Physics of Materials
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Lecture No. # 02
Properties of Materials

Hello and welcome to this second class in this lecture series on the physics of materials. As we mentioned this is a forty lecture series and we discussed in the first class what are the kinds of topics that we will explore through this class, we also considered the manner at which this might relate to your professional activities where this might help you in in your science in your research if you were working in a industry and so on. And we also looked at what are all the kinds of topics that we will discuss the amount of detail that we will look at.

The kind of background that you would need to follow this material and to reemphasize this is aimed at engineering college students pretty much from any discipline. Mostly aimed at materials and metallurgical engineering students but you could pretty much understand this material if you are an engineer in any other discipline as well. And it will give you a good connection between what you learn in material science and engineering or in metallurgy and what you might learn in solid state physics.

So, it it sort of bridges that gap between engineering physics and so on so this is what we did in the last class this is our second class that we will start getting into some of the details that we are that we mentioned in the previous class and begin our exploration of this material so with these words of introduction let us get started

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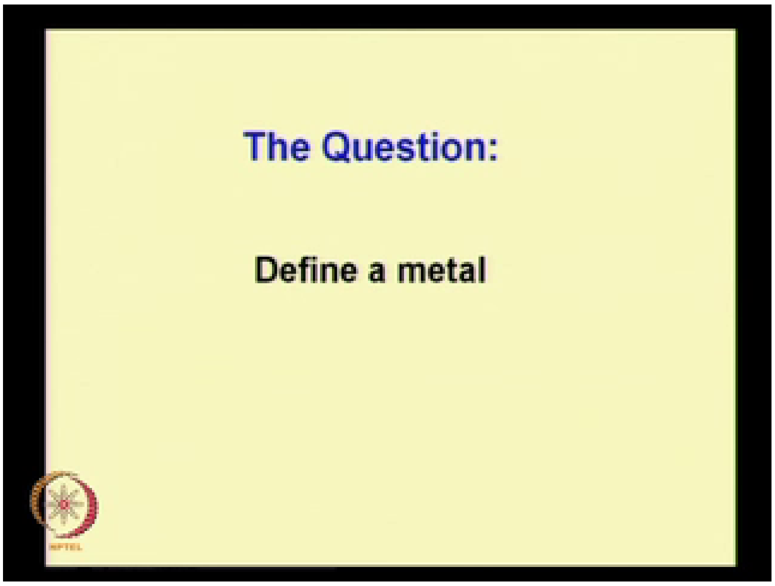

So, I think it is of interest to actually step back and this question which is, define a metal. So, this is a question that I would like you to spend some time thinking about the reason being, it throws up it tells you a lot about how you think about things.

So,, sometimes you intuitively know some information and you have never been asked to put it down in words and therefore, even though you know it if you are actually asked that information you may find it difficult to express yourself. So, when a question is framed saying, what is a metal or define a metal. You often find that the answer was not immediately clear. In other words, if I asked you to go and look up a definition for a metal you would find it difficult to find a definition; in fact this is not just true with metal source.

If I ask you any other material also ask you to specifically define it sometimes, in some cases the definition is possible in many cases you may find the definition is a difficult to get in a clear cut manner. So, and particularly so with the case of metals that if you are asked to define it it is a bit difficult to define. And again you may think that, that is not right you already know so many things about metals and that is the point I wish to highlight the fact is that you know a lot of things about a metal but, there is no formal definition for a metal.

And in fact to go back to the question the you may start by answering saying that it is a good conductor of electricity, it is a good conductor of heat and it reacts gets oxidized if it reacts in an oxidizing environment, it has very good mechanical properties it is ductile you can make sheets out of it you can roll it you can draw wires out of it and so on. There are many things you can but, none of these sentences individually defines the metal. If you just say that it is a good conductor of electricity that does not define a metal that is not the definition of a metal. So, there are lot of things about a metal that you know but, you have a difficulty in actually defining it.

Ok, so and so having explored it this much, I would like you to reconsider the question. So, the question we asked is, define a metal. In fact in a in a roundabout way you have answered it right, the correct the the point I wish to highlight is that this kind of a question is perhaps misleadingly stated. I have deliberately stated this question in a misleading manner just to highlight certain aspects of how we think and what materials around us are. In in a in a strict sense there is no formal definition for a metal, and which is true for most other materials. What always happens is we have we have properties that we are aware of, we are aware that materials around us have properties and over the years we have formally defined this properties, we know how to test for those properties, we have specific formal test for those properties, we know how to quantify many of those properties and we know how to relatively compare those properties.

So, in most cases, when you look at a material a new material that is given to you an unknown material that is given to you, you do not just look up a definition and then see if this fits that definition. It does not work that way in fact, what you do is you actually examine its properties you determine its properties. So, an unknown material of for which you have no idea what it is and no other information is given to you it is just some mystery material that is been given to you, the process that you would follow is you would determine its properties. Once you determine its properties range of properties you would then compare with established literature and established databases and knowledge bases and even your own experience and see where these properties relative to properties of other materials ok.

So, it is in this process of comparison of material properties with an unknown materials properties with that of known materials that you eventually come up with a classification for that material. So, this unknown material if it happens to have a certain level of thermal conductivity, a certain level of electrical conductivity, specific kinds of chemical reactivity, specific mechanical property. So, you just come up with this set of values you compare against what a typical metal might display a typical ceramic might display and so on, and then you find that in fact it shows vastly more of the characteristics of a particular kind of material say in this case it happens to be a metal, it shows more of the characteristics of a metal and then therefore, you define it as a metal ok. So, that is how you define something as being a metal. The reason I say this, is for a number of reasons actually; one of course as I mentioned I wanted you to become alert to the way in which we think about materials the way in which we consider them and evaluate them.

