1.4 Measurement of First order properties of optical systems

(See Sections 5.1 to 5.4 in book for this material)

Suppose we have a thin positive power $\phi_1 > 0$, we can use the Gaussian imaging eq. to calculate $\phi_1 = \frac{1}{f_{E1}}$

$$\frac{1}{z'} - \frac{1}{z} = \frac{1}{f_{E1}}$$

Set up an object and measure z, z' to calculate f_{E1}. If z is large relative to the focal length, then $z' \doteq f_{E1}$. How large does z need to be in order to consider the object at ∞?

The Newton imaging eq. in air is

$$z z' = -f_{E1}^2$$

if $z = \alpha f_{E1}$ and $z' = \beta f_{E1}$ where α, β constants

$$\beta = -\frac{1}{\alpha}$$

For example, if z is 10 focal lengths, then β is $\frac{-1}{10}$ focal length

Things are a little trickier with negative thin lenses since the image is virtual $(z' < 0)$. Suppose we have a thin negative lens with power $\phi_2 < 0$. We can use the technique above if we combine it with a positive lens $\phi_3 > 0$ as long as $\phi_3 > -\phi_2$. In this case

$$\frac{1}{z'} - \frac{1}{z} = \phi_2 + \phi_3$$ ← thin lenses in contact

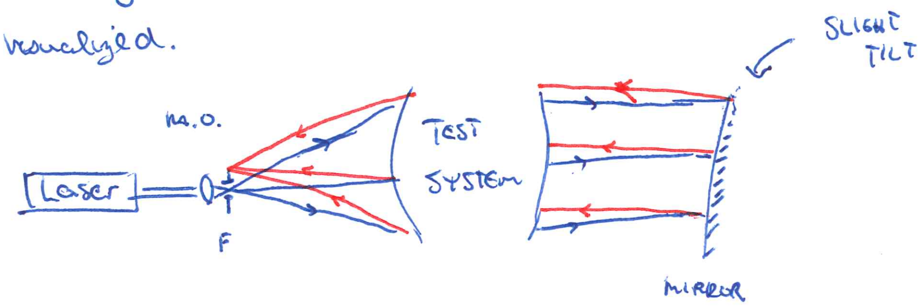
~~Extended as long as~~ forms a real image.

Show demo with +3D and -1D lens.

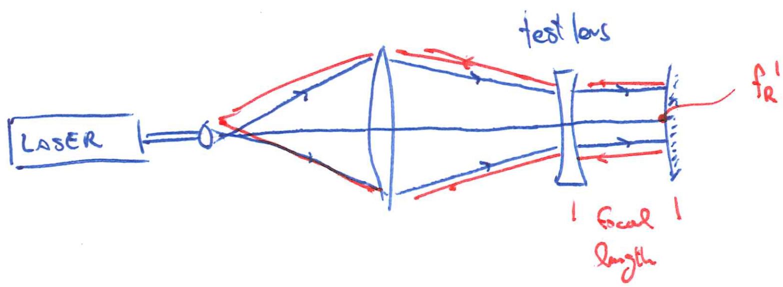
1.4.2 AUTO COLLIMATION TECHNIQUE

Place a point source in front of a lens under test and a plane mirror behind the test system. When the point source is located at the front focal point, the return beam from the mirror will focus at the point source.

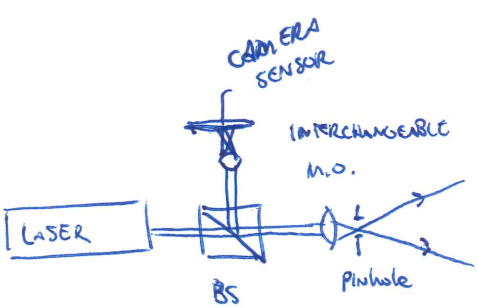
NOTE: A slight tilt in the mirror allows the return spot to be visualized.



