ENGINEERING GEOLOGY

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LECTURE - 6

Crystallography and Optical Properties of Minerals

Hello every one and welcome to lesson 3.2 of engineering geology. Today's topic is crystallography and optical properties of minerals.

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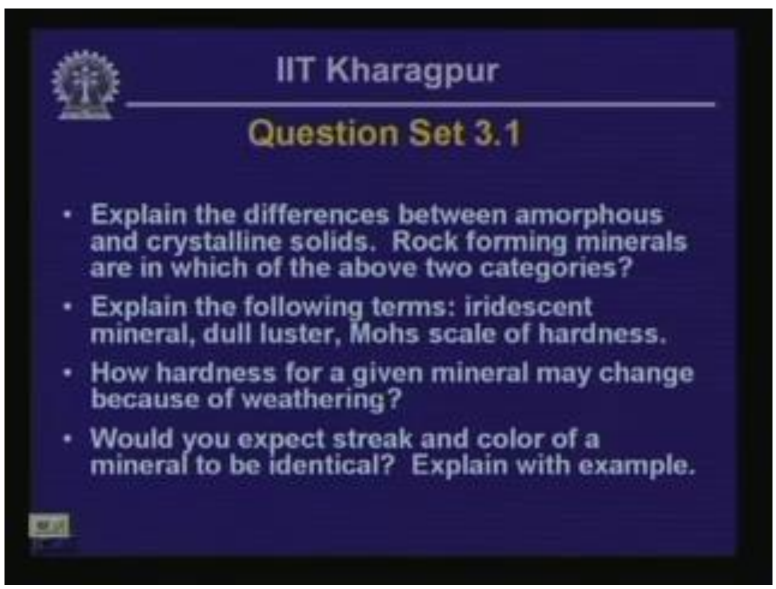

As usual, we are going to begin with a discussion of the previous lesson's question set. The first question that I asked last time around when we met was, I asked for an explanation of the differences between amorphous and crystalline solids. Now, amorphous solids do not show any regular pattern of individual atoms that constitute the solid. On the other hand, crystalline solids have got a regular pattern of atomic structure, regular and repetitive pattern of atomic structure and this is the main difference, this is the difference actually, this is the essential difference between amorphous and crystalline solids. Now, rock forming minerals are in a sense, crystalline solids.

Second question that I asked was explanation of a few terms; the first one being iridescent mineral. Now, what is meant by iridescent mineral is that in minerals often time what happens; there are inclusions of refractive, inclusions that I have got different refractive index compared to the host material. As a result, what happens? There is a column I mean, the material actually shows rainbow like colour appearance, a play of colour really because of that difference in optical property.

Now, in contrast, we also talked about; in the previous lesson, we also talked about basically brilliance or play of colour and we also talked about a thing in which the colour of a material changes, of mineral changes. So, these two things are also because of interplay of refractive index within the different parts of the body of the mineral really but the type of the characteristic, the optical behavior is different in those two cases.

For instance, in case of a situation where play of colour is involved, like for instance, diamond, the mineral diamond in which you can see a play of colour; that one comes because of diffraction from within the crystal lattice. Whereas the other behavior in which a mineral changes colour, that is also called by the name labradorescence because labradorite is the mineral that actually exhibits that kind of property; that one is because of the optical behavior of a particular plain within different parts of the crystal structure that is called the twining plain. So, that is basically the difference between play of colour brilliance and iridescence.

Now the second part, second question, second part of this second question asked for an explanation of dull luster. Dull luster essentially is a non-metallic luster which gives a dull appearance as the name suggest of the mineral. Now, a good example of dull luster is the luster of a chalk, for instance. Then I asked as a part of this question itself, an explanation of Mohs scale of hardness.

Now, it is a comparative scale really that distinguishes hardness, surface hardness of different types of minerals. Now, I discussed this thing in detail in the last lesson but just to recapitulate what I said is that the mineral talc is basically the softest one and then we have got gypsum and then we have got calcite, then we have got fluorite and next comes apatite, next comes orthoclase, then comes quartz, next is topaz, then comes corundum and then comes diamond.

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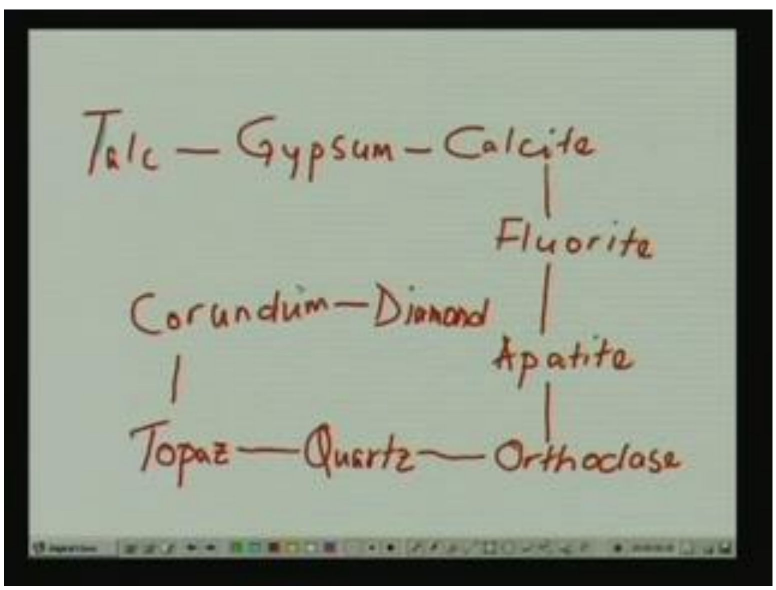

So, what is actually is a 10 point scale in which talc has got a value of 1 and diamond has got a value of 10. So, if there is a material for how to use this scale is like this; if there is a material which scratches gypsum but it does not scratch talc, then that particular, actually it scratches gypsum but it does not scratch calcite, then that particular material has got an hardness in between 2 and 3. So, that basically actually is the use of this particular scale and it gives you in relative terms, what is the surface hardness of a particular type of mineral. Reverting back to the question set the next question that I asked was how hardness for a given mineral may change because of weathering.

Now, hardness in terms of moh is actually a characteristic of mineral. Now, if because of weathering, a mineral changes its chemical characteristic or it changes from being one mineral to another mineral because of weathering effect, then for obvious reason, hardness will also change as a result. What normally happens is because of weathering, hardness actually most of the time decreases with time; that is not true always but it is a general or in general, that is what happens.

Now, the other question that I asked, the last one was whether you would expect streak and colour of a mineral to be identical. Now, streak and colour are two different characteristics as I explained in the last lesson. Now, streak is the color of a powdered mineral whereas color is that of the intact mineral. Now, these two things are distinct mineral property. I indicated this one in the last presentation itself that for instance, you consider the material, the mineral chromite and let us examine the colour of the streak and colour of the mineral itself.

The streak of chromite is brown whereas the mineral itself is black in colour. Consider another mineral, magnetite. For magnetite, both streak and colour are black. This actually, by the way streak, magnetite and chromatic, they are actually very similar in many different ways; the only way to distinguish these two minerals or one of the very few in which these two minerals can be distinguished easily from each other is by looking at the colour of the streak.

