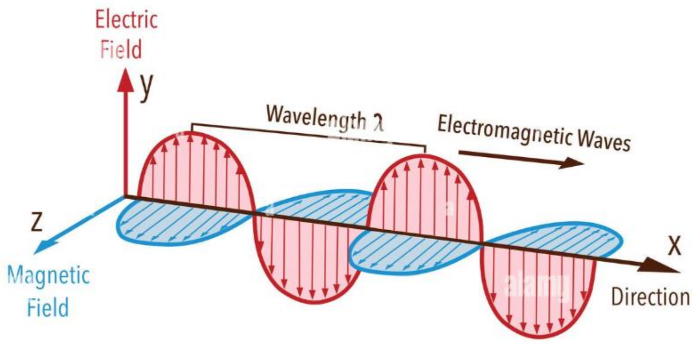
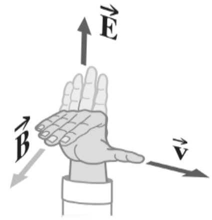
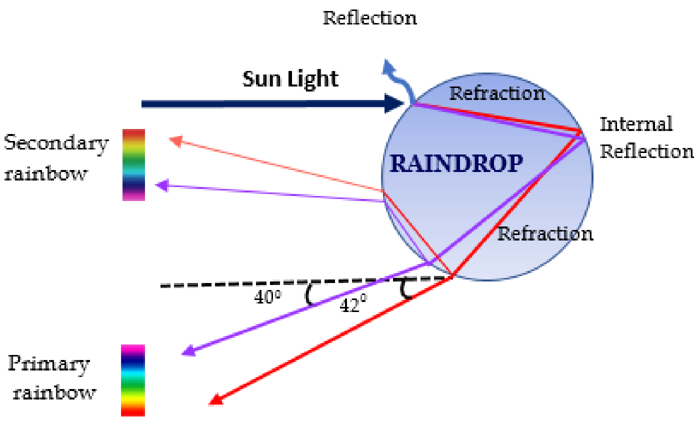
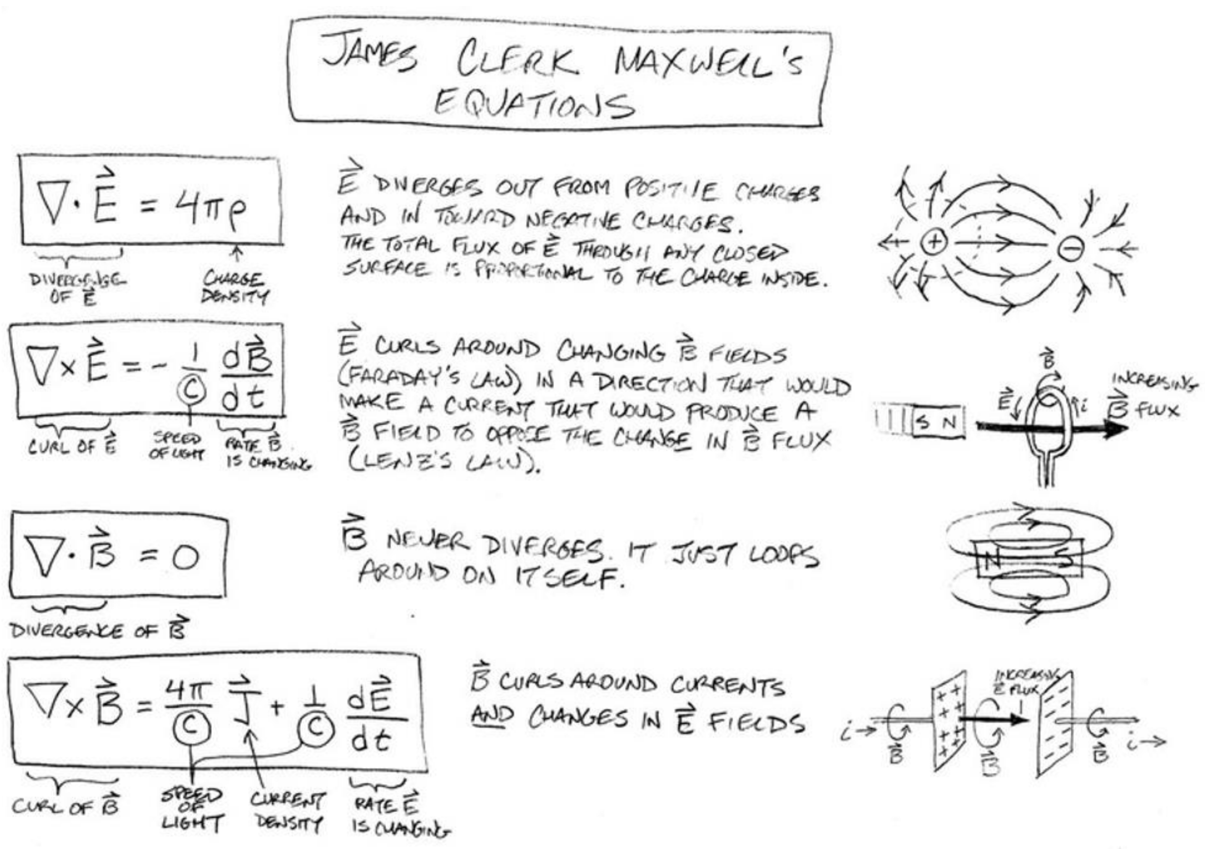
1. Electromagnetic rays