For a negative lens, use an auxiliary lens to create a converging beam onto the test lens



POINT SOURCE MICROSCOPE (PSM)

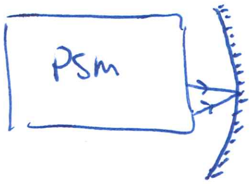


In PSM, we add a beamsplitter and camera to view return image without needing to tilt mirror

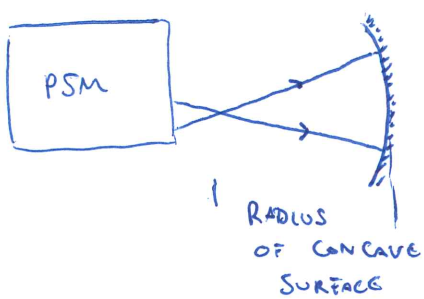
Focused spot appears in camera image when return rays retrace exiting rays.

Measurement variations

CAT'S EYE

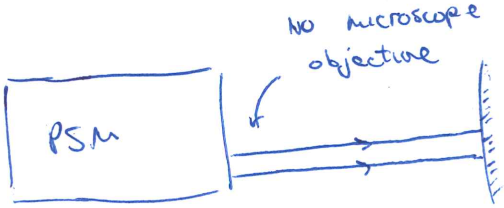


CENTER OF CURVATURE

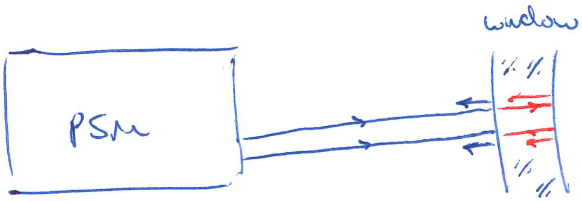


Place surface at point source and then slide until a second point is focused in PSM image. The distance traveled is the surface radius.

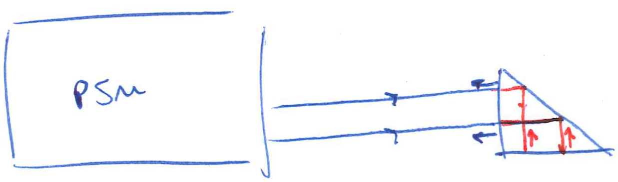
Remove microscope objective



Surface is perpendicular to PSM axis when spot is in center of image.



Window surfaces are parallel when spots are superimposed. Separation between spots can be translated into wedge error.



