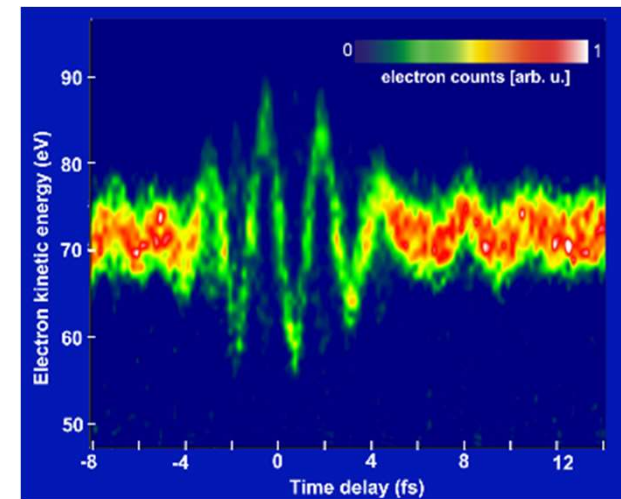
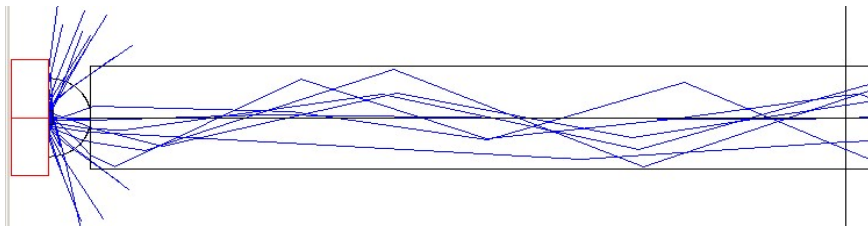
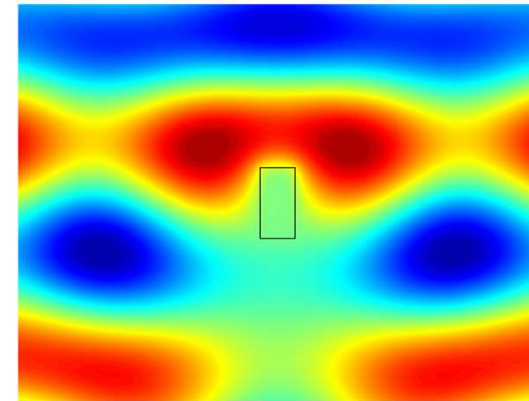
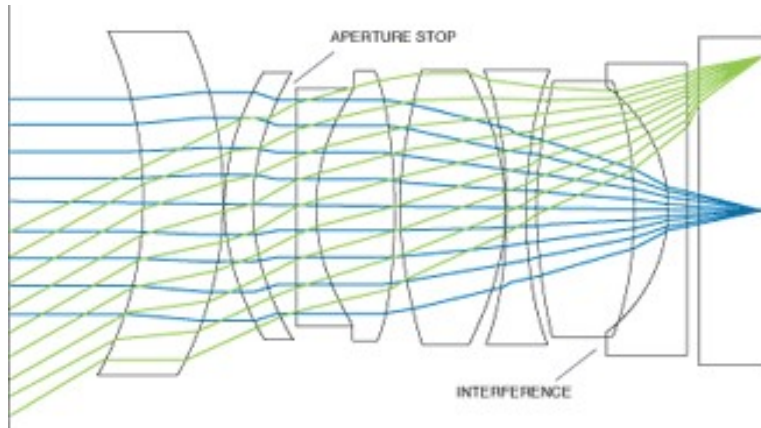


Optics

Investigates phenomena of the creation, detection and propagation of light



Historical light models

Euclide: Optics (BC.280) **Light is emitted by the eye**

Alhazen: (11th century, Bhagdad)

Light emitted by light sources, eye is a detector

Déscartes: (1637 La dioptrique)

Light: particles moving in „ether”

Laws of reflection and refraction (Snell’s law,)

Huygens (1679) **Light is an elastic wave of „ether”**

Newton (1704 Opticks)

Light: particles moving like mechanical objects

Dispersion observed, color~ size of particle

Composition of white light

Newton’s rings

Fermat: (18th century)

Principle of shortest propagation distance (time)

