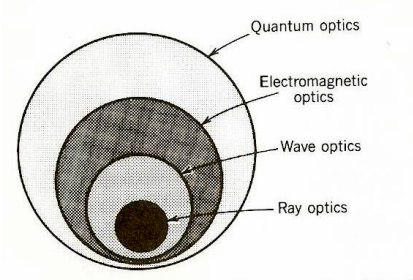
Optics

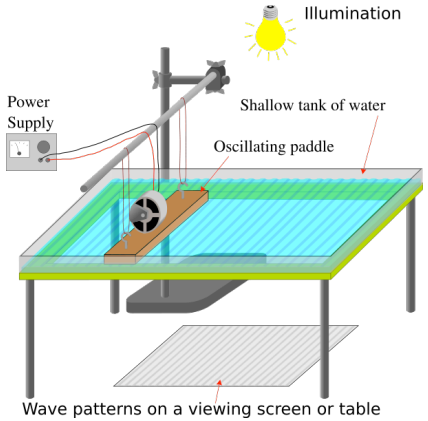


Christiaan Huygens
(1629 - 1695)

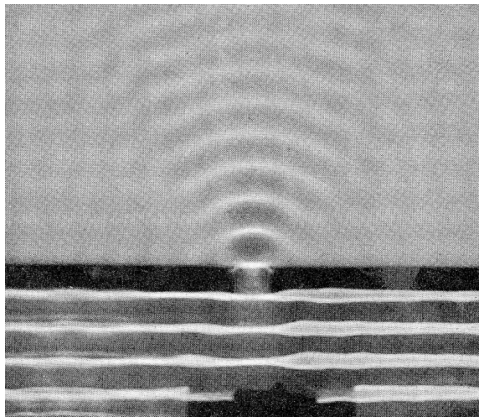
Thomas Young
(1773 - 1829)

Wave Optics
Diffraction & Interference

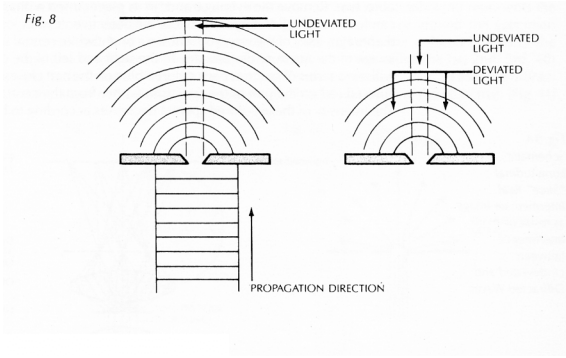
Ripple Tank



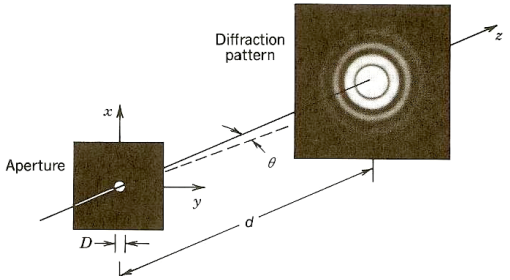
Diffraction is a characteristic of wave dynamics



