this case we are looking at micro meters. Then, obviously the bulk scale it can go from couple of centimeters, so in that case we can see the overall bulk properties dictated at we can see what is happening at the micro structure, the micro structure dictated by what is happening at the molecular level.

Obviously, at the atomic level the structure, the context of the structure is very important to understand at what lens level we are talking about this structure. Obviously for nano structure, more worried about how these atomic entities come together in terms forming nano grain and nano entities or molecules at this particular level. So, that becomes very essential that we learn what is happening at the atomistic scale and that is actually leading to the generation of certain properties for a particular application.

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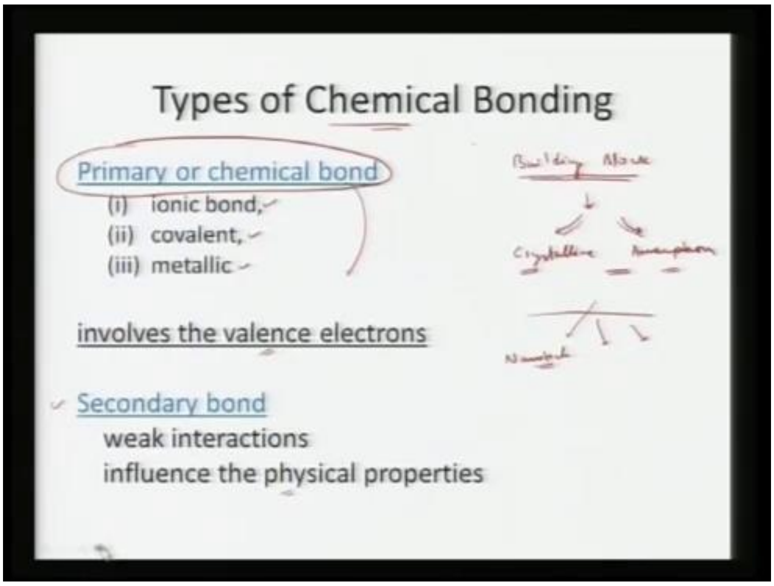

Types of Chemical Bonding

Primary or chemical bond
(i) ionic bond,
(ii) covalent,
(iii) metallic

involves the valence electrons

Secondary bond
weak interactions
influence the physical properties

Again the types of chemical bonding they can come under primary and these are also called chemical bonds, they can be ionic covalent and metallic in nature. We will learn about all these three entities as we go alone and that involves the electrons to participate and that is either by sharing of electrons or by transfer of electrons or of forming a cloud of electrons. That involves valence electrons and the core electrons of the fill electrons become part of the ion core and then there can be secondary bonding in which we have only very weak interaction.

They somehow influence the physical properties such as surface energy that generate out of this particular bonding or the brittleness of a particular material and one thing to understand in the atomic bonding is the atomic structure.

Once we have the atomic structure, it forms the building block and that goes off and constructing itself at the higher level. So, that is the reason in which the criticality of understanding the atomic bonding because how this building block array eventually give rise to either a crystalline material, there is no order. It can form amorphous material and there is a class of semi crystalline or quasi crystalline material as well, but I have mainly the way in which the bonding atoms are somehow arranged. It can either form structure a crystalline or it can form a amorphous material, so in this case we have long range order or in this case we have short range ordering.

The importance of this goes to may be forming certain application engineering application certain nano such as nano technology or how to arrange how to cells properties around. Then, we make use of these structures in terms of sensing and reverting back and as a switch or as a response to the stimuli it can also act as a sensor. It can also influence the mechanical properties, physical properties chemical properties also it can give rise to a different combination of how the metals are formed or how ceramics are formed. Eventually, lead to its own properties, this is how we see in terms of how what are the types of chemical bonding what is primary bonding and what is secondary bonding.

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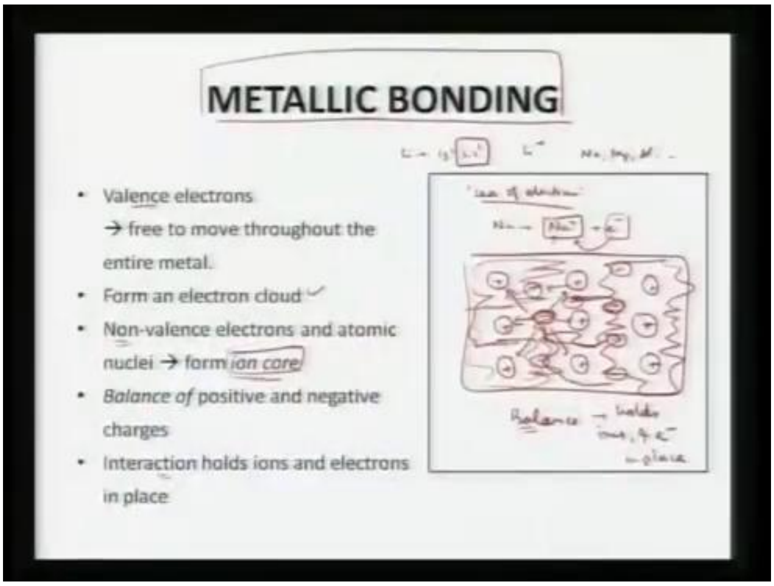

METALLIC BONDING

- Valence electrons
  → free to move throughout the entire metal.
- Form an electron cloud
- Non-valence electrons and atomic nuclei → form *ion core*
- *Balance of* positive and negative charges
- Interaction holds ions and electrons in place

In primary bonding, we have mainly the three categories one is metallic bonding second is ionic bonding and third one is the covalent bonding. So, in metallic bonding what is happening generally the metals which are electro, they give rise to electrons, so metals all the metals first column of the periodic table and second and third column of periodic table they tend to give rise to electrons. So, they can stabilize the outer most electronic shell configuration, so like lithium we have on e is to 2 is to 1, so it try to give out its outer most shell to lithium positive. Similarly, with sodium, magnesium, aluminum and so on, so the couple of metals try to give out electrons.

So, these are nothing but valence electrons and now these electrons now come out and they can form a kind of cloud of electrons. So, they can form a something called see of electrons around the particular atom and sodium becomes sodium plus and it gives out electrons. Around all these ions, we have cloud of electrons, which have which are not limited to only this sodium atom, but to other sodium atom as well. Now, they are free to move throughout the entire material, so we can see the charges of plus which can be sodium and we have c cloud of electrons which have roaming without any restriction. We can see this is the cloud of electrons, which is basically the electrons are free to move alone any of these region and all these electrons can go everywhere.

Apparently, this is also has to be observed that these positive ions are held because of the lector static interaction of the negative charges. So, it is more like negative cloud in which you have all the positive ions which are staying there because of the electro static interaction between these negative ions that gives rise to a stable structure. This negative ion is being held because of the all the positive ions which are nearby, so in this case we are forming a electron cloud and these non valence electrons which are still. They are still with the ion sodium ion, they will form ion core, so only the valence electron is free to move and other electrons become part of the atomic nuclei surrounding it.

It forms something called ion core in this case what we can see valence of positive and negative charges all the negative charges are roaming around and these positive ion staying stationary. These interaction between these positive and negative ions causes the balance between the charges, so this is the interaction between ions and electrons so like bond like electrons which acts like glue and hold the positive ions. So, interaction between these positive ion and negative ion and again positive ions and negative ion, it creates a balance, which holds both ions and electrons in place.