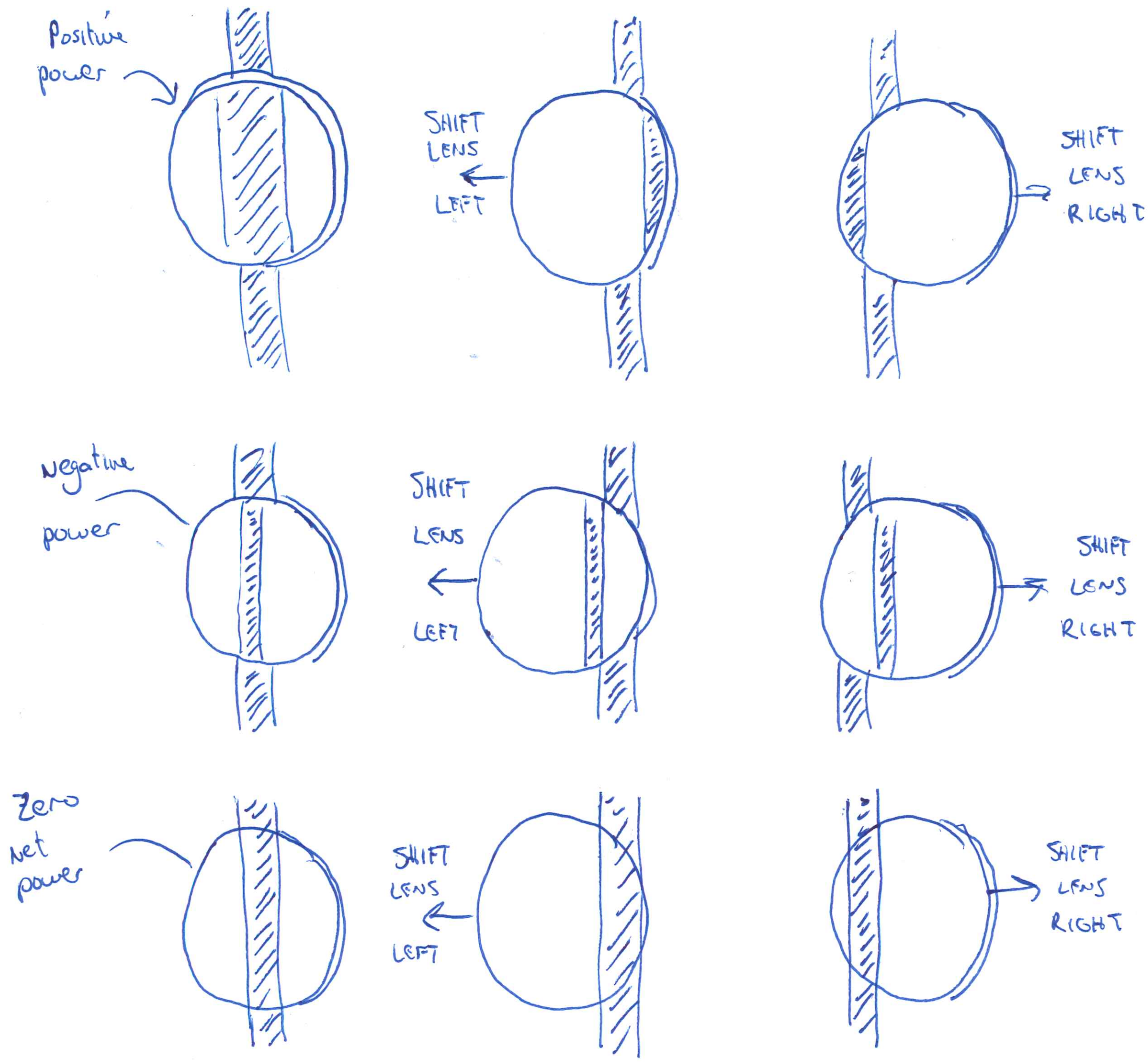
Similar concept for checking the angular errors in right angle prisms.

<u>Autocollimator</u> - optical instrument which projects collimated beam and analyzes return beam either visually or digitally.

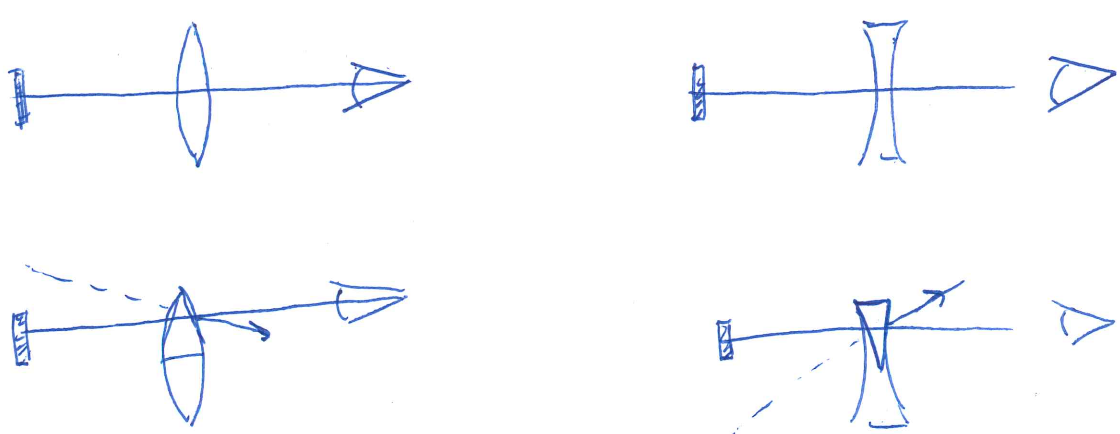
1.4.3 Neutralization Test

Place an unknown thin lens against a series of known lenses until the net power is zero. The test lens then has equal magnitude, but opposite sign as the known lens

HAND OUT ±3D lenses.



