Magnifiers

Bob Koppany

Sometimes, it is not easy to look at a slide rule to try to get that fourth digit out of it. We interpolate, and interpret where the hairline is. And, at times, we get cross-eyed because the lines are so tiny and the area we are supposed to see is so small that it makes our head hurt. Admittedly, we know we need help. And, help has been given in the form of magnifiers, special lenses to make the objects appear larger to the viewer.

Many slide rules have magnifiers. Some magnifiers are placed directly on top of the cursor. Some are placed above the cursor. They can be of differing strengths. If we look at slide rule magnifiers in detail, let us first review optics a bit.

Magnifiers are made of a single lens, or combination of lenses. The lenses are typically made of glass and occasionally of plastic. In optics there are either minimizing (diverging) or magnifying (converging) lenses. Minifying lenses can be flat on one side and have a cavity on one side; and are called plano concave. Or, minimizing lenses have a concavity on both sides; and are called biconcave lenses. Surfaces that are not straight are also called meniscus surfaces, just like water in a glass seems to have the edges slightly higher than the center of the water. Magnifying lenses are flat on one side and bulging out on the other; and are called plano convex lenses. Or, they are bulging out on both sides; and are called biconvex lenses. For this article on magnification, we will be exclusively referring to plano convex or biconvex lenses.

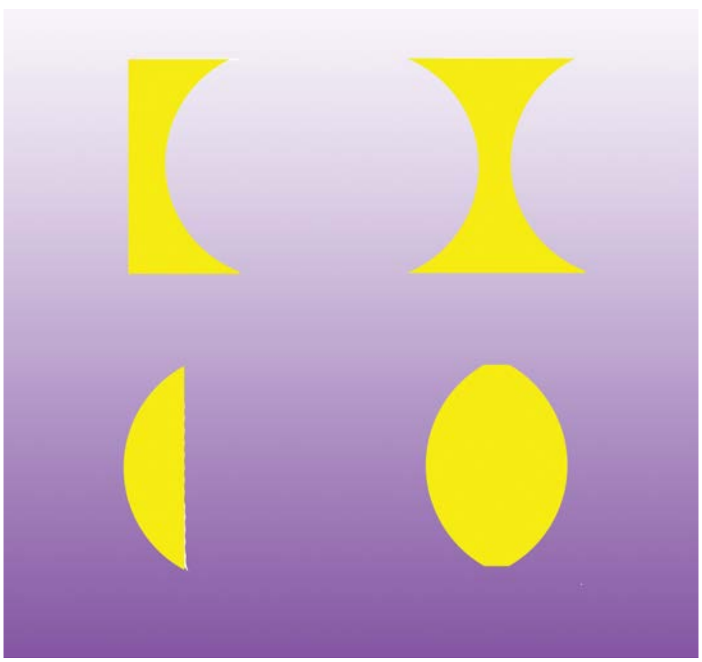

FIGURE 1.
Minimizing lenses above and magnifying lenses below

Typically, most lenses before the 1940s were made of glass. Plastic lenses did not show up until the 1950s. During World War II, plastic, being a long chain carbon molecule, was being rationed in many countries, as were all petroleum products. Glass, which is long chain silicon molecules, was plentiful in those days, although the machinery to grind and polish the lenses typically used petroleum based lubrication.

All single curvature lenses have one point to which they focus. To the viewer, this is the only spot where the optical image is sharpest. If the object to be magnified is in front of that point or behind that point, it is out of focus, and blurry. The amount of curvature for each surface determines the power of the lens.

To determine the power of a lens, we have to divide the lens into four components, its light bending or refractive power of the front service, refracting power of the back surface, the thickness of the lens, and the refractive index of the lens material. The refractive index of the lens material, or how much the material bends light rays, has been determined for various materials.

Refractive index was discovered by Dutch physicist Willebrord Snell (1591-1626). Glass, the primarily used material, has an index of 1.53. Air has an index of 1.00. Water has a refractive index of 1.33. Plastic has a refractive index of 1.46, Plexiglas 1.50, and flint glass used in the bottom of bifocal lenses has a refractive index of 1.62. As the index number increases, the material has the ability to bend light more. These days, for optical glasses that people wear, the index can vary up to 1.71 or so. After that number, the light bending is so great that it breaks white light into spectra, or acts like a prism. This is one of the many aberrations or distortions that optical lenses have, called chromatic aberration. Distortions can also include spherical aberration, coma, and flare. These will not be discussed further here.

