Electroceramics
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Lecture - 25

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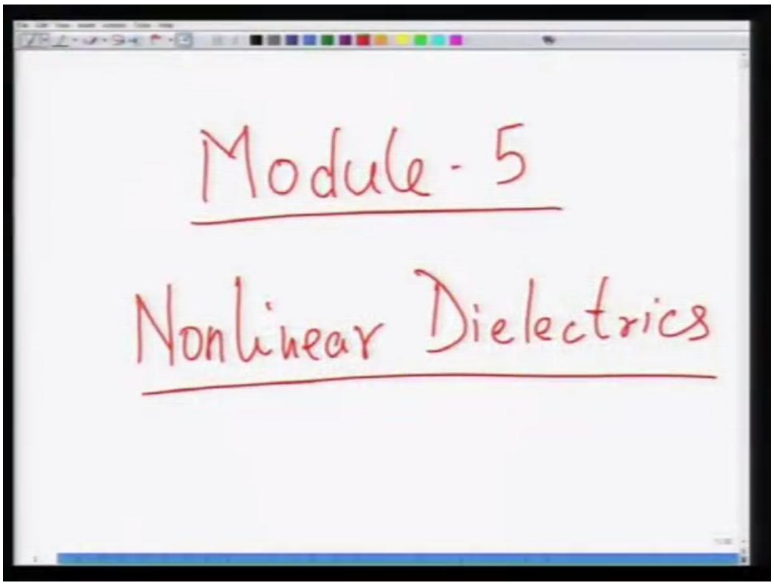

So, welcome to this new lecture. And now, here last time what we did was, we finished our discussion on module 4 in which we discussed frequency dependence of a dielectric constant. And we found that the dielectric constant has various regimes, and first high to high frequency regimes are 2 regimes; one is this electronic polarization, and second is ionic polarization. And in those 2 regions, you see presence of this resonance, and this resonance is characterized by a characteristic resonance frequency. And above this frequency, the mechanism seizes to the particular mechanism seizes to operate, because the field is switching faster than the dipoles can respond, then the speed at which dipoles can respond to.

And then, we looked at the low frequency region which is which corresponds to the dipolar polarization or orientation polarization. And in that case, the mechanism changes from resonance to relaxation, because there it is about a movement of molecules or group of molecules from one position to another. And that requires that is the diffusive process as a result, you have a characteristic relaxation time. And from that we got what is called as a relaxation equation. And solution of that relaxation equation gives rise to what we call as debye equations.

So, debye so when we now, when we then plot, when we plot there is dielectric constant versus frequency, you get a complete understanding of the picture that emerges as a result of frequency dependence. And then finally, we looked at impedance spectroscopy which was essentially away to model, these dielectric materials, because the response of these dielectric materials in reality is never ideal. So, as a result you have various deviations from ideality that could be, because of presence of variety of defects, such as grain boundaries, such as electrode material interfaces. And all of these they give rise they give various contributions, and impedance spectroscopy as we looked at was basically if you have perfect dielectric it should give you one circle one half circle.

And if you have more than 1 or 2 contributions coming from various other mechanisms then, you will get multiple circles. And many times these circles overlap with each other half circles overlap with each other. And it is very essential in that case to understand what is happening there, and it is it is not easy affair it is a complicated affair. But by proper modeling, and proper designing an electrical equivalent circuit, you can come out with some good answers. And then finally, we looked at what we called as break down mechanisms. So, dielectrics do breakdown as you must have often seen that the electrics poles on the streets have dielectric the capacitors.

And often, there is a sparking there, and that is sparking is a sign of their break down. And there are break downs with intrinsic mechanism, and then secondary mechanisms or primary or secondary mechanisms. And all of these mechanisms lead to dielectric failure which means there is dielectric, no longer remains the electric it becomes conducting or it becomes a hit becomes useless as a dielectric. So, the dielectrics that we discussed essentially linear dielectrics, so in the,

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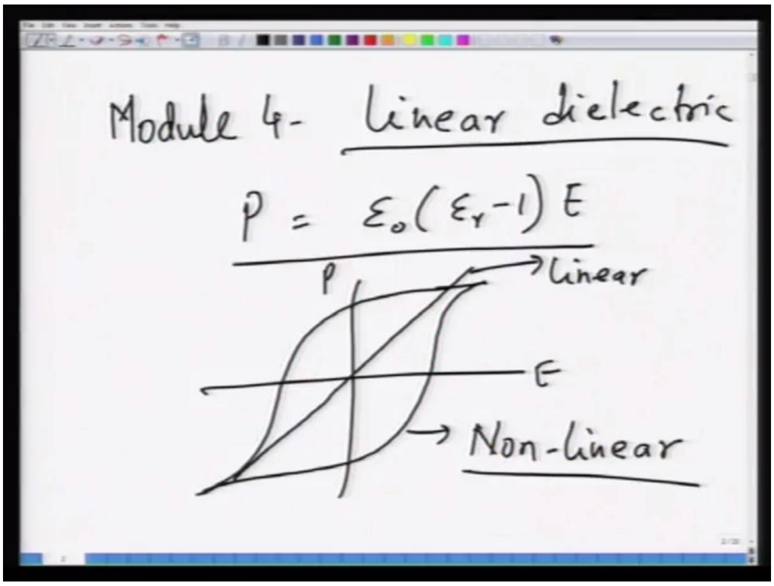

So, module 4 was about linear dielectrics. And what essentially it means is that, when you in these linear dielectrics, the dependence of polarization electric field is linear, because we looked at that this P was equal to epsilon naught epsilon r minus 1 into E. There was this overall, this linear dependence upon the field. So, when you change. So, when you plot polarization versus electric field, the plot must be linear, it is a linear plot. Now, there are some dielectrics other than these dielectrics which are non-linear. So, these non-linear dielectrics have a curve which is not like this, rather you might have a curve something like this.

Now, here there is no linearity associated as compared to previous. This is your linear dielectric, and this is what is called as non-linear dielectric. And there are varieties of classes of these non-linear dielectrics, and that is what we are going to look at in this lecture by considering variety of these dielectrics. And how they work? What are their different characteristics, etcetera? Now, these non-linear dielectrics are very special dielectrics, because where they have very special characteristics.

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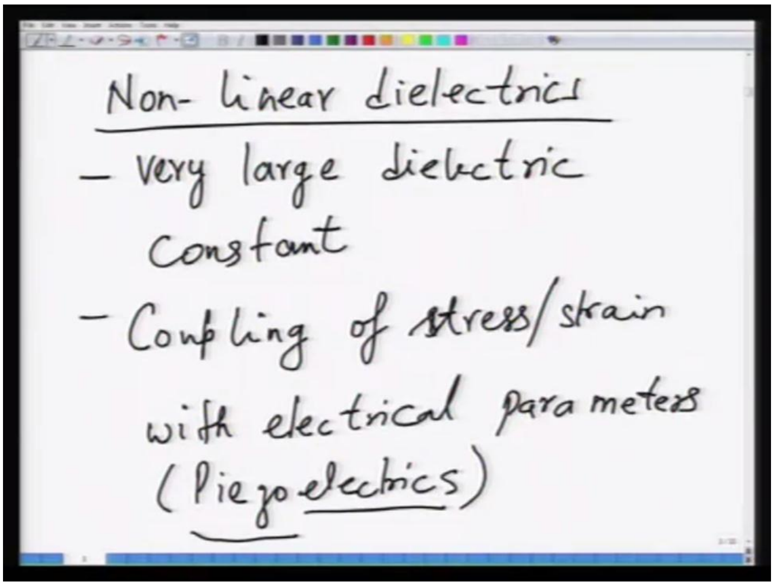

And some of those characteristics could be so, if we just. So, these characteristics for instance could be very large dielectric constant. This is only one feature, there are many other features for instance they show some very special effects. And these effects could be for an instance interdependence of or coupling of strain or mechanical or electrical order parameters. So, you can say, coupling of, let us say, stress or a strain with electrical parameters. And this is referred as you know piezoelectric ceramics, the materials which show this kind of behavior are called as a piezoelectrics, Now, the word piezo electrics, it itself means piezo means piezo or piezo it means stress or force. And it is a Greek word, and then electrics of course, you know that it is it means pi electrical force.

