Introduction to Soft Matter
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Lecture No 11
Atoms and Bonds

Welcome everybody, welcome back to another lecture on Introduction to Soft Matter. So, last, till last class we had seen, we have taken a continuum mechanics approach to this particular problem. And then at the end of that lecture I had said that today what we are going to do is, we are going to take a very different approach to things we know that no material is really a continuum.

We know that matter is made of, of small units called atoms and molecules and the behavior of any material must necessarily depend upon how it is made at a small scale. So, there is a whole different way of looking at the soft materials altogether. And in doing so, let us go back to a definition of soft materials that we had looked at in the beginning itself.

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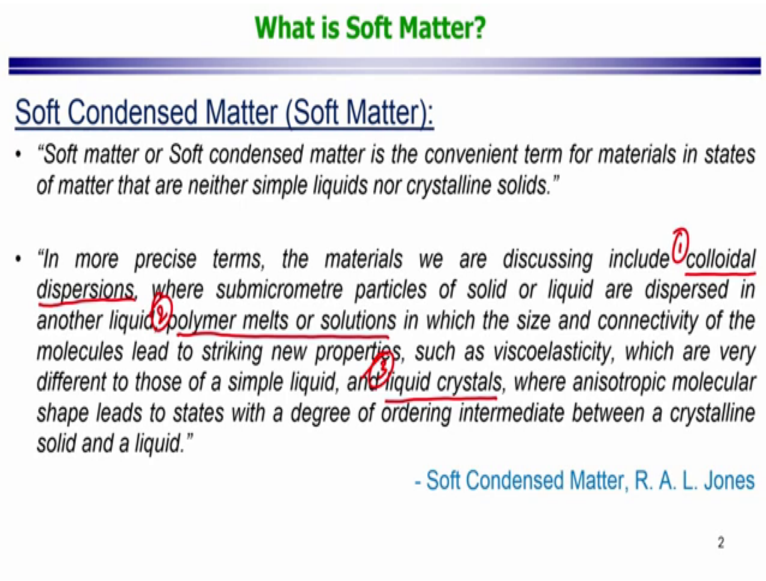

So, the definition was that soft matter or soft condensed matter is a convenient term for materials that are in states of matter that are neither simple liquids nor crystalline solids. And in the same book R.A.L Jones he says that, in more precise terms the materials we are discussing include colloidal dispersions, where sub micrometer particles of solid or liquid are dispersed in another liquid.

So, this is the colloidal particle is one example of Soft Matter he there is talking about colloidal dispersions, which is often in short just called colloids. And then we have another example in the form of polymer melts or solutions in which size and connectivity of the molecules lead to striking new properties such as viscoelasticity which are very different from those of a simple liquid and liquid and then another example is liquid crystal, okay, where an isotropic molecular shape leads to states with a degree of ordering intermediate between a crystalline solid and a liquid. Okay.

So, he takes three examples here, colloidal dispersions, polymer melts or solutions and finally, liquid crystals. So, he is once again trying to give us examples of what are the different type of colloidal, sorry, soft materials that are possible.

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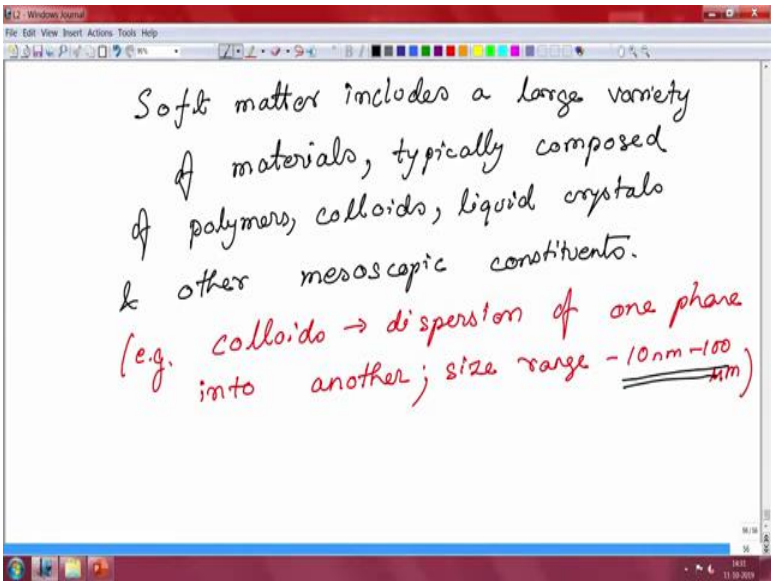

Okay, so, basically soft matter includes a variety of materials, okay and it includes a very large variety that is very difficult to fully enumerate. It includes a large variety of materials typically composed of polymers, colloids, liquid crystals as the examples were provided and other mesoscopic constituents. What does mesoscopic mean? What is this new word? Well, mesoscopic is a length scale that is larger than your microscopic lens scale, okay.

