Electron Diffraction and Imaging

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Lecture - 13

Microscope – 01

Welcome you all to this course on electron diffraction and imaging, today's class we will devote to the basic principles of transmission electron microscope a brief introduction and this forms the basis of all other lectures which goes into details into how we get images and diffraction pattern various modes in which we can operate the microscope.

The first question arises when we talk about a microscope is that why do we require this tools that is the first question that answer to that is that we wanted to observe features beyond the resolution limit of our I; that means, that many features we are not able to see like if some small spec of a broken glass or a thorn is lying we are not able to see it why is it so; that means, that what is the resolution of the eye that is the question which arises the resolution of the eye is around 0.1 to 0.2 millimeter.

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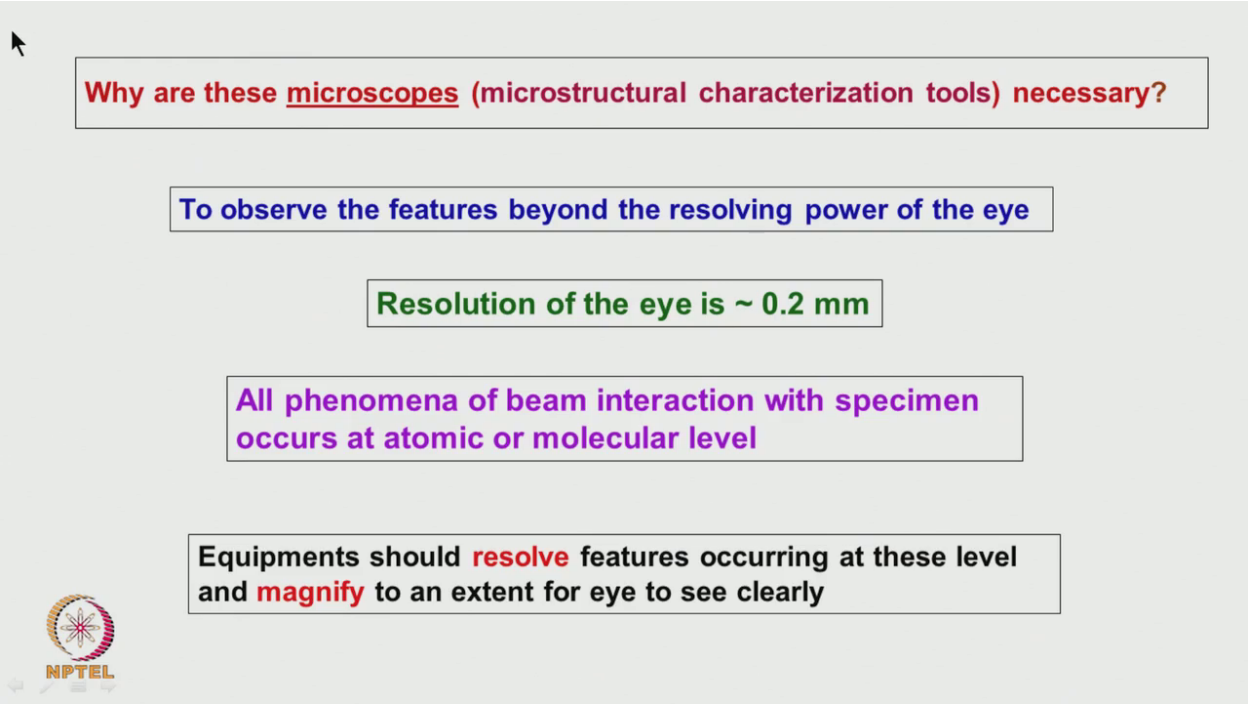

Then now what we need is that we require equipments which can magnify it to a large extent, but what did happens in reality essentially is that when we a beam whether it is a light radiation like when this falls onto this wall this phenomenon occurs at some resolution which is dictated by the nature of the radiation and the nature of that sample, but and the signal which is coming to our eye is also coming with that resolution, but we are not able to see it because our eye does not have that resolution. So, if we can magnify those features. So, that they are well separated for eye to be resolved then we can see that that is what it dictates what is a magnification which is required that is what the job which all these equipments do.

The dictation of resolution that is what determines the resolution is essentially the capability of the equipment and the probe sampled interaction, but finally, we have to look with our eye and analyze the result for which it has to be magnified to that extent that is what all the lenses do that job.

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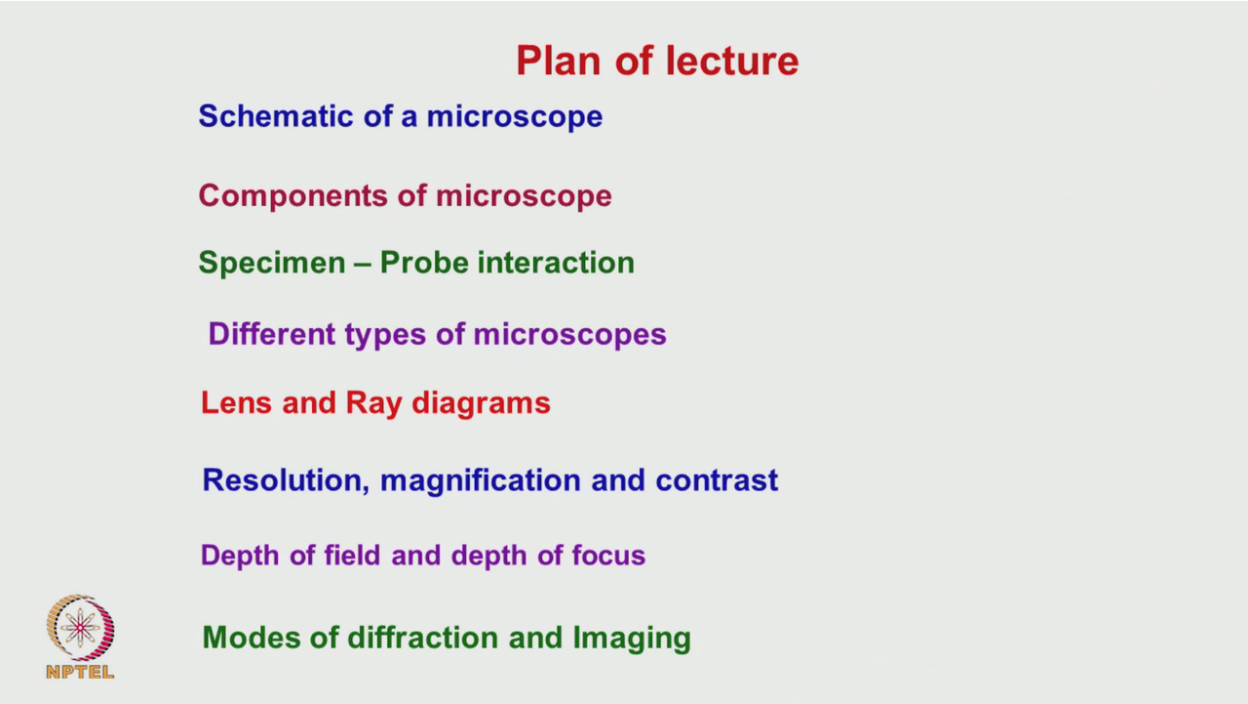

What is the plan of this lecture first I will give you a schematic of a microscope then what all the components which are there in the microscope then I will talk about the specimen probe interaction because that forms the core of the microscopy study then different types of microscopes which are formed transition based on this interaction the classification I will give.

Then we will talk about the lenses and ray diagrams how the different rays gives raise to different type of the images and magnification which we will talk about then another thing which is important for any microscope or anything is that resolution magnification and finally, when we have see it a contrast has to be there otherwise will not be able to see any features that we will talk about then another aspect of it when we use any lens system is what is called as a depth of focus and depth of will this is very important this aspect will talk about then the last one is the different modes of diffraction and imaging with these brief introduction to electron microscopy I will cover.

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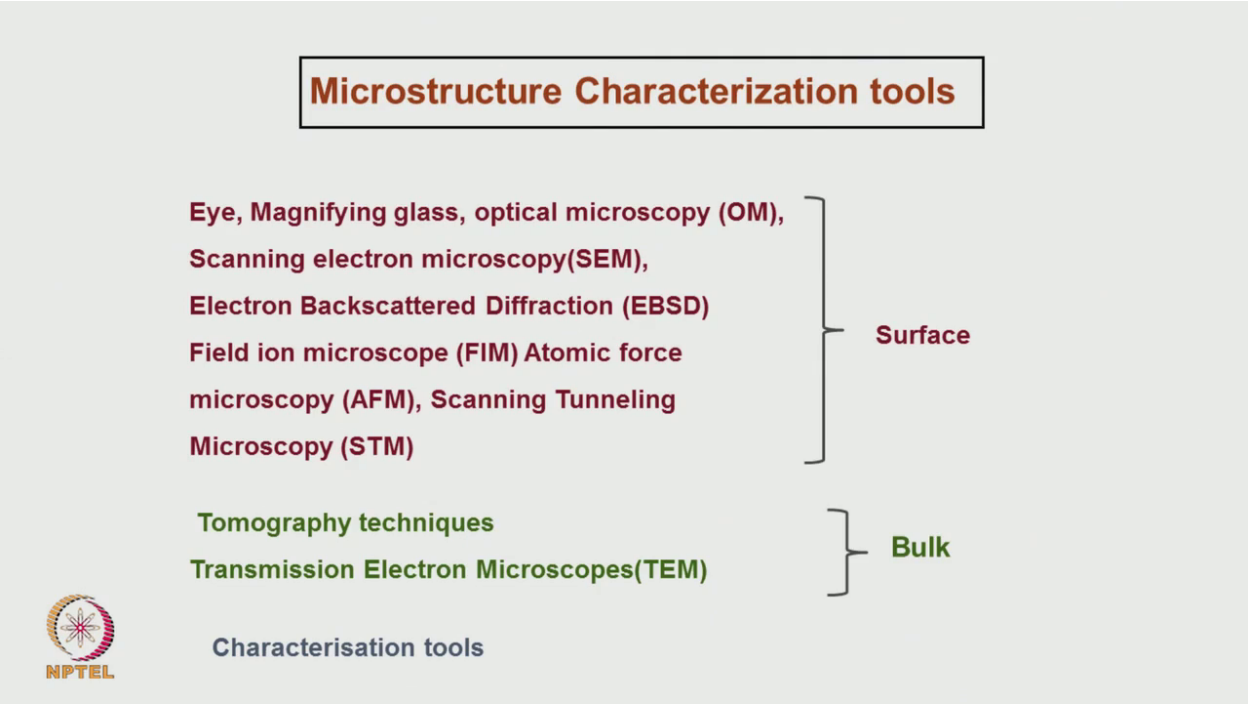

What all microstructural characterization tools as such we have we have eye itself is a having lens and a retina which is like a CCD camera. So, that itself acts as a to some extent it maybe magnifying to depending upon the position it can de-magnify essentially what happens is that eye is also like a magnifying lens then we can have a magnifying glass we have optical microscopes scanning electron microscopes then we have field ion microscope atom probe atomic force microscopy scanning tunneling microscopy atom probe microscopy then transmission electron microscopy generally many of these techniques are called the surface techniques and transmission electron microscopes is called the this bulk technique, but attaching tomographic technique to many of this equipments we can make them also into a bulk characterization tool.