So, coupling of electrical and mechanical order parameters which can be taken as order parameter in case of electrical order parameter in dielectrics can be taken as polarization. And in case of mechanical order parameter, it could be strain. So, coupling of strain, and polarization is called as is piezoelectric effect, and these are very useful effects, because they give rise to variety of applications.

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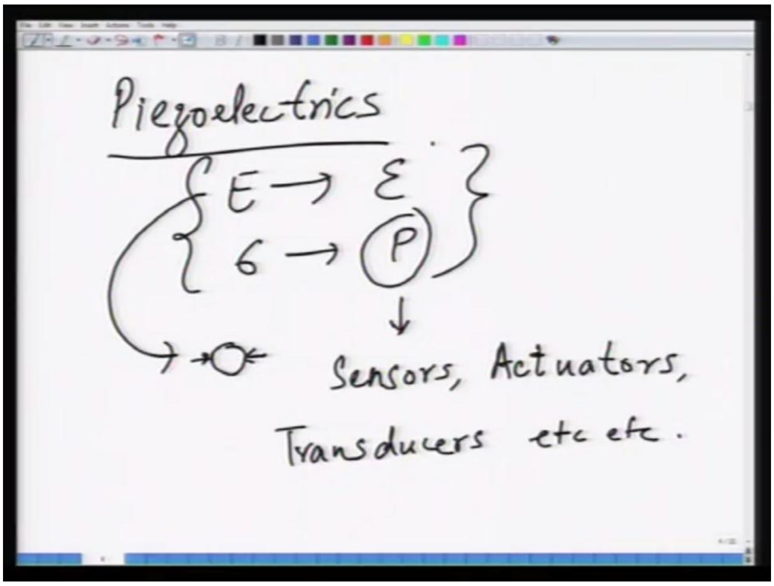

So, when you have this for instance a material, so piezoelectric, what happens is in piezoelectric is when you apply. So, electric field application gives rise to what is called as strain and why conversely if you apply stress to the material? It shows polarization. So, there is the coupling between these two order parameters, and this effect is extremely useful, because if when you applies for a for instance when you apply electric field, and you get strain out of it what can it be, you can use it for variety of applications, you can for instance make a transducer or an actuator. So, by changing the electric field slightly, you for instance you make an opening in a pump. And this size of this opening can be changed by changing this changing the magnitude of electric field, because electric field will induces a strain which was allow, which will allow this opening to collapse or expand.

Similarly, when you apply stress then, you can measure the charges that are created on the surface of this material, and this is nothing but your piezoelectric converse piezoelectric effect. And this can be again used for the variety of applications, and these materials are used for sensors variety of sensors, strain sensors. For example, you can use them for actuators, there are used for transducers, etcetera. We will look at some of these applications when we discuss these materials in detail. So, this is one effect that is not seen in normal dielectric or linear dielectrics. So, that is why it is a special effect t and this is effect t is non-linear in nature, it is not linear.

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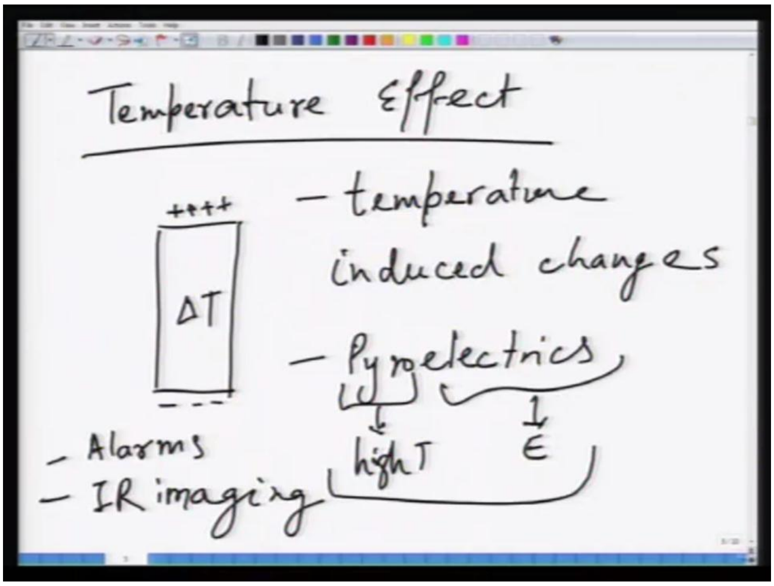

Second; you can have a temperature dependence of polarization .So, in this temperature effect what will happen is, if you have a dielectric material, and you subject this dielectric material to change in temperature. Then, you have some charge which is introduced on the surface. So, this is basically temperature induced changes. So, this is such kind of materials are called as pyroelectrics. Now, here again, you can see this word pyro means high temperature. And electrics mean of course, a something to do with electricity or electrical parameters. So, coupling of these two temperatures and electric parameters gives rise to this pyroelectric effect. And this is again a very useful effect, because it is used in variety of applications such as, your alarms, it is used in it is used in I R imaging, etcetera. And we will again look at this effect in detail.

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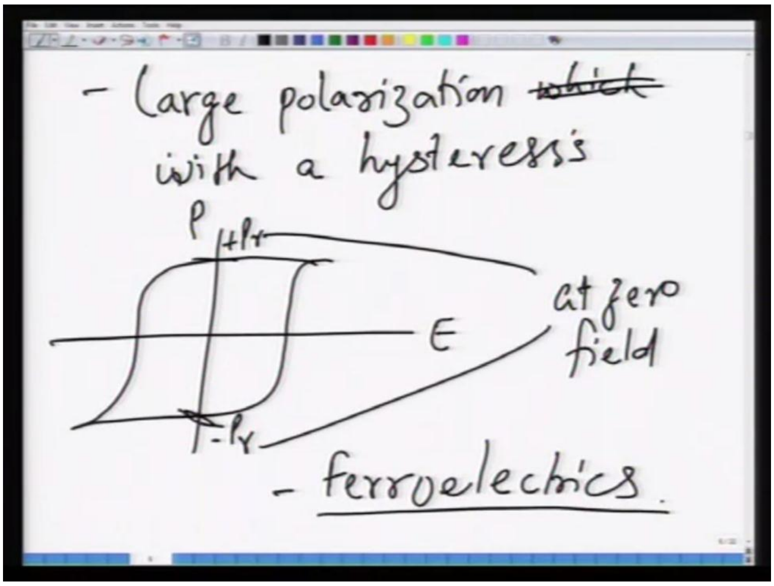

And the third effect which is again which is a very special effect again is presence of large polarization large polarization which is with or rather with a hysteresis behavior. So, when you switch material, it shows this kind of behavior. So, this is your polarization electric field. So, what it has a two non zero states of polarization. So, minus P r and plus P r pr is remnant polarization. And these 2 states are available at zero fields and this effect is called as, and materials which show this effect is are called as ferroelectrics.

