Chapter 34

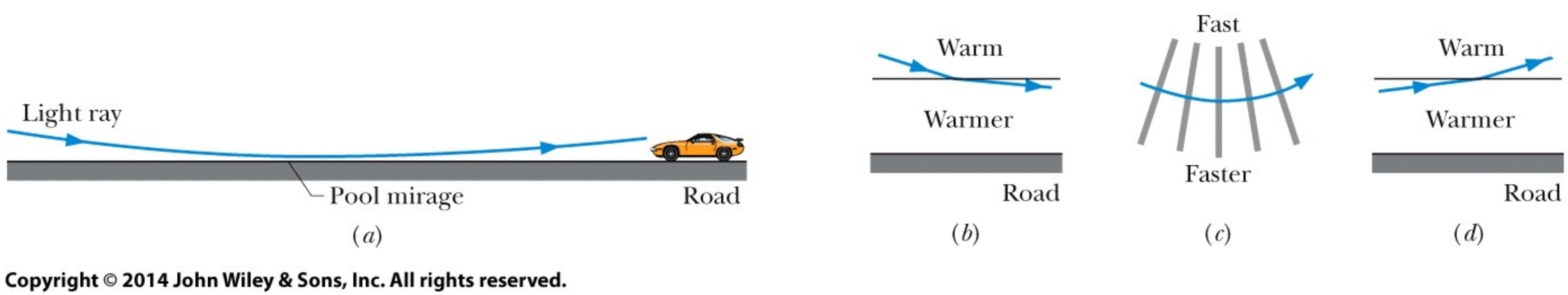
Images

WILEY

34-1 Images and Plane Mirrors

An image is a reproduction of an object via light. If the image can form on a surface, it is a real image and can exist even if no observer is present. If the image requires the visual system of an observer, it is a virtual image.

Here are some common examples of virtual image.



(a) A ray from a low section of the sky refracts through air that is heated by a road (without reaching the road). An observer who intercepts the light perceives it to be from a pool of water on the road. (b) Bending (exaggerated) of a light ray descending across an imaginary boundary from warm air to warmer air. (c) Shifting of wavefronts and associated bending of a ray, which occur because the lower ends of wavefronts move faster in warmer air. (d) Bending of a ray ascending across an imaginary boundary to warm air from warmer air.

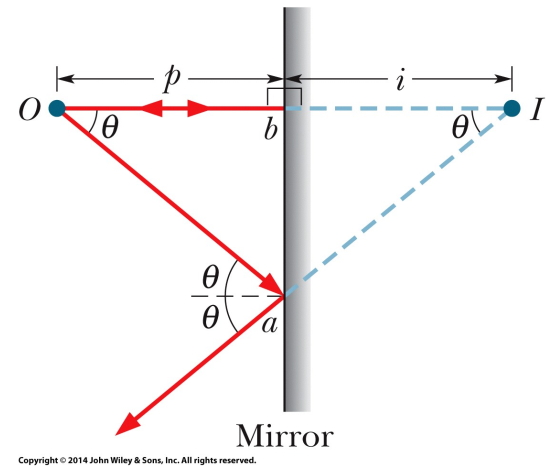
34-1 Images and Plane Mirrors

As shown in figure (a), a plane (flat) mirror can form a virtual image of a light source (said to be the object, O) by redirecting light rays emerging from the source. The image can be seen where backward extensions of reflected rays pass through one another. The object's distance *p* from the mirror is related to the (apparent) image distance *i* from the mirror by

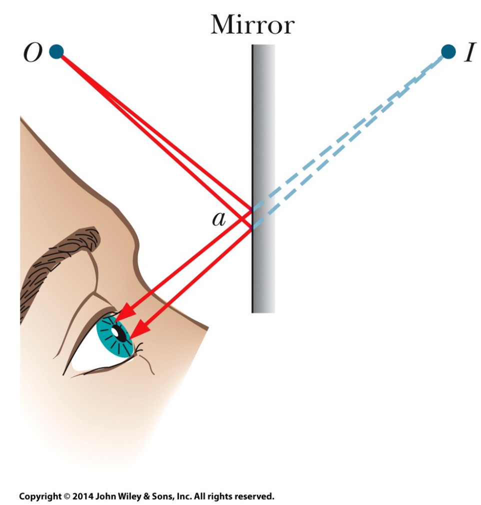
$$i = -p$$

Object distance *p* is a positive quantity. Image distance *i* for a virtual image is a negative quantity.

Only rays that are fairly close together can enter the eye after reflection at a mirror. For the eye position shown in Fig. (b), only a small portion of the mirror near point *a* (a portion smaller than the pupil of the eye) is useful in forming the image.



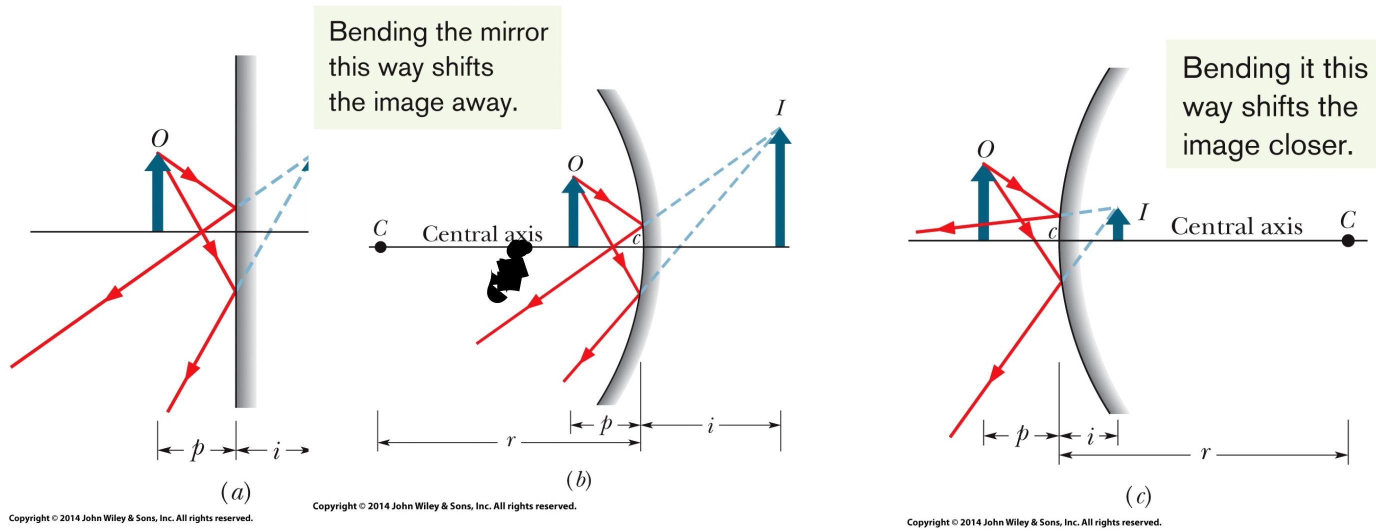
(a)