And let us maybe discuss it with the example of colloid. So, remember in colloids we had said is a dispersion, so colloids itself is soft material, can be a soft material or it can be an ingredient of another soft material. So, colloids themselves by a dispersion of one phase into another.

And the other important thing to remember here is the size range that is specified. So, the size range is usually 10 nanometers to 100 micron some authors may say one nanometer. So, their size ranges might slightly differ, but that is not very critical, we are referring to certain slightly just to write this clearly, 100 microns.

So, we are referring to a set of length scales that are there and these length scales see are much bigger than your atomic length scale. Remember? So, when we said, when we say atoms, the length scale that should come to your mind is approximately of the order of Armstrongs but these are much bigger than that.

So, it tells you that the material is made up of constituents, which you cannot characterize by a length scale of simple like a hydrogen atom of that length scale, you cannot characterize it by that the length scales involved are much bigger.

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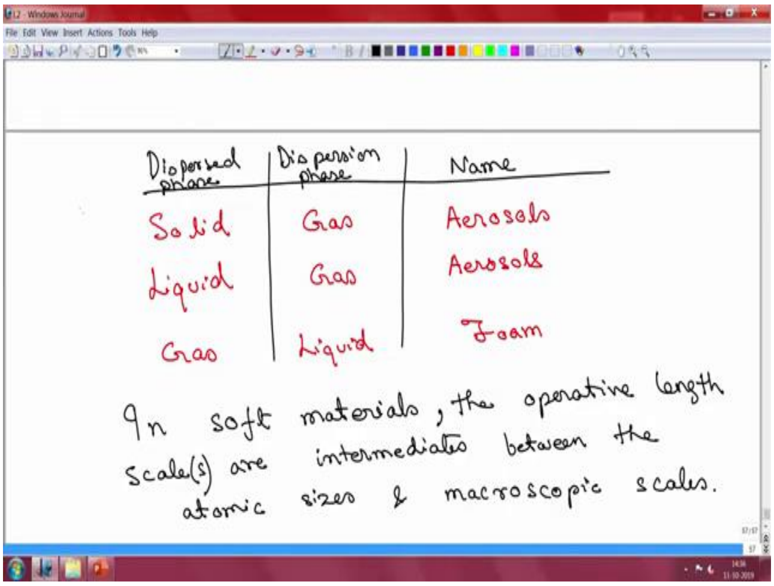

Now, since we are just discussing colloids, I just quickly want to point out (())(6:21) dispersion of any phase, type of phase into any type of phase. Okay, so I will just for completeness, I will name or give you some examples. So, this is dispersed phase and this is let us say the dispersion phase. This is the name. So, for example, you can have a solid body or solid particles that are dispersed in a gas phase and then they are usually called Aerosols.

You can also have a liquid which is dispersed in a gas phase. And which case you again call them Aerosols. You can also have gas dispersed in a liquid in which case, they have a special name Foam. But usually we are considering some kind of solid, which is dispersed in a personal liquid phase. Now as, so it does not say that this, definition you will note does not say what percentage. So, you can have the dispersed phase in any percentage you want.

And if you have a very dilute solution, you can have a solution of let us say, some solid particles in liquid and then the liquid will behave more or less as the dispersion phase itself. So, the quantity of the dispersed phase is very small. Let us say polystyrene particles in water, the percentage is, let us say, 1 by 100 of even 1 percent. That is a very dilute solution. And the behavior of that overall liquid is going to be resemble more or less, the dynamical behavior is going to resemble more or less the behavior of water itself.

