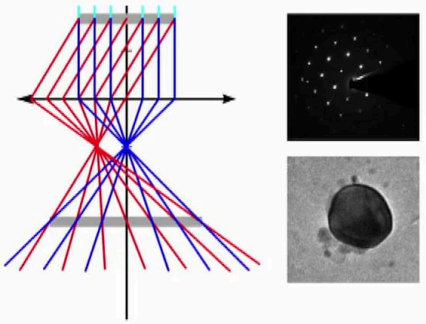
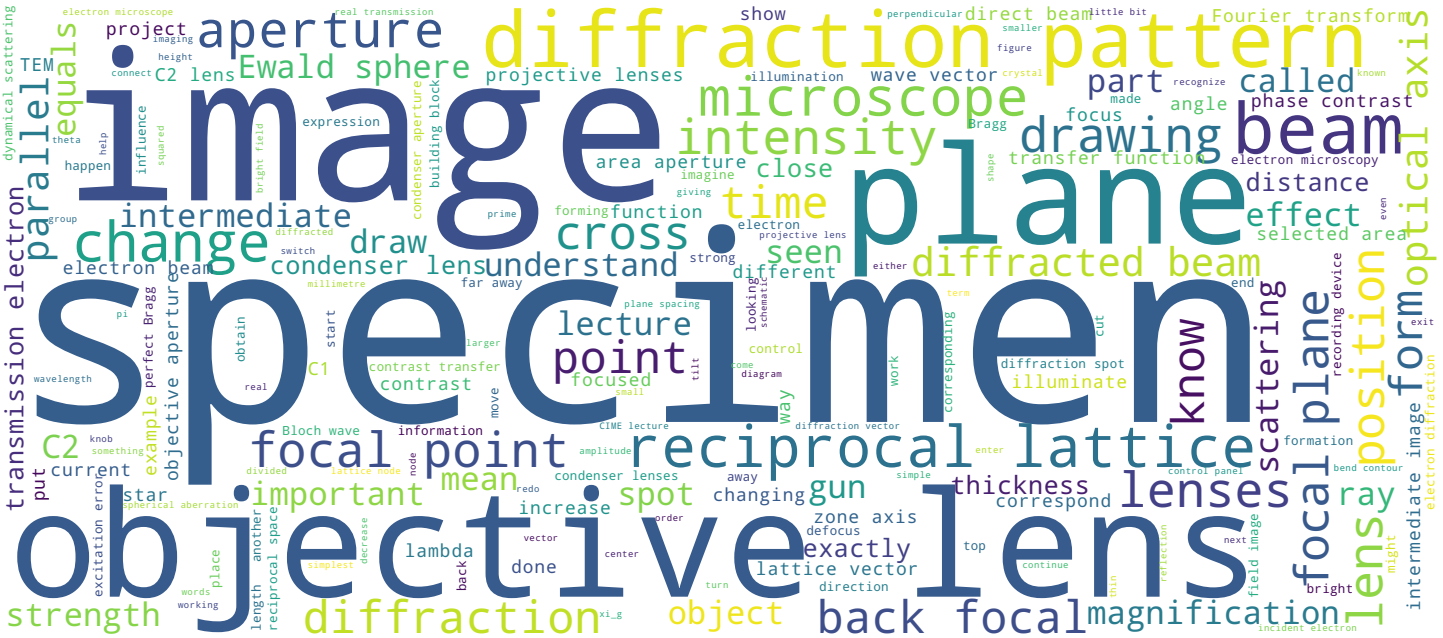


Introduction: the instrument II

Transmission Electron Microscopy

Prof. C. Hébert & Dr. D. Alexander



Search MOOC

Video

EPFL

Lenses at work

Transmission Electron Microscopy

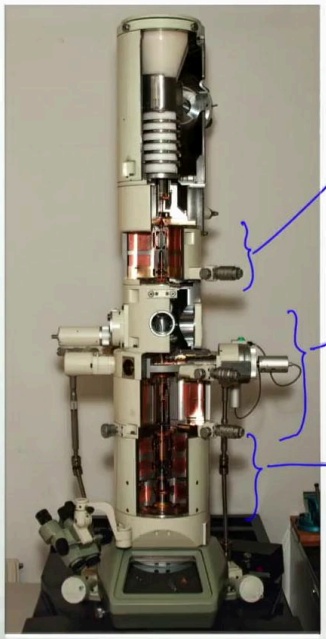
Welcome to CIME's lecture on transmission electron microscopy for material sciences. In today's video, we will use the building blocks that we have seen before, the lenses, and see how we can put them together to get a working microscope, with all its parts able to make the image of a specimen.

Notes

Summary

0m 05s

Groups of lenses



A typical TEM: Jeol 200cx

Condenser lenses → Forms the beam → specimen

Objective lens → Image of the specimen

Intermediate and projective lenses → project the image or diffraction pattern on the recording device