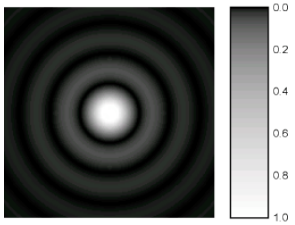
Diffraction



"Airy Disk" Diffraction Pattern

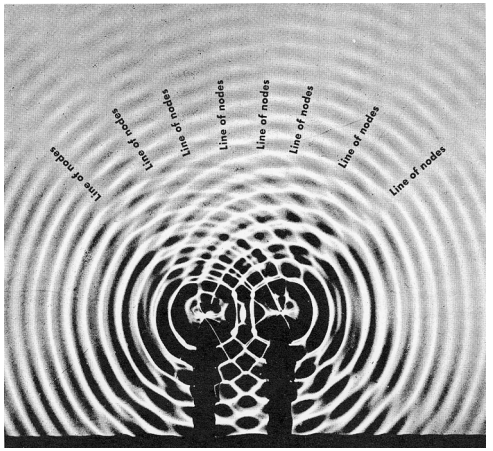


"George Biddell Airy

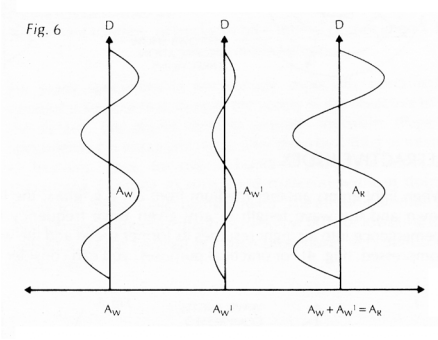


Airy Disk

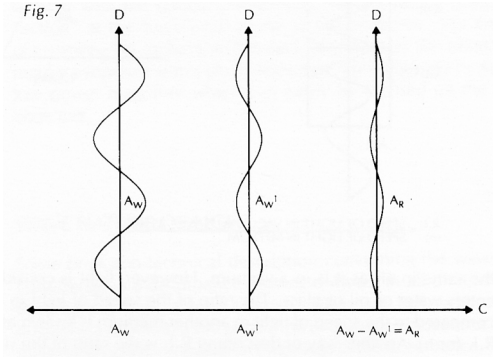
Interference



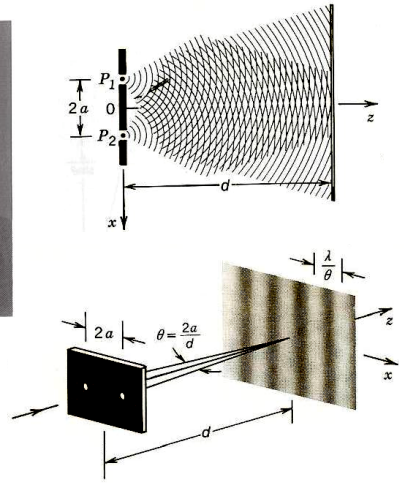
Constructive interference

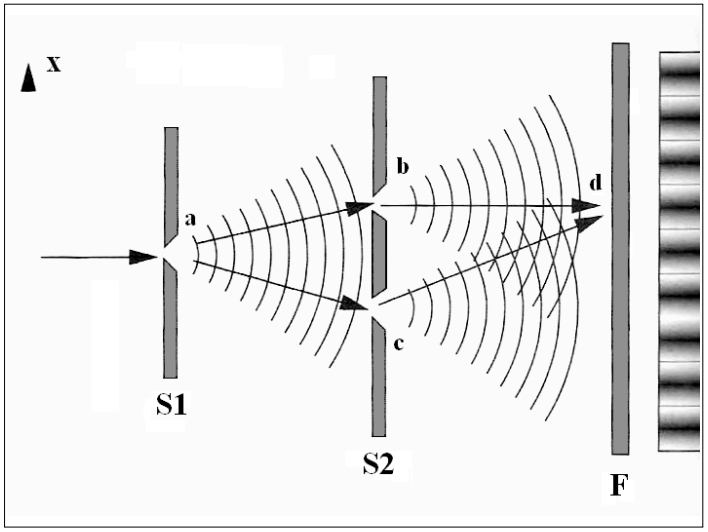


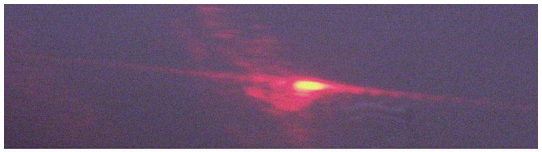
Destructive interference



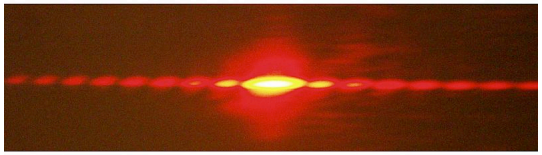
Thomas Young
(1773 - 1829)





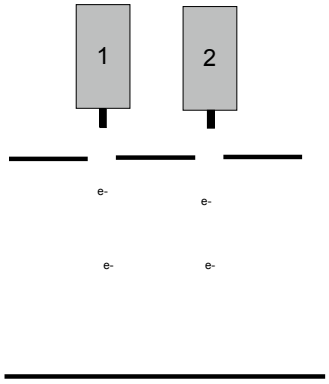


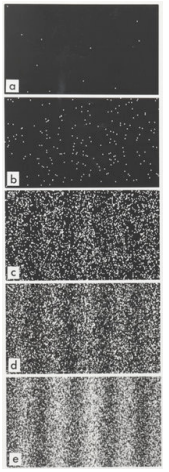
Pattern produced from a single slit.



