# the Keeling Lab: Van Leeuwenhoek Microscope

**Introduction**

Antonie van Leeuwenhoek was a wealthy cloth merchant who lived in the city of Delft, in the Netherlands, from 1632 to 1723. He is best known for his pioneering work on microscopy: from 1673 onwards he created as many as 500 microscopes and from these made numerous significant discoveries. This included determining the existence of single-celled organisms, a discovery that ironically brought his scientific credibility into question for some time.

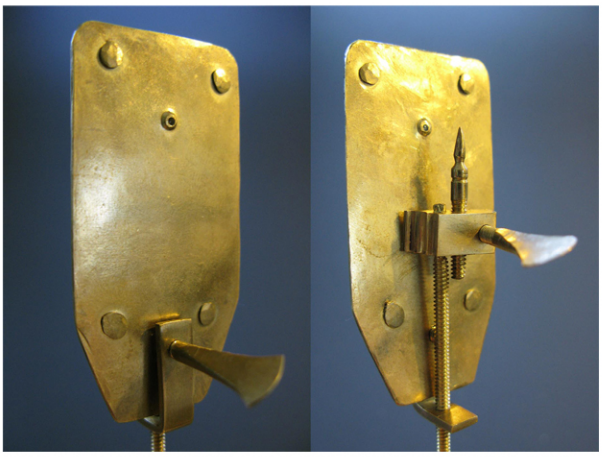

Figure 1-1. Front and back views of a brass replica of a van Leeuwenhoek microscope. Building such a replica requires a few tools and some skill with them, but below are instructions for building a microscope out of simpler materials, with the same optics and similar operating principles.

The success of these microscopes can be attributed to many things, but a number of technical matters stand out. First, his microscopes relied on a single lens. Compound microscopes (those with more than one lens in the light path) theoretically provide better resolution, but they are also much more technically challenging to fabricate. As well, Leeuwenhoek devised a relatively simple means to produce his single lens. In particular, his methodology appears to have reduced the need for precise grinding techniques, and grinding was a laborious and technically difficult process.

The few examples of Leeuwenhoek's microscopes that remain today are elegant creations
Figure 1-1. Front and back views of a brass replica of a van Leeuwenhoek microscope. Building such a replica requires a few tools and some skill with them, but below are instructions for building a microscope out of simpler materials, with the same optics and similar operating principles.
of brass or silver with many working parts. Although much less complex than modern microscopes, replicas of metal with the same working features are challenging to build and require some skill with a small number of tools (Figure 1-1). However, the basic functional aspects of the design and lens production can be replicated in a few minutes, using a few simple raw ingredients.

Following the steps available here, you will be able to construct a working microscope using van Leeuwenhoek's general design and method of lens production. From this, you can then measure the size of the lens you make, and calculate its magnification. Lenses capable of 100X to 200X magnification are not too difficult to produce, and this article will also suggest and illustrate a number of interesting samples one can examine.

It's amazing to consider how we often take microscopy for granted in this day and age. However, when you use the microscope you build yourself, try to imagine what it must have been like to peer through one of these creations and discover a completely unknown realm of life, because your instrument will reproduce the microbial world as it would have looked like using the technology of the seventeenth century.

**Further Reading**

The purpose of this guide is not to create a working replica of a Leeuwenhoek microscope. There are already detailed instructions available on this, in particular I recommend Alan Shinn's instructions (see below). However, in the process of building such a replica from original documents, it became clear that it would be possible to create a microscope of similar design and power using only inexpensive materials that were easy to work with, and almost no tools. In a class environment this process has been successful with high school students as well as advanced undergraduates.

For further information on making more realistic replicas of Leeuwenhoek microscopes there are several sources, and I particularly recommend Alan Shinn's site (www.mindspring.com/~alshinn/Leeuwenhoekplans.html). For additional information on creating various types of lenses, see Baker, RC 1991 Science PROBE (April) pp. 53-62. For the method described below to calculate the power of the lens, see part 4 of John Davis' article (http://www.microscopy-uk.org.uk/mag/indexmag.html?http://www.microscopy-uk.org.uk/mag/artoct07/jd-lens.html). All of these contain numerous other references of interest.