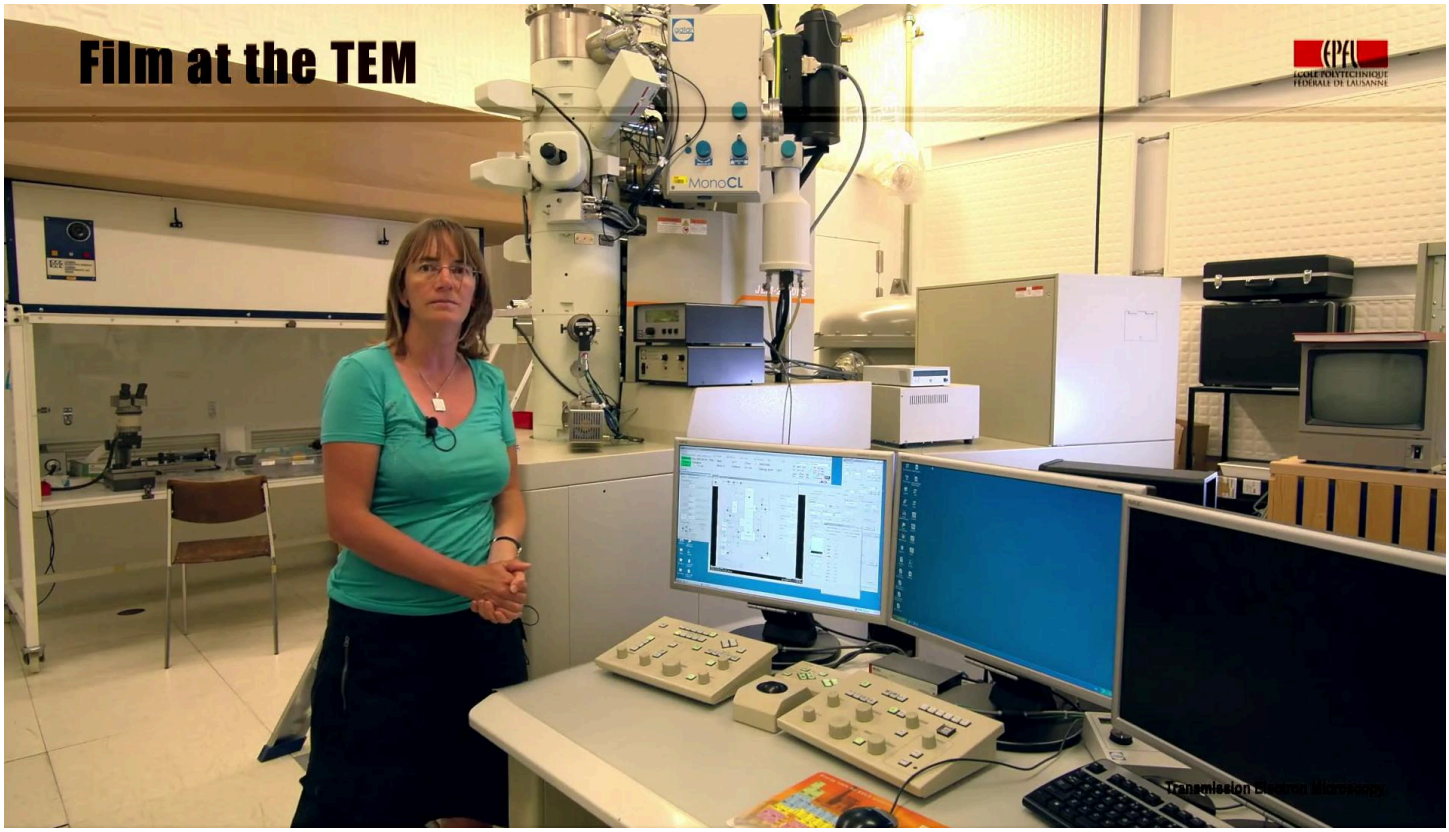
Transmission Electron Microscopy

There are many lenses in a microscope. They belong to 3 main groups which have different functionalities. The first one before the specimen is called the condenser lenses. These are the lenses used to form the beam that is exiting the gun and project it onto the specimen. The second block is the objective lens and its apertures. It is where we have the specimen and that is a very important lens used to make the first intermediate image of the specimen and also a diffraction pattern. And finally, we want to be able to change the magnification to look either at the image of the specimen or at its diffraction pattern, and also to change the magnification of the diffraction pattern. That is done by the third group which is made of the intermediate lens and projective lenses. So the first group, condenser lens, forms the beam, projected on the specimen. The objective lens makes an image of the specimen, and the intermediate and projective lenses will project this image on the recording device, magnify it, or project a diffraction pattern eventually magnifying it. Why is it important to understand those lenses and how they work? Let's go to the microscope.

Notes

Summary

0m 29s



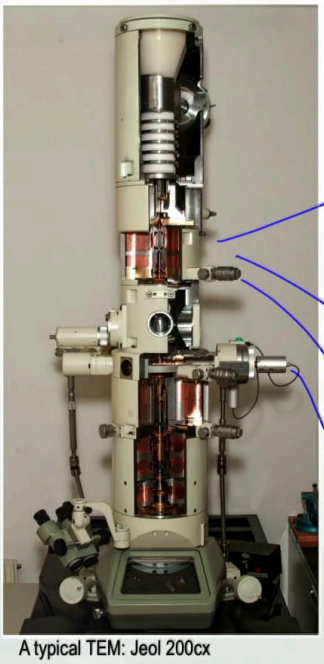
So here we are at the real transmission electron microscope. This is a JEOL 200kV and you can recognize the same structure as we had before in the lecture. On the top, we have the gun. This is a 200kV field emission gun. Then we have the condenser lenses with condenser aperture. And below we have the objective lens with the specimen, the objective aperture, and hidden behind, we have the selected area aperture. Further down, we have the intermediate and projective lenses. And here on the table, we have the computer to control the microscope and the control panel. There are a lot of knobs on this control panel, and each of these knobs will have some influence on some of the lenses of the microscope. So, for example, this brightness knob controls the condenser lenses and the illumination on the specimen. If I change the focus knob, it will change the current in the objective lens. I can change the magnification which will have an influence on the projective lens. I can switch to diffraction, that will change the projective and intermediate lenses. And I also can deflect the beam on after, before the specimen. So it is very important to understand what you are doing when you operate the microscope. And for this you know to understand the functioning of all those group of lenses. And that is what we ill see now in the following part of the lecture.