But as you increase the solid percentage, you will start seeing that viscoelasticity becomes dominant at some stage. And for example, you have clay particles in water which becomes mud. So, as your amount of liquid becomes lesser and lesser and lesser, you have more and more viscoelasticity, apparent viscoelasticity that you see, so, in all these different examples, and we had discussed two more examples, at least in that definition, which was there which is polymers and liquid crystals we will look at those individually also.

But the important point to note is that in soft materials, the operative length scale or the important length scale, what operative means whatever is determining the properties of the matter, the operative length scale are inter, length scale or scales are intermediates. Usually there are length scale, so intermediates, between the atomic sizes and the macroscopic, sorry macroscopic scales. Scales means length scales.

So, you can have let us say a cheese ball, which is 1 millimeter. And the atomic length scale here is going to be very small obviously, as we discussed the atomic length scale, we will look into more detail about that in a bit. But the question is, what is the real operating length scale or what is the length scale that is determining the properties of that material that is somewhere between the large macroscopic length scale where the thing becomes an object you can handle and between the atomic scale.

So, to understand this perspective, we actually have to look at the fact that matter is no longer can be considered as a continuum as we had been doing in the previous lectures. We have to necessarily adopt an atomic lengths sorry anatomic perspective to things the.

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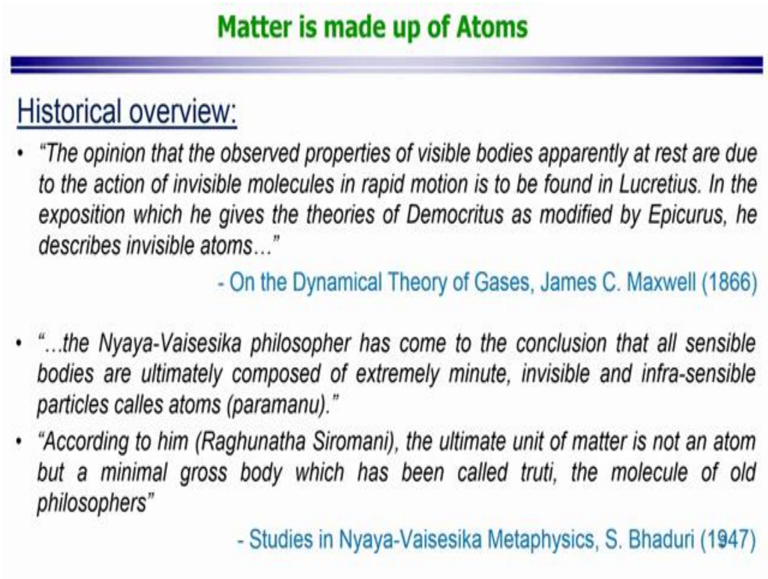

So, just like we have done in the past let us look at a historical overview here. So, the fact that matter is made of atoms is actually a very old idea. It goes back to ancient Greeks and ancient Indians who realized this and wrote extensively on this topic. And many of the textbooks often cite the Greek ideas, and that is why the word atom comes from the Greek word Atmos.

And these ideas have been well cited previously. So, for example, in a paper of James Maxwell, and there is a reason I have chosen this paper, by the way, I will tell you in a moment, he says that the opinion that the observed properties this is in the introduction section of this manuscript, and this is our great Maxwell to whom the electromagnetic theories are credited to.

He says that the opinion that the observed properties of visible bodies apparently at rest are due to the action of invisible molecules in rapid motion is to be found in Lucretius. In the exposition, which he gives the theories of Democritus as modified by Epicurus, he describes invisible atoms and then he goes on to say that this is the Greek the ancient philosophy of the atomic structure of, of matter.

And there is a reason I have picked out this paper, by the way we will refer back to this manuscript when we are discussing the Maxwell's viscoelastic model. So, this idea is actually extremely old that matter is made of the small small constituents and in the Indian system, the Indic philosophy, which is usually credited to the school is credited to the philosopher Rishi and Rishi Kanad.

He says that the Nyaya-Vaisesika, so this is from a different text by the way, and there is a system of philosophy called Nyaya-Vaisesika philosophy, “and the Nyaya-Vaisesika philosopher has come to the conclusion that all sensible bodies are ultimately composed of extremely minute invisible and infra sensible particles called atoms Paramanu”.