2. Maxwell's equations

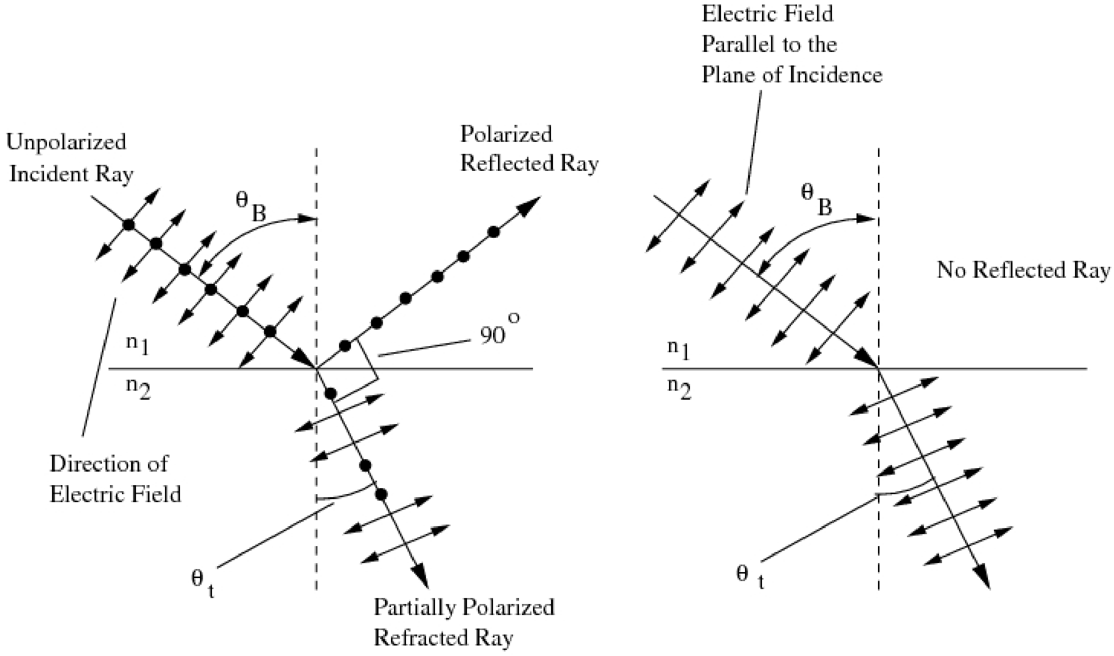


3. Brewster's angle (polarization angle)

- The reflected beam is perpendicular to the plane of incidence.
- The transmitted beam is strong light parallel to the plane of incidence and weak light perpendicular to the plane of incidence—it's partially polarized.

$$tan\theta_B = \frac{n_2}{n_1}$$

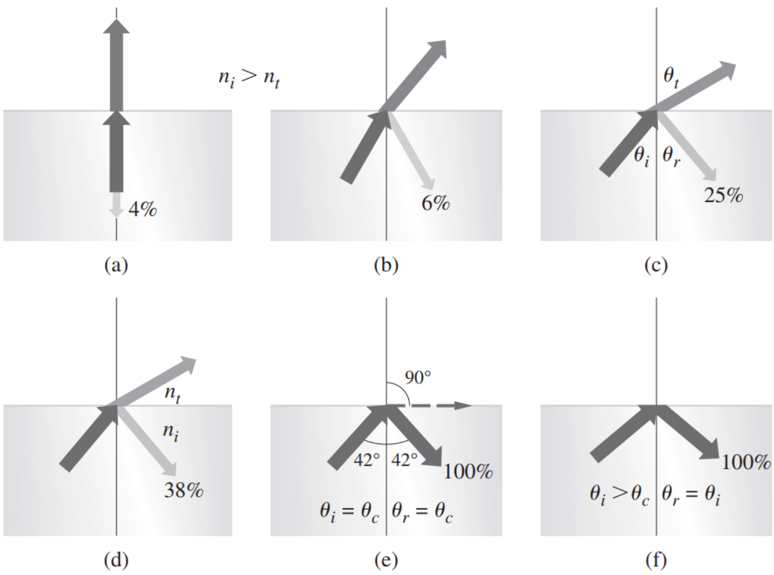
$$\theta_B + \theta_t = 90^0$$



4. Total internal reflection

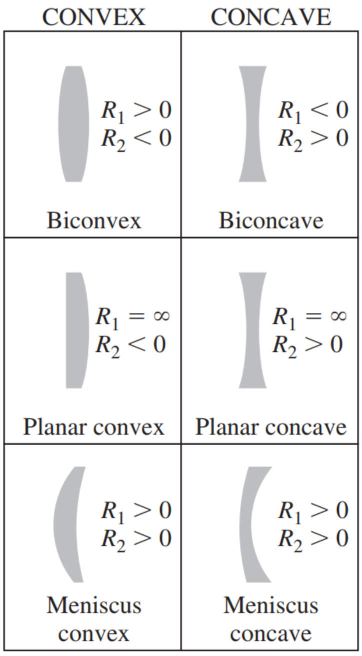
$$\sin\theta_i = \frac{n_t}{n_i}\sin\theta_t \text{ , when } \theta_t = 90°, \sin\theta_t = 1 \text{ , } \sin\theta_c = n_{ti}$$

- θ_c: Critical angle, when $\theta_i \geq \theta_c$: total internal reflection



5. Geometrical optics

Thin-lenses, imaging, imaging law:

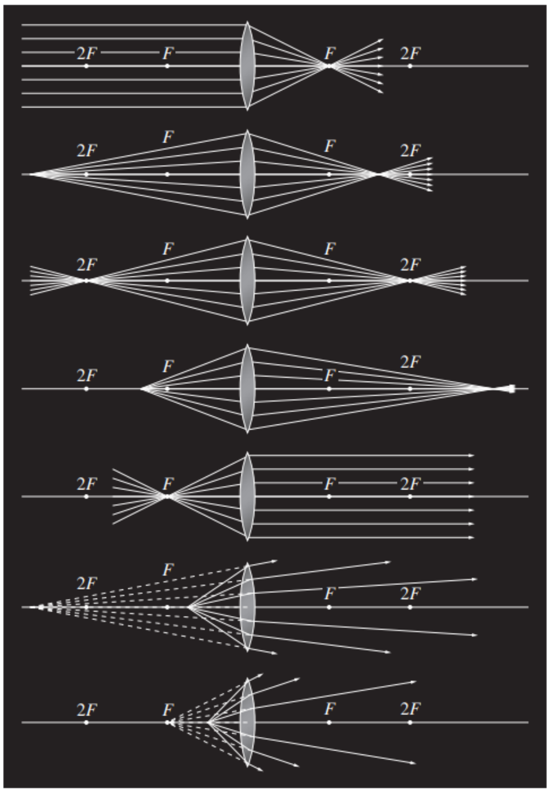


Convex (converging, or positive)