Notes

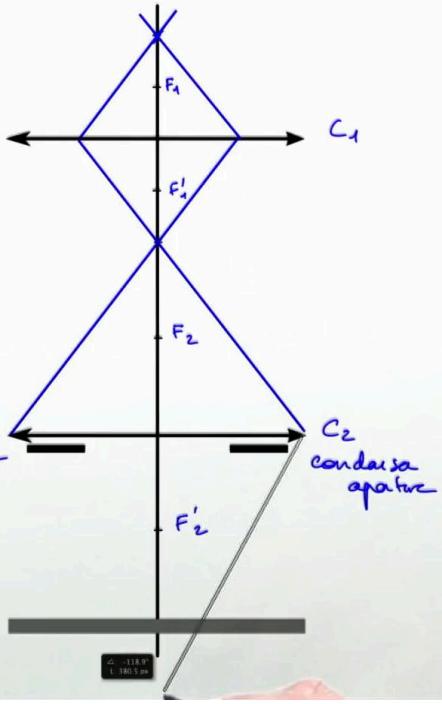
Summary

2m 08s

The condenser system



A typical TEM: Jeol 200cx



Transmission Electron Microscopy

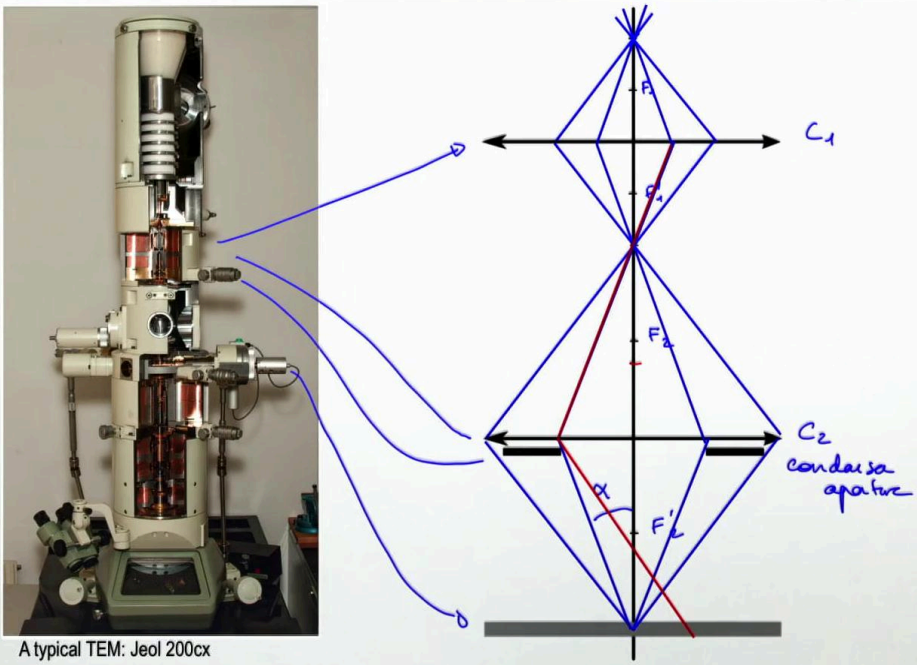
The condenser system forms the beam after the gun and projects it on the specimen. It is the first set of lens before the specimen and after the gun. And it is made of at least two lenses and one aperture. We will start with the simplest case of two lenses and one aperture. The first one on the top is called condenser 1. The second one just below is the condenser 2. And the aperture is the condenser 2 aperture. The specimen is further away and the beam formed by the set of lenses will be projected on it. The gun is producing a cross-over which is a point where all the electrons will cross on the optical axis. These set of lenses will then form an image of this cross-over and project it on the lens. In that simplest case which I have taken, the distance between lens and focal point is the same as the distance between focal point and object. So I know that in this schematic I will have a magnification of exactly one, and the image will form at the same distance as the object is. The drawing is therefore very simple. Depending on the strength of the C2 lens, I can form my last cross-over exactly on the specimen, before the specimen, or after the specimen.

Notes

Summary

3m 58s

The condenser system



Transmission Electron Microscopy

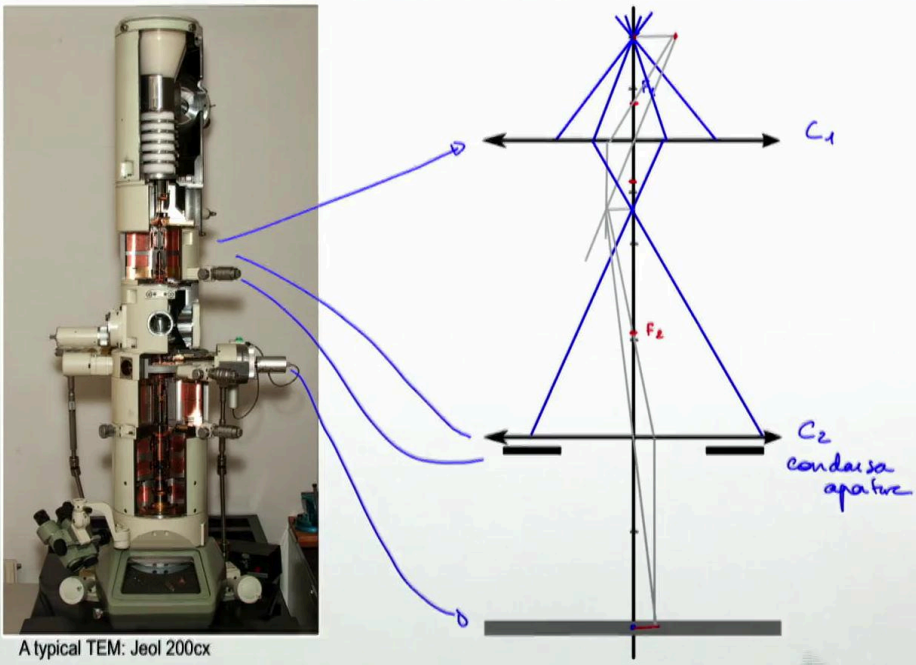
I will take the case where I form it exactly onto the specimen. You see that the condenser 2 aperture actually limits the extension of the beam. I can redo the drawing in the reverse direction and I will know exactly what is the maximal opening of my beam. This part of the beam, is cut by the aperture while this one is kept by the aperture. I have here, a maximal angle that will illuminate the specimen. It is called the illumination semi angle alpha. If I change the excitation of the C2 lens, I will change the position of the focal point. By doing this, I will also change the position at which the cross-over is formed. For example, if I increase the strength, the focal point will move closer to the lens and the strength of the lens will be stronger. I will have the same ray path after C1. But after C2, as I will have a stronger lens, my cross-over will form earlier. My lens will be in over focus. My cross-over, before the specimen. The reverse is if I decrease the strength of C2, I will form my cross-over after the specimen.