That is nothing but metallic bonding, we can say in metallic bonding we in heritably have a metal which is tends out to give electrons become an ion and all these extra valence electrons they are free to move around anywhere. That negative charge and positive charge of the ion creates an interaction and holds everything together, apparently the ion it has certain non valence electrons as well those and nucleus. They form the ion core and the balance between this ion core, which is the again some positive charge because the electrons has gone out of it. The negative charge of the electron together they interact and they render a stable structure and that interaction holds the ions and electrons as single entity and that is the metallic bonding which we call.

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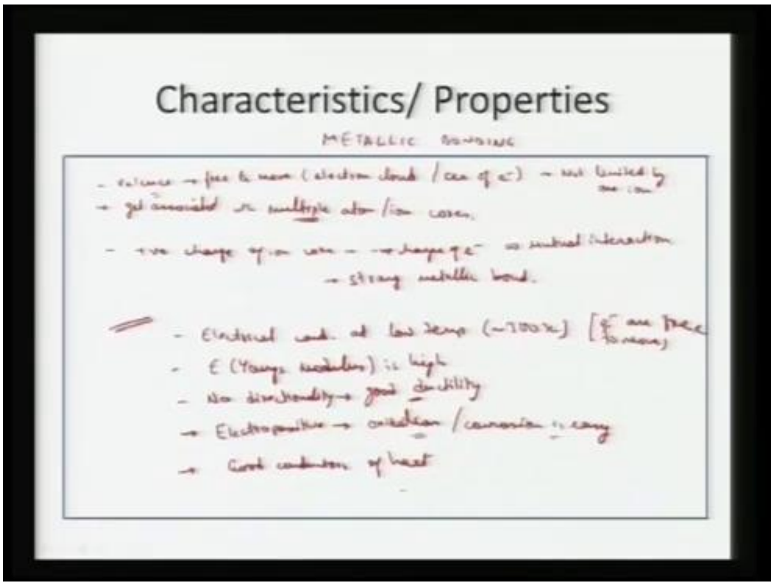

Characteristics/ Properties

METALLIC BONDING

- valence → free to move (electron cloud / sea of e^-) → not limited by one ion
→ get associated with multiple atom / ion cores.
- +ve charge of ion core — -ve charge of e^- ⇒ mutual interaction
→ strong metallic bond.
- Electrical cond. at low temp (~300K) [e^- are free to move]
- E (Young's modulus) is high
- No directionality → good ductility
→ Electropositive → oxidation / corrosion is easy
→ Good conductor of heat

Now, coming to some characteristics and properties of this metallic bonding, first of all these valence electrons they are free to move because they from something called electron cloud or sea of electrons. Apparently, these valence electrons which are free to move, they get associated with multiple number of with multiple number of this atom or ion cores. So, first of all these valence electrons are free to move they are not limited by only ion, they limited by one ion they are free to move throughout. They are associated with multiple number of ions cores and this positive charge of ion core and the negative change of the electron.

It now holds everything together provides the mutual interaction and this mutual interaction is very strong. That results the strong metallic bond apparently as the electrons are free to move anywhere else they show very good electrical conductivity even at low temperatures say around 300 Kelvin because the valence electrons are not fixed at certain location. They are free to move because the electrons are free to move apparently the negative and positive charge very strong metallic bond, so our anstrome modulus of e is very high. Also, the bonds are not directional because electrons are free to move anywhere else, there is no directionality.

So, there is no directionality and that yields very good ductility, but going to the fact that there are so many electrons roaming around and the nature of particular metal is electro positive. It can easily donate electrons, so once when it comes to contact with oxygen or something or some oxidizing entity, it becomes easily corrodible, it can easily undergo oxidation or corrosions and also serves as very good conductors of heat. So, we can see that the valence electrons are free to move, because it form a cloud of electrons and because of that they can conduct electricity even at very low temperatures and said they bonds are not directional. It is one electron is not only associated with one ion, they are now free to move and that can render much more ductility to the material.

Also, the bonding is also very strong that gives rise to very high angstrom modulus and all these ions and metals they the metals are electro positive in nature. It can easily donate an electron that create some poor oxidization effect, so they can get easily corrode or oxide by the environment, at the same time they are very good conductors of heat. Those are the characterizes and properties of metallic bonding, coming to the next category of covalent bonding, here we can see that in the covalent bonding we have nothing but sharing of electrons and those sharing of electrons.

Now, the electron I sound with 2 atoms and this covalent bonding is shown when both the materials both the atom shows the similar electro conductivity. It means there is no tendency for any one atom to donate electron to the other. To satisfy the outermost shell, they want to share the electrons because they do not want to donate the electron by share the electron so that they can fill out, they can complete the outer most shell.

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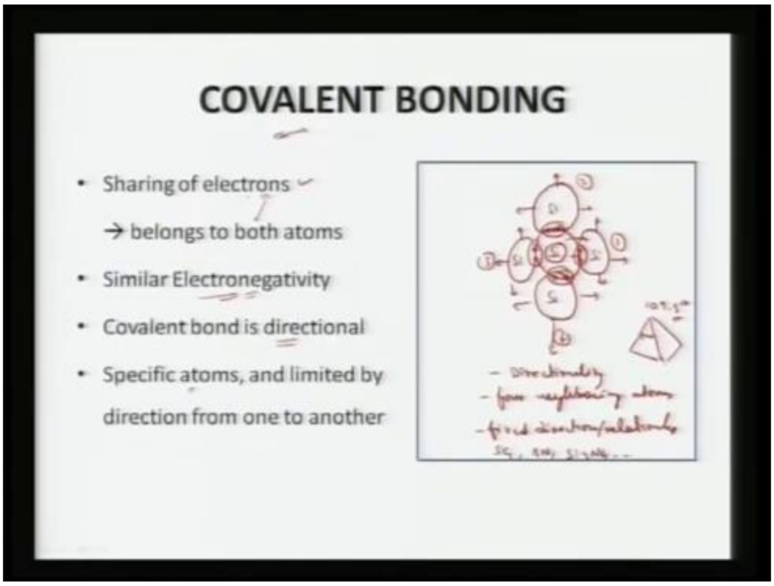

COVALENT BONDING

- Sharing of electrons
  → belongs to both atoms
- Similar Electronegativity
- Covalent bond is directional
- Specific atoms, and limited by direction from one to another

- Directionality
- four neighbouring atoms
- fixed direction/relationship

SiC, BN, Si_3N_4 ...

Then, that makes it bond much more covalent in nature and that also gives rise to directionality. It means that specific atoms they are limited by direction from one to another because in order to share the electron the two atoms have to be in a certain location so that they can share the electrons. Let us take the example of silicon, so we know that the silicon has 4 electrons in the outer most shell and to complete the electronic structure, it needs to share electrons with the other silicon at the 4 edge. It has to share the four electrons, the other silicon atom we can see two electrons here, one electron here, one electron here, one electron here.