And more importantly, I want you to understand that often a material which is classified as something say, it is classified as a gas or it is classified as a liquid or some such thing some or it is classified as a polymer, some some specific classification you have given it. The same material under drastically different circumstances may behave more like an, other material ok. So, you could have something that you would normally classify as a gas but, under hypothetically under certain extreme conditions it may show you many of the characteristics of a metal ok. So, so you need to understand this so that so when you when we specify certain things we are often taking other things for granted ok.

So, for example, many of the test where, even when I said you know you evaluate its properties and then you compare and then you make a decision whether it is a metal or a ceramic or whatever it is; the unstated information there is that often these test are conducted at room temperature and pressure, so often this is the case. So, you are often running it under some control conditions which are mostly at room temperature and pressure the very same material at extremely high pressures or extremely high temperatures or extremely low temperatures may behave very different ok. So, we have a lot of examples of materials which behave I mean several orders of magnitude different in a particular property when the conditions under which they are tested are changed.

So, it is very important to understand that when we talk of a material and certainly in this case we happen to be talking of the metal we are only looking at properties and the classification of that material into that particular category is only based on the properties it is displaying under the conditions it has been tested. So, this is the important aspect and a great example I will tell you is that certain materials which are ceramic materials under other conditions actually behave as super conductors. So, they show you diametrically opposite properties simply because the condition under which they have been tested has been changed.

So, so any assumption we make some many times we read in books and we also have some general ideas that a certain material behaves only in a certain way we need to be careful and realize that there are boundaries for all of those definitions, there are boundaries within with that kind of an information is ok and if you cross those boundaries the information changes. We also need to recognize that as our discovery of materials keeps going up as we create more and more synthetic materials we create a variety of materials which show you properties which would mimic different kinds of materials simultaneously. So, you you may see something that is highly conducting but, may have certain other properties which may make it look like a ceramic. So, so you have a lot of mixture of properties that is possible; so our own definitions then start getting blurred our own understandings starts getting blurred, but we need to understand that we can step back and we can look at old fashion classical materials that we are more comfortable with old well known materials from the past and we can specify that certain things are more metallic certain things are more ceramic and and so on ok.

So, this is the issue about how we define materials and so on incidentally having come so far about material properties and materials definition perhaps the one property that is most uniquely identified with a metal is its, is the behaviour of its thermal resistivity as a function of temperature ok. Metals are usually identified as those materials which have a positive coefficient of thermal resistivity ok. In other words, if you raise the temperature its resistance will go up ok. So, if you measure electrical resistance of a material you raise its temperature its resistance will go up, typically that behaviour is associated only with metallic materials.

If you look at, there are other conductors see when we talk of conduction itself we have a variety of different conductors; we have electronic conductors, we have ionic conductors and so on. The, when we talk of an ionic conductor actually the behaviour is different from that of a metallic conductor and we will explore this in greater detail later but, the point is that in those cases when you raise the temperature the conductivity actually improves ok. So, so this is very distinctly different from what you see in a metal. So, hence our that is these are all the reasons why I wanted you to consider and examine this question in considerable detail and the question being define a metal

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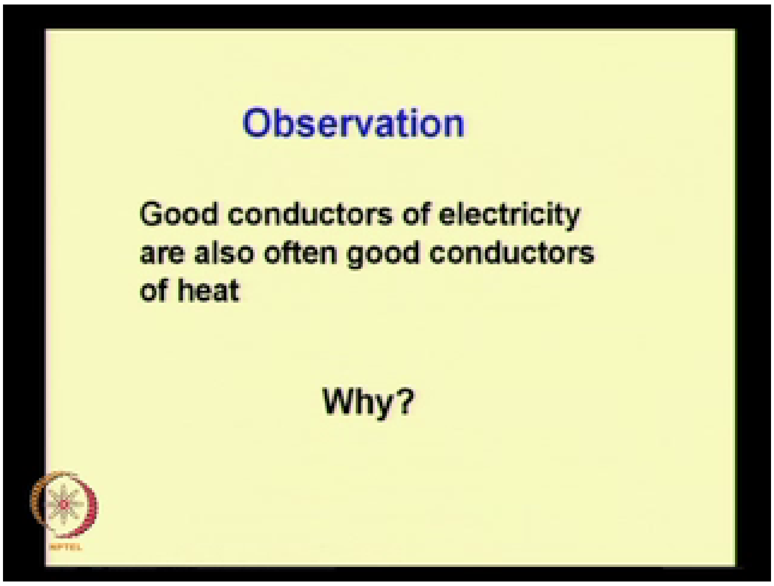

So, having done this definition having discussed this at such length, I would like you to also consider another observation. The observation is that often materials that are good conductors of electricity are also good conductors of heat ok. So, this is often the case, in fact when you talk of metal and you are asked for its properties you will automatically say these things; you will say that it is a good conductor of electricity, it is a good conductor of heat. You may never have asked yourself why that is the case that if it is a good conductor of electricity it is also a good conductor of heat.

So, what we realise is that when you see this kind of a correlation of property when you see that something that is a good conductor of electricity apparently also happens to be a good conductor of heat we would like to ask ourselves why, why is this the case. More importantly we would like to at least figure out for ourselves from an understanding perspective, whether or not this coincidence happens to be purely a coincidence is it just an accident that something that was the good conductor of electricity is also a good conductor of heat or is there something more fundamental. In other words, in that material is there something more fundamental about how the process of conduction occurs in that material that enables something, which is a good conductor of electricity to also become a good conductor of heat ok.

So, these are our understanding of such a more fundamental understanding of this nature really helps us take make better use of those materials we can take advantage of characteristics of those materials and use it. So, I have just highlighted one combination which happens to be this electrical conductivity and thermal conductivity of typically of metals but, if you actually examine lot of materials you may find other combinations of properties which may coexist in a material. Not simply by action but, due to some specific fundamental reason of how the constituents of the material behave that those properties happened to have some co-relation ok. So, so, so far you have tended to passively look at material properties what I encourage you to do is to re examine all your knowledge of the material properties and see if there is more to it than just independently knowing that something happens to be a good conductor of heat, something happens to be a good conductor of electricity, something has high resistivity something has good optical properties and so on. So, we would like to look more and more into these correlations so this is the reason why I wish to highlight this observation.