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**Part 1: Build the microscope**.

**Materials.**

1 glass Pasteur pipette or capillary tube, or whatever glass source is handy
5 x 10 cm piece of 1mm posterboard (thick side)
5 x 10 cm piece of cardstock (thin side)
1 small dab (about 1 ml) of tacky putty or chewing gum

**Tools.**

Drill with 1/16 bit
Stapler
Flame (portable plumbing torch or Bunsen burner work best, but a disposable lighter or even a candle also works if your glass is thin – e.g. a capillary tube)

**Instructions.**

1. Cut out microscope plates. Cut out two roughly equal sized pieces of posterboard and cardstock. They can be any size and shape, but if you want to pay homage to Leeuwenhoek's microscopes they should be about 6 X 3 cm, with a slight taper at one end.

2. Drill light path (Figure 1-2). Drill an approximately 1 mm (1/16 inch) hole in the posterboard and cardstock. It is best to drill both at once and to drill into something like wood or additional posterboard to give a clean hole. The hole should be 1.5 cm from each side and the top, and about 4.5 cm from the bottom.

2a (optional steps). If you want to make a little pocket between the posterboard and cardstock for your lens, you can drill a shallow depression on the inside face of the posterboard using a 7/32 bit. This is not necessary since the cardstock will bend around the lens, but it makes a cleaner finished product. Alternatively, you can use two pieces of posterboard, but if you do you need to drill this pocket or the lens will be too far from the surface to be used (the lens has a short working distance). It is also helpful to carefully shave off any protruding paper around the holes with a sharp razor blade as lose paper fibers can be magnified along with your specimen.

3. Create the lens. The lens will be a sphere of glass whose diameter dictates the magnification. Aim for a lens of about 2mm in diameter since this is big enough to work with and gives a decent magnification. There are two main steps to this (wear eye protection when melting glass):

> Step 1, stretch some glass (Figure 1-3 & 1-4). Holding the pipette/tube at both ends, place the centre in the flame and hold it there until the glass melts and wobbles freely between your hands. It helps to roll it in the flame to equally expose all sides of the heated area. When the glass is soft, remove it from the flame and immediately pull the two ends apart to stretch the glass very thinly. How far you must pull depends on the thickness of your glass source. You are aiming for a glass tube of >0.5mm. Too thick and your lens tends to be teardrop shaped rather than spherical, too thin and you have to feed a tedious length of glass into the flame or the lens can break off during step 2.

Figure 1-2. Drill a light path in both cardstock and posterboard at the same time using a 1/16 (or smaller if you have one) bit.

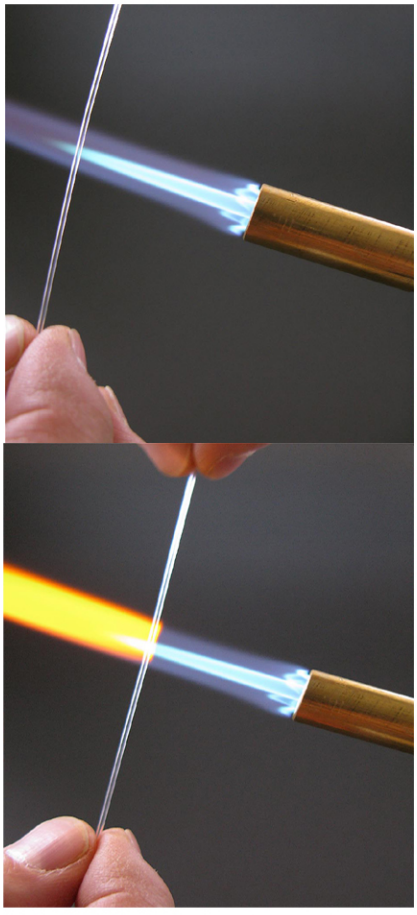

Figure 1-3. To stretch the glass, first place it in the flame, rolling it to heat it evenly until it is quite soft and wobbly.

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**Instructions** (continued).