(b)

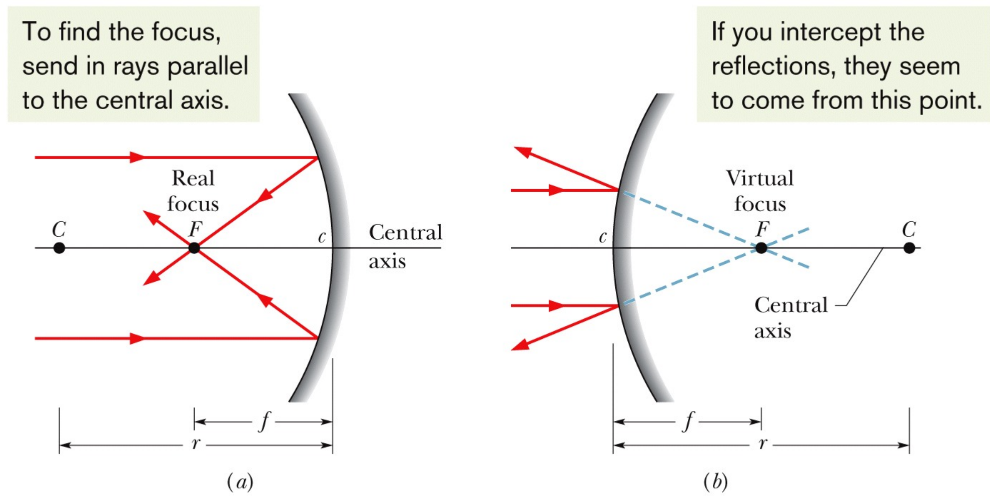
34-2 Spherical Mirrors

A spherical mirror is in the shape of a small section of a spherical surface and can be **concave** (the radius of curvature *r* is a positive quantity), **convex** (*r* is a negative quantity), or **plane** (flat, *r* is infinite).



We make a **concave mirror** by curving the mirror's surface so it is concave ("caved in" to the object) as in Fig. (b). We can make a **convex mirror** by curving a plane mirror so its surface is convex ("flexed out") as in Fig.(c). Curving the surface in this way (1) moves the *center of curvature C* to behind the mirror and (2) increases the field of view. It also (3) moves the image of the object closer to the mirror and (4) shrinks it. These iterated characteristics are the exact opposite for concave mirror.

34-2 Spherical Mirrors

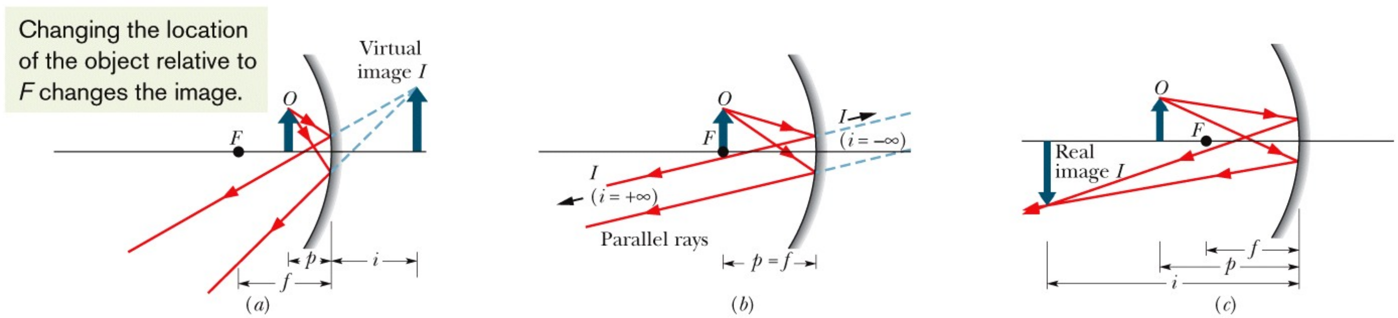


If parallel rays are sent into a (spherical) concave mirror parallel to the central axis, the reflected rays pass through a common point (a real focus *F*) at a distance *f* (a positive quantity) from the mirror (figure a). If they are sent toward a (spherical) convex mirror, backward extensions of the reflected rays pass through a common point (a virtual focus *F*) at a distance f (a negative quantity) from the mirror (figure b).
For mirrors of both types, the focal length *f* is related to the radius of curvature *r* of the mirror by

$$f = \frac{1}{2}r$$

where *r (*and *f)* is positiv ve mirror and negative for a convex mirror.

34-2 Spherical Mirrors



(a) An object O inside the focal point of a concave mirror, and its virtual image I. (b) The object at the focal point F. (c) The object outside the focal point, and its real image I.

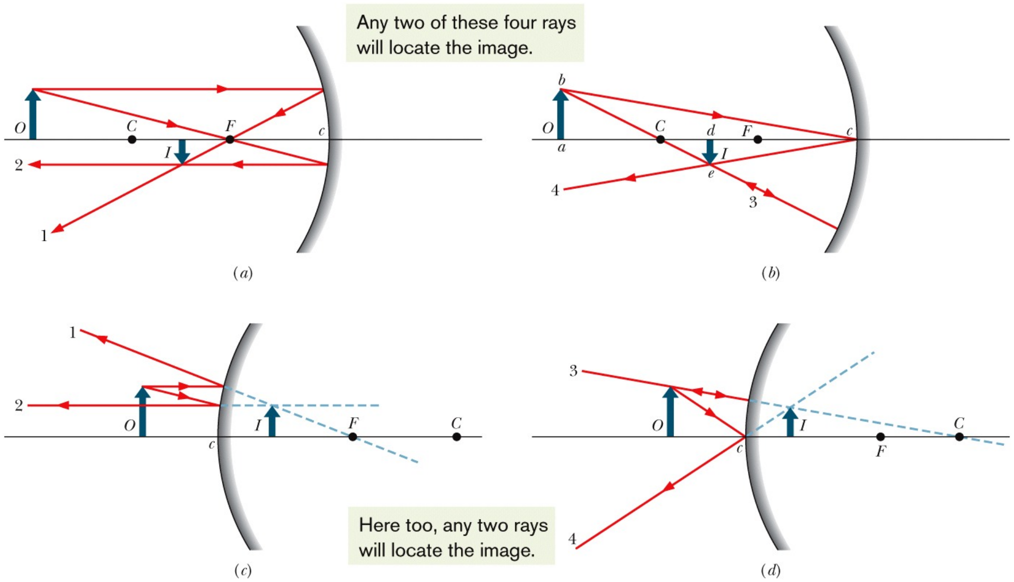
- A concave mirror can form a real image (if the object is outside the focal point) or a virtual image (if the object is inside the focal point).
- A convex mirror can form only a virtual image.
- The mirror equation relates an object distance *p*, the mirror's focal length *f* and radius of curvature *r*, and the image distance *i*:

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f}$$

- The magnitude of the lateral magnification m of an object is the ratio of the image height h' to object height h,

$$|m| = \frac{h'}{h} \quad \Rightarrow \quad m = -\frac{i}{p}$$

34-2 Spherical Mirrors



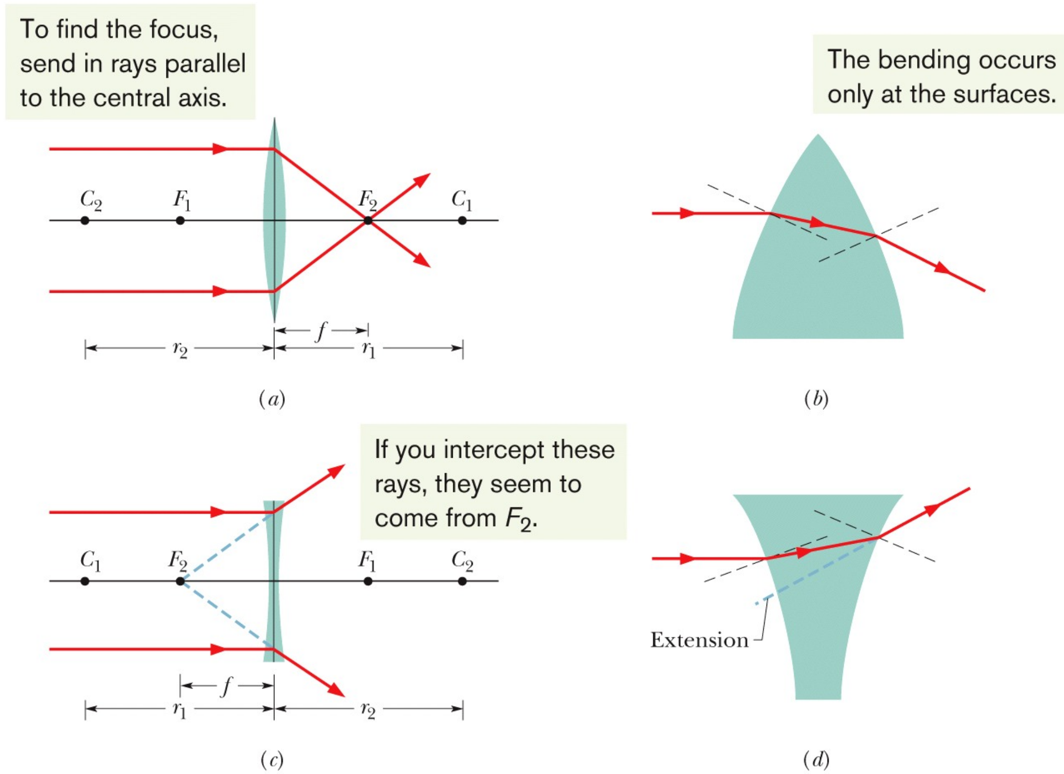
Locating Images by Drawing Rays

1. A ray that is initially parallel to the central axis reflects through the focal point *F* (ray 1 in Fig. a).
2. A ray that reflects from the mirror after passing through the focal point emerges parallel to the central axis (Fig. a).
3. A ray that reflects from the mirror after passing through the center of curvature *C* returns along itself (ray 3 in Fig. b).
4. A ray that reflects from the mirror at point *c* is reflected symmetrically about that axis (ray 4 in Fig. b).

The image of the point is at the intersection of the two special rays you choose. The image of the object can then be found by locating the images of two or more of its off-axis points (say, the point most off axis) and then sketching in the rest of the image. You need to modify the descriptions of the rays slightly to apply them to convex mirrors, as in Figs. c and d.