Young (1802): **Double slit experiment, wave explanation**

Fresnel (1819) **Wave theory of light**

Maxwell: (1862) **EM wave theory of light**

Michelson & Morley: (1881) **There is no „ether”,**

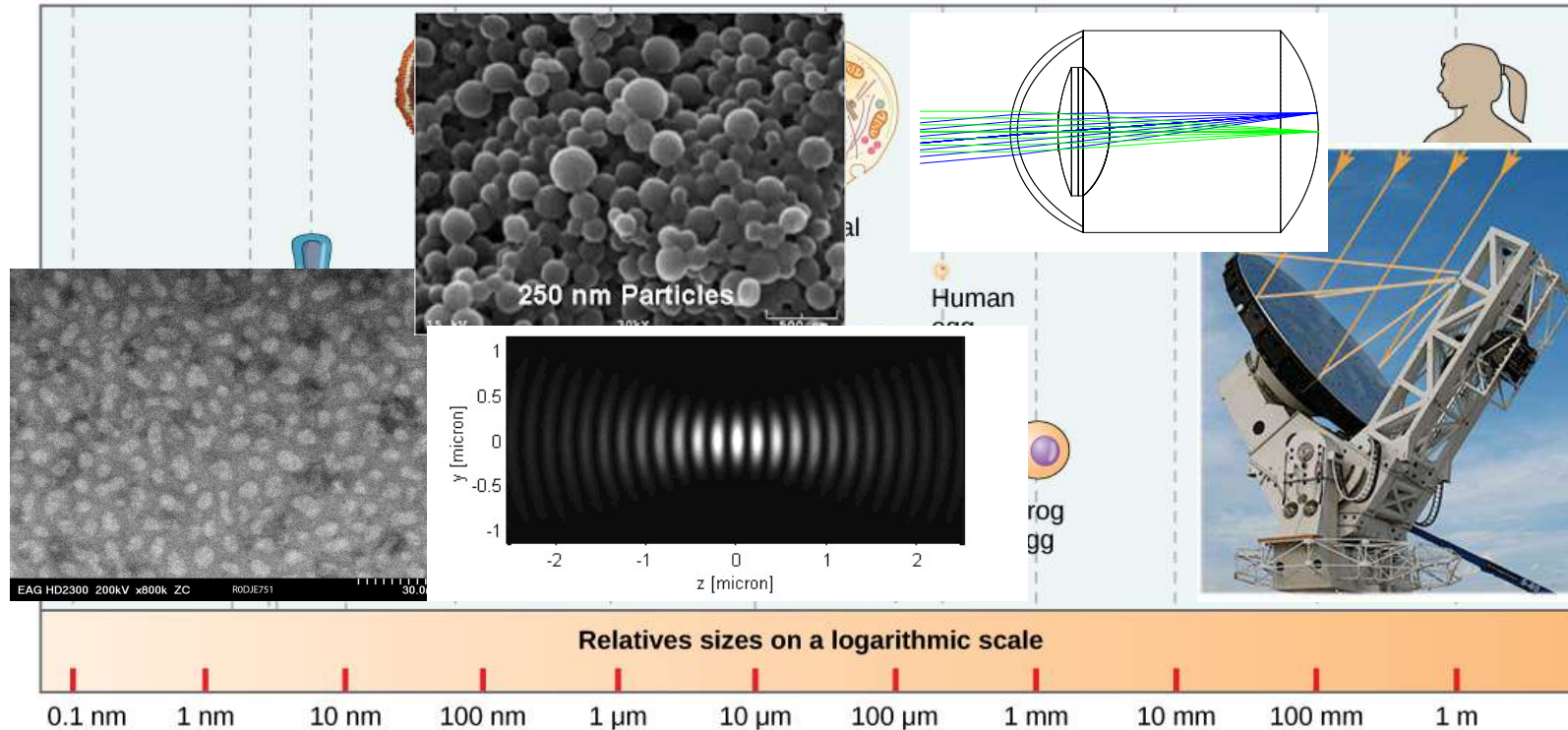
c is independent of coordinatte system

Planck (1900) **Black body radiation, energy quanta**

Einstein (1905) **Photoelectric effect, light particles, photons**

Today: **Dual nature of light (and of matter)**

Modern light models

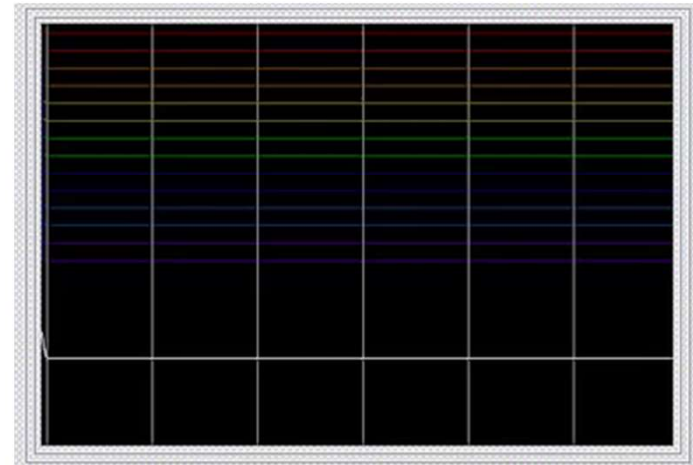
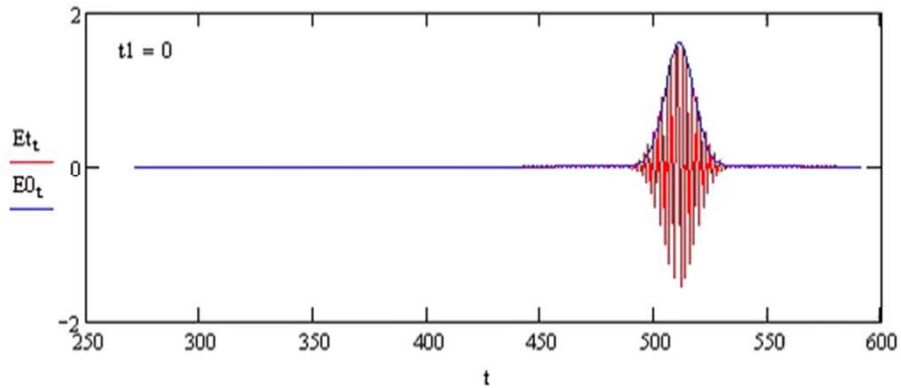
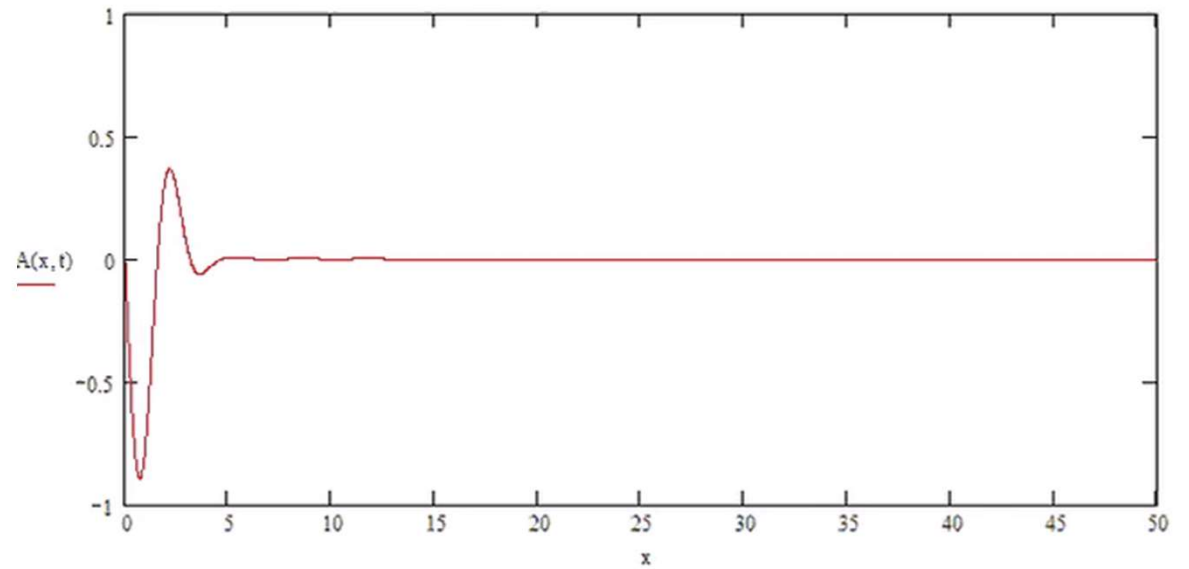
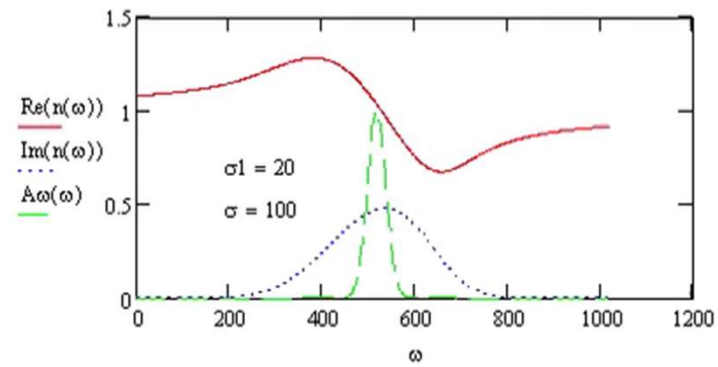


- Quasistatic approximation
- Dipolar (Rayleigh) scattering
- Quantum effects!
- Interactions!

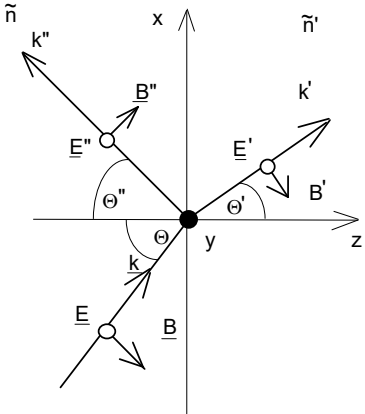
- Rigorous methods (RCWA, FEM, FDTD)
- Right approximations (Born, Green functions...)

- Ray tracing
- Scalar diffraction

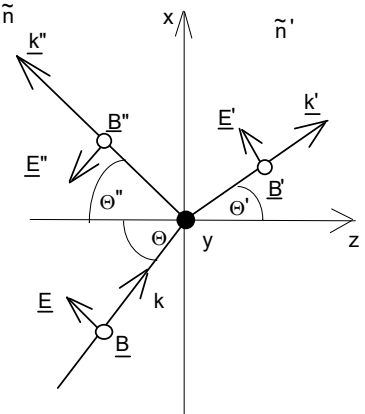
Wave dispersion



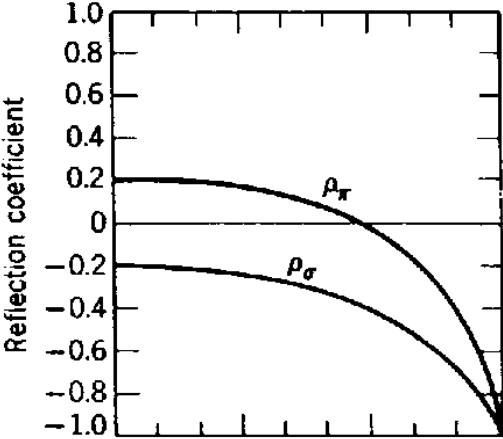
Reflection on a planar interface



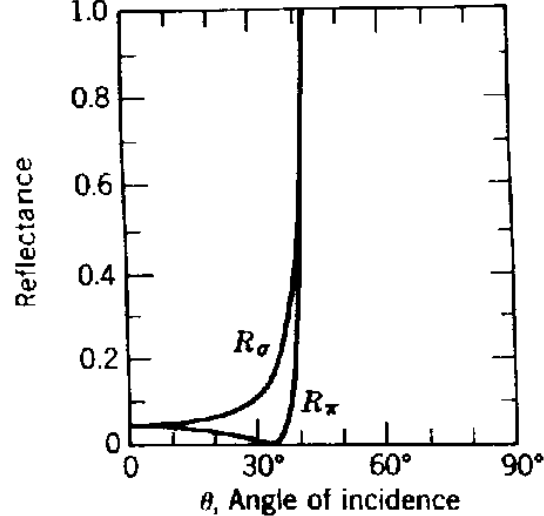
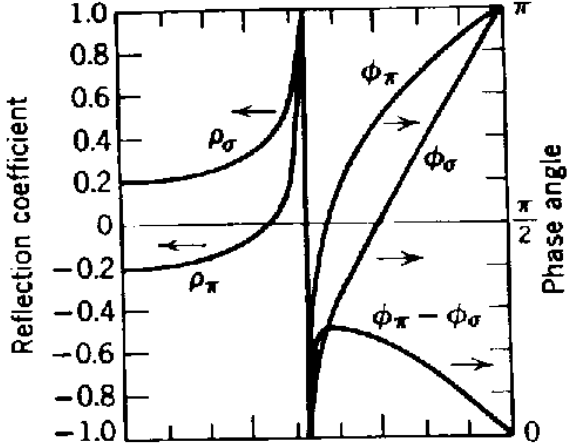
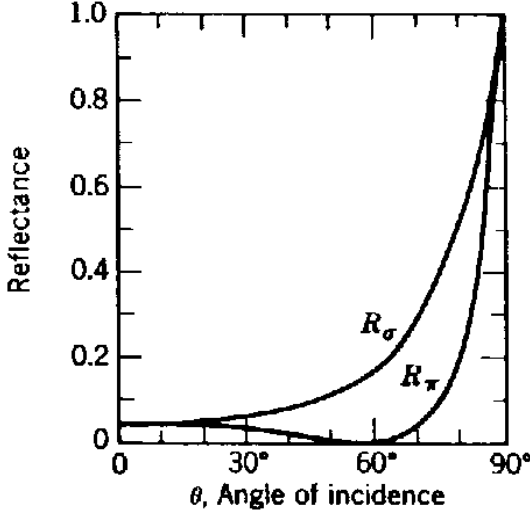
S or σ polarization, TE



