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Lecture-36

Materials Characterization

Fundamentals of Transmission Electron Microscope

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Hello everyone welcome to this material characterization course. In the last class we just started looking at some of the diffraction principles in a transmission electron microscopy. I started talking about conventional selected area diffraction as well as the converging beam electron diffraction. And then and I was saying that a SAD pattern or SAED pattern is obtained in a TM using a parallel beam. And a small probe or a microprobe Nano probe is obtained using the selector I mean converging beam electron diffraction. So we will continue that discussion and if you use an incident beam is convergent.

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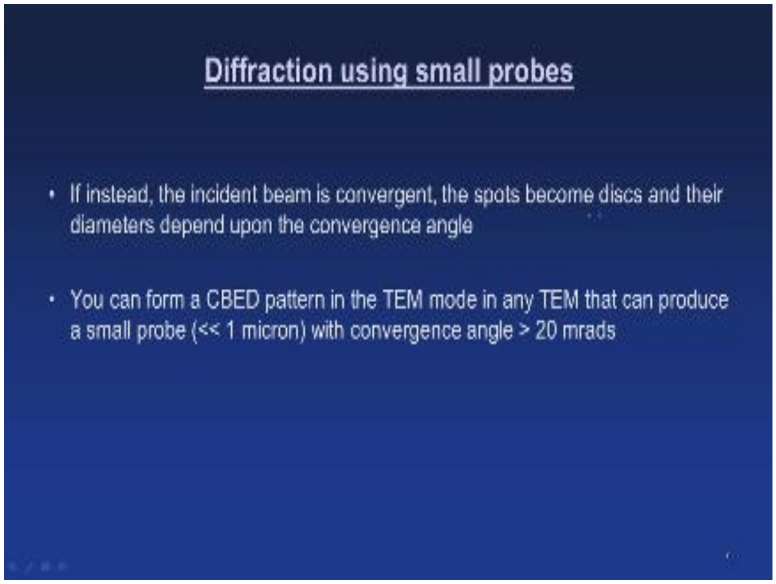

The spots become discs and their diameters depending upon the converging angle 2θ or 2α. Something like that you can form a converging beam electron diffraction pattern in a TM mode in any TM. That can produce a small probe which is less than 1 micron with convergence angle greater than 20 milli radians. So I will just play some of the ray diagram using schematic which will distinguish between a conventional selected area diffraction patterns.

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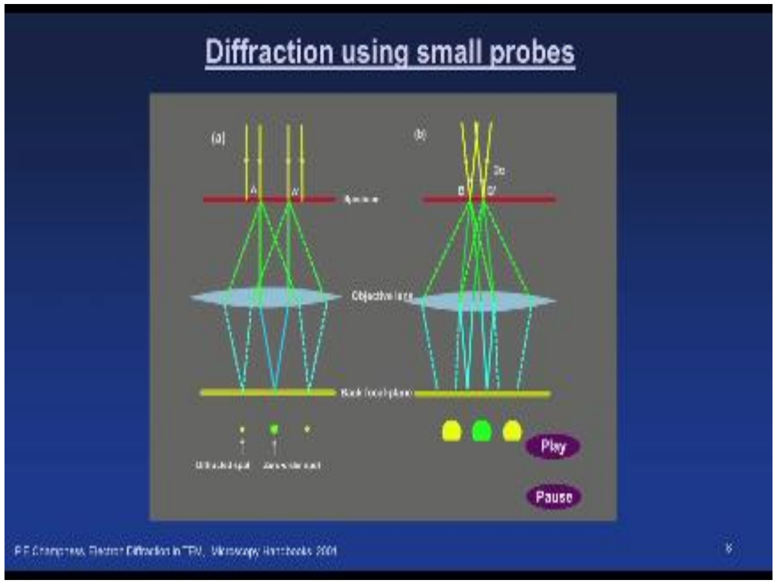

And a converging beam electron diffraction pattern what you are seeing in this schematic a is the conventional electron diffraction. Where you have the transmission transmitted beam is also called as zero or spot. And then you have the diffracted spot which is there this is a conventional a parallel beam elimination. Otherwise you have a converging beam operation where you see at there are 0 or spot and you have the diffracted spot which appears as a disk as compared to the spot in a conventional SAD pattern. So this is an idea we will talk about this and it is application much more detail in the coming slides.

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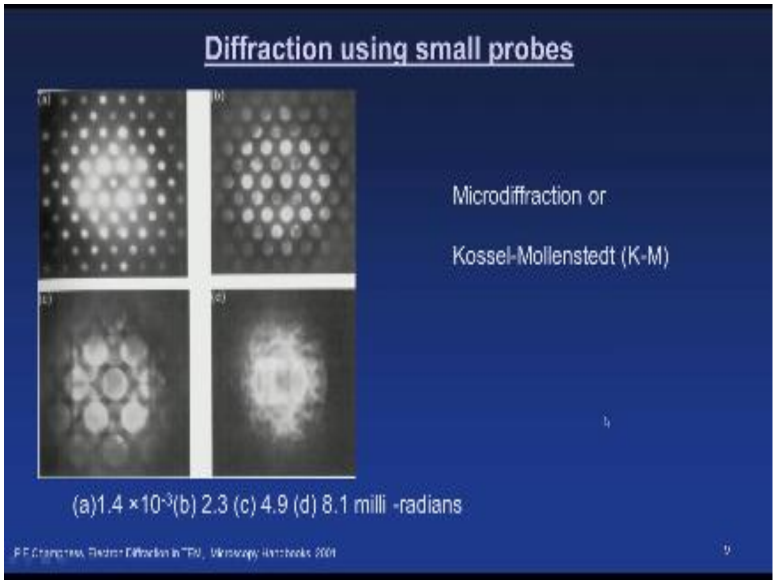

And this is one of the actual electron diffraction pattern taken from this textbook and what it shows is four different kind of patterns you get depending upon the, the angle. Your angle so the first one is 1.4 in10 to the power minus 3 and second one is obtained with the 2.3 and third one is 4.9 and fourth one is 8.1 millions. So you can obtain a micro diffraction or Kossel molested diffraction pattern depending upon the different converging angles. So this is first information about the diffraction using small probes okay.

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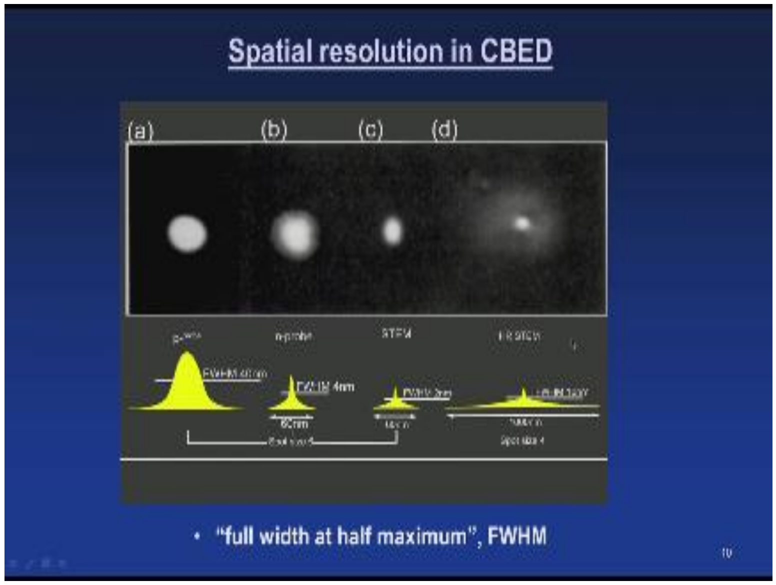

What is important here is always we talk about a probe size at a probe diameter what is the physical meaning of this. So in order to explain that I brought this slide so the, the probe normally what we see in a in an electron microscope is nothing but a full width of maximum. So you see that you know the corresponding you see that corresponding profile intensity profiles are shown in this here. And then you have the actual image in the microscope they will appear on the fluorescence stayed like this. So you have the different probe for example if you take a spot size of six which will have a probe diameter of this order that is 40 nanometers 4 nanometers and 2 nanometers.

So on you have Nano probe or a stem mode or a normal probe you will have this kind of an intensity profile. And if you go to the HR stem high resolution mode you, you see that the probe diameter is as small as possible nearly 10 nanometers. So which belongs to the spot size 4 so if you go to the microscope they will give the inner dial with the numbers which one each side each number will belong to particular probe diameter. The physical meaning of the probe diameter is a full width of maximum so just you have to appreciate that fact that is why I brought the slide what is the meaning of a probe diameter.