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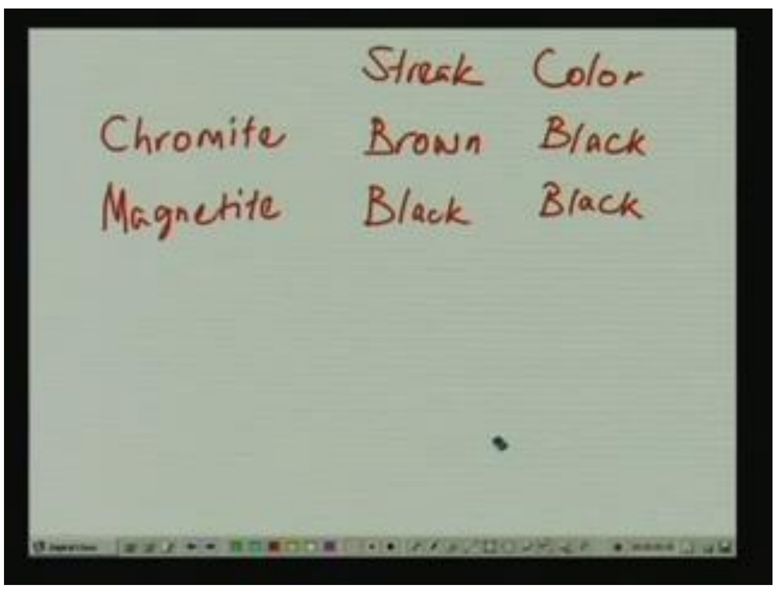

Streak of magnetite and chromite are different all though both the minerals are black in colour. So, that kind of gives you an example that streak and colour are two distinct mineralogical properties.

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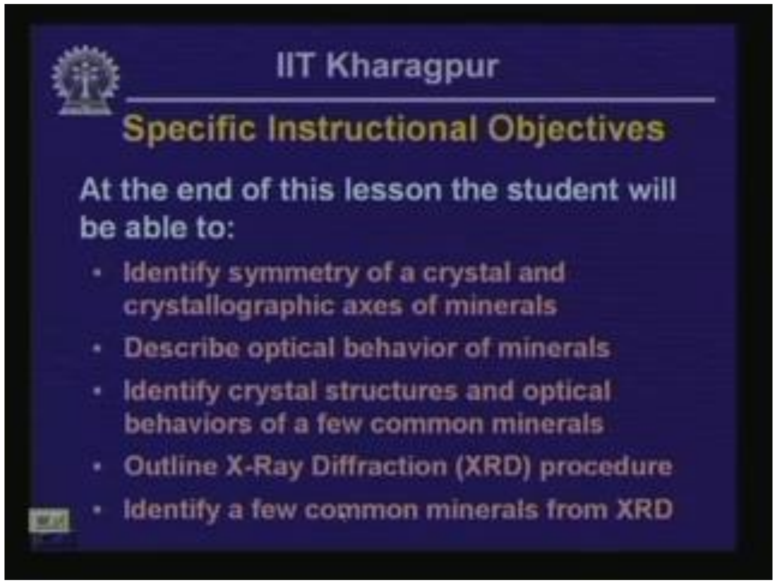

Now, with that set, let us get back to the core topic of this presentation. Now, what are the objectives of this particular lesson? In this particular lesson, we will be able to try to understand; what are the different types crystals, symmetry issues of crystals and crystallographic axes, we going able to describe optical behavior of minerals and distinguish one mineral from the other by looking at the different optical behaviors, then thirdly, we would like to identify the crystal structures and optical behavior of a few common minerals.

Fourthly, we are going to look at the procedure, essentials of the procedure of X-ray diffraction technique which is used to identify or distinguish one mineral from the other and again finally we are going to look at a few examples by which XRD can be used or X-ray diffraction could be used to find out to identify different minerals. So, these are the topics that we are going to cover in this presentation.

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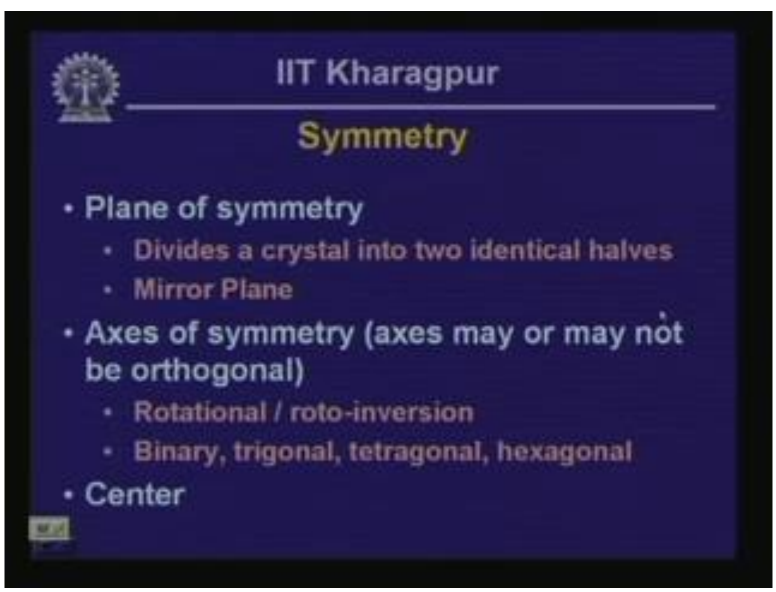

The first one we want to look at is what we mean by symmetry. Now, symmetry is essentially, symmetry essentially means that if for example, there could be planes of symmetry or there or axes of symmetry. Now, what is meant by plane of symmetry is that the two parts of a particular body that are on either side of that plane of symmetry, they are identical to each other, that is called the plane on symmetry. Now, axes of symmetry, how do you define it is that if you rotate the body about the axes of symmetry; patterns or identical physical appearance, they are going to repeat as the body rotates about that particular axes.

Now, that repetition could be, it generally occurs at discreet angles of rotation and in that way there could be several different ways of classifying symmetry. For example, we can have binary symmetry, trigonal symmetry, tetragonal symmetry, hexagonal symmetry and what it means by that is that in case of binary symmetry, if we rotate the mineral about the axes of symmetry, then an identical physical appearance is going to repeat after the mineral rotates by 180 degree.

In case of tetragonal symmetry on the other hand, identical pattern is going to repeat after every 90 degree rotation of the mineral, whereas hexagonal symmetry involves repetition of the pattern after every 60 degree rotation. So, you can see that in case of hexagonal symmetry, there is a six fold similarity if you consider a particular cross section. We are going to look at the details of these categories as we progress with the presentation of this lesson.

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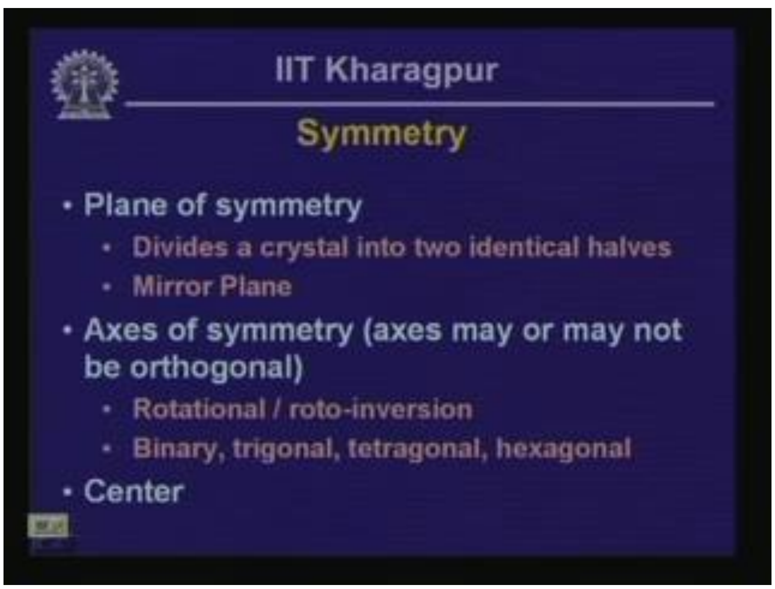

Now, there could be also a center of symmetry. What it means by a center of symmetry is that if you look at two opposite faces across the center of symmetry, they are going to be identical; they are going to be having an identical appearance in terms of their orientation and geometry.