P or π polarization, TM



$n_2 < n_1$
 $n_2 > n_1$



Total Internal Reflection

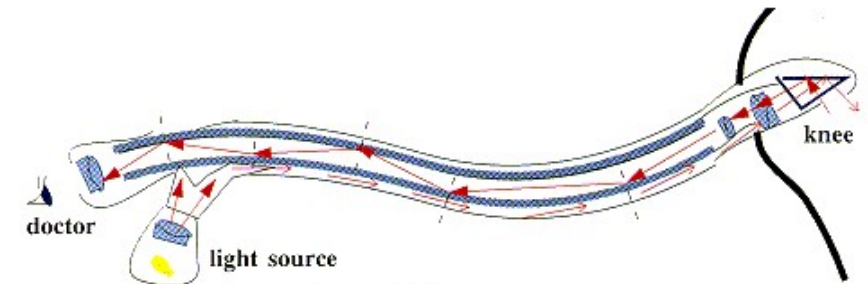
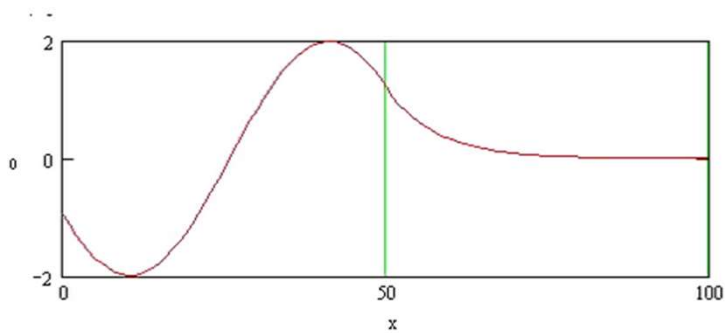
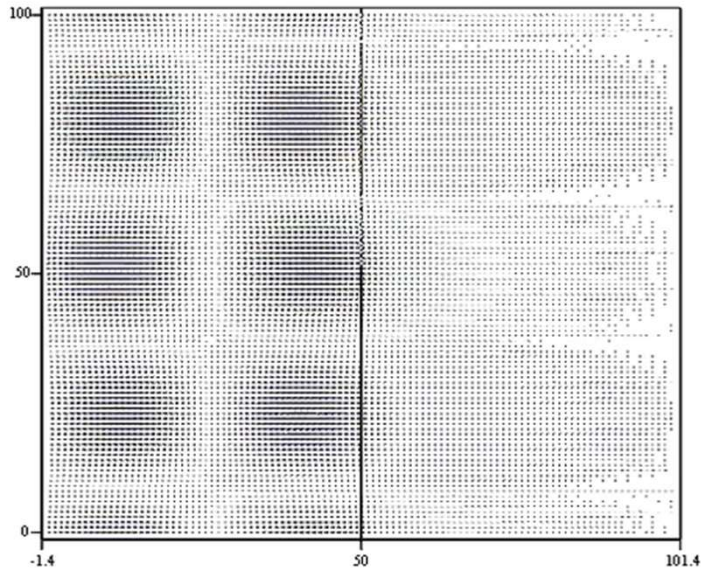
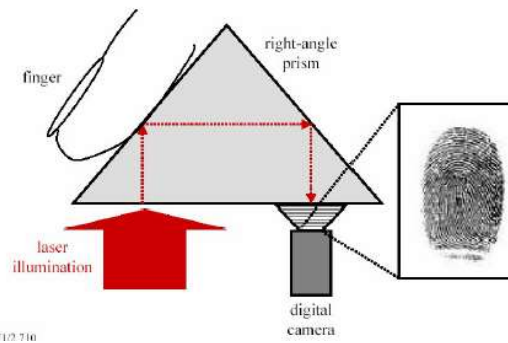
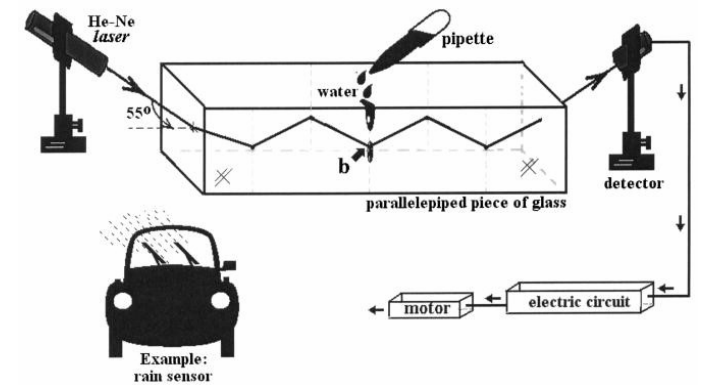


Diagram 7: Medical use of optical fibres

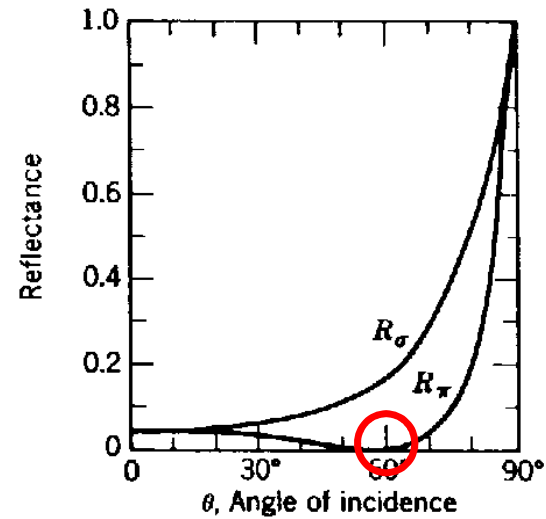
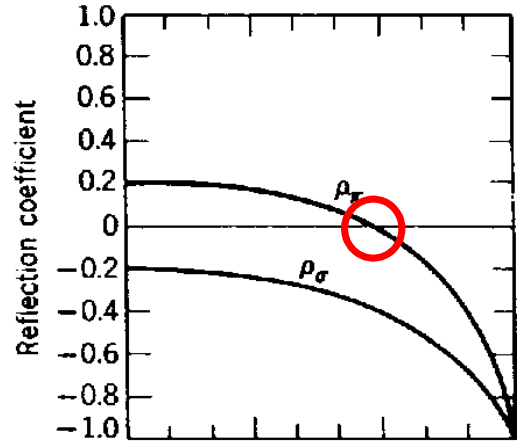
Fingerprint sensors



MIT 2.71(2.716)



Brewster effect



Polarized sunglasses
 Brewster window
 Polarizing beam splitter

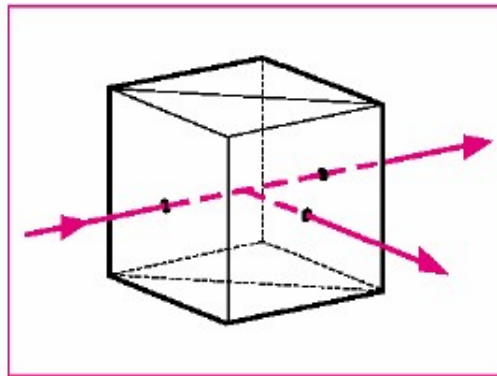
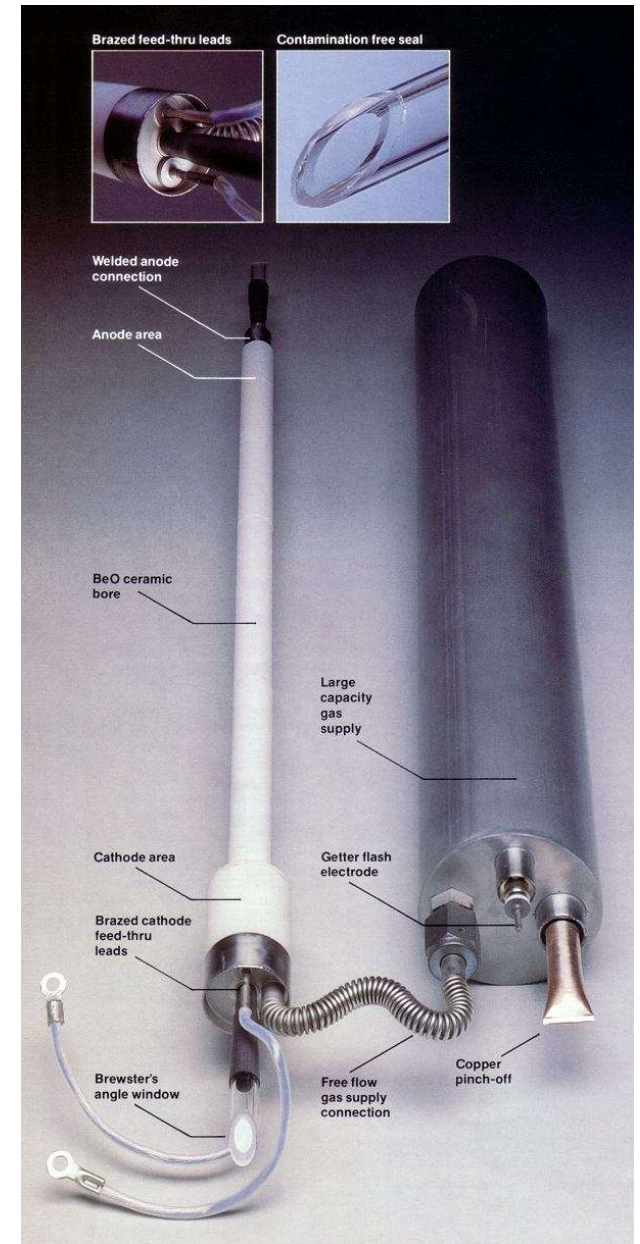
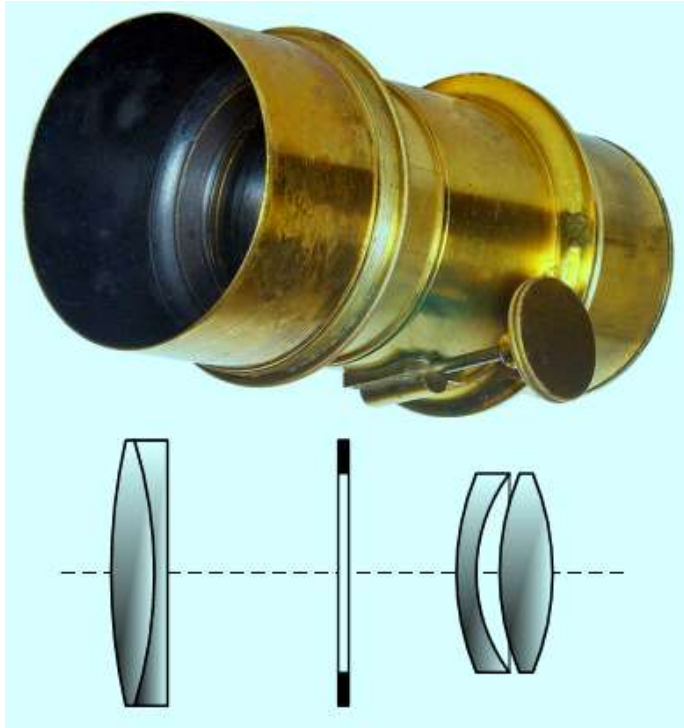


Fig. 1 Beam Splitter Cube.