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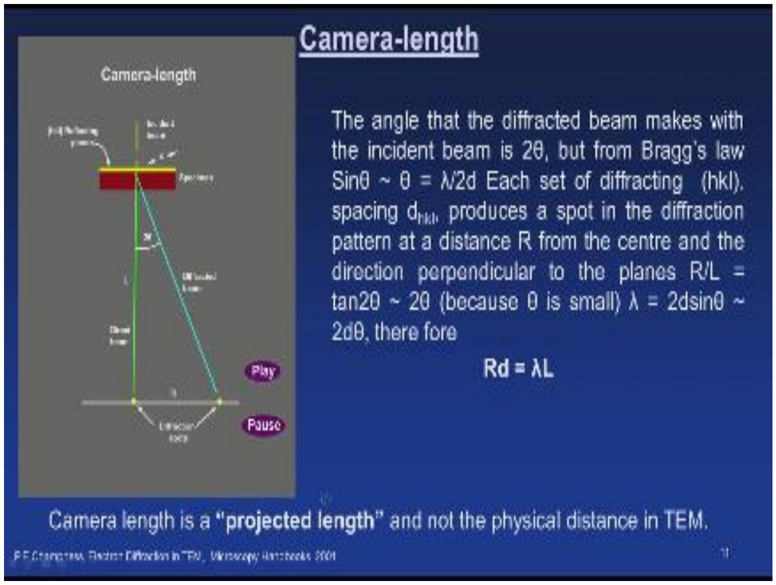

Next important thing is camera length just now in the last class we have seen the one of the operations I mentioned that we need to calibrate the camera length. We will look at the details how do we get this relation with the camera length and the D spacing of the specimen. So it is a similar ray diagram what we have gone through incident beam this is as sample. And then you have the back focal plane transmitted beam a diffracted beam the distance between the specimen and the back focal plane is L. And then you have the 2 θ diffraction angle. The distance between the transmitted beam and the one of the diffracted beam is R. So the angle that the diffracted beam makes with the incident beam is 2θ.

But from the Bragg's law we know that sine θ is equal to theta sin θ is too small which is equal to λ by 2D each set of diffracting plane spacing BHKL produces a spot in the diffraction pattern at the distance R from the center. And the diffraction are sorry and the direction perpendicular to the planes R / L = R /L tan2θ. Which is approximately equal to 2θ because θ is small so you can write λ = 2D sine θ = 2D θ. Therefore RD can be written as L λ. So this relation comes from this approximation and the camera length what we are calibrating are using is a projected length and not a physical distance in Tm. So you have to be very careful about this aspect it is always a projected length and not the physical distance in the TM.

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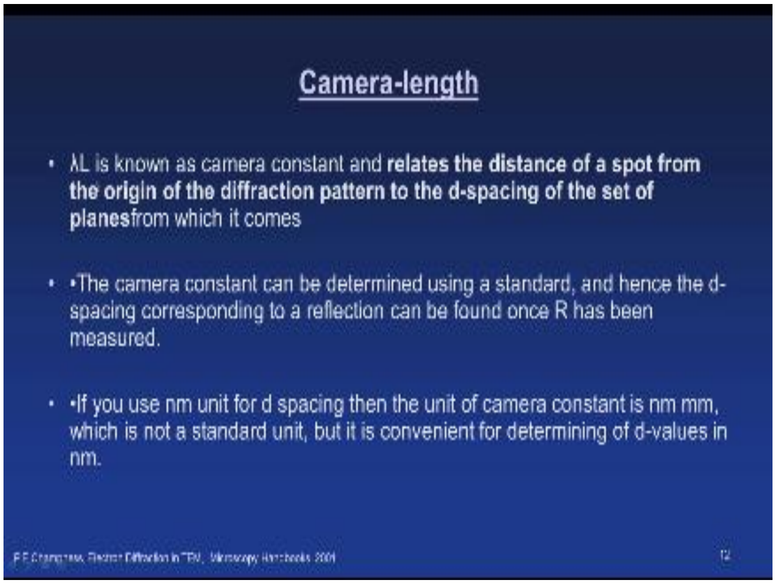

So you have to know this basic idea about this camera length if λ L is known the camera constant and relates the distance of a spot from the origin of the diffraction pattern to their d spacing of the set of planes from which it comes. The camera constant can be determined using a standard and hence the D spacing corresponding to a reflection can be found once are as being measured. So this is the experimentally measured quantity from the film or from the diffraction image you measure the distance R. And if you use a nanometer unit of for D-spacing then the unit of a camera constant is nanometer mm.

Which is not a standard unit but it is convenient for determining their D values in the nanometer scale. So we will we will appreciate this a simple concept when we actually try to index some of the diffraction pattern using a camera, camera length as well as the corresponding distance R from a given pattern.

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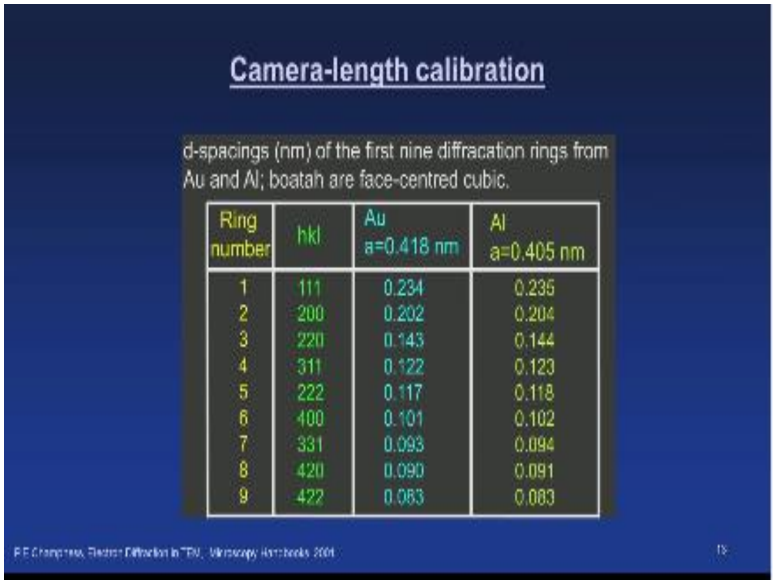

Camera-length calibration

d-spacings (nm) of the first nine diffracation rings from Au and Al; boatah are face-centred cubic.

Ring number	hkl	Au a=0.418 nm	Al a=0.405 nm
1	111	0.234	0.235
2	200	0.202	0.204
3	220	0.143	0.144
4	311	0.122	0.123
5	222	0.117	0.118
6	400	0.101	0.102
7	331	0.093	0.094
8	420	0.090	0.091
9	422	0.083	0.083

So this is the typical calibration I again I am repeating this D spacing in nanometer of the first nine diffraction genes from gold and aluminum. Both are no face centered cube that is so you can have these values for the reference.

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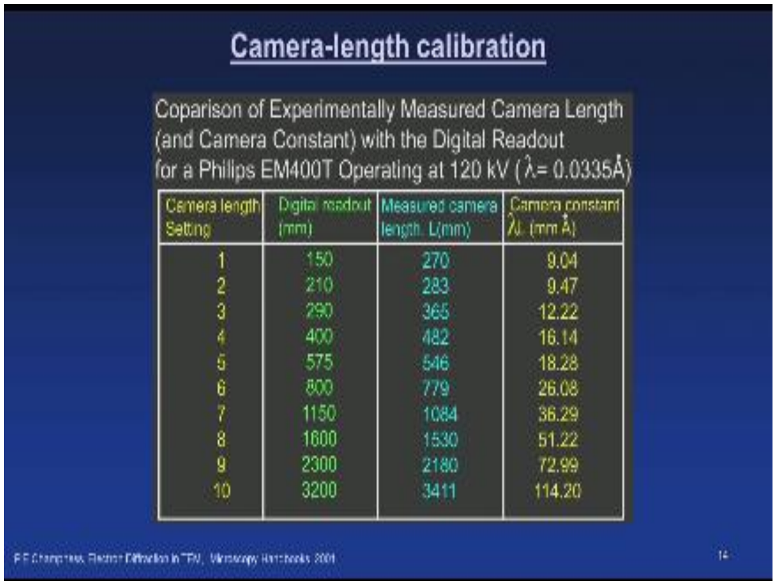

Camera length Setting	Digital readout (mm)	Measured camera length. L(mm)	Camera constant λL (mm Å)
1	150	270	9.04
2	210	283	9.47
3	290	365	12.22
4	400	482	16.14
5	575	546	18.28
6	800	779	26.08
7	1150	1084	36.29
8	1600	1530	51.22
9	2300	2180	72.99
10	3200	3411	114.20

And this is a calibration chart we will come back to this when we do an exercises then that will be that we make more sense rather than I go through this values.

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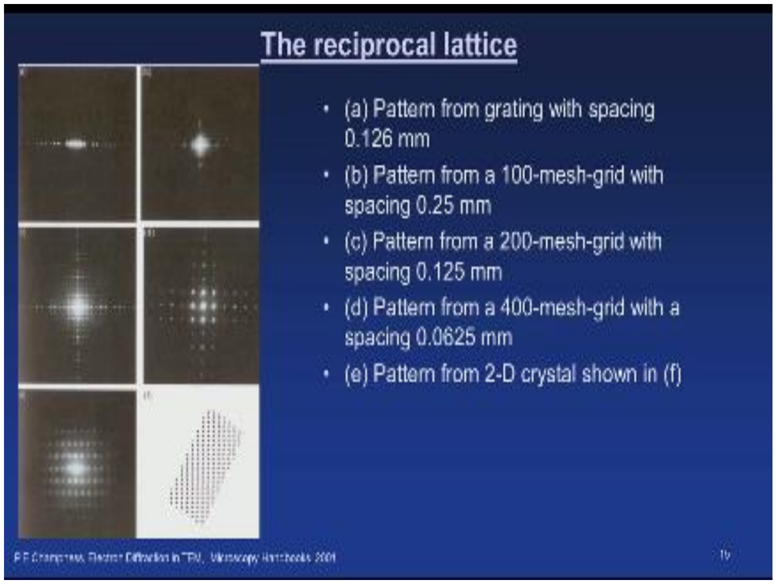

Now I will come back to the reciprocal lattice concept which I talked about a during the fundamentals of electron optics as well as that I mean fundamental of this course self be discussed about this. This is the second time you are seeing this image and the assets the reciprocal lattice concept has been discussed again in X-ray diffraction here also it the same just to have much more confidence. Let us go through this what you are seeing is in an optical diffraction pattern taken from the grid. Grid is nothing but kind of mesh it could be a metallic mesh or it could be of any material made of any material it is like something related to something similar to grating it is a mesh.