3. Step 2, form the lens (Figure 1-5). Once the stretched glass has cooled sufficiently to handle, break it somewhere in the middle of the stretched portion. Position the flame horizontally, and slowly feed the stretched glass into the flame from above. Watch this step carefully. A small, white hot glass sphere will grow at the tip of the tube as you feed it into the flame. It is critical to keep this sphere in the flame and not to let it cool before it is done (or when you reintroduce it bubbles will form in it). Keep feeding the tube into the flame until the sphere is about 2 mm in size. A nice trick to help keep this motion constant and the sphere in the flame is to feed the stretched glass though the loop of a pair of scissors so that about 5 cm of glass extends from the loop. Then hold the scissors by the blade and twist slightly so there is mild tension on the glass. This will hold the end of the glass steady as you feed it into the flame. Once the sphere is the size you want, remove it from the flame, let it cool completely, and break the tube off about 0.5 cm from the sphere. This gives you a short handle, like a lollipop, so you can avoid touching the lens during later construction. This also ensures the light path will be perpendicular to the 'wound' inevitably caused by breaking the lens from the tube (see below).

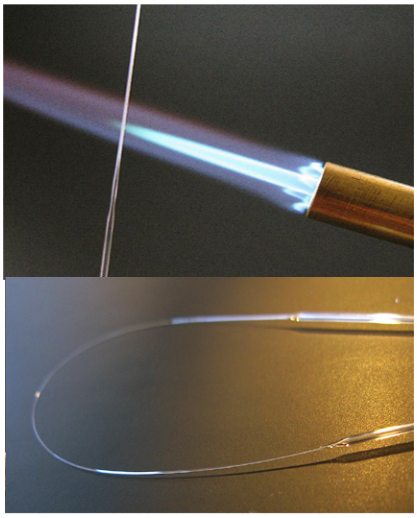

Figure 1-4. Once the glass is thoroughly soft, remove it from the flame and immediately pull apart the two ends so the softened part is stretched to a uniformly thin filament or tube.

Things to note: your sphere should be a sphere, and not a teardrop shape. If you get a teardrop your glass was likely not stretched sufficiently, so go back to step one and stretch a new one to be thinner. Also note that you can make several lenses from one stretched segment of glass: when one sphere is done snap it off and start again. If you want to work with a smaller lens, you may need to drill holes smaller than 1/16th. Not only can the lens actually fall through the hole otherwise, but you need the hole smaller than the lens to limit the visibility of your light source background and ensure proper contrast.

4a (optional step Figure 2-1). If you are going to measure the diameter of your lens to compare with the calculation of its power (see part 2 below), do it now, before you assemble the microscope).

5. Assemble the microscope (Figure 1-6 & 1-7). Holding your sphere by its handle, place the sphere over the hole you drilled in the posterboard (in the pocket if you followed optional step 2a) with the handle laying flat on the inside surface of the posterboard. Set the cardstock on top so the lens and handle are sandwiched between the two layers. Hold the two layers firmly together with the holes and lens lined up, and staple it twice about 0.5 cm from either side of the hole.

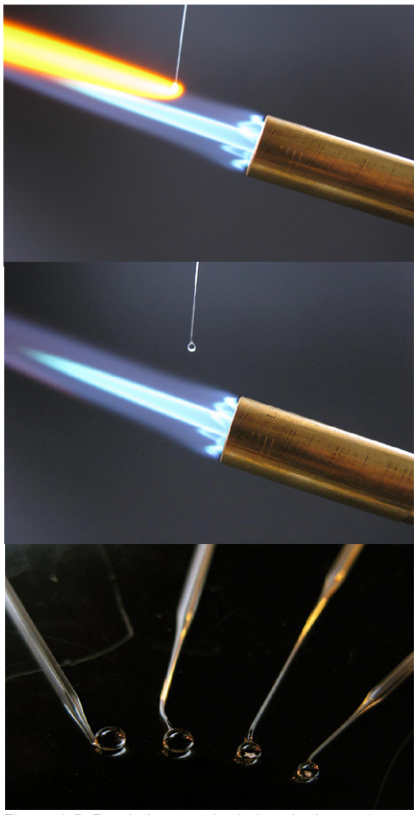

Figure 1-5. Break the stretched glass in the centre, the slowly feed one end of the thin portion into the flame (preferably a horizontal flame). As it heats, the tube will melt to a filament and a small ball will form at the end of the filament (upper panel). Once you are happy with the size of the ball remove it (bottom left). These are easy to make, so make several and chose the best sphere with no visible imperfections (like bubbles). Snap off the sphere leaving a short length of tube attached to it.