Ray tracing



Petzval lens, the first photographic portrait objective lens
Calculated by 8 artillery gunners and 3 corporals using ray tracing. ~ 1 year. Today: ~1 minute of CPU time

Microscope objective



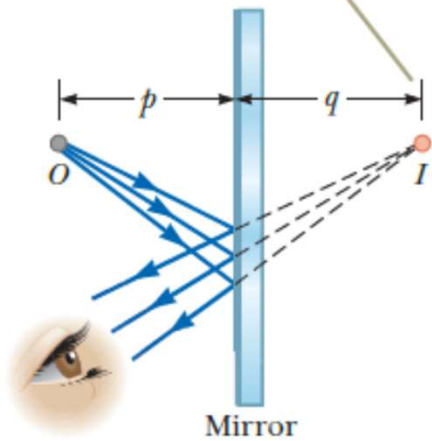
Figure 1

Lithographic system

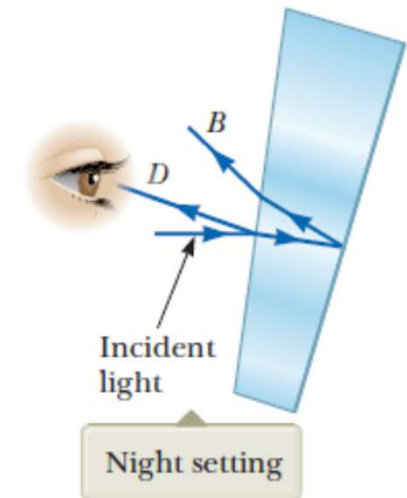
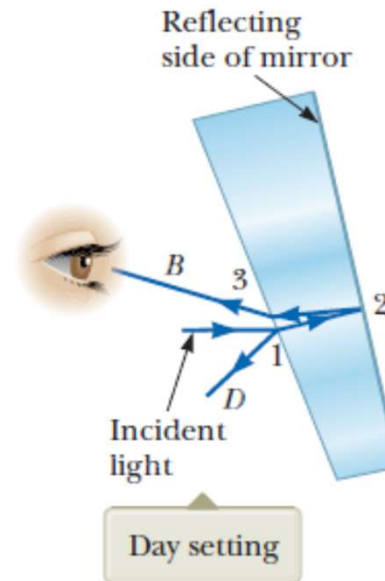
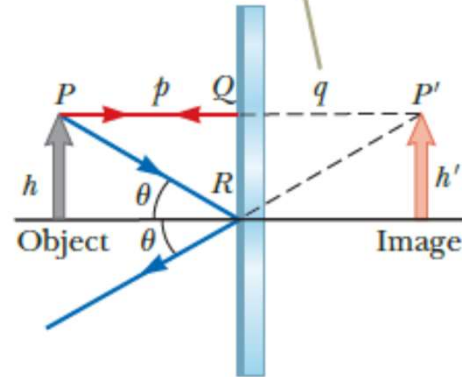


Image Formation of a plane mirror

The image point I is located behind the mirror a distance q from the mirror. The image is virtual.

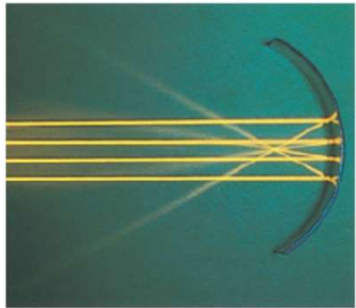


Because the triangles PQR and $P'QR$ are congruent, $|p| = |q|$ and $h = h'$.



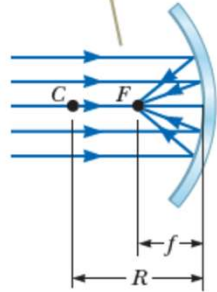
The image in the mirror is reversed front to back, which makes the right hand appear to be a left hand.

Images Formed by Spherical Mirrors



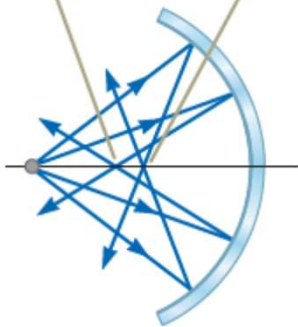
Courtesy of Henry Leap and Jim Lehman

When the object is very far away, the image distance $q \approx R/2 = f$, where f is the focal length of the mirror.



Parabolic surfaces: eliminate spherical aberration

The reflected rays intersect at different points on the principal axis.

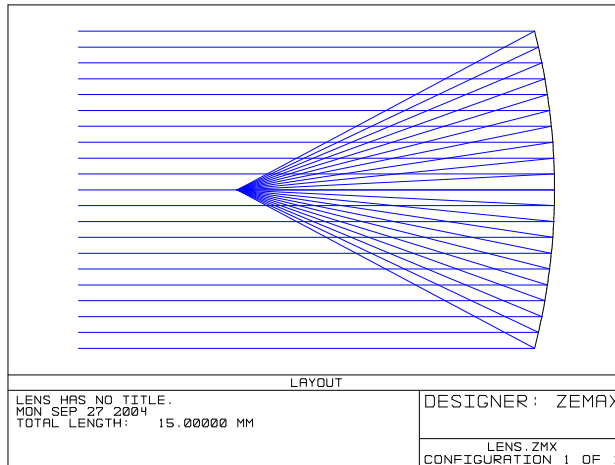


- Spherical aberration
- Coma, Astigmatism etc...
- Chromatic aberrations
- Paraxial optics

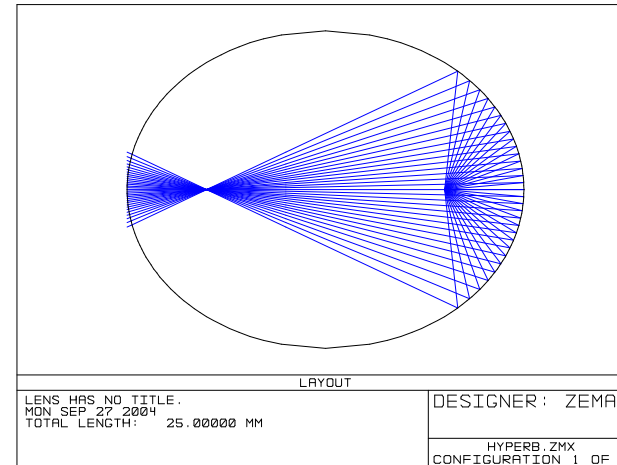


- Stigmatism: point-to point Imaging

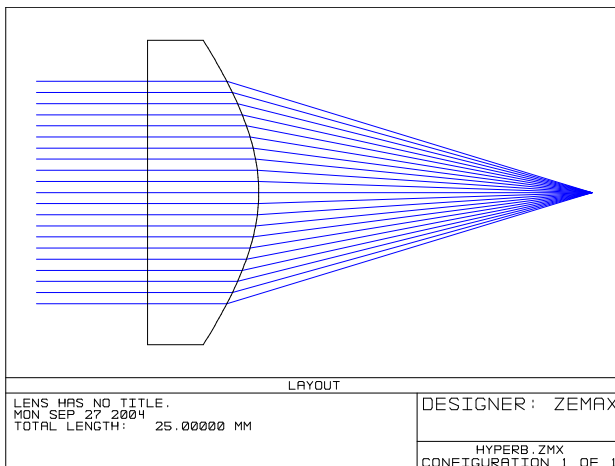
Parabolic mirror



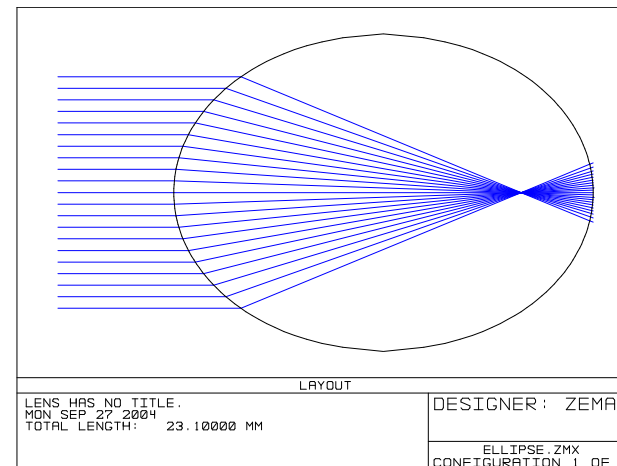
Elliptical mirror



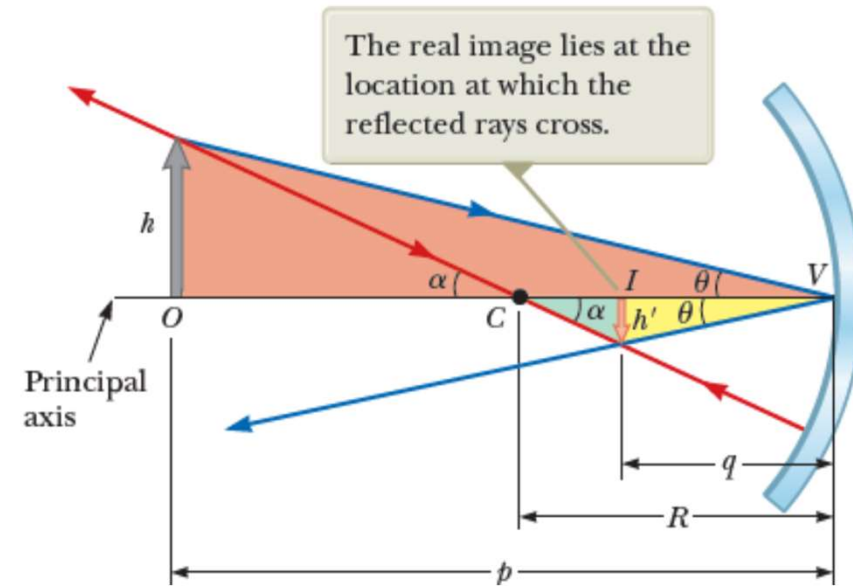
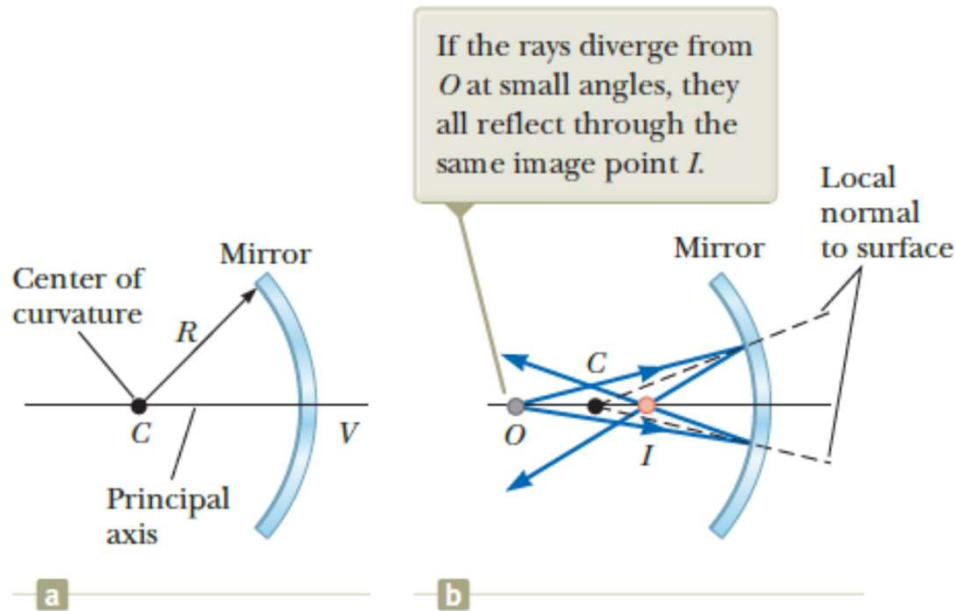
Hiperbolic lens