And in this text, and I will tell you what text this is, in a second, the author again states later on that according to him, and here, this is a different portion of the text. This is I have taken it from a different part of the (())(13:32) book. And he says, there is a mathematician Raghunatha Siromani, who I believe was somewhere in the 14th century, Common Era. And according to him, the ultimate unit of matter is not an atom, but a minimal gross body which has been called truti, the molecule of old philosophers.

And here we see that word truti once again. And if you remember, we discussed this, when we are discussing timescales, natural timescales, so you see that in the indic system different, same words are often used by other people, by different people for different meanings, so we have to be careful. And this is taken from the book studies in Nyaya-Vaisesika metaphysics by S. Bhaduri. This is very old text 1947.

And unfortunately, the Nyaya, the Vaisesika philosophy which is credited to kanad, I believe Kanad goes to, is before Common Era. So, some people say it is some second century or third century, although I am not exactly sure of the date right now. But this is an ancient school. And it was even in the Bhashans of Shankar Acharya, where Vaisesika School has been referred to and their idea of how matter is made of atoms.

In this context, neither of the schools ever to the best of my knowledge ever made any conclusion or any guesses about how small the atom is, but we are trying to do is to figure out how small that is. So, it is not just enough to say that matter is composed of atoms, and you have to figure out how small they are, how they are made of.

So, these are ancient ideas, but in more recent history, we have, obviously, the Brownian motion as an old phenomena, I believe it was observed in 1820s if I am not mistaken, by Robert Brown, it was also observed by other researchers, but Brown is credited to have done the most systematic study of Brownian motion and that is why that phenomena is named after him.

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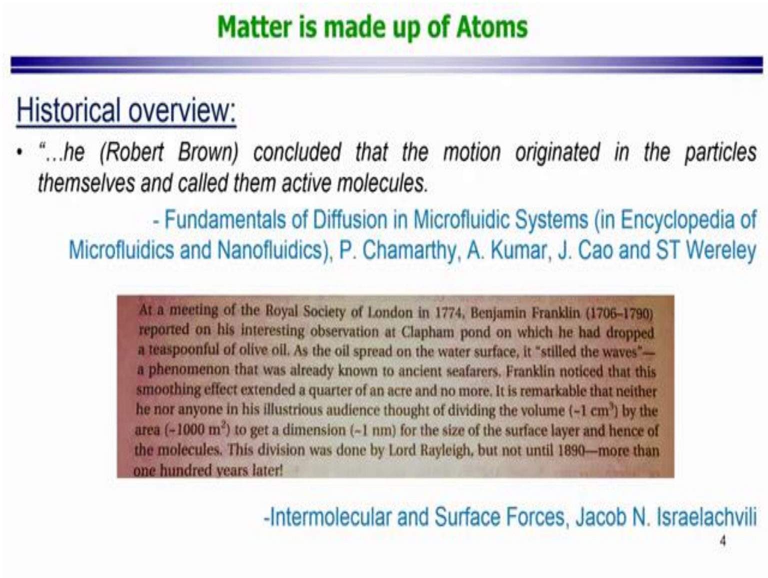

And in this, this again, I have taken from a text he concludes Robert Brown, that the motion originated in particles themselves and call them active molecules. And this is from a book chapter in which I am one of the coauthors is the book chapter is titled Fundamentals of Diffusion and Microfluidic Systems. It is available in the Encyclopedia of microfluidics and nano fluidics. And I wrote part of this book chapter.

And see in the 1800s, they have not seen how small they are. But people have started to make some conjectures about how small they are. And this is, I did not want to write so much I took a picture of this book I have. The book is called Intermolecular Surface Forces by Jacob Israelachvili.

Apologies to the author for mispronouncing the name. But this is a very interesting story where he says that at a meeting of the Royal Society of London in 1774, Benjamin Franklin reported on his interesting observation, at the Clapham pond which he had dropped a teaspoon of olive oil.

As the oil spread on the water surface it still the waves a phenomena that was already known to ancient seafarers. Franklin noticed that this smoothing effect extended a quarter of an acre and no more. It is remarkable that neither he nor any one in his illustrious audience thought of dividing the volume by the area to get a dimension and says one nanometer for the size of the surface layer, and hence of the molecules. This division was done later by Lord Rayleigh, but not until 1890s more than 100 years later.

