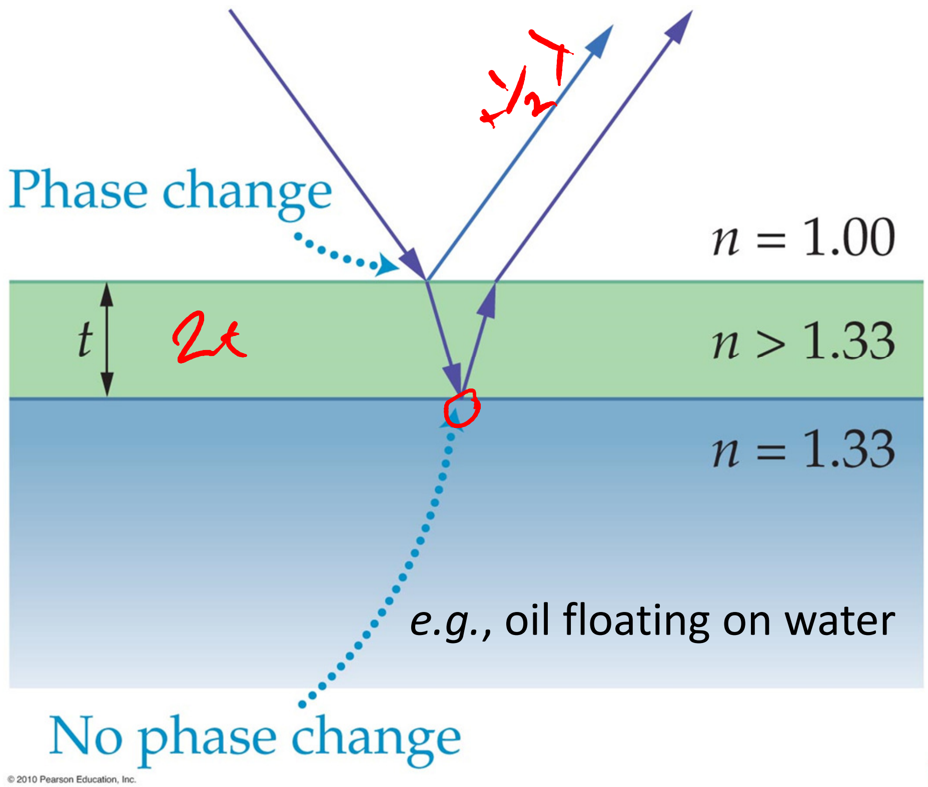
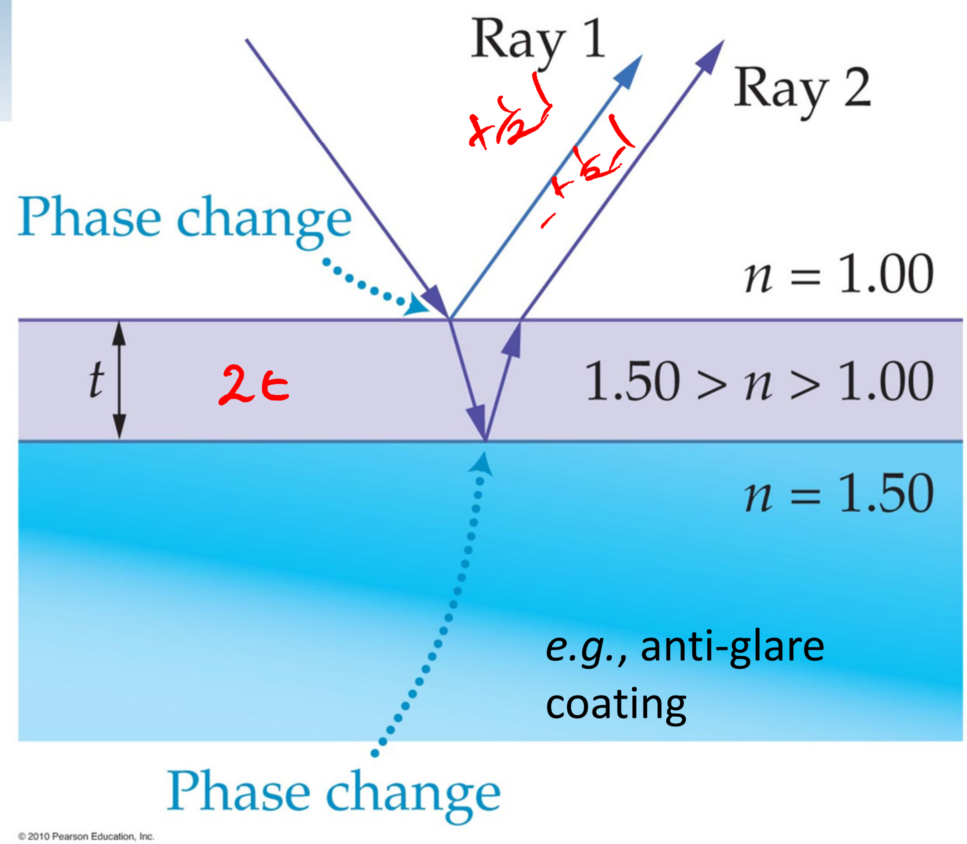
Final Exam Scheme

- Wednesday 12 December, 2pm-4pm
  - In our normal room, MWAH 347
- There's been ~one midterm's worth of new stuff since last midterm
  - So about half the final will look like a midterm on the EM waves & optics stuff
- However, it is a final exam after all, and there are two hours to take it, so the other half the final will be comprehensive, reviewing older stuff
  - That's more than a usual test, so you can bring two pages of notes instead of just the usual one

How to review old stuff?

- Start with your old midterms. Can you work them out, starting fresh?
  - Fresh? I mean read the problem, put your answer aside, and pretend you're taking the test again for the first time: then grade your new answer yourself
  - For topics that give you trouble, then go work out problems from HW (assigned, practice, online, whatever) related to that topic
- An old test, as per usual, is posted for more practice