So the pattern A, B, C, D and E they are all optical a diffraction pattern obtained from the grading. The pattern A from a grading with the spacing of 0.126 mm pattern B from a 100 mesh grid with the spacing of 0.25 mm pattern C from a 200 mesh grid with the spacing of 0.125 mm pattern D from a 400 mesh grid with the spacing of 0.0625 mm pattern E a pattern from the 2D crystal shown in F. So what you have to appreciate here is the there is a relationship between the distance we in the spot in a diffraction pattern to the grid spacing. There is a relationship so you can appreciate that the as the spacing in the grid decreases the distance between this part increases.

So this is a reciprocal relation here so we can make some statement about based on this sub reservation.

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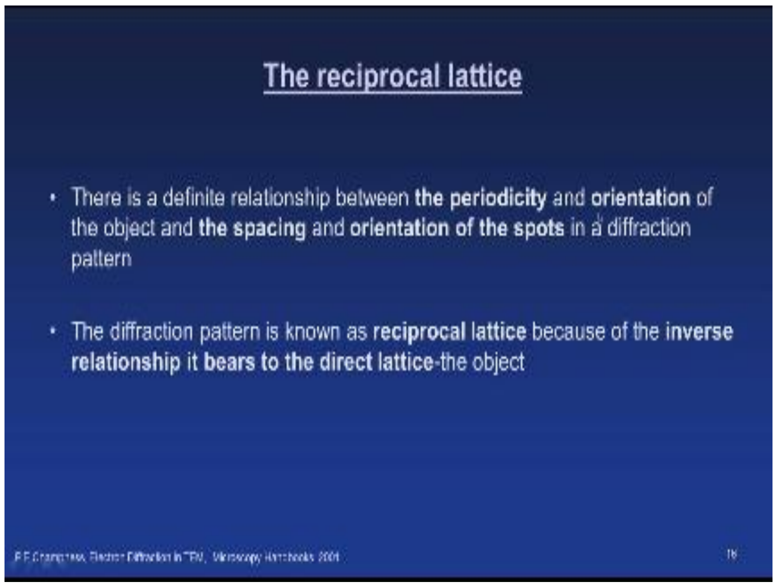

There is a definite relationship between a periodicity and orientation of the object and the spacing and orientation of the spots in the diffraction pattern. So the diffraction pattern is known as a reciprocal lattice because of the inverse relationship it bears to the direct lattice that is the object. We have seen this already I will just play some animation.

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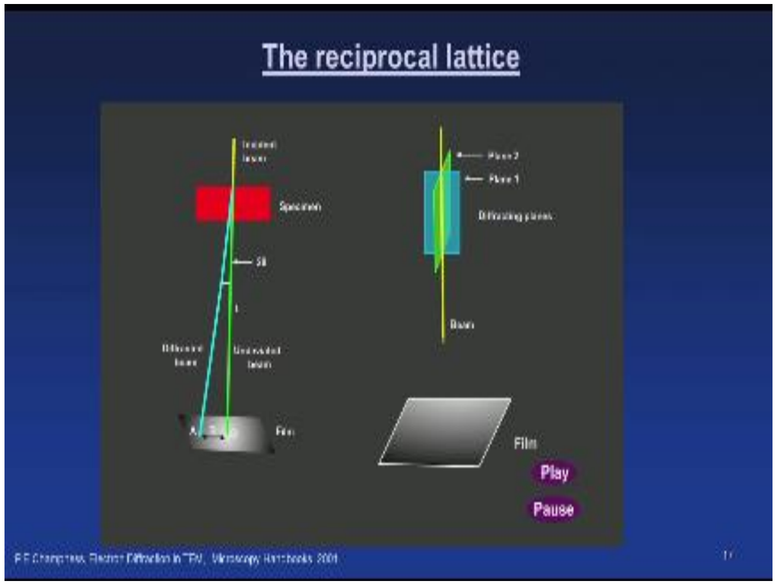

So what you are seeing in this animation is this is a undeviating beam from the specimen and this is a diffracted beam here. And what is shown in this right-hand head I turned head image is the intersection of two planes plane one and plane too and this is the electron beam and this is the screen on which you see the diffraction spots appearing here. And I want you to look at this schematic much more carefully because you see that a plain one is drawn in one color and plane to is drawn in another green color. And then, the diffracted spot corresponding to plain one and plain two are also indicated with this same color of the plane.

So you see that a plane to you see the diffracted spot appearing in the line which is 90° to the plane orientation you can see that it is 90° to the plane orientation. Whether this side or that side similarly you look at the plane one the diffraction some diffracted spot appears exactly on that space which is a 90° to the plane one orientation. So this is very important and for a clarity only two planes are shown here in principle you can have N number of planes or it could be more planes also. Where a diffraction can occur and then you will see the corresponding defected spot in the screen like this.

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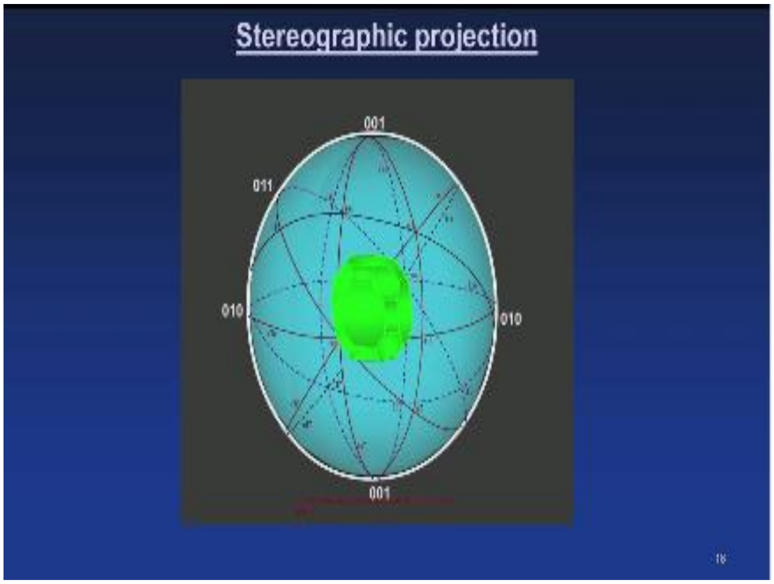

Now we will take you to another concept which is very important in analyzing the diffraction pattern called a stereographic projection. So like you have NM an atlas where all the you know countries regions are drawn in one scale they are all called you know area true projections here. You have angle true projections so stereographic projections are called angle true projections similar to atlas where you have area true projections. So the idea of the stereographic projection is what you are seeing on the screen is like you assume that you assume that you are placing a small cubic crystal inside the center of the sphere.

And you try to draw a normal to this cube and then which comes and interesting intersects the surface of the sphere. And each one is each one plane normal which comes out and hits the surface of the sphere from the center is called a poles each one poles. So I will just show one very nice animation.

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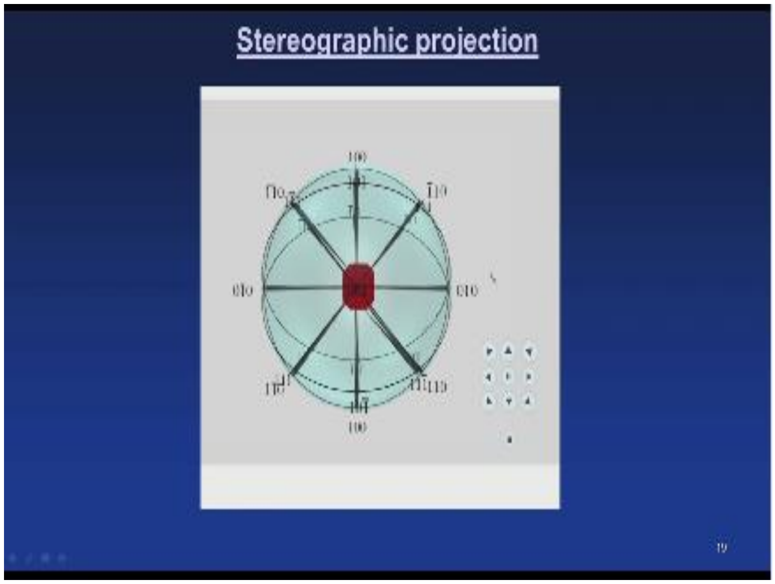

Where you will appreciate what I am trying to say you imagine that I have kept one a cubicle crystal inside the sphere. Now the assume that the sphere is transparent and I have just put that in 2001 orientation from this from. The plane of the screen the purple is the plane normal of the screen itself 001. So in that projection I have put the crystal inside the sphere now I will try to rotate this sphere you will appreciate what I am trying to say you see that the crystal each plane normal which comes and intersect the surface of the sphere.

You can see these are all poles individual poles so the top one is 100 the bottom one is the opposite in fact it should be bar100 here it is 0, 0, 1 and the opposite side is you can see that 00 bar one you can see that. So like that you have all opposite poles here and there the idea is if you represent your I mean plane under directions with this we will be able to analyze the crystal crystallographic orientation much more easily. So I have just shown one simple thing you can look at this kind of a projection system and as I just mentioned all these poles. And which will have a perpendicular I mean particular angle for example 1, 0, 0 and 0 1 0 will have a 90° and 1 10 and 0 1 0 will have about 45°.