But most of the characterization rules are combination of these various types of phenomenon which occur and that is how the equipments are made depending upon the convenience and what all information we frequently require on that basis it is being done at this juncture I should just mention that there are 2 types of microscopes are there or 2 types of equipments I should say which reveal the characteristics of the sample micro-structural characteristics one is using lens another is without any lens the ones which do not use any lens are atom probe and scanning tunneling microscopy then atomic force microscopy they can give any sort of a magnification.

I will not going to any of these details, but one should be aware of it that these also magnify that object, but they do not use any lens that will form a separate lecture later, but in a microscope like whether it is an optical microscope or a scanning electron microscope or transmission electron microscope we have some lenses. So, some lens operations are associated with it. So, we will talk about that is why I said that we should know about lenses and resolution lens operations magnifications all these things come to the picture.

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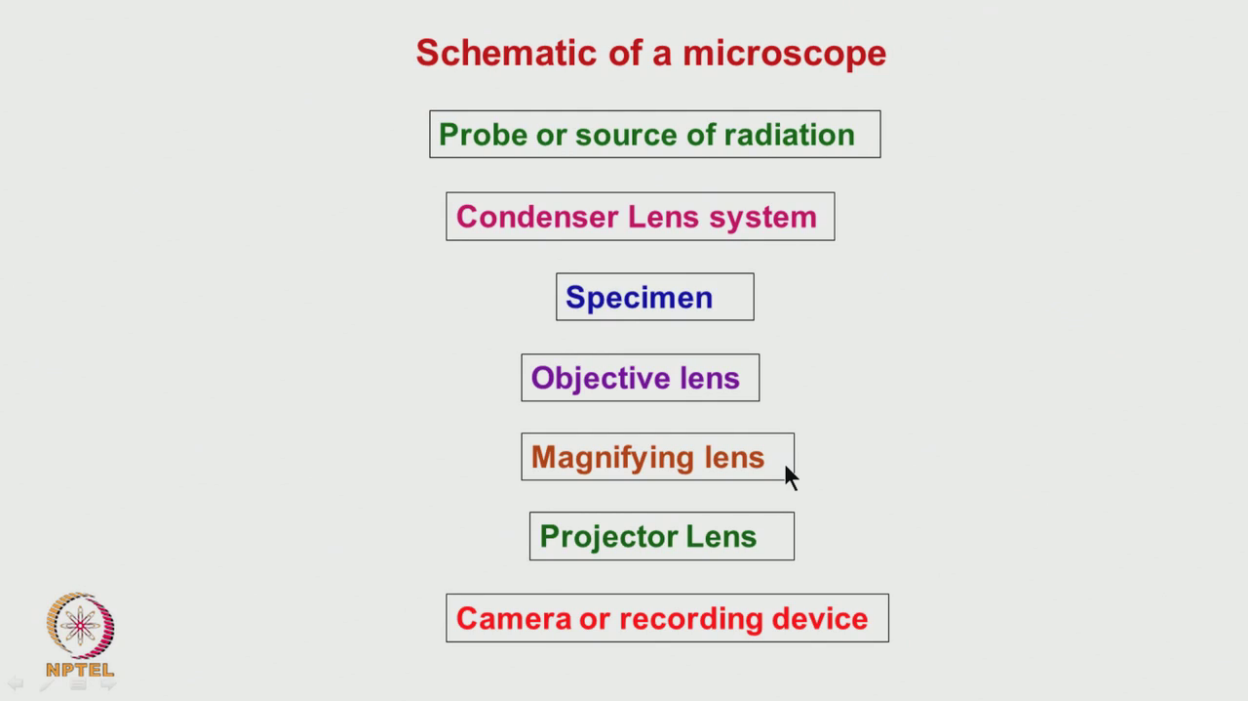

If you look at a schematic of any microscope which is should be constructed what all things which we require one first a probe of radiation has to be there that probe of radiation falls on that sample surface quite often the radiation which comes from the probe like for example, if it is a source from which the radiation is coming it may be emitted in all these directions.

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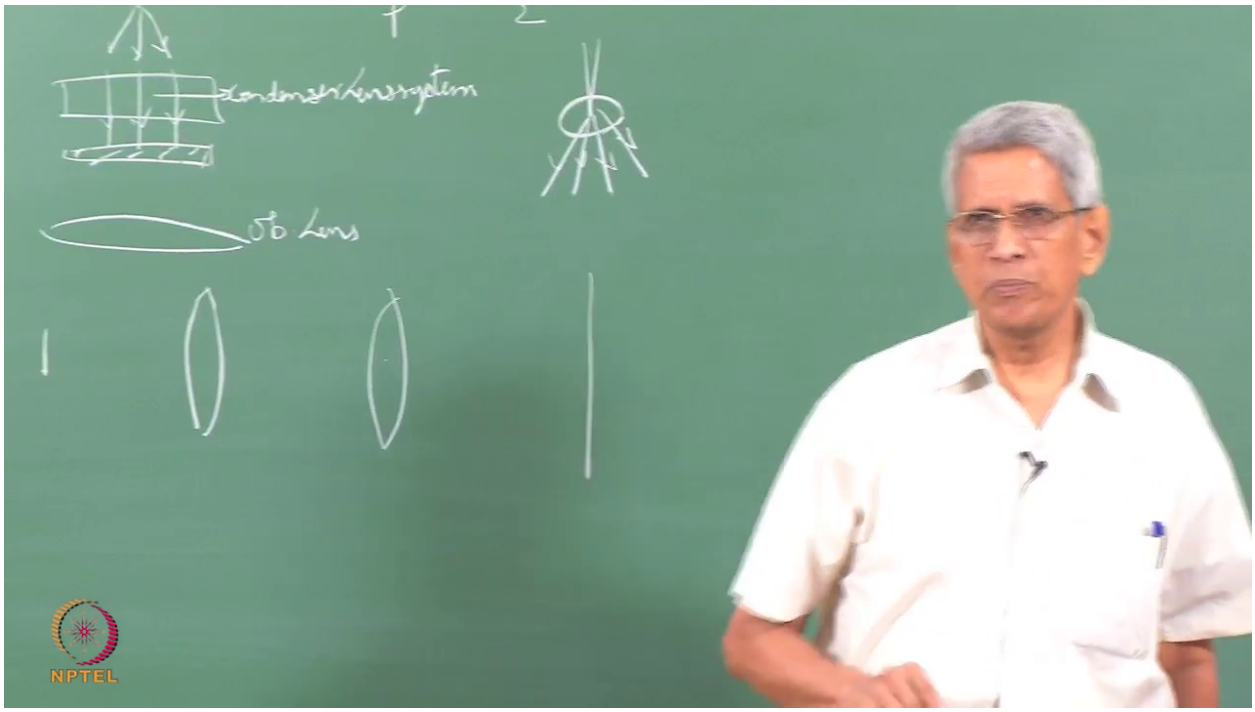

It can so happen that there can be a variation in that intensity of the beam. So, we require some illumination system which makes that beam fall on that sample and this system we call it as the condenser lens system, correct.

So, what does condenser lens systems do essentially it makes the beam uniform. So, if the beam is uniform then what is the difference which comes from place to place that is what the contrast and that shows how the beam has interacted with the sample at different regions and we can do a quantification only if we make sure that the beam which falls on the sample is uniform correct that is what the condenser lens does that job then comes the specimen the sample itself depending upon the microscope we should have different types of sample which we will talk about it as we progress through the lecture what are the specifications which is required for the specimen to be examined in a TEM.

Then comes the objective lens is the one which the beam which passes through the sample and comes now the real part of the microscopy comes objective lenses essentially gives their magnified view of the object it acts like a magnifying lens and then what we have is that a few more lenses are there because the type of magnification which we go one lens cannot give this sort of a magnification. So, many more lenses will be required then there is a projector lens which projects it onto the screen then we have a camera because finally, we have to record this we require a recording device it could be a camera

with a photographic film or it could be a CCD camera there are various types which we can have.

First let us look at a schematic diagram of an optical microscope.