So, silicon here, silicon here, so the outer most shell of this particular electron shell atom is satisfied because of sharing of electrons with the four nearby silicon. Similarly, this also has to go on like this in order to satisfy their outer most shell, so for this particular silicon, we can see there are total of 8 electrons and for yet to form the bond with silicon one silicon one has to at certain location. So, it can share the outer most electron so that provides the directionality to the bond, so in this case we can see the directionality associated with and form a tetra hidden with the angle of around 1.95. Otherwise, this bonding may not be possible an the electrons have to be at certain direction.

So, it can go un interrupt from one silicon to the number once silicon from number two to the main silicon and number 3 to number 4. So, there is some sort of directionality and each atom has now four neighboring atoms and each of these electrons are not restricted to only two of the silicon atoms because it has to be shared with those two atoms. So, it create a certain strict directionality or a relationship, so in this case it resulting with a tetra hidden angle of 1.95 and in certain examples can be silicon carbide borne nitrite silicon nitrite.

You can see in this case we have the covalent bonding sharing of electrons and because of this electrons are being shared. So, because of the directionality of the electrons because the electrons are being shared the two items has to be positioned in a particular manner that they are conduct with each other and share the electrons. As a result of that, the electrons now have a certain relationship in which they can be restricted and they can have directional associated alone these two particular atoms, so in this particular case it forms a tetrahedron.

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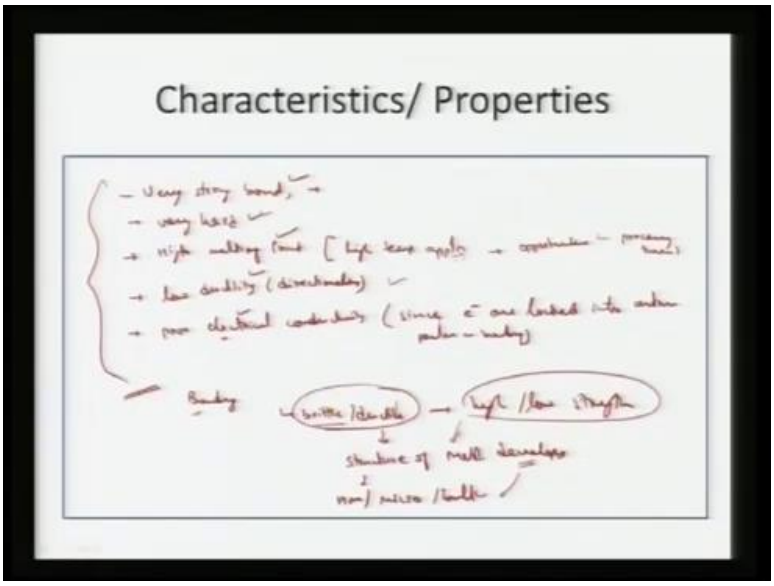

Characteristics/ Properties

- Very strong bond ✓ →
- → very hard ✓
- → high melting point [high temp applns → [illegible] – [illegible]
- → low ductility (directionality) ✓
- → poor electrical conductivity (since e^- are locked into [illegible] [illegible] – [illegible])

Bonding → brittle / ductile → high / low strength

structure of matl developed

nano / micro / bulk ✓

Now, going to that sharing is occurring and sharing creates a very strong bond and there is a certain directionality and that restricts the moment of all these atoms or ions, all these atoms and which are sharing the electrons.

Also, it makes the material very hard and since the bonding is also very good, it has a high melting point high melting point. It should be mentioned that the covalent bond is strong and that extends to long range, but in case of small molecules like methane the bond may be strong, but secondary bond with material solid or liquid at a given temperature. So, it should be clear that covalent solids are hard that, but the not the covalent molecules, so again the pros and cons of this material go in hand in hand. These are good for very high temperature applications, then this needs to develop a new processing techniques of utilizing their melting in air and then forming some useful chips out of it.

So, it has both challenges and advantages opportunities because of their high temperature application high temperature application, but also opportunities in processing them and because of the direction of generality they are also hard. At the same time, they have very low ductility because of the directionality which is associated with these particular materials. Apparently, they also have very poor conductivity since the electrons are somehow low, so we find very poor electrical conductivity since electrons are logged into certain positions and bonding and we can see the covalent bond.

They are very strong very hard, but they have very poor ductility and because of they are very stiff nature very strong bonding and high melting point since electrons are also show very poor electrical conductivity. One thing has to be noted that the strength of material depends on the structure of material atomic or micro scale, so these bonding they can’t really predict material will be brittle or ductile or will have high strength or low strength. That totally depends on how the structure of material the structure of material is developed both have nano meter scale and micro scale and as well as bulk scale.

So, the design or the structure in which the material is developing finally, so though we say ionic bonding or the metallic bonding or covalent bonding is predominant in the particular material. That will tell just how the bond will behave once forces is applied or how the temperature is applied, what will be the nature. The overall properties mechanical such as brittleness or ductility or even the strength of a material highly depended on how the structure is evolved in a particular material not really the bonding is jus t forms the short range orders of a material. Then, how that short range extends to long range that is become critical in designing a material.

That basically tells how the properties will evolve at particular material, so in this case we can see covalent bonding that all these properties are predominant poor electrical conductivity low ductility very hard high melting point and very string bonding. This bonding, generally does not cannot tell predict what will be the nature of the material in terms of mechanical properties. When the brittle ductile low strength or high strength that is more dictated by the structure of the material that will basically develop.

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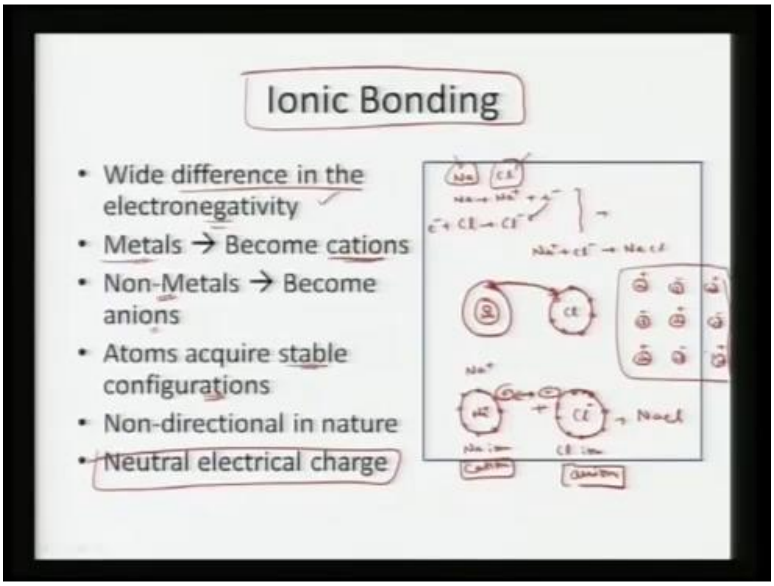

Ionic Bonding

- Wide difference in the electronegativity
- Metals → Become cations
- Non-Metals → Become anions
- Atoms acquire stable configurations
- Non-directional in nature
- Neutral electrical charge

Now, coming to the third hard after metallic bonding and covalent bonding this is again one more type of primary bonding called ionic bonding. In this case we can see in this case we have more than one type of atom and they have difference in electron negativity. Generally, the way we can see is this one atom will be the left most side of the periodic table other element will be from the right side of the periodic table. So, because of that they will have very high difference in electron negativity, so those metals which have a tendency to donate electrons such as metals they become cations or positively charged.