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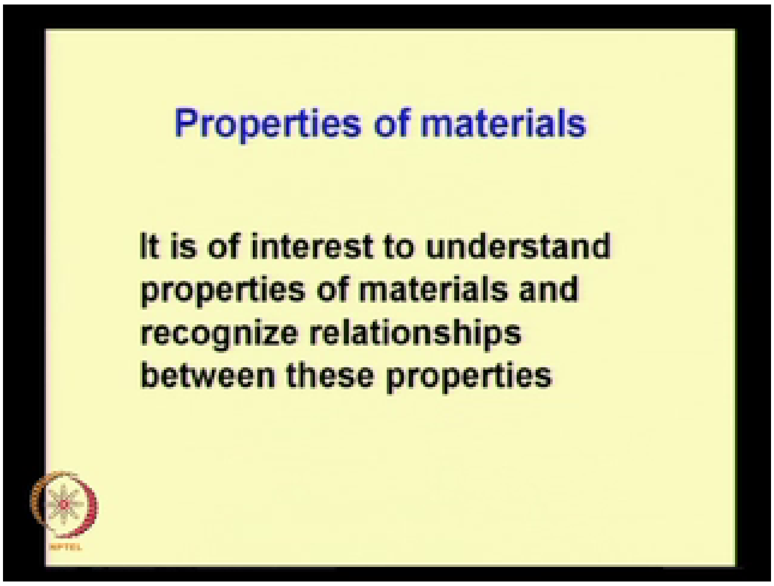

So, it is therefore of interest to understand properties of materials not merely know the property of the material which is probably what you have traditionally done so for you are aware of the material properties and you are able to state them you are able to give values to them and so on but, we would like to go a step further in this course and which is to understand the material properties and to recognize the relationship between the properties.

So, these are two things that we would like to increase our we would like to have better for what the material properties are where they are coming from what is the fundamental reason for that material to have that property and in that process, see if we are able to independently get this information for a variety of properties we would also like to get a better feel for how those properties are relating to each other and what are those common things about though the manner in which those properties manifest themselves that enables them to get related to each other. So, this is the kind of understanding and depth of information and knowledge that we would like to aspire.

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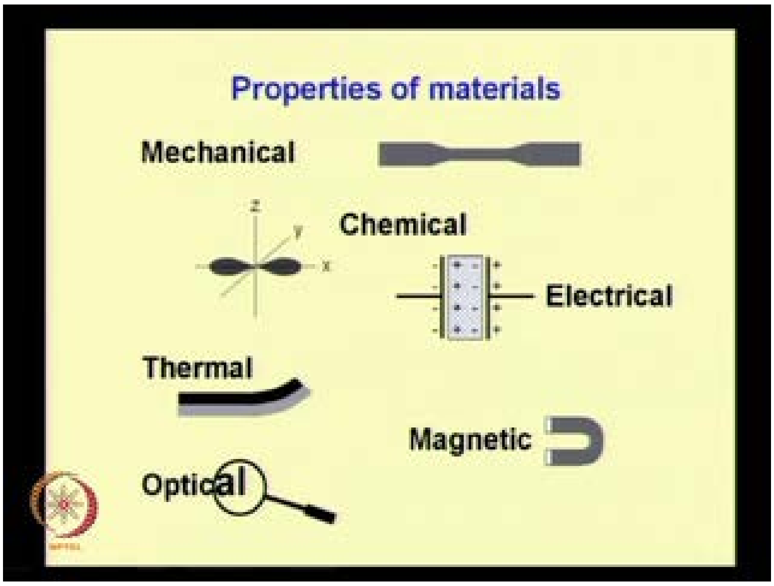

So, as I mentioned you may already be very well aware, when we talk of material properties there are a variety of properties that we are interested in looking at and we tend to commonly get values for. The most common ones that we tend to encounter in an industrial sense for most manufacturing purposes are mechanical properties ok. So, certainly for metallurgical engineering students and materials engineering students most of the properties that we tend to handle with respect to manufacturing a product happen to be mechanical properties. So, many of the consumer goods that we buy at some level its mechanical properties very important to us because at the very least the mechanical properties tell tell us how much of structural integrity that good or item that you are buying will have ok.

So, therefore, mechanical properties form fairly common base of information that you would like to know of any material that you encounter then there are chemical properties we will look at these in more detail but, in principle this is just the overview of those properties we have chemical properties which can be looked at a variety of levels. At a more superficial level we would just like to know what reacts with what under what circumstances because that again decides where you can use the material where you cannot use the material and what are the limits that you will place on the material because any material you buy they often give you; if nothing else you know even it is a normal household appliance that you buy, they will often tell you something about the care that you should take of that appliance ok. So, the kinds of things you should do with it the kinds of things you should not do with it and they will tell you not to wash it with certain types of cleaning fluids or to wash it with certain types of cleaning fluids and so on that comes from the reactivity of that material.

So, so therefore, they have already done some tests and they know that certain types of cleaning agents will actually damage that surface and therefore they tell you upfront do not use those cleaning agents even though those cleaning agents are commonly available ok. So, that is how on a day to day basis we become aware of the chemical reactivity of materials even though it is not formally mentioned as chemical reactivity in a household appliance, it is simply given to you as a general care instruction ok. So, so that is how we see it but actually if you wish to get to the science of it that is what it is it is all the chemical reactions that the material will undergo given the various environments that you can place it in.

We are also, if you wish to know it in greater detail we would also like to know the inner workings of those atoms and molecules present inside that material. In particular we would like to know about the bonds the orbitals present there and so on. So, that is the kind of information we look at when you looking at the chemical properties of materials. Electrical properties again wide range of properties almost any equipment we use these days has some amount of electricity involved in in its operation. The components in it use electricity, the characteristics they display are critically related to their electrical properties and the device itself is designed to utilise those properties and give you a certain kind of response based on what you input into the device ok.