The equation for the lens power is

$$F \text{ (total lens power)} = F1 + F2 - (t/n)(F1F2)$$

where F1 is the power of the front surface. F2 is the power of the back surface. The index of refraction for the lens material is n (no units). The thickness is the thickness of the lens, given in meters typically. For a thin lens, the third term in the equation approaches zero, so we get the power equaling F1 + F2. Many lenses with which we will be dealing with here can be considered thin lenses.

When we look through a lens, although the image we see looks larger than the actual object on the slide rule is, which is because what we see is an image of the object. This is called the virtual image of the object. For slide rules, we will always have this combination, where the object to be magnified and its image are on one side of the lens, and the observer is on the other side of the lens.

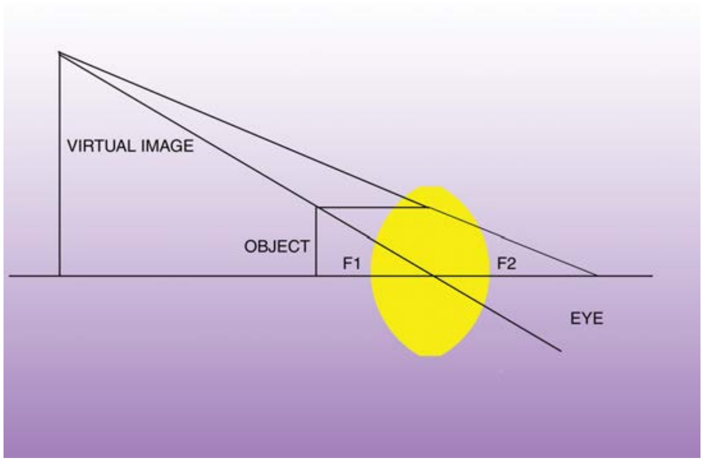

FIGURE 2.
Ray tracing showing a virtual image

The power of the front surface is one divided by the focus distance from the center of the lens in centimeters. The unit of lens power is called the diopter, and is represented by a small superscript triangle ($^{\Delta}$), or a delta symbol in scientific notation. One diopter is defined as the power of a lens to bend light one centimeter at a distance of one meter.

For magnification, four diopters will make the object appear to the viewer the same size it is, or a one times magnification. This is called a 1X magnifier. Eight diopters will give a 200% magnification to the viewer, or a 2X magnifier. Twelve diopters will give a 300% magnification to the viewer, or a 3X magnification. This author knows no slide rule magnifier in his limited knowledge that will give above a 3X magnification, but would be interested to know if such exceptions occur. As an aside, in the real world outside of slide rules, if one has a handheld magnifying glass to see medicine bottle print or for electronic assembly, they are typically less than 2X power. There may be magnifying lenses that go up to a 12X power, but there are design constraints with such lenses to minimize distortion and aberrations.

As lens power increases, the size of the lenses must decrease to avoid aberrations. It should not be overlooked that in such magnifiers, the amount of light on the object to be viewed becomes a more important consideration.

How can we measure magnification in the differing slide rules? There are four methods:

1) The most accurate method is to use a lensometer, which measures the power of the lens to within an eighth of a diopter. This method is called neutralization of the lens.

2) The reader can take a ruler and put it over the top of the magnifier and measure the thickness between slide rule divisions. Then, not moving the ruler, the reader can then look at a division to the immediate right or left of the magnifier and measure that. Dividing the measured portion next to the magnifier by the measured portion under the magnifier gives you the magnification.

FIGURE 3.
An optical lensometer

3) A piece of graph paper can be slipped in between the slide rule body and the cursor. The process is similar. The reader looks at size of the graph paper square under the magnifier and the size of the square immediately next to the magnifier and then divides to get the power of the magnifier.

4) For a single lens above the magnifier, the reader can measure the distance from the center of the lens to the slide rule body in centimeters. The reader then divides 100 by the distance and that is the dioptric power of the lens. Then, the reader can divide that by four to get the actual magnification of the lens.

Let us look at some of the magnifiers on slide rules:

FIGURE 4.
The RotaRule

The RotaRule lens. This is perhaps the strongest lens on a slide rule. The lens is a 12 diopter lens, or 3X magnification. It was noted that the actual RotaRule lens holder moved up and down. Perhaps the designer of the RotaRule did not know what lens he was going to put in it when it was in concept form? When the RotaRule slide was measured, it would extend from about a 15.3 diopter lens (3.82X) to a 10 diopter lens (2.5X) in length, or from 6.5cm to about 10 cm distance from the lens to the slide rule body.