Things to note: these lenses have very short working distances, so your samples has to be very close to the lens. This is why you use the thinner card-stock on one side, and it means your microscope works in one direction: you look through the posterboard side and place your sample on the cardstock side. When you staple, do so with the cardstock side up so the staple is less likely to get in the way of the sample.

6. Make your focus mechanism (Figure 1-8, 1-9 & 1-11). The biggest challenge to making a microscope from paper is how to focus your specimen. The solution is to take advantage of the simultaneously elastic and sticky properties of tacky putty (e.g., Elmer's Tack Adhesive Putty: the kind used to stick posters on a wall) to both mount the specimen and pivot it in relation to the lens. Recently used chewing gum works as well if you can't find putty. To illustrate how this works, we will use mounting the barb of a feather as an example, but later will also explain how to mount other kinds of samples.

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**Instructions.**
6. (continued) To start, put your onion skin on a flat surface. Take a dab of putty about the size of a pea and press it over one edge of the barb, as illustrated. Pick the putty off the surface, and the barb will stick to the putty and project from it. Now stick the putty to the cardstock side of the microscope just below the hole (don't get putty on your lens) so the barb is right over the hole. This will be your stage, focusing device, and your movement controls.

To view the specimen, hold the microscope as close to your eye as is comfortable (realistically this means holding is sideways), looking from the posterboard side directly into a light source (any light bulb, or a bright sky – don't look directly at the sun). To focus, place your thumb on the putty. Pushing the putty up towards the top of the microscope will cause the sample to pivot closer to the lens, pulling down will cause it to pivot away from the lens. Movement from side to side will position the sample over the lens as desired.

The same principle is used to mount other kinds of samples. To mount any dry, solid specimen place it on a surface and press the putty over it and attach it to the microscope as described (I like feather barbs, insect wings, or onion skin to see the microscope in action easily). To mount a wet specimen, place a glass coverslip on a surface and mount it as described. Then drop your sample onto the coverslip and hold the microscope horizontally with the coverslip side up (so your sample does not drip) and look from the bottom. Wet samples can also be mounted between two coverslips, although this take a bit of practice. For this I suggest diatoms since they are big and regularly shaped. Forams and radiolaria are also good, but not as easy to find in nature (for some sample images see Figures 1-11, 1-12 & 1-13).

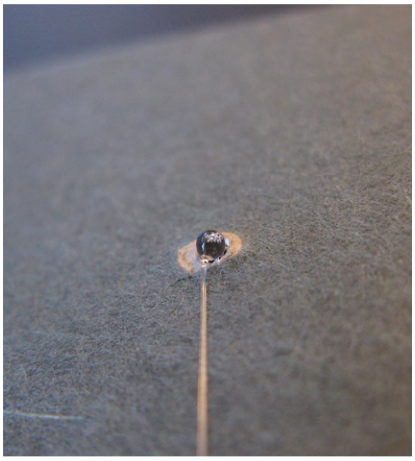

Figure 1-6. Place the lens in the hole on the inside of the posterboard, laying the remaining tube flat on the surface.