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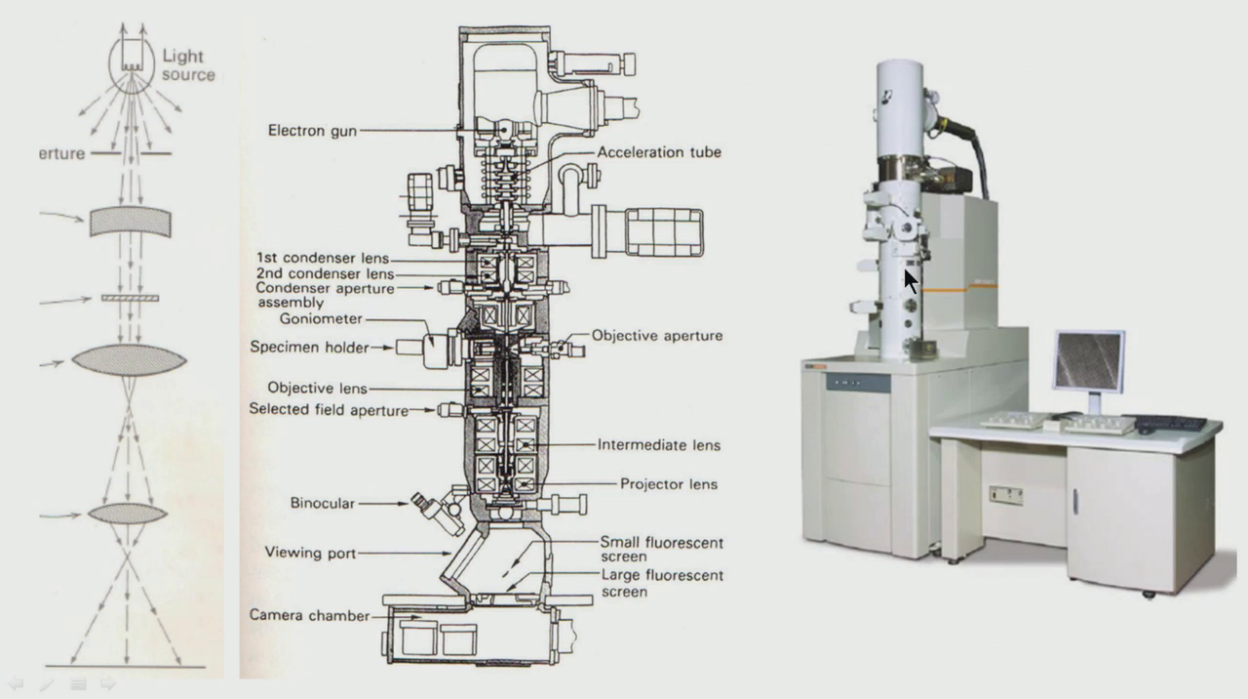

Whatever I have explained exactly that same thing which we look at it because everybody is familiar with a optical microscope or you people have some idea of the what are the basic components which are there in an optical microscope we have a light source and then there is an aperture then there is a condenser lens system then in a transmission mode of a optical microscope it falls onto a sample that is this will be falling onto sample here and then when it come out we have an objective lens then we have a projector lens which projects it onto the screen in an actual microscope it is like a schematic of a transmission electron microscope is shown in this diagram.

In transmission electron microscope instead of a light we use essentially a electron beam of the source and in a normal microscope what we do is that the light source generally we use a monochromatic beam and the beam has to be highly coherent here also the beam has to be monochromatic for which some voltages have to be applied to the electrons which are emitted from the source. So, so we can have requisite wavelength this we will come later then we have a condenser lens system generally in a transmission

electron microscope 2 or 3 condenser lenses are there if you look at this diagram here it is being shown with some classes this is because these are all magnetic lenses which I will show later schematically how it resembles in principle like a convex lens.

Then we have a objective lens then we have some few projector layer few intermediates lenses are there 2 or 3 and then we have projector lens which projects this onto the screen then we can have a camera here or a CCD camera here with which we can record it this is just a photograph of a conventional transmission electron microscope how it looks like in this microscope this is the gun part we have condenser lenses which are there here then we have an this is where the sample is introduced objective you cannot see any of these things this is a microscope which is a essentially a remote controlled one. So, that you do not see a screen also these details about latest developments I will go in deep later, but not in this class.

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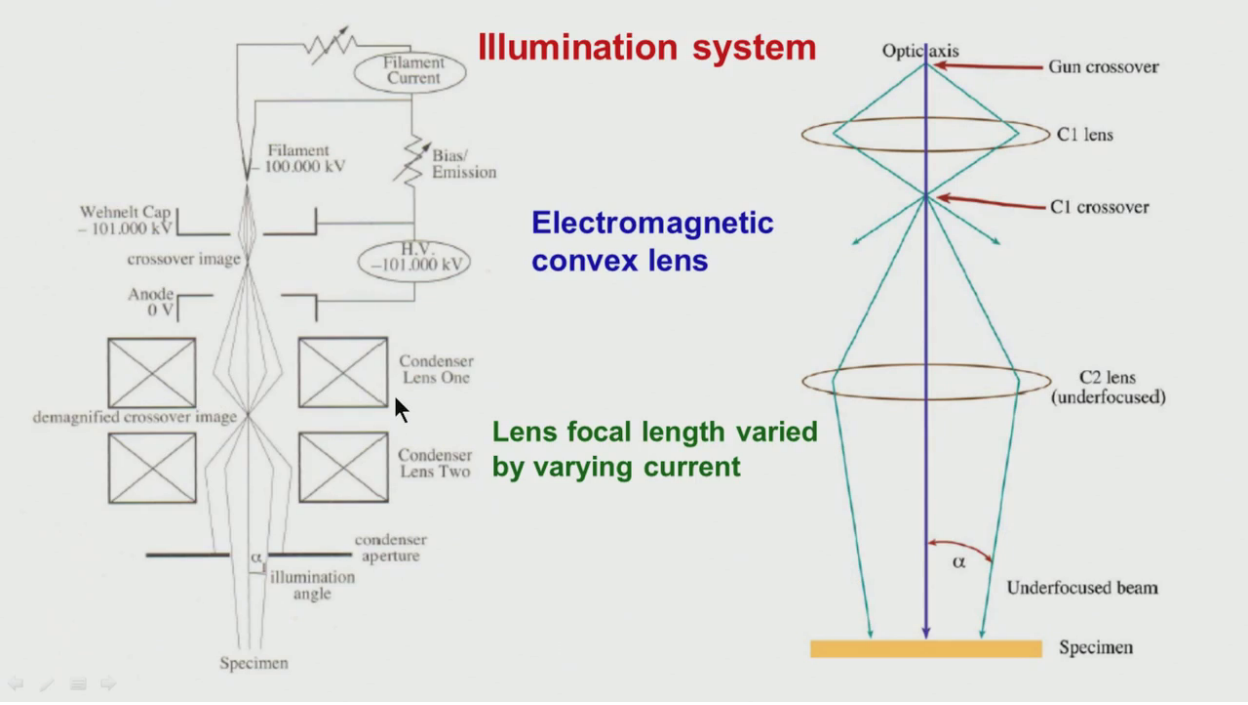

Let us first now look at the illumination system before the specimen what it happens the first thing which we should have is a electron gun which is the source of a electrons as you look at these diagram the it is in these; it is a thermionic it could be an emission where a filament is heated to a high temperature. So, it emits electron then we apply some voltage to control the beam current and in that process application of the voltage

this acts like a lens and focus it onto your point this point is called as a point over and the size of this and how much is the beam current which is going to be there that decides the characteristics this will come shortly.

Then we have condenser lenses are there which are used to make the beam either parallel or convergent or divergent, but uniform on the sample surface this is only just a schematic of the ray diagram and the another important thing is that in an optical microscope we use lenses, but if you use the glass lens glass lens problem associated with this they come with fixed focal length. So, we cannot change the focal length of the lens. So, if 2 lenses we use if you want different magnification.

Suppose one lens is kept here with respect to an object and another lens is kept here then we may get some magnification of that image, but suppose we want a higher magnification we may have to move the positions of these lenses to get higher magnification or choose lenses which have different focal length these are all the 2 options we have whereas, in a since the lenses are electromagnetic lenses just by changing the current which is applied to the lens, we can totally change the focal length of the lens that is the advantage in a electron, we do not have to change the position of the lens you just change the current all the focal lengths are changed then as I mentioned parallel convergent or divergent beam we can obtain.

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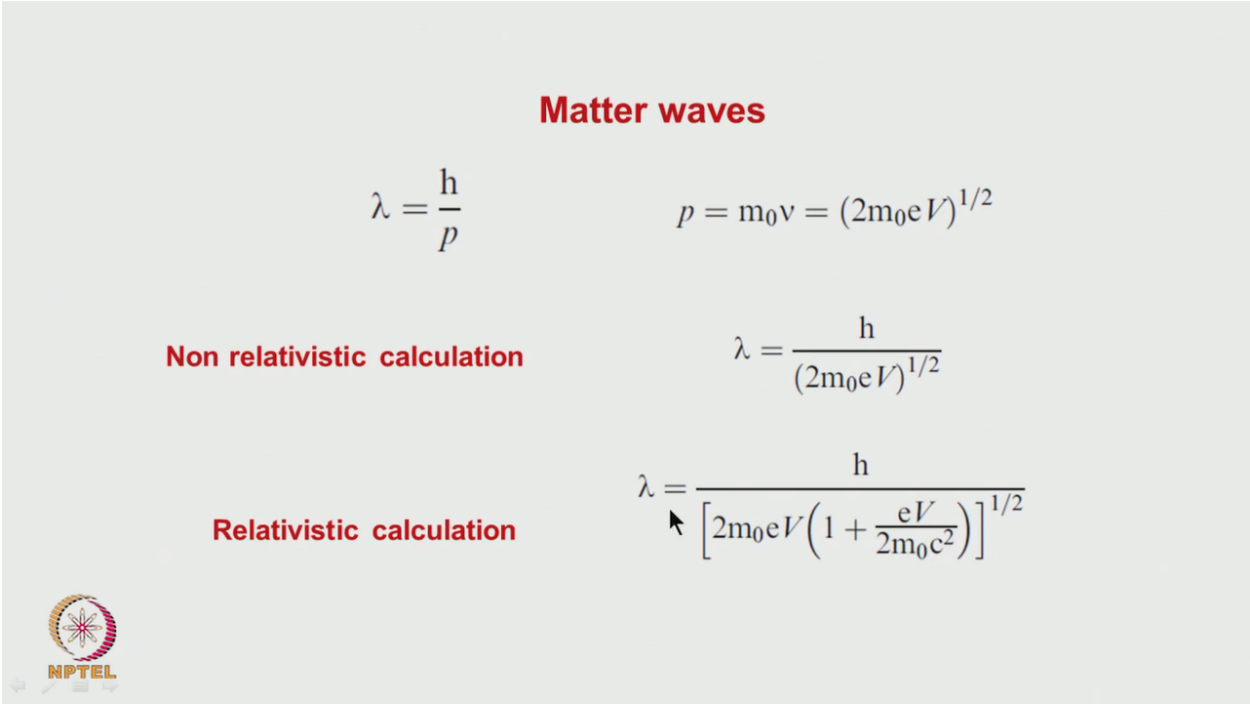

Now, we will talk about the source of radiation in the case of a transmission electron microscope the source of radiation is essentially electrons as we know electrons are particles, but we know from the de Broglie's concept with every particle which is moving we can associate a wavelength with it, it can be considered as a wave as well this wave concept is very much necessary because all the explanations or quantification the theoretical development of electron microscope is all based on this wave concept and the wavelength of the radiation lambda is essentially given by h the planks constant divided by p the momentum then the p depends upon m the rest mass into velocity this if you apply a particular voltage to accelerate it then we know that if a voltage is applied then we equate half m V square.