FIGURE 5.
The RotaRule magnifier.

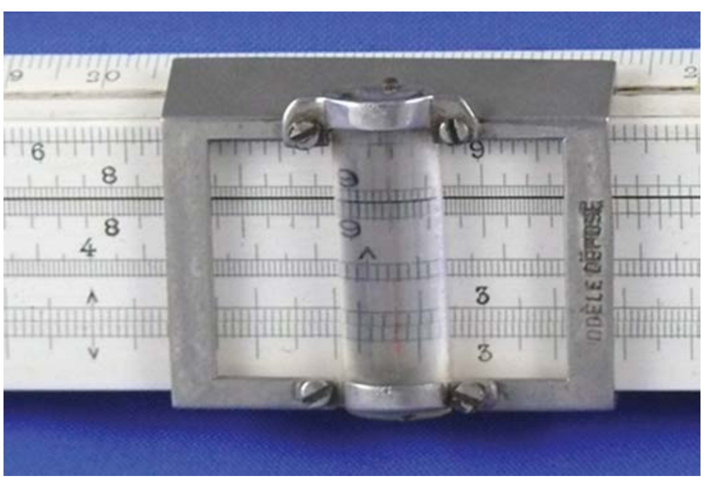

FIGURE 6.
A Tavernier Gravet long rule magnifier.

For the next slide rule, the K&E 4091-3 log log duplex decitrig slide rule, we have to introduce a new term, astigmatism. That is where one side of a lens essentially has two focus points. Think of a glass rod, that is sliced longitudinally through the diameter. What you end up with is a lens with a flat part, and a radial part. This is essentially three lenses. The flat side has no power as it has no curvature. The rounded side portion has two sections to that we need to look at. The flat part of the rounded side goes up and down on the slide rule and has no power. There is no curvature to it, and it is essentially the second lens. The rounded side has power and is the third lens. The reader may ask what is the advantage to this? The advantage is that we are looking at a partial magnification of the object. In this case, there is no magnification from up to down. So, there is no vertical magnification. That is why horizontal lines on a slide rule with this sort of combination do not seem to move. However, the rounded side magnifies the object from left to right only.

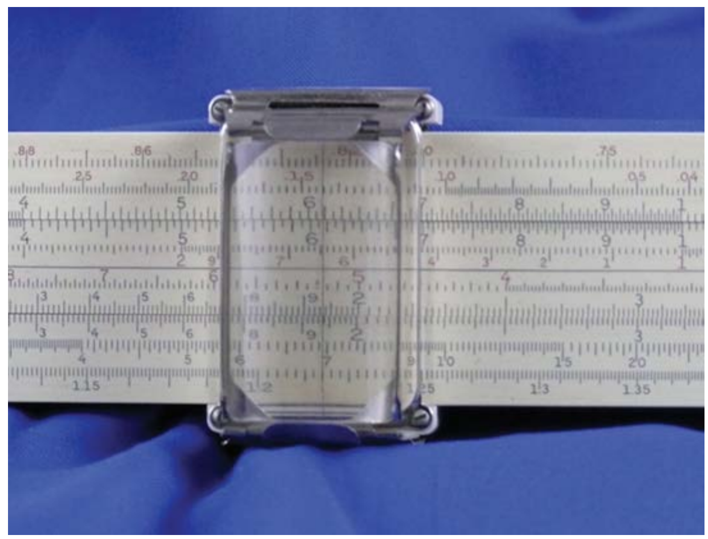

FIGURE 7.
The K&E 4091-3 magnifier.

For the K&E magnifier, it is an astigmatic lens. The power of the curved side is about a 25 diopter lens through a lensometer. Although this would typically be a 6.25X magnifier when we divide by four and focus at about 4cm from the slide rule body, it is only 2X because the lens must be considered a thick lens. If one take a rough index of refraction to be 1.53, the reader can arrive at the thickness of the lens using the lens formula stated earlier. The lens has approximately a 10mm distance to the body of the slide rule. Working this in reverse, we can also measure the thickness of this lens and knowing the powers, derive the index of refraction for the magnifier.