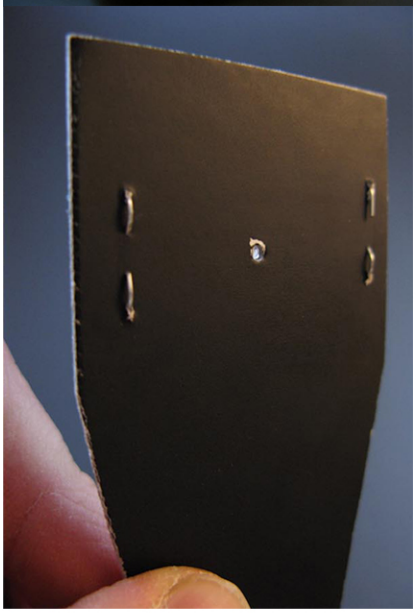

Figure 1-7. Staple the two pieces of paper together with the lens between them, and your microscope is assembled.

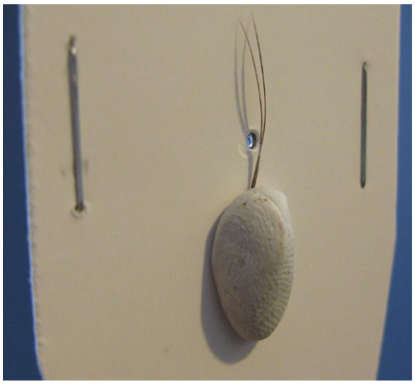

Figure 1-9. Press the putty with subject attached to the cardstock (thin) side of the microscope with the subject laying over the lens.

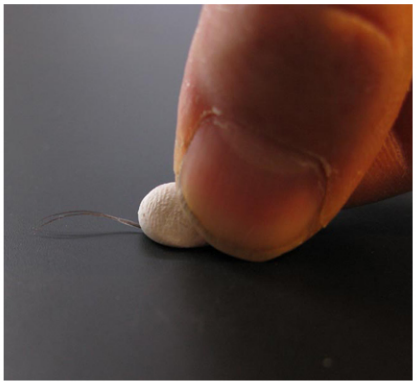

Figure 1-8. Take a pea size piece of tacky putty and press it on the subject (a feather barb is shown). The subject should stick to the putty when you remove it from the surface.

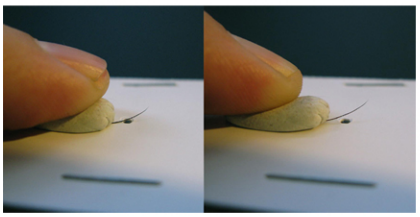

Figure 1-10. To focus, place your thumb on the putty. Pushing up will pivot the sample towards the lens, while pulling down will pull the sample away from the lens.

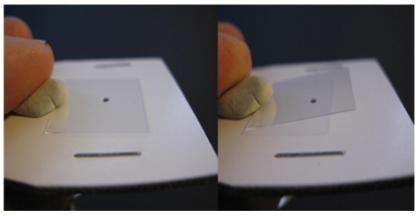

Figure 1-11. To view a liquid sample, follow the procedure of Figures 1-8 to 1-10 using a glass cover slip, and once attached to the microscope, drop the liquid sample on to the glass.

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**Some examples of images:**
These were taken with a Canon G9 point and shoot camera and do not do the image quality justice because to get the field of view to a reasonable size you must zoom in fully and Canon cameras do not function in macro mode while zoomed in (so the depth of field is bad).

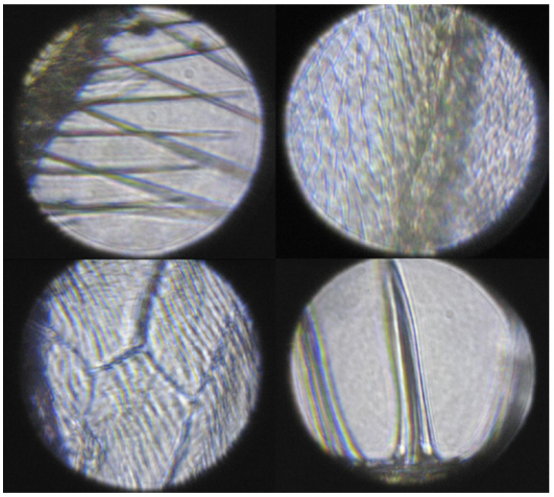

Figure 1-12. Clockwise from lower left these are a vein of an insect wing, the hairs on the trailing edge of an insect wing, cells in an onion skin, and the spikes on the surface of a radiolarian skeleton.