And interestingly, one more estimate of the molecular size is attributed to young and it was probably around 1815 or something around that time. And he also got a value of 1 Angstrom if I am not mistaken for the atomic size. Although he published it in a place where people did not look and he was forgotten. And it was only later on found that he had done this. Our understanding of the atoms obviously, comes much later proper understanding.

Although obviously there are a lot of scientists who have, who, even before the molecule is seen and seen is in quotes, if I may use that they have started using the idea of the molecular nature of matter, including Boltzmann and others. But only in the later part of the 1900s. We really understand how small the atom is with the Bohr model.

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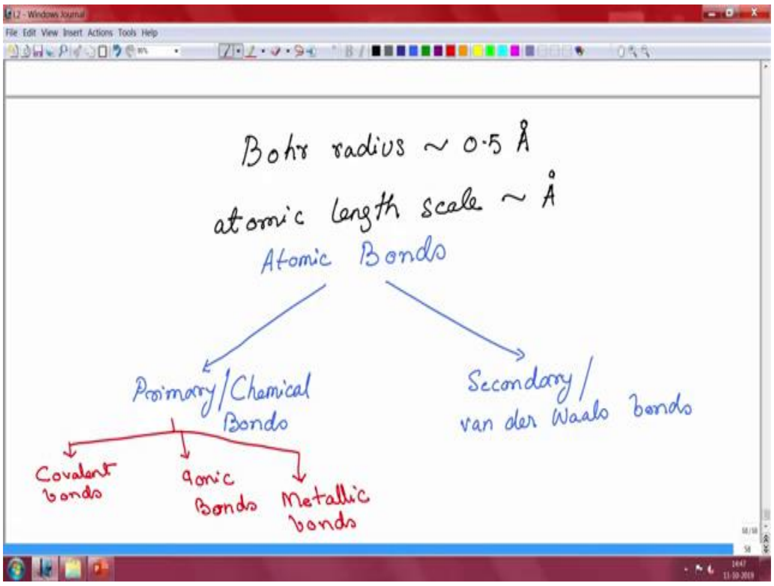

So, you saw that how this idea of the atoms has developed and in 1900s, we start to have a very good idea of how the atom looks like and the Bohr radius. So, one often says that the hydrogen atom and its ground state is approximately of the order of Bohr radius, which is somewhere around 0.5 Angstrom. So, the atomic length scale that we just discussed. Is in the order of Angstrom, okay. The exact number is not important. For us, it is not if it whenever it is we will come to that.

So, we are discussing atomic sizes. So, the atomic size is the order of Angstrom and we know that atoms come together through bonds and through the bonds they form larger units called molecules. So, Bonds are usually of or Atomic Bonds are usually of two types. One is called the primary or the covalent bonds and other is secondary or Van der Waals bonds. Primary or covalent bonds, a sorry just a second I think I have, wait a minute sorry, it is primary or chemical bonds.

Primary or chemical bonds can be of different types, including probably the first thing that would come to you should, come to your mind is covalent bonds. Another type is Ionic bonds and still another type are metallic bonds.

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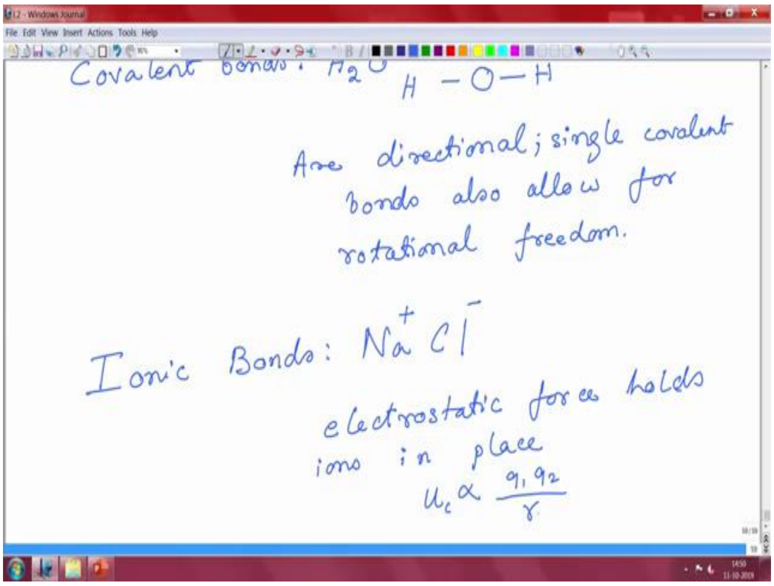

So, in the covalent bonds so example, I ran out a space there, so I am just going to use. So, covalent bonds, so the water molecule is composed of, what is the formula that H2O here your oxygen atom this is just a schematic of this can be represented as the oxygen atom having two covalent bonds with the two hydrogen atoms. Usually covalent bonds are highly directional and single covalent bonds also allow for rotational freedom.