Now, you should also try to notice that a mineral can have a several different axes of symmetry while it may have no plain of symmetry or it may have no center symmetry and similarly, it could have plains of symmetry, several plains of symmetry but there could be situations where there is no axes of symmetry or center of symmetry.

We will see these things as we proceed with the lesson of this, as we proceed with this presentation.

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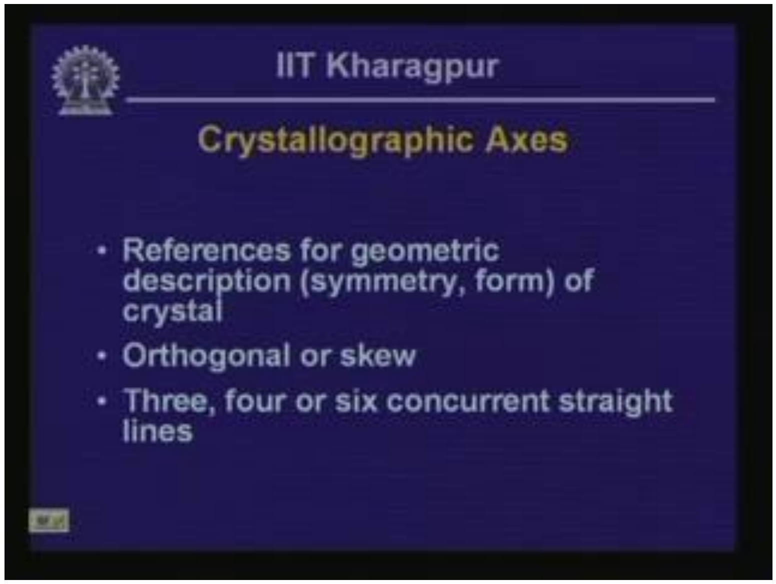

Now, crystallographic axes; what is meant by that? I explained this term in the previous slide. What it means or what is crystallographic axis in a sense is; it gives you a reference to describe the geometry of a particular crystal more often than not, these reference axes are the axes of symmetry. That is not to say that always crystallographic axes will be identical to axes of symmetry.

Now, crystallographic axes could be orthogonal or skew, they do not to be at 90 degree to each other, they can be some other angle than 90 degree and there could be 3 4 or 6 concurrent straight lines that form a set a crystallographic axes.

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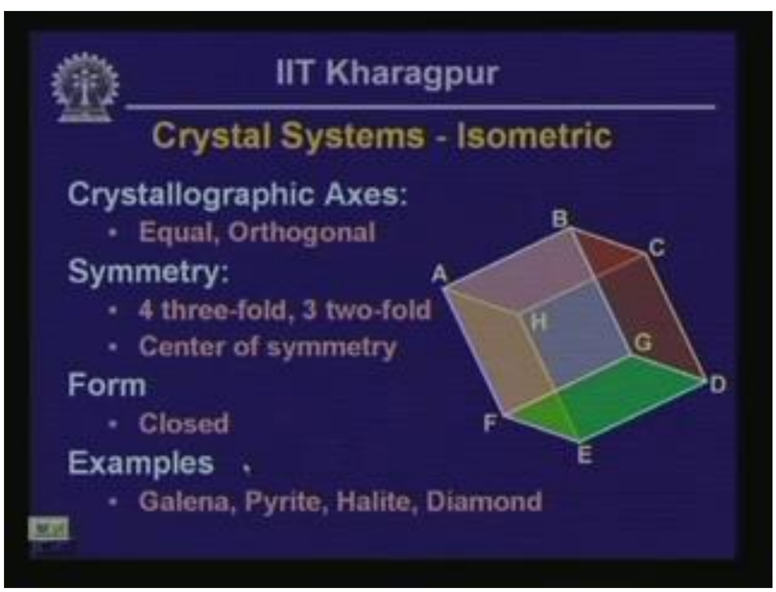

Now, let us look at the most simple crystallographic structure, the most the simplest crystallographic structure is called isometric structure. Now as the terms, as the names suggests, the crystal, the set of crystallographic axes in this case, they are all going to be equal to each other and they are going to be orthogonal. So this crystal, we will have similar appearance when you look at the crystal from all different sides.

Now symmetry; symmetry of isometric crystals it should have 4 three fold axes of symmetry and 3 two fold axes of symmetry. This is the minimum requirement for a crystal to be classified as of the isometric family. So, it should have 4 three fold symmetry and 3 two fold symmetry, it should also have a center of symmetry.

Now this thing, for explaining this aspect, I just consider a simple crystal shown on the right side of this slide. Now, this is actually in the form, you can easily see that the crystal is of the cubical form and actually halite crystals, halite is essentially rock salt; halite crystal is of this type of appearance, it has got a cubic appearance. Now, for this type of crystal, this the simplest structure really. In this case, you got to have 4 three fold symmetric axes; now, those axes are the solid diagonals of this particular form.

So, what we have here? The 3 fold symmetries are essentially this one, this one is we have got AD, this is one of the solid diagonal, then we have got BE another solid diagonal and also the third solid diagonal we are going to have is CF. So, these three solid diagonals we will form, actually there will be another one sorry, there will be another one and that is going to be HG.

So basically, we have got one here, we have got one here and we have got one here and fourth one is between H and G. So, these are the 4 solid diagonals that are going to cut at a point within the body of the crystal and that is going to give you also the center of the symmetry. Now, we are going to show, we are actually going to show, how these solid diagonals are going to give you three folds symmetry. In addition to these things, we are going to have 3 two fold symmetries which are going to be, you can consider those axes as the straight lines that pass through the center of the faces like A, F, E and H.

Let me erase, let me erase the drawing that I did to make it a little bit clear; so three folds symmetries in this cases are going to be along the centers of faces A H F E. So, there will be one line that is going to be connect to the center of A H F E and the center of the opposite face which is B G D C and similarly we are going to have another one from here and we are going to have a third one that is going to connect the centers of H E D C and ((A B F…)) A B G F. So, these three axes are going to be two fold symmetric axes.

Now, let us look at the solid diagonals of this particular type of crystal to understand ((what we mean by 4 three fold…)) what we mean by there being a three fold symmetric axes. Let us consider holding a particular cubic structure across one of solid diagonals. So, what we are going to see in the case, what we are going to see at the top are three faces and let us give different color to these three faces; so in this case, our axes is going to be coming out of that point out of the tablet here and what we are going to see when we look down from the top along the axes, we are going to see as I mentioned three faces one of them is a red face, the other one is going to be a green face and the third face that we are looking at in this case is going to be a cyan face. So, these three faces, we are going to have a look, we are going to able to see when we look top down in the direction of solid diagonal.