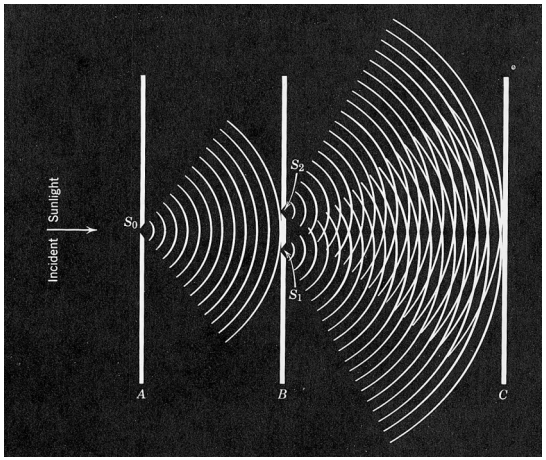
Pattern produced from a double slit.

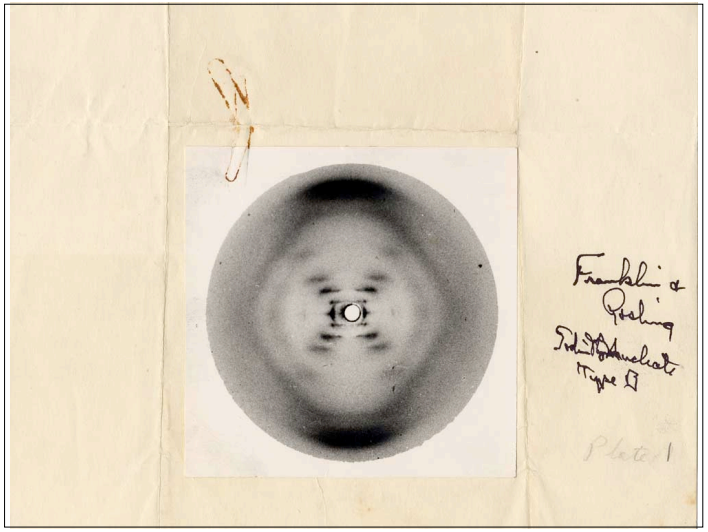
Single Photon Sources

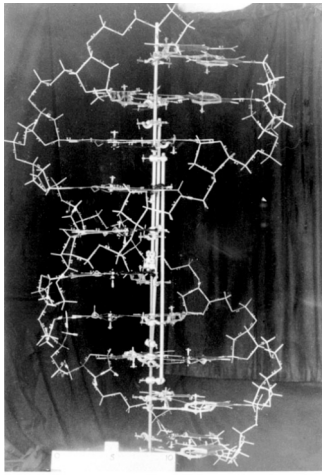




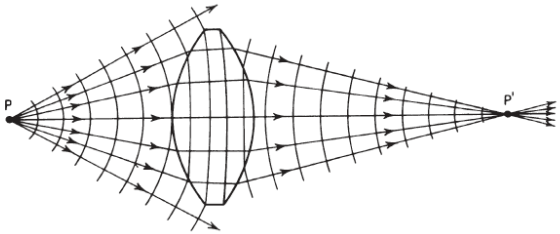
Interference



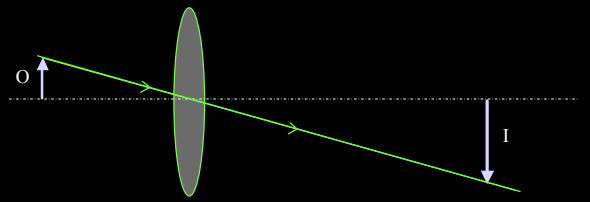




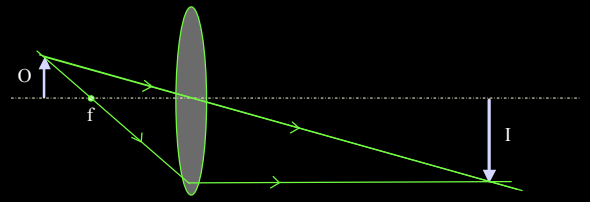
The lens is a light gathering instrument that collects a cone of light emanating from the object