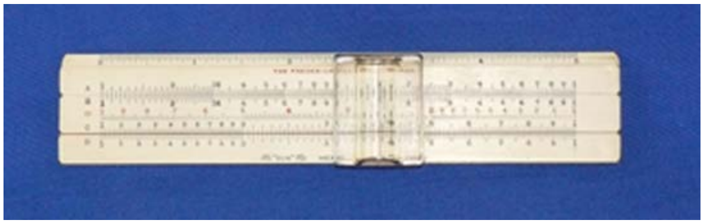

FIGURE 8.
The Post 1444 slide rule

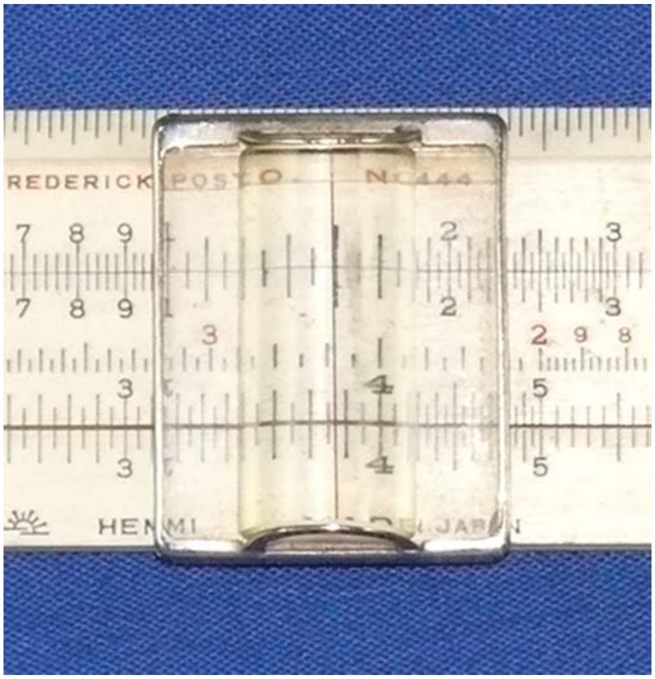

FIGURE 8B.
The Post 1444 Magnifier.

The Sun Hemmi magnifier on the #1444 Post slide rule is also an astigmatic lens, but it is located on the cursor. It is a plano convex lens. However, it is only about a 1.5X magnifier. The magnification of the rounded side is approximately 5.00 diopters. It too must be considered a thick lens and not a thin lens as the RotaRule magnifier is, even though the lens is directly above that of the slide rule body surface.

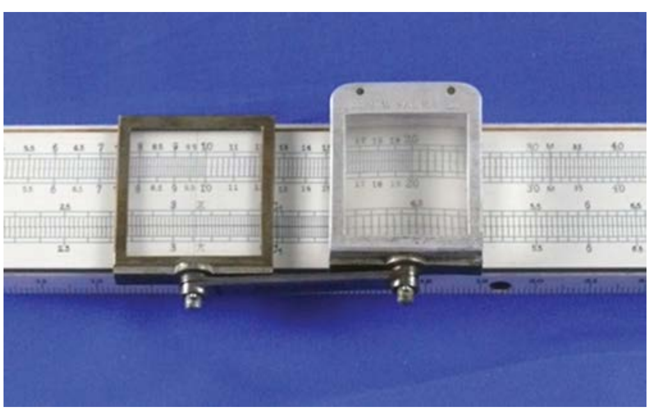

FIGURE 9.
The Faber Castell Magnifier

Perhaps the Faber Castell magnifier mounted to the Faber Castell 369 pocket slide rule is the most complex. It is two lenses, separated by a small air gap of approximately 1 mm. The magnifier is labeled D.R.P. No. 222297. Each lens is a plano convex lens, when combined they are called a doublet. Additionally, the curved side of each lens is an astigmatic surface. The lower of the two lenses is approximately 34mm above the slide rule body. Under a lensometer, both lenses have a power of approximately 16.75 diopters. Like the K&E and Hemmi rules, it only magnifies in one direction.

FIGURE 10.
Detail of the Faber Castell magnifier doublet

Magnifiers help make the slide rule an even more wonderful instrument. They show the care, thought, design, and implementation to make slide rules the technological marvels they are.

Bob Koppany worked as an engineer at Jet Propulsion Laboratory and currently is an optometrist. His interests include Frank Lloyd Wright, writing, and graphic design.