So like that you can you can just visualize the angle between two planes normal so that means you will be able to identify the angle between the planes. And then you will be able to represent the crystal crystallography orientation much more easily. And then we will use this concept to I mean explain some of the reciprocal lattice concept as well as some evolves fear concepts we will use it. And this is just for your introduction just you have to just imagine how this stereographic projection can be viewed in all these four five directions. So you can see all the important poles are indexed and then how they rotate. So now after going through this I believe that you have some idea about this what a stereographic projection.

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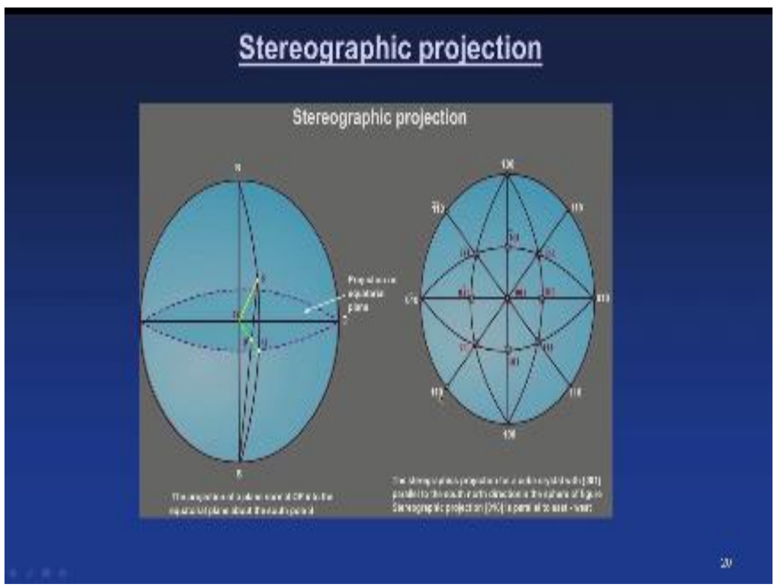

So now what you are seeing is all a 2d projection what I have just shown in animation is a 3d so this is the same thing what I have shown 001 projection I have shown it is represented in the 2dlike this. So this is the stereo graphic projections for a cubed crystal with 001parallel to the south north direction the sphere of the figure, figure 3geographic projection is 010 is parallel to the east west. So this is what it is shown here so here how you can just look at the sum of the poles.

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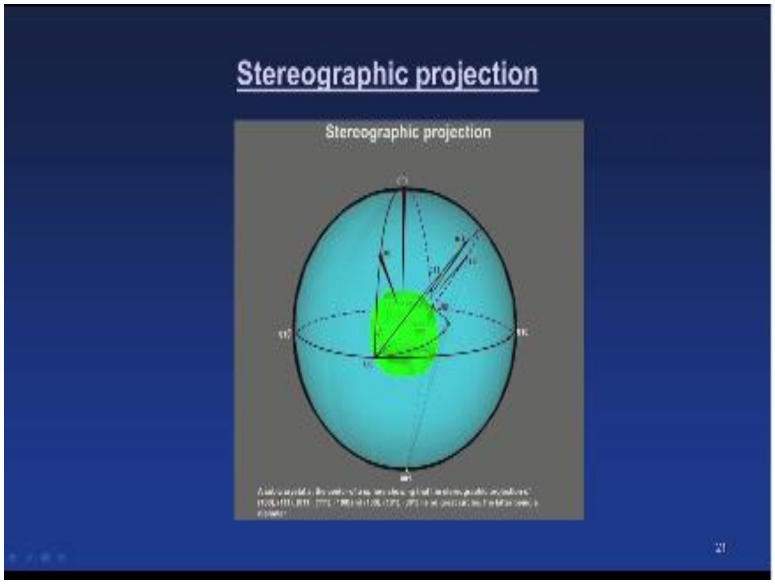

Are returned here this is how the sum of the economic nature which I am not going into the detail and the basic idea I want to show it here is in using the stereogram you will be able to represent the crystallographic direction that is all I would like to say. And if time permits we will solve some small problems using the stereographic relation and also try to plot some of the polls am on a graph like this a wolf net divided into two degree divisions.

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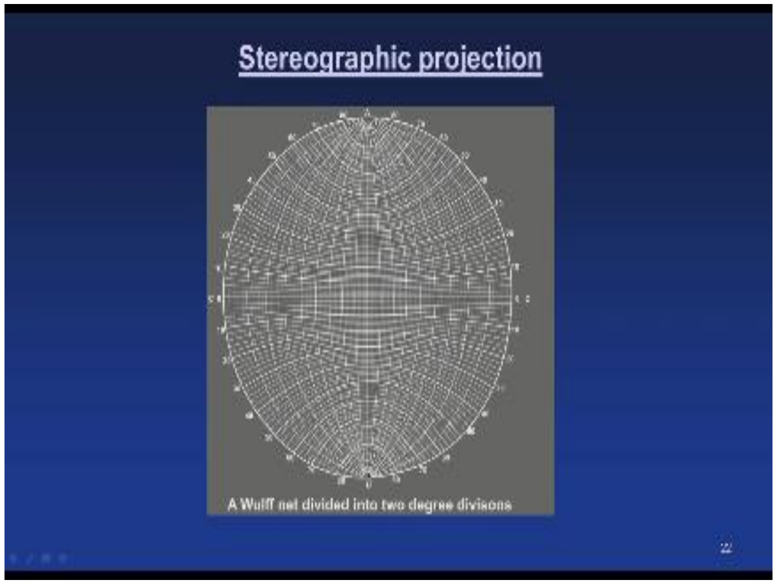

You can actually plot some of the poles and then try to do some kind of an exercise of rotating each pole what will happen what kind of stereographic projections you will be able to visualize that we can do it. And I am introducing this technique as a tool which can be with this tool we can represent the orientation of the crystal much more clearly. That that is the information I want to give at this point of time and when we actually go through some of the exercises are solving the tutorial problems we will be able to appreciate how this tool can be used.

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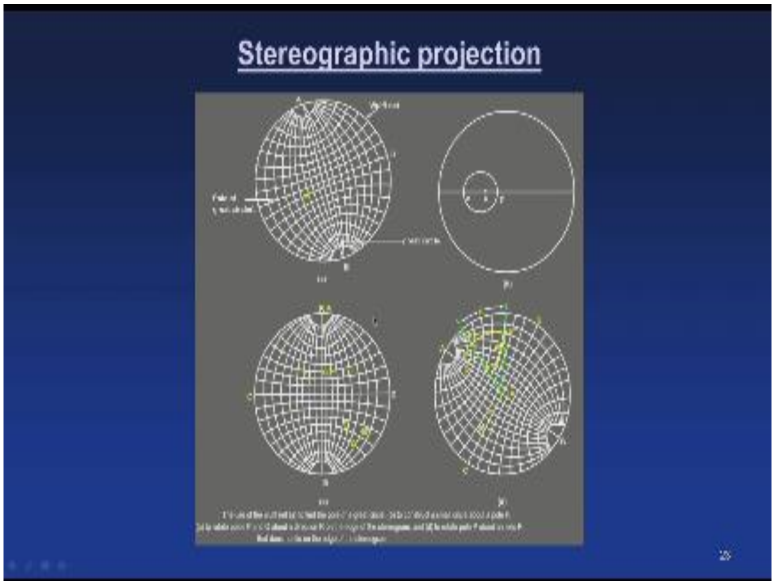

So this is just for one their references where some of the polls are being rotated here and you can appreciate that how the angle true projections is very effectively represented in a 2 d fashion. That is the basic idea and this is the standard stereographic projection for a cubic structures 1 is 0, 0 1 and 1, 1 0 C 1, 1, 1and D 1 12.

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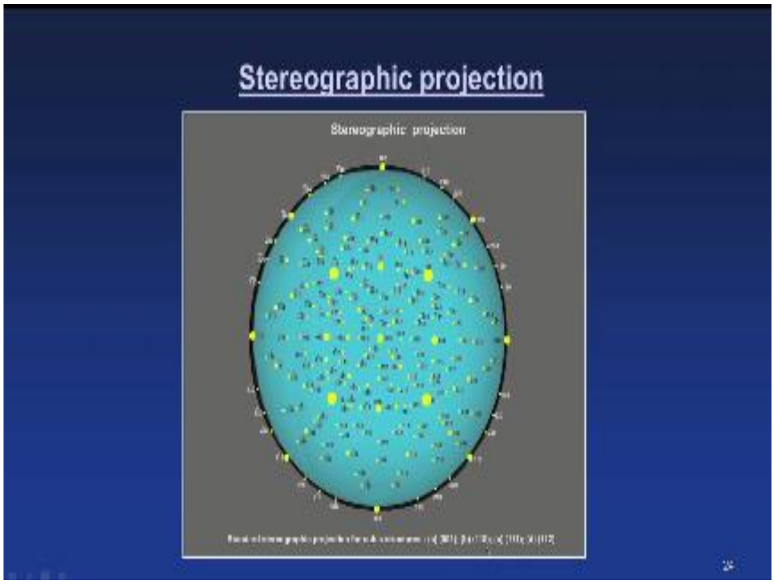

So here is this there is only one projection is shown here but other projections I are not shown and what you are seeing here is this is for a 0, 0, 0 1projection for cubic system where all this spot shows the parallel orientations of another system like this. And suppose if you look at the stereo projection of both BCC and FCC their poles our index like that so you will be able to measure the angle between the two poles of the different crystal system here. And for example some of the poles are very closely parallel that means 0, 1, 1 of BCC is parallel to one, one, one of FCC are 111 of BCC is parallel to zero sorry 101 of FCC and211 of BCC is parallel to one to one of FCC something like that.