They donate electrons and non metals which are on the right hand side of the periodic table they have the tendency to accept the electrons and become anions. So, in one case if we have any NEL n is tend to give out of electrons, so it becomes positive plus electrons and then chlorine then except electrons becomes negative negatively charged.

It takes the particular electrons, so we have the electrons plus chlorine becomes chloride ions and intern what we get is any plus plus cl minus get any cl that is what we can see here and in this cases we can see this sodium atom. It has one extra electron in the shell where as chlorine has 7 electrons in the shell to satisfy itself. This electrons will be transferred here and then we get a plus which is now in the electrons in the outer most shell. Then, we have chloride which is around now 8 electrons, in the outer most shell we can see the this become plus and chlorine has become chloride ions. So, we have sodium ion and chloride ions to give rise to NaCl, this is rising because of positive charge and the chloride ion is negative share.

So, these positive and negative charges electro static interaction they tend to attract each other, so this has become now cation sodium ion is nothing but a cation and chloride ion become now an ion. This positive and negative charges they attract each other and they acquire stable configuration, so we have sodium chloride sodium. So, we have we have Na Cl Na Cl, we have positive and negative charges negative positive negative positive negative positive negative positive. So, this is a cloud of positive and negative ions, so it cations, then they somehow hold each other, they hold on to each other because of the difference in the charges and again that is non directional in nature.

Now, sodium is also satisfied and chlorine ion is also satisfied, so it creates the overall neutral electrical charge, there is no directionality involved in out her and that is nothing but ionic bond. Now, we can wee wide difference in the electron negativity sodium has the tendency to give out electrons chlorines has the tendency to accept electrons sodium become cattail chlorine becomes an ion. Then, the electro static integration between them they acquire stability and these charges finally give out stability and again no directional in nature.

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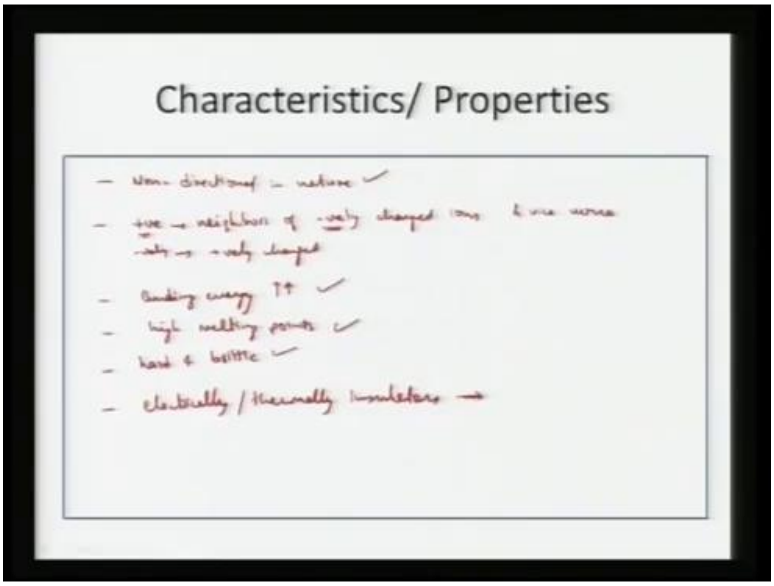

Characteristics/ Properties

- Non-directional in nature ✓
- +ve → neighbors of −vely charged ions & vice versa
  −vely → +vely charged
- Bonding energy ↑↑ ✓
- high melting points ✓
- hard & brittle ✓
- electrically / thermally insulators →

Coming to the characteristics and properties, first of all them are non directional in nature one more thing is to note is that all the positive ions they have nearest neighbors of negatively charged ions and vice versa. It means all positively charged ions have neighbor of negatively charged and all the negatively charged ions. They have neighbors which have positively charged and that create the overall electric integration and because of that bonding energy is generally very high and because of that again have very high melting points and again they are pretty hard and brittle in nature. Again, since everything is now satisfied and there is no directionality involved and again the electrons are not free to move alone.

They are generally electrically and thermally insulators because there are no free electrons are available so there are no electrons which cannot move around entire space freely. They make very poor electrical or thermal conductors that part we can see from here that the that are bonds are non directional the binding nature is pretty high very high because f the interaction between them and all the positive charge. They have the nearest neighbors of negatively charge an all that all that negatively charged ions will have positively charged neighbors and these particular material are very hard and brittle.

They have high melting point and they form electrically or thermal insulators, so do we see the contrasts between the properties of the ionic bond the covalent bond and the metallic bond. So, that part we can see in this particular case and these all are primary bonds, it means the bonding between the atoms and ions are very strong.

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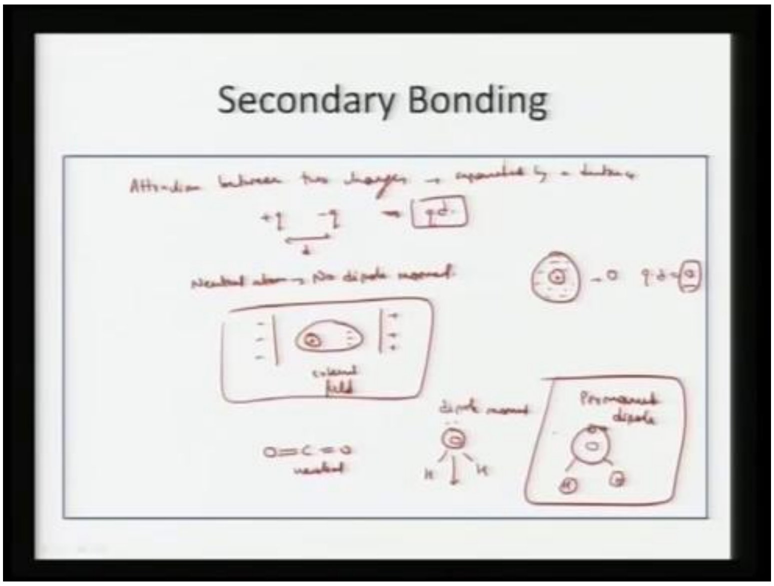

Secondary Bonding

Now, let us come to the second part which is nothing but the secondary bonding, so in the secondary bonding, there is an attraction between two charges. There is no bonding and there is no sharing of electrons or interaction of no sharing of electrons donation of electrons, but in this case the attraction between two charges which are separated by a distance. So, charge of plus q and minus q that forms the dipole, which is separated by a distance d and that forms the dipolar q into d and again we can see the neutral atom will not have any dipole movement and because what is happening here is we have an atom.

It has some positive charge and again it has some negative charge around it and the center of each and every thing is the same and again the overall charge is also the same. So, what is happening the distance of the centre is 0, so apparently the q into d also become 0, there is no charge or dipole which is happening in the particular neutral atom, but when some external field is applied. Then, if I apply some external field, the negative charge will tend to go towards this side and positive charge will try to come to this side.