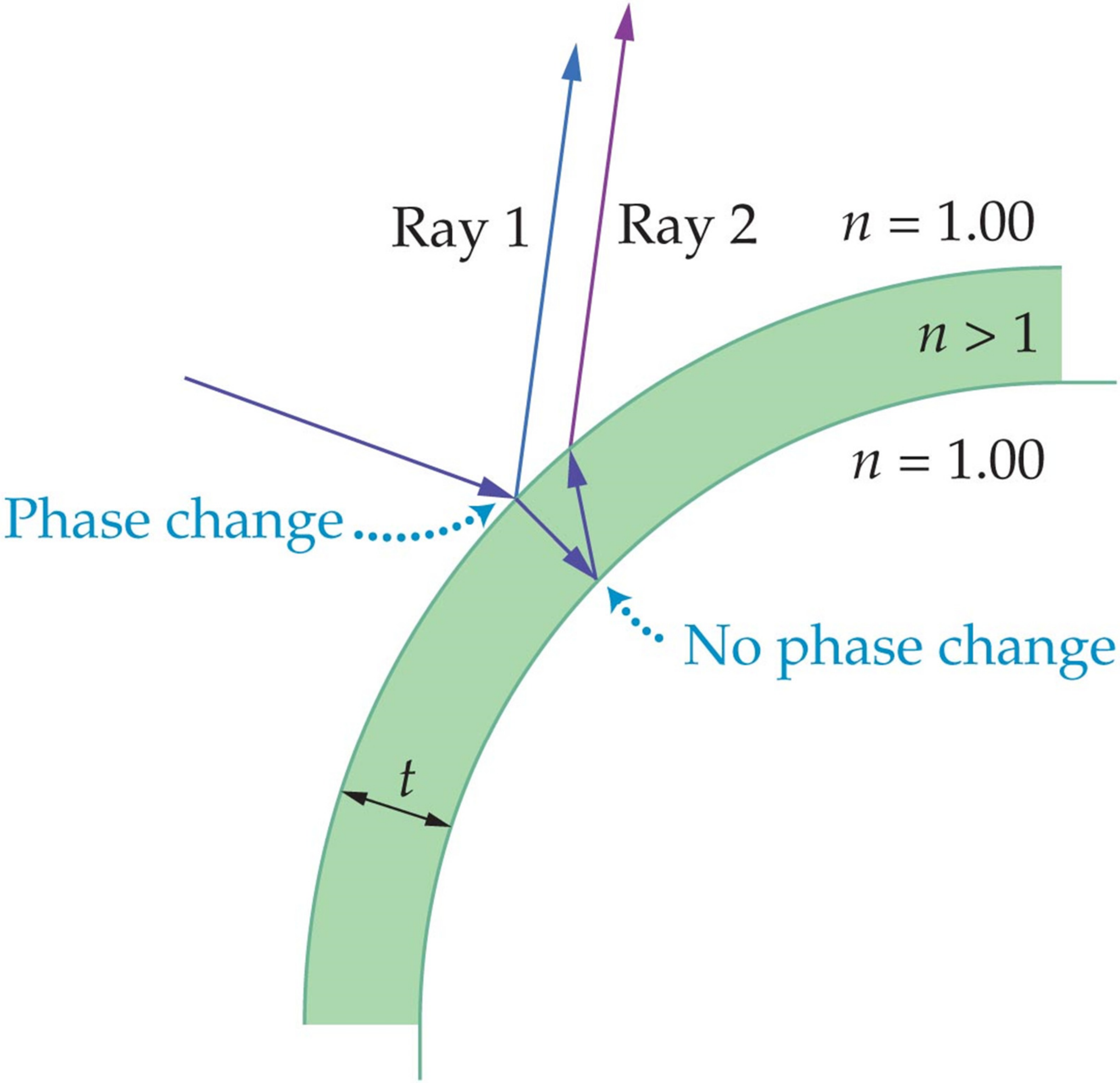




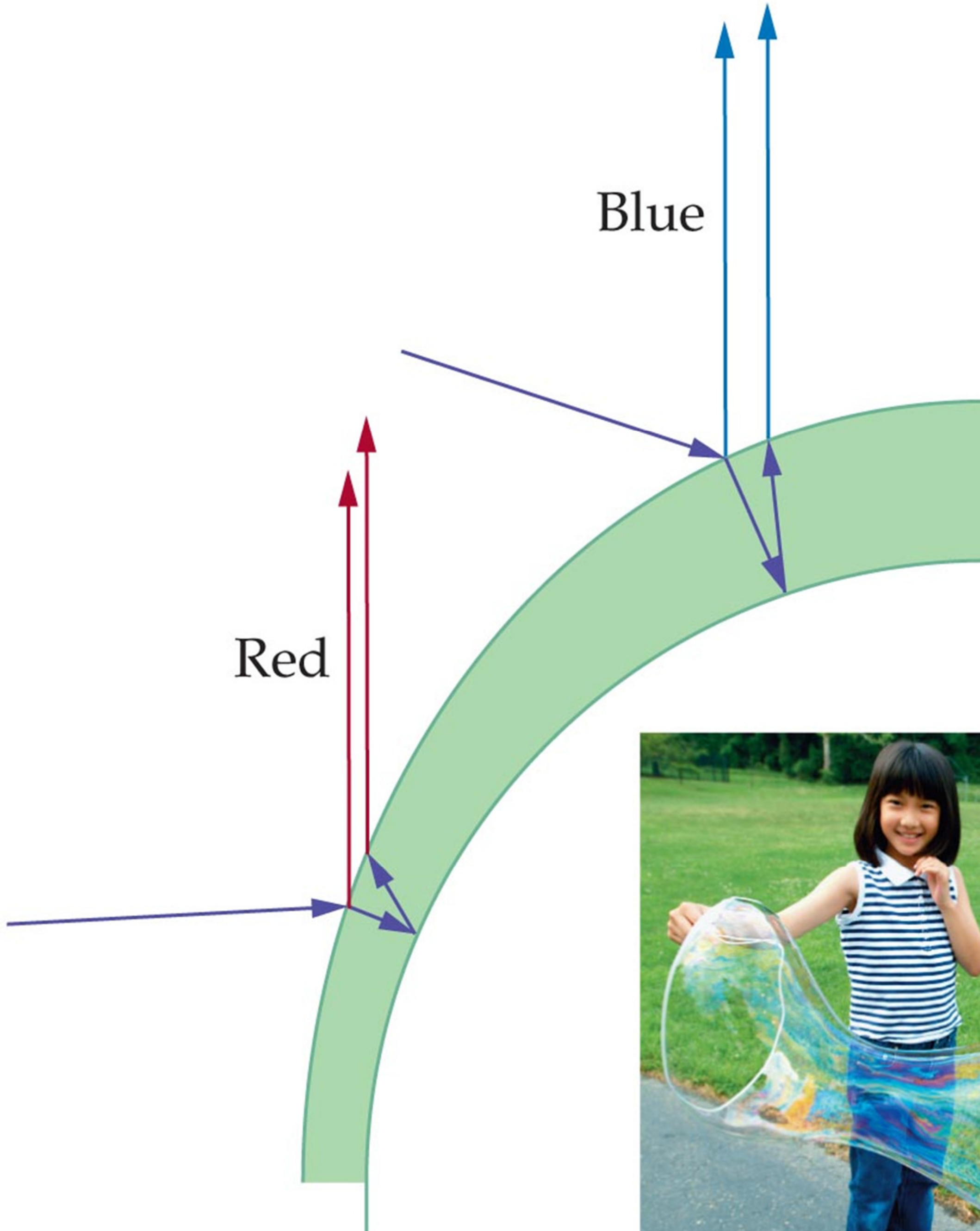
"Low to high, shift of pi,
High to low, shift of no"

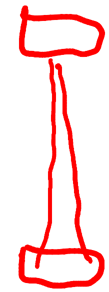
Do Problem #3 on the "Interference" handout from last week

Running behind in class – practice these on your own!