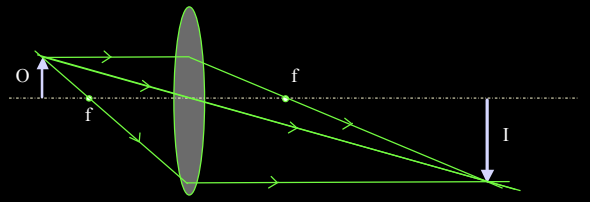
Basic optics: simple thin lens



Basic optics: simple thin lens



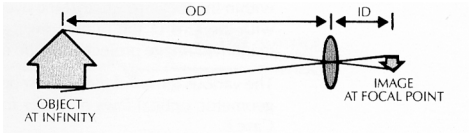
Basic optics: simple thin lens



$1/I + 1/O = 1/f$

$mag = -I/O$

Image Formation



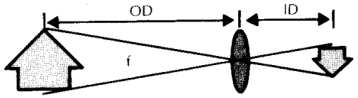
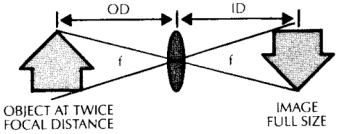
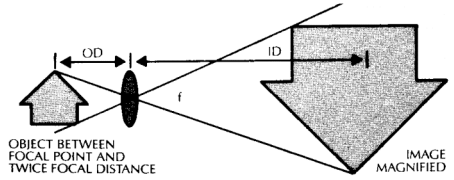
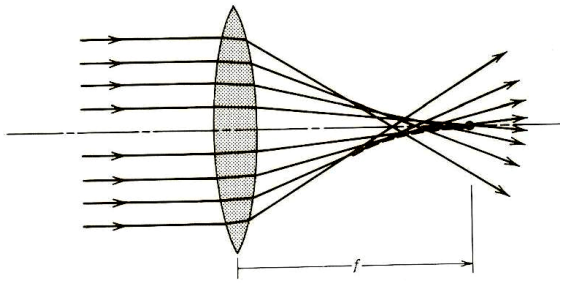


Image Magnification

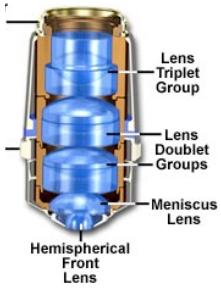




Spherical Aberration



non-paraxial rays do not meet at the paraxial focus

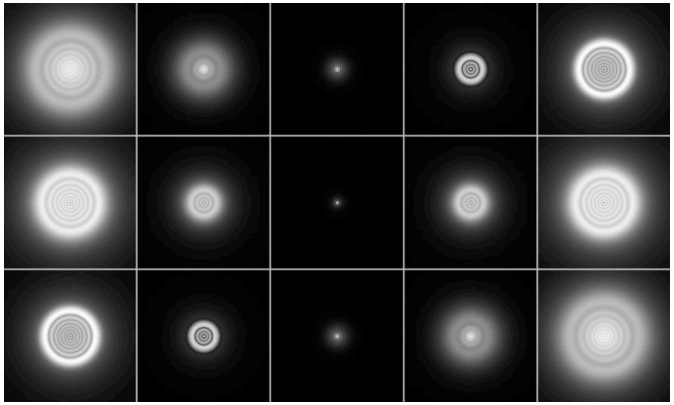


Spherical Aberration can be reduced by introducing additional carefully designed lenses into the optical path.

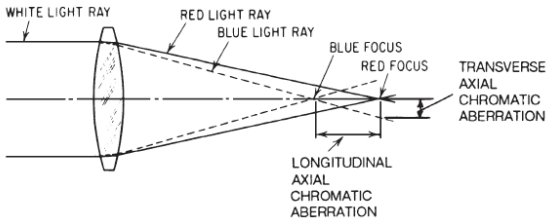
Each lens element scatters light and costs photons -- resulting in loss of image contrast

Spherical Aberration of a Point Source

"Negative" "Zero" "Positive"

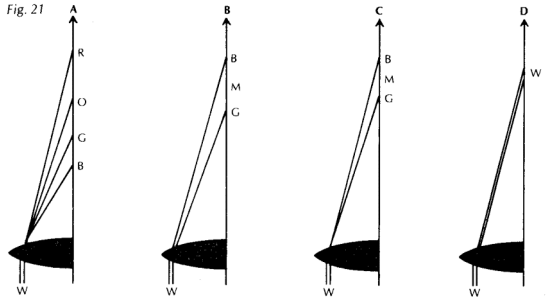


Chromatic Aberrations is due to wavelength dependence of refractive index of transparent media



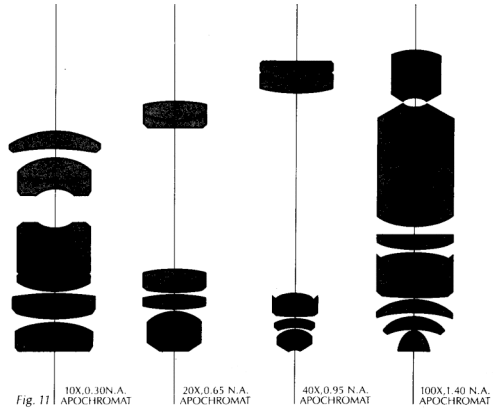
Can be reduced by coating lens elements to selectively correct refraction of various wavelengths