Concave (diverging, or negative)

Thin-lens equation (the surrounding medium to be air):

$$\frac{1}{s_o} + \frac{1}{s_i} = (n_l - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$



(Conjugate object and image points for a thin convex lens)

Focal points and planes:

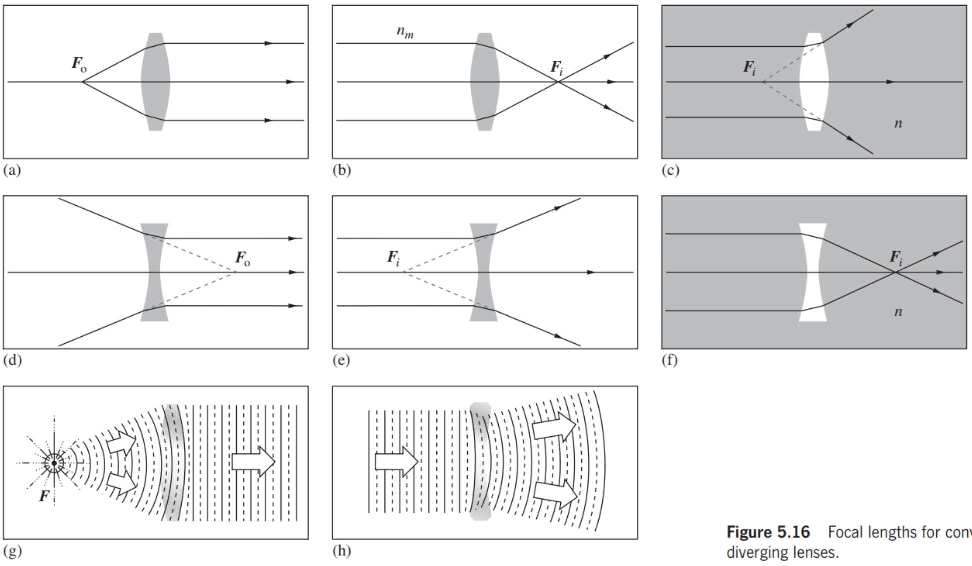


Figure 5.16 Focal lengths for converging and diverging lenses.

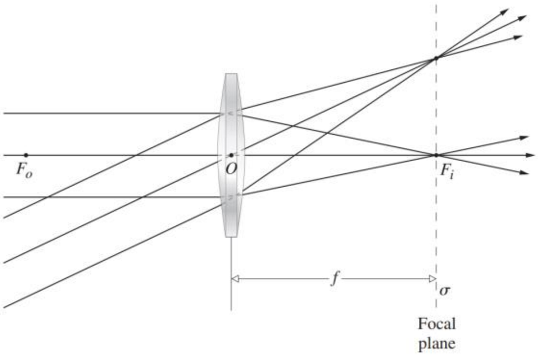
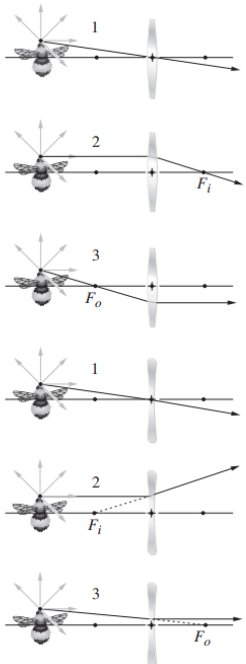


Figure 5.19 The focal plane of a lens.

Finite imagery:



Tracing a few key rays through a positive and negative lens.

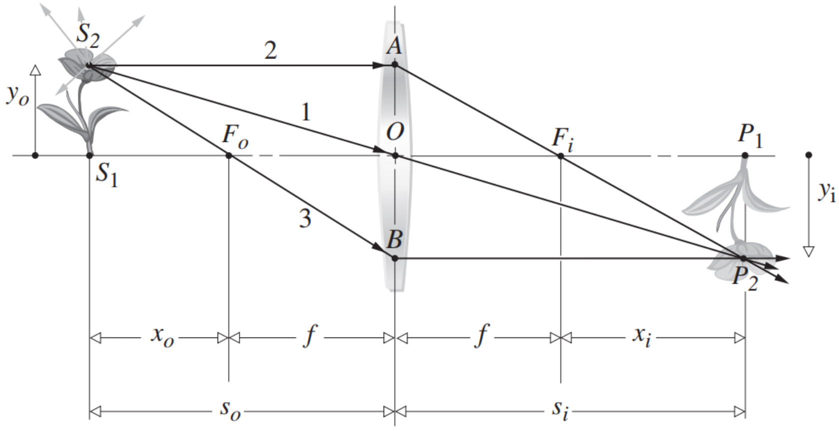


Figure 5.24 Object and image location for a thin lens.