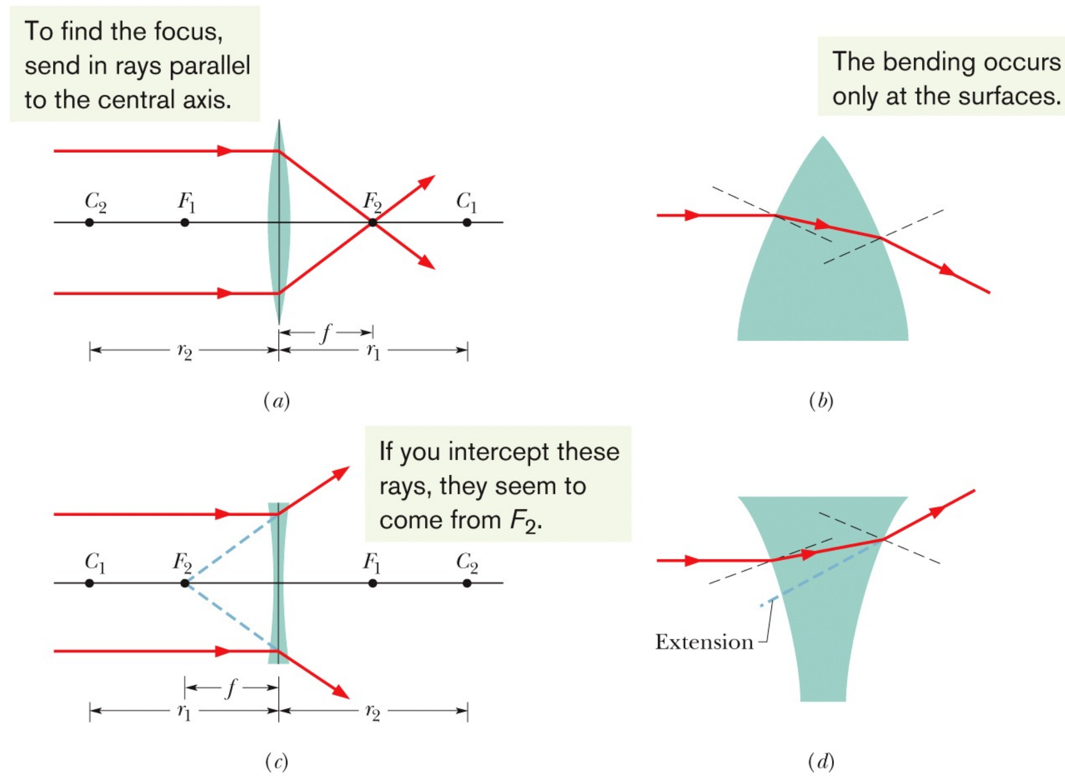
34-4 Thin Lenses

Forming a Focus. Figure (a) shows a thin lens with convex refracting surfaces, or sides. When rays that are parallel to the central axis of the lens are sent through the lens, they refract twice, as is shown enlarged in Fig.(b). This double refraction causes the rays to converge and pass through a common point F_2 at a distance f from the center of the lens. Hence, this lens is a converging lens; further, a real focal point (or focus) exists at F_2 (because the rays really do pass through it), and the associated focal length is f. When rays parallel to the central axis are sent in the opposite direction through the lens, we find another real focal point at F_1 on the other side of the lens. For a thin lens, these two focal points are equidistant from the lens.



34-4 Thin Lenses

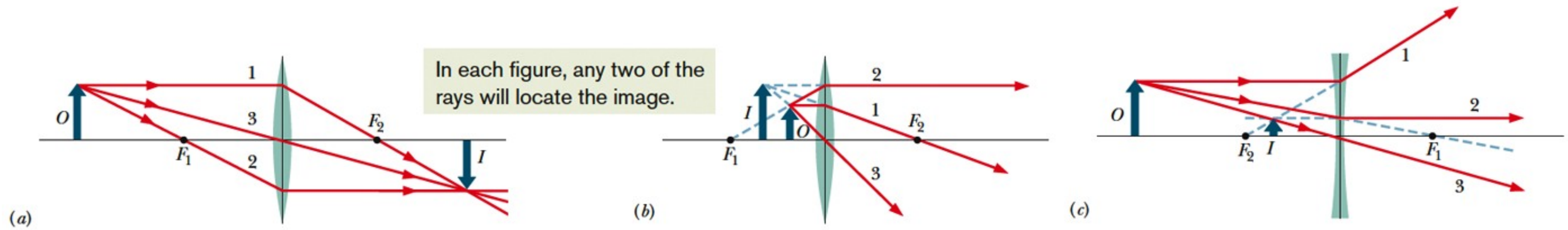
Forming a Focus. Figure (c) shows a thin lens with concave sides. When rays that are parallel to the central axis of the lens are sent through this lens, they refract twice, as is shown enlarged in Fig. (d); these rays diverge, never passing through any common point, and so this lens is a diverging lens. However, extensions of the rays do pass through a common point F_2 at a distance f from the center of the lens. Hence, the lens has a virtual focal point at F_2. (If your eye



intercepts some of the diverging rays, you perceive a bright spot to be at F_2, as if it is the source of the light.) Another virtual focus exists on the opposite side of the lens at F_1, symmetrically placed if the lens is thin. Because the focal points of a diverging lens are virtual, we take the focal length f to be negative.

34-4 Thin Lenses

Locating Images of Extended Objects by Drawing Rays



1. A ray that is initially parallel to the central axis of the lens will pass through focal point F_2 (ray 1 in Fig. a).
2. A ray that initially passes through focal point F_1 will emerge from the lens parallel to the central axis (ray 2 in Fig. a).
3. A ray that is initially directed toward the center of the lens will emerge from the lens with no change in its direction (ray 3 in Fig. a) because the ray encounters the two sides of the lens where they are almost parallel.

Figure b shows how the extensions of the three special rays can be used to locate the image of an object placed inside focal point F_1 of a converging lens. Note that the description of ray 2 requires modification (it is now a ray whose backward extension passes through F_1).You need to modify the descriptions of rays 1 and 2 to use them to locate an image placed (anywhere) in front of a diverging lens. In Fig. c, for example, we find the point where ray 3 intersects the backward extensions of rays 1 and 2.

Chapter 35

Interference

35-1 Light as a Wave

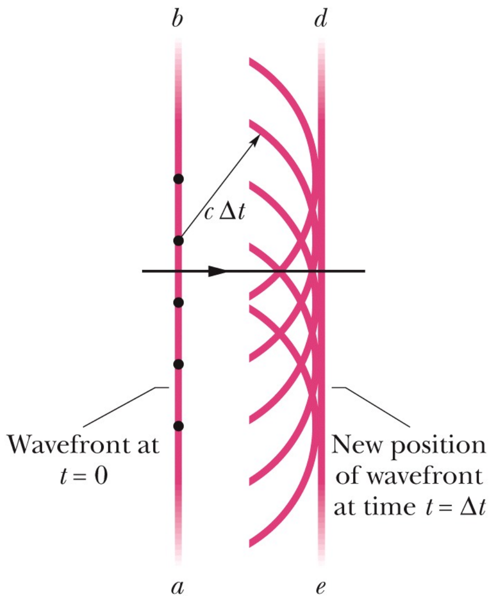
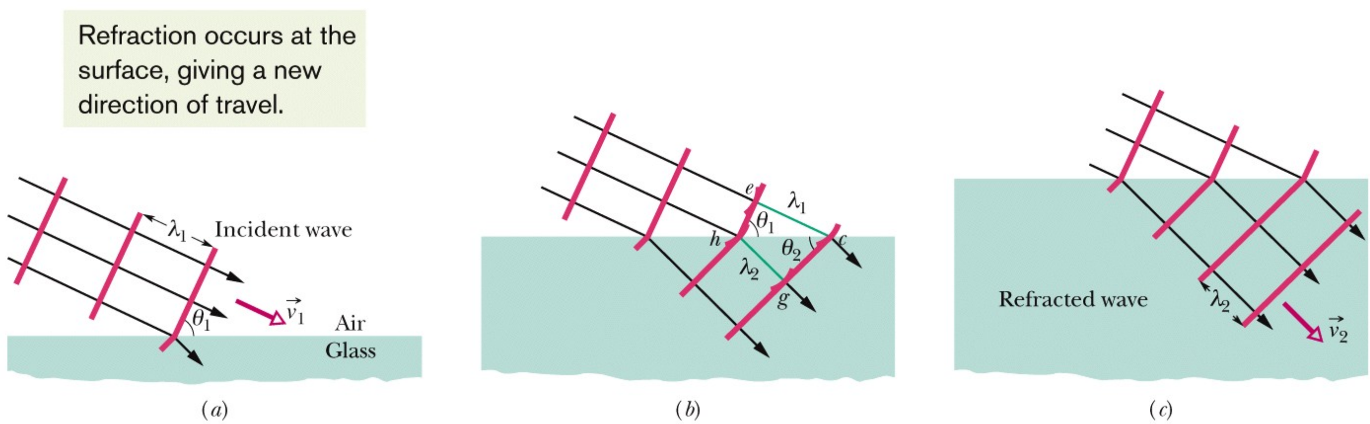