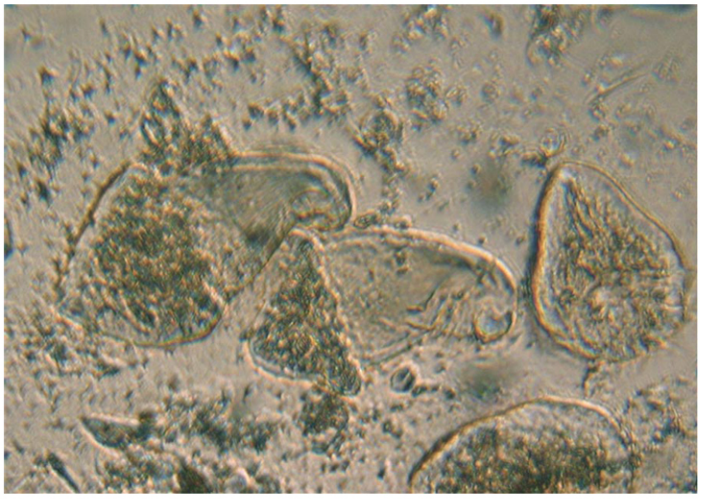

Figure 1-13. A example of an image with a lower magnification lens of live cells in liquid on a cover glass. This is the hypermastigote parabasalian *Trichonympha* from the hindgut of the termite *Zootermopsis angusticolis*.

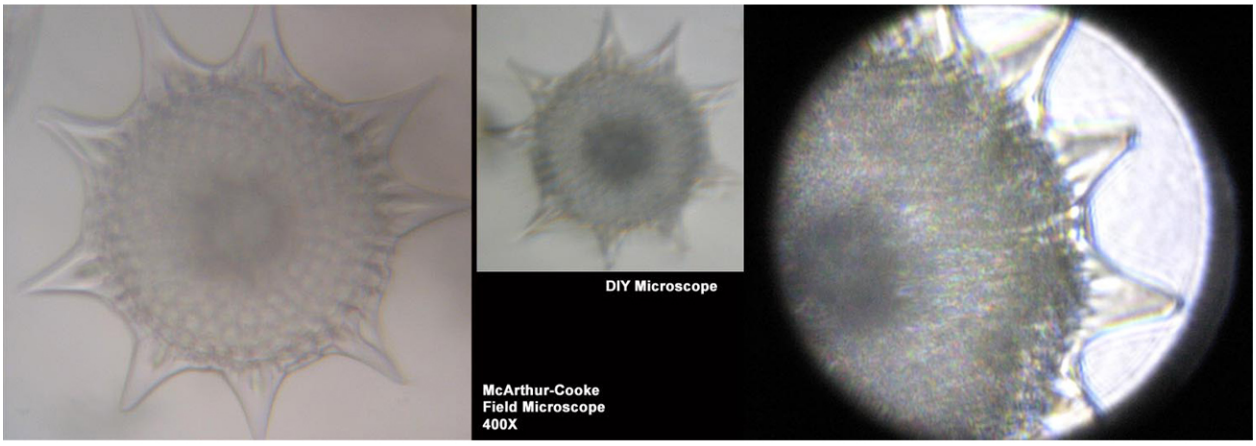


Figure 1-14. Comparison of the same Radiolarian skeleton with three different microscopes. At left is a commercial McArthur-Cooke field microscope set at 400X. In the centre is the same skeleton photographed with the same camera (a Canon Elph) and at the same scale (showing the power of this lens to be about 200X). On the right is the same sample again but photographed using the Canon G9 and a different microscope with a much higher power lens..

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**Part 2: Determining the power of the lens**.

**Introduction.**
In addition to using your microscope to look at tiny things, it is a good exercise in optics to determine the power of the lens. It works especially well if a whole class compiles their measurements of the lens diameter and magnification. Because everyone will make slightly different sized lenses, they can graph the class results and see the relationship between the two values.