So, in this case we can create a dipole via some external applying a field apparently some atoms or molecules they have permanent dipole like in case of carbon dioxide. It is a neutral atom, it does not have any dipole, but in case of H 2 O, we have oxygen, so in this case we have a permanent dipole, which is in this particular direction. So, do we have dipole movement which is because of 2 electrons of n oxygen atom, so how this charges when applying through an external field or they have permanent dipole.

So, these charges can somehow interact with each other and that interaction is very feeble it is not as strong as the primary bonding. It is very feeble interaction between those two because of the opposite charges which is separated by the distance and that forms a secondary bonding that part we can see.

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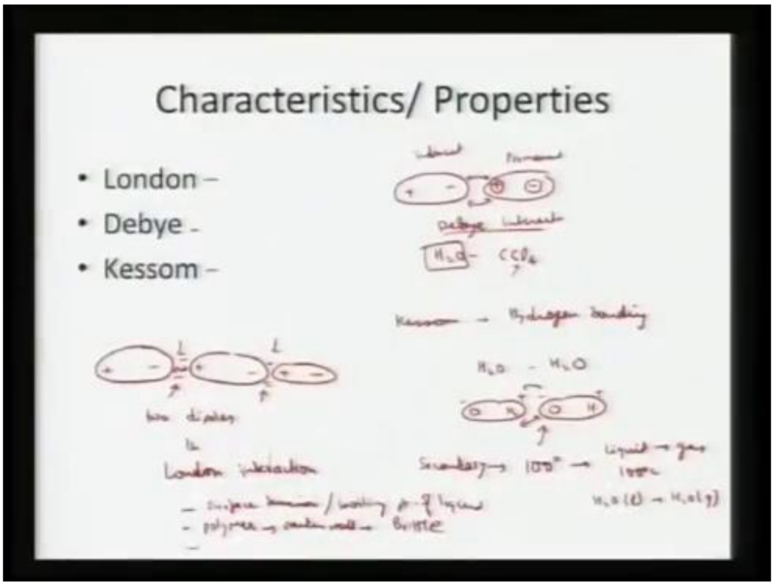

Characteristics/ Properties

- London –
- Debye –
- Kessom –

These interactions can be defined into three categories first one is the London charges second one is the Debye third one is Kessoms is also known as hydrogen bonding. So, London forces what is happening is interaction between two dipole these are no permanent dipoles, but induce dipoles plus minus plus minus. So, interaction between these two and similarly it will go on, so there will be some interaction at these locations. So, we can see interaction between two dipoles and that is called London interactions, so this interaction can also happen between the induced dipoles.

So, the plus and minus in a permanent dipole, so we can have a permanent dipole which any way has plus and minus along certain region, so we have a permanent dipole and this is induced. Now, these two entities can interact and that is called a Debye interaction example can be H 2 O and this carbon tetra chloride. So, we can see the interaction this is the permanent dipole and that can interact, we can induce the dipole and NaCl 4 and that can interact and that can that result scale d Debye interaction and the third type of interaction is called the Kessoms interaction. Kessom interaction is also called hydrogen bonding, in this case we already have two permanent dipoles such as H 2 O and H 2 O.

So, we can see we have oxygen and then hydrogen and again we have positive charge, negative charge, it can interact with oxygen, which is negative and again we have positive charge this interaction is called hydrogen bond. Apparently, what can happen, these secondary bonding are very feeble like if we heat this particular material to hundred degree centigrade water will convert to steams we have liquid to gas transition at 100 degree centigrade. So, we have water which was liquid it has now gone to gassiest state it is breaking the bonds so that there is a phase transition, but at this temperature the bonding between hydrogen and oxygen is not breaking off and that is the primary bond and bond between oxygen and hydrogen is primary bond.

The secondary bonding is hydrogen bonding is much feebler in nature at hundred degree centigrade that bond is particularly breaking. So, the water is converting in to steam, but much higher temperature is required to break the bond between oxygen and hydrogen which is forming the entity H 2 O, so that part we have to keep in mind. So, apparently the secondary forces which determine the surface tension or surface energy of a material they also dictated the boiling point of liquid. Again, this also must be kept in mind once we have those secondary interactions some polymers what can happen, it can creates some secondary linking of all bonding and that will limit the manner in which the polymer can deform.

So, once the secondary linking is available then that makes the polymer very hard to slip alone certain directions and that makes the polymer very brittle what we can see the secondary bonding are very they may not be very good. Once we form a polymeric material and also they are very helpful in once we going to disperse one entity. So, we can take a material and tendency to accumulate then we care release those, release those.

We can disperse, reduce the surface energy by dispersing them in to certain liquid media or some organic media those are also requires for dispersing a particular material. We can see how those secondary bonding are very necessary in terms of using certain applications such as surface tension or evolving the evaluating the volume part of the material or defining the brittleness of the particular polymer or dispensing a particular material.

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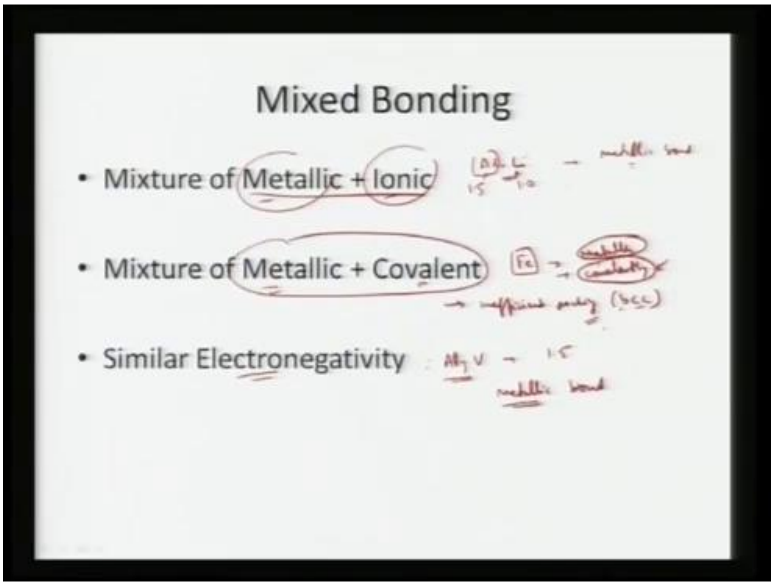

Mixed Bonding

- Mixture of Metallic + Ionic
- Mixture of Metallic + Covalent
- Similar Electronegativity

Now, that brings the concept of whether we can have mixed type of bonding that can occur in a particular material like in once case we can have mixture of metallic and ionic bonding. So, once we have metallic and ionic bonding, so like this in this case we have to see this we have aluminum and lithium and both are try out to give out electrons, they will give rise to metallic bond at the same time out aluminum has 3 plus where as lithium has 1 plus. So, again some sort of an ionic interaction between then because of the electronic activity which is 1.44 for aluminum and for lithium.

So, in this case they primarily metallic as well as ionic in nature when we go with only metallic bonding like we have case of aluminum Al 3 the both have electricity of 1.5 and both have now monitored by metallic bond. The measure of metallic and covalent can be a case of ion because ion is metallic in nature.

At the same time, it is bonded valiantly with other ion items and that is one more reason it is metallic same time it is covalent and because of covalent in nature, it has to be placed at certain location only. It cannot be free to move around the place or so the direction between the between the ion ions and atoms has to be specific. That gives rise to very in efficient packing which s noting but BCC for ion at the room temperature what is centered at cubic at room temperature.