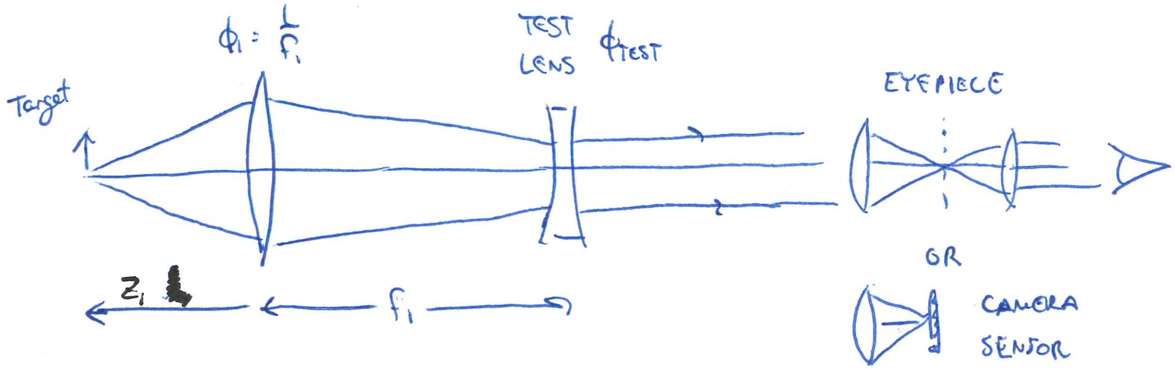
Why do you get these motions?



Periphery of lens acts like a prism.

1.4.4 FOCOMETER, FOCIMETER, LENSMETER, LENSOMETER

System for measuring power of a thin lens



Separation between known lens with power $\phi_1 = \frac{1}{f_1}$ and the test lens is f_1. Adjust target distance z_1 until beam emerging from test lens is collimated.

$$\frac{1}{z_1'} - \frac{1}{z_1} = \frac{1}{f_1} \Rightarrow z_1' = \frac{z_1 f_1}{z_1 + f_1}$$

$$\frac{1}{z_2'} - \frac{1}{z_2} = \phi_{TEST}$$

want $z_2' = \infty$

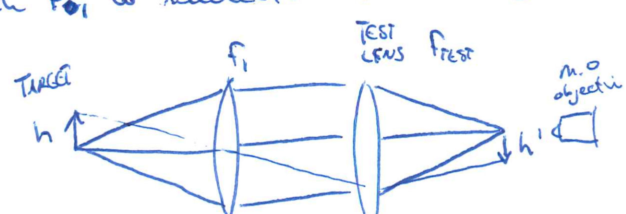
$z_2 = z_1' - f_1$

$$\phi_{TEST} = \frac{-1}{\frac{z_1 f_1}{z_1 + f_1} - f_1} = \frac{z_1 + f_1}{f_1^2}$$

POWER IS LINEAR IN z_1

1.4.5 Focal Collimator

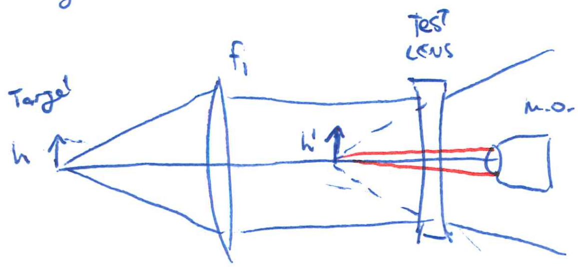
For thick lenses, we can use a focal collimator to find the focal points, focal lengths and principal points. A lens of known focal length F_1 is needed. Size of image is measured with microscope.