Figure 1

The three-dimensional transmission of waves, including light, may often be predicted by Huygens' principle, which states that

> All points on a wavefront serve as point sources of spherical secondary wavelets. After a time t, the new position of the wavefront will be that of a surface tangent to these secondary wavelets.

Figure 1 shows the propagation of a plane wave in vacuum, as portrayed by Huygens' principle.

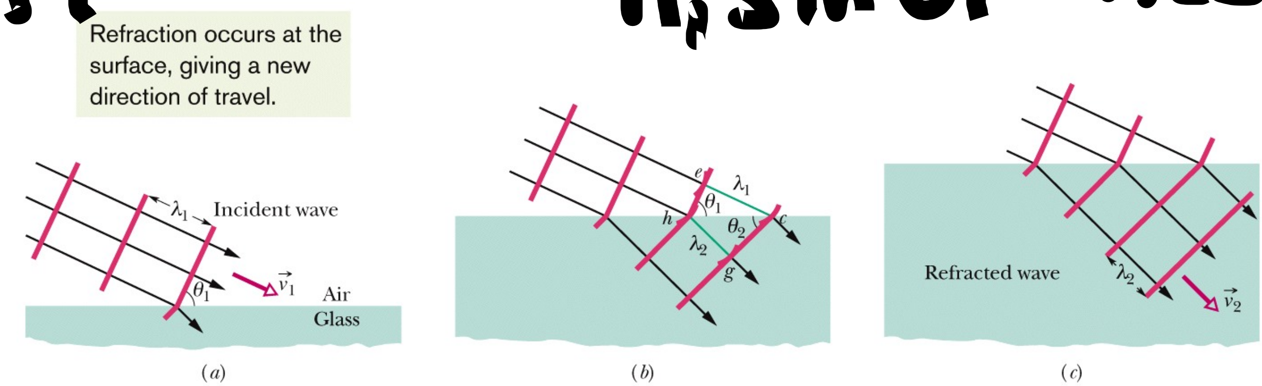


The refraction of a plane wave at an air–glass interface, as portrayed by Huygens' principle. The wavelength in glass is smaller than that in air. For simplicity, the reflected wave is not shown. Parts (a) through (c) represent three successive stages of the refraction.

$v = \frac{c}{n}$

35-1 Light as a Wave

$n_1 \sin\theta_1 = n_2 \sin\theta_2$



The refraction of a plane wave at an air – glass interface, as portrayed by Huygens' principle. The wavelength in glass is smaller than that in air. For simplicity, the reflected wave is not shown. Parts (a) through (c) represent three successive stages of the refraction.

The law of refraction can be derived from Huygens' principle by assuming that the index of refraction of any medium is

$$n = c/v,$$

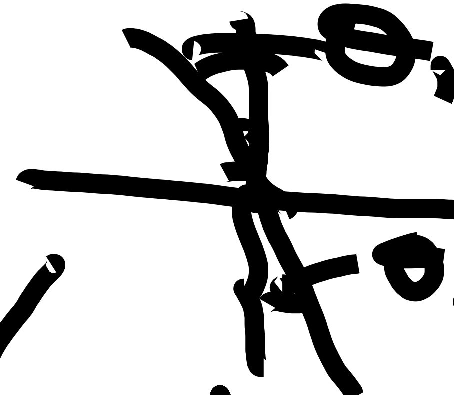
in which v is the speed of light in the medium and c is the speed of light in vacuum.

The wavelength λ_n of light in a medium depends on the index of refraction n of the medium:

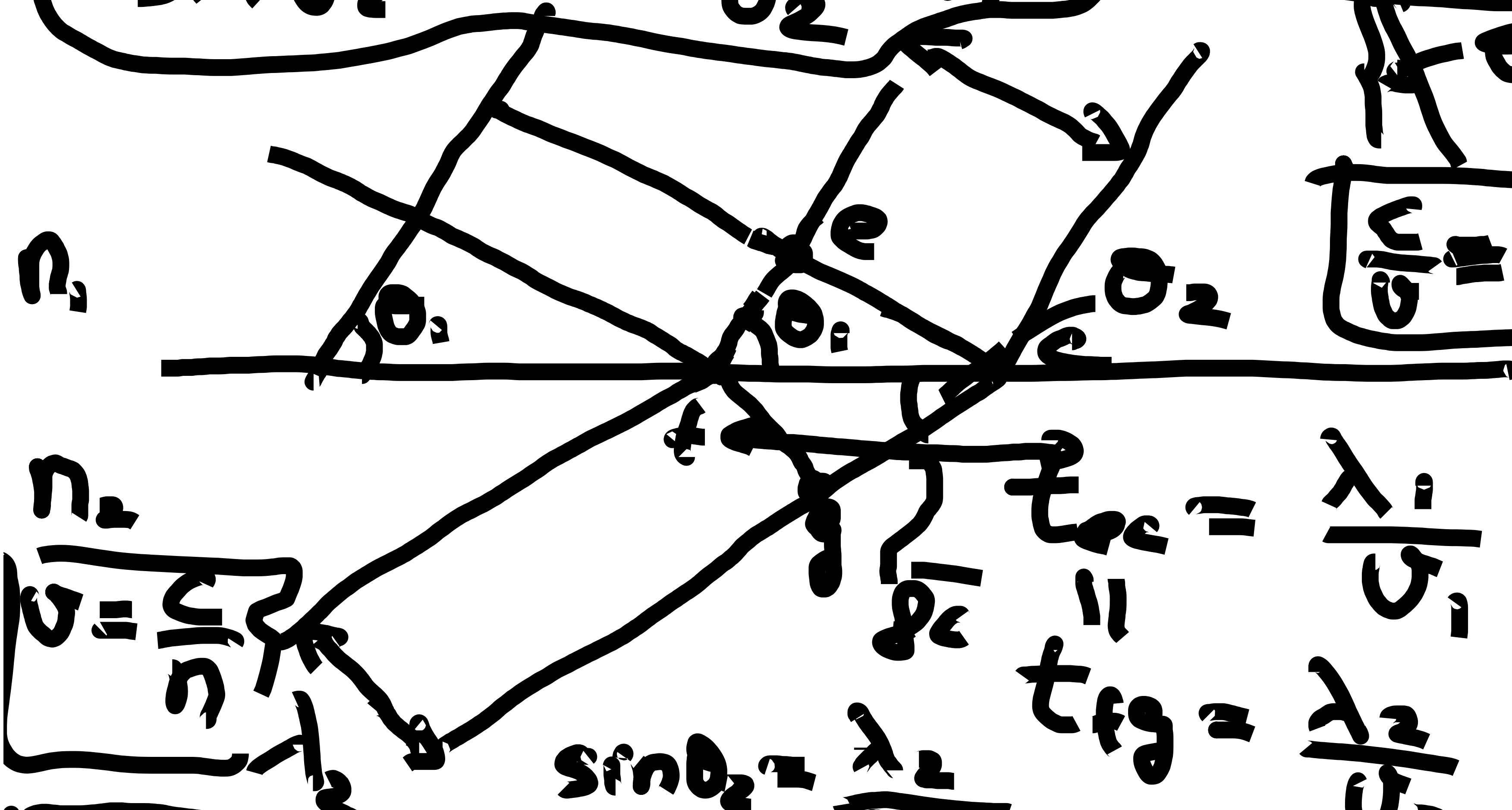
$$\lambda_n = \frac{\lambda}{n},$$ where λ is the wavelength of vacuum.

Because of this dependency, the ph nce between two waves can change if they pass through different materials with different indexes of refraction.

$$\boxed{\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}}$$



$$\boxed{\frac{c}{v} = n}$$



$$\boxed{v = \frac{c}{n}}$$

$$t_{ec} = \frac{\lambda_1}{v_1}$$

$$\parallel$$

$$t_{fg} = \frac{\lambda_2}{v_2}$$

$$\sin\theta_2 = \frac{\lambda_2}{fc}$$

$$\sin\theta_1 = \frac{\lambda_1}{fc}$$

$$v = \lambda f$$

$$\boxed{\frac{\lambda_1}{v_1} = \frac{\lambda_2}{v_2}}$$

$$\frac{\lambda_1}{v_1} = \frac{\lambda_2}{v_2}$$

vacuum

$$\boxed{v = \lambda f}$$

$v_1 = c$

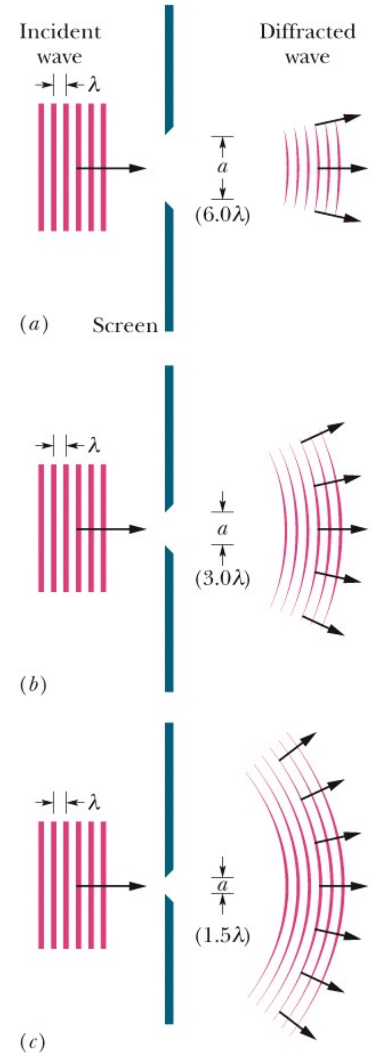
f stays same

$$\lambda_2 = \frac{v}{c}\lambda$$

$$\lambda_n = \frac{v_n}{c}\lambda = \frac{\lambda}{n}$$

35-2 Young's Interference

The flaring is consistent with the spreading of wavelets in the Huygens construction. **Diffraction** occurs for waves of all types, not just light waves. Figure below shows waves passing through a slit flares.

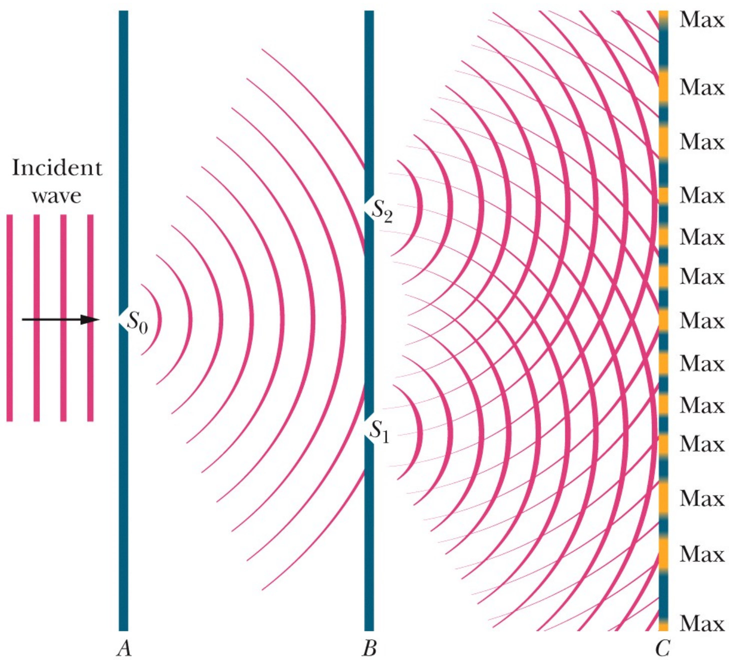


A wave passing through a slit flares (diffracts).