That is very inefficient packing because of the covalent nature of the ion we can see that all sort of mix sort of bonding it is metallic plus ionic. So, in this case we have aluminum and lithium, so they will have both characters of metallic as well as ionic and that part we can see similar electron negativity. We can have mostly metallic bonding and the difference in the electron negativity, it can be both metallic and ionic and nature of metal as well as covalent lie in case of a ion, it generally yields to a inefficient packing.

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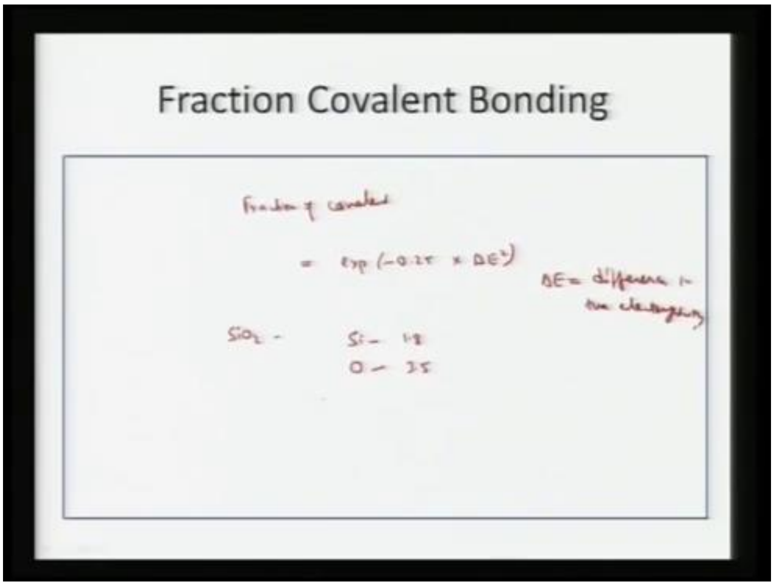

Fraction Covalent Bonding

Fraction of covalent

$= \exp(-0.25 \times \Delta E^2)$

ΔE = difference in the electronegativity

SiO_2 - Si - 1.8

O - 3.5

Apparently, the fraction of covalent can also be calculated, so we can see the fraction of covalent bond that can be calculated by exponential of multiplied by delta e square. The delta e is the difference in the electron negativity of a particular material and like silicon outside, we have taken an example, silicon has a electron negativity of 1.8 for oxygen, it is 3.5.

So, in this particular case fraction covalent once we have a fraction covalent in case because bonding will have both the characters ionic as well as covalent or even metallic. So, the fraction covalent bonding can be calculated with the difference in the electron negativity.

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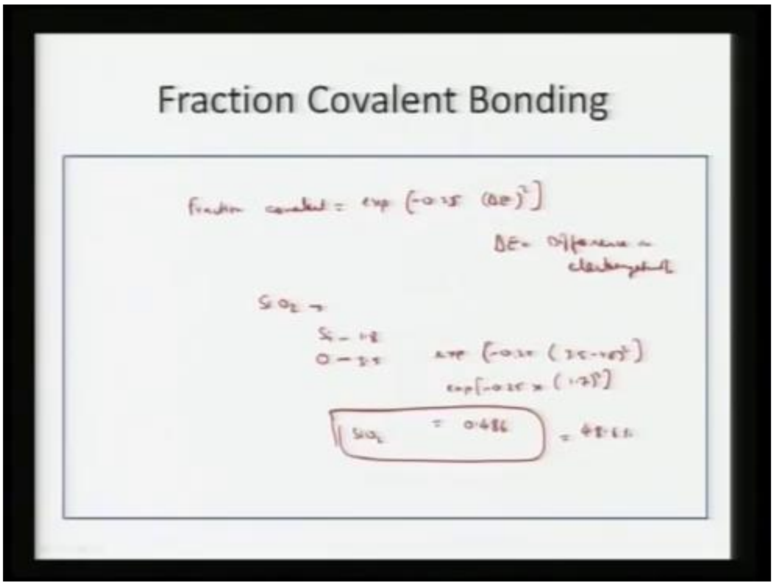

Fraction Covalent Bonding

fraction covalent = $\exp[-0.25\ (\Delta E)^2]$

ΔE = difference in electronegativity

SiO_2 →

Si – 1.8

O – 3.5 $\exp[-0.25\ (3.5-1.8)^2]$

$\exp[-0.25 \times (1.7)^2]$

$\boxed{SiO_2 = 0.486}$ = 48.6%

So, we can find the fraction covalent is equal to the exponential of minus t2.25 multiplied by delta e square delta e is the difference in the electron negativity. So, we can see if you have silicon is O 2, so silicon has a electro negativity of 1.8, where a oxygen it is around 3.5. So, we can see the fraction covalent can be exponential of minus 2.5 multiplied by 3 minus 1.8 square. That becomes exponential of minus 2.25 multiplied by 1.7 square and that comes out to be around 0.86, so for silicon oxide the fraction covalent is around 48.6 percent, so we can easily see the fraction covalent bonding how it is arising it in a particular material.

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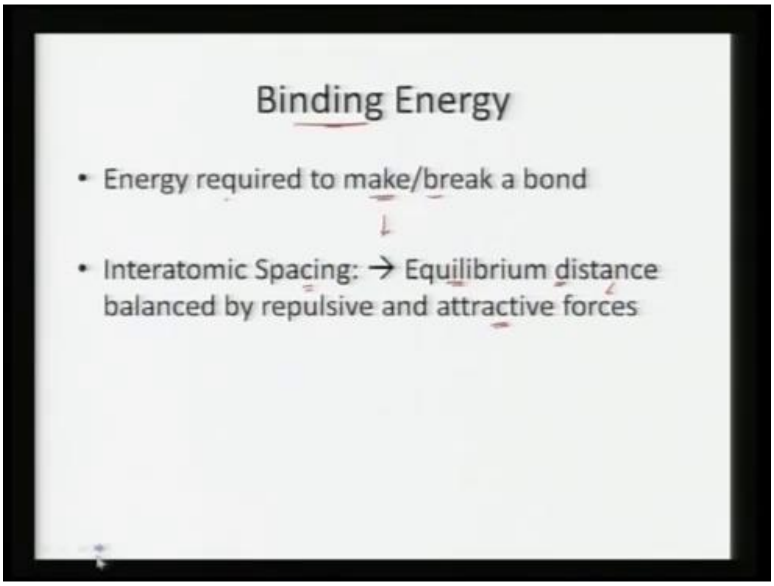

Binding Energy

- Energy required to make/break a bond
- Interatomic Spacing: → Equilibrium distance balanced by repulsive and attractive forces

Now, it become essential to learn what is the binding of the energy binding of the energy is nothing but the energy required to make or break a bond. Apparently, that dictates the spacing that is that will arise as a equilibrium distance e and which is being balanced by a repulsive in that attractive forces. So, let us see what the overall interaction is once we increase or decrease the distance and how are the forces act on a particular material.