Transverse magnification (M_T):

$$M_T \equiv \frac{y_i}{y_o} \qquad M_T = -\frac{s_i}{s_o}$$

TABLE 5.2 Meanings Associated with the Signs of Various Thin Lens and Spherical Interface Parameters

Quantity	Sign +	Sign −
s_o	Real object	Virtual object
s_i	Real image	Virtual image
f	Converging lens	Diverging lens
y_o	Erect object	Inverted object
y_i	Erect image	Inverted image
M_T	Erect image	Inverted image

TABLE 5.3 Images of Real Objects Formed by Thin Lenses

Convex

Object Location	Image Type	Image Location	Image Orientation	Image Relative Size
$\infty > s_o > 2f$	Real	$f < s_i < 2f$	Inverted	Minified
$s_o = 2f$	Real	$s_i = 2f$	Inverted	Same size
$f < s_o < 2f$	Real	$\infty > s_i > 2f$	Inverted	Magnified
$s_o = f$		$\pm\infty$		
$s_o < f$	Virtual	$\|s_i\| > s_o$	Erect	Magnified

Concave

Object Location	Image Type	Image Location	Image Orientation	Image Relative Size
Anywhere	Virtual	$\|s_i\| < \|f\|$, $s_o > \|s_i\|$	Erect	Minified

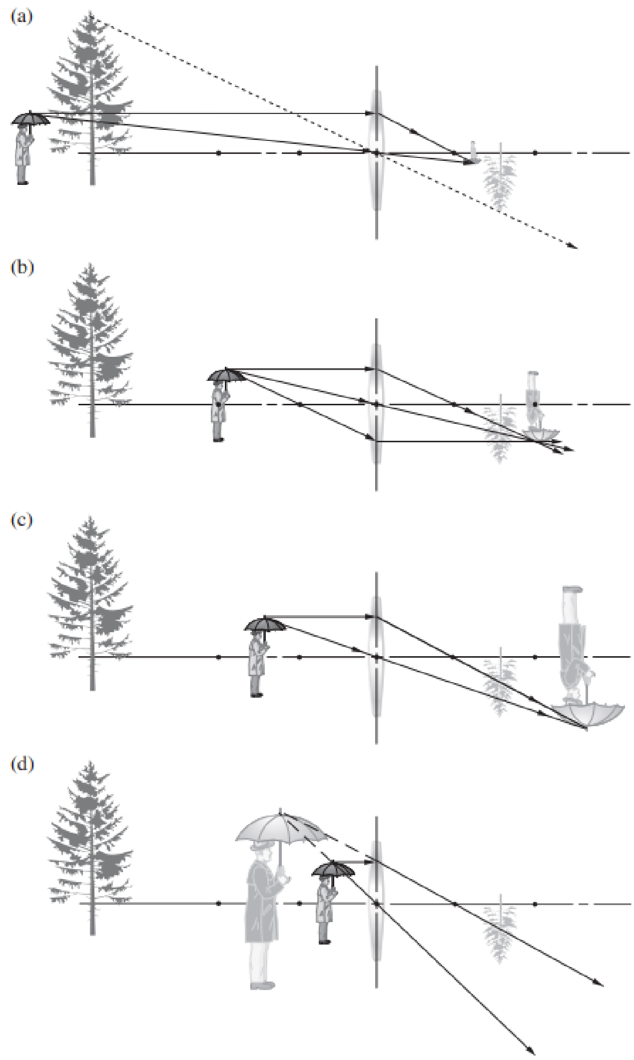


Figure 5.26 The image-forming behavior of a thin positive lens.

Virtual objects:

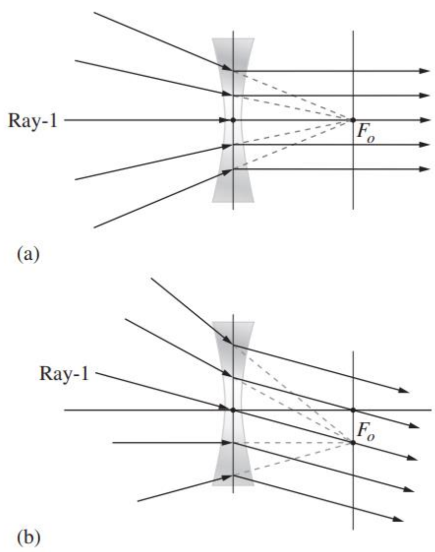


Figure 5.31 Virtual point objects for a negative lens (*a*) on and (*b*) off axis. When rays converge to the object, the object is virtual. That often happens in multi-lens systems.

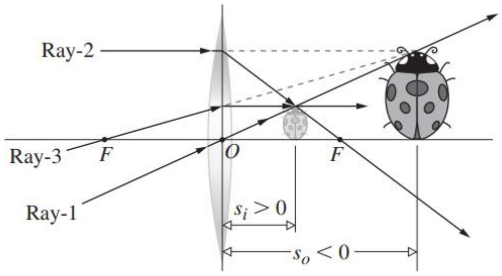


Figure 5.32 A virtual object (far right) and its real, upright image (just to the right of the lens). This can happen in a multi-lens system.

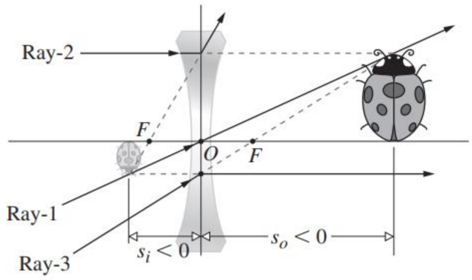


Figure 5.33 A virtual object (on the right) and its virtual, inverted image (on the left). This kind of situation can arise in a multi-lens system.

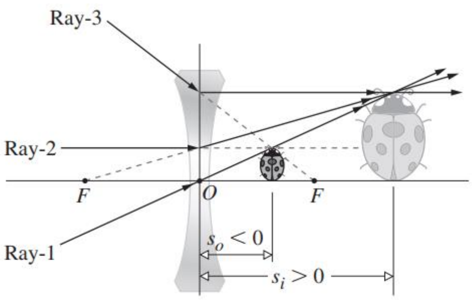


Figure 5.34 A virtual object (just to the right of the lens) and its real enlarged, upright image (far right). This can happen in a multi-lens system that causes the rays to initially converge.