Elliptical lens



Images Formed by Spherical Mirrors 2

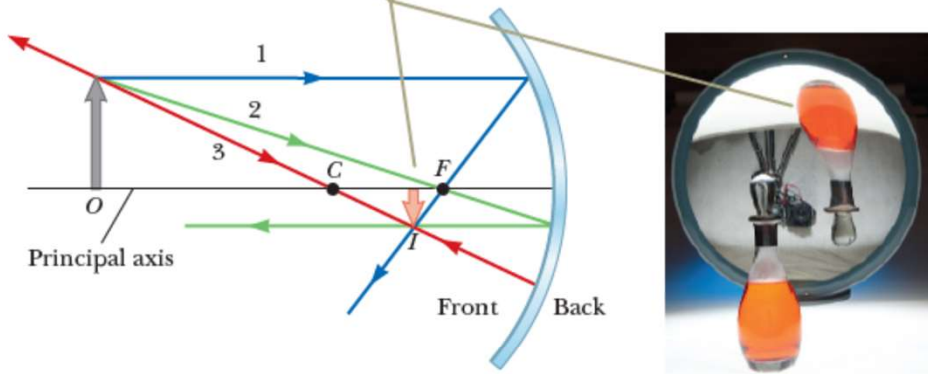


$$\frac{1}{p} + \frac{1}{q} = \frac{2}{R}$$

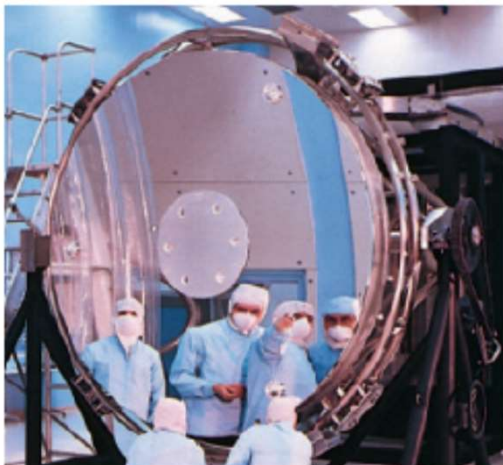
$$M = \frac{h'}{h} = -\frac{q}{p}$$

Images Formed by Spherical Mirrors 3

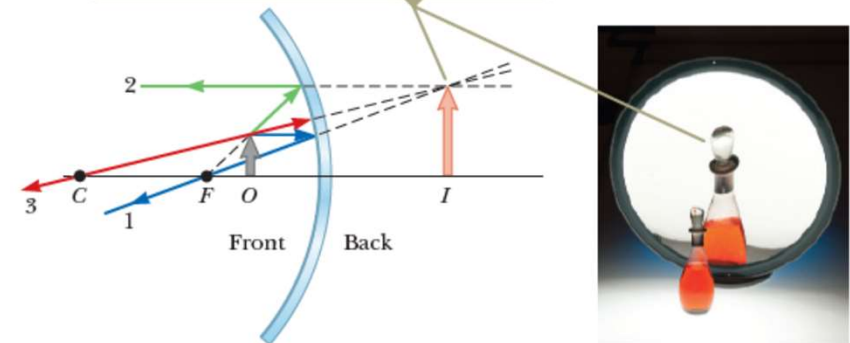
When the object is located so that the center of curvature lies between the object and a concave mirror surface, the image is real, inverted, and reduced in size.



a

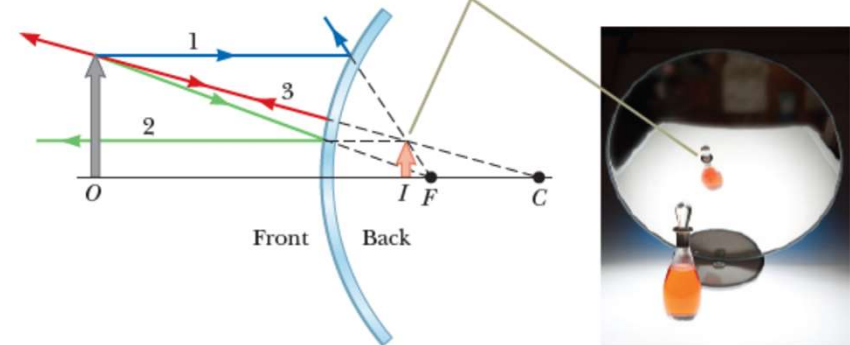


When the object is located between the focal point and a concave mirror surface, the image is virtual, upright, and enlarged.



b

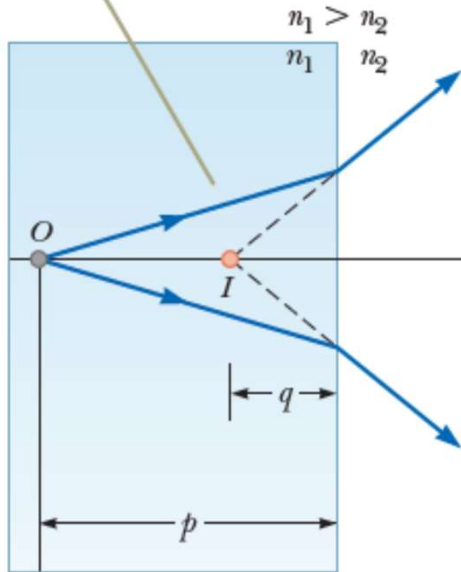
When the object is in front of a convex mirror, the image is virtual, upright, and reduced in size.



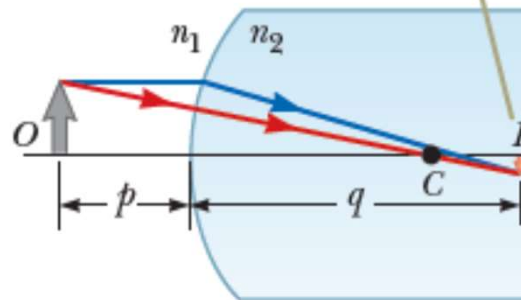
c

Single refractive surface

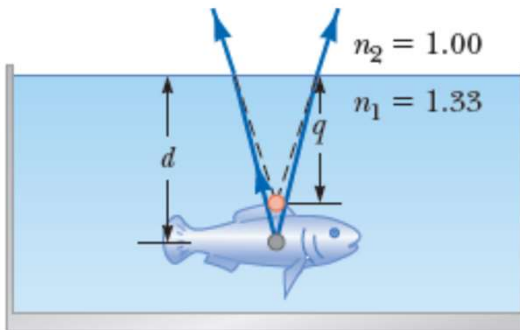
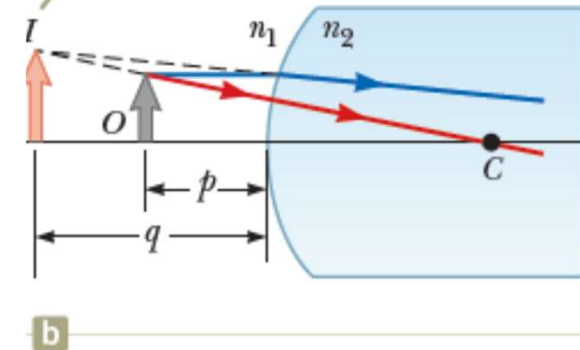
The image is virtual and on the same side of the surface as the object.



The image due to the surface is real, so I is to the right of the surface.

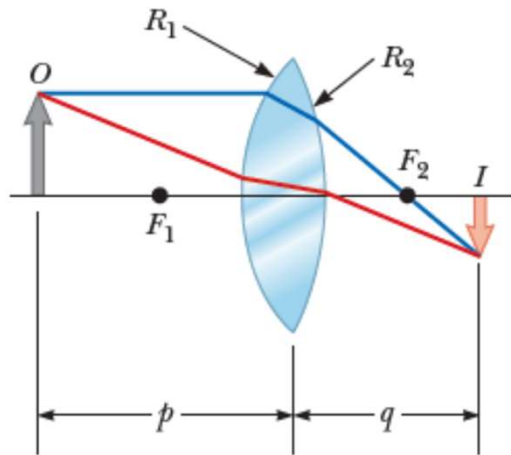
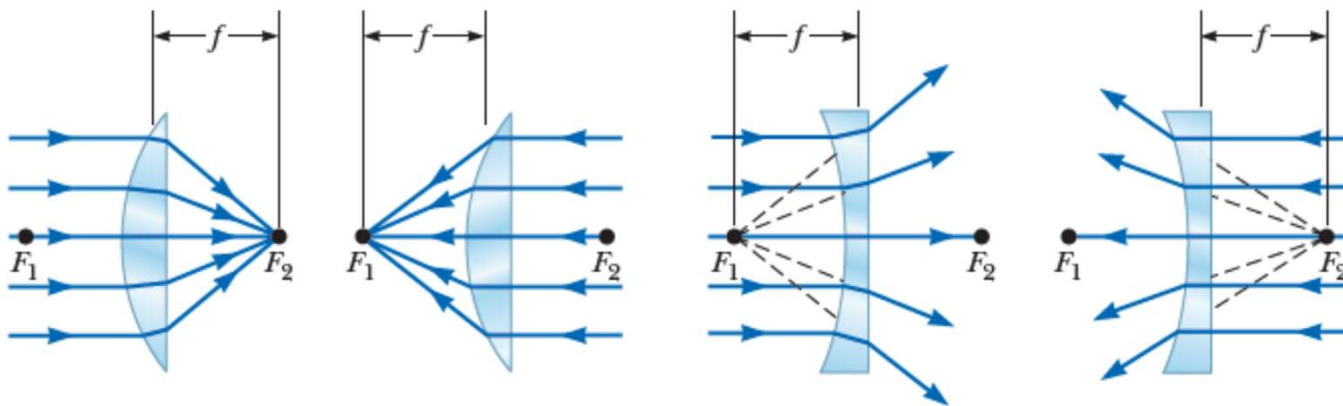


The image due to the surface is virtual, so I is to the left of the surface.