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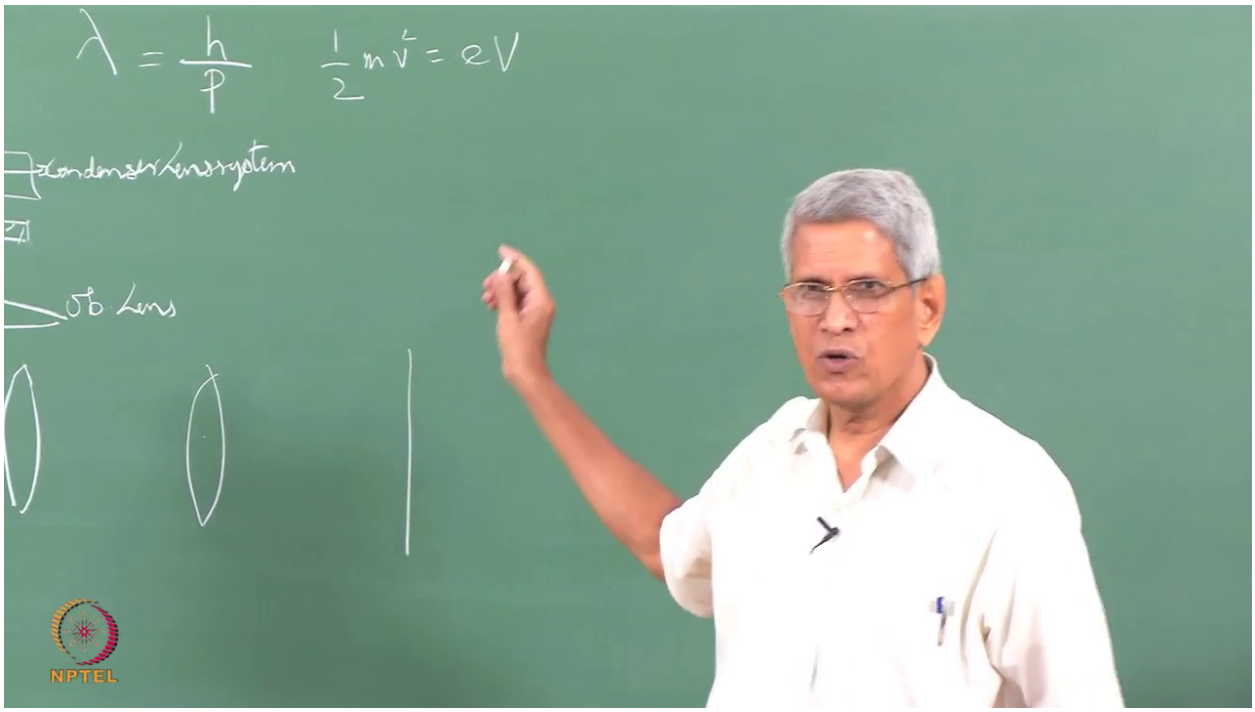

This will be into e V is the voltage applied is the charge that is also in terms of energy from this we can find out what the velocity and the substitute and get formula for the non relativistic calculation which is given here, but we know that electron mass is very small even for hundred k V if we applied the speed with which the electron travels is very fast. So, we have to take the relativistic correction into account when we do that this is the sort of a formula which we get it this which you might have studied in a physics or relativistic theory all other topics one might have studied.

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Characteristics of electron gun

	Units	Tungsten	LaB_6	Schottky FEG	Cold FEG
Work function, Φ	eV	4.5	2.4	3.0	4.5
Richardson's constant	A/m^2K^2	6×10^9	4×10^9		
Operating temperature	K	2700	1700	1700	300
Current density (at 100 kV)	A/m^2	5	10^2	10^5	10^6
Crossover size	nm	$> 10^5$	10^4	15	3
Brightness (at 100 kV)	A/m^2sr	10^{10}	5×10^{11}	5×10^{12}	10^{13}
Energy spread (at 100 kV)	eV	3	1.5	0.7	0.3
Emission current stability	%/hr	<1	<1	<1	5
Vacuum	Pa	10^{-2}	10^{-4}	10^{-6}	10^{-9}
Lifetime	hr	100	1000	>5000	>5000

Essentially in this particular slide, I will talk about so for what we talked about how to find out given on particular voltage to the electrons what is the wavelength which is associated with it and as I mentioned that there are many types of electron sources are there the sources are one we can have a tungsten filament and just heated to where you. So, electrons will be emitted by thermionic emission and these electrons can be accelerated or lanthanum hexaboride that also by applying voltage and heating it to a temperature and the temperature is 1 1700 k.

Then another is that even without raising a temperature if we take a very fine tip apply a voltage teed the field line that is generally what happens is that if a tip is there like this a tungsten, if we apply field like this if the electric field closer to the tip is very high then it could extract electrons from that sample that is what is done in a field emission, one is a cold emission gun; fill emission gun that is the best, but it has lot of associated problems and technology which is required the maintaining more than the technology; however, maintaining it is going to be difficult if you wanted to use an equipment routinely you would like to have a system which is very reliable and break down this (Refer Time: 17:25).

For that the Schottky field emission gun is there where it is heated to a slightly higher temperature. So, that that emission of that electron becomes much faster what is essentially important is that if we look at the current density it is about something like 5

for tungsten and if you take the number it is a board something like 20 times more here it is about compared to LAB6, there are Schottky around something like another thousand times more and compared to Schottky another 10 times more is the cold FEG.

But cross over if we see where that beam that decides what is going to be the current density, for many application the current density is important here the cross over is quite large 10 to the power of 5 nanometer or more whereas, it is 10 to the power of 4 for LAB6, here it is only 15 nanometer you can see the (Refer Time: 18:24) here it is 3 nanometer; that means, that if the beam all the beam very high intense beam that been that is what we call it as the brightness of the beam if the beam come from the point and if it is monochromatic then it satisfies all the condition for diffraction or interference you can say that; that means, that the beam is monochromatic and beam is highly coherent and it has got both special as well as temporal coherence.

This sort of and then another is there for many applications we have to look for what is the energy spread that energy spread if you look for in the case of Schottky and cold emission gun that energy spread is less why do the energy spread is important it should be less energy spread because the chromatic operation depends on that the simplest which we can think of at this stage and since it is electron source we require a vacuum the vacuum which is for a cold emission gun if you look at it, it is around 10 to the power minus 9 whereas, with 10 to the power of minus 6 minus 7 Schottky field emission gun could be maintained others the requirements are less, but about the vacuum system we will talk towards that end of the this lecture and the filament lifetime also if you look at it this is about 5 thousand hour lifetime for this Schottky detectors nowadays most of the microscopes are coming with essentially field emission guns their Schottky filed emission gun then, so far we have talked about the gun.

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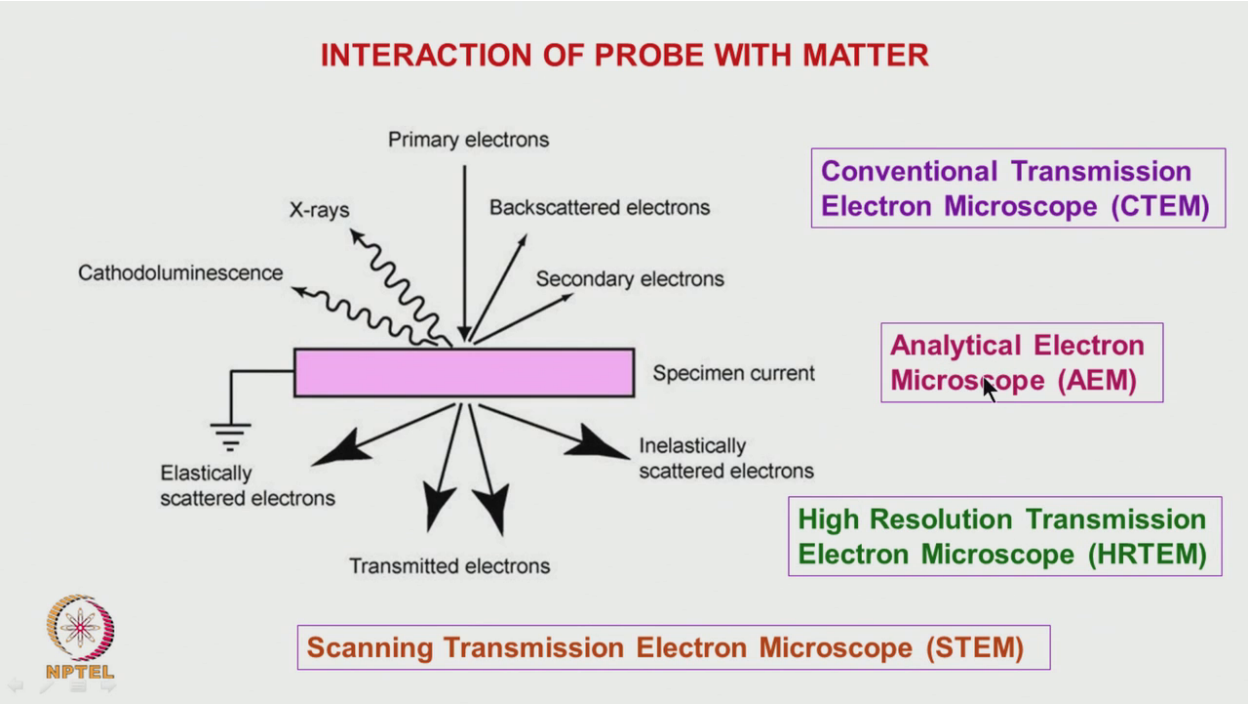

The condenser lens system I had just shown also that 2 types of condenser 2 lenses are used or sometimes 3 lenses are there to make an uniform beam fall on the sample surface, but when that electron beam falls onto the sample surface the type of information which we require is what is most important to construct a microscope. So, let us look at what is the type of beam interaction if your primary beam is falling onto the sample their the primary beam itself could be scattered from the sample itself correct that is what we call it as the back scattered that will also happen that is what is used in scanning electron microscopy.