So, ferroelectric is a very special class of materials. And again, you know when you see this kind of. So, what you have here is two non-zero states of charge at zero field which means, this can be used as used as a material for binary data storage. So, this can be used as a 0; this can be used as a 1. So, 0 1 is binary data storage. So, this material can be used in the form of memories which are non volatile in nature. And this is very important, because in contrast to this is very important application, because in contrast to magnetic memories as you know that most of the memories currently are in magnetic in nature.

The problem with magnetic memories is that they have their speed of operation is slow in contrast speed of operation of ferroelectrics, and for some reasons which we will see later are is very fast. So, as a result this material is extremely fast in nature, but at the same time it is non volatile. The reason why magnetic memory is used? Because it is non volatile in nature, when you take the power off, it still stores the data.

However, in order to run the computer beautifully in a fast manner, you have to use a buffer memory, and this buffer memory is called as DRAM, you know it is called as dynamic random access memory. So, if you can make this ferroelectric work as a memory you can get it of DRAM, and magnetic memory altogether. So, you will just work on the one hard disk which will be operating extremely fast. So, this is one of the very well perceived applications of a very well thought over application of or thought over applications of ferroelectrics. And there have been challenges in making those memories. So, that is a fabrication problem, but characteristic wise the or a as a principle, this is a very neat principle.

So, again so these typically these three effects piezoelectric effect, pyroelectric effect and ferroelectric effect put together they make these materials extremely interesting for variety of commercial applications. And that is why they are extremely fascinating to study, and they have been studied for long time. And what we will do in this module is that we will look at characteristics of individually each of these materials separately. However we will before, we do that, we have to establish a basis on which we can define these materials in a different class. So, what we will do is that, we will first establish a crystallographic basis which separates these materials from other materials, and then we will individually go into that. So, these materials, so now what makes them, what makes these materials stand out as compared to other materials?

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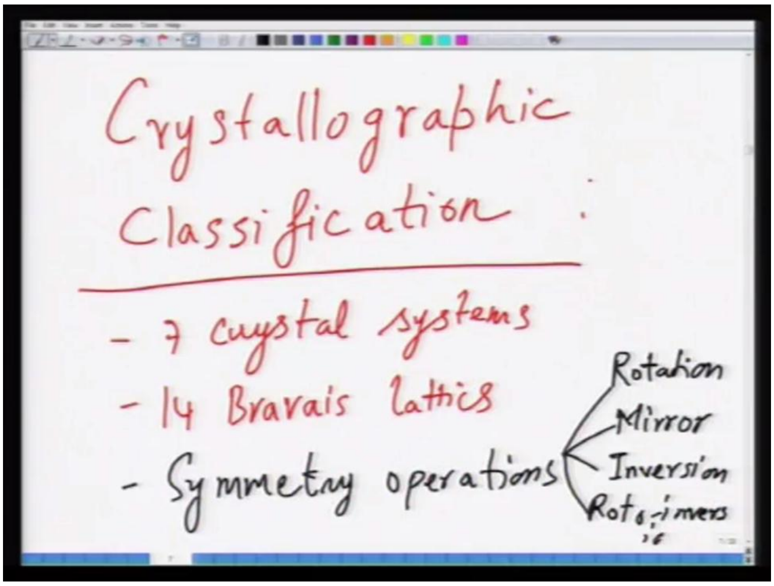

The reason the basis for this is the crystallographic basis. So, crystallographic classification let us say now these materials are different, because crystallographically they also happen to be a rather different from other materials. Now, before we do that we have to understand now we know there are 7, there are 7 crystal systems as we have learnt in module 1 then, you have 14 bravais lattices. And on top of that, you have variety of symmetry operations that we talked about in the first module. And as we know that these symmetry operations were rotation you had a mirror plain. And then, you had inversion and then, you had rotation inversion or roto inversion.

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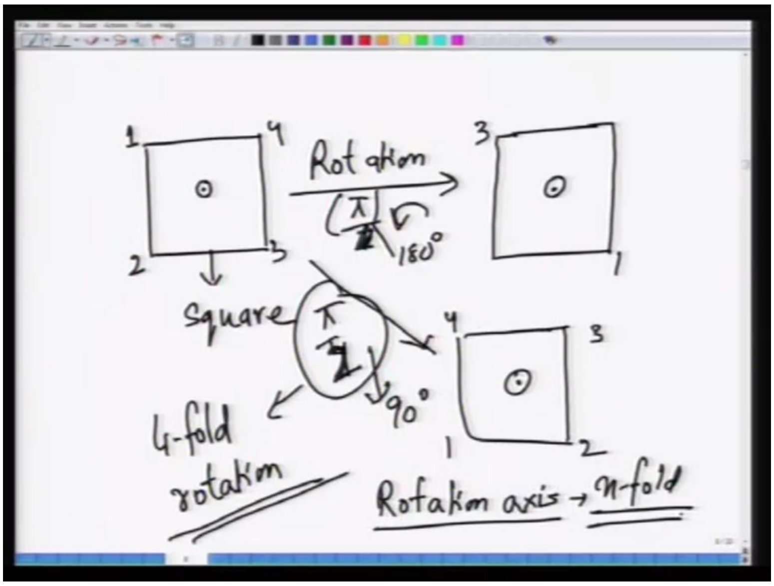

So, what rotation was I just briefly go through that rotation is essentially, so, suppose you take a cube or you take a, you take this square in 2 d. So, for instance I rotate this material perpendicular to the phase of. So, this is that this circle and the dot represent the axis which is going perpendicular to the phase of this square. So, what is the symmetry operation? So, this is position number 1. Now, what is the symmetry operation that you need to perform? So, this is let us say square. So, in order to bring this square back into the same position which means one should look like 1, you need to perform a rotation. So, let us say I do rotation operation here. So, when I do rotation operation here, if I do by pi by 2 then, I basically if this is 1 2 3 4 if I do pi by 2, let us say anti-clock wise then, I take 1 here, and 3 here, but since it is a square which means it looks same. So, this pi by 2 is a rotation operation which allows this crystal to or this phase to come back in the original position.

Now, question is what is the minimum angle by which you can rotate it to? And that minimum angle is pi by 4. So, if you do it by pi by 4 90 degrees. So, which means 1 goes here 2 goes here, 3 goes here, 4 goes here, and still it looks the same. So, this pi by 4 is essentially, hang on this should have been pi and this should be pi by 2. So, this is 180 degrees, this is 90 degrees. So, please make that note that this was pi and this was pi by 2.

So if you make, if you now rotate this by 90 degrees, it again comes back to the original situation and this is called as 4 fold rotation. So, as we looked earlier the rotation axis is defined as.