You can you can see all these things are if they are exactly parallel both of them both the points will coincide and if it is not parallel then you can see that how far they are away from each plane that means the angle will tell you the orientation of each plane. That means you can relate the plane which is suppose if you have a two phase system one is BCC and an FCC you will be able to relate the parallel planes of the two systems. So when they are in parallel, parallel to each other then you will form what you will obtain a diffraction pattern straight so that means because diffraction patterns are obtained only.

When the planes are parallel to each other so by looking at the stereogram you will be able to identify the poles which are parallel that means the plane normal are parallel then that in actual physical meaning it is a plane sir parallel. And then you will get a corresponding diffraction pattern in a back focal plane you will be able to analyze both the patterns and then you will be able to correlate the relationship between are the orientation relationship between at two crystals using this stereographic projection so that is the basic idea about this stereographic projection I do not want to get into the detail due to the lack of time.

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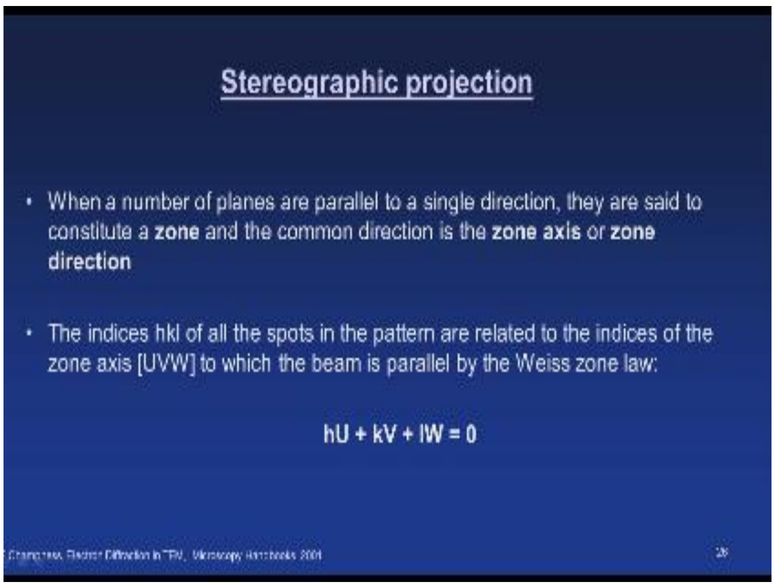

But you should know why this is being used when a number of planes are parallel to a single direction they are said to constitute a zone and the common direction is the zone axis or a zone direction.

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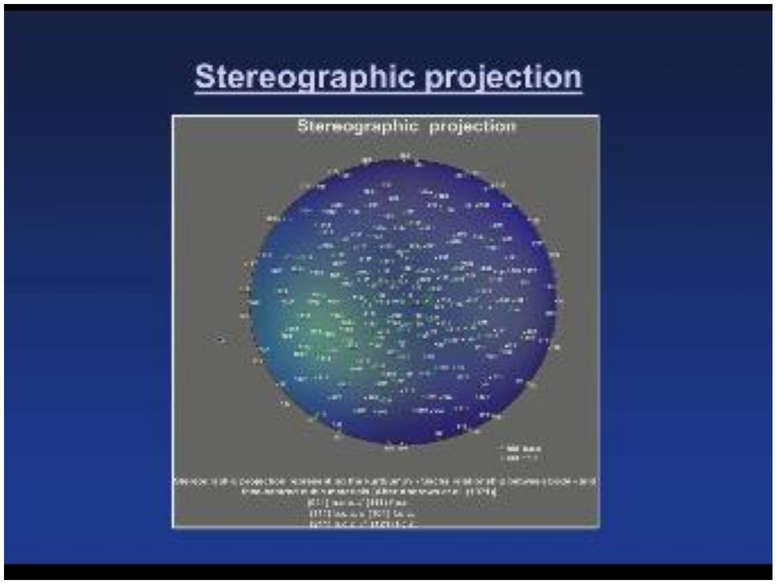

For example if you go to this particular zone for example 001 what are all the parallel directions you will be able to identify with this geographic.

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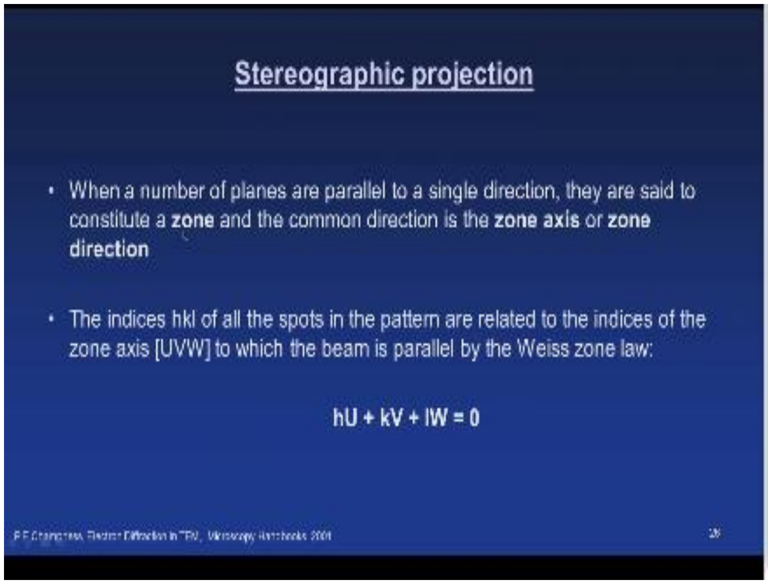

So when you say a zone axis so you will be able to identify number of planes that are parallel to the single direction which can be easily identified by using stereographic projection the indices hkl of all the spots in the pattern are related to the indices of the zone axis UVW to which the beam is parallel by the v's zone law so you have the very powerful relationship which is given by V is own law.

You can identify the HKL and the scale of the spots in a pattern and it is zone axis they will have the relations like this hu + kv + l w is equal to 0 so this releasing this relation you will be able to identify some of the planes which are parallel to this zone so this is very powerful law and we will be able to we will be using this relation when we index some of the diffraction pattern and finding out the parallel planes.

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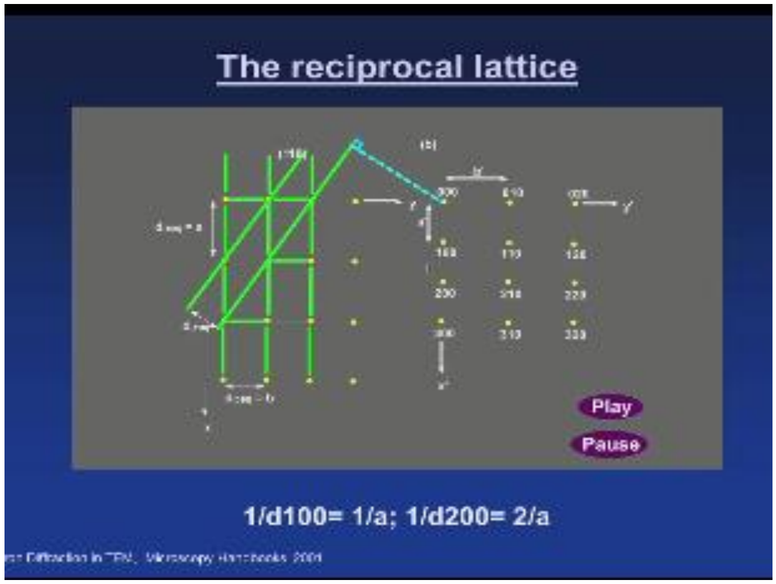

Now what I will do is I will again come back to this reciprocal lattice what you are now seeing is a schematic animation where you have the real lattice and it is relation with the corresponding reciprocal lattice here you will be able to draw this physically because all that you need to know the information about for example it is 1/ D of 100 plane which is equal to 1/a or 1/ D 200 type of plane is equal to 2/a.

And then the angle between them so you will be able to draw physically when you have the basic information from the real lattice for example this is a and this is me and this is a di-spacing you will be able to generate this kind of a reciprocal lattice of your or.

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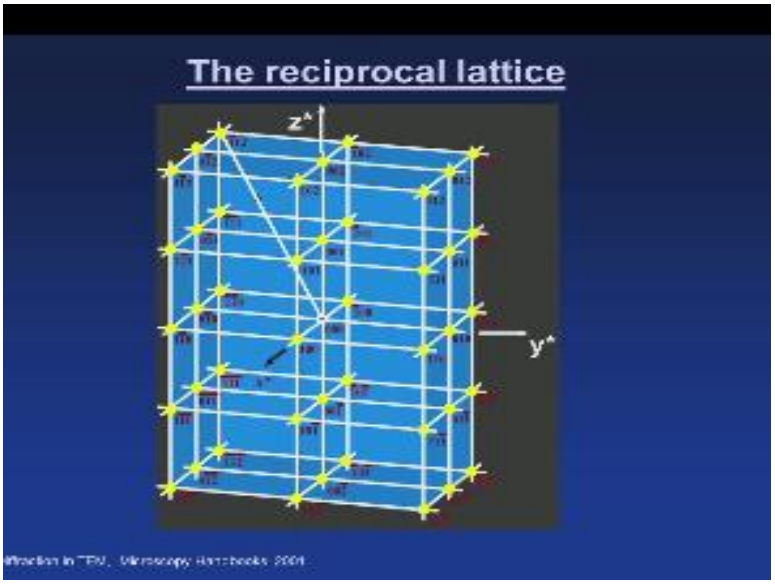

Similarly you can do it in a 3d because we know the relation so this is just give you an idea please remember in an electron diffraction experiment even in a TM what you generate in a microscope is a three-dimensional protocol lattice but you project it on a 2d screen so you get only the 2d information so because in a please understand in a transmission electron microscope it is a your crystal is transparent to the electron beam so you get a 3d information it is a three-dimensional information.