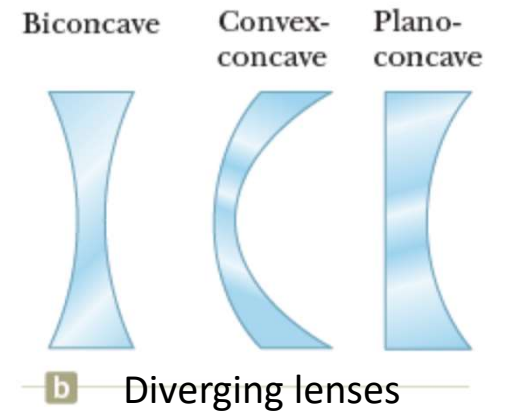
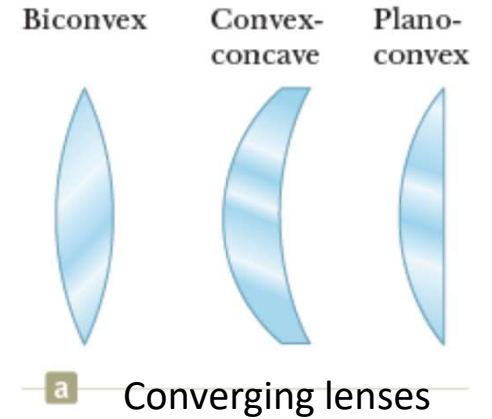
$$\frac{n_1}{p} + \frac{n_2}{q} = \frac{n_2 - n_1}{R}$$

Images Formed by Thin Lenses



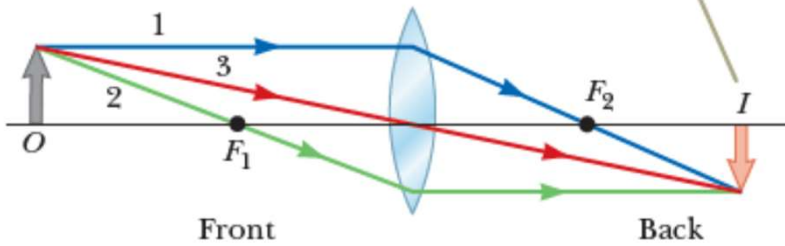
$$\frac{1}{f} = (n - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

$$\frac{1}{p} + \frac{1}{q} = (n - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

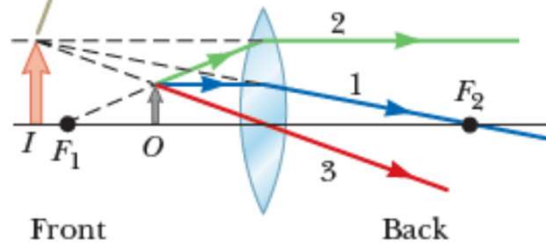


Images Formed by Thin Lenses 2

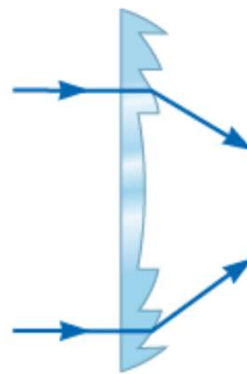
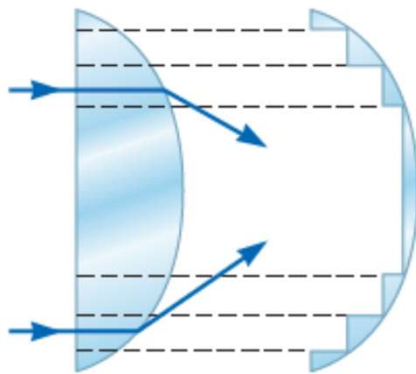
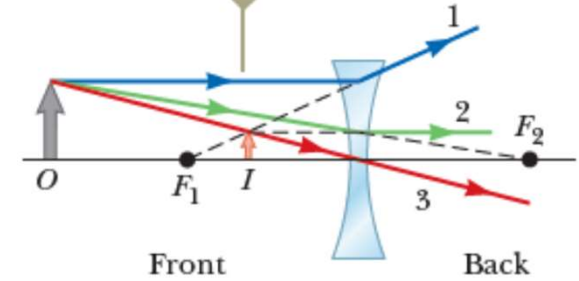
When the object is in front of and outside the focal point of a converging lens, the image is real, inverted, and on the back side of the lens.



When the object is between the focal point and a converging lens, the image is virtual, upright, larger than the object, and on the front side of the lens.



When an object is anywhere in front of a diverging lens, the image is virtual, upright, smaller than the object, and on the front side of the lens.



Kent Weakley/Shutterstock

Optical Instruments: eye

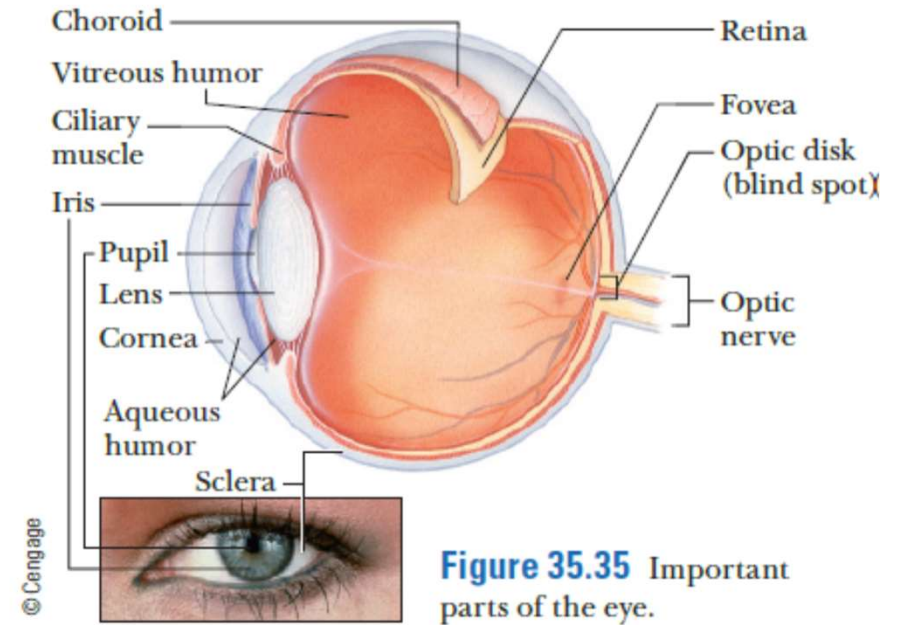
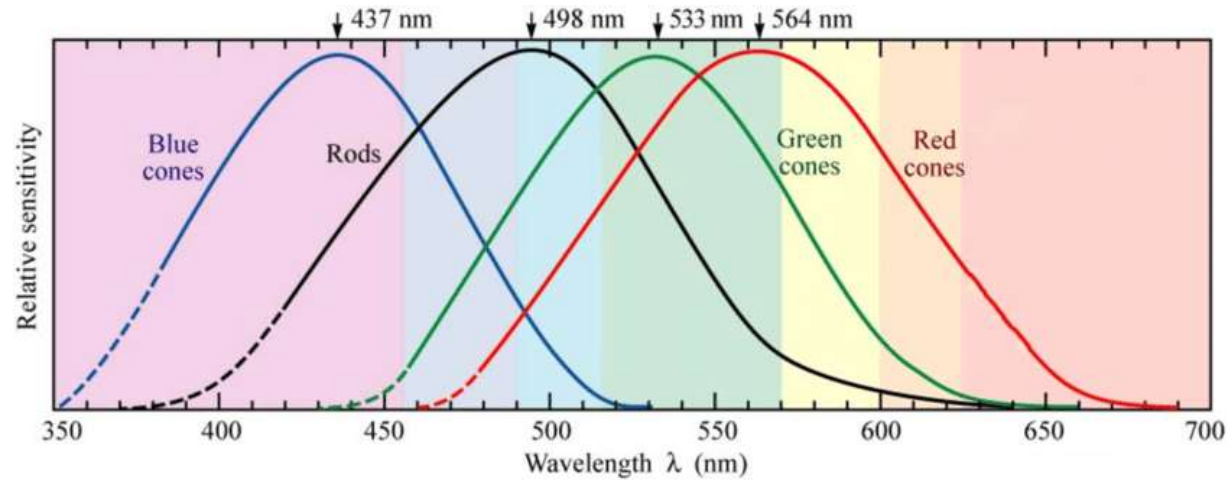
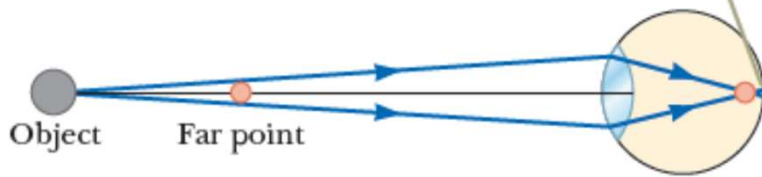


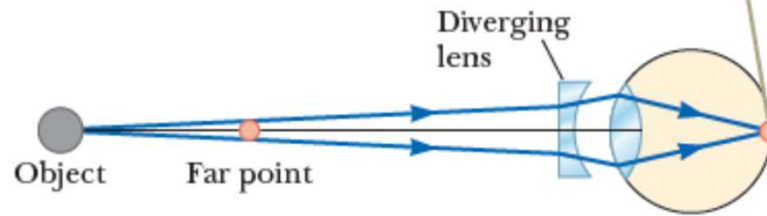
Figure 35.35 Important parts of the eye.