Focal-plane ray tracing:

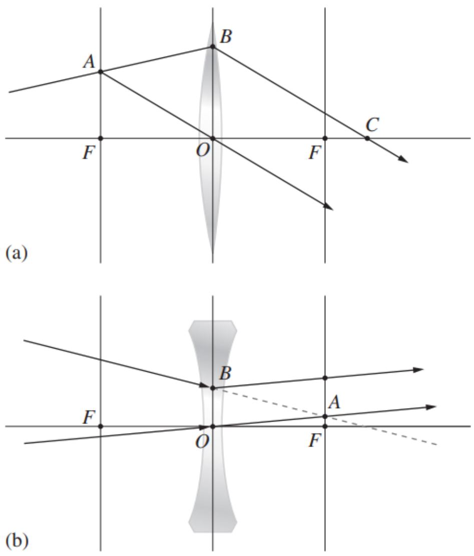


Figure 5.35 Focal-plane ray tracing. Reexamine Fig. 5.31*b*.

Simple optical instruments: magnifying glass, microscope, telescope:

Magnifying glass:

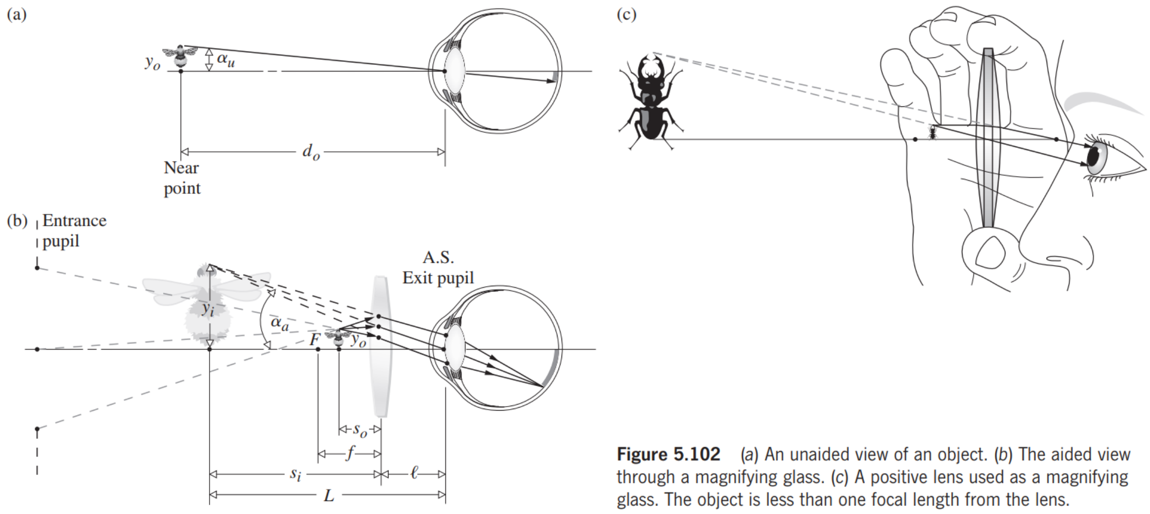


Figure 5.102 (*a*) An unaided view of an object. (*b*) The aided view through a magnifying glass. (*c*) A positive lens used as a magnifying glass. The object is less than one focal length from the lens.

Magnifying power (MP):

$$\mathrm{MP} = \frac{\alpha_a}{\alpha_u}$$

$$\mathrm{MP} = \frac{d_o}{L}[1 + \mathfrak{D}(L - \ell)]$$

$\mathfrak{D}$ of course being the power of the magnifier $(1/f)$

Microscope:

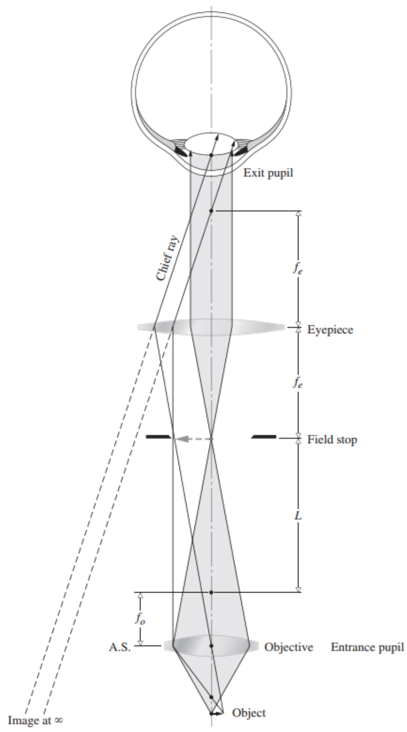


Figure 5.110 A rudimentary compound microscope. The objective forms a real image of a nearby object. The eyepiece, functioning like a magnifying glass, enlarges this intermediate image. The final virtual image can be bigger than the barrel of the device, since it needn't fit inside. With parallel rays entering the eye it can remain comfortably relaxed.

Thus the magnifying power of the entire system is the product of the transverse linear magnification of the objective, M_{To}, and the angular magnification of the eyepiece, M_{Ae}, that is,

$$\mathrm{MP} = M_{To} M_{Ae} \tag{5.80}$$

Telescope:

- Refracting telescopes

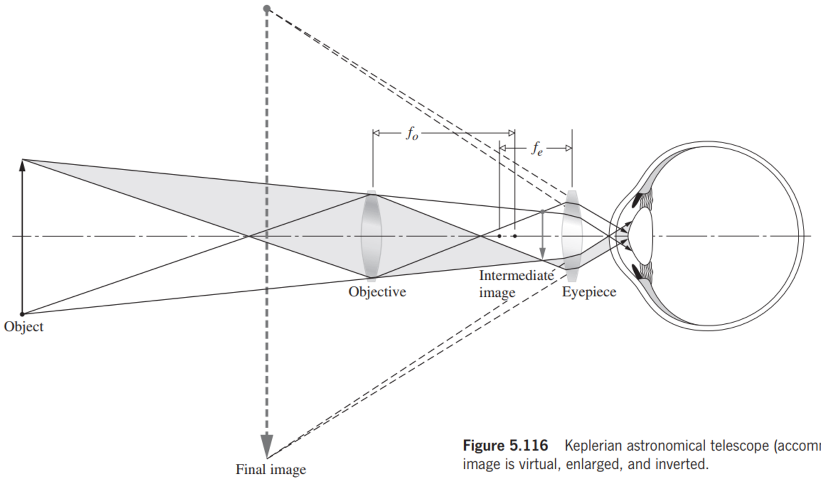


Figure 5.116 Keplerian astronomical telescope (accommodating eye). The final image is virtual, enlarged, and inverted.