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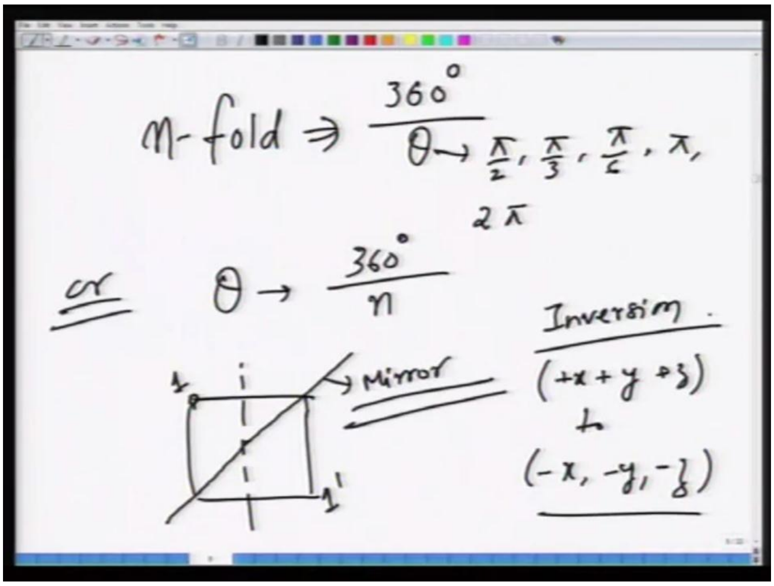

So, n fold would mean n fold would mean 360 degrees divided by theta, and that theta could be pi by 2, it could be pi by 3, it could be pi by 6, it could be pi or 2 pi or alternatively this angle theta would be 360 degrees divided by n. So, this n fold symmetry for instance a 4 fold symmetry for a material would mean that you need rotate that material or that crystal along around a particular access by that much angle, which is sufficient to bring that material back into the original position.

Similarly, you had this, what we called as mirror plain. So, again if you draw this cube; this face here and if I draw this plain here. This is the mirror plain, because anything of the left of this plain looks exactly similar to this right plain. Similarly, you have a mirror plain here; it is not a very good drawing by me. So, again this is the mirror plain. So, these are the variety of mirror plains that you can have. So, mirror plain is again an operation which makes a crystal exactly look similar on the both sides of the mirror plains, and then you have inversion. So, inversion would be bring this point from 1 to, let us say one prime or take basically from let us say if we take in 3 d then, take plus x plus y plus z to minus x minus y and minus z. So, this is your inversion and the fourth operation that we looked in module 1 was called as rotation inversion. So, you rotate and then invert.

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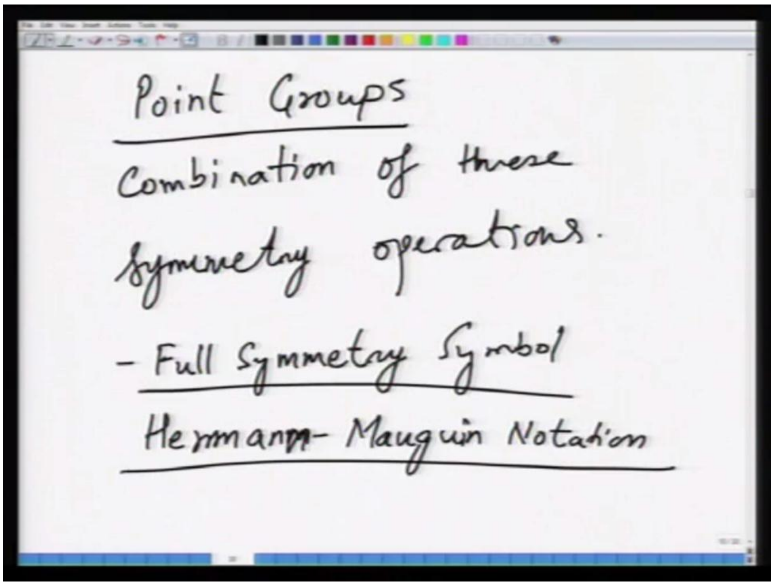

Now, combination of these geometric symmetric operations gives rise to what is called as point groups. So, point groups are combination of these symmetry operations, and based on these 7 crystals, for these 7 crystal systems, you have 32 point groups. Now, point groups are of course, denoted in various different ways, one of the ways to differentiate point group is you can use full symmetry symbol. So, for instance, this full symmetry symbol and this notation is often called as your Herrmann Mauguin notation which is basically a method to represent the symmetry elements in the point groups. And it is basically a notation named after this German scientist a Hermann and French scientist Mauguin. So, this is often it is called as an international notation as well. So, this is a very convenient way of representing the symmetry.

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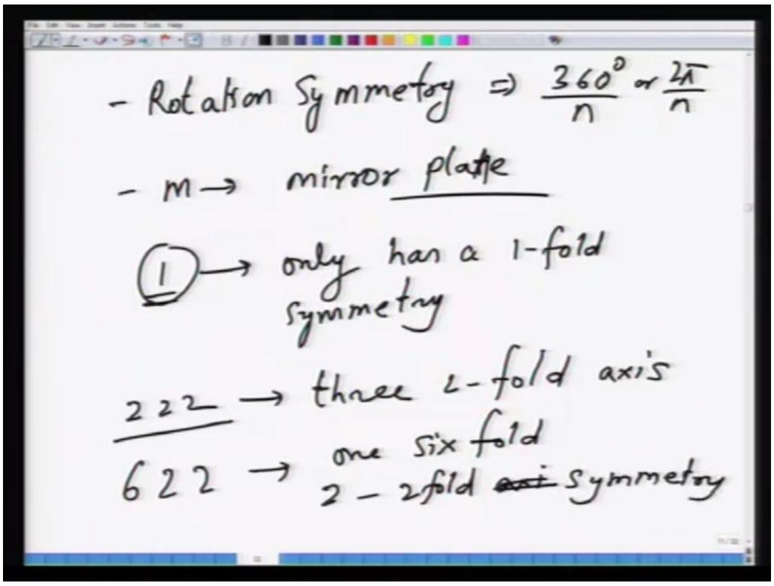

So, for instance this; so, rotation symmetry is given as 360 degree divided by n or 2 pi by n, where n is the rotation fold rotation symmetry then, you have m which represents mirror plain. So, for instance if you have for a given material let us say a cubic material you have 4 by 1 is this symmetry element for material which means the material only has a 1 fold symmetry which is nothing but 2 pi. So, which means this material is the worst possible candidate in term of symmetry operations. And then for a for instance you can also have 2 2 2, and this 2 2 2 will mean this material has 3 2 fold axis and for instance, if you have something like 6 2 2. So, this has 1 6 fold and 2 2 fold axis symmetry.

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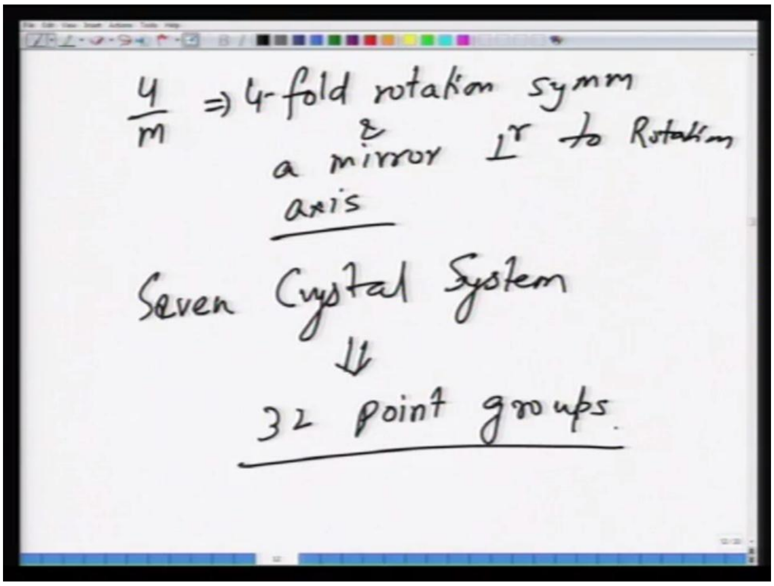

If you have symmetry like written as 4 by m, what it means is that it has a 4 fold rotation symmetry combined with and a mirror perpendicular to rotation axis. So, likewise there are, if you take for 7 crystal systems. So, 7 crystal systems, there are 32 point groups, and you know what these 7 crystal systems are. So, these 7 crystal systems happen to be. So, if you go to.