**Materials.**
Micrometer
Laser Pointer
Transmission electron microscope grid, 100-mesh
(e.g. Pelco product 1GC100:
http://www.tedpella.com/grids_html/Pelco-TEM-Grids.htm)

**Instructions.**

1. Measure the lens diameter (Figure 2-1). If you wish to plot the relationship between lens diameter and power, use a micrometer to measure the size of the glass sphere (a $1 plastic one works just fine for this) before the microscope is assembled.

2. Project laser beam though TEM grid and lens – Basic principles. To measure the power of the lens, set up the components in this order: the laser source, then the EM grid, then the lens, then a surface, with the EM grid and the lens situated very close to one another. The EM grid is a small, usually copper disk with a fine metal mesh, the size of which is known exactly. For the 100-mesh grid suggested above, the hole width is 204µm and the bar width is 50µm. When the laser beam is passed though the grid and lens, it projects a greatly enlarged image of the grid pattern on to the surface. If you then measure the distance between two grid bars on projected image and compare it to the known size of the grid (i.e. 204µm), taking into account the distance it has been projected, you can calculate the power of the lens using the following two equations.

First,

(X (mm) / d (mm)) x 250mm = D (mm)

Then,

(D (mm) / A (mm)) = P

Where,
d = Distance between lens and projected image
X = Measured size of grid hole in projected image
D = Size of projected grid hole at 250 mm
A = Actual size of grid hole (0.204 mm)
P = power of lens

There are two equations because the power of a lens is dependent on how far you are from it, so there is a convention in optics to record the power as being from 250 mm. So we first measure your projected size at whatever distance you chose, then convert that size to what it would be if the distance between the lens and the projection were 250 mm. In the second equation you take that projected size and compare it to the known size to determine the power of the lens.

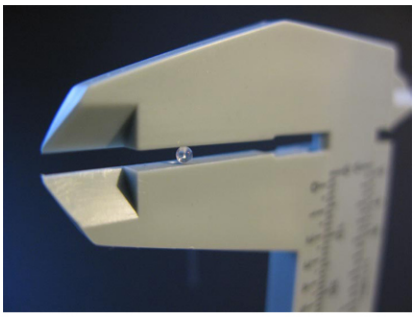

Figure 2-1. Measure the diameter of the lens using a micrometer.

Figure 2-2. The basic set up for a stand to measure the power of a lens using a laser..

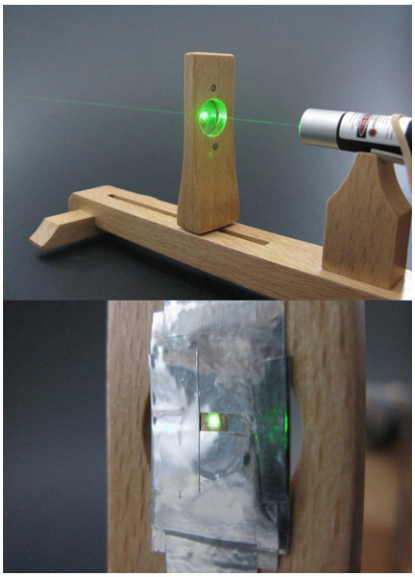

Figure 2-3. Align the laser so that the beam passes through the centre of the EM grid.

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**Instructions** (continued).

Project laser beam though TEM grid and lens:

**Method 1** – using a stand (Figures 2-2, 2-3, 2-4 and 2-5). I built a wooden stand for this . This is convenient if you are measuring the power of several lenses, but it is not really necessary, so an alternate method is presented below. A stand holds the laser steady and provides a platform to attach the EM grid (I stuck it to over a hole in a sheet of tin foil using film tape, Figure 2-2). The laser beam is first aimed at the centre of the grid by placing paper shims under the pointer to align the beam, with the switch held on by the elastic that holds the pointer in place. When aligned (Figure 2-3), the microscope is mounted using bulldog clips so that the lens is against the grid (Figure 2-4). Now turn on the laser and point it at a surface to measure the projected image size and projected distance (Figure 2-5).