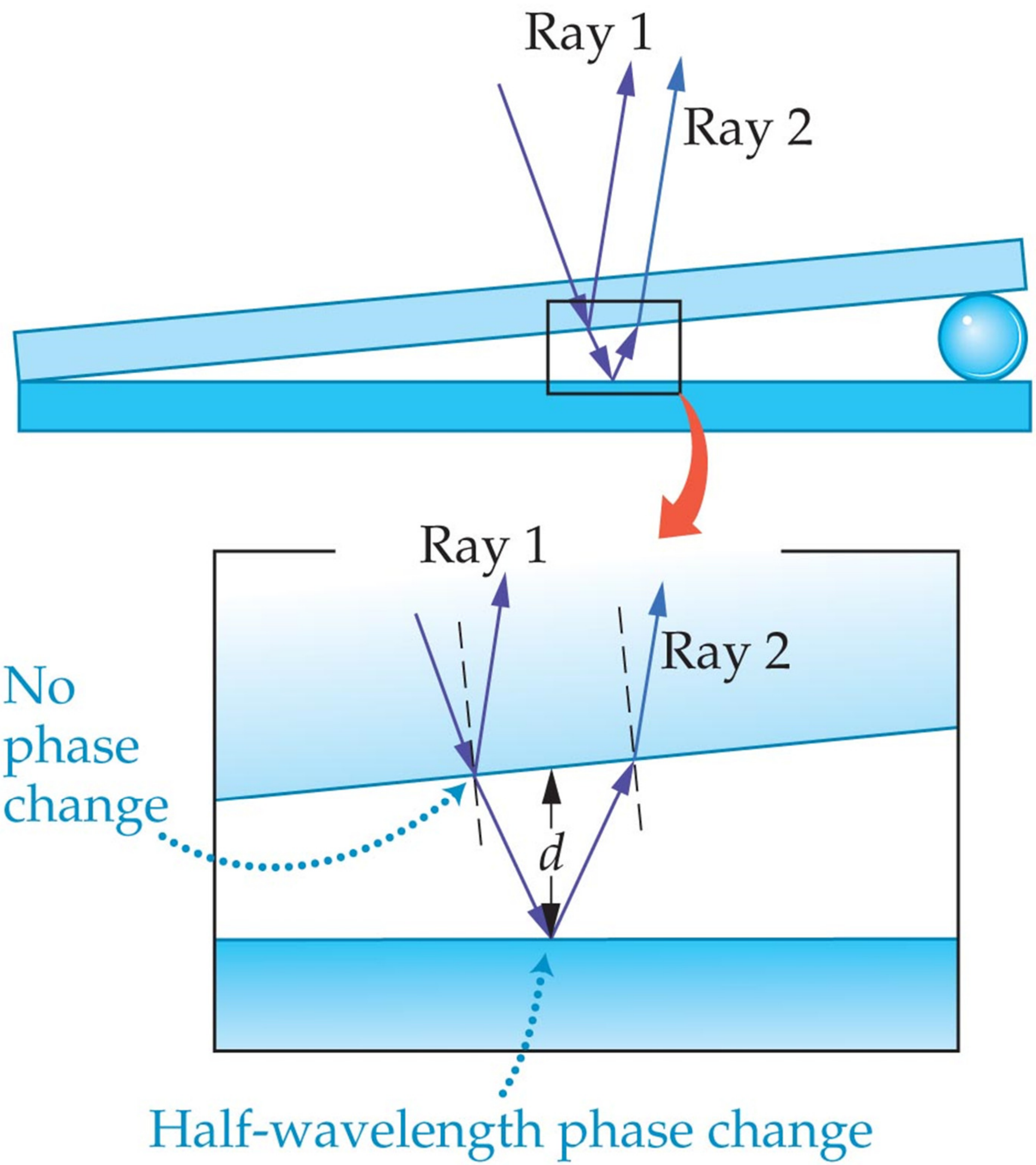


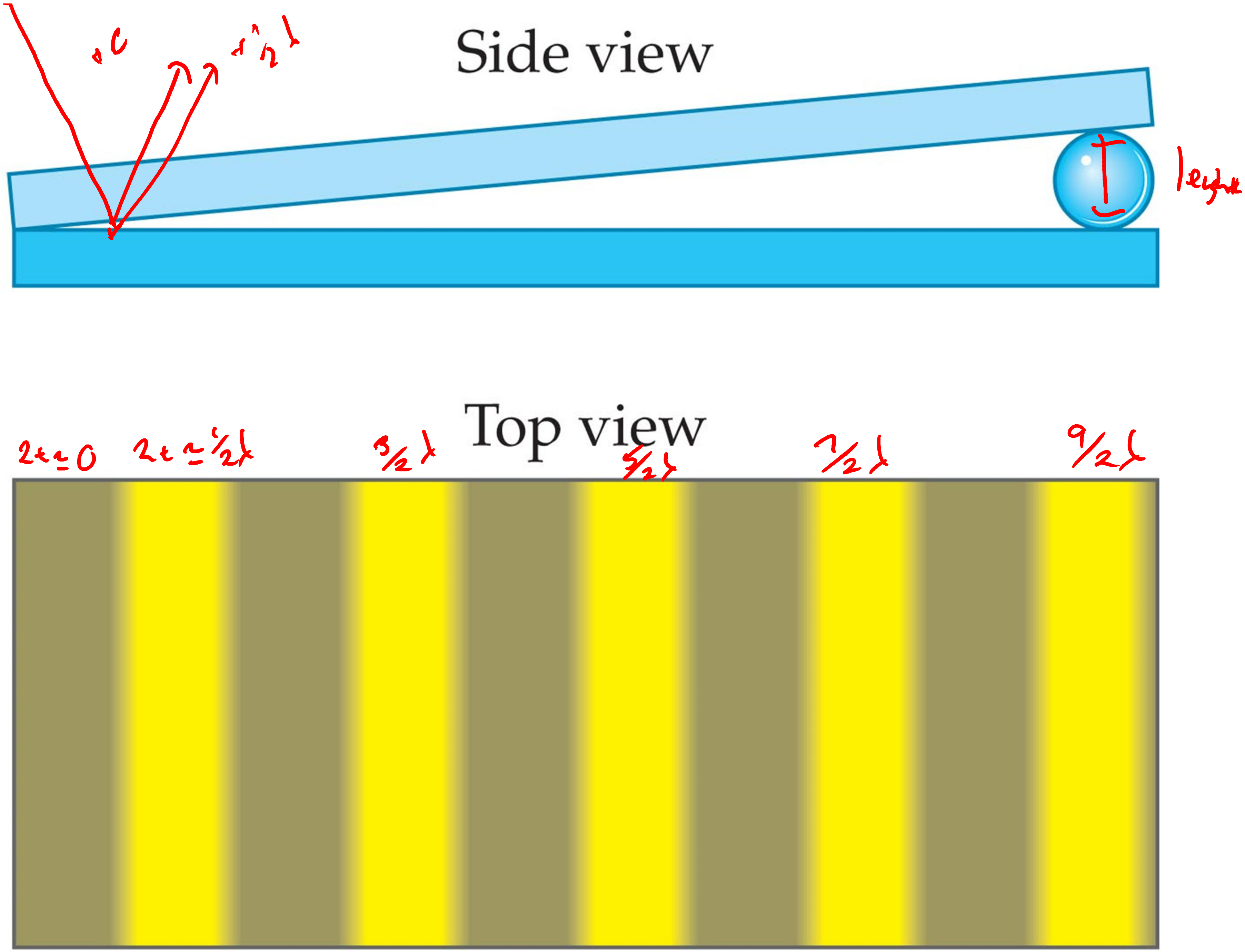
Ray 1
Ray 2
n = 1.00
n > 1
n = 1.00
Phase change
No phase change
t


Blue
Red

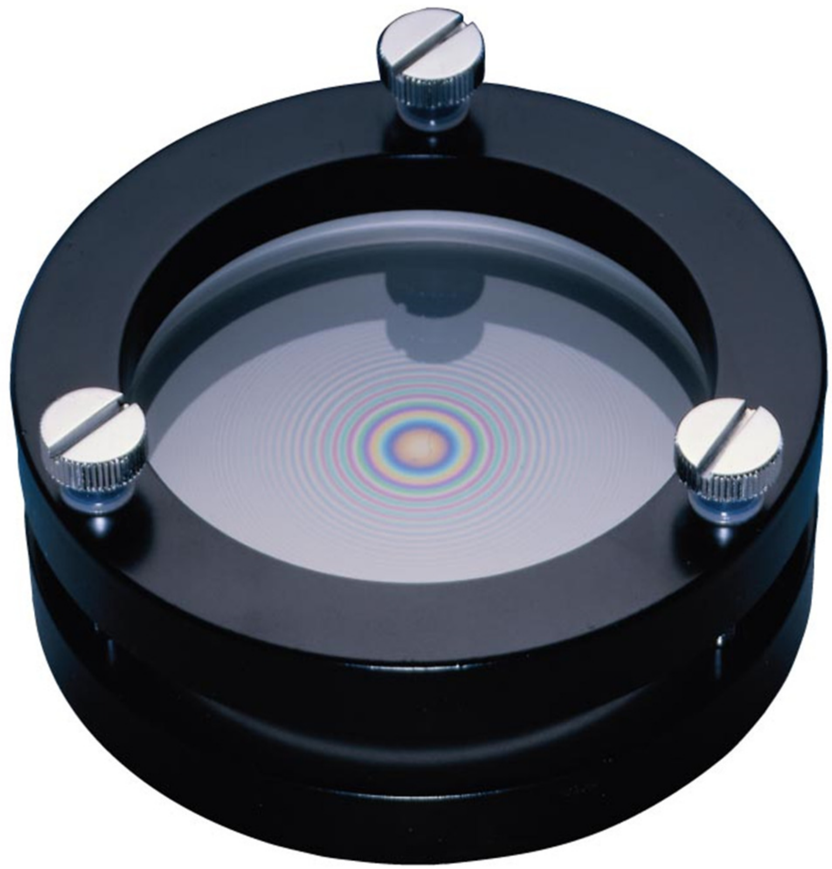


Richard Megna/Fundamental Photographs halliday_9e_fig_35_18


Ray 1
Ray 2
Ray 1
Ray 2
No phase change
d
Half-wavelength phase change

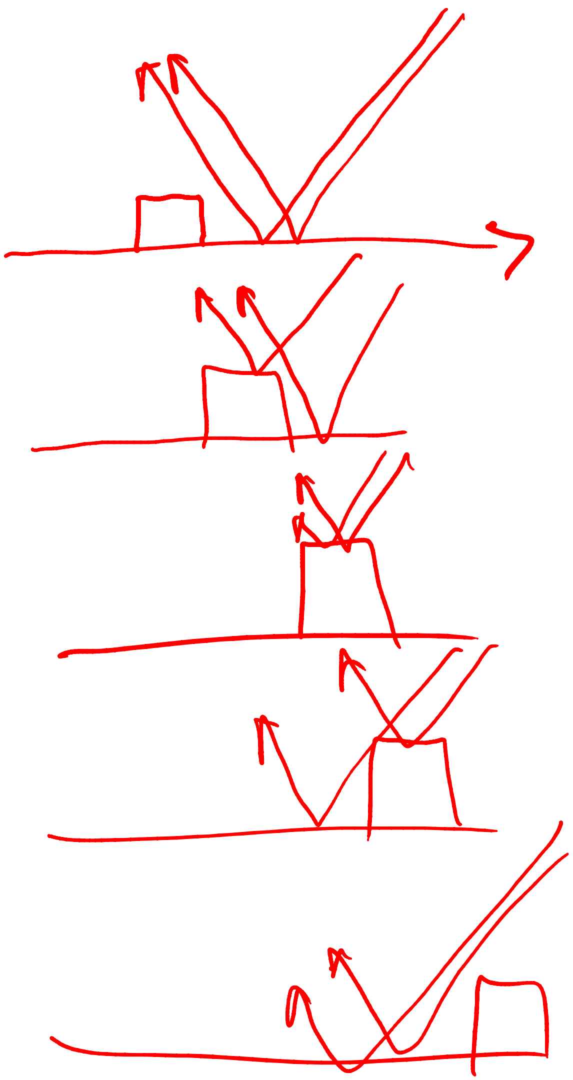

Side view
Top view

(a)