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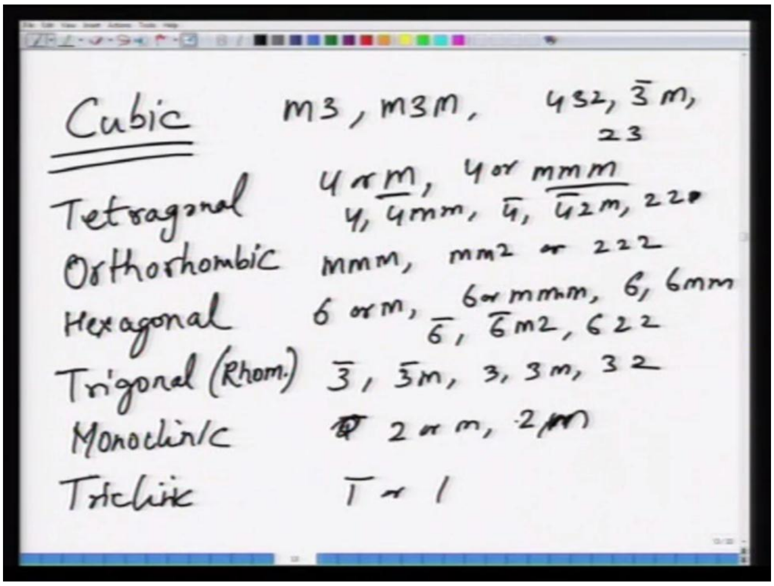

So, first is cubic and for cubic the symmetry elements happen to be the point groups happen to be m 3 and m 3 m and then, 4 3 2 and bar 3 m and 2 3. So, m 3 would mean it has a mirror axis, and a 3 folds rotation then, it has mirror plain. Then, 3 fold symmetry and rotation symmetry is another mirror plain. Similarly, a 4 fold rotation, 3 fold rotation and 2 fold rotation. And this would mean a 3 fold roto inversion followed by a mirror plain and then this 2 3 will mean 2 fold rotation axis, and 3 would mean a 3 fold rotation axis.

So, cubic has these symmetry elements, likewise tetragonal, orthorhombic, and then, you have what is called as hexagonal, and then trigonal; trigonal is nothing but a rhombohedral, and then monoclinic, and then triclinic. So, there are 7 triclinic. So, there are 7 crystal systems for all these 7 crystals they are well defined this notations. So, for instance now I will go to for cubic, you had m 3 m 3 m 4 3 2 bar 3 m and 2 3, for tetragonal, we will have 4 4 or m. So, basically 4 fold symmetry or a m which is equivalent mirror plain or you will have 4 or m m m. So, either m or m mm and then, you will have 4 4 m m bar 4 bar 4 2 m and 2 2. So, these are the symmetry elements for tetragonal. For orthorhombic, we will have only 3 m mm or m m 2 or 2 2 2. For hexagonal, we have only 6 or m which is similar or 6 or m mm. Now, this 6 will mean 6 fold rotation and then 6 and then 6 m m. Now, you must be wondering why I have this sixes differently I will explain to that in a minute to you in a minute. And then, you have bar 6 and bar 6 m 2 and then, 6 2 and then so on. And so forth, so these again will have some limit elements so or may be, let me just write them.

And then, trigonal you have bar 3 bar 3 m 3 3 m and 3 2. For monoclinic you have bar 1 2 or m 2 and then again m. And then for triclinic you have either bar 1 or 1 only 2 symmetry element. So, here you have 2 m or 2. Now, further these symmetry elements for each crystal system can be defined on the basis of whether the material is center symmetric or non center symmetric.

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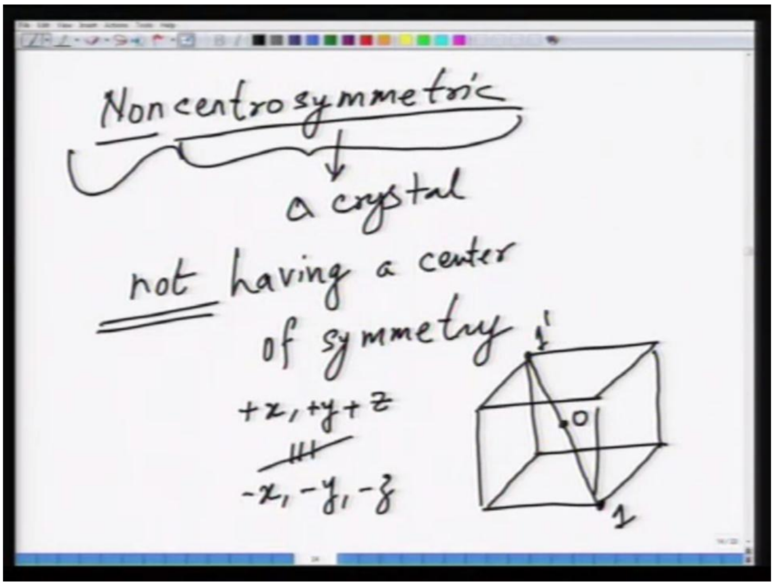

So, the question is what is non centrosymmetric or centrosymmetric. So, non centrosymmetric; centrosymmetric means a crystal which has a center of symmetry. So, centrosymmetric means a crystal having a center of symmetry and geometrically what it would mean is that, you have a center for instance you draw this cube here alright.

So, in this cube, let us say I draw this body diagonal, and this is let us say a point o around. This point I have symmetry operations center of the, this point o is center of symmetry, because anything that you see here at this position. Let us say 1 is equivalent to what you see as 1 prime. So, this o becomes center of symmetry in a more general fashion what it means is that whatever you see at plus x plus y and plus z is equivalent to minus x minus x minus y and minus z. So, a center of symmetry would be between these 2 positions and on that particular center of symmetry, if you look either at plus plus x plus y plus z or if you look at minus x minus y minus z across that center of symmetry you would find the environment to be similar, which means that crystal has a center of symmetry.

Non center of non center of symmetric material would mean a material which does not have a center of symmetry, which means a crystal not having a center of symmetry. So, this not will come here, which means this plus x plus y plus z environment would not be equivalent to minus x minus y minus z across that center of across that point, which means that material does not have center of symmetry. So, based on this you can classify these crystals in two groups. So, 1 would be Centro symmetric crystals and other would be non centro symmetric crystals. Now, what I am going to do is that i am going to further classify these crystals.