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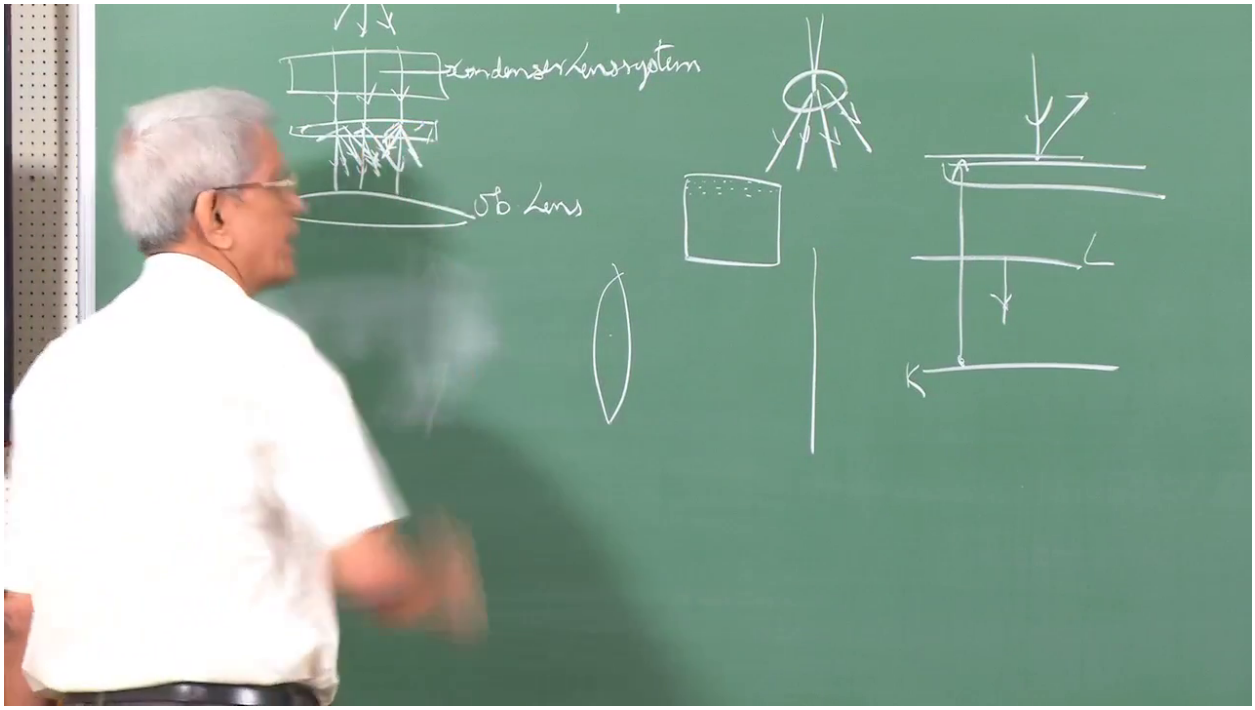

Then from the samples some secondary electrons could be emitted, this secondary elements could be just electrons with below energy or like (Refer Time: 21:02) electrons or x-ray photo electrons they are also secondary electrons these are all the various signals which come out from the sample this what this are going into a phenomenon it will be covered in a later class at this juncture you should know that these are all the types of signals which come and x-rays characteristics of the sample will also be emitted suppose the sample is and then the current the beam which is absorbed that is specimen current that also you can used as a signal other than that if the sample is thin the electron beam will pass through the sample or come out through the some sample interacting with the atoms which are going to be there.

Here during this interaction the electrons are reflected back here through the interaction the electrons are travelling in the forward direction. So, in these direction there are

electrons which are coming transmitted electrons which might have been elastically scattered they have not lost any energy that is one type of an electron some electrons can interact with it and lose some energy and then the beam energy might have reduced by some particular amount these electrons are called a inelastically scattered electrons this inelastically scattered electrons could be used as an a technique which is called energy lost spectroscopy that also give information about the type of atoms which are there. So, chemical composition information we can get it.

And when the primary beam has lost some energy what is the another thing which happens this energy loss means that it has exited the atom from one state to an another state k level to an l level e t c removed an atom from to a vacuum level then when a vacancy is created and an electron from l level can come down to fill the vacancy that is what it comes out in the as the characteristic x-rays. So, these characteristic x rays also gives information about the elements which are present on that sample surface these are all the information which we can get it from the microscope and another important thing you should remember is that since it is an electron beam we use it electron beam can be focused to a point. So, that we can make the beam fall at one particular point or it can be made to fall over a larger region. So, the various modes in which we can design a microscope depending upon whether it falls on a region and whether it falls on a specific point which is determined by the beam size we can have different types of microscope that is why how an another microscope which has come which is called as scanning transmission electron microscope or STEM.

Now, let us look at what are this type of microscopes which we can have the earlier microscopes which are made are called conventional transmission electron microscope where the beam passes through the sample the transmitted electrons which are coming out which are elastically scattered they are used form images and look at the diffractional imaging mode that is one now with the availability of various detectors which can be incorporated into the microscope column now we can have new inelastically scattered electrons and x rays also to get some image information these microscopes are called as analytical electron microscope that is one class of microscope which is available.

Then another is that depending upon the resolution of the microscope if the resolution is smaller than the atomic that spacing between atoms in the sample it is about less than

one Armstrong then we will be to resolve atoms on the sample that is how an image should come. So, this is called as a high resolution transmission electron microscope.

Then the other is scanning transmission electron microscope which I mentioned that is if you can make the beam focus the beam under very fine pine and then scan the beam on that sample surface and the signal which comes out we collect it and used that to form an image then we can this mode of operation is called as scanning transmission electron microscope in the present year microscope with FEG detector we can make the beam as point one nanometer that is almost about one Armstrong beam sees; that means, that there also we can get atomic resolution.

So, this is these are all the way or the in which the electron beam interacts with matter and this o this has opened up that is scope having different types of microscopes now various microscopes are available with different types of configurations like this and some of them will have all, but it is always better to have microscope with each of them because that is the one which gives the best capability of each technique. So, far I talked about various types of signals which are coming out now the question arises is what is the microstructure general concept of a microstructure what we have is that we think that if a light is scattered from a sample and the scattered variation in intensity gives rise to a contrast that image is what is conventionally we call it as a microstructure.

But that is not true microstructure is nothing, but mapping of a property distribution suppose we have a sample like an nano intender if it is there we can have a sample and put the nano intender to take the indentation on various look at what if the hardness value and plot it this is also microstructure. So, microstructure if you ask me the way I will define is a mapping of a property distribution in a specimen or a sample is a what a microstructure is that could be done using lenses which is where we use for scattered beam like the way we are in a scanning tunneling microscope or an atomic force microscope is essentially atomic force when we bring probe close to a that is also one way in which we get a microstructure it is a essentially we get a atomic resolution microstructure there, right.

So, all are microstructures. So, general definition of microstructure is microstructure is nothing, but it is a property distribution in a specimen which is been mapped now when the beam has fallen on to the sample it comes out of the sample surface we can assume

that the beam is initially I think we have got a parallel beam that parallel beam when falls onto the sample surface depending upon the interaction with each of the atoms beam will be scattered in different directions. So, what can happen beam could be scattered from this region in various directions similarly here also similarly here also various directions the beam could be scattered.

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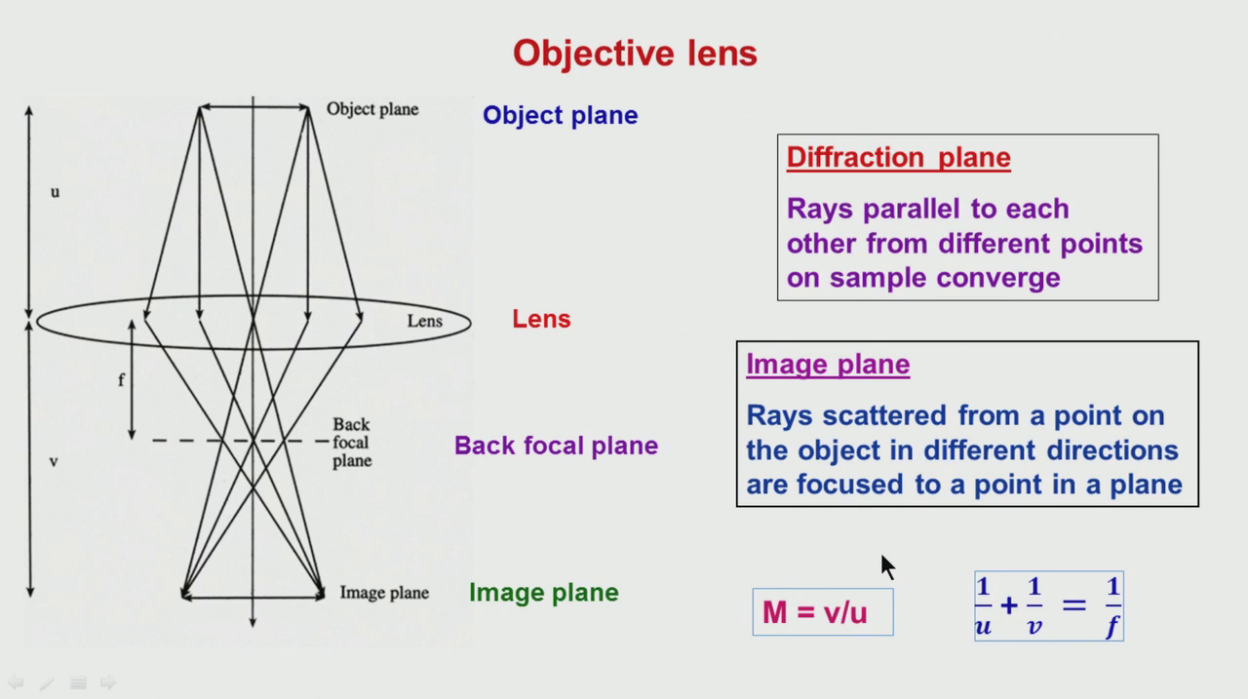

This scattered beam which comes out beam which has been scattered in various direction is what is falling on the lens correct that is what essentially is being shown we have taken 2 points on the object from here a beam is scattered in this direction which is the we can say that it is the same direction as the incident beam. So, it is a we call it as a transmitted beam and then these are all the scattered rays these scattered rays bow let us look at what is property of a lens, we have studied about the lens in may be intermediate class essentially from the ray optics what we know is that the rays which are parallel to the optic axis all of them are focused at the back focal plane correct and the ray which are all parallel where parallel to each other and also close to optic axis they are also focused to a back focal plane.