But of course as I mentioned in the beginning it is an averaged information but you get the projection on the 3d information projected on a 2d screen and which is seen as a spot we will get into the details WYD appearing I kept spot what is the physical meaning of this part and so on in that you course.

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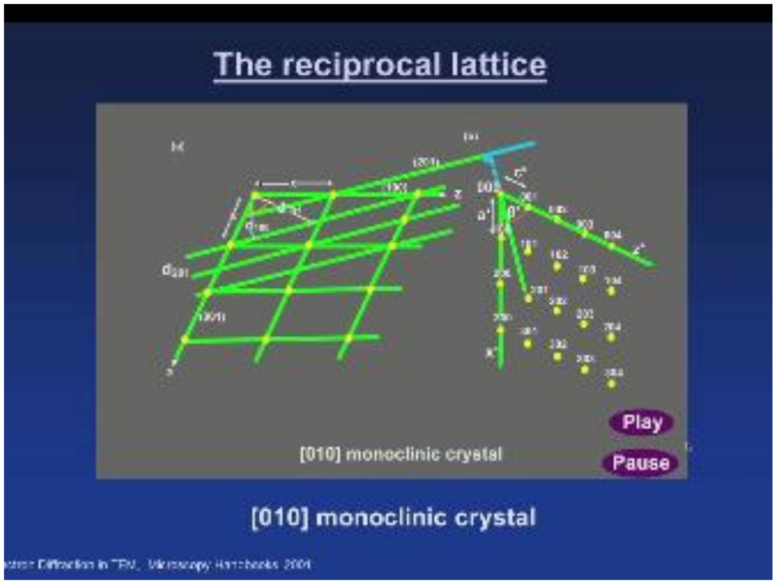

So this is again a reciprocal lattice construction for a monoclinic crystal so you can try one of this systems because you know the basic relationship between the real crystal and reciprocal lattice system so this can this can be a good exercise if you do as a an exercise for a few systems then you are a ability to analyze this reciprocal lattice or a diffraction pattern will be a manifold you will be more comfortable if you theoretically solve and then get into the selection rule and then see that which are the spots will be allowed at which are the spots will be not allowed you can mark them.

And then if you if you can have the basic idea of calculating this theoretically then you will have much more confidence in analyzing the electron diffraction pattern which I will show with some few examples on a on a on a blackboard are in tutorial classt hen you will appreciate this so this is just for our information.

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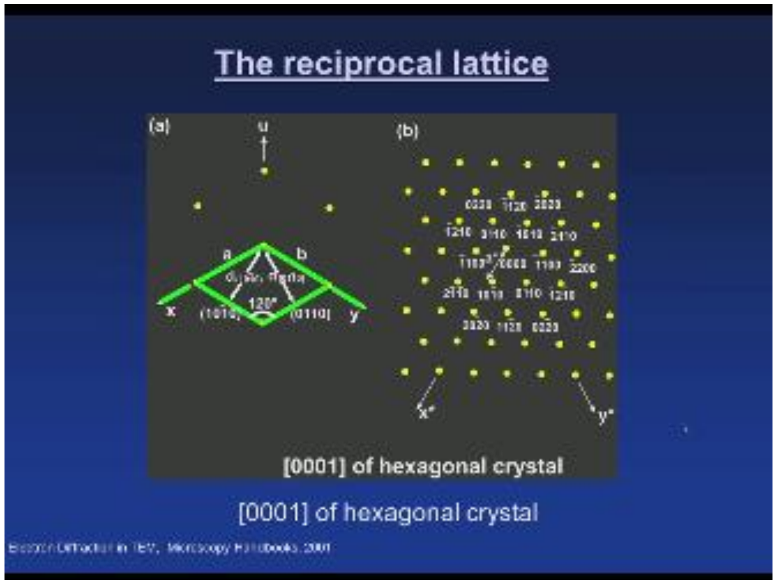

This is for a hexagonal crystal lattice you have the reciprocal lattice system.

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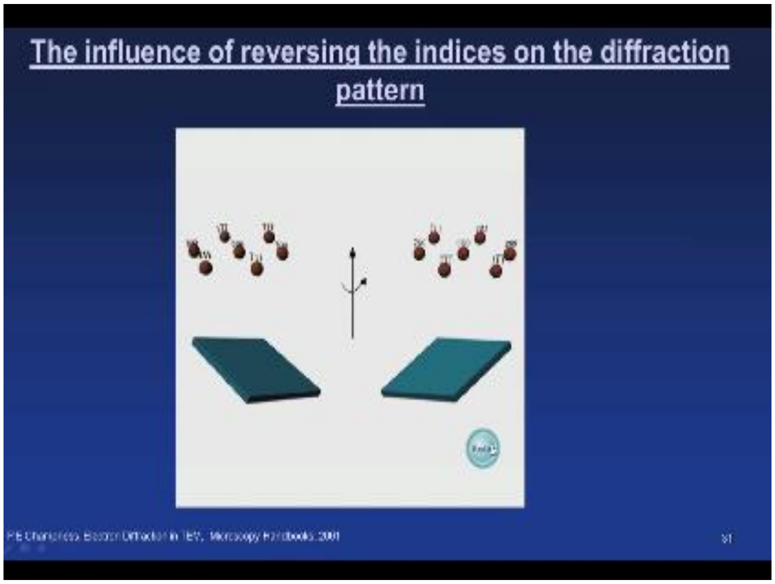

And another important thing is when you index the reciprocal lattice then you have the kind of 180 degree ambiguity so you have what I what is the schematic showing is suppose if you have a set of spots which you have indexed with one type of an indices and if you rotate this like this then the indices should be different you can see that indices are opposite so you have to confirm this it is not that once you rotate this the indices are having different sign it is not completely wrong.

But then there is an ambiguity you have to fix this which particular correct indices is given we will talk about it when we do a indexing exercise so this is coming because of the symmetry.

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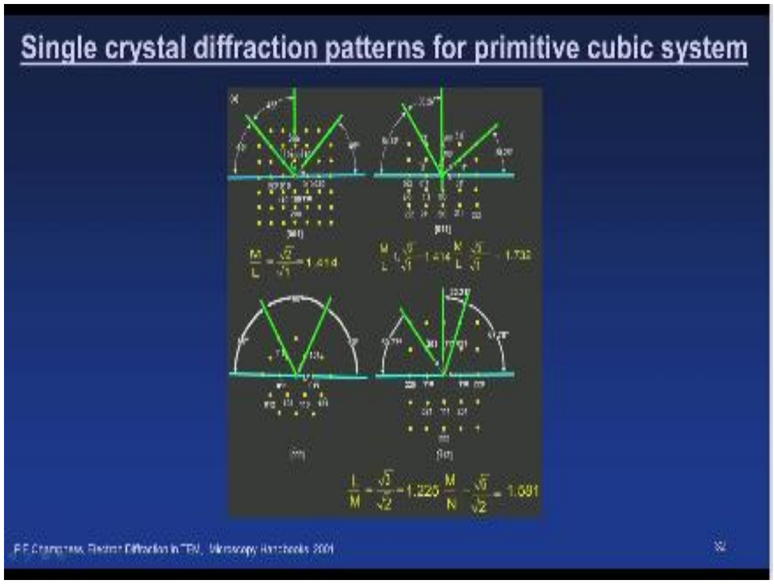

And this is some of the single-crystal electron diffraction pattern for a primitive cubic system these are all available in the literature in most of the books electron diffraction book you will find it you will be able to suppose if you are able to find out the ratio from your electron diffraction pattern you can directly see this kind of an indexed pattern here then you will be able to transfer this indices to your system if it is if it is a cubic system and if you are able to match the angle between the each.

I mean the orientation and the spacing and the ratio everything matches then you will be able to use this kind of an indexing system nevertheless it is better to calculate of your own and index I will demonstrate in couple of exercises it is always better to do it do a calculation and do it but in if you fit is a well-known system like the a cubic system there is nothing wrong in looking at this pattern and then.

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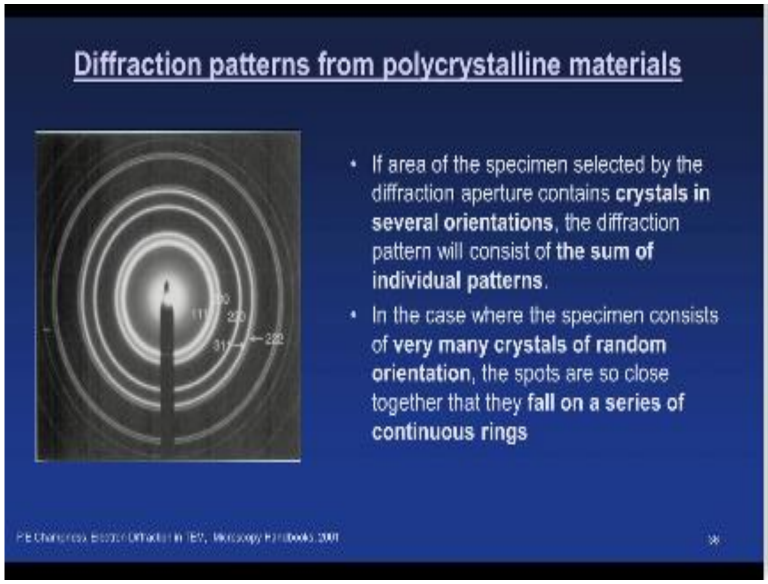

Look at the solutions so I will skip this these are all basic information the another important point I want to emphasis here is whatever we have just seen so far is a single crystal electron diffraction pattern what you are now seeing is a diffraction pattern from a polycrystalline material so what you are seeing instead of the spots you are you are able to see rings here so if a area of the specimen selected by the diffraction aperture contains a crystal in several orientations the diffraction pattern will consist of some of individual patterns.