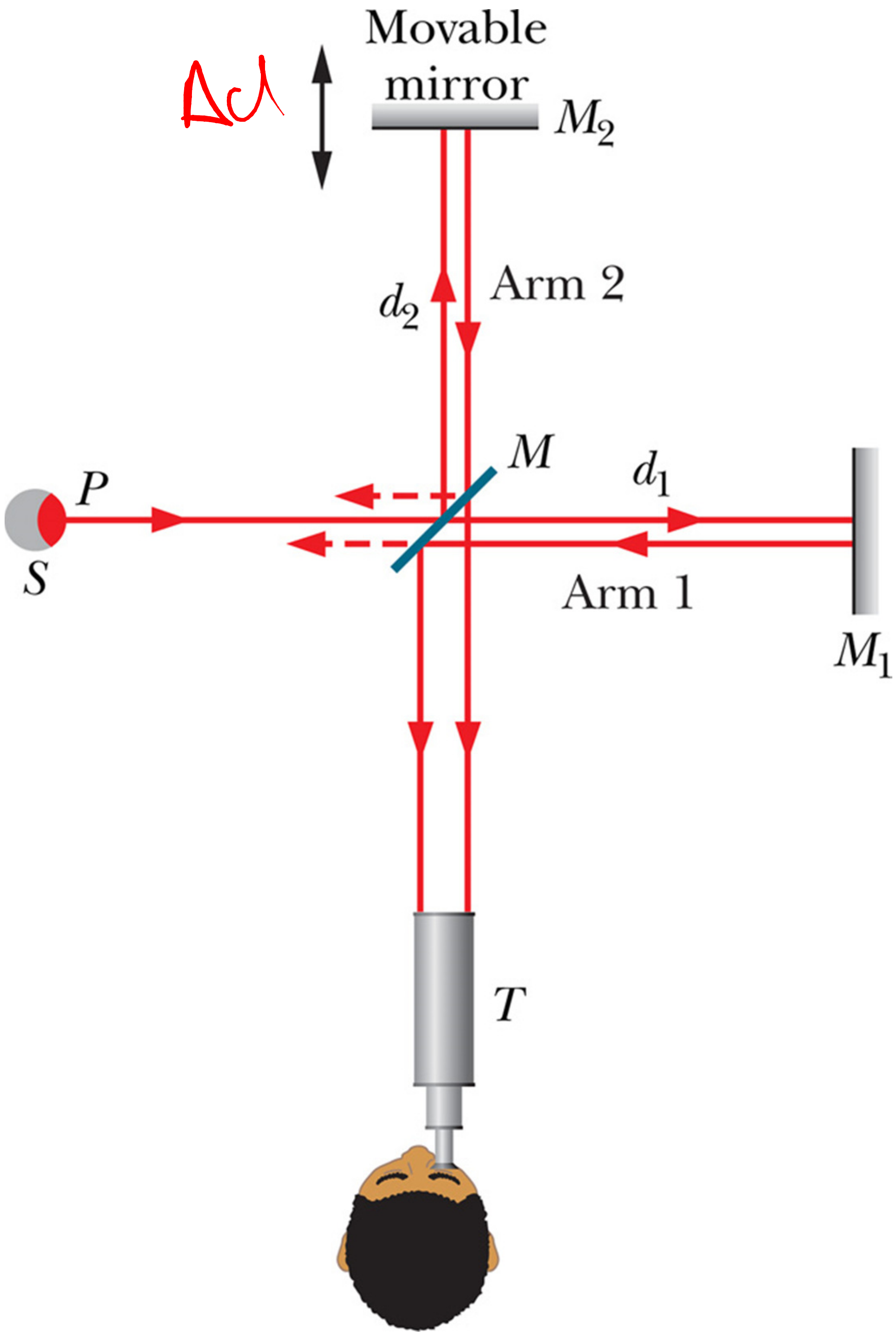


(b)

"Newton's Rings"