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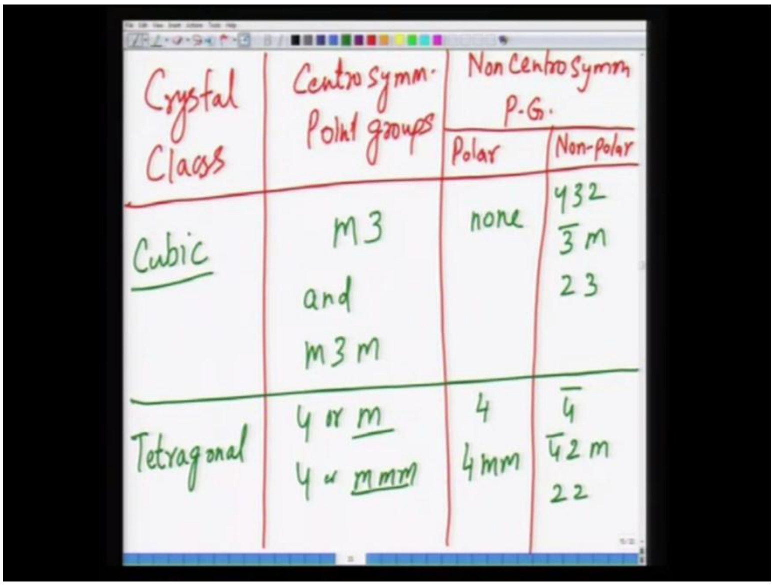

So, if make here a table. So, this is a crystal class and then centrosymmetric point and then non centrosymmetric point groups. Now, even on the non non centrosymmetric all, now all the centrosymmetric point groups by definition are polar. So, non polar means they do not have, if you take the average dipole moment or average polarization, because of symmetry, centrosymmetricity there is no component which survives in the non centrosymmetric point groups again you have two different groups. So, here I can divide this in 2 parts; one would be polar and one would be non polar. So, materials despite being non centrosymmetric happen to be non polar, and this would start from for instance, let us say we start with cubic. So, if you take for cubic systems; for cubic system the centrosymmetric point groups are m 3 and m 3 m. And for this polar it is none, there is nothing in cubic class which is polar and non centrosymmetric. However they were they are few which are non polar 4 3 2 bar 3 m and 2 3; this is for cubic.

And, if you go for a tetragonal; tetragonal would mean you have either 4 or m and 4 or m m m. So, you can say m and m m m and then, you have in polar; you have 4 and then 4. So, I am just rewriting what I wrote earlier in the previous slide. But it is just that now I am differentiating these on the basis of centro symmetric and non centro symmetric point groups, and further on the basis of whether the material is polar or non polar. So, this becomes bar 4 bar 4 2 m and then 2 2, so just keep counting them.

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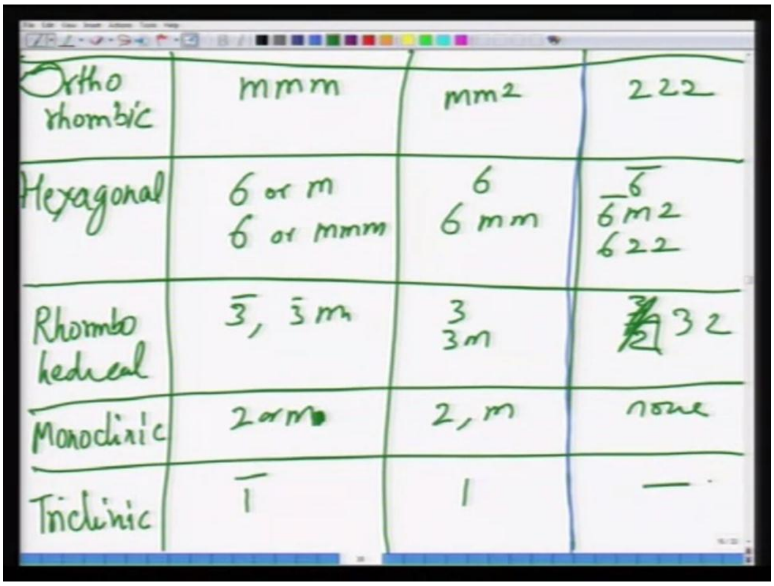

And then again I will not the write the title header. So, here I will take now orthorhombic. So, in case of orthorhombic your centrosymmetric point groups are m m m and non centrosymmetric point groups. So, if I just draw this line differently. So, that this class you associate with non centrosymmetric.

So, this could be m m 2 here only and then 2 2 2. So, now it is trigonal, in case of trigonal, it should be hexagonal in case of hexagonal it will be 6 or m 6 or m m m. And here it would be 6 6 m m, and it would be bar 6 bar 6 m 2 and 6 2 2. And now, we will take rhombohedral. So, you have bar 3 and bar 3 m and here it would be 3 3 m and non centrosymmetric, non polar would be 3 2. And then of course, monoclinic here it becomes 2 or m, and this would be 2 comma m none. And then finally triclinic bar 1 1 none.

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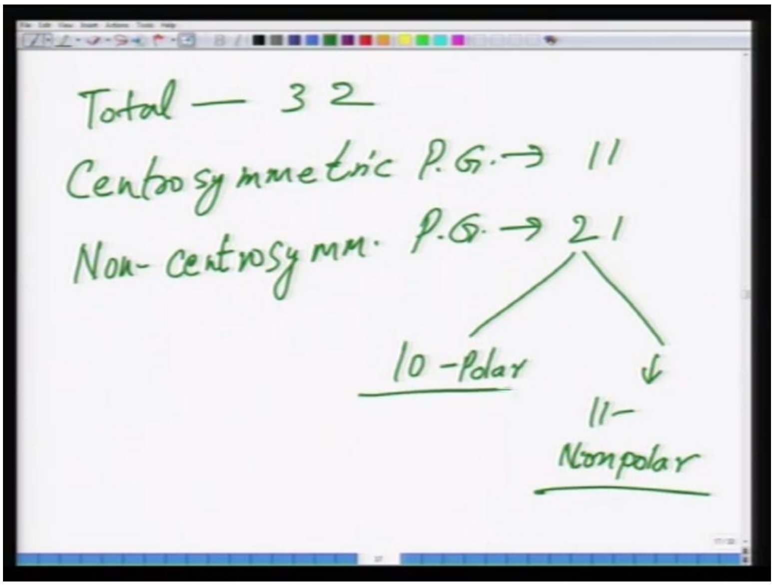

So, if you now count so what you get is total number of point groups total is 32 centrosymmetric out of these out of these centrosymmetric are 11. And then non centrosymmetric out of these are 31, 21 and out of these 21 your 10 are polar and 11 are non polar.

Now, we have established a basis of crystallographic point groups and divided them into various groups. So, what we have is 11 centrosymmetric point groups for all crystal systems put together, 21 non centrosymmetric point groups. And out of these 21 non centrosymmetric you have 10 polar and 11 non polar. Now, these 3 classes of materials piezoelectric, pyroelectrics, and ferroelectrics they first of all they all the materials which represent these effect they have to be non centrosymmetric which means 21.

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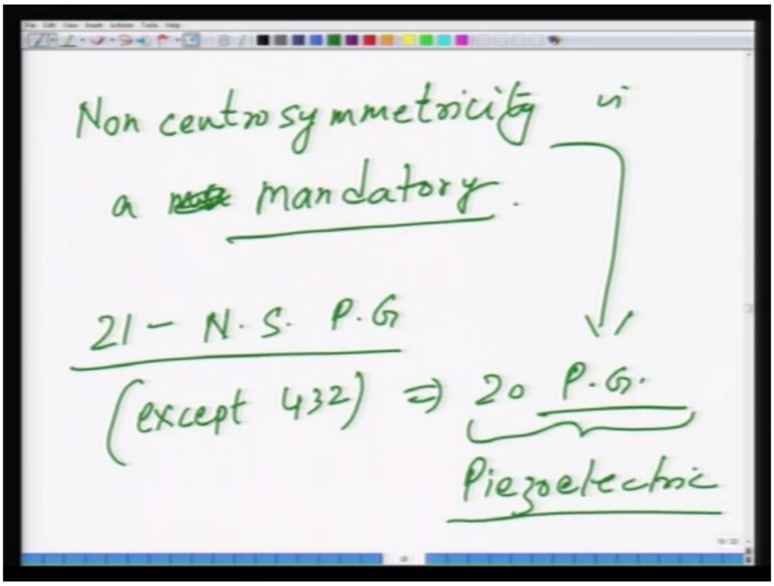

So, non centrosymmetricity is a must, is a must condition is a mandatory condition. So, these materials have to be non centrosymmetric. Now, all the non centrosymmetric point groups which means 21 non centrosymmetric point groups, out of these 21 non centrosymmetric point groups, except 4 3 2. So, this would be 20 point groups, and all these are non centrosymmetric point groups. All these all the materials which belong to this 20 non centrosymmetric point pointgroups whether polar or non polar they are all piezoelectric.