When a nearsighted eye looks at an object located beyond the eye's far point, the image point is in front of the retina, resulting in blurred vision.



a

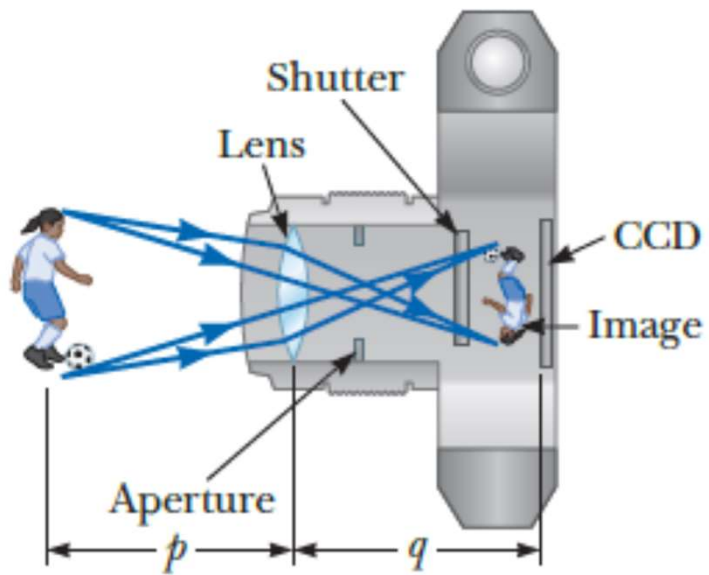
A diverging lens causes the image to focus on the retina, correcting the vision.



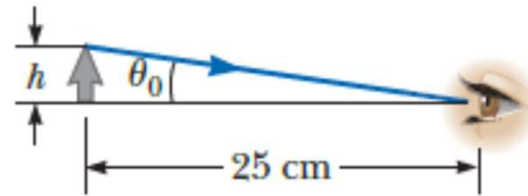
b

- Accommodation
- Sharp Vision: 5°
- Eye motion
- Vergence
- 3D perception

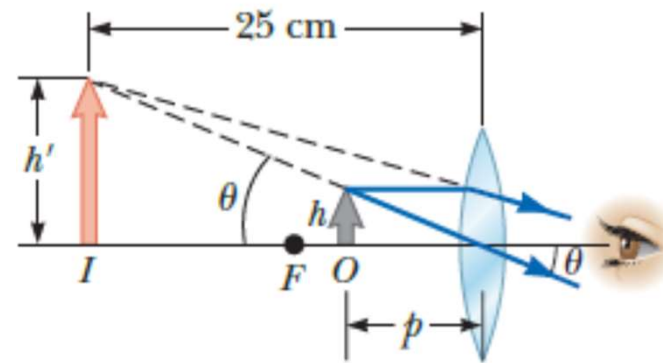
Simple Imaging Instruments



Camera



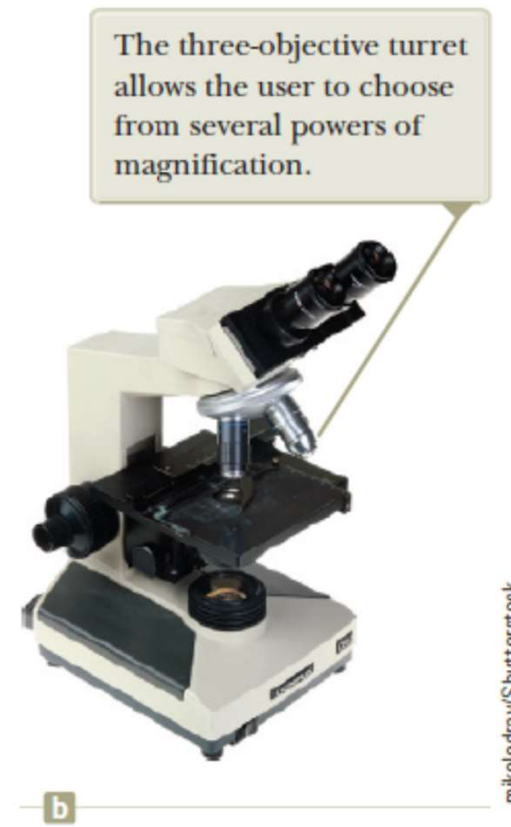
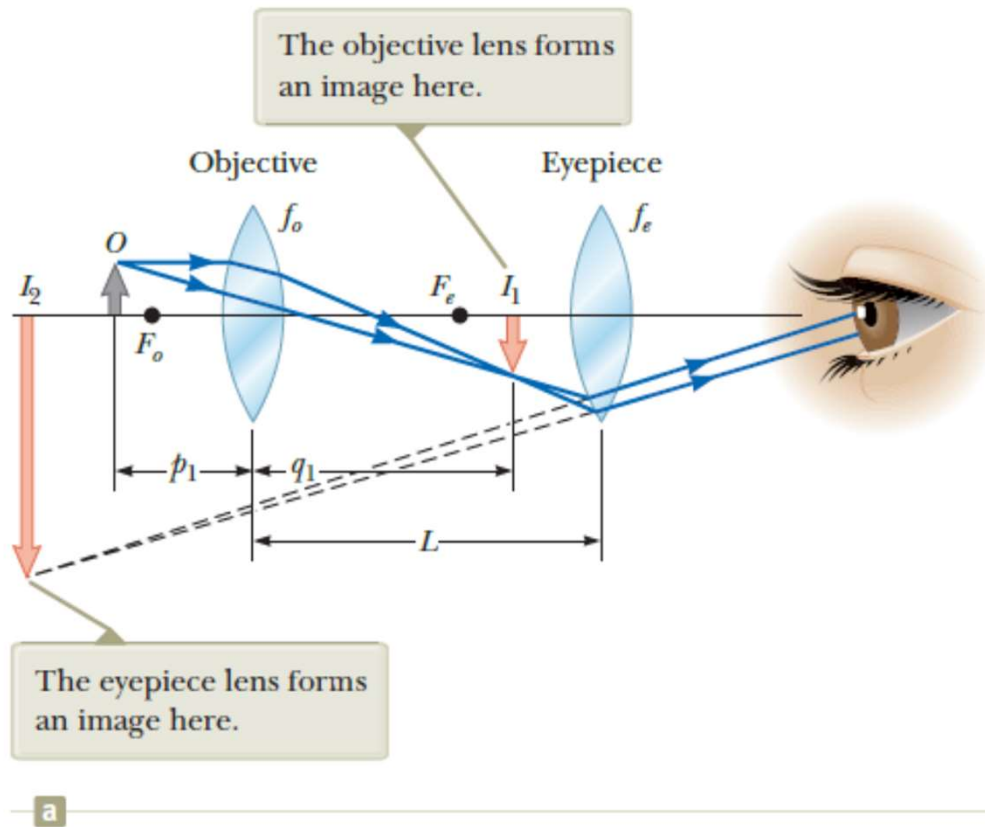
a