That is what essentially being shown in this diagram the ray which has travelling in these direction they all get focused from this point that is, but this rays emanated emanating

from different points on the sample that is rays eliminating from different point of the sample, but parallel to each other they are focused at some particular point what is diffraction; diffraction is nothing, but the ray when it is beam of radiation is falling on to the sample at a particular direction when we look at it all the rays which are emitted from different points on that sample they come together and join when they come together and join if they are all in phase they add together then we say that a constructive interference and a diffraction peak is occurring other regions that intensities will change.

So, this is how we get a diffraction; that means, essentially at the back focal plane is what we are getting especially for a crystalline sample this we are talking with, but this is true for a other material also, but that part of going into the nature of the diffraction on that will be covered in a diffraction separately not here. So, essentially we get what we get it is a k space information or a diffraction information k space because that momentum space is called as a k space or this can be called in a sample if we consider we call it as a this can be called as a reciprocal space also and then where is an image which is being formed.

So, if you try to define what is the diffraction plane diffraction plane is the one in which rays which are parallel to each other, but scattered from different points on the sample surface or focused at a point that plane is called as a back focal plane or the diffraction plane that is what this plane is what is an image plane image is nothing, but a magnified view of the object we consider it which we are getting it; that means, that all the rays which are emitted from this point in all the direction should be brought back to the image plane at a particular point then only we will get a true representation of that object; object has to give a true picture of the images to give the true picture of the object that will come only when all the rays which are scattered in different direction from a pine they are brought together that plane is called as the image plane.

So; that means, that if you look at this figure for any lens it has 2 planes are there one plane is diffraction plane another is an image plane. So, from the sample when the scattered beam comes out it does not matter which the source of that radiation is if the source is coherent you get both diffraction and image information from different regions of the sample which we have obtained this is the property of the lens this is how an image plane is defined and what is magnification; magnification is distance from object

to a lens that is distance from image to a lens divided by the distance from object part to the lens that is v by u we traditionally right that is how we get magnification.

And for a lens how these v and u are related these are related to the focal length by this relation 1 by u plus one by v equals 1 by f.

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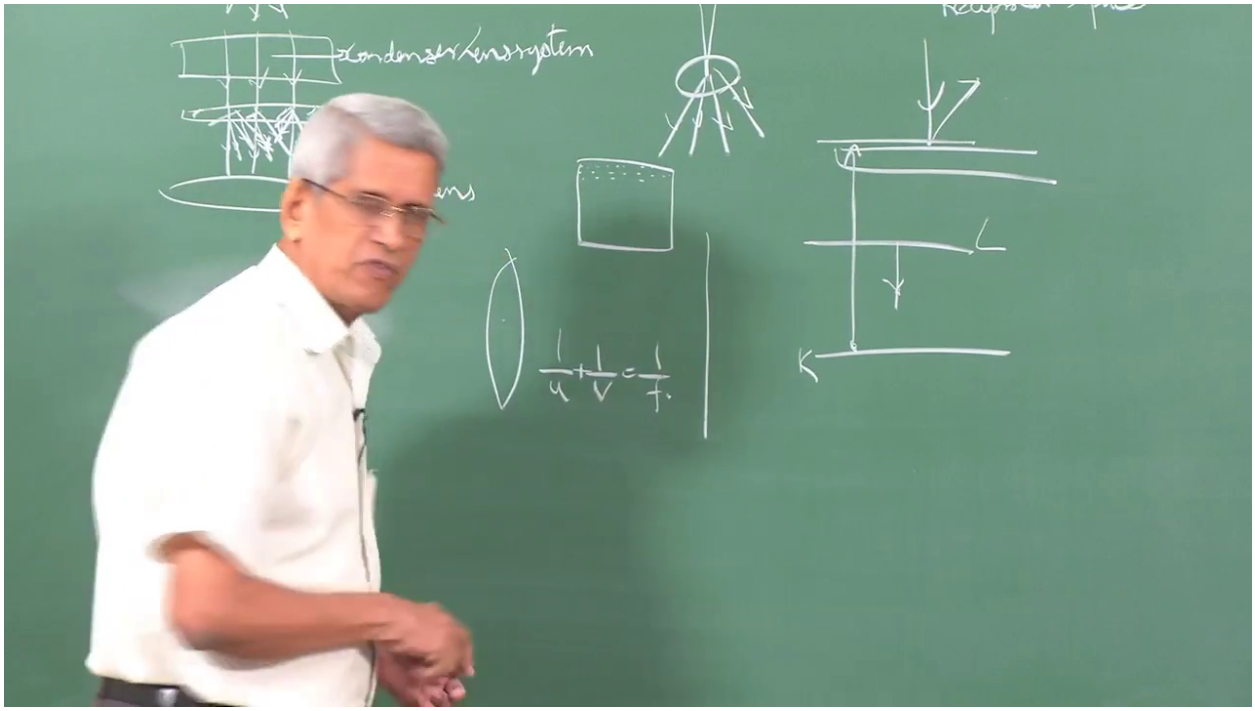

So, this defines what is going to be the magnification which we can get all this information is embedded into this. So, if you kept an object at particular place at what place we have to that image will form because back focal plane is one which is the from the focal length that is well defined for the focal length, but the image plane depends upon where we keep the object correct and that is given by this relation and the magnification also will depend upon that these things you people have studied the in eleventh and twelfth I am not going to any of this details I will leave it here.

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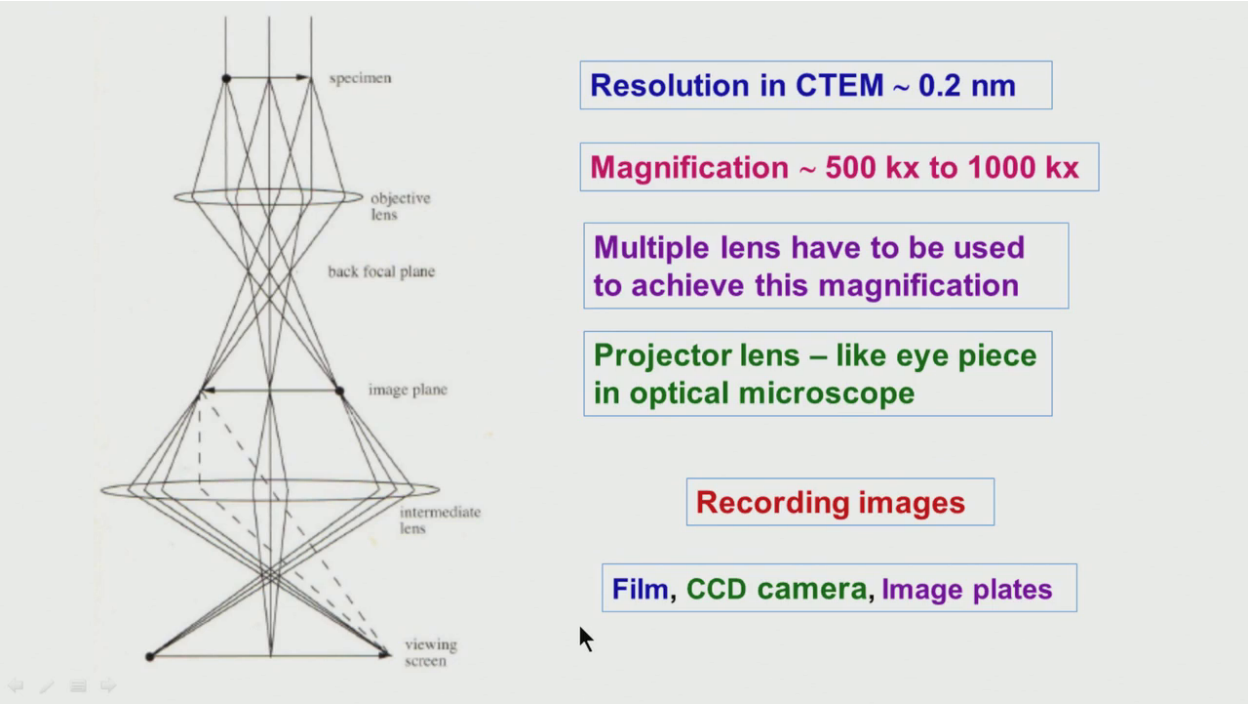

The rest because we considered up to an object objective lens from the objective lens when there is there is a back focal plane where we have diffraction and the image plane we have an another type of an image it is that image of the object here it is the diffraction of the object which we are getting in diffraction also contain some information about the object you can say that both of them are giving information about the object, but in different way now if we wander to get the final image we can use other lenses like many intermediate lenses and projector lens and we can form that image on the viewing screen this is only just being shown in that picture which I had shown about the microscope I said that 3 intermediate lenses are there and then one projector lens to get it.

Generally when we look at that image finally, first we started with stalling that we wanted to see objects or features of an object which cannot be resolved by the eye; that means, the we know in an optical microscope we say that we will resolve up to may be about 400-300 nanometers what is the resolution which we can have in TEM, we will talk about resolution little bit later in a conventional TEM is of the order around point 2 nanometer features of this size we should be able to resolve what is the magnification which we can go in a microscope the magnification we can go up to 500 to 1000 that is one million times magnification which we can go.

The question comes why we require this magnification that is if we take a resolution a feature of this resolution if we wander to resolve; that means, that when we talk about

resolution finally, we wandered to see with our eye; that means, that point one or point 2 millimeter is the separation their feature should have. So, this divided by the resolution gives you what is the minimum magnification which the object should be magnified more further you magnify it we can see it with our eye without any strain to our eye otherwise the minimum magnification it will be still straining, but we can see them separate correct that is what essentially being is done and this magnification when we have to use it no lens can give you 500-1000 magnification correct. So, we require many lenses we have to use it.