Notes

Summary

5m 44s

The condenser system



Transmission Electron Microscopy

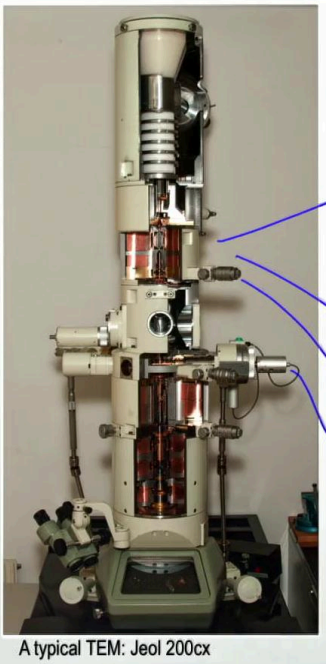
If I want to know what the effect of changing the strength of C1 is, I have to redo my drawing. And this time, I will increase the strength of C1. Which means I will have my focal point closer to the lens, and the symmetric focal point also closer to the lens. In that case, the image of my cross-over will not be at the symmetrical position as before. I have to do a complete drawing to know where to find it. With this drawing, I know the position of the image of my gun cross-over and then I can draw the ray pass. I have to take rays with a slightly lower opening. I need to know the image of this cross-over done by C2. I will adjust my C2 lens in such a way that the image is forming on the specimen, and to have a convergent beam on the specimen. Adjusting the C2 lens, means that I am allowed to change the position of the focal point. Now my constraint is that my object for C2 is there and my image for C2 is at that position. With this drawing, I have the position for my new focal point, F2 of the C2 lens. I also notice something. Before, I had a magnification of 1. Now, I have a magnification between this as an object and that point as an image which is smaller.

Notes

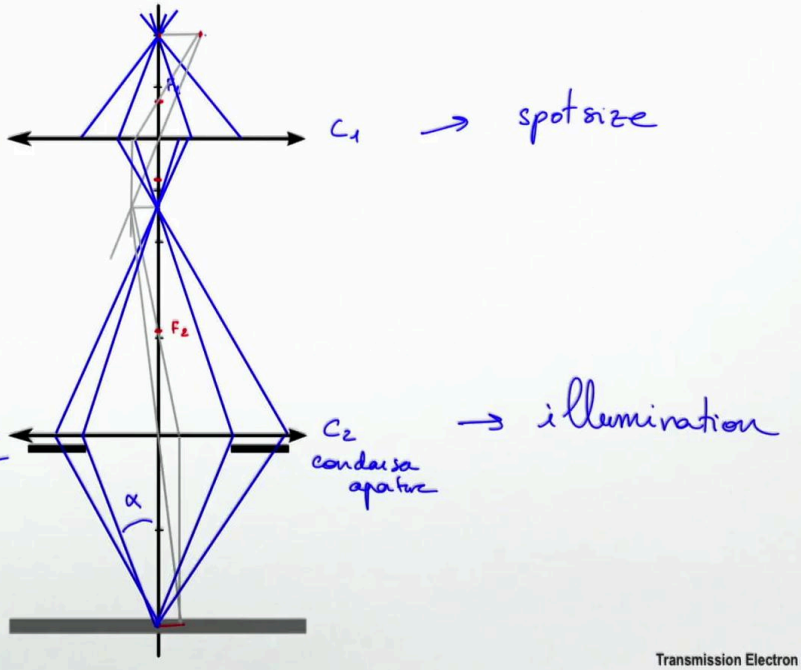
Summary

7m 21s

The condenser system



A typical TEM: Jeol 200cx



Transmission Electron Microscopy

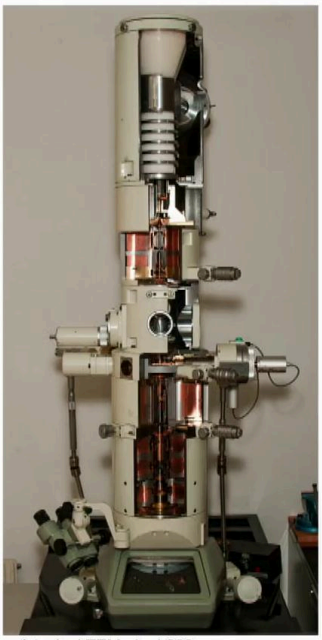
I can finalize the drawing by knowing that the rays will converge to the specimen, and then eventually take into account the C2 aperture. Finally, by changing the strength of C1, I end up with a beam on the specimen with the same alpha as before when I'm converged on the specimen, but with a de-magnified image of my source. I am working with a smaller spot of electrons on the specimen. And that is finally why we say that C1 controls the spot size and C2 with its aperture, will control the opening of the beam and the width of the illumination on the specimen.