So, again and the other property we are interested in is thermal properties. Thermal properties we look at from a wide range of perspectives there are places where we are using a thermal property of a material without necessarily consciously realizing that we using it; but there are other places like I have shown you an example of a bimetallic strip, where specifically specific thermal properties have been utilized to get that strip to operate to your satisfaction ok.

So, similarly, for electrical properties I have just shown you an example of how you would use a capacitance and what it would do. So, these are specific instances of these properties being put to use.

Then we have magnetic properties and again many for example, most of the household I mean stereo systems will have some magnets in them, our fans have magnets in them. So, there are various places we use it we will examine it little greater detail later in this class. Optical properties also, I mean anything that we I mean most of our straight forward things like you know even the glasses that we wear and so on are really based on optical properties but, there are lot of sophisticated places where the optical property becomes critical. And this includes from in all these cases we are looking at instances of these properties being used or being put to use or being taken advantage of from very mundane day to day objects to really high, highly sophisticated equipment and objects.

So, when you look at you know you you have a satellite in space satellite in space is also operating by taking advantage or keeping in track keeping within limits of all the properties that the materials that went into making that satellite are capable of withstanding ok. So, everything in space you have a very high thermal gradient between the side of the space craft that faces the sun and the side of the space craft that is in the shadow ok.

So, just that so there is a distinct difference in temperature between these two sides of the space craft so the material in the space craft, what is inside has to be protected from these thermal gradients so what is outside should shield it. So, there we are using that property sometimes that shielding is again done using variety of means part of it may be simply reflecting away some of that sun light there we are taking advantage of optical properties and then we provide we make use of that the shield some of the radiation going in and then we use other thermal properties like low thermal conductivity to prevent the heat from going.

So, variety of things are done in such a sophisticated piece of equipment or instrument that is out in space even something that is very sophisticated and deep sea like a submarine will have highly sophisticated equipment which are all utilizing these properties.

So, in that sense from mundane things to household appliances, to highly sophisticated equipment that you buy; you will see all of these properties been taken advantage of being utilized being manipulated and deployed ok. So, we will look at this in greater detail in the next few slides.

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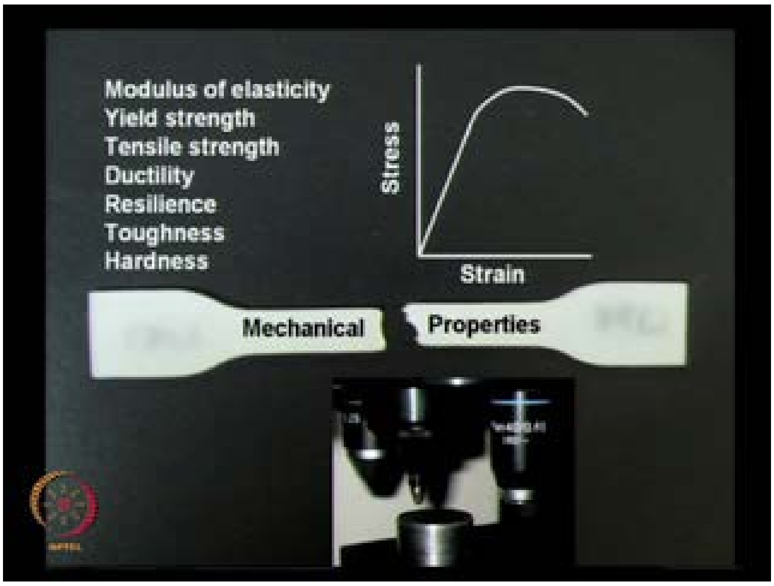

So, when we talk of mechanical properties, the as you see on your slide we have a tensile tested specimen so there are very specific ways in which we evaluate mechanical properties. So, we have a tensile tested specimen so it has a certain shape it we obtain a stress strain curve from it and this curve is obtained till it fractures and we have a schematic of a stress strain curve that I have shown on your slide. So, from this schematic we can actually get lots of properties out of it.

So, for example, the modulus of elasticity would be simply the slope of this of the linear region of the stress strain curve; so there is a certain linear region in the initial part of the stress strain curve there you get get the slope and that gives you the modulus of elasticity. The yield strength is simply that strength or the stress which corresponds to that value at which the linear region just about ends and the non-linear region begins ok. So, at just at the end of this linear region you have a strength corresponding to it and that is the yield strength.

The maximum of this curve the highest point in this curve corresponds to the tensile strength of this material that is the maximum stress it can take before it can fail. Ductility is the extent to which this material can elongate. So, in other words if you look at the strain if you look at the total elongation that it can or the percentage of elongation that it can undergo before it completely fails or fractures, that is a measure of ductility of that material.

Resilience is the energy that it will observe and still stay within its elastic deformation regime so in other words it is the area under the stress strain curve up to the yield point yield strength yield point, so that is the resilience of the material.

And toughness is the general is in general is the total energy that it will absorb to failure ok. So, in a sense it sort of the overall area under the curve of the entire stress strain curve. And finally, in the insight you see a small picture of an indentation machine you actually see a small sample here and then there is an indenter here. So, this is the kind of system that you would use to determine the hardness of the material, wherein the hardness of the material is simply its ability to resist local deformation often attempted using an intender or even if there were an abrasier so the harder the material the more it can resist abrasive action by any abrasive that comes on.

So, these are a range of mechanical properties so what we need to understand is that these mechanical properties even though we measure them in a macroscopic sense ok. So, we have a sample that you can actually hold in your hand and that is the sample that you go and mount on a equipment which you can see and you you under you carry out the test and you note down these properties. But, what is also true is that these properties have not independently arrived in the macroscopic sense. They are a result of something that is existing in a microscopic sense; so in other wards more specifically if the bonding between the atoms present in that material is very strong, then you tend to see correspondingly some of these strength values going up ok. So, but not necessarily the toughness but, certainly the strength goes up.