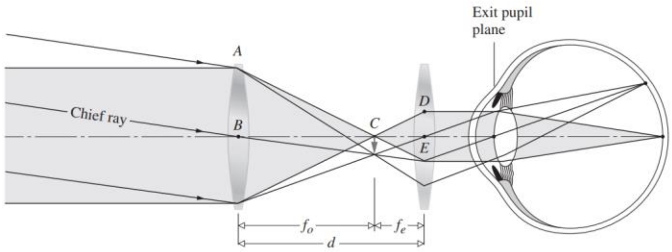


Figure 5.117 Astronomical telescope—infinite conjugates. The viewer's eye is relaxed.

- Reflecting telescopes

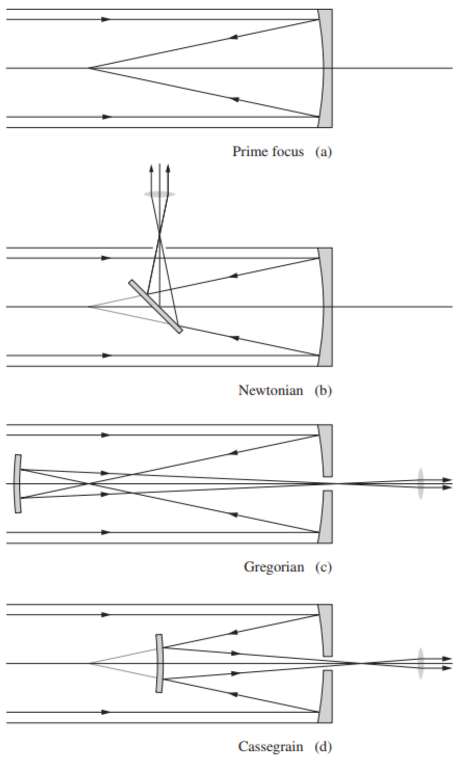


Figure 5.122 Reflecting telescopes.

6. Lasers

Stimulated emission:

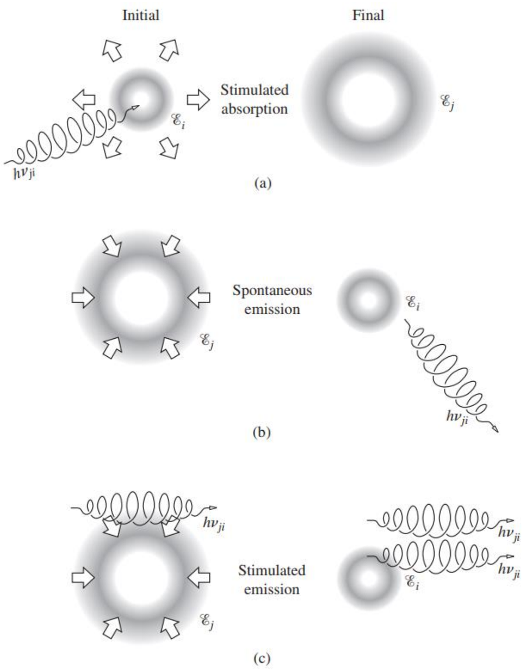


Figure 13.5 A schematic representation of (*a*) stimulated absorption, (*b*) spontaneous emission, and (*c*) stimulated emission.

The laser:

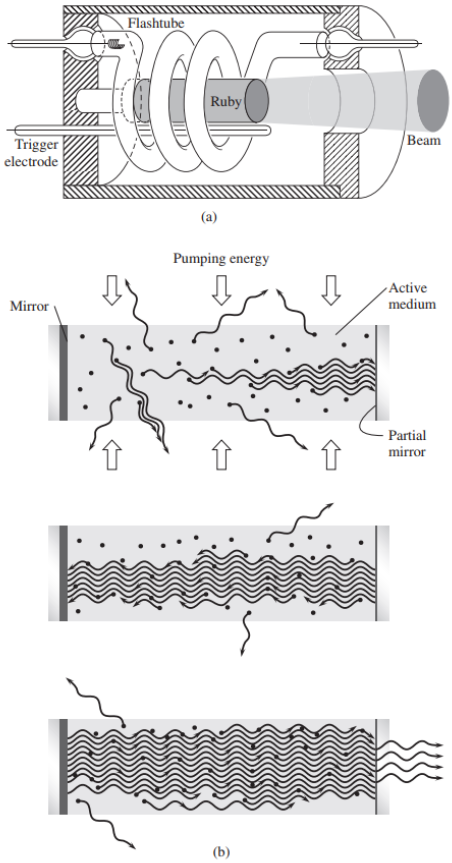


Figure 13.7 The first ruby-laser configuration, just about life-sized.