Notes

Summary

9m 16s

The objective lens



A typical TEM: Jeol 200cx

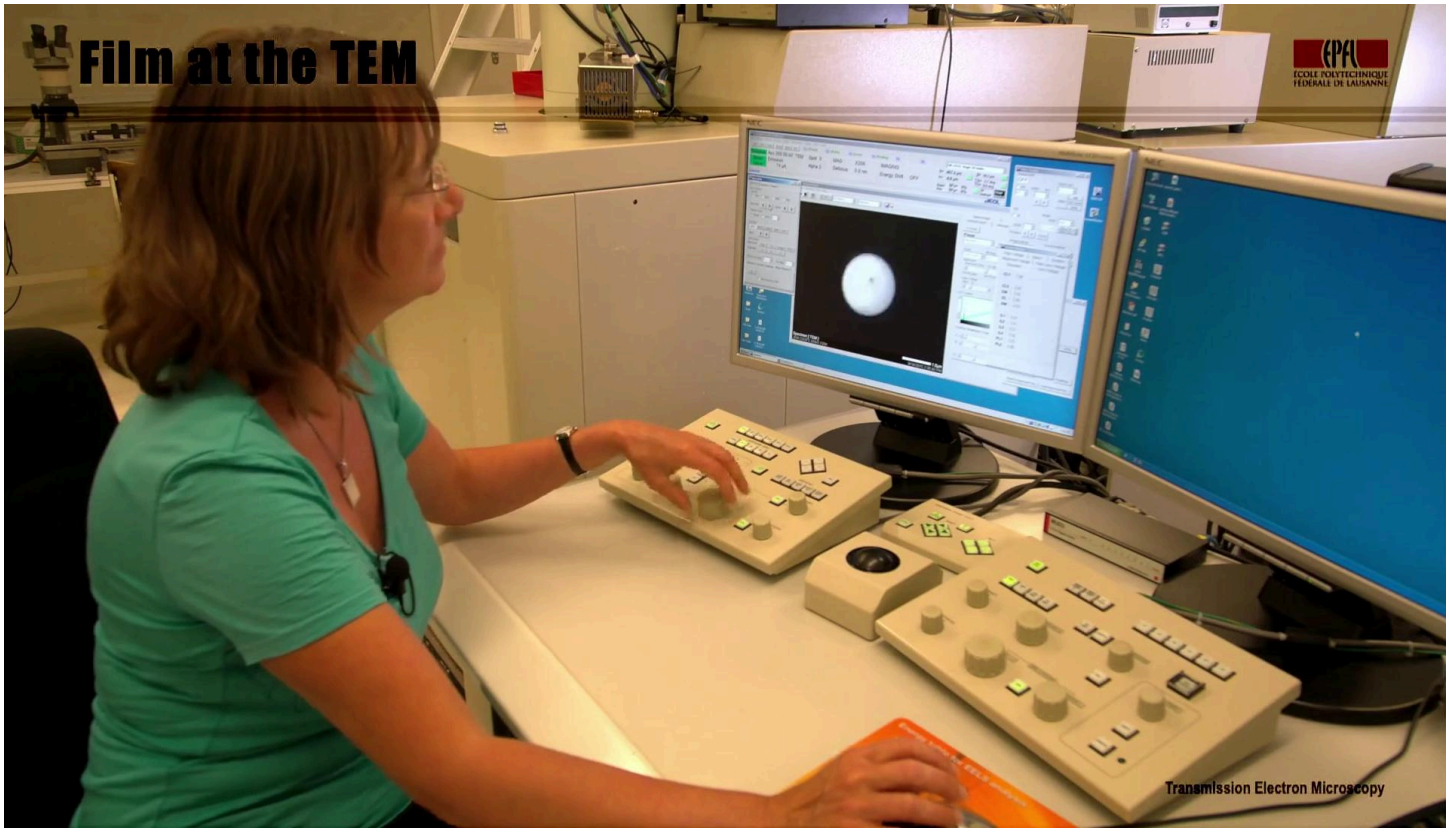
Transmission Electron Microscopy

So, that was for a two condenser lens system. With the help of the appendix video, you will figure out by yourself how it works for a three condenser lens system. But now let's go to the microscope.

Notes

Summary

10m 10s



Okay, here we are again at the microscope. And I will show you the effects of the condenser lens system. This time, we see the image of the beam of electrons that will illuminate the place where we have the specimen. If I turn the knob called brightness, I can illuminate a larger or smaller place on my specimen. And this is done by changing the current in the second condenser lens which is called CL3 here. I can also change the spot size. Now we have spot 1, to increase it for example, to spot 3, 4, 5, etc. This changes massively the current in the first condenser lens and with this I'm able to have a smaller illumination on my specimen.