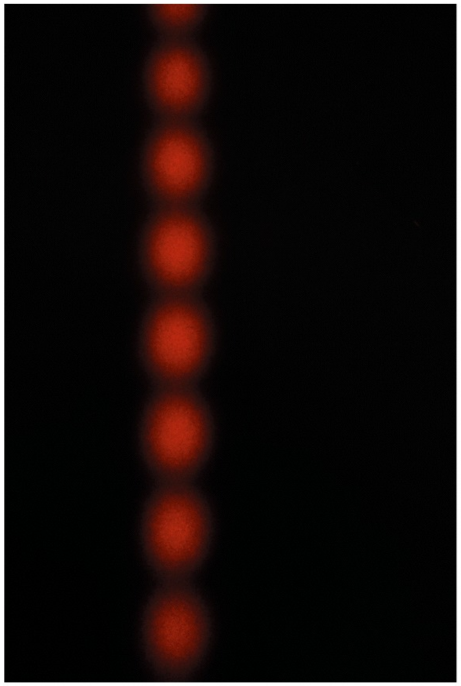
Figure (a) shows the situation schematically for an incident plane wave of wavelength λ encountering a slit that has width $a = 6.0\,\lambda$ and extends into and out of the page. The part of the wave that passes through the slit flares out on the far side. Figures (b) (with a = 3.0 λ) and (c) (a = 1.5λ) illustrate the main feature of diffraction: the narrower the slit, the greater the diffraction.

35-2 Young's Interference

Figure gives the basic arrangement of Young's experiment. Light from a distant monochromatic source illuminates slit S_0 in screen A. The emerging light then spreads via diffraction to illuminate two slits S_1 and S_2 in screen B. Diffraction of the light by these two slits sends overlapping circular waves into the region beyond screen B, where the waves from one slit interfere with the waves from the other slit.

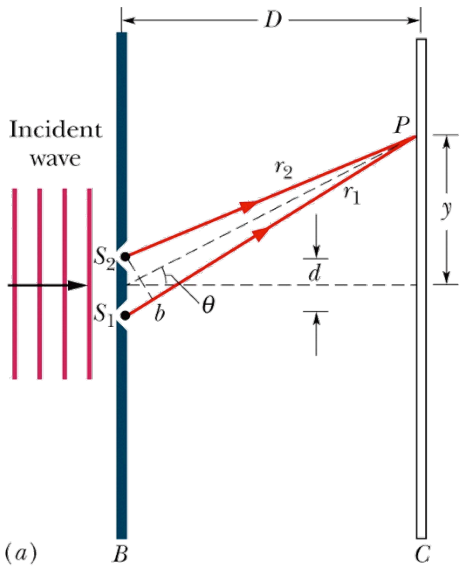


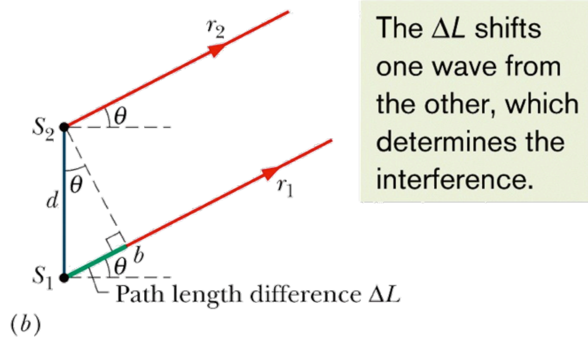
A photograph of the interference pattern produced by the arrangement shown in the figure(right), but with short slits. (The photograph is a front view of part of screen C of figure on left.) The alternating maxima and minima are called interference fringes (because they resemble the decorative fringe sometimes used on clothing and rugs).



Courtesy Jearl Walker

35-2 Young's Interference





(a) Waves from slits S_1 and S_2 (which extend into and out of the page) combine at P, an arbitrary point on screen C at distance *y* from the central axis. The angle ϑ serves as a convenient locator for *P*.

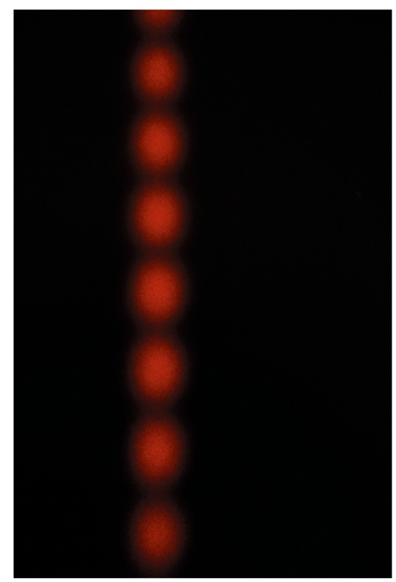
(b) For D >> d, we can approximate rays r_1 and r_2 as being parallel, at angle ϑ to the central axis.

> The phase difference between two waves can change if the waves travel paths of different lengths.

The conditions for maximum and minimum intensity are

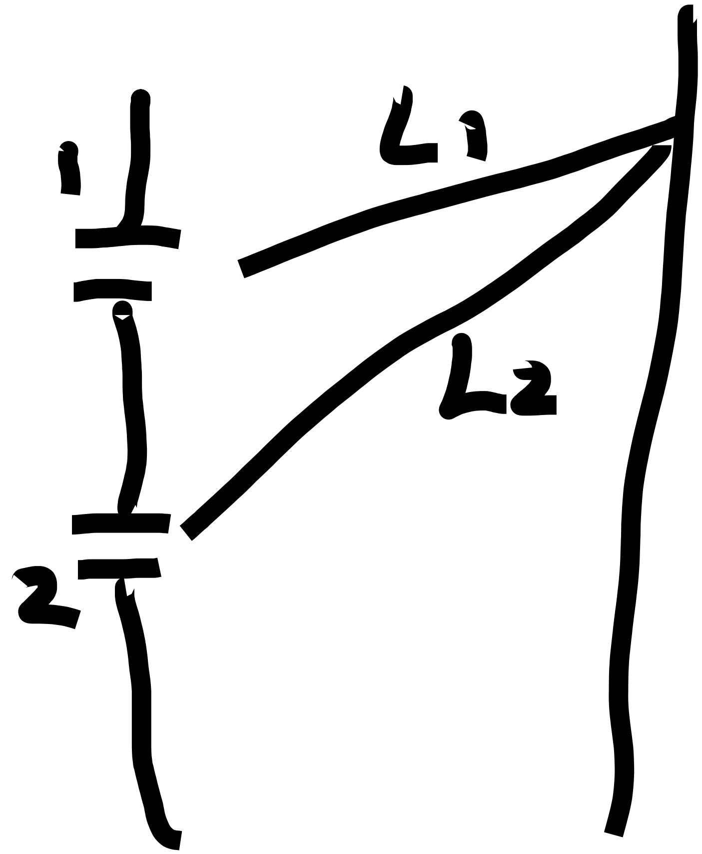
$$d \sin \theta = m\lambda, \qquad \text{for } m = 0, 1, 2, \ldots$$

$$d \sin \theta = (m + \tfrac{1}{2})\lambda, \qquad \text{for } m = 0, 1, 2, \ldots$$