(resonant cavity)

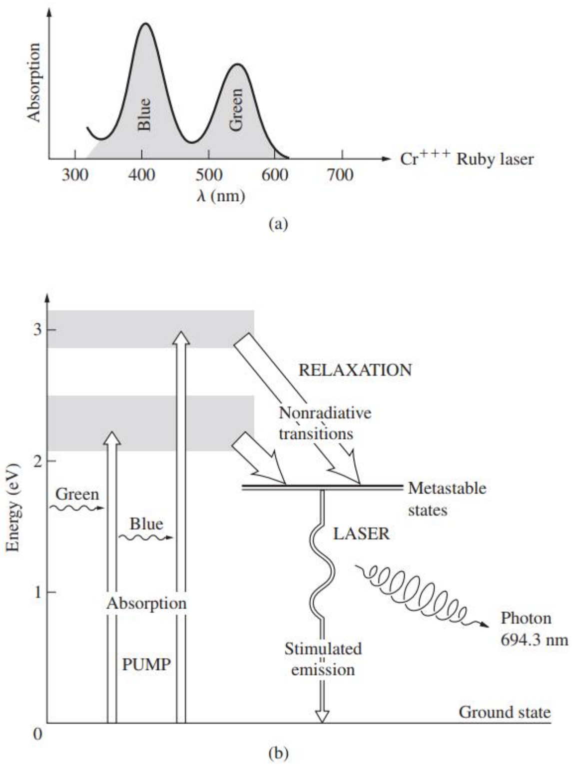
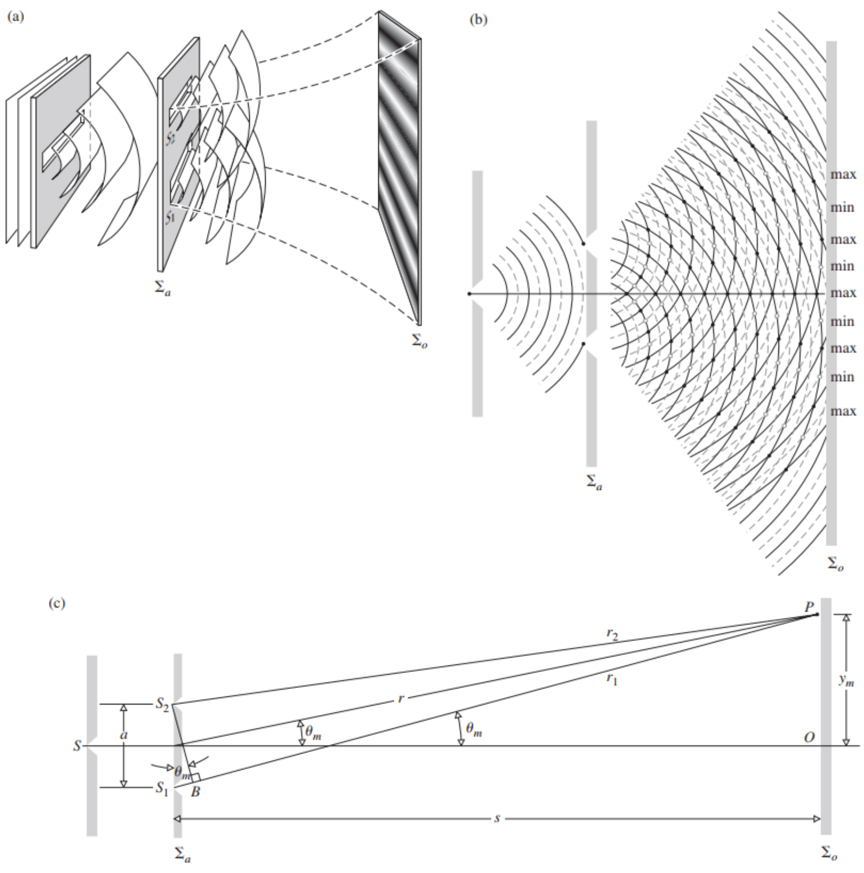


Figure 13.8 Ruby-laser energy levels.

7. Interference, two-beam interference

Double-slit experiment:



Young's experiment.

Standing wave: Two harmonic waves of the same frequency propagating in opposite directions.

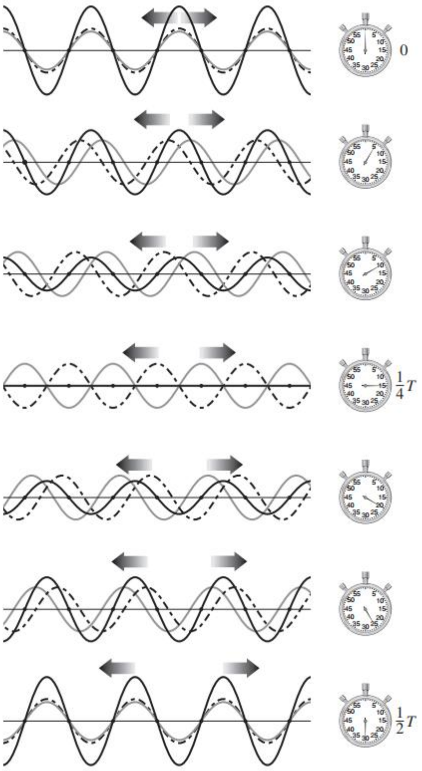


Figure 7.10 The creation of standing waves. Two waves of the same amplitude and wavelength traveling in opposite directions form a stationary disturbance that oscillates in place.

$$E(x, t) = 2E_0 \sin kx \cos \omega t$$

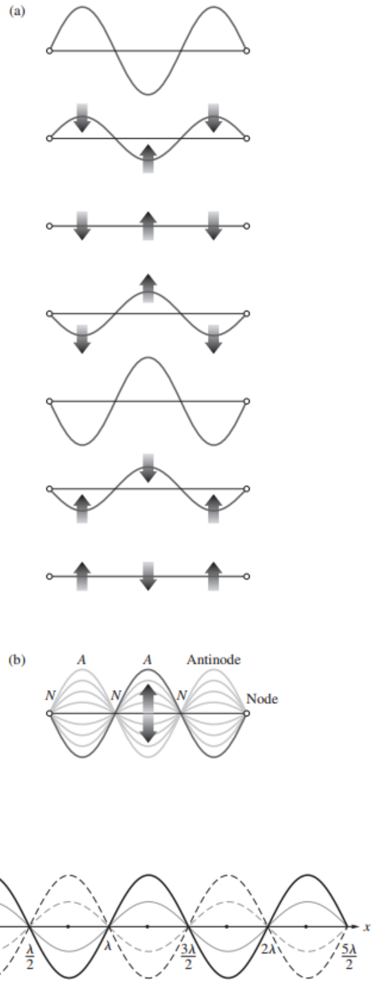
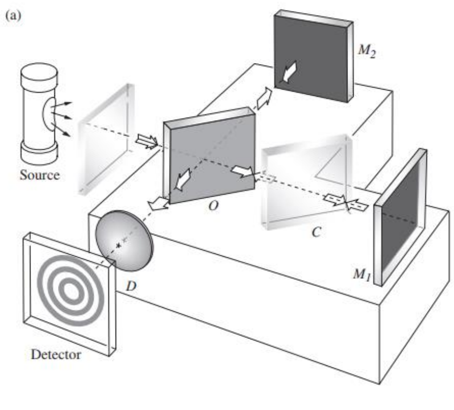