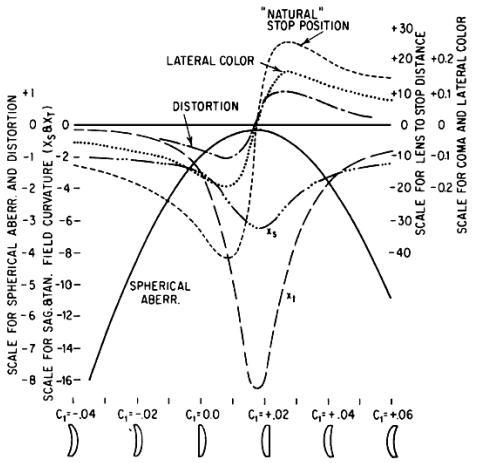
lenses corrected for achromatic aberration



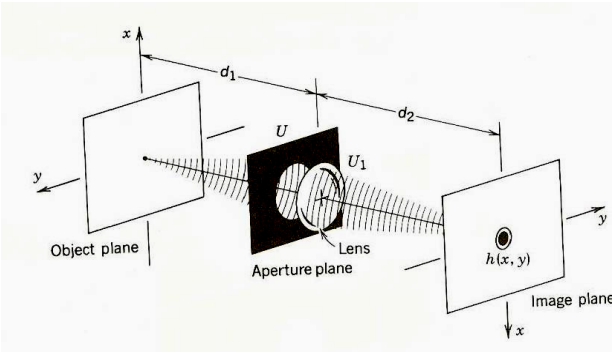
uncorrected | achromatic | semi-apochromatic | apochromatic

Objective lenses

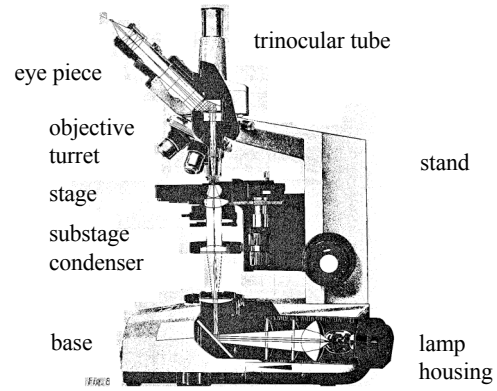




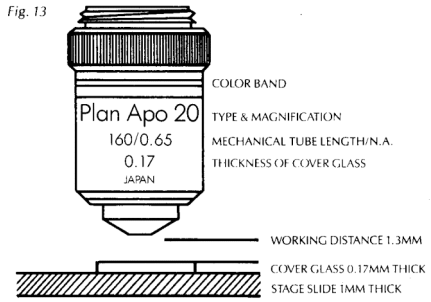
Single Lens Imaging System



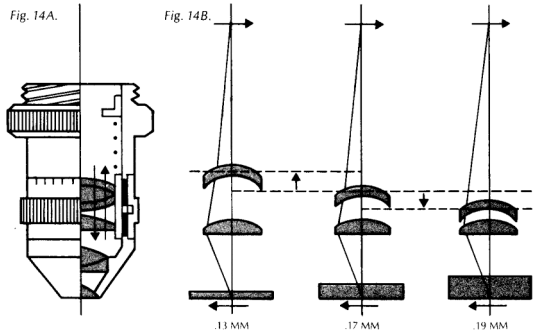
Anatomy of a Compound Microscope



Nomenclature

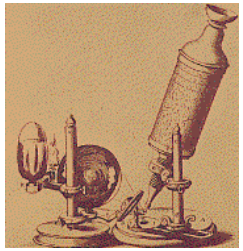


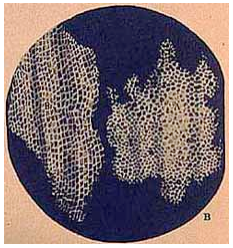
Correction collars



Robert Hooke (1635 - 1703)

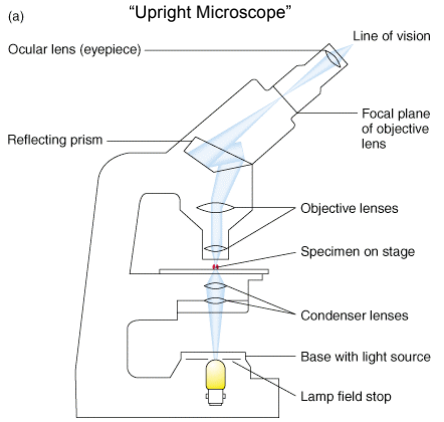
Built one of the first useful compound microscopes
Observed structure of cork
Coined the term “Cell”.
Published *Micrographia* (1665)