So, in that sense something about the bonding reflects on the strength something about the crystal structure, which then tells you things like the slip planes and slip direction and slips system and so on; that gives you an idea of how easily the material will deform when it is in the plastic regime and so on. So, therefore, there is will I mean there are elaborate classes available on just the mechanical properties courses available on mechanical properties. This is just give you gist of what you are really dealing with, what I wish to highlight is that there are lot of things occurring at the atomic level and the crystal structure level which then reflect directly on the mechanical properties that you measure ok. So, so therefore, we now see that something you measure macroscopically is associated with something that you see at an atomic level so that is what I wish to highlight in our discussion on mechanical properties.

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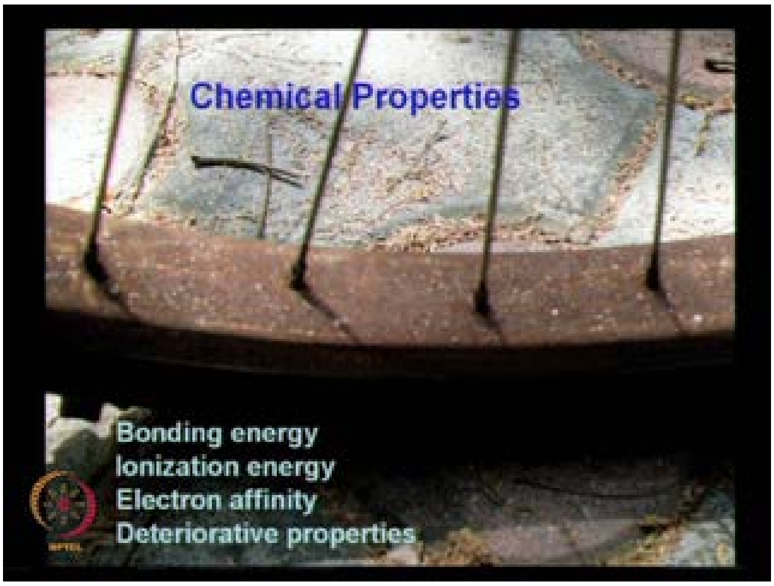

Then there are chemical properties ok. So, chemical properties at front we know that it is we are intuitively we are aware that it is something to do with the chemical reactivity at an atomic level ok. So, this is something that we are very comfortable with this is what we understand of the chemical behaviour of of some material ok.

So, already we see that something, the mechanical properties related to something at an atomic level and chemical properties we know upfront relates to something at the atomic level and again things like bonding energy which would again represent the strength of the bond between two adjoining atoms, is a direct reflection of will give you some idea of how it will react under various circumstances. So, from chemical property perspective we look at ionization energy, we look at electron affinity and so on; there we know move to sub atomic level ok. So, we start with something that an is under atomic level then we would like to see how easy it is to remove an electron from this atom or how easy it is to add an electron to this atom. Now this ability to remove or add an electron then reflects on how easy it is to oxidize the material or reduce the material so and therefore, a reflection of the reactivity of this material ok.

So, therefore, we see that chemical reactivity goes down to what is what is happening at the atomic level and that this atomic level and this reflect itself in a engineering sense in the presence of its deteriorative properties ok. So, as you see on your slide you see the rim of a bicycle, rim of a bicycle wheel that is corroded so this is the common site in various places you will see it and what you see corrosion is an electro chemical reaction. So, it false under the broad category of the chemical behaviour of the material but, more specifically it is a electro chemical behaviour at least where corrosion the way you see it here. And therefore, you see another property that you would measure which is the deteriorative properties of the materials which relates to the electronic structure of the material, the way in which the bonding exist between the material and and so on.

So, already we see; we begin to see that there are reasons why properties need to be are likely to be related to each other or likely to show you some connections when you examine them more closely.

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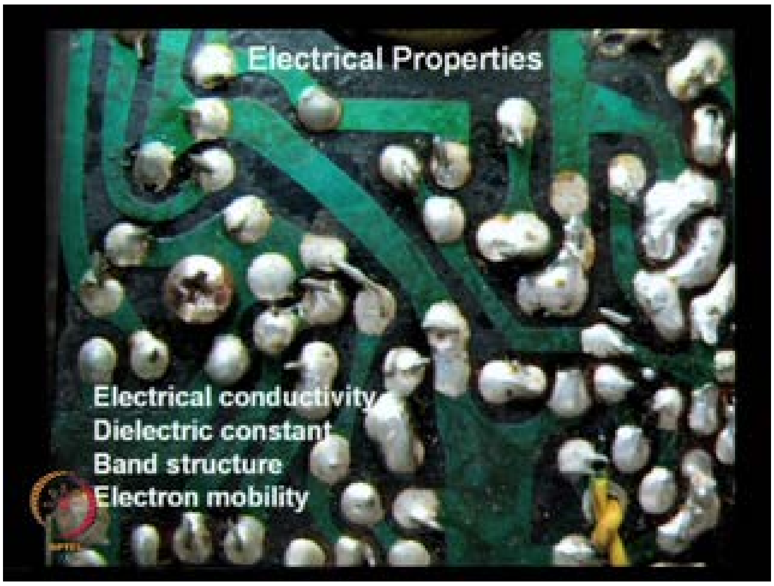

The next we have most commonly that we tend to encounter one of the more commonly encountered properties that we would we examine are the electrical properties. So, when we talk of electrical properties the property that we most commonly measure is electrical conductivity ok. More in a more general sense it is conductivity that we measure and the reason I say that is because when we talk of conductivity we are simply talking of the transport of charge ok. So, the, there are different ways in which the charge could be transported more specifically there are different carriers of the charge you can carry that charge using different species and based on which species is carrying the charge you you more specifically say that it is conductivity related to that species.