Single covalent bonds also allow for rotational freedom, not so much the double and the triple bonds and when we say it allows for rotational freedom, we understand that there has to, the opportunity for rotational freedom has to be there. So, it has to be in solution form. So, you can have crystals, where even though there are single bonds, you not have any rotational freedom or rotational movement is very much restricted.

The other type of bond as we saw, so covalent and then the other was ionic. So, Ionic bonds are also very interesting and important for example, NaCl and these are composed of two atoms Na plus Cl minus and they are arranged in a lattice type of structure where, the force by which this entire thing is held together is provided by electrostatic force.

So, electrostatic force holds Ions in place and this force is basically given by the two charges the cuolombic force, cuolombic potential energy is given by the charges divided by the radius between the two, the force is in the square. Force has r square, this is the potential energy. Metallic bonds, just one more second here. So, I deliberately took to an example of water and NaCl.

So, water is a simple molecule and we can see that the size of the molecule itself is of the order of the atom itself. Slightly larger than obviously an atom but it is off that order. Now, NaCl dissolves in water. But let us remind ourselves it is not going to form a colloid by the way, when you dissolve NaCl, Na plus and Cl minus go into the interstitial spaces and it breaks up into Na plus and Cl minus ions.

And the size of Na plus and Cl minus again are in the order of Angstroms. So, those are smaller than the length scale, the colloidal length scale that we discussed. So, that is why that length scale is important. So, Na solved in water forms a solution and not a colloid.

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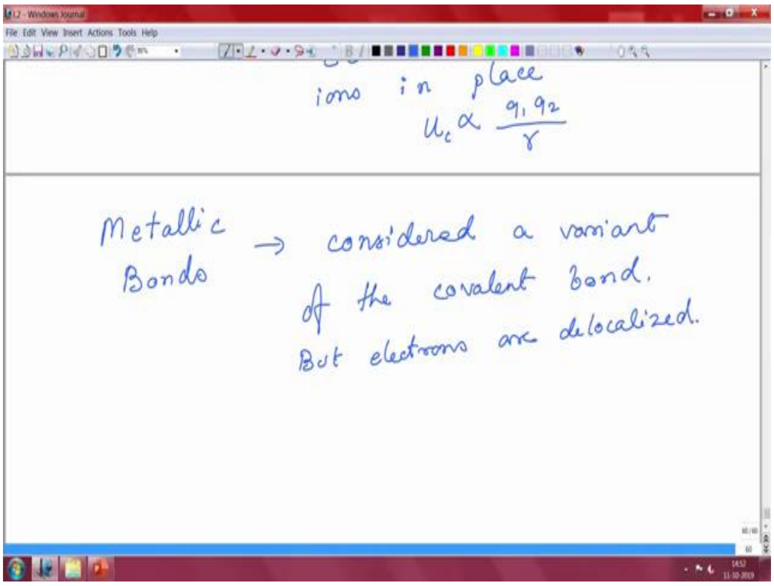

And then we have the Metallic Bonds which are considered a variant of the covalent bond but the electrons are delocalized here. So, but electrons are delocalized. So, the bonds are not that directional. So, the directionality is much lesser than that of a covalent bond, but interestingly the strength of a metallic bond is of the similar order as a covalent bond that is why they are important.

Okay, so, what we will do is we will stop here for today. And what we had, we have started doing in this particular lecture is that we have started taking the atomic view of things. We are just getting started with it. So, that is why the first things we wanted to discuss is the atomic length scale. So, I gave you a small historical perspective and then we know that what the atomic length scales are of the order of Angstroms and that they are put together different materials will have this different atomic bonds holding the molecules together.

So, we just got acquainted with the covalent, ionic and metallic bonds for this class. And the next class we look at the Van der Waals bonds also and go on to discuss how these are going to help us create larger and larger units from singular atoms. Okay, so, we are going to stop here for this class.