Now, you can see easily that if you give a 120 degree turn, a 120 degree turn to this crystal that way, counter clock wise; then what we are going to end up with is that the green face is going to be taking position of where the red face was earlier and the red face is going to occupy the position which was earlier occupied by the cyan face and cyan face is going to be a occupy the place space which was occupied by the green face before the rotation.

So, since these three faces are going to be identical, in other words what is going to happen actually, let me draw this thing, let me draw this think and make it a little bit clear; if you give a 120 degree rotation, then you are going to have a situation like this and this one here is our earlier green face and the cyan face has gone here and the face that was red is here. So, this is actually a transformation that you get after a 120 degree rotation.

Then again if you apply another 120 degree rotation, then you can imagine what is going to happen; the red face is going to come back to where now cyan face is and so on and so forth. So, what that tells you? This tells us that since all the faces or in a sense identical to each other, we are actually getting the same pattern from rotation of 120 degree about the solid diagonal that is at this location. So, we are going to get in that case, three different configurations for a complete revolution of 360 degree which is going to be out identical appearance. So, this is what meant by a three fold symmetry.

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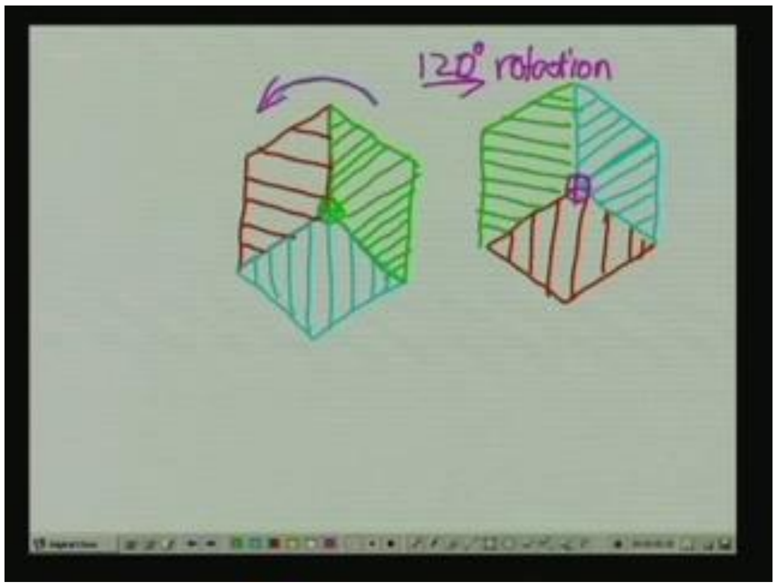

((What are the…)) The form of this family of crystals, this family of crystals is called the closed form. Closed form means, what we mean by closed form is going to become more apparent as we continue with this presentation, as we continue with this presentation.

Now, what are the examples of this class of minerals? The example of halite I have already talked about, diamond also is of this category of minerals and then you have got pyrite and galena. If you recall Pyrite is actually ferrous sulfide and Galena is lead sulfide.

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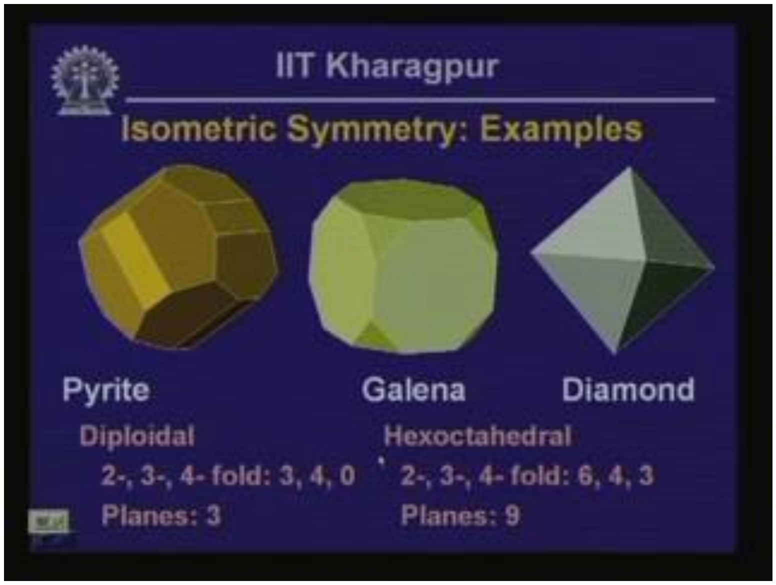

Now, these are the examples that we talked about; Pyrite is on the left of this particular side and this type of mineral is as I mentioned is of isometric class and the sub category within the isometric class is diploidal. Now, pyrite has got two, three and four folds symmetries; the number of two folds symmetries is 3, number of three folds symmetries is 4 and the number of four folds symmetry in this case is 0. It has got three planes of symmetry and early as I mentioned before, it has got a central symmetry as well.

Now, you can see here that it meets the minimum requirement of this type of crystal being minimum requirement of that of an isometric form. So, that is the reason this particular type of crystal can be classified as of the isometric family. Now, galena and diamond, they are on the other hand of hex-octahedral sub class, sub category of the isometric type of crystal and they have got 6 two fold symmetry, 4 three fold symmetry and 3 four fold symmetry and these two types of minerals have got 9 planes of symmetry and they, as you can see, these minerals also meet the minimum requirement for being classified in the isometric family.

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Now, the second type of crystal system that we are going to consider here; actually you can see that we are going to increase the complexity as we go down the line. So, the second type of crystal system that we are going to get is called that tetragonal family of crystals. Now these crystals, what are the requirements for this type of the crystals? For them, you have got one axis longer than the other ones; all the axes are orthogonal to each other. So, this is the requirement for a crystal to be classified to be of the tetragonal family.

Symmetry; Symmetry requirement here is not very obvious and that will vary as mineral from subcategory to subcategory of the tetragonal system. The form of this family could be closed or open and we are going to actually, this is going to be the place where I am going to explain what is meant by a closed form and an open form and examples of this one is this class of crystals is Zircon and Chalcopyrite.

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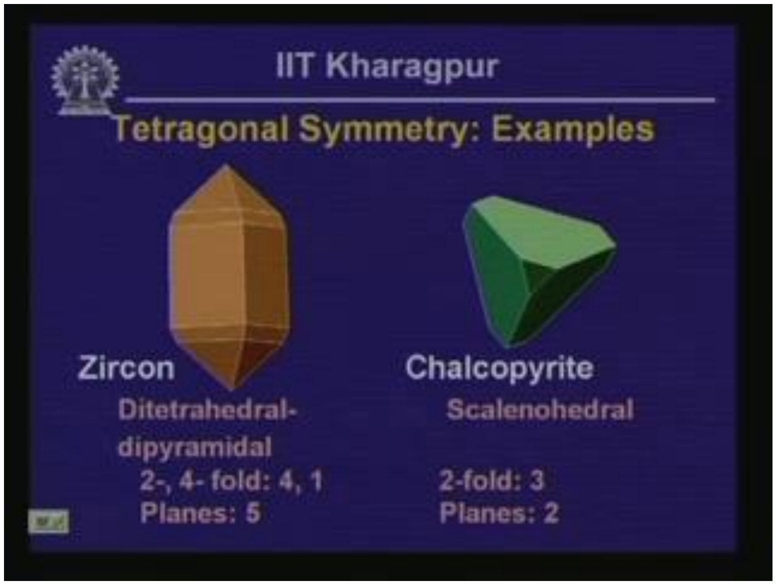

So, as I mentioned that tetragonal cemetery, two of the very prominent type of minerals that appear that are of tetragonal cemetery are Zircon and Chalcopyrite and these are the examples. Now, both of these types of minerals are of the closed form. Now, to give you an example of an open form let we draw something here; say instead of a crystal of this shape, the shape of zircon is where to get a crystal which is identical, more or less identical but of slightly different type, then this type of crystal would be called an open form.