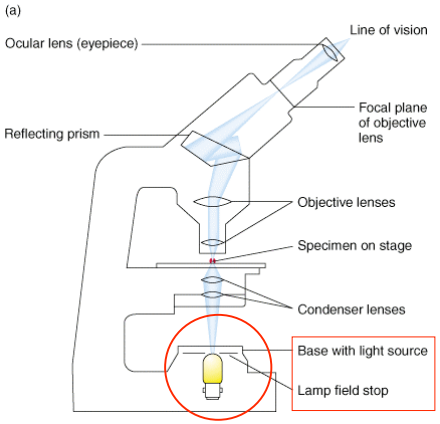


1665	Hooke publishes Micrographia
1678	van Leeuwenhoek observes protozoa (“little animals”)
1838-9	Schleiden & Schwann proposed “Cell Theory”
1860	Pasteur confirms Cell Theory
1931	Ruska invents electron microscope
1932	Zerniki develops phase contrast microscopy
1955	Minsky invents the laser scanning microscope (LSM)
1989	Webb, Denk & Strickler invent multiphoton LSM

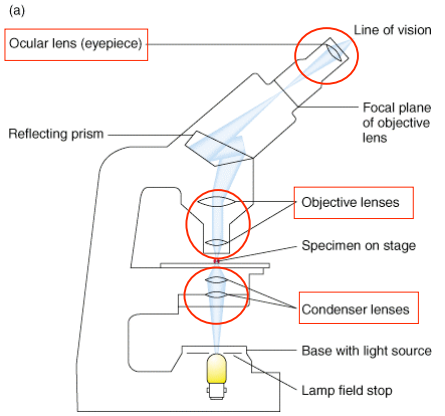
Light Microscopy



Upright Microscope



Upright Microscope



Objective Lens

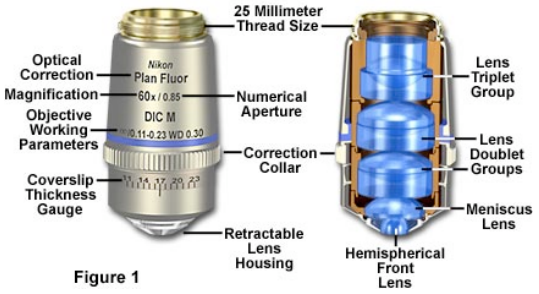
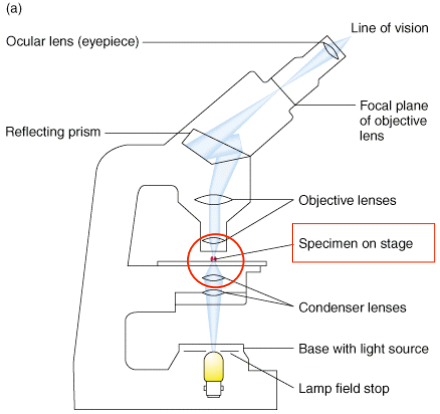
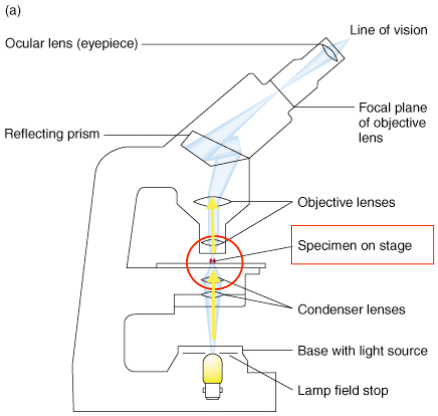


Figure 1

Upright Microscope



Upright Microscope



Specimen

- Must be “transparent” to visible light
- Usually either single cells, or …
- A thin section of tissue
- Usually “stained” to reveal structures of interest

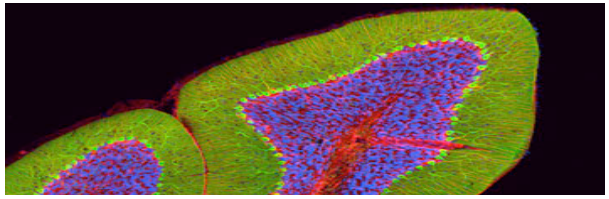


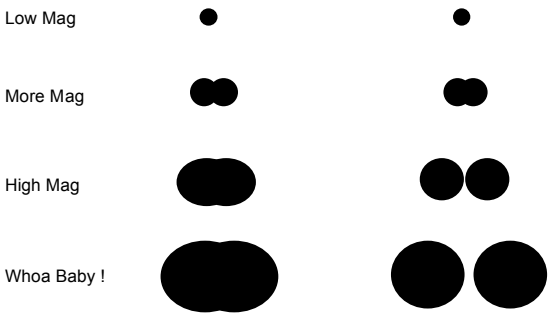
Image is NOT Everything

The image is the product of the interaction of incident light with the object.