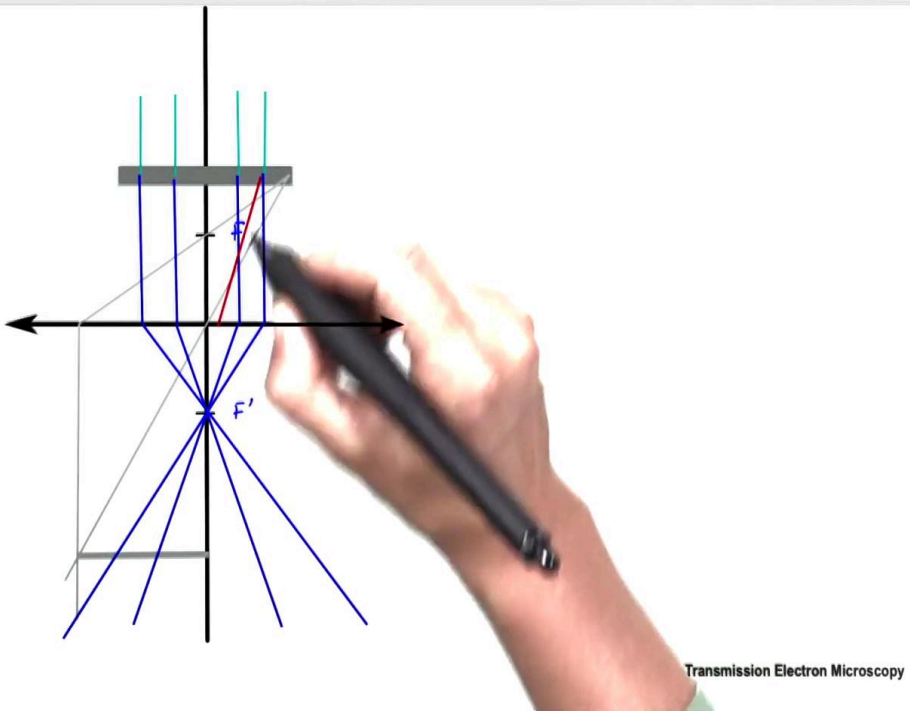
Notes

Summary

10m 24s

The objective lens

A typical TEM: Jeol 200cx



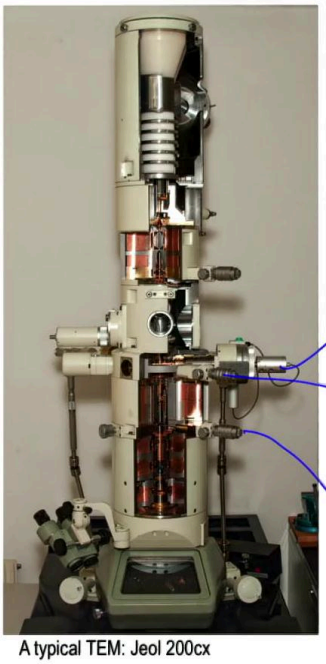
But now let's move on to the next building block of the microscope. The objective lens makes the first intermediate image and diffraction pattern after the specimen. <It is a very important one. It has 3 main components: the lens itself and two apertures. At that height, we have the specimen. We can generally make a simple sketch where we have the optical axis, the specimen, and the objective lens. We suppose that we know where we have the focal point F and F prime of the objective lens. First of all, we need to figure out where the image of the specimen is forming. With this, I see that I have an image formed below the lens with a small magnification. For simplicity, I will imagine that my illumination system, the condenser lenses, produces a parallel illumination on the specimen. Some of the electrons will interact weakly with the specimen, and will exit the specimen parallel to the optical axis. Those electrons will be focused to the back focal plane of the objective lens. With this drawing, I know exactly that this point of the specimen corresponds to this point of the image. If I imagine that I have a series of electrons that are diffracted in the specimen, they will exit the specimen with the beam making an angle to the optical axis.

Notes

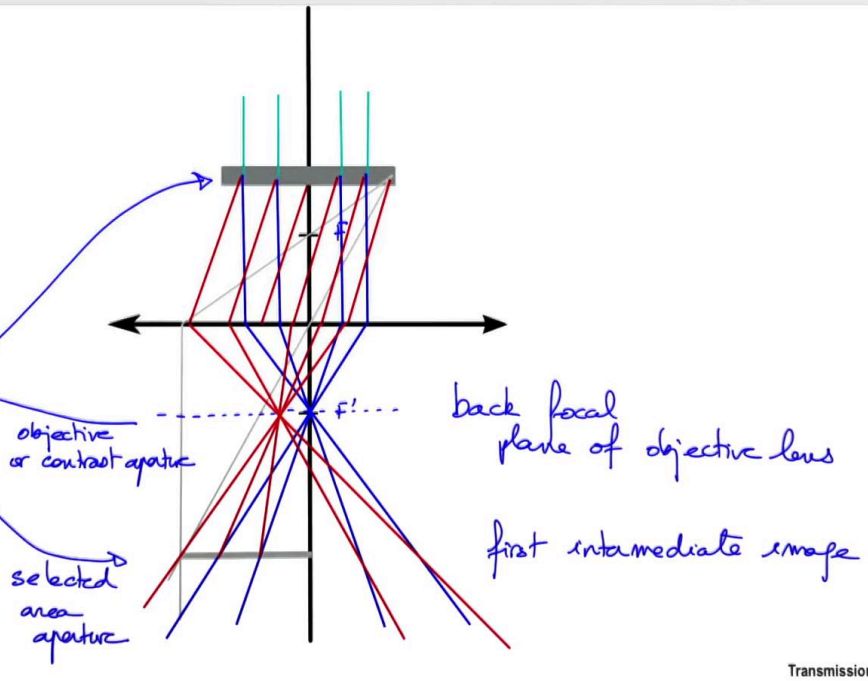
Summary

11m 33s

The objective lens



A typical TEM: Jeol 200cx



Transmission Electron Microscopy

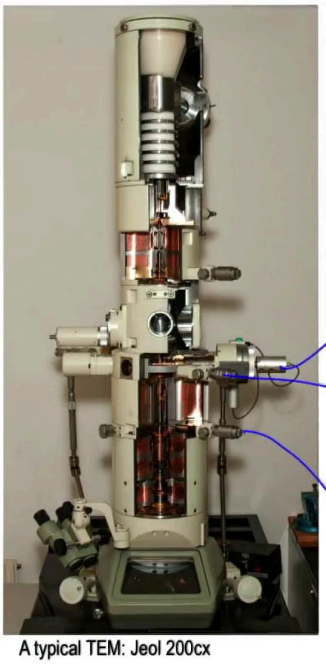
But all this part of the specimen will diffract the same way, which means that all these rays will be parallel to each other. Still, rays exiting the specimen from that point will correspond to the same image point on the specimen. They will be focused by the objective lens to this point. The same holds for the next one. And I can continue my drawing. Now, what you can observe is that all those red rays cross at the same position in the back focal plane of the objective lens. that is something that you might have seen in your optics lecture. Rays that enter the lens parallel to each other but at an angle to the optical axis, will be focused to a point in the back focal plane of the objective lens. Now we can connect the different parts of this drawing with the microscope. At that position, we have the specimen holder with the specimen. We have a first aperture. This one is the objective aperture, and it is exactly situated in the back focal plane of the objective lens. We have a second aperture further down. This one is situated at the height of the first intermediate image of the specimen. This aperture is called a selected area aperture.