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You can see that the two pyramids that appear at the ends of zircon actually closes the form; whereas on one that I have drawn here, let me label it as an open crystal, here you do not have a pyramid at the bottom of the crystal. So, this essentially is an open form. Now open form, if you can imagine that if there is a crystal which looks like a simple column, flat ended column that would be an open form or if the column actually closes in one of the ends that is also an open form; whereas if both the ends are closed, then it is a closed form.

On the right hand side, actually you have got a crystal of a Chalcopyrite; here you have got each of the faces closes the volume actually, encloses the volume. So, this one also is of the open form sorry, closed form. Let me get rid of this.

Now, let us consider the subcategory; both these minerals I said Zircon and Chalcopyrite, they are of the tetragonal symmetry, tetragonal family but they are of different subcategory. Now, Zircon belongs to di tetrahedral di pyramidal subcategory whereas chalcopyrite it is of the scalenohedral subcategory. Zircon has got 4 two fold symmetry and 1 four fold symmetry, it has got 5 planes of symmetry.

On the other hand, Chalcopyrite has got 3 two fold symmetries and 2 planes of symmetry. Both of them actually, both of them meet the requirement and they are being categorized as tetragonal crystal is because you can see that the crystallographic axes in all the cases, they are oriented to each other at 90 degree; the angle, the inclusive angle between them are 90 degrees. Let me draw that also.

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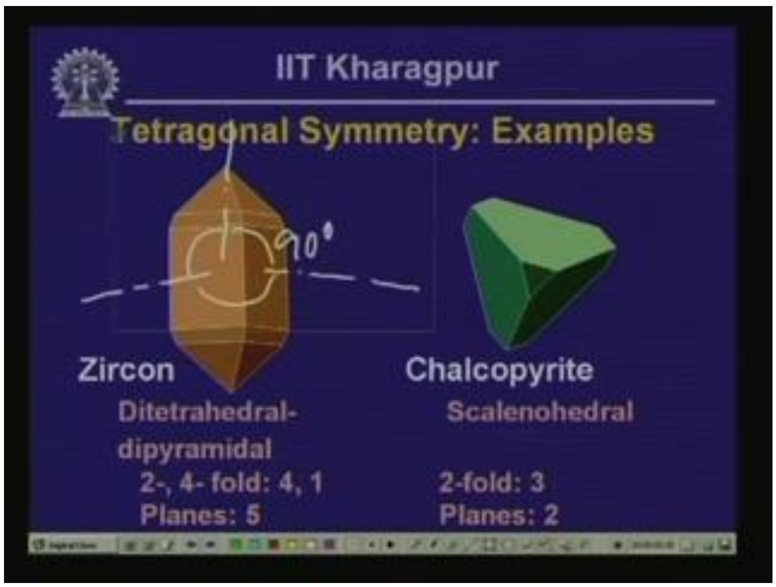

For example, in case of zircon, you are going to have one axis in that orientation, you are going to have another one in this orientation and obviously you are going to have one axes in this direction and they are going to be, they are going to be, the angles between these axes all of them are 90 degree.

Now, it is also obvious that the axes towards from top to bottom or longer than the other two axes in this case. So, you can see why zircon gets categorized as tetragonal sorry a tetragonal crystal.

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Getting back to the crystal systems, the next one in the order of added complexity is orthorhombic. You can see the first one that we discussed was isometric, we had three crystallographic axes, all of them were at 90 degree to each other and all of them were equal.

Then we considered the tetragonal family where we had orthogonal set of crystallographic axes but in this case, we had the angles in between them; in other words, the angles in between them were 90 degree as well but one of the axes was longer than the other axes.

In case of orthorhombic, what we got is all the axes are unequal, although all of them are orthogonal to each other. That means here we are going to have again all the axes are at 90 degree to each other but all the axes are unequal. Symmetry requirement; the crystals should have atleast 1 two fold symmetry, the form of this crystal system could be open or closed in contrast to the isometric system, you could only have an closed form in that case but here you could either have open or closed, its quite the same way as a tetragonal crystal family.

What are the examples? One of the very common mineral that appears in this family is Barite and you have got a picture, you got a schematic of barite crystal on the right hand side of this particular slide.

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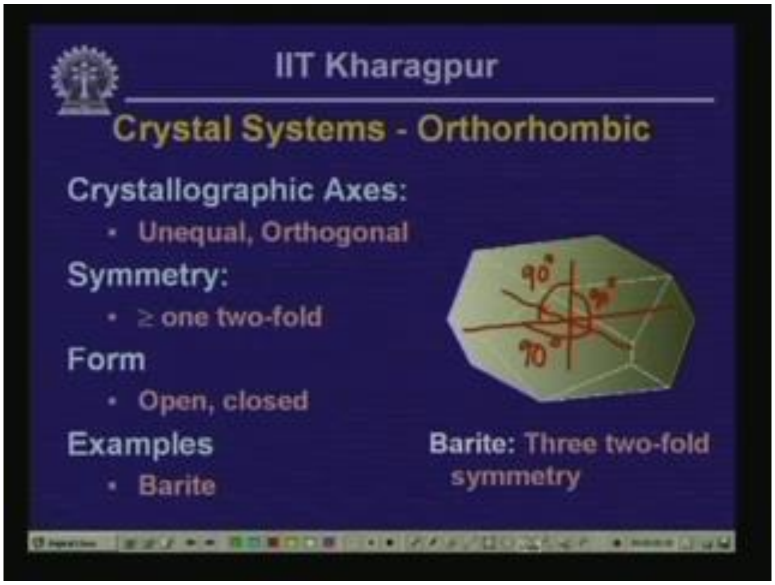

What is or what barite has? It has got 3 two fold symmetries and you can see that this meets the minimum requirement for its being classified as orthorhombic, as of the orthorhombic family. And also, you can easily see that the length of the crystallographic axes in the three directions namely in this direction, in this direction and in this direction; these three crystallographic axes, they have got 90 degree angles in between them but all the axes are of unequal length. So, that is the reason why this type of mineral gets classified as an orthorhombic mineral.

Next one up in the order is a crystal system called the hexagonal crystal system and the name makes it very clear that you are going to have a hexagonal symmetry in this case. That means you are going to have at least one - three or six fold symmetry.

Now, the example is shown on this particular slide is that of Beryl, mineral called Beryl and first of all let us discuss how the crystallographic axes in this case are going to orient with each other.

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This family requests at least 4 orthogonal crystallographic axes. So the angle between, angle between the between the major axes; let us let me consider the example that is given here is that of Beryl, so in this case what you have got is one of the axes is going to be like this and then perpendicular to it will be will be 6 axes.