So, for example, we could say ionic conductivity in which case we have, that is a different kind of a material we would use that in fact in places for example, normally when you go to an the many of the automobiles these days have what are called oxygen sensors and a typical design for an oxygen sensor uses a material which can conduct oxygen ions so that is typically how those devices work.

But, we also conventionally when we say electrical conductivity we are talking of transport of electrons so that is the more conventional way in which we have thought of conductivity but, these are and I the reason I wanted you to understand the we have think of conductivity in a more general sense, is because if you simply look at conductivity values you cannot just link up two materials because, in one case the charge may be carried by an electron and in another case it may be carried by ion and so you simply cannot build a circuit by just connecting up different materials simply based on conductivity values ok. So, you need to understand the circumstances under which those ions will move, to what degree they will move, would you need a supply of gases on either side to continue that ionic conductivity to sustain the ionic conductivity or will it simply build up charge and halt the conduction process.

So, these are things that are specific that you need to figure out for that particular material so electrical conductivity is a very fundamental electrical property that we tend to find determine. But there are other properties such as dielectric constant and this would be very important property for you to figure out for various electronic circuit usages then there is the band structure of the material ok.

So, band structure of the material is something that we are at least as you come off of high school you are aware that one way of looking at metallic materials is to look at the band structure ok. So, this is something that we are aware of but what we would like to examine more in this course in the later classes is, to get a feel for why there are bands in the material? What is the necessity for a band structure to come up, to exist in a material? What do we know of the material that tells us that, these are the reasons these are the kinds of constraints within which the material has to behave and as a result of these constraints as a result of the interaction of the constituents of those materials with and their attempt to stay within these constraints that the bands evolve.

So, this is the kind of understanding that we would like to generate out of or look at these materials. And one of the other properties you would look at is electron mobility which directly in fact again mobility is a more general term it simply represents the ease with which a particular species in this case an electron will move when it is subject to some driving force ok. So, you subject it to some driving force in this case an electric field and see the ease with which the electron would move which would be reflected in terms of the velocity of the electron in the presence of that field ok.

So, you apply a field the electron starts moving in response to that field, you find out what is the velocity of that electron and that gives you a sense of how easy it ist for the electron to move you put all these information together you get what we call as the mobility of the electron; and as I mentioned mobility is a more general term we also talk of mobility of diffusing species when when you are talking of diffusional processes. So, these are terms again it reflects the fact that many of the phenomena that we see have similarities and that is why some of the terminology that we use for for something that is occurring at a sub atomic scale in a at an electronic level is the same kind of terminology that we would use at something that is occurring at a atomic scale in this case a diffusional process ok.

So, so that there itself you see the there is some interrelationship between various scales of phenomena and various scales of the material process so these are some electrical properties incidentally in the background of the slide you do see part of a circuit and there this is I have deliberately chosen a very old circuit to give you both view of a circuit in the background plus also show you that this circuit is actually corroding. So, you can see various spots of corrosion in it and so you already see chemical deterioration or electro chemical deterioration of this material occurring so it would always be of interest for when you wish to estimate the lifetime of a product for you to understand what level of corrosion will, particular device that you make handle ok.

In other words you make a device or equipment and it has to perform certain activities you would like to see how long it can perform those activities under the conditions that it is designed for and no matter what the conditions slowly ever so slowly the materials will start degradation degrading unless you have taken you know under unless it is under very special circumstances typically normal day to day use the materials will degrade. So, you would like to estimate how much of degradation can occur before the degradation then impacts other properties of the material the such that it no longer carries out the performance that you are expecting from it or delivers the performance that you expecting from it.

So, therefore, again you wish to know how when this properties relate to each other.

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We are also interested in thermal properties of materials and I mentioned right at the beginning we find that good conductors of electricity also happen to be good conductors of heat in many cases and in this case for example, you see a big earth moving type of equipment which is seated in a extremely cold weather.

So, we would like to look at all those properties so if you are interested in thermal expansion or thermal contraction in this case one when you attempt to turn on this equipment there will be parts of the equipment which will be quite hot there will be parts of the equipment which will be very cold. It could be minus thirty degree c centigrade outside it could be close to thousand degree c somewhere inside that may inside that equipment machinery. And so how well will it handle this temperature gradient; will things expand in such a way that they cannot carry out their performance, will parts of the of this equipment go out of scale with respect to other parts which are holding them in place simply because they are at two different temperatures. So, these are all questions that are of interest. So, thermal expansion the expansion of materials as a result of change in temperature is something that we are interested in this again relates to what kind of strength the bonds of those materials have in the atoms of those materials have and what is that specific behaviour of the atoms as a response to temperature

In fact we will later see that simply raising the temperature of material does not guarantee significant thermal expansion we would like we will we will examine why certain materials expand significantly when you raise the temperature while certain other materials barely expand when you raise the temperature for the same temperature gradient ok. So, this relates to something that is occurring at the atomic scale which reflects again in all the other properties such as mechanical properties and so on; it will also relate the thermal conductivity which is the other thermal property that we are interested in relates to something that may be occurring both at the atomic scale as well as at the sub atomic scale in in the sense in the sense of electron in electrons present in the material.

So, you will see the thermal expansion occurring due to something at the atomic scale thermal conductivity occurring based on something that is occurring both at the atomic scale as well as the electronic scale or the sub atomic scale and specific heat again something that depends on phenomena occurring at the atomic scale as well as at the electron level so these are all various properties that we associate as thermal properties and they all relate to something occurring at to the constituents of the material which again reflects itself in properties which are other than thermal properties.

So, therefore, we begin to see there are reasons why these things should be related to each other.

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Then we have magnetic properties we utilize magnetic properties fairly routinely it has been known in fact magnets were known long before people understood what magnetism was was and why it occurred. There are various things that we look at for example, curie temperature we look at the transition between ferromagnetic behaviour and paramagnetic behaviour and the temperature at which it occurs.