How a laser reads a CD



Michaelson Interferometer

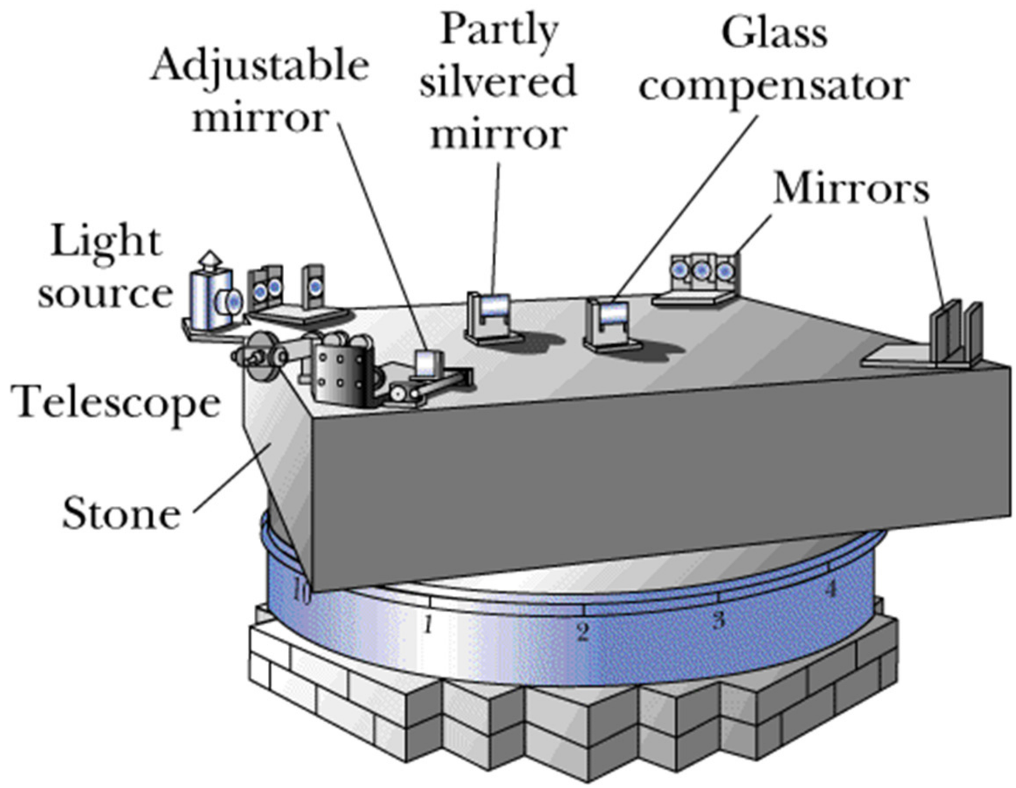
change ℓ by 2x $\Delta d = m\lambda$

see bright → bright

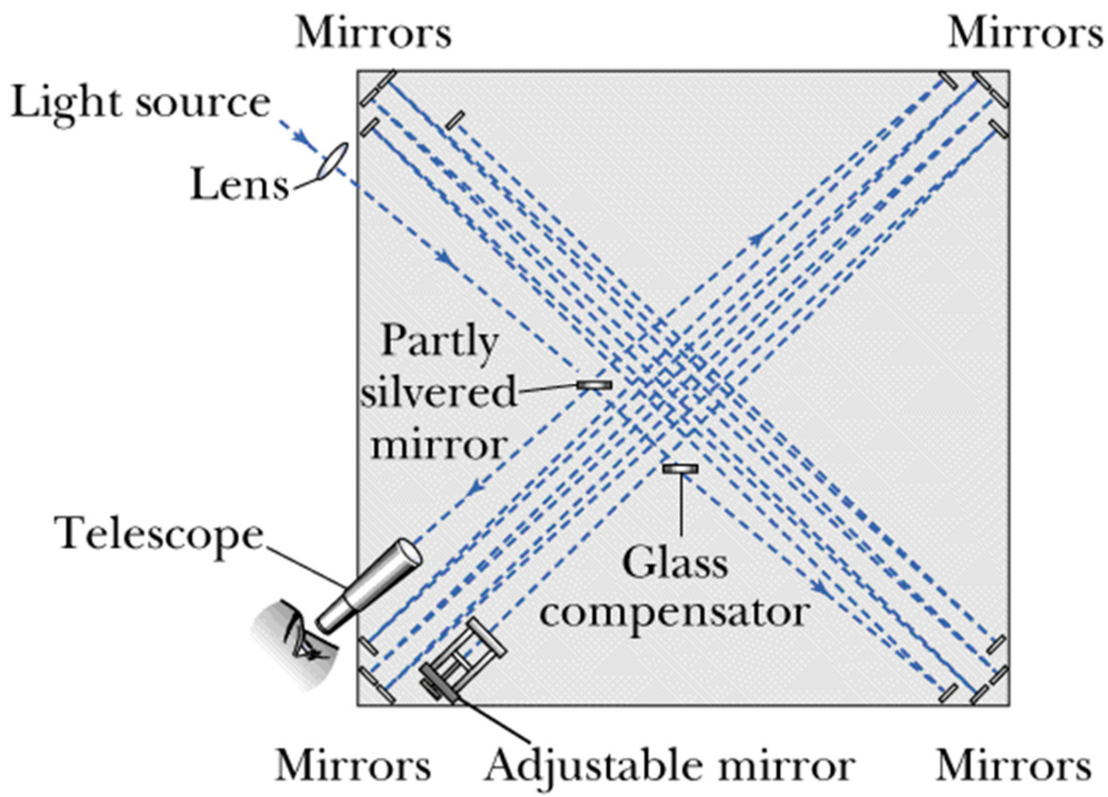
or by $(m+\frac{1}{2})$ to dark

one bounce, $\Delta l = 2L$
2 bounce $\Delta l = 4$
4 8

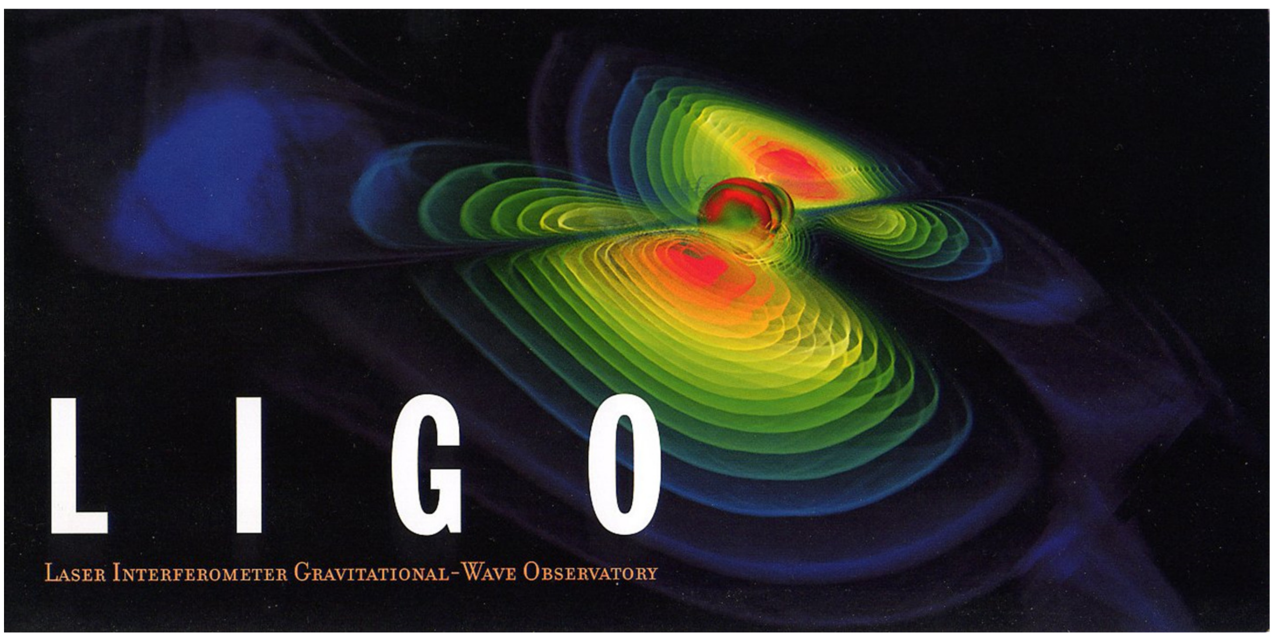
Thornton/Rex, Modern Physics for Scientists and Engineers, 2/e
Figure 2.4 (part 1)

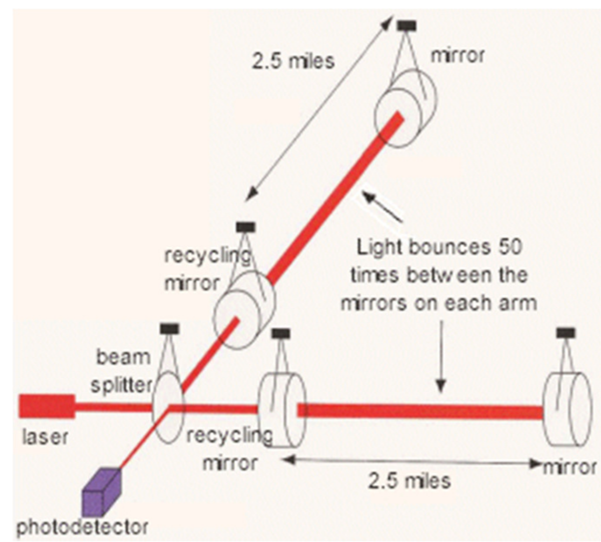


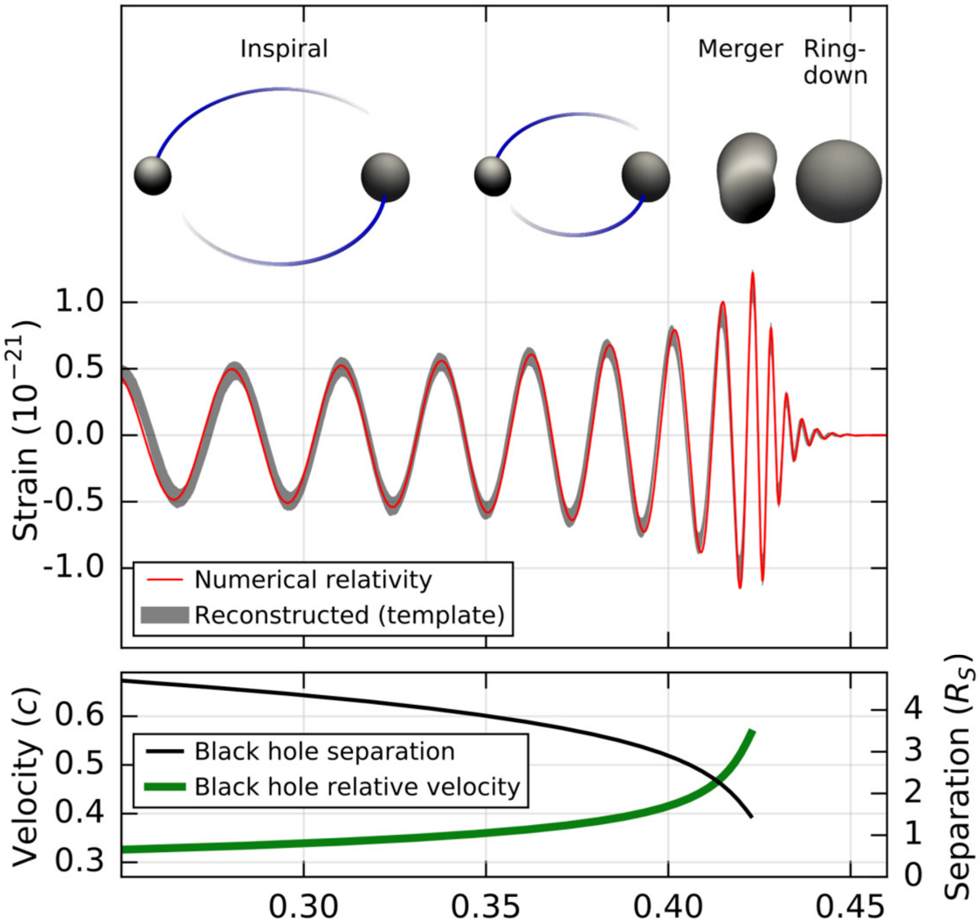
Thornton/Rex, Modern Physics for Scientists and Engineers, 2/e
Figure 2.4 (part 2)



Looked for a change in the speed of light
with respect to Earth’s motion through space.