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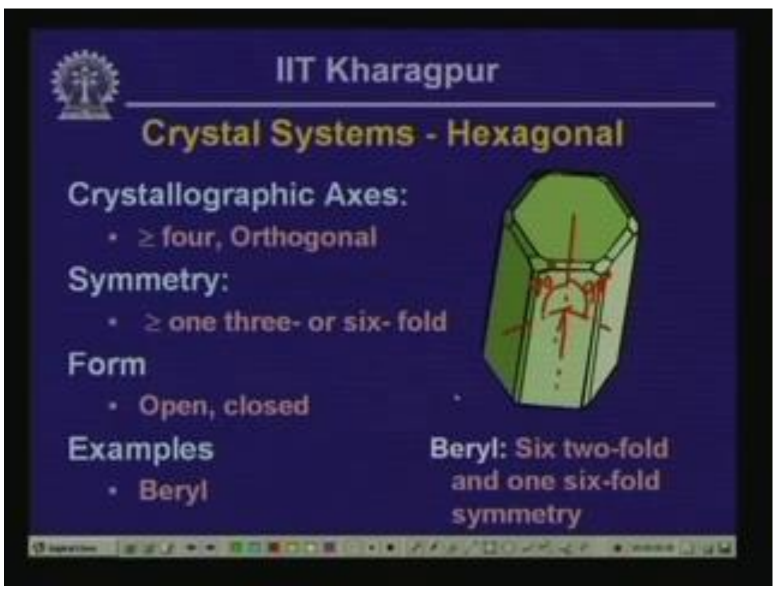

So 3, to the center of the 3 faces that you can see in the front and there will be another 3 axes on the back side. So the angle, these angles are going to be 90 degree. That is not to say that the angle between the set of crystallographic axes in the horizontal plane are also going to be 90 degree, they are going to be in this case inclined to each other at 60 degree angles.

Now, this type of crystal could be again open or closed crystals and we already have considered the example of the mineral Beryl; it has got, this particular mineral has got 6 two fold symmetry and 1 six fold symmetry. So, if you rotate this mineral about the axes which goes from top to bottom, you are going to repeat the pattern 6 times for a 360 degree rotation, so that gives you a six fold symmetry and for each one of the horizontal axes, crystallographic axes, you have got similar appearance on 180 degree on similar appearance 180 degree apart. So, you have got six axes that are going to give you two fold symmetry. That explains this type of crystals, hexagonal crystals.

Let us move on to the next one. Next one, we have got trigonal crystals; here we have got 4 set of axes and the 4 axes, they are going to be orthogonal to each other.

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Now, what you got here, the symmetry requirement in this case is that you need 1 - three fold symmetry. The form in this case could be again open or closed form and examples include Tourmaline and Dolomite. Tourmaline crystal, a schematic of a Tourmaline crystal is shown here and you can see the Tourmaline is an open form crystal and the three fold symmetry is pretty obvious by looking at the, looking at the nature of this crystal. Let me explain this one little bit more.

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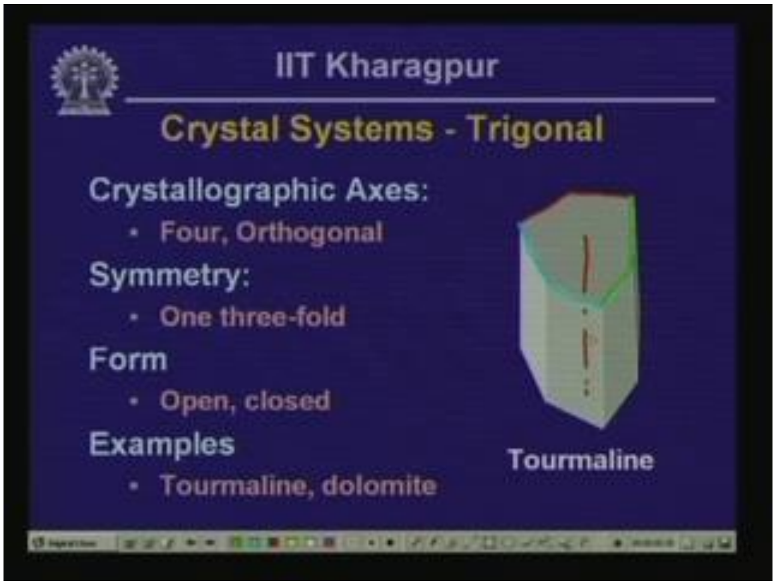

So, if you consider this axis here which goes from top to bottom, if you rotate the crystal, if you rotate the crystal by 120 degree, then the face, this face, let me label the faces by different colours; so let us say we begin with a configuration as shown on the slide here and we turn the crystal 120 degree about the axes marked on the crystal.

So, if we turn it 120 degree, then the red faces are going to occupy the face that is occupied previously that was occupied previously by cyan faces and the cyan face is going to go to the place that was previously occupied by the green faces and the green face will occupy the position of the red face and that also gives you an identical appearance as compared to the original configuration of, original configuration of this particular crystal. And again, you can give it another, you can imagine that the crystal is turned by another 120 degree; again you will be able to see that the symmetry is going to be ensured for that particular rotation as well.

So, what we are going to get in this case is 3 different orientations, angular orientation in which you are going to repeat the patterns, repeat the appearance; so thereby, you have got 3, actually you have got 1 - three fold symmetry in this case.

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So the next one, next one of the crystal systems is called the monoclinic crystal system. The name makes it very clear what is meant by this type of crystal, by this type of geometry; mono means one and clinic means inclined. So here, what we have got one of the axes is going to be skewed to the other axes.

Symmetry requirement, it really depends on the crystal type that you are going to that are considering. So, the essential requirement in this case is that one axis is going to be skewed and if that is met, then the symmetry requirement will depend on the individual type of crystal that is being considered.

Two of the examples; gypsum and orthoclase, both of these crystals are shown on the right of the particular slide. Let us move on to the next one.

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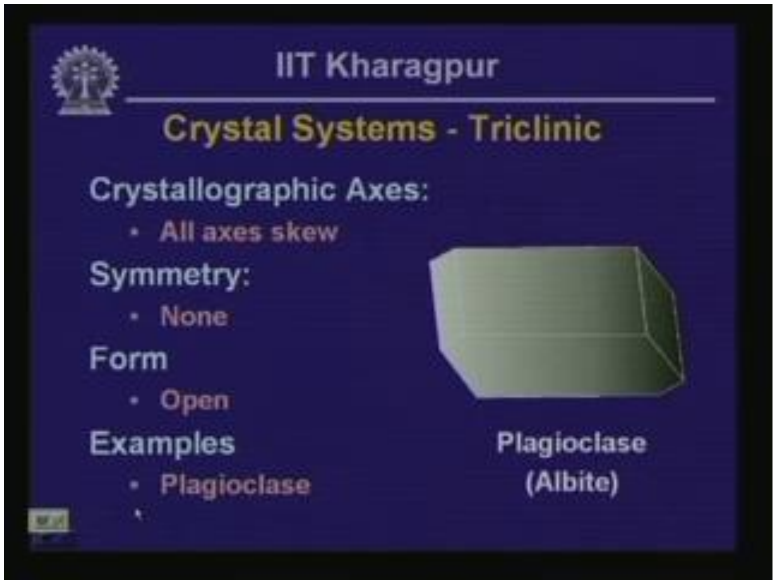

Finally, we have got a triclinic system, crystal system and this one, the name again is very obvious, the meaning of name is very obvious; all the axes in this case are going to be skewed and here you would not have any symmetry. There will be no symmetry, the form in this case is going to be open and example, one of the examples in this case is Plagioclase or Albite and a schematic of an Albite crystal is shown on the right side of this particular slide.