We would like to see how the material behaves when you apply a magnetic field on the material and you see what kind of induction occurs in the material and in this relationship we see parameters such as remanence coercivity and so on; and based on the kinds of hysteresis that these material these materials display, we have we have definitions such as soft magnetic materials and hard magnetic materials and so on.

So, these are all magnetic properties our understandings shows us that this occurring due to phenomena that are occurring at the electronic level the kinds of theories required for it are relatively sophisticated we will see to some degree what what are the issues involved in it. Of course, a common common places where we use it as I mentioned I mean as you see on your slide, is for example a compass that you would use for finding the directions but, many common household appliances speakers in stereo systems fans and so on routinely use magnets. So, it is a very integral part of many of the equipment that we use and in fact as a result depending on the proximity physical proximity of equipment between one another you need to ensure that there is some shielding if you do not have shielding then you can have one equipment affect the other a specifically in fact if you get a very high quality audio systems and you keep them next to television the c r t based cathode ray tube based televisions you can have the adverse impact of the magnetic fields on the overall picture quality and so on. So, therefore, you you get what are called you have to get speakers that are magnetic shielded magnetically shielded and and so on.

So, this is these are some of these things that you we need to look at when you look at magnetic properties there are other places in in for example, in medical field where we use very strong magnets. So, when you are doing specific scans which are done these days where they are looking at magnetic they are taking advantage of magnetic behaviour to identify specific aspects of how persons body is, they are using very high magnetic fields. So, this is something we will examine more when we look at superconductivity and associated magnetic behaviour and that is what we will look at

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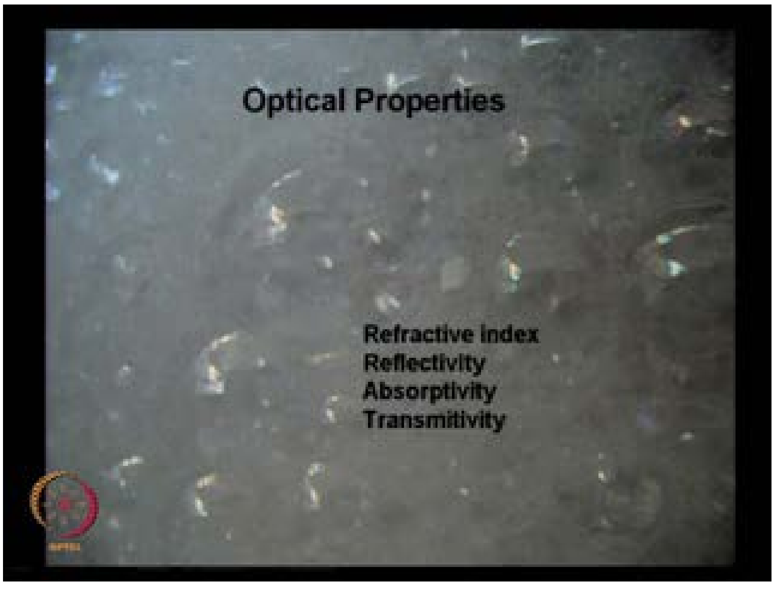

Optical properties well a variety of places we utilize optical properties we use films often to I mean the simple film that we use for protecting our ourselves when we are inside a vehicle from the sun that is out there sun control films, they are all directly utilising optical properties for you. Reflectivity, absorptivity, transmitivity, these are all things that we are directly or indirectly using whenever we are using any sun control film. Many times the fundamental principle or phenomenon that we are utilizing in terms of optical properties is the refractive index and so that is again something that relates to how the behaviour is of that material responses of that material to light.

In terms of how it relates to structure and such; if you can you may you will definitely be aware that something if you take carbon if you take it in the form of graphite it is opaque if you take it in the form of diamond, it is transparent. So, it turns out that this is got directly to do with electronic structure of that material and and how those electrons what kinds of energy levels those electrons can occupy and so on. And therefore, the optical property is seen to be directly related to the electronic structure which we will see in greater detail later but, as you have already seen the optical property the electronic structure also has a direct impact on the electronic properties itself like electrical conductivity even any semi conducting behaviour that the material shows ok. So, therefore, you can see as it is that there is there is reason now since both these properties depend on essentially the same structure of material same structure and also at the same level meaning in this case is sub atomic level; there is there are there can be reasons where these properties might interact with each other ok.

So, when you see photo electric effect when you see other phenomena there there are reasons why these properties can interact with each other.

So, in this case for example, in your background of this slide you see soap bubbles. So, there you can see all the intricacies of how light is interacting with this material and various interfaces that are involved and so on. All these properties are of course, made use of extensively are studied extensively and controlled in in manner that they can, when you look at high end photographic equipment ok.

So, if you if you see you can easily make lenses even at home by simply taking some spherical surface and filling it up with water some spherical transparent surface which can be filled with water you will see a lens of significant power.

Now the point is, there is a world of a difference between that lens and lens that say a sophisticated microscope uses or optical microscope uses or the lens that is there in a sophisticated camera. A lot of that is sophistication comes from the kinds of films the use on the lenses, those films there are very special films that are used which ensure that there are no undue additional reflections because light passes through those various interfaces ok.