LIGO
Laser Interferometer Gravitational-Wave Observatory


2.5 miles
mirror
recycling mirror
Light bounces 50 times between the mirrors on each arm
beam splitter
laser
recycling mirror
2.5 miles
mirror
photodetector



At September 14 2015, 09:50:45 UTC. Both Hanford and Livingston detectors see the same thing, seperated in time by the time it takes light to get from WA to LA.

Works out to 36 and 29 solar mass black holes merging into a 62 solar mass black hole, 160-180 MPc away

2017 Nobel Prize in Physics!

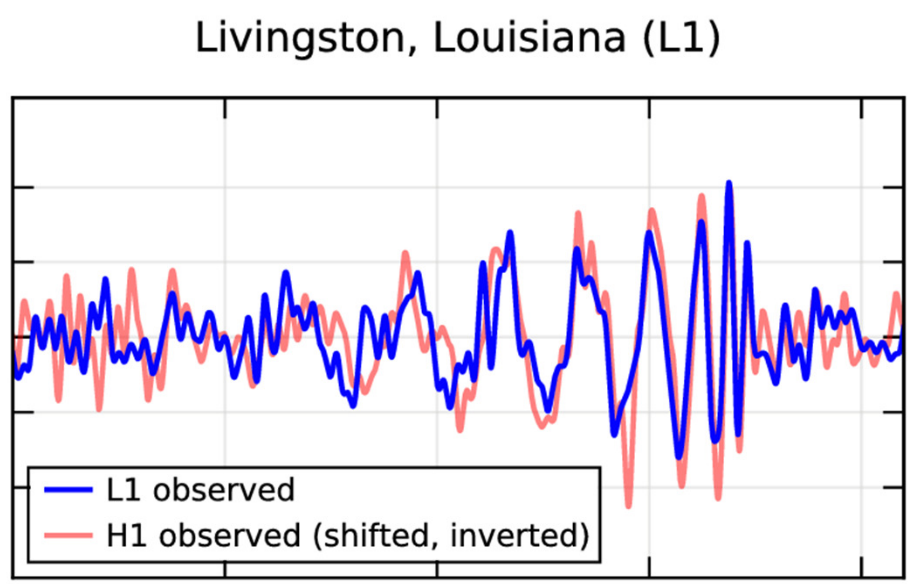
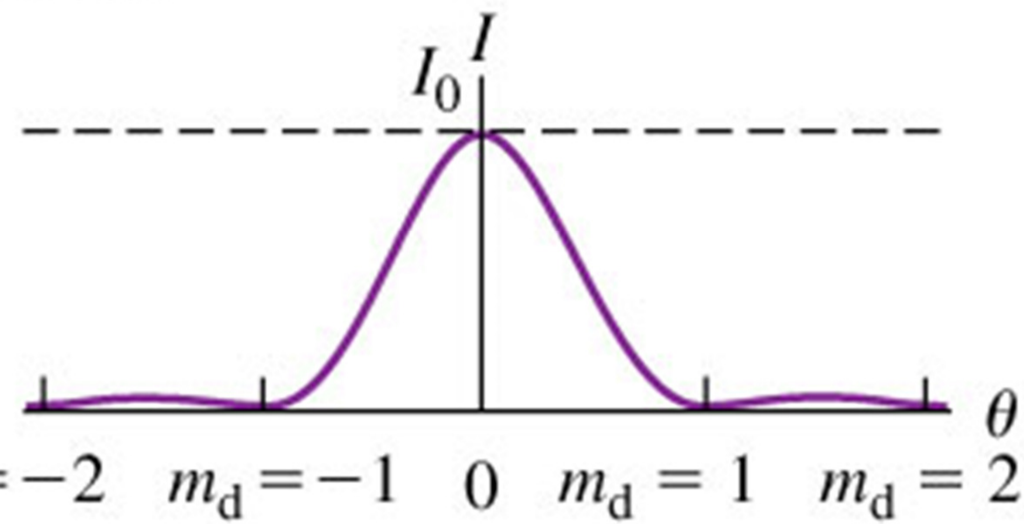


Fig.36.12a

(a) Single-slit diffraction pattern for a slit width a



Combining single-slit diffraction and double-slit interference is next…

Fig.36.12b

$I = I_0 \cos^2\left(\frac{\phi}{2}\right) \quad \phi = \frac{2\pi d}{\lambda} \sin\theta$

(b) Two-slit interference pattern for narrow slits whose separation d is four times the width of the slit in (a)

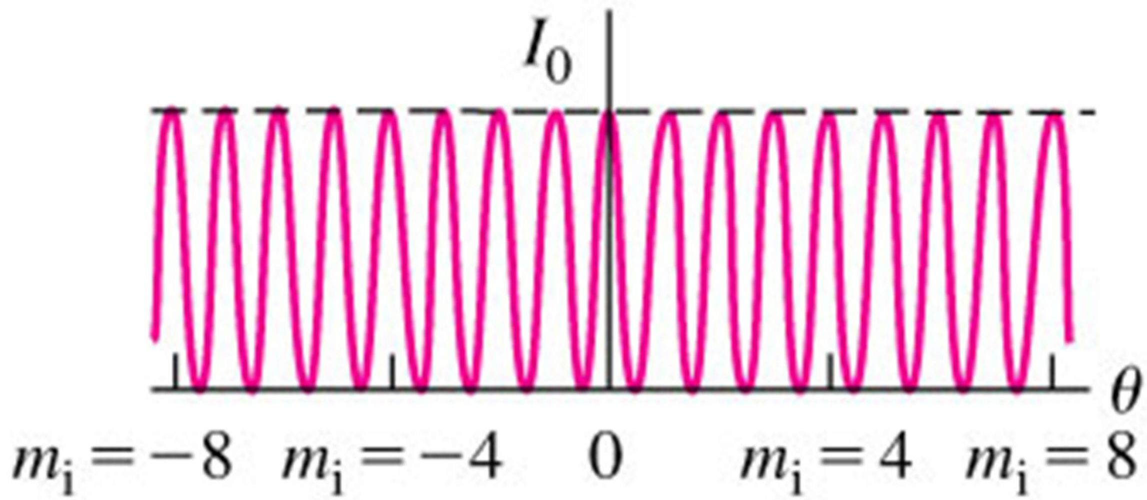


Fig.36.12c

$$I = I_0 \cos^2\frac{\phi}{2}\left[\frac{\sin(\beta/2)}{\beta/2}\right]^2$$

(c) Calculated intensity pattern for two slits of width a and separation $d = 4a$, including both interference and diffraction effects