**Method 2** – no stand. Since the only requirements of this procedure are the alignment of the laser beam with the grid and then lens, there is another way that does not require a stand, but more patience. The EM grid can simply be taped on to the cardstock side of the microscope over the lens (with the tape to the side of the grid, not over the light path). Hold the microscope steady and carefully point the laser beam into the grid, while another person measures the projected image size.

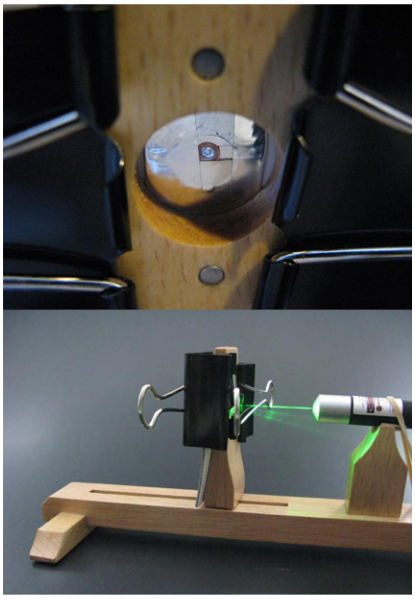

Figure 2-4. When the beam is centred, clamp the microscope onto the far side of the EM grid, so that the lens is directly behind the grid..

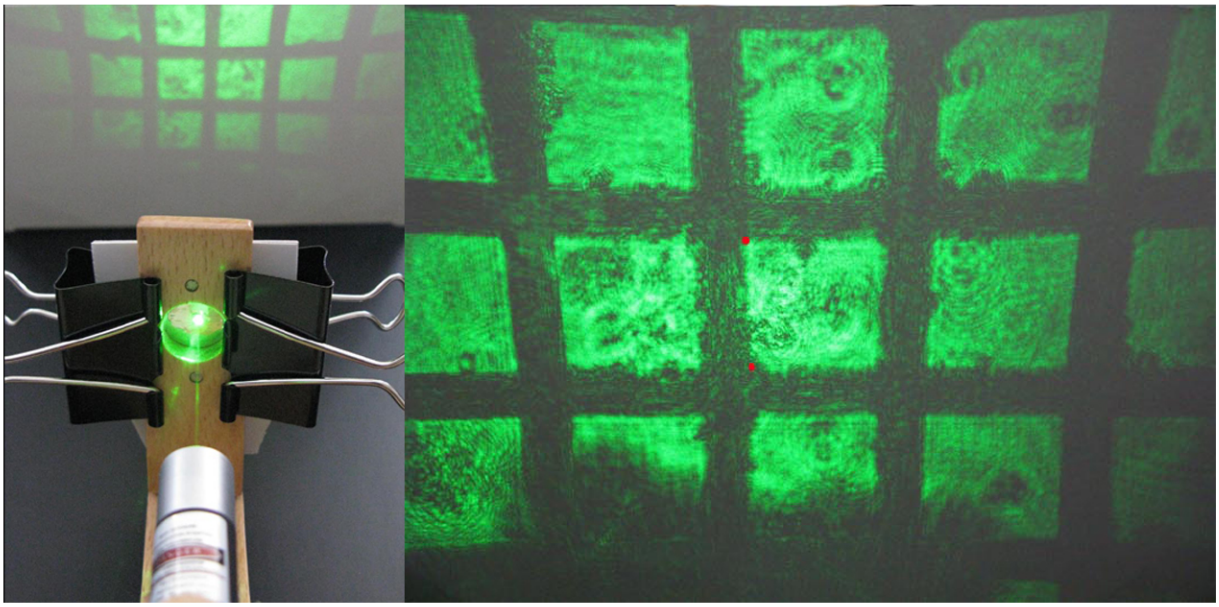

Figure 2-5. Turn on the laser, and the beam will pass though the grid, then the lens, projecting a magnified image of the grid onto a surface. Measure the distance between two points on this projected image (where the actual size on the grid is known), and measure the distance from the lens to the surface. For example, measure between the positions indicated by two red dots, which are 0.204mm apart on the actual grid. From these values using the equations given, the power of the lens can be calculated.