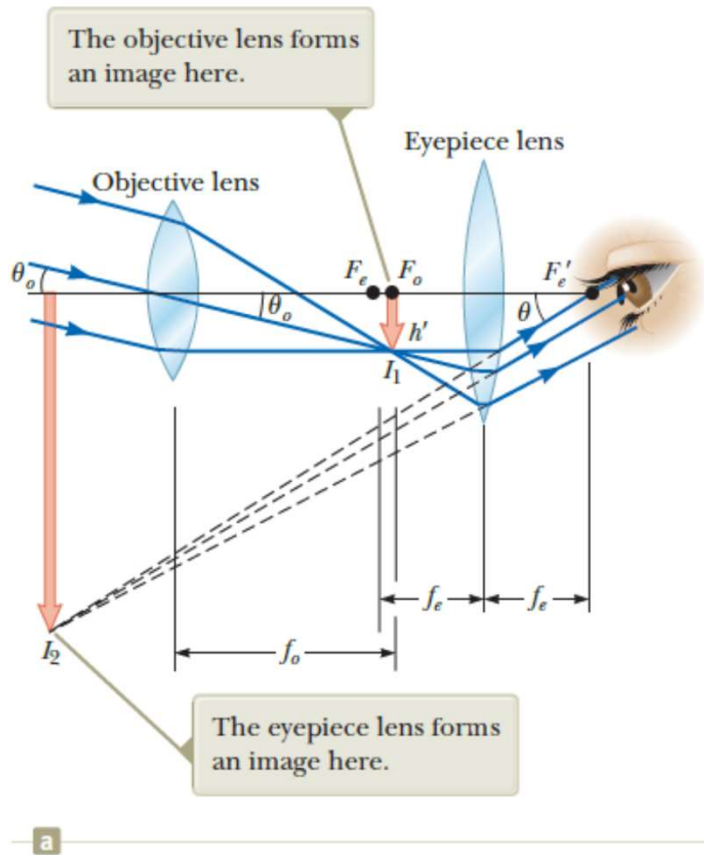
b

Magnifier

Composed Imaging Instruments: Microscope



Composed Imaging Instruments: Telescope

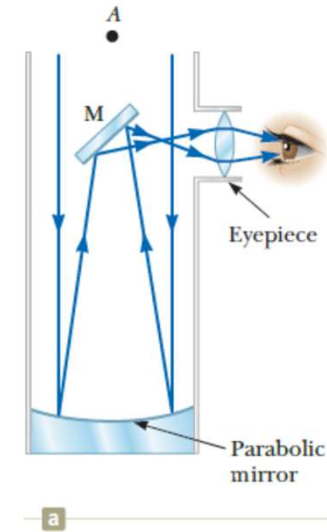


Refractive (Kepler's) telescope



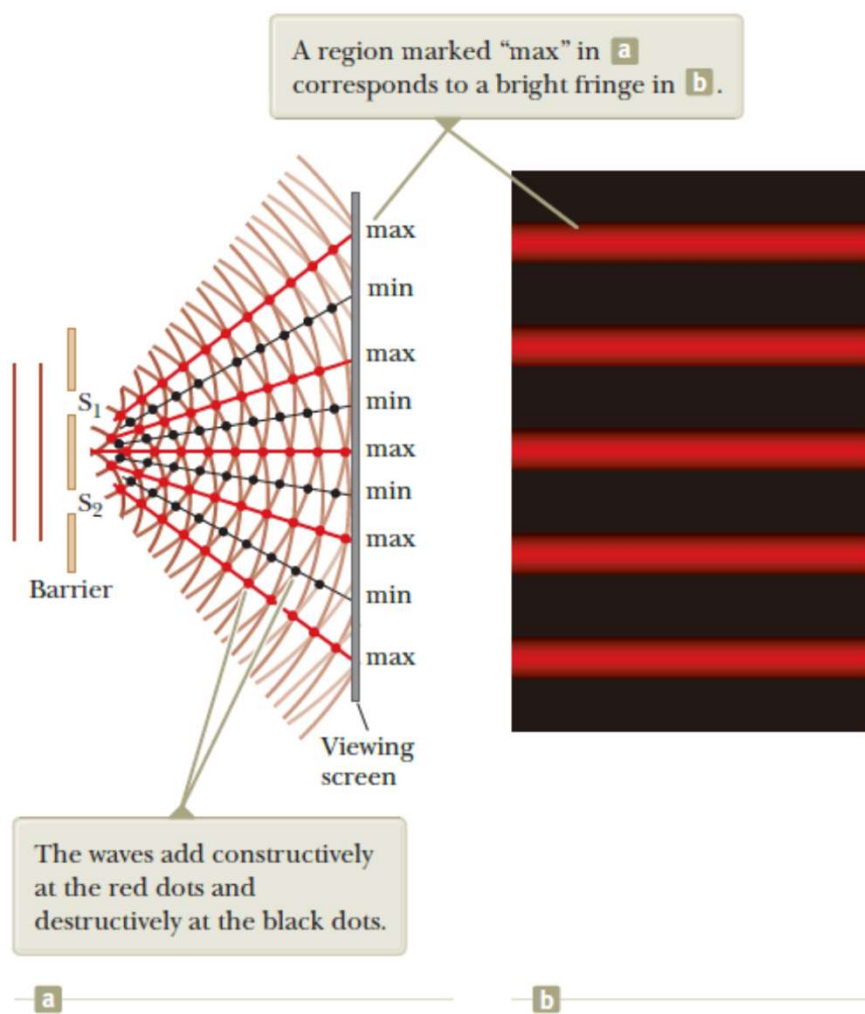
doomu/Getty Images

Reflective (Newtonian) telescope

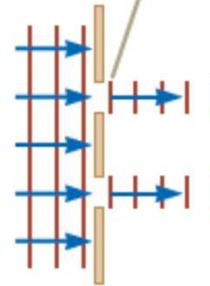


Orion ® Sky View Pro

Interference: Young's Double-Slit Experiment

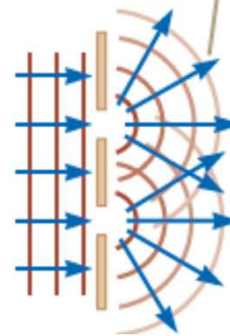


Light passing through narrow slits does *not* behave this way.



a

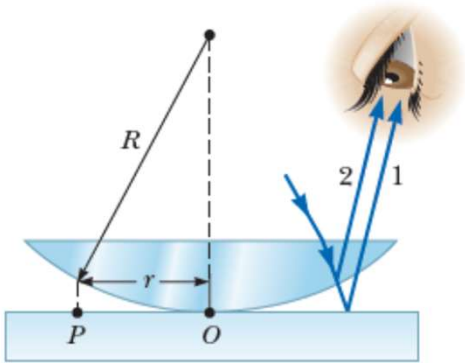
Light passing through narrow slits *diffracts*.



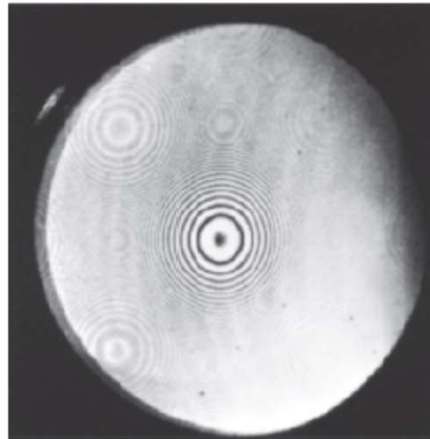
b

Interference in thin films

Newton's Rings



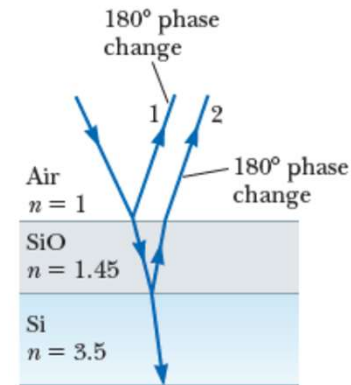
a



b

Courtesy of Bausch & Lomb

Anti-Reflective Coating



a

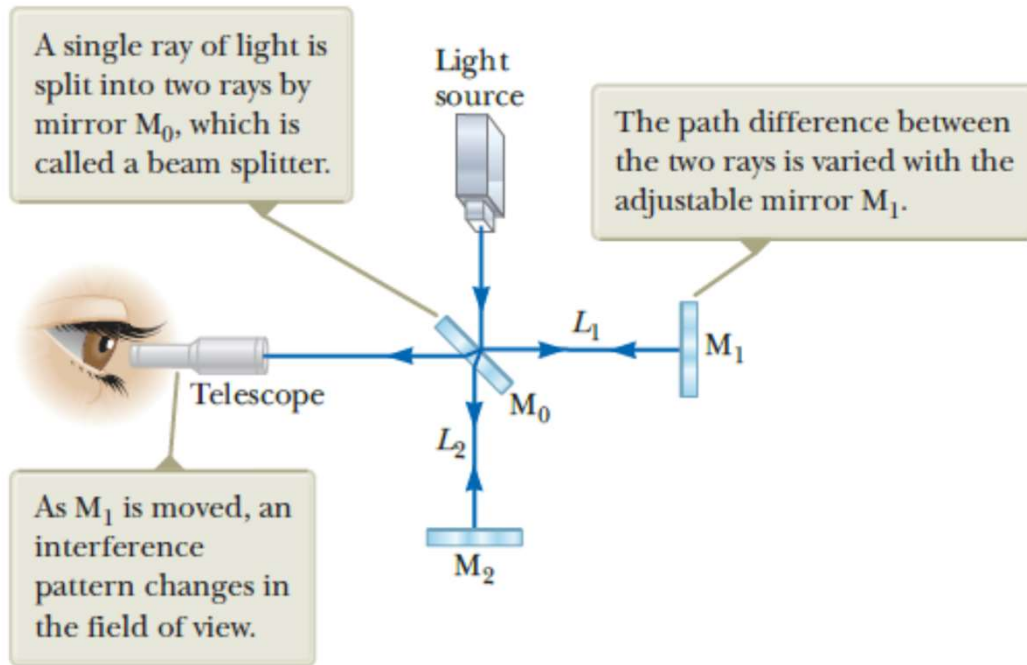


Christopurdov Diny/Shutterstock

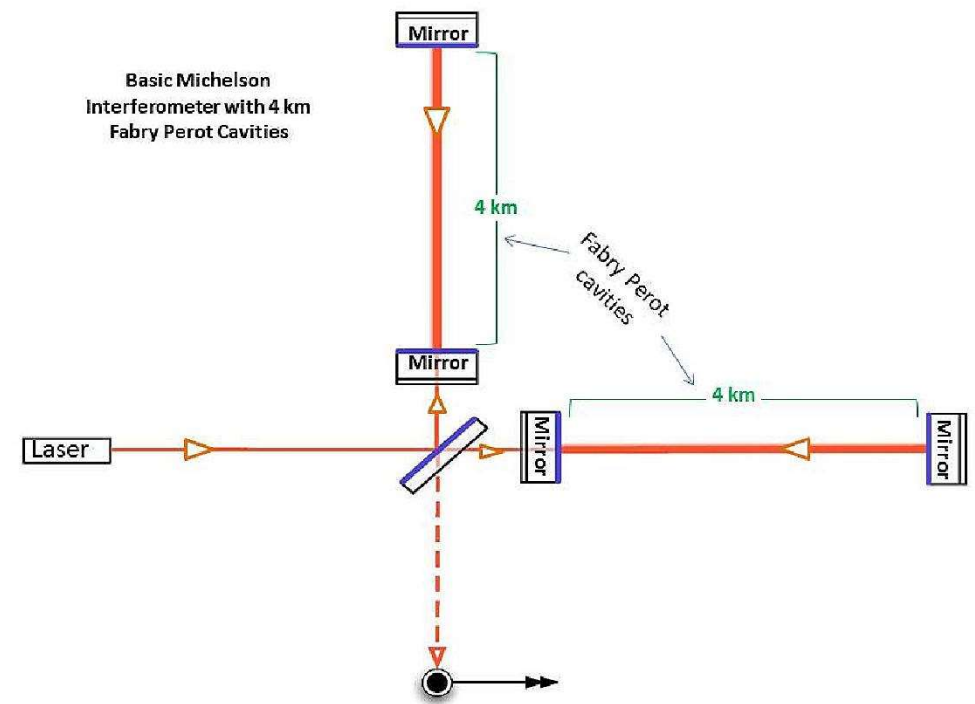
b



Famous Interferometers



Michelson Interferometer



LIGO (Laser Interferometric Gravitational-wave Observatory)