In the case where the specimen consists of very many crystals of random orientation the spots are so close together that they fall on a series of continuous rings so what does it mean you have an a single crystal pattern of different orientation whatever you have just seen some of the I just showed us for a cubic systems FCC BCC and HCP systems is that they are all single crystal that means a diffraction is occurring from a single crystal or a single grain when you when your aperture focusing a region with that region contains a lot more crystal single crystals or the crystals oriented in much more random positions or orientations.

Then your diffraction will be not a spot but a ring because the pattern will consist of a sum of all individual patterns suppose if you put all the patterns together then that will fall in the ring so all the individual are independent orientations that can be put or superimposed that is why it is called sum of individual patterns then you will find a ring pattern that means the physical meaning is all the know the many crystals of random orientations will contribute to the diffraction conditions that is all it means suppose if you look at the basic diffraction conditions that means you have all the orientations that means many crystals are obeying the Bragg conditions and then contributing to the diffraction intensity that is all it means.

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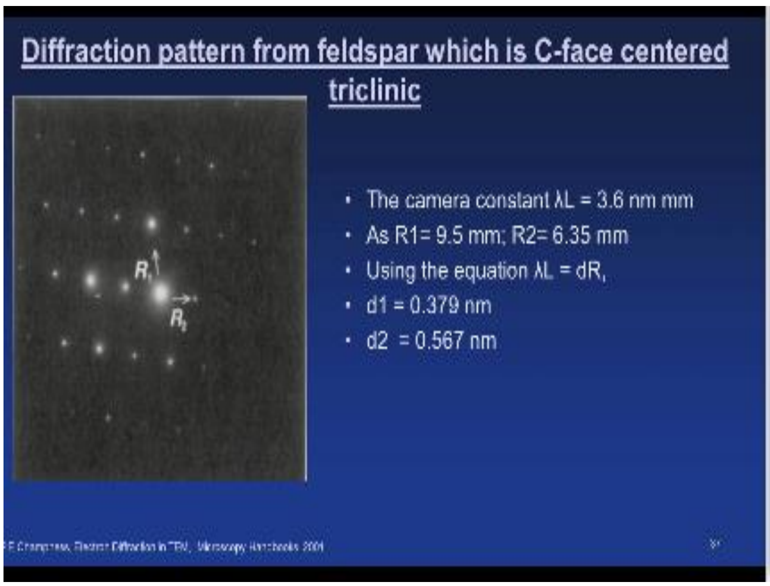

So now this is one simple example of how to use this camera constant to identify the single I mean single crystal electron diffraction pattern so this is a diffraction pattern from feldspar which is C phase centered triclinic crystal structure so the electron diffraction pattern appears like this the camera constant for this particular feldspar is $\lambda 1 = 3.6$ nano meter millimeter this is this is how you have to do the measurement from the center that is a transmitted beam to the diffracted beam is R1, R2.

So r 1 is about 9.5 mm and r2 is 6.35 mm using the relations you can $\lambda 1 = rd$, $d1 = 0.3\ 79$ nanometers and $d2 = 0.567$ nanometers so like that we can readily index this electron diffraction button provided the camera constant is calibrated and well known otherwise this kind of indexing procedure is not valid I will show some of the other procedures of indexing the diffraction pattern in some of the tutorial class.

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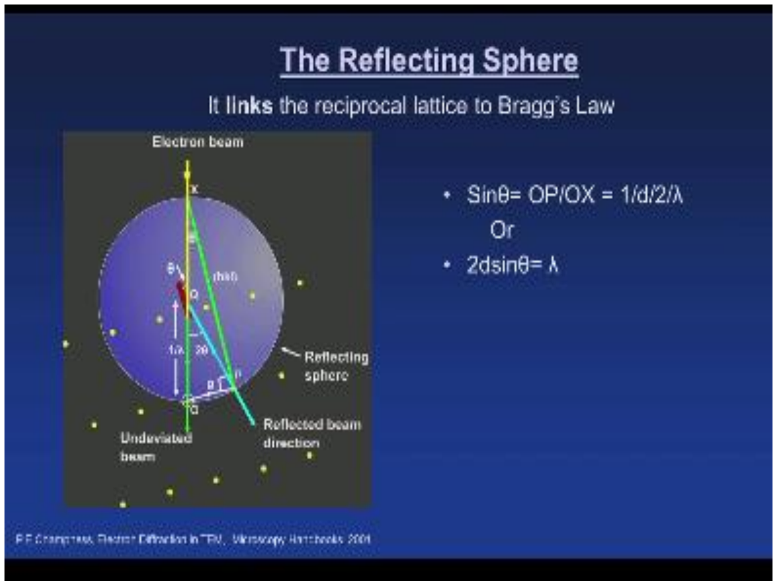

So now we will look at the how the evolve sphere is related to a reciprocal lattice so evolve sphere it links that reciprocal lattice to the Bragg law this we have already seen in an x-ray diffraction phenomenon just to recall you see that this is a evolve sphere and here you have this sample incoming ray this is a transmitted beam and this is diffracted beam for this geometry the radius is 1/ λ and then you can write sine theta for this geometry OP/OX = 1/D/ 2/ λr 2B Sin θ = λ.

This is simply a brag law derivation from this schematic so what it signifies the signification is so wherever the vaults fear cut through the lattice the wherever the reciprocal lattice point exactly intersects with the surface of the sphere then you will though only those parts will appear in the diffraction pattern what is the physical meaning only those parts will satisfy the mirage law so that is that is why only those spots are appearing in the diffraction pattern not the other pattern.

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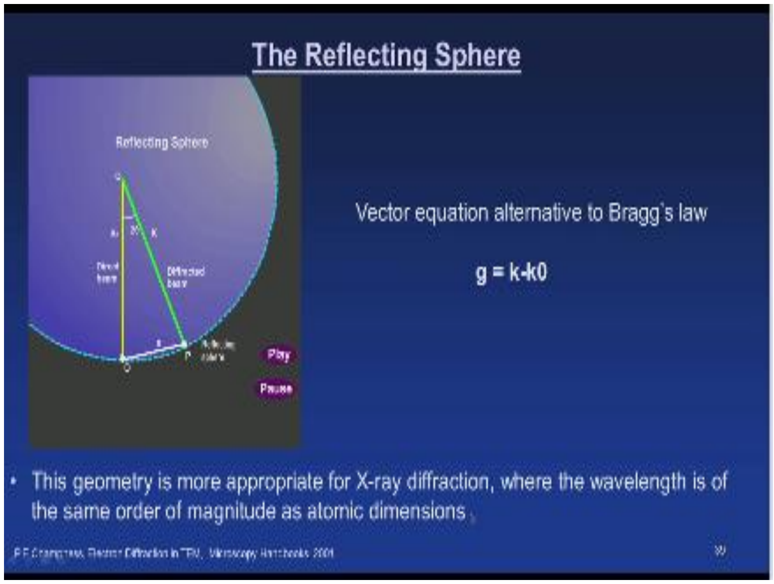

Now we can also look at this brag law using this vector equation so you have the evolve sphere and this is an incident beam that is A K^0 and this is a diffracted beam with k and this is the g vector there is a diffraction vector and $g = k – k^0$ so this is a vector equation alternative to the Bragg's law is shown like this geometry is more appropriate for x-ray diffraction where the wavelength is of the same order of the magnitude as anatomic dimension that is the only difference.

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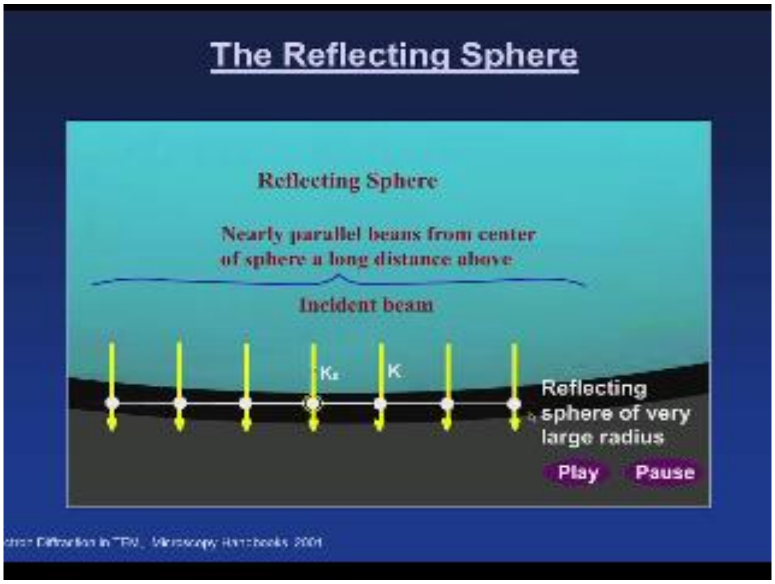

And what you are now going to see an animation is very interesting animation you see that as I mentioned that in the beginning of the today's lecture or when I talked about the difference between an x-ray diffraction on a electron diffraction the only difference is the wavelength one of the important aspect of the diffraction between x-ray and electron so here you see that I will play this animation again what you see you are now the evolve sphere is so big that you know most of your diffracted spot are falling exactly on the periphery of this the evolve sphere.

