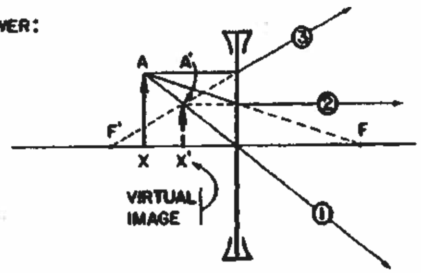
ANSWER:



If you wish to construct the rays from an object through *multiple* thin lenses, you must use the same method shown here for *each* lens separately and consecutively. First locate the first image by lens 1. That image then becomes the object for the second lens; this lens forms another image which is "seen" by the next lens and becomes its object, etc. The final image is fixed when all lenses have exerted their own particular influences on the original object rays.

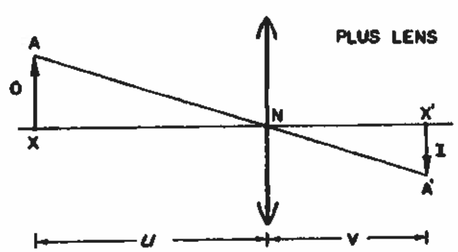
LINEAR MAGNIFICATION

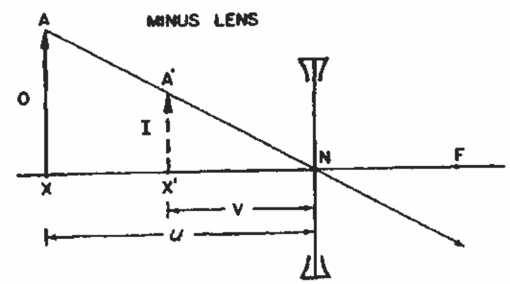
Though we will get into a more complete discussion later of magnification as it pertains to vision, we should mention *linear* magnification here to complete our image construction section.

So far we have not mentioned anything about the relationship of the linear size of the object to that of the image. That is, when object point A is off the lens axis, how far off the axis is the image? Simple geometry tells us this answer in all cases.

Aside from the lens axis, the only other ray necessary for us to see this relationship clearly is ray 1 — that through the nodal point.

These rays establish 2 similar triangles AXN and A'X'N.





No matter what the power of lens (plus or minus) — no matter where the objects and images are in relation to the focal points — these triangles will always be similar, even, of course, if the object and image are on the same side of the lens (as in the figure above).

You should, therefore, be able to see that the *sizes* of the object and image are always directly proportional to their *distances* from the lens. The LINEAR MAGNIFICATION (M) is hereby defined as the ratio of the size of the image to the size of the object. Refer now to the above diagrams:

Image size I = A'X'
Object size O = AX
image axial distance v = NX'
object axial distance u = XN

By definition,

$$M = \frac{I}{O} = \frac{A'X'}{AX}$$

But since the triangles involved are similar,

$$\frac{A'X'}{AX} = \frac{NX'}{XN}$$

Thus;

$$\frac{I}{O} = \frac{v}{u}$$

Since

$$v = \frac{1}{V} \text{ and } u = \frac{1}{U},$$

$$\frac{v}{u} = \frac{U}{V}$$

So, we have three different, but exactly equivalent, ways of expressing the linear magnification M:

$$M = \frac{I}{O} = \frac{v}{u} = \frac{U}{V}$$

M may be greater, equal to, or less than 1, depending on whether the image size is (respectively) larger than, equal to, or smaller than the object size.

That's all there is to it; and it makes no difference whether the objects or images are real or virtual. Continue to use our same sign convention for vergences and distances and you will find that when Magnification Power turns out to be *minus,* this will always indicate that the image is *inverted* compared to the object, while plus "says" the image is upright.

To find the magnification M, you can use either a geometrical construction (to a set scale) or our simple $U + P = V$ relationship. The algebraic expression is obviously the easiest and most direct method to use routinely.

PROBLEM: What is the overall magnification and the actual size of the projected image produced by a 5 cm focal length projection lens using a 35 mm width slide transparency located 6 cm from the lens. The image is sharply projected on a screen.

ANSWER:

To obtain the Magnification, we must know the image distance (or its vergence) at P.

$$U + P = V$$

$$-\frac{1}{.06} + \frac{1}{.05} = V = \frac{1}{v}$$

$$-16.7\text{ D} + 20\text{ D} = V$$

$$+3.3\text{ D} = V$$

$$\frac{1}{V} = v = +30\text{ cm.}$$

So, the screen is 30 cm to the right of the lens; $u = -6$ cm
$v = 30$ cm

a) $M = \frac{v}{u} = \frac{30}{-6} = -5\text{ X}$

Or even simpler, just use the vergences U and V themselves:

$$M = \frac{U}{V} = \frac{-16.7\text{ D}}{+3.3\text{ D}} = -5\text{ X}$$

This means the image is 5 times the size of the object; the minus sign signifies that the image is inverted related to the object.

b) Since the object is 35 mm wide and the magnification is 5 X, the image is 5 *times* 35 = 175 mm wide.

PRINCIPAL PLANES AND POINTS

I would like now to introduce another set of terms to complete (*not* complicate) our introduction to the nomenclature applied to optical systems. I will expend slightly more space on this subject than it warrants for the level of optics required by students, but so many budding ophthalmologists continue to ask me to explain (not just define) the concept of *principal planes* that I felt it would save time in the long run to do so here.

When we were studying image formation by a series of thin lenses, we showed that we could locate the final image by either numerical or graphical means, but only after processing object rays successively through *each* lens element in the total system. We will now demonstrate diagrammatically a way to simplify the situation, even with a complicated optical set up. (See the next figure). We will then eliminate all the refracting elements and replace them with two theoretical (though mathematically proper) "refracting" planes. The positions of these planes will be determined. These planes will permit us to neglect all the lenses shown in the figure; that is, each ray emanating from object point A will be able to be treated as if it were influenced only by these two planes. These key reference planes are called the PRINCIPAL PLANES — one primary and one secondary. Their intersections with the lens axis are correspondingly called the PRINCIPAL POINTS.

To see how these planes are located, let us begin with a diagram; but don't let it frighten you. I have *purposefully* chosen a rather complex system of seven assorted lenses to demonstrate how these reference planes can simplify the optical considerations.