Figure 7.11 A standing wave at various times.

Michelson interferometer:



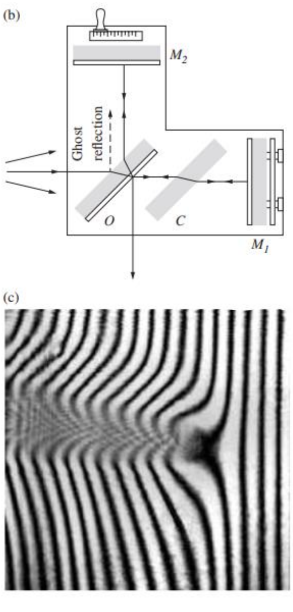


Figure 9.36 The Michelson Interferometer. (a) Circular fringes are centered on the lens. (b) Top view of the interferometer showing the path of the light. (c) A wedge fringe pattern was distorted when the tip of a hot soldering iron was placed in one arm. Observe the interesting perceptual phenomenon whereby the region corresponding to the iron's tip appears faintly yellow. (E.H.)

Mach–Zehnder interferometer:

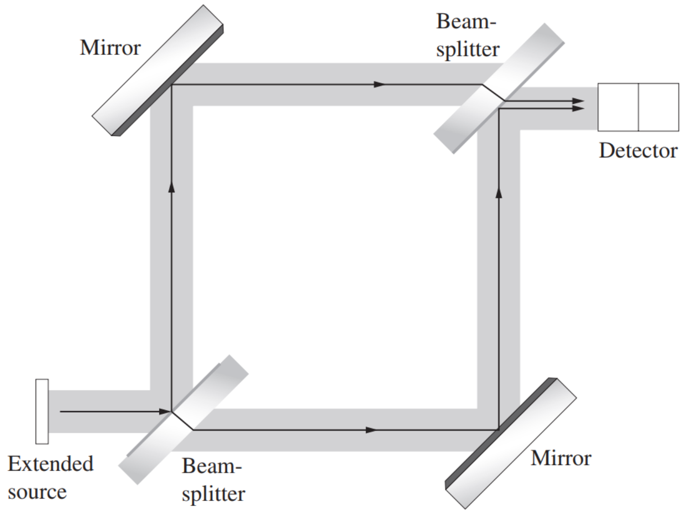


Figure 9.40 The Mach–Zehnder Interferometer.

Sagnac interferometer:

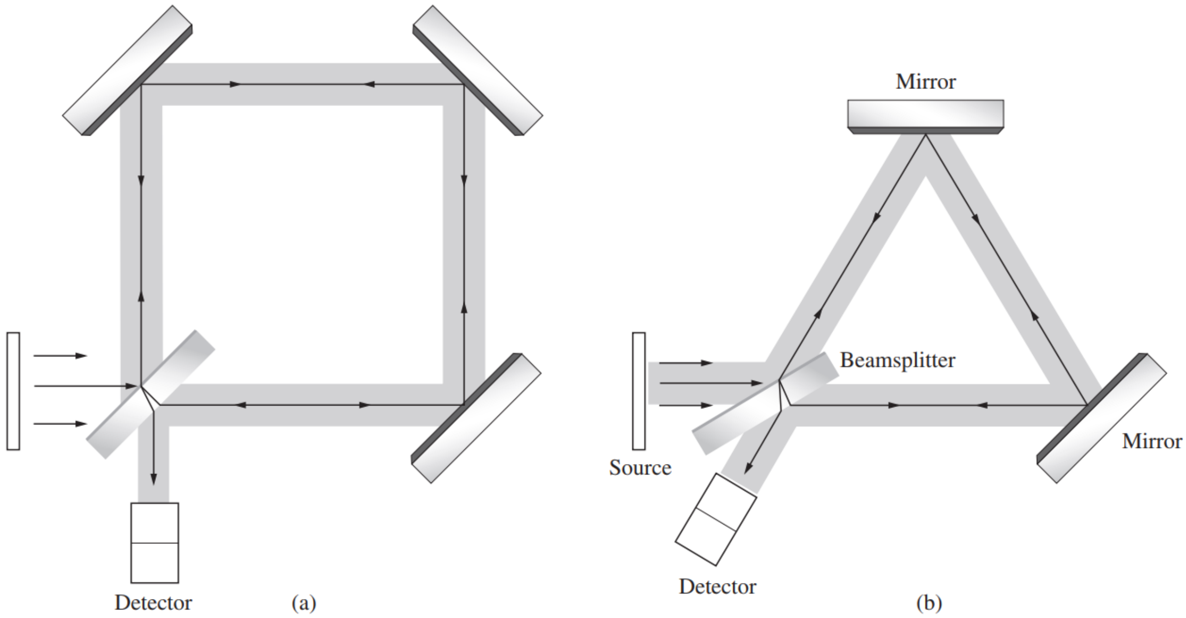


Figure 9.42 (*a*) A Sagnac Interferometer. (*b*) Another variation of the Sagnac Interferometer.