So, essentially now the definition of a piezoelectric material would be piezoelectric materials are those class of materials which are non centrosymmetric in nature they could be polar or non polar except 432; 432 is an exception to this for the reasons simply, because it is a it happens in the non polar category. And for some fundamental reasons it does not give rise to piezoelectricity. So, 20 non centrosymmetric point groups happen to be piezoelectric. Now, so a piezoelectric material as I said earlier also 20 non centrosymmetric point groups exception of exception is the only exception is 4 3 2 point group that is why it is 20.

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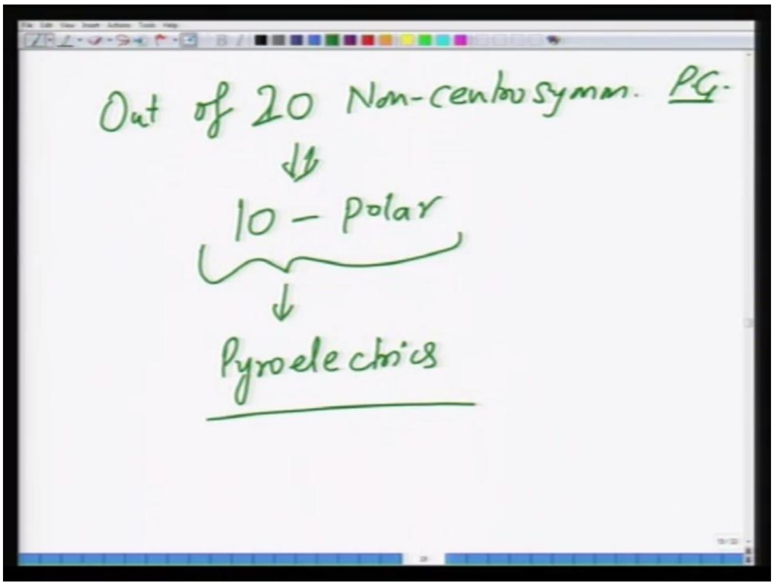

Now, out of these 20, out of 20 non centrosymmetric point groups, you have 10 which are polar. And all of these 10 polar non centrosymmetric point groups represent those materials which are called as pyroelectric. So, by definition you can see that all the pyroelectric materials are piezoelectric materials, but only those piezoelectric materials are pyroelectric which are non centrosymmetric and polar. So, which means only 10 classes, and out of these 10 polar they are a few which are ferroelectric.

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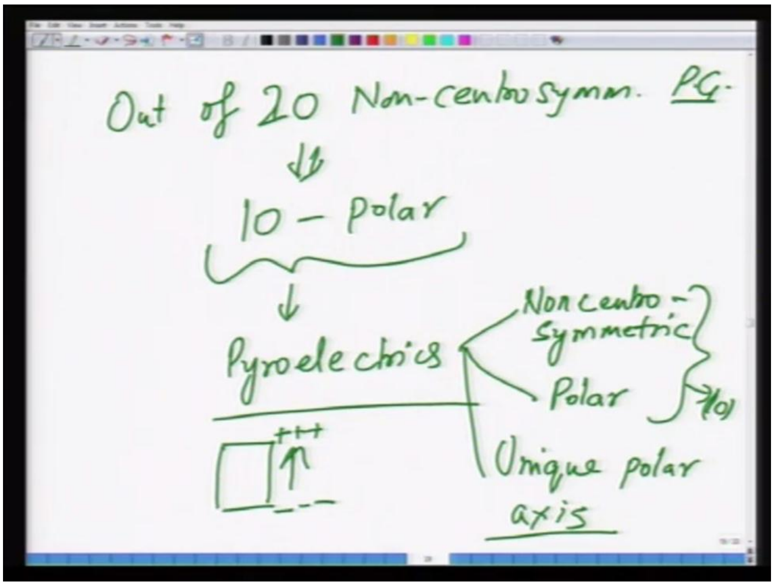

Now, another so another definition of this pyroelectric material is, so non centrosymmetric, so, 1 is non centrosymmetricity polar which gives rise to only 10 point groups, and then they have a unique polar axis. The fact that the material is polar, which means they have this unique polar axis, and along which shows. So, you so basically, if you have a material like this; this is the polar axis which means the properties at the end 2 ends of this axis will be different. So, which means this is a unique polar axis. So, these are the requirements for pyroelectric materials.

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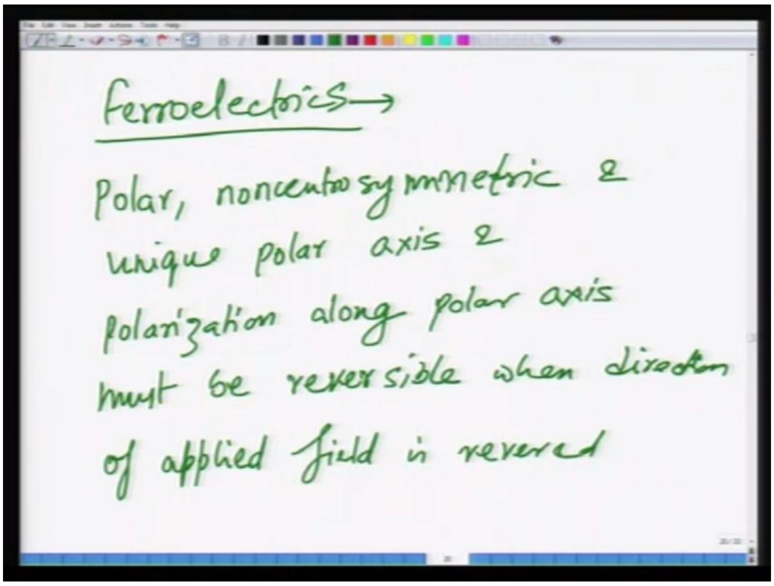

Third is called as a ferroelectric which is you have to now impose certain more constant in on the piezoelectric materials. So, ferroelectrics would be polar non centrosymmetric, and unique polar axis, and the polarization along this polar axis must be reversible. So, which means the polarization along polar axis must be reversible when direction of applied field is reversed.