$$f_{TEST} = \frac{-h'}{h} f_1$$

magnification is ratio of the focal lengths

For negative lens

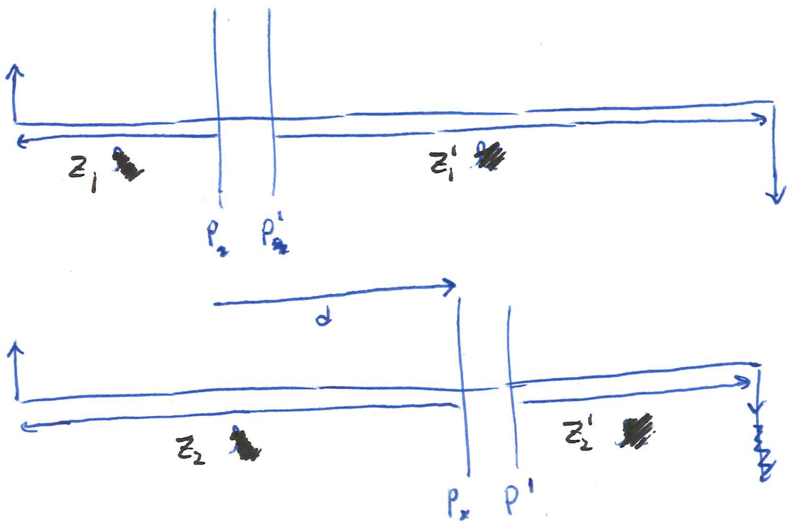


microscope objective working distance needs to be longer than $-f_{TEST}$

1.4.6 Reciprocal Magnification

Technique for finding cardinal points of thick lens system.

Position 1



Position 2

keep same object

$$\frac{1}{z_1'} - \frac{1}{z_1} = \phi \quad \text{and} \quad \frac{1}{z_2'} - \frac{1}{z_2} = \phi$$

Choose special case where $z_2' = -z_1$ and $z_2 = -z_1'$

$$\frac{1}{-z_1} - \frac{1}{-z_1'} = \phi$$

Identical to first position means same object/image plane

$$m_1 = \frac{z_1'}{z_1} \qquad m_2 = \frac{z_2'}{z_2} = \frac{-l_1}{-l_1'} = \frac{1}{m_1}$$

Hence the name reciprocal magnification

From the drawing $d = z_1 - z_2 = z_1 + z_1'$

The gaussian imaging eq. can be written as

$$z_1 = \left[\frac{1-m_1}{m_1}\right] f_E$$

From above $z_1' = m_1 z_1$ and $d = z_1 + z_1' = (1+m_1) z_1$

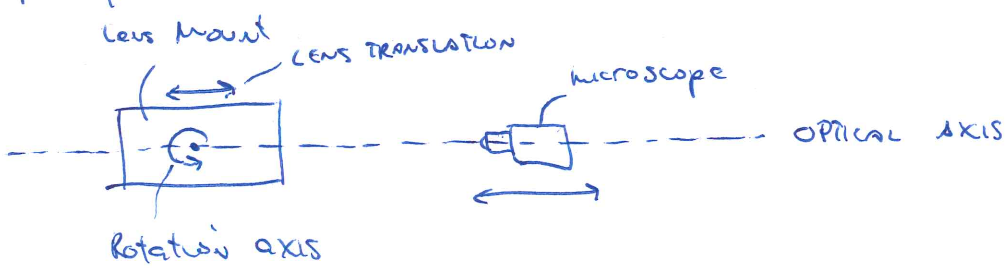
$$f_E = \left[\frac{d}{1+m_1}\right]\left[\frac{m_1}{1-m_1}\right]$$

$$\boxed{z_1' = \frac{m_1 d}{1+m_1}} \qquad \boxed{z_1 = \frac{d}{1+m_1}}$$

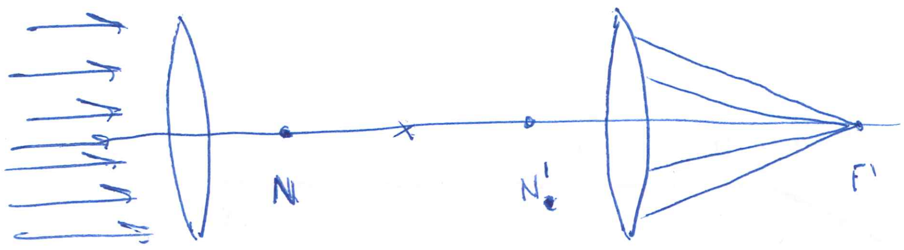
$$\boxed{f_E = \frac{-m_1 d}{m_1^2 - 1}}$$