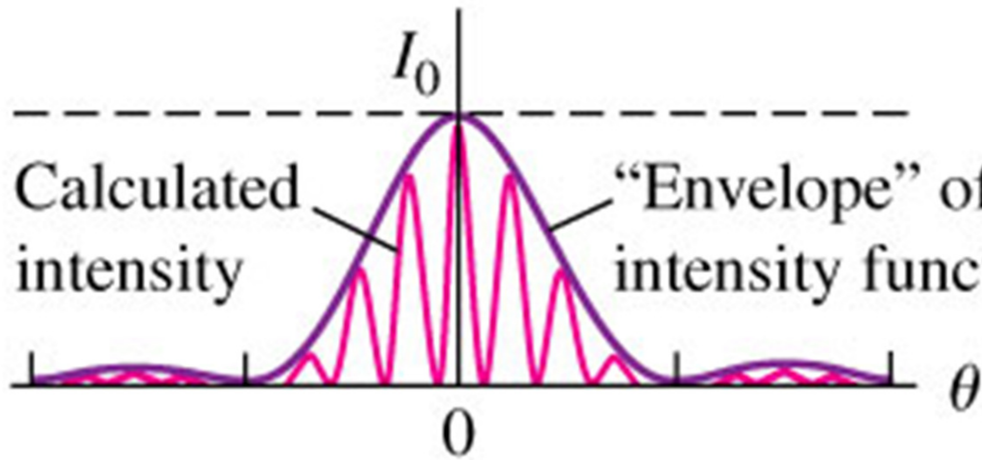
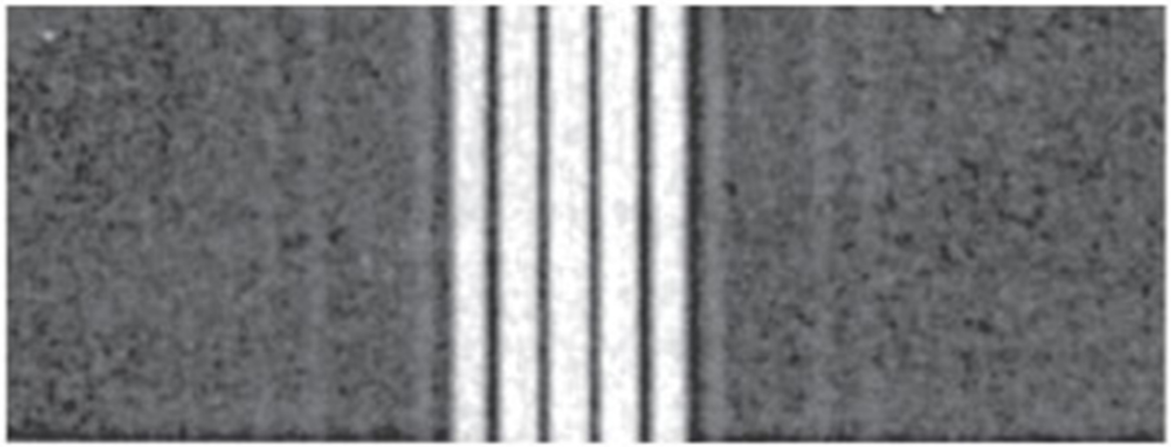
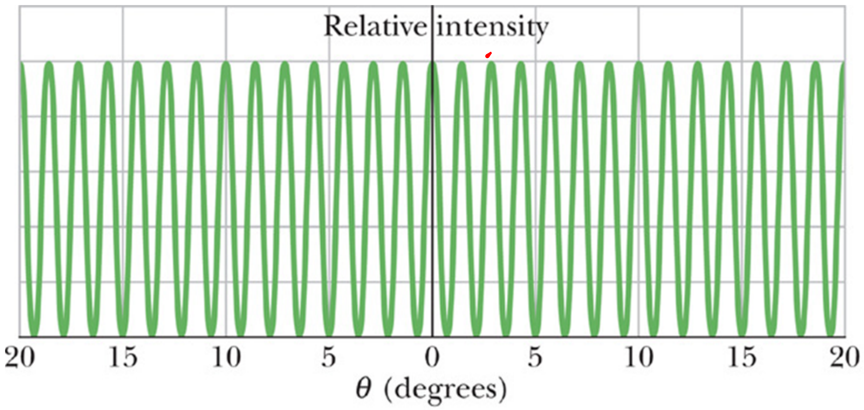


Fig.36.12d

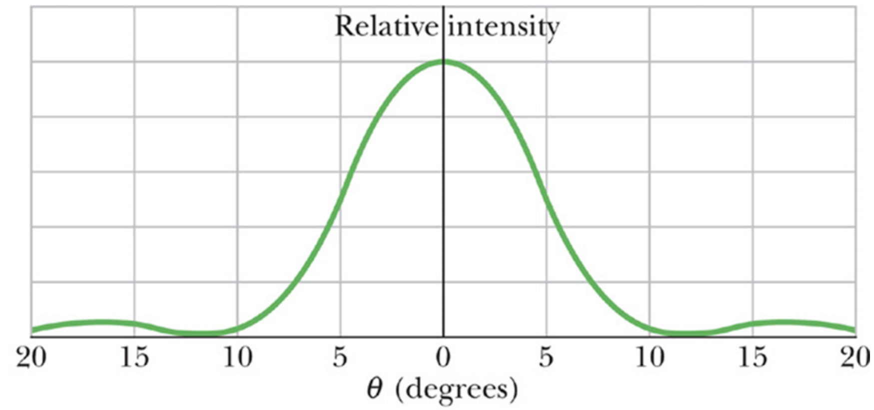
(d) Actual photograph of the pattern calculated in (c)



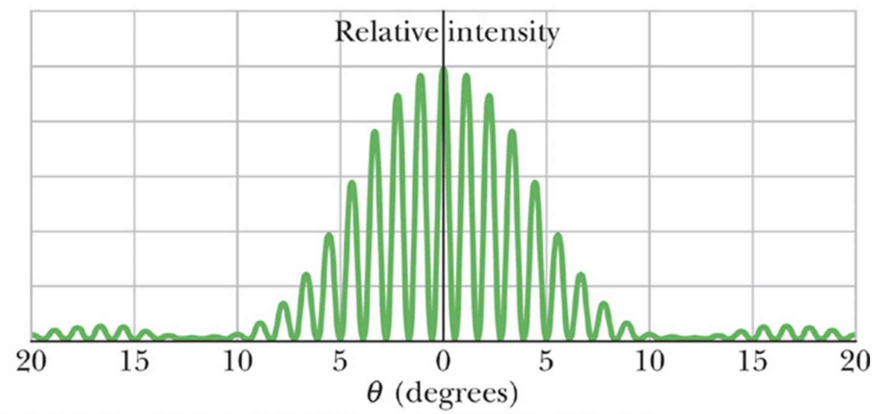
For $d = 4a$, every fourth interference maximum at the sides ($m_i = \pm 4, \pm 8, ...$) is missing.


Relative intensity
20 15 10 5 0 5 10 15 20
θ (degrees)

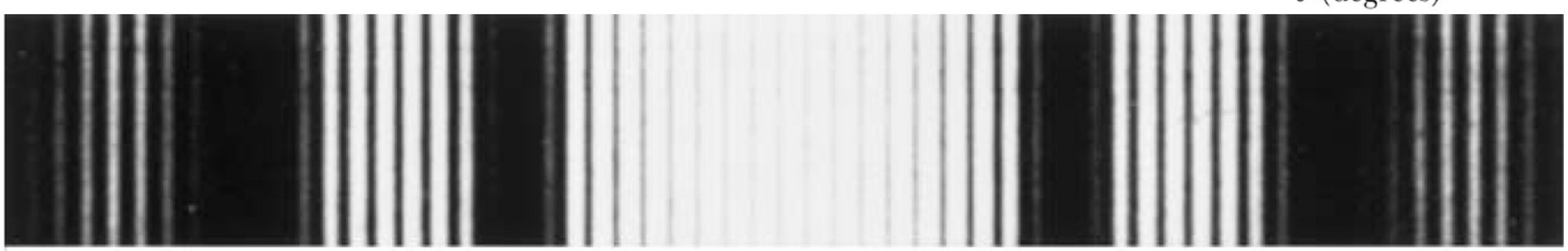
(a)


Relative intensity
20 15 10 5 0 5 10 15 20
θ (degrees)

(b)


Relative intensity
20 15 10 5 0 5 10 15 20
θ (degrees)

(a)



(b)

Fig.36.15a

(a) $N = 2$: two slits produce one minimum between adjacent maxima.