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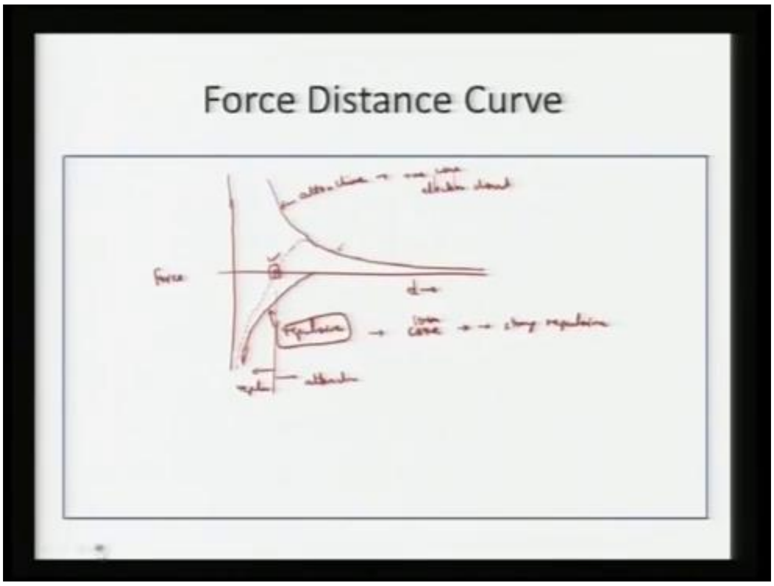

Force Distance Curve

So, distance curve can be given like this that we have as we go near the nuclei, what can happen we can experience the strong repulsive forces, we can have very strong repulsive forces as we go. We can have some attractive forces which will predominate at higher overall, we can see the overall call will generate like this this is a repulsive force. This is attractive force, this is our force this is distance this repulsive forces arises because of interaction of two ions or nuclei or the core ion core. They have the ions positive charge ions are there because of that we experience very strong repulsive force when we reach the very near of the atom this attractive forces arise the interaction between or positive or the core and the electron cloud.

So, we see the attractive forces they vary alone very long distances, whereas the repulsive forces are predominant mostly in the nearby region of the of the of the atom. Apparently, we the net charge which is arising the net force is dominated by the repulsive forces in the near region in the near atomic nuclei where as it conforms to the attractive forces at certain distance later on. So, at certain point, we have 0 force that acting on the two nearby entities, two nearby atoms isolated atoms that is becomes the stability point. Below this distance, we have mainly repulsive and above this we have mainly attractive forces apparently those coverts to energy.

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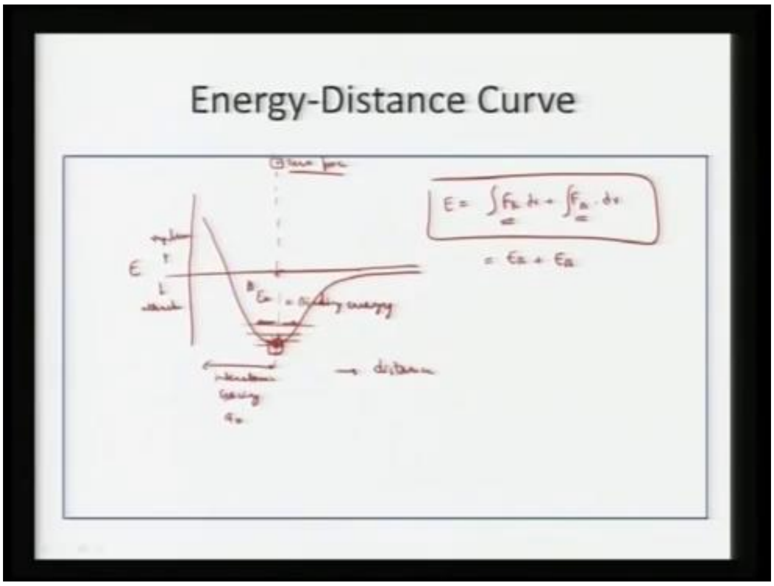

Energy-Distance Curve

So, in this particular case when we have minimum or the 0 force that gives rise to minimum energy. So, we can see our energy curves looks more like this, so here when we see apparently when we draw it will see that the force it will be 0 and that has the minimum energy. That is nothing but the binding energy of the material and up this distance energy, we can see that this is nothing but your energy minimum energy is nothing but the binding energy. This distance is nothing but you inter atomic spacing and in this case you will feel attraction we can see at this particular level we have exactly the lowest energy.

In that case, we have 0 force acting on the material, so if we increase the distance or decrease the distance increase or decrease the distance, we can see an increase in the energy value that may not be very stable. So, at this exact point we have interaction point which is equal to a not this is the minimum energy that is nothing but your binding is energy or we also call net energy which is nothing but your e naught. So, we can see the combination of forces, we had repulsive force and we had attractive forces that gives rise to the overall energy. Net energy is the sum of repulsive forces and attractive forces along the distance and that gives rise to energy of which is repulsive energy plus the attractive energy.

Apparently, thus steeples is also very critical, how deep these particular curve goes to what is the ratio of these particular force to slope of this particular force by distance curve.

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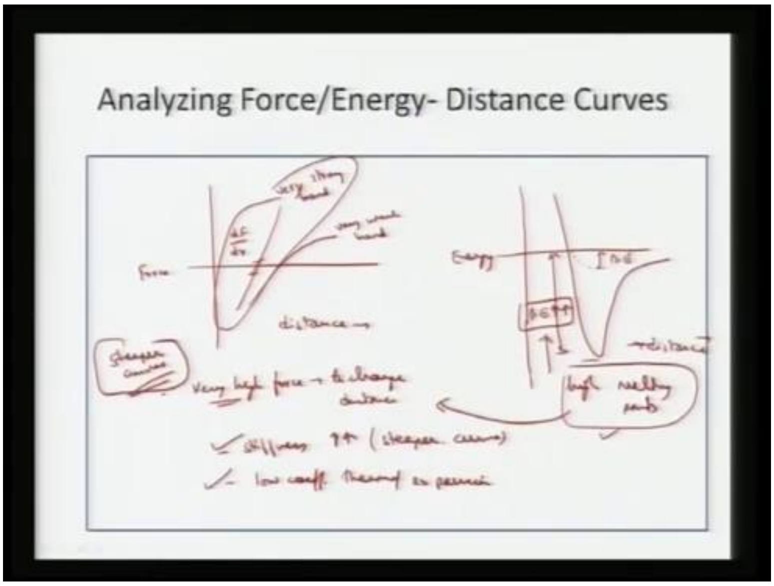

Analyzing Force/Energy- Distance Curves

So, we can see the slope is pretty high and here the slope is pretty low, we have force and distance and then we have energy very steep. So, in this case we can see our d f by d r is very steep, it means it falls very high force, if you want to bring any change in the distance or in another words the bond is very strong in this case are require very high energy. If you want to separate the material, you have to bring them much closer, so we have to spend very high energy and in this case we have very weak force. If you see it in this case, we have very steeper and very deeper trap, in this case our binding energy will very high had we had a shallow.

It means out binding energy is very low, so generally the binding energy is very high means generally we have very high melting points and apparently the overall structure is also very high. When we have a steeper curve and since we have to spend very high energy in order to go the apart in order to go apart from the closer they also have very low coefficient of thermal expansion.

