

DIFFRACTION KIT INTERACTIVE CD-ROM

Ernst Abbe developed the Zeiss Diffraction Kit to demonstrate to sceptical microscopists at the turn of the century the validity of his diffraction theory of microscope image formation. It was produced by the Zeiss firm for many years thereafter as an educational resource, but sadly it is no longer available. Our aim is therefore to recreate it in the form of a CD-ROM which will reproduce all the experiments of the diffraction kit in a form which is cheap, light and portable. This will bring the experiments, and the understanding which comes from carrying them out, to a far wider audience than would ever have access to the original kit.

The software on this CD-ROM is a demonstration version to illustrate the concept, but it contains several key experiments which can be performed with the Kit. It is on the CD in three forms:
Diffkit.exe - a PC executable (standalone program) which runs under Windows 95 or later.
Diffkit.hqx - a Macintosh program in Binhex form for portability. Drop it into Stuffit Expander (or any other utility which can handle Binhexed files) to extract the Mac executable.
Diffkit.swf - a platform-independent Flash file which will run on any computer which has a compatible Flash viewer (version 4 or later is required). Players - and instructions - for Mac and PC are on the CD in the folder Players, but the latest versions are always available - free - from www.macromedia.com and if your computer is reasonably new they will probably already be on it. (If your computer - Mac, PC or Unix - doesn't recognise the file, try opening it with your Web browser.)

Our objective has been to keep things as close as possible to using an actual microscope. When you focus the image, the focus knob turns; when you insert the Bertrand lens, you see the slider go in. Other controls which were not suitably located for display in this way are shown as animated icons which reflect their actual shape and operation. They are mostly operated by arrow buttons - the appropriate pair of arrow keys on your keyboard will have the same effect as clicking on the buttons. *(The keyboard alternative may not work on some viewers when using the .swf version).*

The diffraction kit has a short, low-power objective (x6.3, NA .16) which fits on to a rotating collar with a slot cut in it, where various 'tools' can be inserted. This collar in turn fits on the nosepiece of the microscope. The other key component is a slide with seven 'specimens' (photo-etched patterns) on it. Most of the experiments need parallel illumination of the sample, which is simply achieved by removing the condenser from its holder and closing down the field iris.

In the present demonstration version of the CD, only one specimen is available, consisting of parallel clear lines on a dark background. These are 16 μ m apart in the upper part of the sample and 8 μ m apart on the lower part. You simply need to click on the 'Insert Specimen' button to put it in. On the lower left, by the microscope, is a 'Start Over' switch which brings you back to the start at any time, while at top right is the red Quit button, labelled just 'Q' (Shift-Q is the keyboard alternative).

When the specimen is in place the image - in the upper window - is naturally out of focus. You must focus it before proceeding further. Notice that as you focus the image of a specimen like this you see all sorts of confusing patterns when you are out of focus, and it may even seem to get sharper then fuzzier again as you approach focus.

When the image is in focus you can insert the Bertrand lens which gives a view of the *Back Focal Plane* (BFP) - see the section below for more detail on the BFP. The Bertrand Lens (or its alternative, the phase telescope) also needs to be focused, and you will see that the further we get from the BFP the more 'image-like' the pattern becomes, as you might expect.

Once both image and BFP are in focus we can pick one of the tools and see its effect. You can freely swap between these tools at any time. Only those tools with a green background are currently available.

The Iris Diaphragm

This is one of the simplest and most important of the tools. When it is closed it effectively reduces the Numerical Aperture of the objective since the rays entering at a larger angle are prevented from going any further. Open it fully and it has no effect - the image is just the same as when it was not inserted. Closing it down a little just makes the image look less sharp, but a drastic difference is seen once only the first order diffracted spots are passed. These contain information only about the larger - $16\mu\text{m}$ - spacing so the $8\mu\text{m}$ spacing just disappears, and only comes back when we open enough to let in at least one second order spot. The aperture is not quite central so we can see that only one first order spot is still enough to image the $16\mu\text{m}$ spacing, but when we close further than that we see only the gross outline of the pattern - neither of the line spacings is visible.

The 2mm Hole

This is a simple fixed aperture which we can slide in and out. Note that if only two diffraction spots pass through the aperture (whether or not either is the central spot) we will only resolve the larger pattern - to see the $8\mu\text{m}$ spacing three spots must be transmitted. Also note that when we move the aperture well out we can change the colour of the image by only capturing certain wavelengths in the second-order spot. Remember that the longer the wavelength the larger the angle of the diffracted rays.