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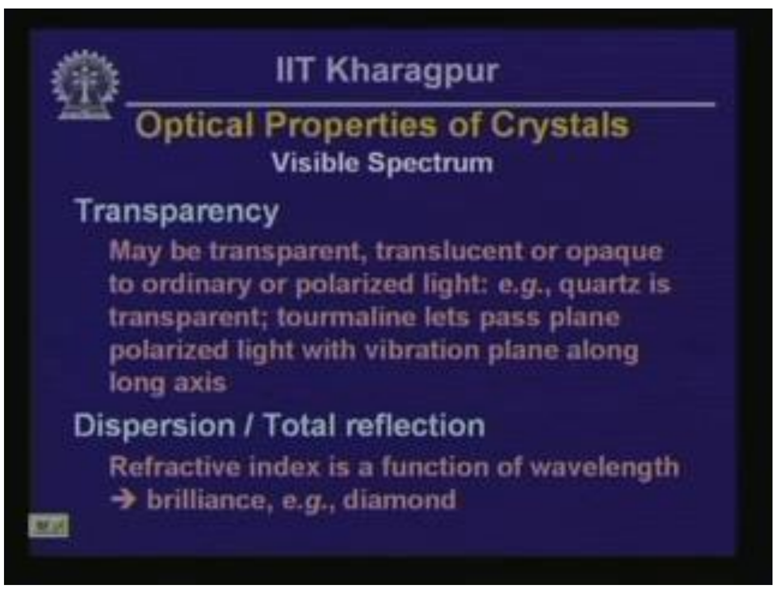

Now optical properties, optical properties of a crystal system in the visible spectrum; what are the different types of optical properties that allows us to distinguish one crystal, one type of mineral from one another? The first one is transparency.

A crystal may be transparent or translucent or opaque. That means it is going to be giving passage to optical signals or light, visible light without much hindrance, then you have got a crystal that is transparent. Then secondly, if it is partially blocking the passage of light, then you have got a translucent crystal or it could be totally opaque in which it does not allow any light to pass through.

Examples are quite or you can usually think about some examples. For example, Quartz will allow the light to pass without difficulty, whereas if you have got a crystal of Galena that is going to be totally opaque and it is not going to allow any passage of light through.

Now, this opacity will depend on the wavelength as well. That means some of the crystals may be opaque to visible light but it may not be opaque to X-ray. So, this gives you a handy tool of, one of the handy tools of distinguishing one mineral form the other.

Then some of the crystals, they will be even opaque they will be opaque to non-polarized light, whereas if you let through a polarized light oriented in a particular direction, oriented along a particular crystallographic axes; then the light is going to pass through. Example is Tourmaline. Tourmaline is going to let through lights polarized through the longer axes and that is the reason why Tourmaline crystals are used in diffraction gratings in optical instruments quite frequently.

Then the second one, the second one that we are going to consider, second optical property that are used very frequently in classifying minerals is dispersion and total reflection. Now, refractive index is a function of wavelength as you all know and this gives rise to brilliance, example of that is Diamond.

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The other important optical property that allows us to distinguish between different types of crystal families is double refraction or it is also known as by birefringence. What is meant by birefringence is that if you actually allow light to pass through an isotropic mineral, then light rays are going to split into two rays and on the other hand, if the ray that is passing through is oriented along a particular, it is oriented in a certain preferred direction that is called a preferred direction, they will be known by birefringence and this special direction is called the optical axes.

If you have got isometric crystals, you should remember that there will be no birefringence. Hexagonal and tetragonal crystals have got one optical axes and orthorhombic, monoclinic and triclinic crystals have got two optical axes and they are generally skewed.

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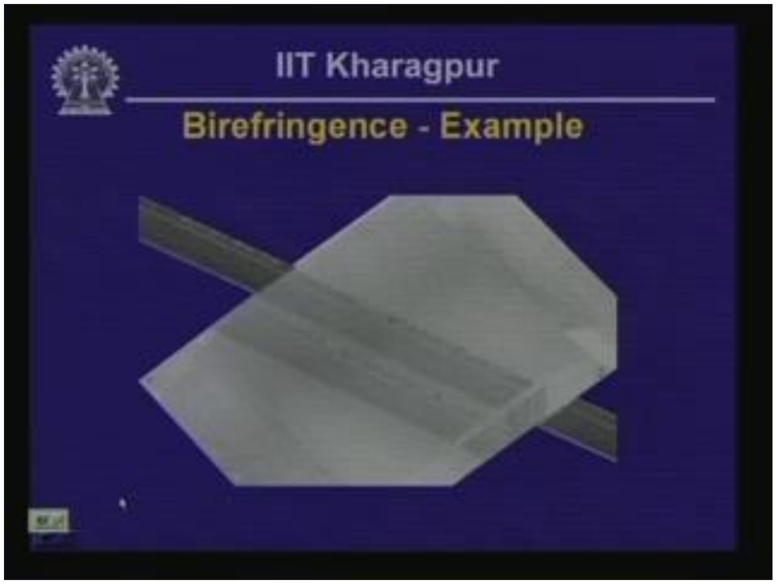

This cartoon here actually shows, give you an gives you an example of birefringence in which an object is placed underneath a Calcite crystal and you can see that that particular object is splitting into two; one of them is appearing here and the other one is appearing here.

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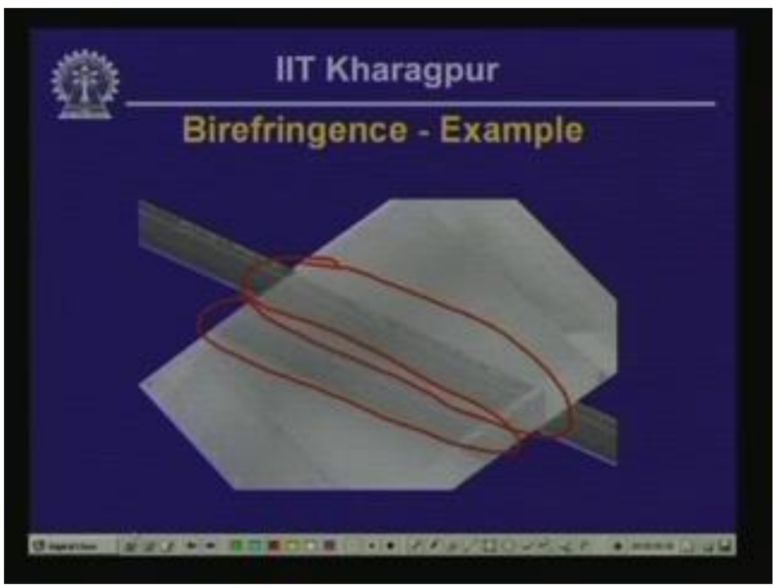

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Now, we are going to actually consider another tool that is used to distinguish optical properties of crystals and that is X-ray diffraction. What is done in this case is X-ray is made to incident, X-ray is x-impinged on a sample of powder crystals and because of the regular distribution of the atoms in the body of the crystal, of the powdered material; there will be a scattering.

Now, scattering will be these scattered lights, scattered light is going to interfere with each other constructively or destructively depending on what is the direction in which the scattered light is scattered X-ray signal is observed and the pattern of destructive and constructive interference actually is a finger print. Actually, it is a unique characteristic of a type of mineral and that allows us to distinguish, identify actually, one mineral from another.

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A schematic of an XRD instrument, X-ray diffraction instrument is shown on this cartoon here and you can see here what we have got is an X-ray source that actually made to impinge on a powdered sample, powdered crystal sample and then we have got a receiver that we can move actually along this graduated scale and we can note the intensity of the signal that is coming out of the powdered sample.