So you are able to see the many number of spots in an electron diffraction pattern as compared to x-ray diffraction pattern in x-ray diffraction pattern you see only few peaks not so many number of speaks as you see in an electron diffraction pattern you have n number of spots around a transmitted beam so that is because the lambda is so small so that 1 by lambda is you know so big so you are the evolve sphere become very big.

And then all this reciprocal lattice point or exactly intersecting the are cutting through the or I would say that the vault sphere is cutting through all the reciprocal lattice points so you are able to see so many spots around the transmitted beam.

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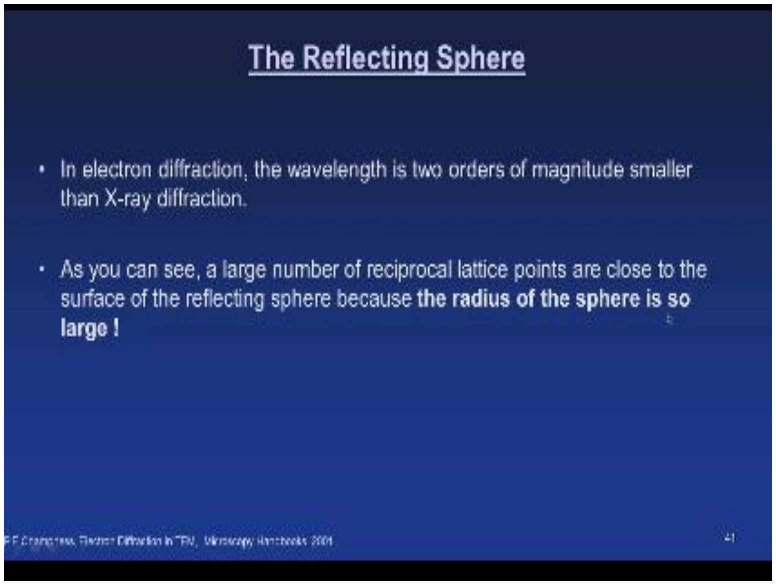

So in electron diffraction the wavelength is two orders of magnitude smaller than x-ray diffraction as you can see a large number of reciprocal lattice points are close to the surface of the reflecting sphere because the radius of the sphere is so large.

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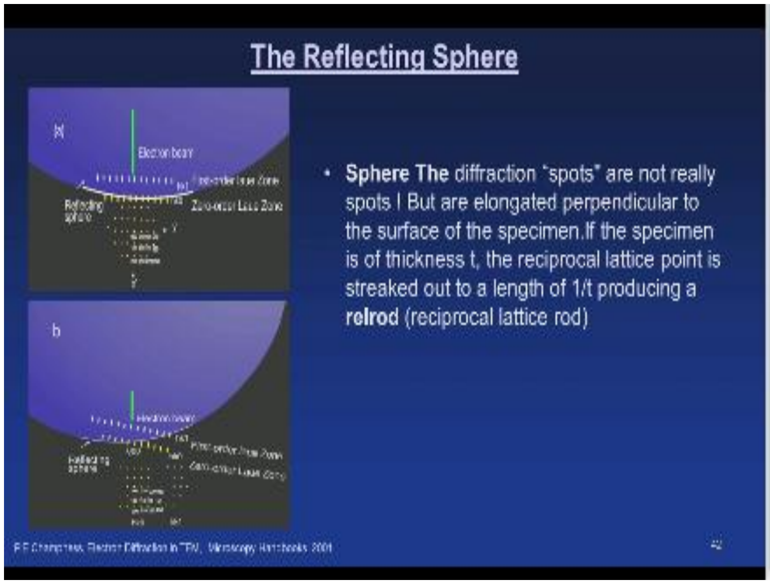

So that we have seen so the other information about this reflecting sphere or involves fairness you have to appreciate you have to see why we see a spot in a in an electron diffraction so what I really mean here is the sphere the diffraction spots are not really spots but are elongated perpendicular to the surface of the specimen if the specimen is of the thickness T the reciprocal lattice point is strict out to a length of 1/T producing a rail road that is a reciprocal lattice rod.

So since we are talking about a reciprocal relationship in the diffraction intensity so it is suppose if your specimen is having a thickness in one direction that is important suppose in the suppose this is the specimen direction I mean and this is your electron beam so this is the thickness of the sample then you are diffraction intensities are going to be produced perpendicular to the I mean the orientation of the specimen so that is what it is shown here.

So in three dimension what I just mentioned before when I showed a theoretical calculation of the reciprocal lattice in three dimension I just mentioned about the each spot in an electron microscope I mean the reciprocal lattice produced in electron microscope is in three dimension and then each spot intensity profile depending upon D the specimen shape suppose if this if our specimen is a foil or a thin sheet of a thickness T then your intensity profile will be perpendicular to that orientation, so similarly you have a cubic specimen then your intensity profile will be uniform in all the three directions so if your sample is oriented in this direction and your intensity profile will be in the opposite direction so it is a reciprocal relationship so similarly if you in most of the conventional TM analysis your sample is a thin foil and your electron beam is passing through this thin foil perpendicular to this so you will see that your reciprocal actual point will have intensity profile like a rod that is what it is shown here so you actually you produce a rod like this in 3d.

Since you are I mean evolves fear cuts through all the rail rod and when you cut their rod in across section you will see a circle so that is what you see as a circular point of intersection that is what is being projected on the fluorescent screen that is why you see as a very small circular spot as a diffraction spot in a actual diffraction pattern so this is one of the a concept you will be able to appreciate in fact the very effective usefulness of the evolve sphere concept is this where you are able to appreciate the actual what you are seeing on a screen why it is appearing in a circular spot.

So this is one of the usefulness so you can see that in the clearly in this schematic a where the vaults fear cuts through the rail rod and then you see that that particular in fact it is not cutting in a line it is a complete it is a sphere so it is the surface so the whole surface cuts through the air reciprocal rod in a three dimensions though you get there a 2d surface like this what is shown in this schematic here and you can also appreciate that if the if the orientation of the you know your reciprocal lattices slightly different you can see that this is a zero-order diffraction spot and then you see the first order and second order and so on.

So another important aspect is so whatever we conventionally get a diffraction pattern is the zero order diffraction pattern and as we talked about in a convent I mean converging beam electron diffraction you will see that higher order lava zones will be identified and you can see that how these higher order zones are being identified using this a waltz fear concept you can see that this is a zero order this is a first order suppose if I have a reciprocal lattice here then it will appear like this first order second order and so on.

So this is another important aspect you how to remember what you are seeing is across-section of I mean a reciprocal lattice rod in three dimension what you see in a two dimension as a diffraction pattern.

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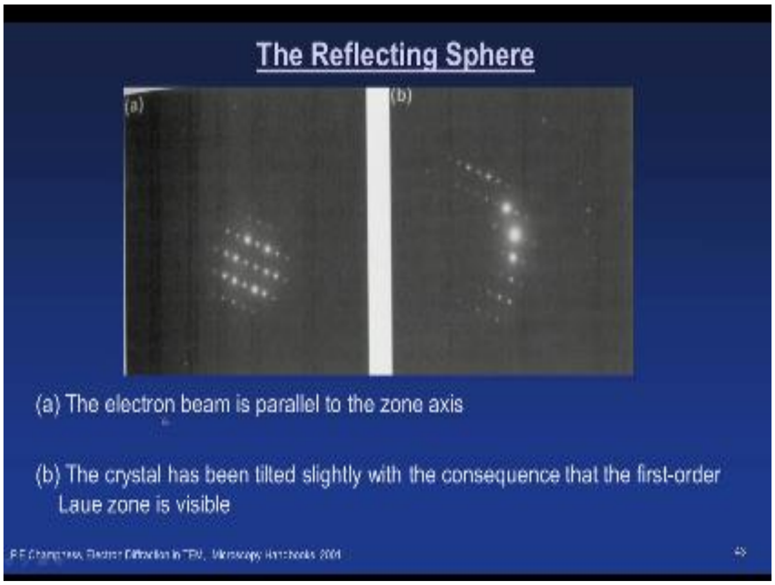

So you can see that some of the examples this is a zero-order zone this is a first order in a TM you can see the second order I mean this first order and second order higher order zones are visible using this concept you can see that the electron beam is parallel to the zone axis the crystal has been tilted slightly with the consequence that the first order love is own is visible so this is a first order for that we need to just do the tilting experiment you will be able to appreciate this remember using a converging beam electron diffraction this experiment can be done and we will be able to identify higher order lava zones.

Which will enable as to characterize some of the symmetry elements in a material so we will see it when in the converging beam electron diffraction when we take it up so I will stop here and then I will continue this diffraction concept an ATM and in the next class I will discuss the importance of ki-ku-chi lines and how they are generated what do with the ki-ku-chi lines and so on and similarly we will look at little more detail about a converging beam electron diffraction and its use in general very briefly we will look at it if not much more detailed and will then we will move on to some of the imaging aspects of TM, thank you

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