Microscope

[Reading assignment: Hecht 5.7.3, 5.7.5]

Simple microscope (magnifier)

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

\[
\alpha' = \frac{h'}{s'} = \frac{h(f-s')}{fs'}
\]

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

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

One may adjust the lens to put the image appearing at \(\infty\), 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 total magnification is the product of the linear objective magnification times the eyepiece angular magnification.

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

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\( \times \) 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

\[ Z = \frac{0.61\lambda}{NA} \]

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

\[ R = \frac{0.08 \text{ mm}}{M} \]

The magnification at which these two resolutions are equal is

\[ \frac{0.08 \text{ mm}}{M} = \frac{0.61\lambda}{NA} \]
\[ M = \frac{0.08 \text{ mm}}{0.61\lambda} \cdot \frac{1}{NA} = \frac{0.13\lambda}{\lambda \text{ NA}} \quad \text{with } \lambda \text{ in mm} \]

Take \( \lambda = 0.55 \mu\text{m} \rightarrow M_{\max} \approx 240 \text{NA} \).

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