In a microscope the objective lens normally in an electron microscope gives a magnification of about 50 and the focal length generally are of order of 2 to 3 millimeter.

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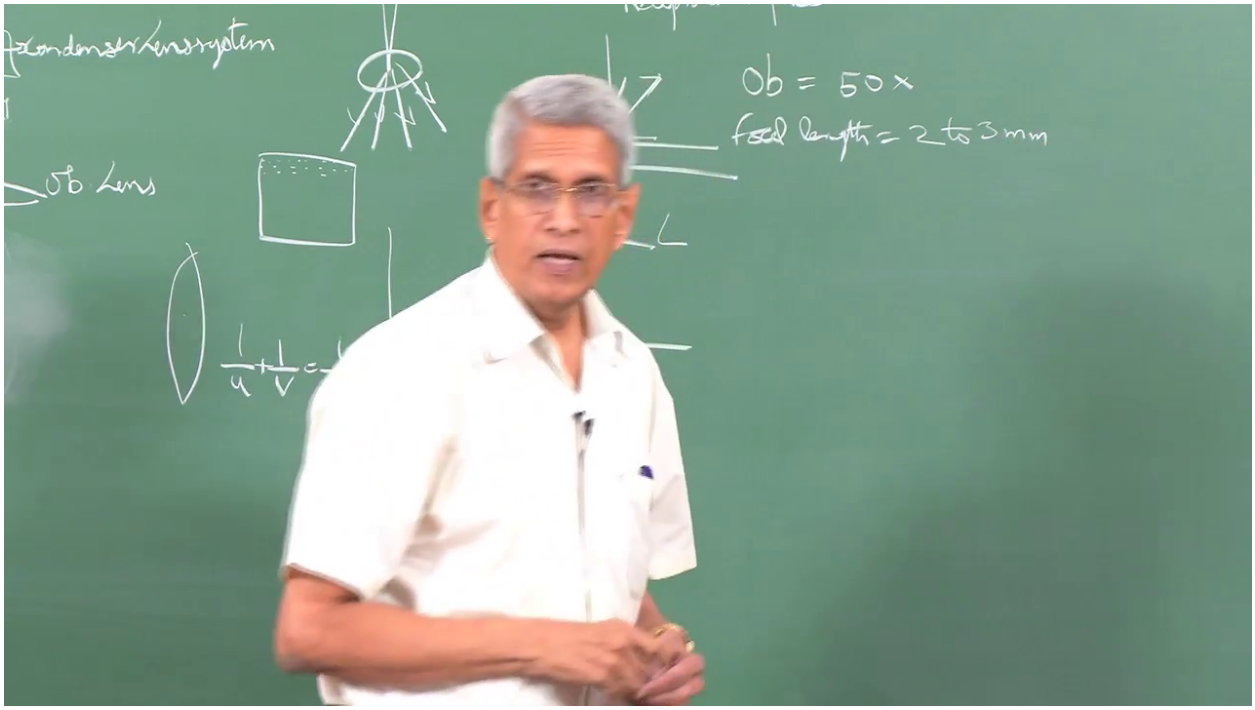

Objective magnification is around fifty times focal length is around 2 to 3 millimeter and what we are thinking of is 500-1000 or 10 million for that if we use further another 3 intermediate lens and the projector lens each having a magnification between 10 to 15 times then we will be able to reach this magnification.

Essentially what we do in this is that when we wanted to see a very magnified view the microscope size is limited. So, the screen is of a particular size; that means, that we choose smaller and smaller region from the sample and magnify it that is what

essentially is happening it is not that the full sample can be magnified then we will not be see it. So, the area which will be scanning may be a few nanometers that will be magnified to a few centimeters that is how the magnification is done because the beam has to pass close to the optic axis and then only the operations will be minimized. So, that is limitation correct as the magnification increase a only a smaller area is being seen right.

This I had mentioned the projector lens acts like an eye piece in an optical microscope then recording of images how we can record this screen is essentially florescence screen which we use where as the electron beam hits on this lights are emitted and the intensity of the light radiation depends upon what is the energy with which the beam is not the energy it is the number of electrons which are falling on each pine that determines the intensity which is coming from the and if the variation in intensities from region to see region then we see that there is a contrast that is how we are able to see an image.

But this is one way of looking at it, but quite often we have to quantify then what we have to do we have to record them the recording can be done using either a CCD camera I will just mention about a CCD camera it will be or another technique which is called as an image plates image plate is also looks like a normal film camera in which we can expose it and we can use that to read using laser light and convert that into a quantitative signal

And the advantage between of CCD camera and image plate over film is that in film when it is get recorded the intensity variations from region to region is on a logarithmic scale. So, when it gets on a logarithmic scale to convert it back to a linear scale is different whereas, CCD camera and image plates.

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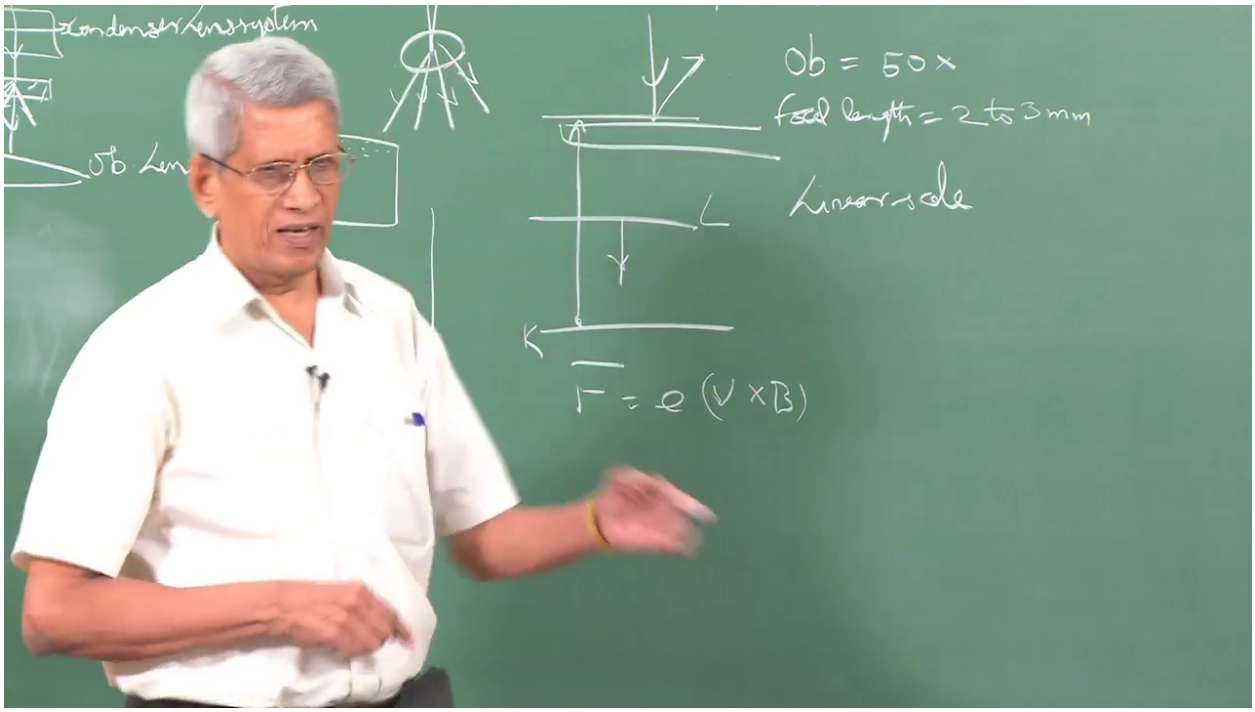

Both it is essentially a linear scale in which the each photon comes it countered as a one like that are some proportionately. So, it is an linear its becomes easy to do processing of the inform the signal which has been collected that is the advantage. In fact, image plates which is something that it is now being used not not in a in a electron microscopy it is being used for if you go to any radiography place where you wandered an chest x ray or any of these x-ray is to be taken they do not use films now they it looks like a plate they put it, take it, expose it and then they immediately put it to this one scanner that scanner immediately scans that and it is the same image plate which is being used here also.

As I mentioned that so, far we have almost covered about the various components of the microscope and since the electron beam we are using it we cannot use a glass lens it will be absorbed. So, we have to use a lens which can deflect electrons.

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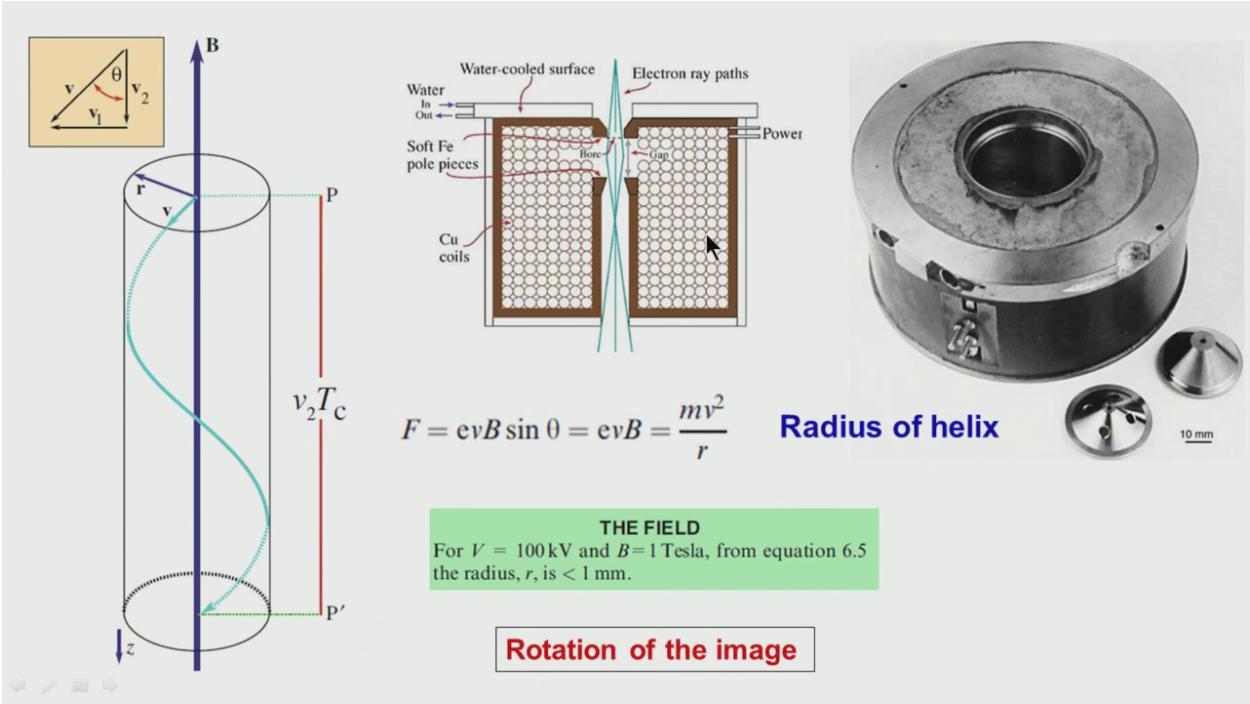

So, we can have either an electrostatic lens or an electromagnetic lens and in a microscope we use an electromagnetic lens here you look at it in a electromagnetic if this is the direction in which the facts is being applied all the electron beam which are travelling parallel to this direction this electron beam will be un-deviated if any electron beam has got a path which is slightly away from this axis flux lane that will be a force which be Lorentz force is acting on that ok.

