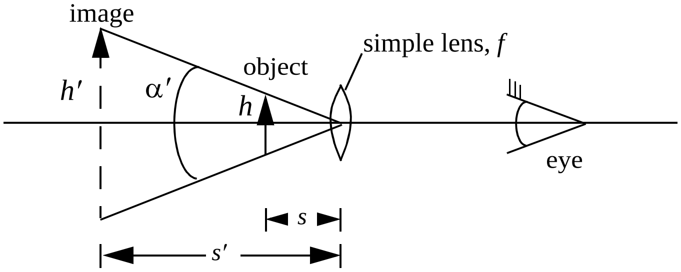
Lecture 11

Microscope

[Reading assignment: Hecht 5.7.3, 5.7.5]

Simple microscope (magnifier)



– object located inside lens focal length f

– virtual image is formed at s'

Simple application of the lens law gives:

$$h' = \frac{h(f-s')}{f}$$

If the eye is located at the lens, the angle subtended by the image is

$$\alpha' = h'/s' = \frac{h(f-s')}{fs'}$$

If the eye views the same object at standard viewing distance (25 cm), then the angle would be

$$\alpha = \frac{-h}{25}$$

The magnifier enlarges the object by the ratio

$$M = \frac{\alpha'}{\alpha} = \frac{h(f-s')}{fs'} \cdot \frac{-25}{h} = \frac{25}{f} - \frac{25}{s'} \qquad (f, s' \text{ in cm})$$

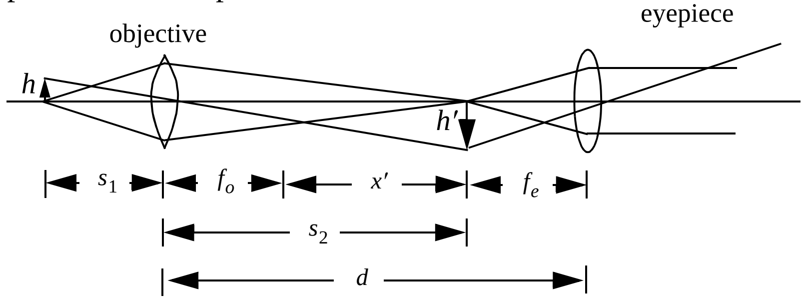
One may adjust the lens to put the image appearing at ∞, which means that it is viewed with a fully relaxed eye, then

$$M = \frac{25}{f}$$

With the image appearing at 25 cm (standard viewing distance), then

$$M = \frac{25}{f} + 1$$

Compound Microscope



- The objective lens produces a real (inverted), magnified image of the object.
- The eyepiece re-images to a comfortable viewing distance and provides additional magnification.

The total magnification is the product of the linear objective magnification times the eyepiece angular magnification.

$$M_o = \frac{h'}{h} = \frac{s_2}{s_1} = \frac{-x'}{f_o}$$
$$M_e = \frac{25}{f_e}$$
$$M_{\mathrm{TOT}} = M_o \cdot M_e = \frac{-x'}{f_o} \cdot \frac{25}{f_e}$$

In laboratory microscopes, x' is called the "tube length" and is standardized to 160 mm. So, the objective magnification is given by $M_o = \frac{16}{f_o}$. Thus, a 20× objective lens has a focal length of 0.8 cm.

Resolution. The aperture stop is usually set by the size of the objective (NA). Recall that the diffraction limited linear resolution is

$$Z = \frac{0.61\lambda}{\mathrm{NA}}$$

. This is the smallest object that can be resolved.

The eye can resolve an object size of ~0.08 mm at the distance of 25 cm, so the equivalent object size in the microscope is

$$R = \frac{0.08\ \mathrm{mm}}{M}$$

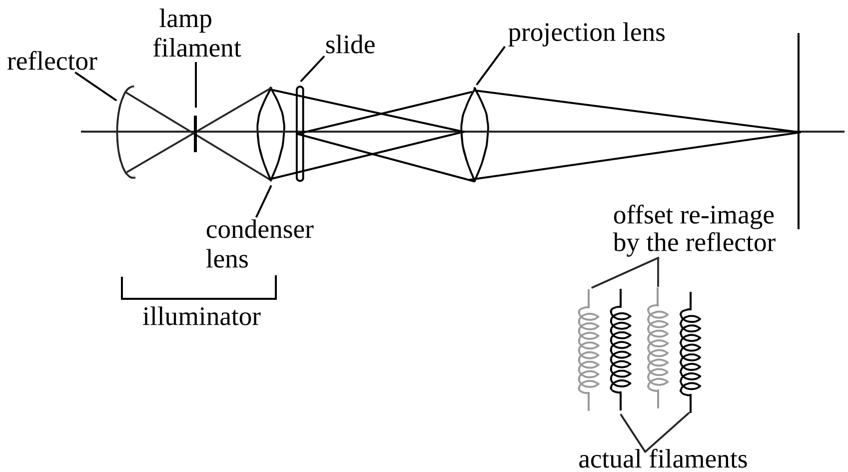
The magnification at which these two resolutions are equal is

$$\frac{0.08\ \mathrm{mm}}{M} = \frac{0.61\lambda}{\mathrm{NA}}$$
$$M = \frac{0.08}{0.61\lambda}\mathrm{NA} = \frac{0.13}{\lambda}\mathrm{NA} \qquad \text{with } \lambda \text{ in mm}$$

Take $\lambda = 0.55\mu\mathrm{m} \rightarrow M_{\max} \cong 240\mathrm{NA}$.