Courtesy Jearl Walker

$$\frac{L_1}{\lambda} = N_1$$

$$\frac{L_2}{\lambda} = N_2$$



constructive:

$N_1 - N_2 =$ integer

destructive $=$ 1/2 integer

$$N_1 - N_2 = \frac{\Delta L}{\lambda}$$

$$\Delta L = L_1 - L_2$$

$$d\sin\theta = m\lambda$$ constr

$$d\sin\theta = \left(m+\tfrac{1}{2}\right)$$ destr

$$E_1 = E_0 \sin(\omega t)$$

$$E_2 = E_0 \sin(\omega t + \phi)$$

$$E = E_1 + E_2 = E_0\left(\sin\omega t + \sin(\omega t + \phi)\right)$$

$$\sin\alpha + \sin\beta = 2\cos\frac{\alpha-\beta}{2}\,\sin\frac{\alpha+\beta}{2}$$

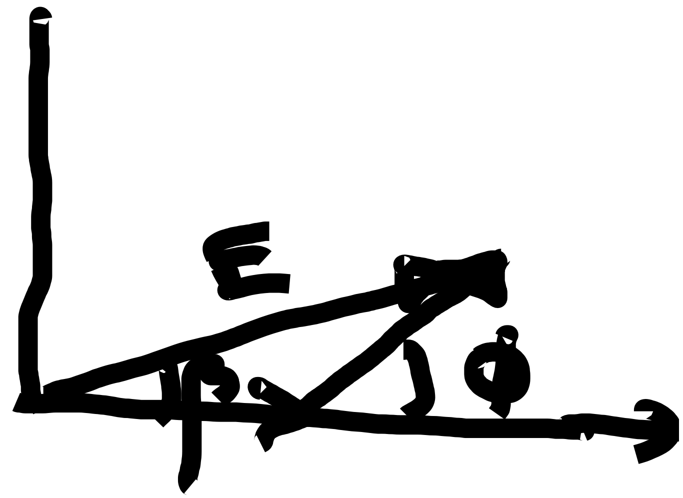
$$E = 2E_0 \cos\frac{\phi}{2}\,\sin\left(\omega t + \frac{\phi}{2}\right)$$

$$I = 4 I_0 \cos^2\frac{\phi}{2}$$

$$I \propto E^2$$

$$E_1 = E_0 \cos \omega t$$

$$E_2 = E_0 \cos(\omega t + \phi)$$



$$E_h = E_0(1 + \cos\phi)$$

$$E_v = E_0 \sin\phi$$

$$\tan\beta = \frac{\sin\phi}{1+\cos\phi} = \phi/2$$

$$E = \sqrt{E_h^2 + E_v^2} = 4E_0^2\cos^2\frac{\phi}{2}$$

$$E_1 = E_0 e^{i\omega t}$$

$$E_2 = E_0 e^{i(\omega t + \phi)}$$

$$E_1 + E_2 = E_0 e^{i\omega t}(1 + e^{i\phi})$$

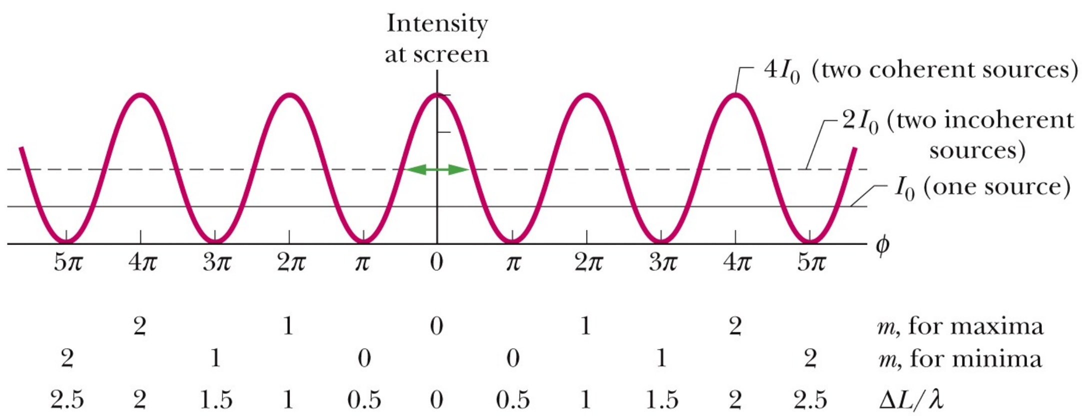
$$|E_1 + E_2| = E_0 |(1 + e^{i\phi})| =$$

$$= E_0 \left| e^{-i\phi/2} \left(\underbrace{e^{i\phi/2} + e^{-i\phi/2}}_{2\cos\frac{\phi}{2}} \right) \right| =$$

$$= E_0 \cdot 2\cos\frac{\phi}{2}$$

35-3 Interference and Double-Slit Intensity

If two light waves that meet at a point are to interfere perceptibly, both must have the same wavelength and the phase difference between them must remain constant with time; that is, the waves must be coherent.



A plot of equation below, showing the intensity of a double-slit interference pattern as a function of the phase difference between the waves when they arrive from the two slits. I_0 is the (uniform) intensity that would appear on the screen if one slit were covered. The average intensity of the fringe pattern is $2I_0$, and the maximum intensity (for coherent light) is $4I_0$.

As shown in figure, in Young's interference experiment, two waves, each with intensity I_0, yield a resultant wave of intensity I at the viewing screen, with

$$I = 4I_0 \cos^2 \tfrac{1}{2}\phi,$$

where

$$\phi = \frac{2\pi d}{\lambda} \sin \theta.$$