What does this force will do it will make a go on a circular path. So, finally, what happens is that if there is a particular region where which the field applies when it is from here when it enters the electron beam which is deviated it since it has a high velocity it is moving also and the Lorentz force is acting. So, it takes a helical path and come backs here and when it comes and joints that optical and the optic axis when it comes the beam has actually not only moved along a helical path this gives rise to a rotation of that image also that one should remember this is the expression which we can write it the force equals e v B sin theta because this is nothing, but sin theta is that theta is nothing, but the angle between velocity and B because it can be written as f equals e into v cross b v cross b if we take the magnitude of it; it is nothing, but v b sin theta it is ok. So, it will be a helix.

And then if you look at the field which we apply one tesla this radius turns out be in most of the microscope less than one millimeter; that means, that the beam is very close to the

optic axis then as I mentioned that is a rotation of that image also is occurring and the how does this electromagnetic lenses are being made if we take a wire and pass a current through it we that perpendicular to this electromagnetic the there is magnetic field is generated in a microscope what is done is that you make a coil like a selenite.

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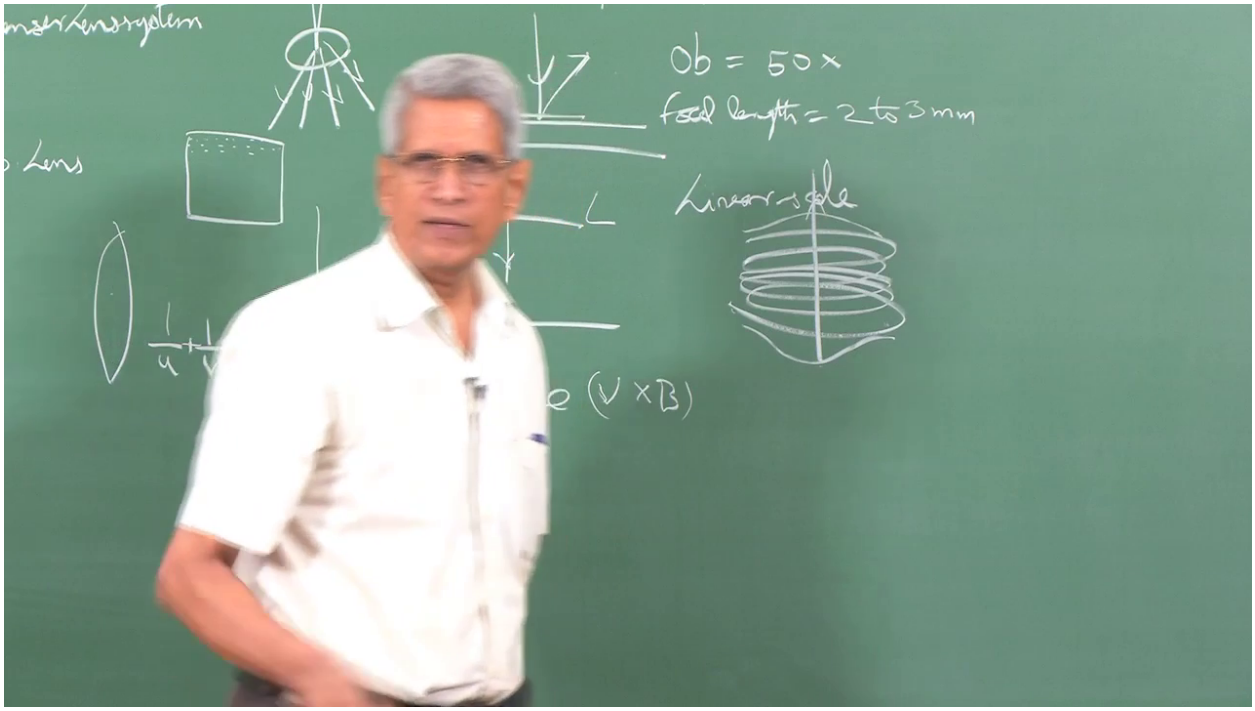

Like this; this is the direction in which the field will be working applied and these 2 ends if you look at it there will be flux line will be there. So, this will be changing their field lines changing it like this that is how it becomes like a look like a lens shape.

Essentially what is happening is that this; what is being shown these are all essentially the wires which are coming through the plane of this screen these are all the copper wires which have bound around it. So, many coil and pass the current through it by controlling the current there are formulas which we will come later on that basis we can make this work as a lens correct. So, when it works as a lens essentially what is going to happen is that and then we can cover it with a magnetic there is it is a soft time if we put it that will absorb all the magnetic field where an opening is there, there is a only where the field lines weak out of it then this acts like a lens and the from a point where the electrons are travelling in directions they are brought back to a focus. So, this is something acts like a lens.

This is essentially how typical lens looks like and the; what is important is as I mentioned is that we pass a current and that determines the focal length. So, when we apply very large quantity of current then that can heat the coil also. So, maintaining the temp then the current will change. So, maintaining that current the temperature the coil has to be cooled that is what essentially is being done in a microscope and by changing the current as I mentioned earlier the focal length can be adjusted this is a typical diagram of a lens.

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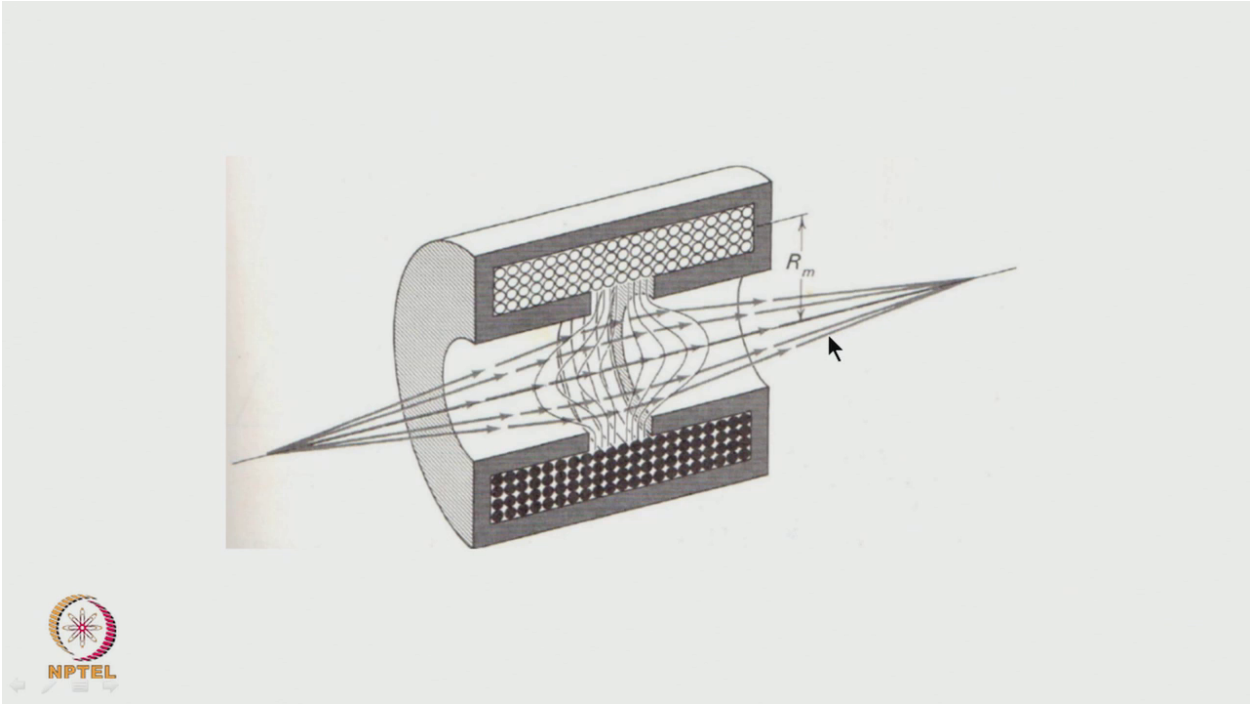

In this if you look at it these are all the various that is coil with the particular number of coils per unit length which has been chosen. So, that that controls the magnetic field and you can see that the magnetic field here it is like this in this you see that the how the magnetic flux the field lines change. So, this looks the shape looks like now that of a convex lens and. In fact, this acts like a convex lens in an electromagnetic lens you can male only a convex lens and you cannot make a concave lens. So, whatever the operations of the lenses we can minimize it, but we have to live with it.

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Now, we have to talk about the resolution of a microscope what we will do is that the resolution magnification and all these aspects we will cover in the next class. So, what we have covered. So, far is essentially a simple construction of a microscope now about basic information about resolution how the lens operations modify the resolution this depth of field depth of imaging which is important for a microscope that we will cover it in then different modes of in which the microscope can be operated in the diffraction mode or in the image mode then little bit about the vacuum systems and all this things then about some simple information about what all information which we can get it from a microscope these aspects we will cover in the next class, we will stop here now.