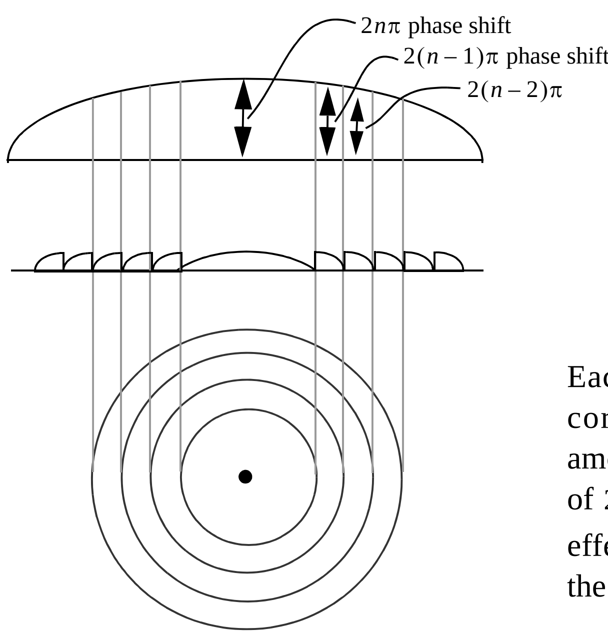
Increasing the magnification beyond this does not allow observation of smaller objects due to diffraction.

Projection Systems



- The illuminator has multiple jobs:
  1. Efficiently collect light from the source (lamp filament)
  2. Uniformly illuminate the object (slide)
  3. Redirect light into the projection lens
- The condenser lens projects a magnified image of the source into the entrance pupil of the projection lens
- The reflector collects more light from the source, and also creates a more uniform effective source.

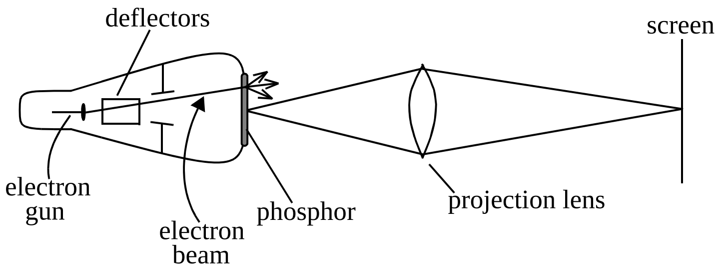
A Vugraph projector uses a *Fresnel lens* for the condenser



Each annular zone has the same slope as the corresponding surface of the full lens. An amount of glass corresponding to a phase shift of $2n\pi$ is "removed" from each zone so that the effect on the light phase is the same as that of the full lens.

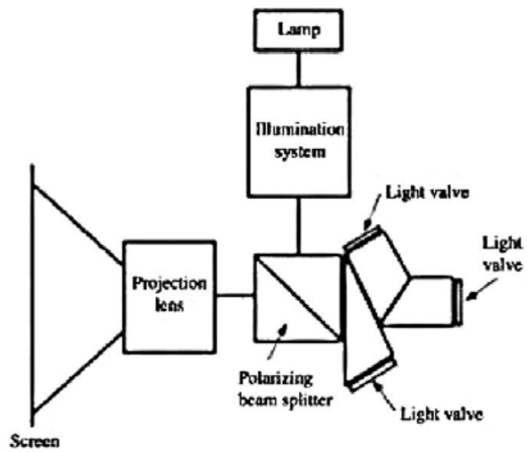
CRT based Projection TV

- High output phosphor

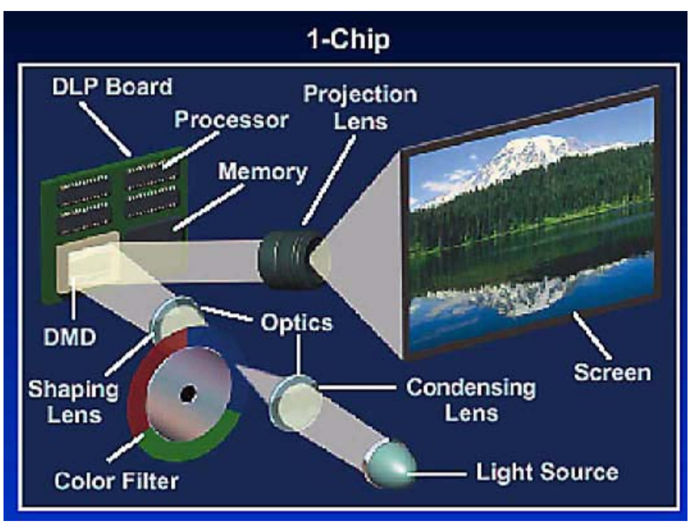


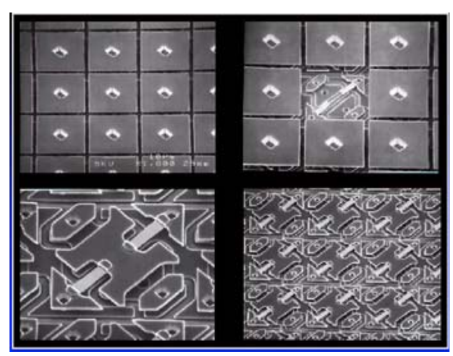
For color, 3 separate systems, merged images on the screen.

- LCD Projector



- Digital Mirror Device (DMD) based display





Micrograph of DMD chip