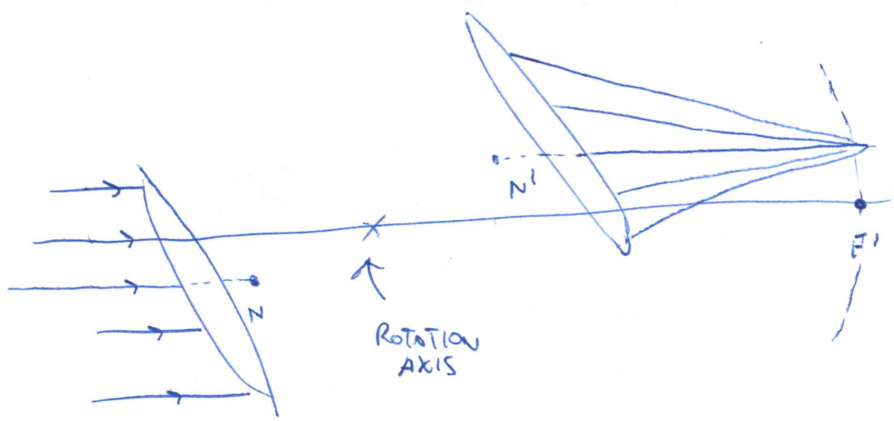
1.4.7 Nodal Slide Lens Bench

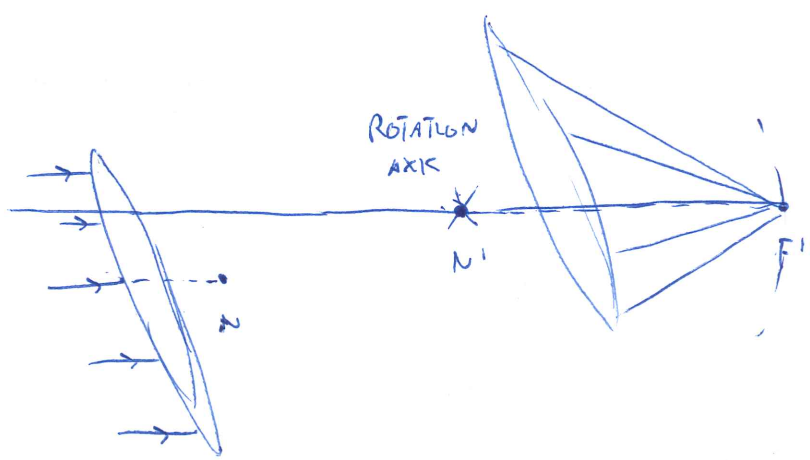
Alternative method for measuring the cardinal points of the thick system. It consists of a specialized lens mount that allows the test to rotate about an axis perpendicular to the optical axis. The other component consists of a microscope for viewing the focal spot of the test lens.



Collimated light is passed through the test lens and the position of the microscope adjusted so the focal spot is seen. The lens is the pivoted about the rotation axis while the focal spot is observed. If the focal spot moves, then the rotation axis is not at the rear nodal point. The test lens is then translated axially and the process is repeated until the focal spot is stable in the microscope. At this point, the nodal point is over the rotation axis. The figures below illustrate the effect.







Since the nodal points have unit angular magnification, the ~~coll~~ ray passing through the front nodal point that is parallel to the optical axis emerges from the rear nodal point parallel to the optical axis. The focal spot is therefore displaced by the same amount as the rear nodal point N'. When the rotation is about N', N' is not displaced, so F' not displaced.