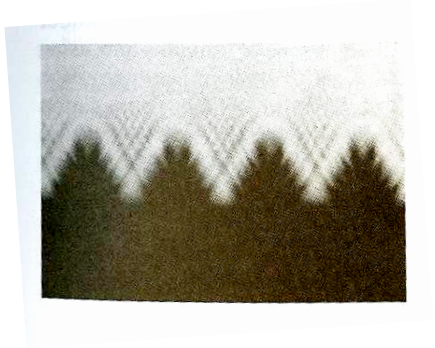
Light must INTERACT with the object

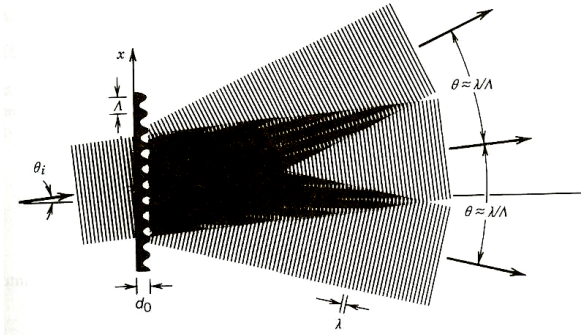
Light interacts with objects through wave-like and particle-like properties.

Magnification vs Resolution

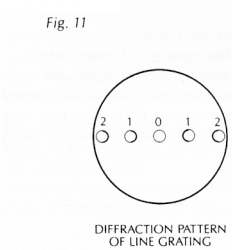


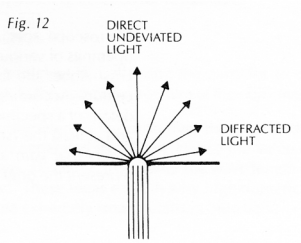
Diffraction pattern of a saw blade



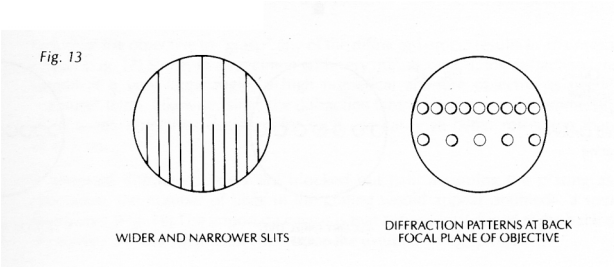


Diffraction through a grating

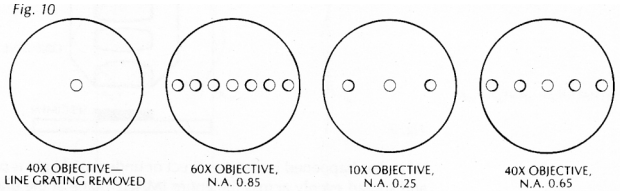




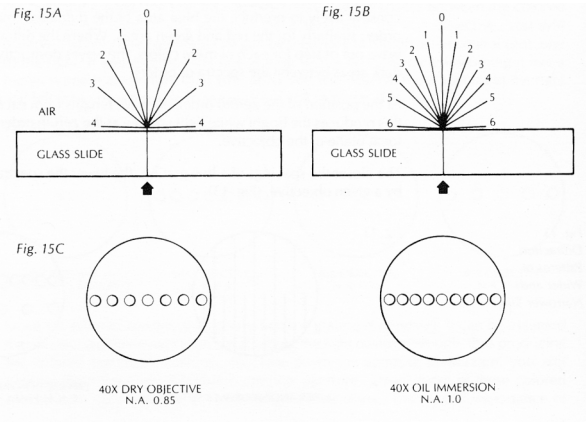
Diffraction through a grating



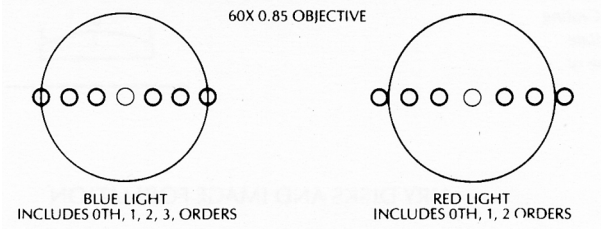
Diffraction through a grating

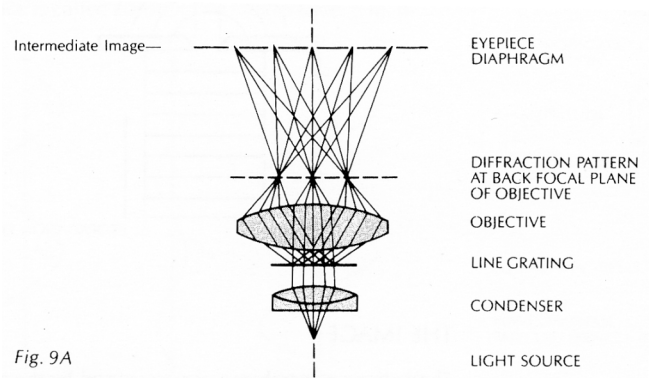


Effect of Oil

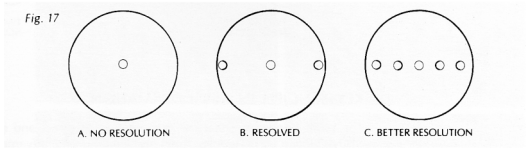


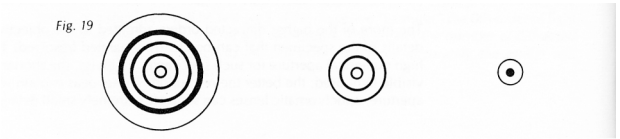
Wavelength dependence



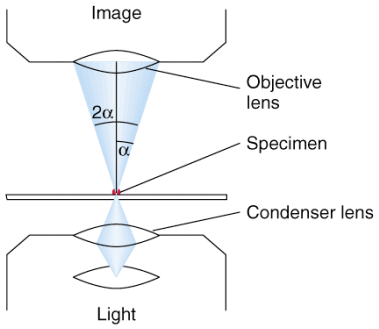