So, there is a lot of matching of the refractive indices and so on there is that is to be ensured so that we when you actually finally take the image it is the crystal clean image of whatever it is that you are looking at ok. So, that is a technology where all of these optical properties are brought together and brought together in a very nice seamless manner, so that when you utilize the equipment you do not realize that you are having an optical system that is that has so much sophistication in it. And only when you compare with a very ordinary untreated specie of glass lens that you might find some where do you realize the difference between a well-made sophisticated lens and something that is easily available and the amount of science and understanding that has gone into it

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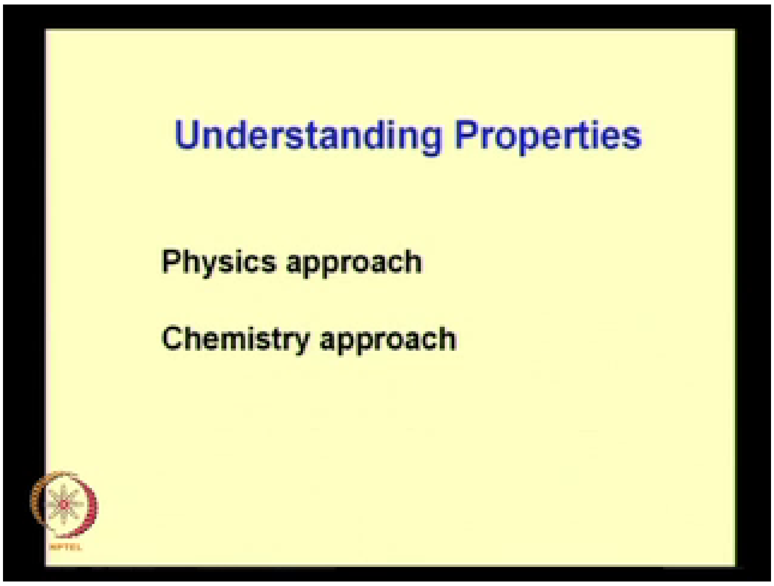

Ok, so we have now seen a variety of properties; we have seen mechanical properties, we have seen thermal properties, electrical properties, magnetic properties, chemical properties and optical properties; a variety of properties. I have tried to bring out the fact that all these properties relate to something occurring at atomic levels crystal structure levels atomic levels sub atomic levels and so on. And and therefore, the fact that it is not surprising that many of these properties tend to impact each other or that trends in one property may imply trends in another property which may show up in some cases more dramatically and may not show up in some cases that dramatically and so on.

So, these are all things that relate to each other ok. So, that is something that we have I have to tried to bring out what I would also additionally like to point out is that, all these properties can be understood if if we go deeper and deeper into the science of how the constituents of the material behave and how they interact with each other and in this case I just wanted to highlight the fact that if you look at physics books versus chemistry books dealing with more or less this same kind of properties, one one difference that you may see is that in in physics books you tend to talk of bands you talk of bands structure and so on in in chemistry base books you talk in terms of molecular orbitals atomic orbitals molecular orbitals and so on and in specifically for example, they would talk of lowest unoccupied molecular orbital or highest occupied molecular orbital and so on.

These are all different ways of viewing the same piece of information, so that is something I wish to highlight so when you read a physics based book and you try to understand some material properties and later you read a chemistry based book you may find the terminology used being different but, in in reality all it is is that there are constituents of a material they have a show they show as certain behaviour and these are simply ways in which we are trying to examine those constituents understand those constituents and understand their behaviour.

So, we may be using slightly different language but, we often are referring to the same parameter same parameter same characteristic and so on and so there is a direct correlation between these two. So, you can understand the properties starting from a chemistry base and you can understand them from a physics base and they will be roughly the same; they should you re final analysis should bringing out bring the same results out regardless of how you start. So, therefore, there is no reason for alarm; if you see that the, it is not like teaching is something different it is a same thing just different way of stating the same thing.

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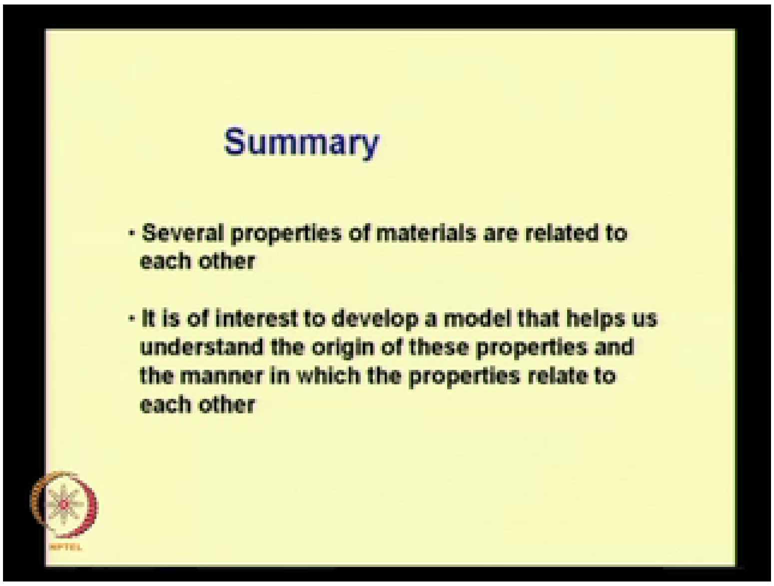

So, in summary we find that there are several properties of materials that are related to each other very intricately and which is something that we have seen now and it is of interest for us to improve our understanding of the materials, it is of interest to us to develop a model or a set of models that we helps us understand the origin of these properties and also understand the manner in which these properties relate to each other ok. So, we would to deepen our understanding of this whole material science and engineering field we would like to develop those models that helps us see that if we start from certain such constituents and you assign certain properties to them that we are aware of that they have.

Then you can see that how how is it that those constituents come together and develop into the overall material property that you actually examine and evaluate and record in macroscopic state and you also get to understand how those properties relate to each other and so that you can understand why the correlation is there between say thermal conductivity and electrical conductivity.

So, this is the kind of information that we are after and we will we will explore in much greater detail in the subsequent classes in the upcoming classes we will start developing models for materials that this will be the goal of it this will be the ultimate goal. In each case as I mentioned we will if necessary take a tangent to get us the tools a quite develop the model, then we develop the model see how well it helps us address this question these questions that we have raised here and where it fails we will recognize what is the extent of failure and then try to improve our model. So, this is the general approach we will take and as we by the time we get on we can except to have the understanding that we see. So, with that we will conclude this class and we will take it up in the next class.