Notes

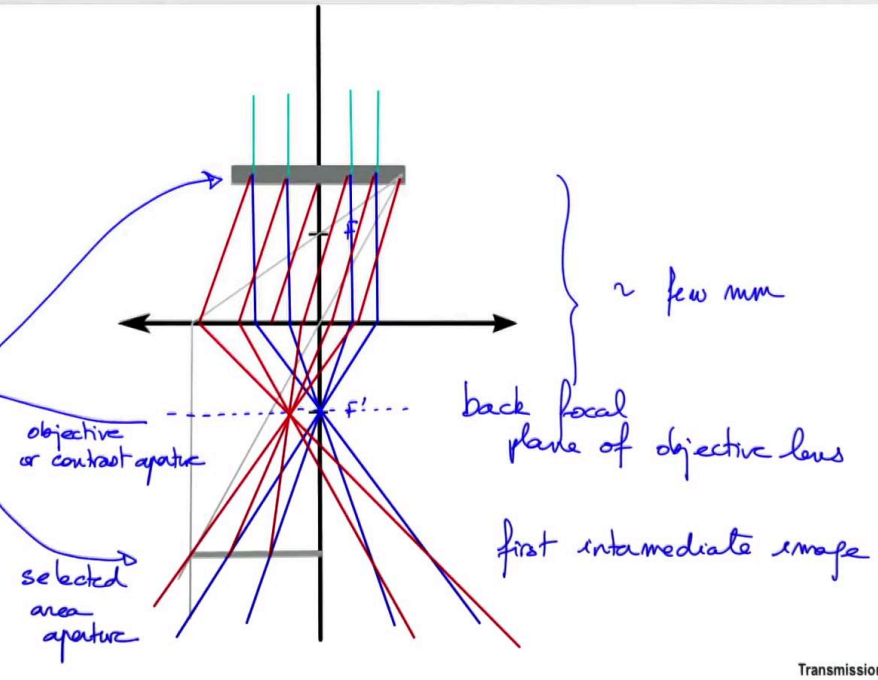
Summary

13m 22s

The objective lens



A typical TEM: Jeol 200cx



Transmission Electron Microscopy

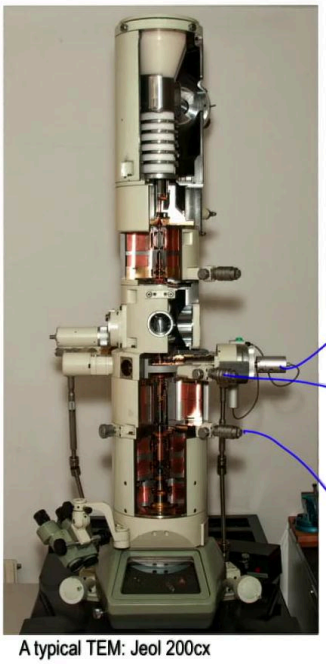
Actually, if you want to go a little bit further, you might have seen in your optics lecture that in the back focal plane of the objective lens, you have a Fourier transformation of your object. The Fourier transforms a specimen if it is a crystalline specimen, you enter the reciprocal space. Which means that in the back focal plane of the objective lens, you have an information on the reciprocal lattice of your specimen. And that is exactly your diffraction pattern. We will come closer to this in the lecture about diffraction contrast, and diffraction in the TEM. But now, let's look into more details at that real transmission microscope. If you look carefully, you will recognize that the objective aperture which is in the back focal plane of the objective lens is very close to the specimen. And that in contrast, the selected area aperture is very far away. A second strange thing is that the objective lens seems to be below its back focal plane. This is absolutely impossible. In reality, you have a soft magnetic material which guides the magnetic field produced by the coil of the objective lens, to be very close to the specimen. All these distances are in the order of magnitude of a few millimetres.

Notes

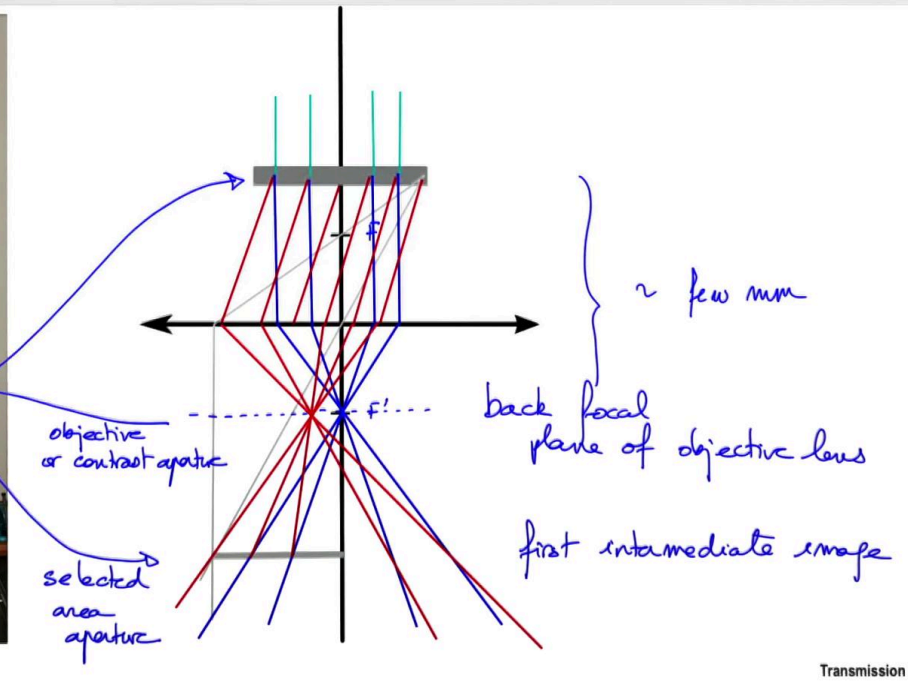
Summary

15m 14s

The objective lens



A typical TEM: Jeol 200cx



Transmission Electron Microscopy

The focal length of the objective lens is generally around two millimetres. The specimen is very close to the front focal plane of the objective lens. What would happen if you would try to draw this exactly?