Airy Disk Patterns

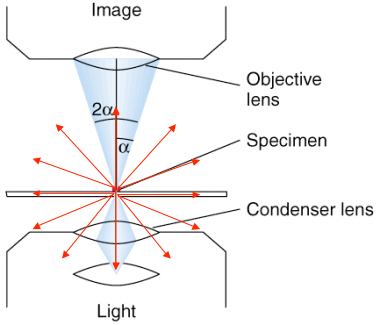




Light Microscopy

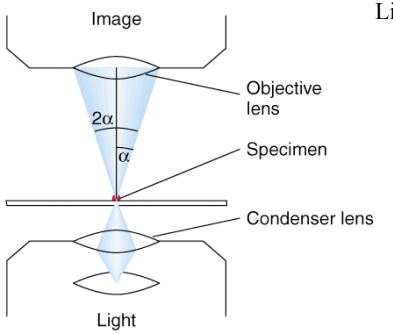


Light Microscopy



Light Microscopy

Limit of resolution (D)



$$D = \frac{(0.61)\,\lambda}{n \sin(\alpha)}$$

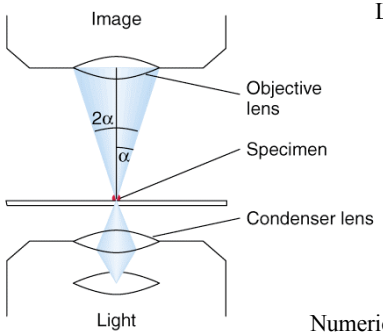
λ= wavelength of light

n = refractive index

α = angular aperture

Light Microscopy

Limit of resolution (D)



$$D = \frac{(0.61)\,\lambda}{n \sin(\alpha)}$$

λ= wavelength of light

n = refractive index

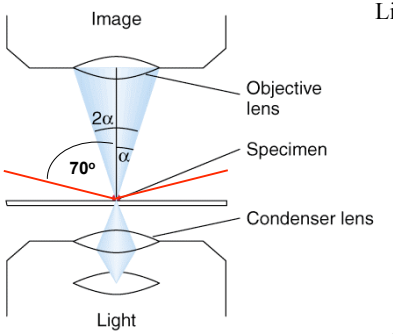
α = angular aperture

Numerical Aperture = N.A.

N.A. ~ 0.3 - 1.65

Light Microscopy

Limit of resolution (D)



$$D = \frac{(0.61)\,\lambda}{n \sin(\alpha)}$$

λ= wavelength of light

n = refractive index

α = angular aperture

$$D = \frac{(0.61)\,(450\text{ nm})}{(1.5)\,\sin(70^{o})}$$

oil

≃ 200 nm

≃ 0.2 µm