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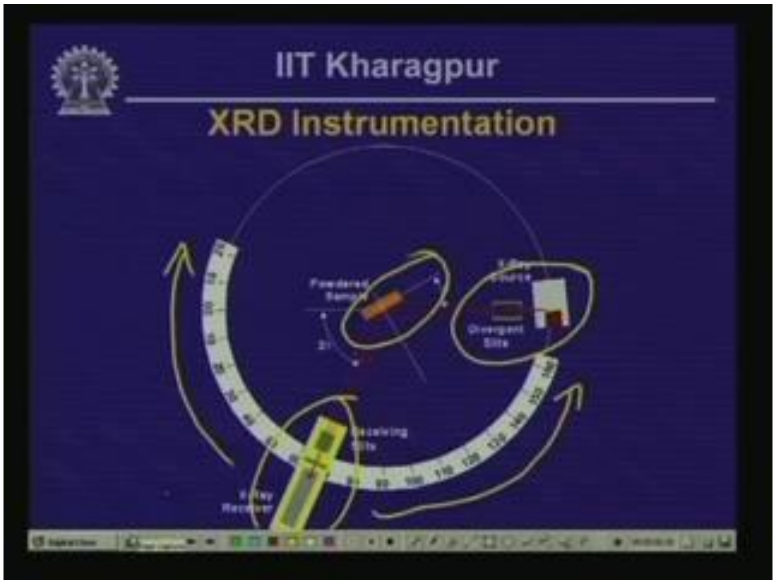

And, what we do actually? We plot the intensity of the received signal as a function of the angle and what we get in that process is this.

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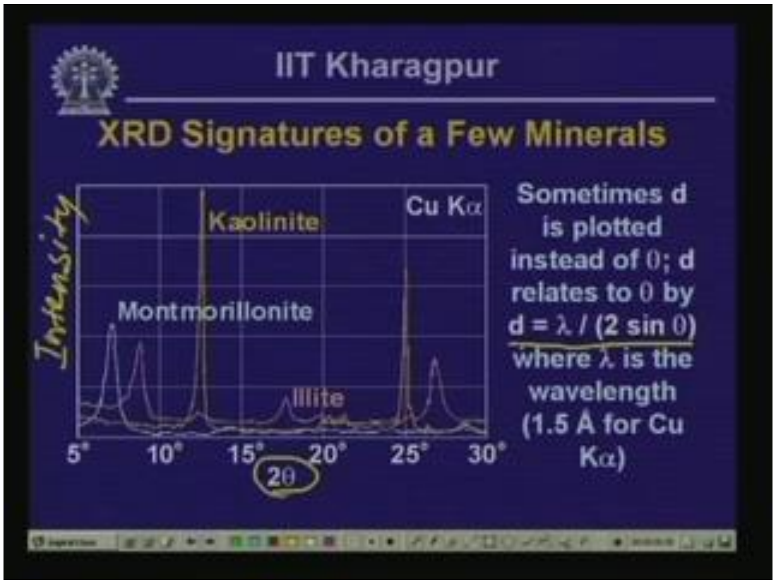

So, here we have got, we plot the angle and on the vertical scale, we have got the intensity of the X-ray signal and you can see at different angles depending on what mineral you are looking at, you are going to receive a very intense radiation. For instance, in case of Montmorillonite, you have got a radiation a signal, a peak signal appearing at 12 degree of angle.

Now sometimes, instead of 2... (55:38), you also could plot a d value really and d converts into theta as shown in that equation there.

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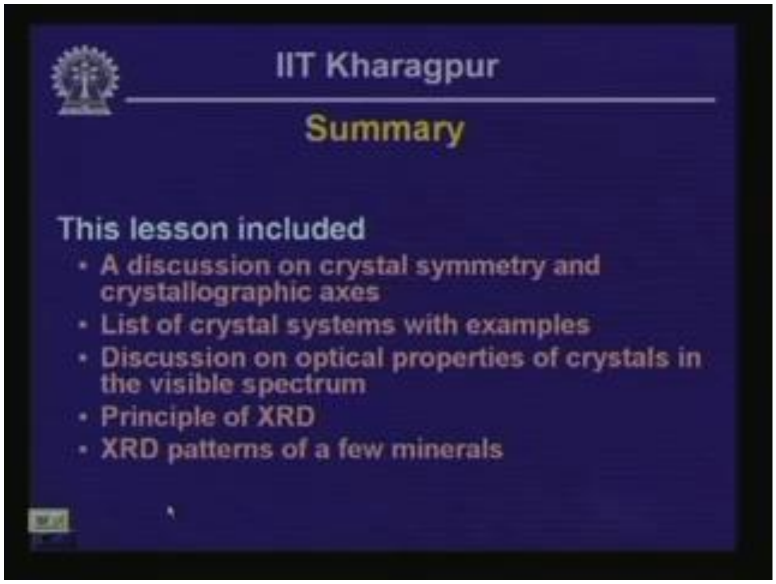

So finally, we summarize what we discussed in this particular lesson; we looked at crystal symmetry and crystallographic axes, we examined different types of crystal systems, we looked at optical properties of crystals which allows us to distinguish one mineral form another, some of these properties are their behavior in visible spectrum, we also considered the principles of X-ray diffraction and we examine different XRD patterns of minerals.

Now actually, by comparing a particular type of mineral with set standard XRD patterns, you could actually identify minerals as we are going to see in one of the questions that we are going to consider in this lesson, I am going to give you part of this lesson.

So, this is the question set which we are going to close this presentation.

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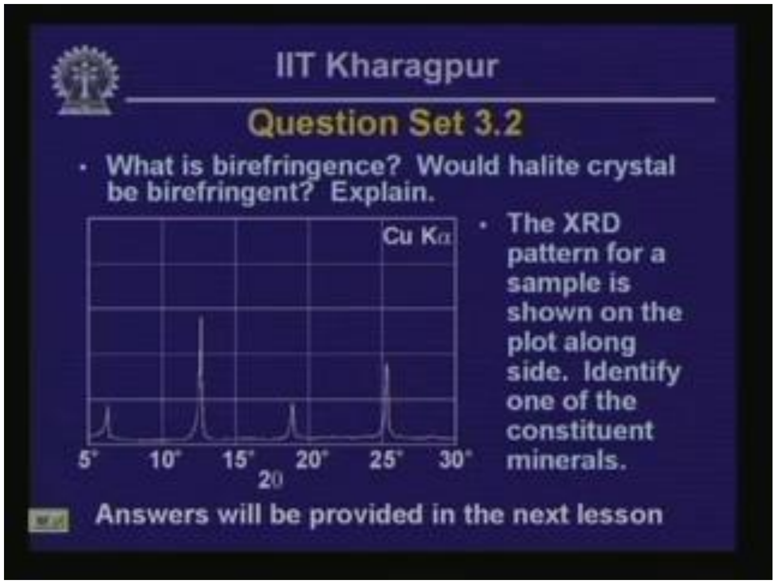

The first question is that what is birefringence and would you expect a halite crystal to be birefringent? You should explain what, why you or why you say, what you are saying. And the second question; in the second question, you have been given a XRD pattern shown on the left of this particular slide and you are asked to identify one of the constituent minerals of this particular sample. So, with that we are going to close with a note that the answers as usual will be provided in the next session. So, until we meet in the next time, bye for now.

Thank you very much.