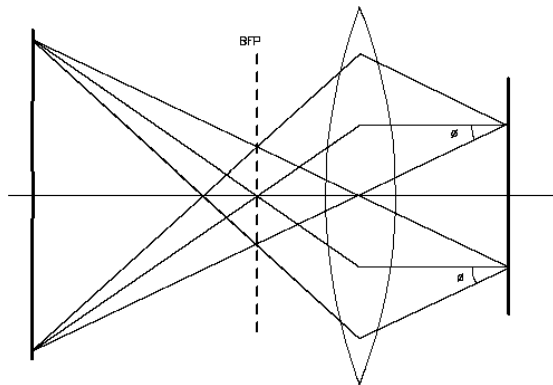
The Triple Slit

When you select this tool it is completely withdrawn, so the image looks unchanged. As you slide it in the end of the slider comes across first, gradually blocking the diffraction spots from the left hand side of the BFP. Note what happens to the image as the spots are progressively removed. As the triple slits themselves move in we see interesting colour effects since they pass only some wavelengths of the diffraction spots. What about the line spacing we see - is it real? When it is fully in we see a most peculiar effect: with only the central and *second* order diffraction spots passing a completely spurious spacing appears!

The Back Focal Plane of a lens

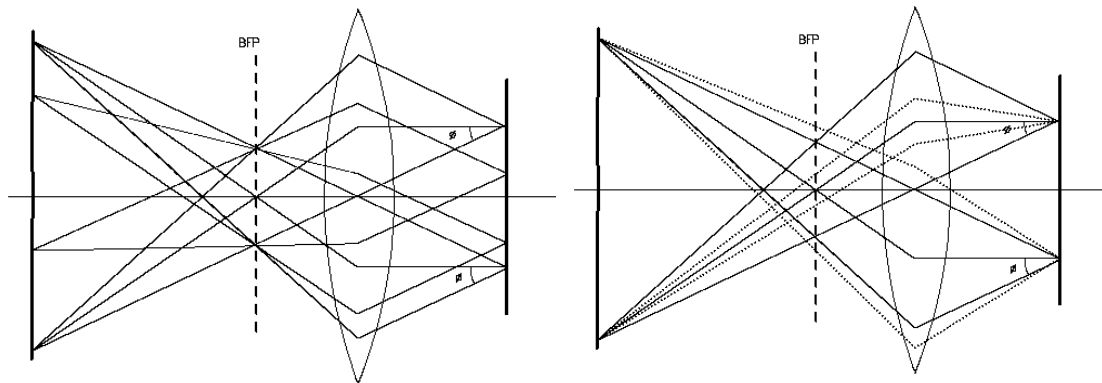
Let's take a look behind the objective lens

We can construct ray paths through a lens in the traditional way, by drawing one ray from the object passing undeflected through the centre of the lens, and a second from the same point running parallel to the optic axis, and therefore deflected through the focus of the lens (the definition of focal length, remember). Having defined the position and size of the image in this way, we can draw in as many more rays as we like.



As a start, here we have added the rays that leave the object at an angle, ϕ , equal to that of the rays passing through the centre of the lens but in the opposite direction. An interesting feature of the ray paths is now apparent. Behind the lens, at the plane of the focus, rays leaving both object points at an angle of $+\phi$ cross each other, above the object axis. The parallel rays, of course, cross at the focus, while at an equal

distance below the optic axis the rays leaving both object points at $-\phi$ cross each other.



More points, and more rays, can be added to the diagram. On the left we see more points, with rays leaving each at $+$ and $-\phi$, and on the right we have rays leaving at larger and smaller angles.

We can see that at this plane, all rays, from any point of the object, that leave *in one particular angle and direction* will meet at *one point*. The larger the angle, the further this point will be from the axis. This plane is called the Back Focal Plane of the lens. (Sometimes called the Focal Plane, or the Diffraction Plane.)

The back focal plane of the objective is easy enough to see. All that one need do is focus the microscope on a specimen, then remove an eyepiece and look down the tube. A larger and clearer image can be obtained by using a phase telescope instead of the standard eyepiece. This is a long-focal-length eyepiece which takes the back focal plane as its object, and gives a magnified virtual image of it, just as a standard eyepiece does with the image. Alternatively, research microscopes often have a Bertrand lens which can be moved into the column on a slider, or swung in with a knob. This lens forms an image

of the back focal plane at the normal image position, where it is magnified by the normal eyepiece just as if it were the image of the specimen.

If a specimen scatters light uniformly, the back focal plane will be a uniformly bright disc, its diameter being determined by the maximum value of Φ that the numerical aperture of the lens will permit it to accept. However, a specimen which scatters light at particular angles and in specific directions, like the one we use here, will give an array of spots in the back focal plane.

There is more to this than just an interesting observation which can give pretty patterns. It means that light can be sorted, at the back focal plane, not according to where it comes from, but according to the angle at which it has been scattered by the specimen. This gives a handle on controlling, and testing, the resolution of the microscope, and it also opens the door to a range of important contrast-enhancing techniques.

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