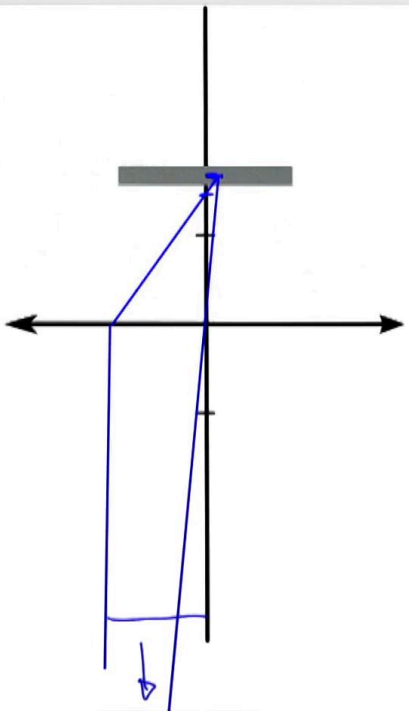
Notes

Summary

16m 52s

The objective lens

A typical TEM: Jeol 200cx



Magnification by the objective lens is ≈ 50 times

Transmission Electron Microscopy

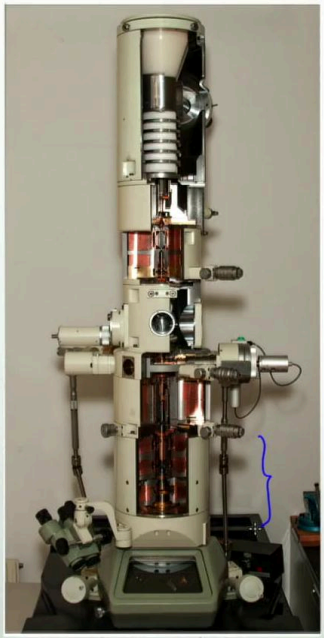
Instead of having the focal point between lens and specimen, we should put it close to the specimen. In that case, when I try to draw the image of my specimen, I will take a point close to the optical axis, passing through the focal point, and then exiting parallel to the optical axis... Oops! I have a problem. I can't do my drawing. The image is forming very far away. A second thing that you notice, is that if this is my object, the image would have this size even if it is much further down. that is exactly what happens in the microscope. The magnification by the objective lens is around 50 times. The specimen is very close to the focal point and the image is forming far away from the lenses. Since such a real scale drawing is not practicable, we will always use a sketch with small magnification. We now remain with the last building block.

Notes

Summary

17m 09s

The intermediate and projective lenses



A typical TEM: Jeol 200cx

Transmission Electron Microscopy

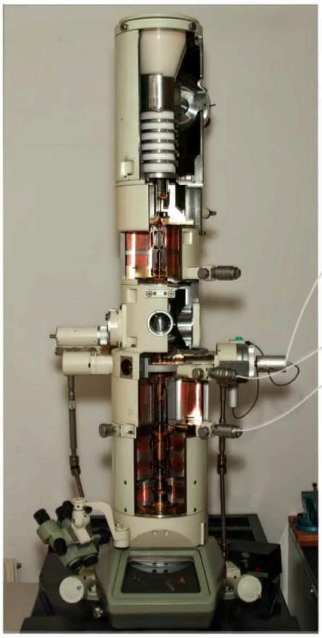
To visualize the image or diffraction pattern formed by the objective lens, we use the intermediate and projective lenses. This is the group that is situated after the objective lens. Generally you have at least one intermediate lens and two projective lenses.

Notes

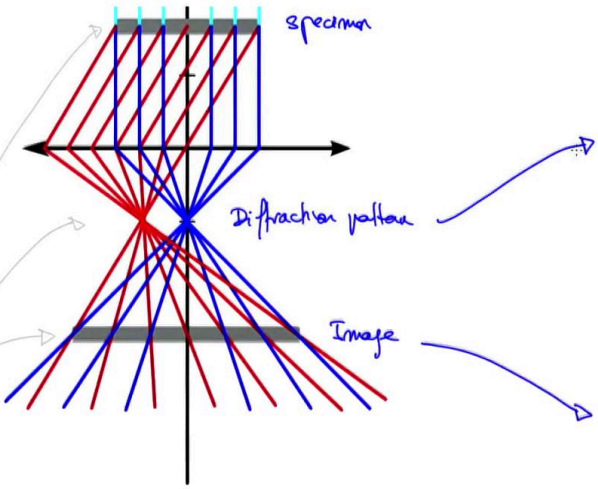
Summary

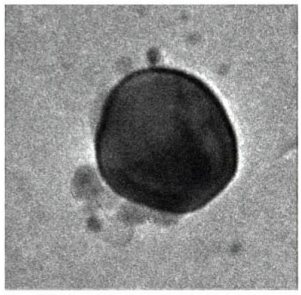
18m 28s

The intermediate and projective lenses



A typical TEM: Jeol 200cx





Transmission Electron Microscopy

Do we really need to draw them to understand how they are working? Actually, we never do it. We stick to the drawing of the objective lens, the one that we have here which I have put a little bit further up. So let's connect all the things together. At that position I have the specimen, then I have the formation of the diffraction pattern in the back focal plane of the objective lens. And the selected area aperture in the first intermediate image. That is the diffraction pattern, the image and that is my specimen. The current in those intermediate and projective lenses is not changed continuously. It has presets, and those presets will help to either project the image of my specimen on the recording device, and when I do this I obtain on my camera something that might resemble this. This is a small oxide particle, and that is the direct image of this particle. By just doing one press on one knob, I can switch all my lenses and then move to the projection of the diffraction pattern on the recording camera. And in that case, I see directly the diffraction pattern of this small oxide particle. Okay, you will see this interplay between the pre-select of this intermediate and projective lens, and those planes in the next part of the lecture where we will show the complete microscope at work, together with demonstration on a real TEM.

Notes

Summary

18m 49s

Conclusion

A typical TEM: Jeol 200cx

Transmission Electron Microscopy

So in today's module, we have seen the three main blocks of lenses that are used first to produce the image of the cross-over after the gun to illuminate the specimen, then to make your first image of the specimen, and finally to take the image or diffraction pattern and view it on your recording device. Next time, we will have a look at the complete microscope at work. Both in diffraction mode, and in imaging mode and see how we can control those lenses to really obtain images and diffraction patterns.

Notes

Summary

21m 00s