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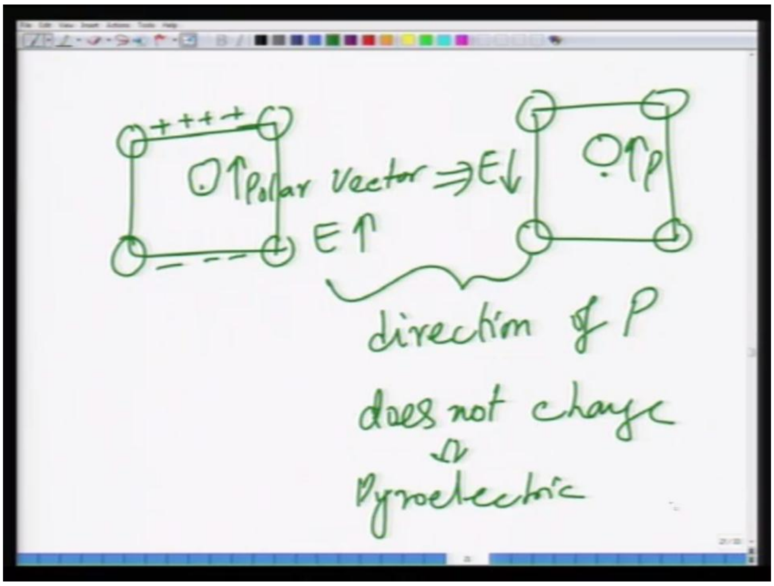

So, basically what it means is that, if you have a pyroelectric material, let us say now a pyroelectric material of course, is non centrosymmetric. So, it will have some deviation of. So, let us say this is the polar vector. So, which means a pyroelectric material is spontaneously polarized. Now, for a pyroelectric material, when you change the direction of electric field, let us say in this case, the electric field was in this direction when you change the direction of electric field. This polar vector does not change so, which means this central atom is still get shifted into this direction. So, which means direction of P does not change when you reverse the polarity of E, and this represent pyroelectric.

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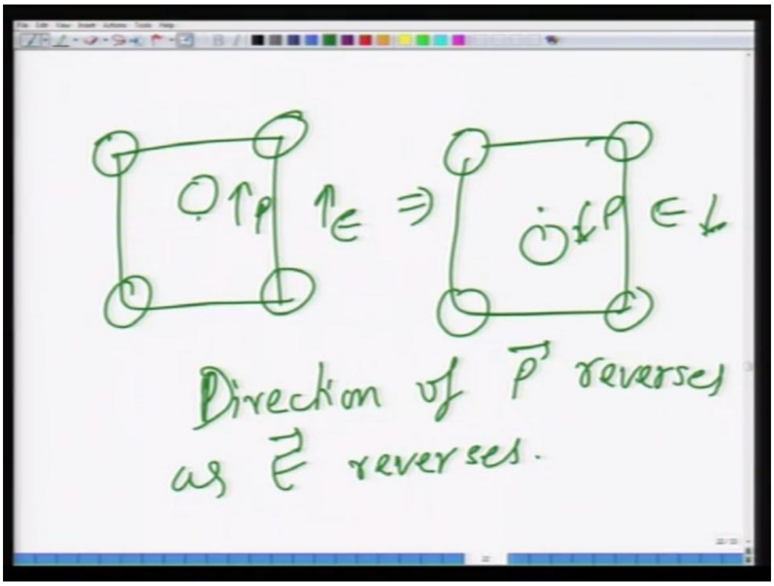

For a ferroelectric what will happen is so, this is let us say P direction. And this is E direction, and when you reverse E when you make E in this direction, the P also becomes in these this direction. So, direction of P reverses as E reverses. So, this is another constraint which has been imposed on ferroelectric material. So, naturally by definition all the ferroelectric materials are pyroelectric materials.

So, now you can summarize these 3, piezoelectric materials are the only constraint tells that they have to be they have to belong to the category of non centrosymmetric point, groups within with the exception of 4 3 2. So, there are 20 non centrosymmetric point groups, and all the materials belonging to these point groups will be piezoelectricin nature. Pyroelectric there is a constraint the material has to be polar in addition to being non centrosymmetric. So, there are 10 point groups the material which, and the material which belong to these point groups are piezoelectric in nature, and they have a unique polar axis which means there are spontaneously polarized.

And then, the third category is ferroelectric material in which not only they are non centrosymmetric, not only they are polar, not only they have a unique axis. But this unique axis the direction of this unique axis is reversible when you reverse the direction, when you change the direction of electric field which is applied. So, naturally there is further more constraint on the pyroelectronic which means not all the pyroelectric materials are ferroelectric, but all the ferroelectric materials are pyroelectric.

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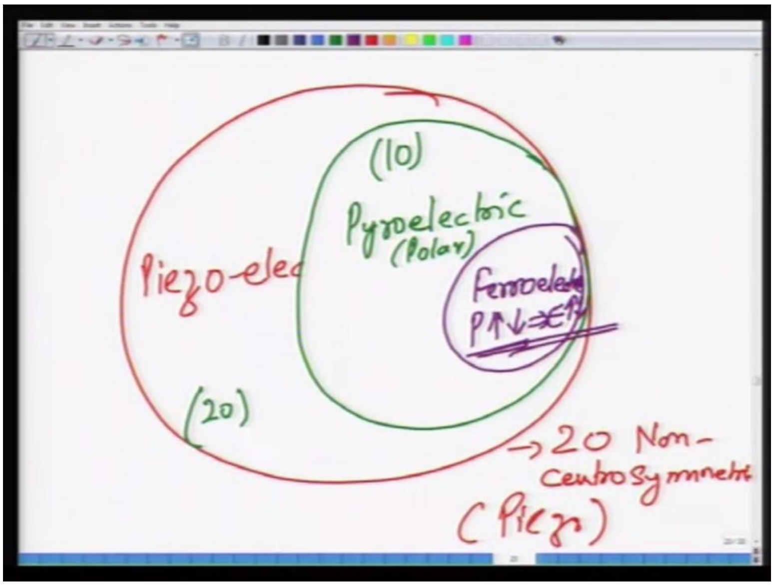

So, when you now make a diagram. So, let us say, so these are 20 non centro symmetric point groups which mean all piezo. So, these are all piezo. Out of these, so this is twenty, out of these 10 are pyroelectric which are also polar in nature. And out of these, you will have some that number is not very well defined, because it depends upon the type of material some which are ferroelectric for which polarization direction can be reversed by reversing the direction of applied electric field.

So, ferroelectric material is the smallest sub class out of all these 20 non centrosymmetric polar groups. And that is why they are very limited in numbers. So, again to retreat all the ferroelectric materials are pyroelectric. But reverse is not true necessarily similarly, all the pyroelectric materials happen to be piezoelectric, but the reverse is not true as well. So, this is a sort of introduction to the crystallographic basis to differentiate ferro piezo, and pyroelectric materials from the other dielectrics that we have learnt in the previous classes.

Now, what we will do is that in the next class, we will finish this lecture here. What we will do in the next class is we will take up the discussion on ferroelectrics materials. To begin with we will look at the, how these materials evolved and the basic characteristics of these materials. And then, we will evolve a thermodynamic basis to understand these materials, because these materials also show certain they are also associated with the certain phase transitions which are unique in nature. And then finally, we will look at the applications

So, we will finish this lecture here. So, to summarize what we learnt was, that you have these non-linear dielectric materials which have very which have unique properties like large dielectric constants. They can also have large polarizations they show effects like coupling of mechanical, and electrical order parameters. And relation co-relation between temperature and the polarization, and then they have this hysteresis loops presence of non zero polarization at zero field. And all these effects are associated with the non-linearity in the, when you plot polarization with electric field. And these classes of materials are unique in nature, and they have huge technological potential, and some of these are already used in variety of applications.

Fundamentally they belong to class of material which are non centrosymmetric in nature. So, out of these non, so most all the non centrosymmetric materials except the 4 3 2 point group materials happen to be piezoelectric which means they have this mechanical and electrical coupling. Out of these non centrosymmetric only polar ones are pyroelectric which means they have a unique polar axis. And out of these 10 polar non centrosymmetric crystal classes point groups, you have not crystal classes rather point groups. So, out of these 10 which are non centrosymmetric in polar, there are some which are ferroelectric in which this unique polar axis. The direction of polarization along that polar axis can be reversed by reversing the direction of applied field. So, we will finish this lecture here and see you next time.