So, when we have very steeper curves like this in this case we have like that, so they will have very high force it required to change the distance and will have very high stiffness. They will go with low thermal expansion and generally they will have very high melting points, so we can see that is how is basically occurring in the material.

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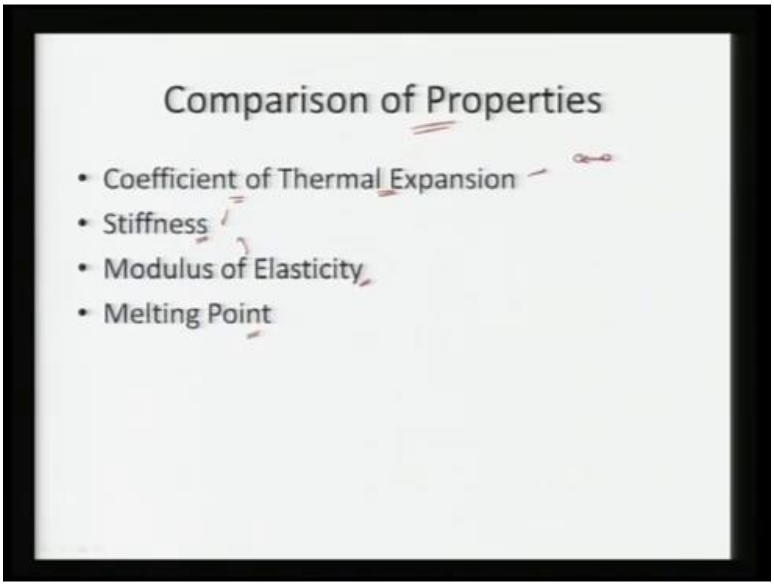

Comparison of Properties

- Coefficient of Thermal Expansion
- Stiffness
- Modulus of Elasticity
- Melting Point

So, we can see the comparison of properties between them the coefficient of thermal expansion it is dependent on how much force or how much energy is required in order that atoms can go further and further. That is dictated by the overall steepness or slope of the curve in the force distance, so as the force distance goes very steep will have lower and lower thermal expansion. That again will have very high stiffness, very high modules of elasticity lead to lot of stiffness and the melting point is dictated by the kind of binding energy and that is that is much more steep in order to have a very high melting point.

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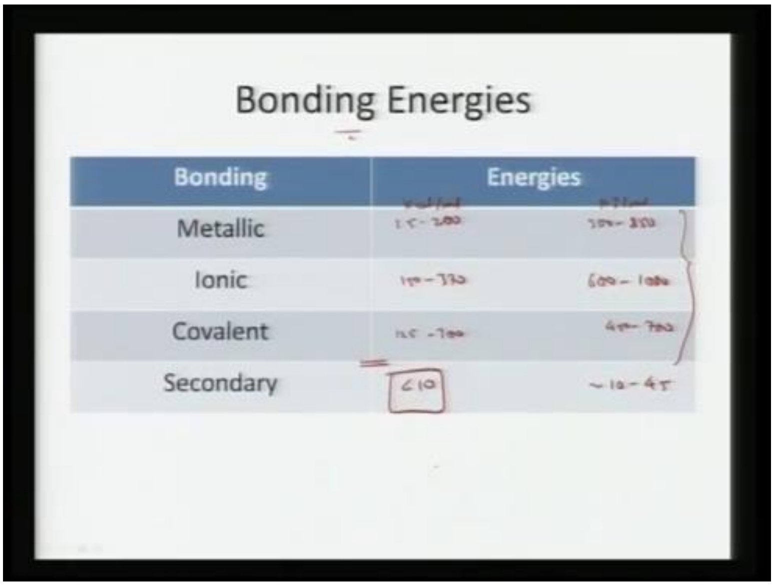

Bonding Energies

Bonding	Energies	
	kcal/mol	kJ/mol
Metallic	25 - 200	300 - 850
Ionic	150 - 370	600 - 1000
Covalent	125 - 300	450 - 700
Secondary	$\boxed{<10}$	~ 10 - 45

So, the typical bonding energy is of metallic material is ranges between around 150 to 370 if we take calories per mole, it can also kilo per joule for metallic, it is around 6000 to 1000 kilo per joule for ionic it is for the ionic. We can see the energy the binding energy or the bonding energies of metallic energies ranging between 25 to 200 kilo calories per more or from 300 to 850 kilo joules per mole for ions. It might range from 150 to 370 calories per mole that converts to 600 to 1000 kilo joules per mole for covalent it is 125 to 300.

Again, that is approximately 452 to 700 joules per mole and in secondary bonding, it is very feeble in nature. So, it can range from 10 to around 45 kilo joules per mole. That part we can see the bonding energies are very high for the primary bond, whereas for the secondary bonding, it is very feeble around 10 times less than that of other type of primary bonding.

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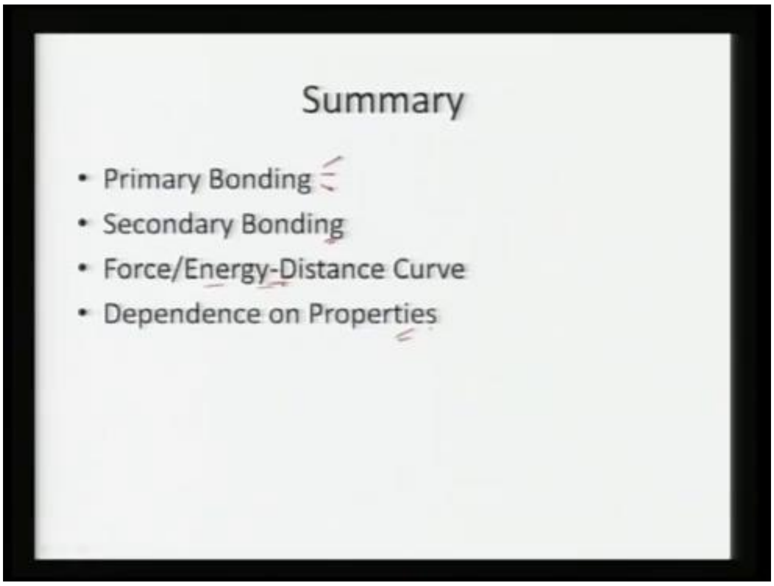

Summary

- Primary Bonding
- Secondary Bonding
- Force/Energy-Distance Curve
- Dependence on Properties

So, in summary we can we have learned the primary bonds generated in terms of metallic covalent and ionic and how each and every one has a different characteristic in itself and again. Coming to secondary bonding, we have Debye interaction London interaction and Kassem interaction and how these values are much more feeble 10 times lesser than that of a primary bond. Again, the characteristics of metallic bond is very different in this case we sea of sea of electrons and in ionic boning, we have seen a donation of electrons and acceptance of electrons and in covalent. It is sharing of electrons apparently, then force distance and the force energy distance curve is also play a very strong part and defining what is the stiffness of the material.

What is the coefficient of thermal expansion and again what is the modules of elasticity and the melting point. All these things are very important in very important in dictating them in design of a material and those are being defined by the force distance and the energy distance curve. So, we can see those dependences out here so the depending on the force distance curve and the energy distance curve behave at more fundamental level. That dictates the overall functionality of the material, so with this particular summary I will end my lecture here.