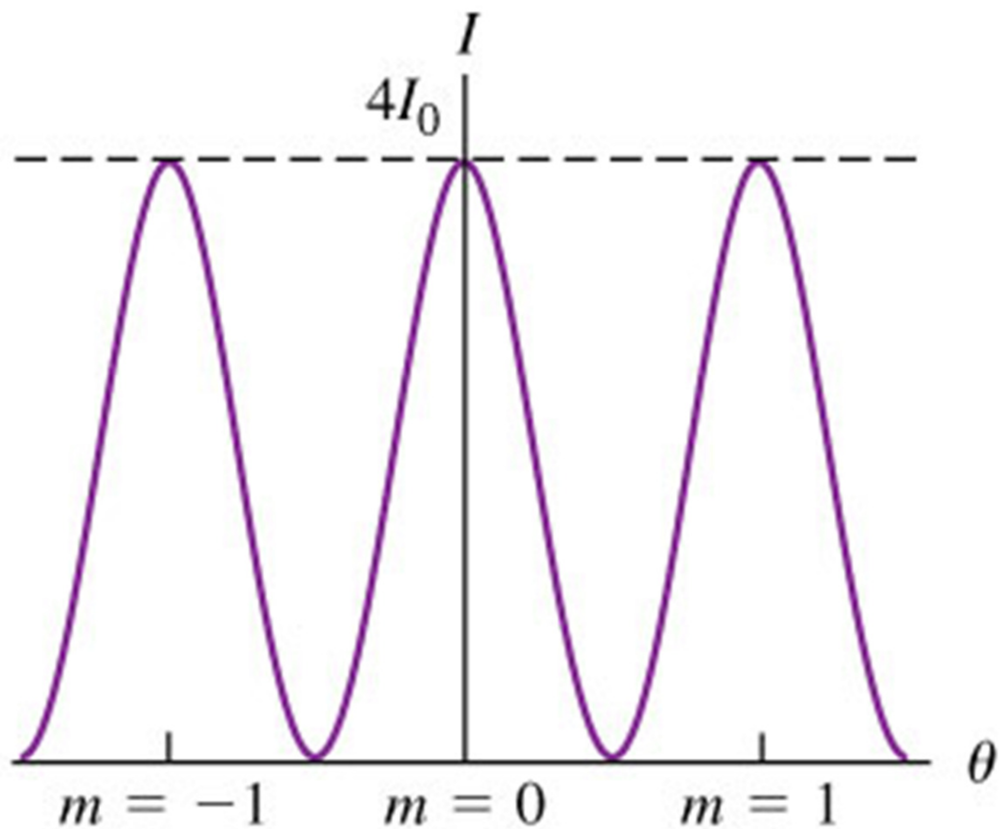


Fig.36.15b

(b) $N = 8$: eight slits produce taller, narrower maxima in the same locations, separated by seven minima.

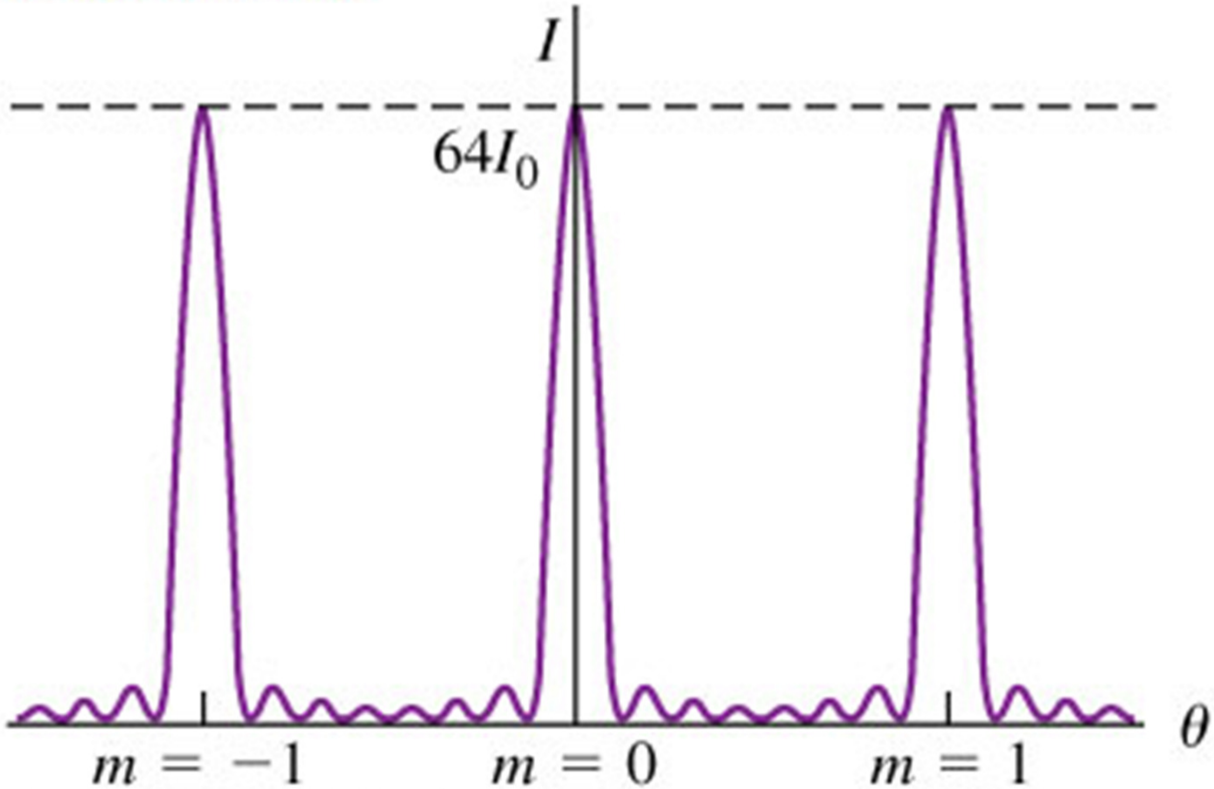


Fig.36.15c

(c) $N = 16$: with 16 slits, the maxima are even taller and narrower, with more intervening minima.

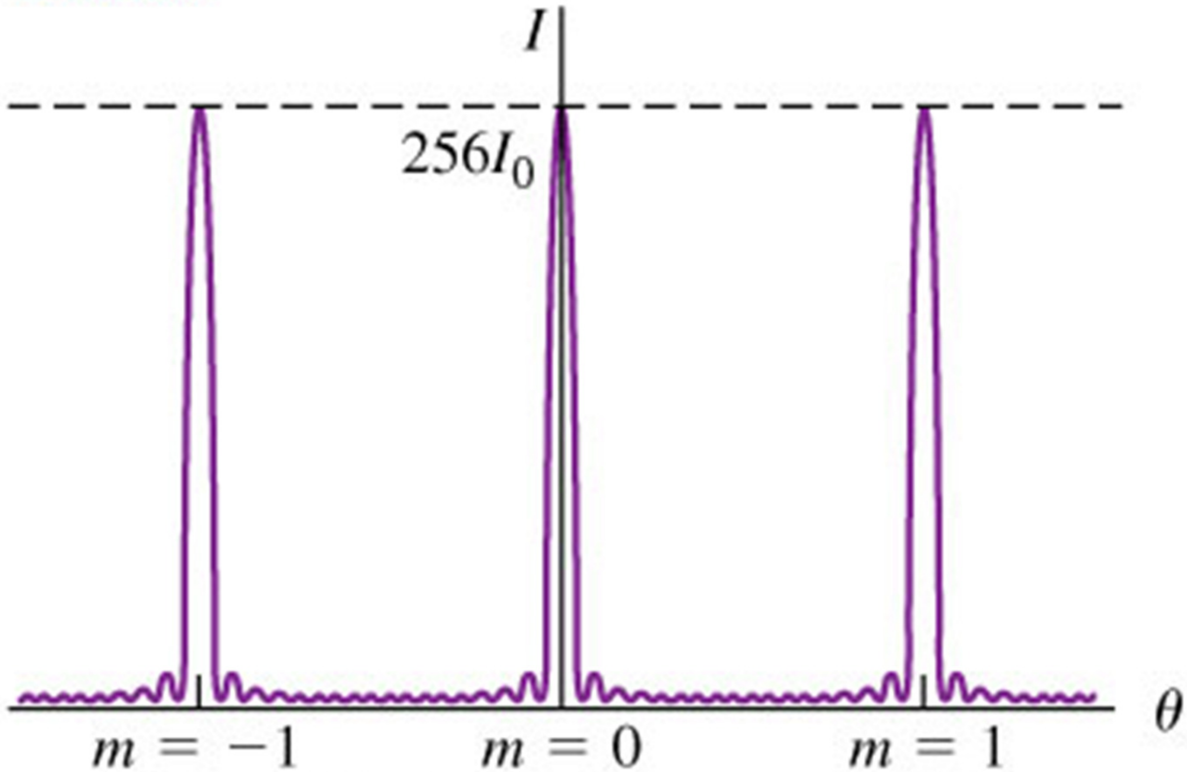
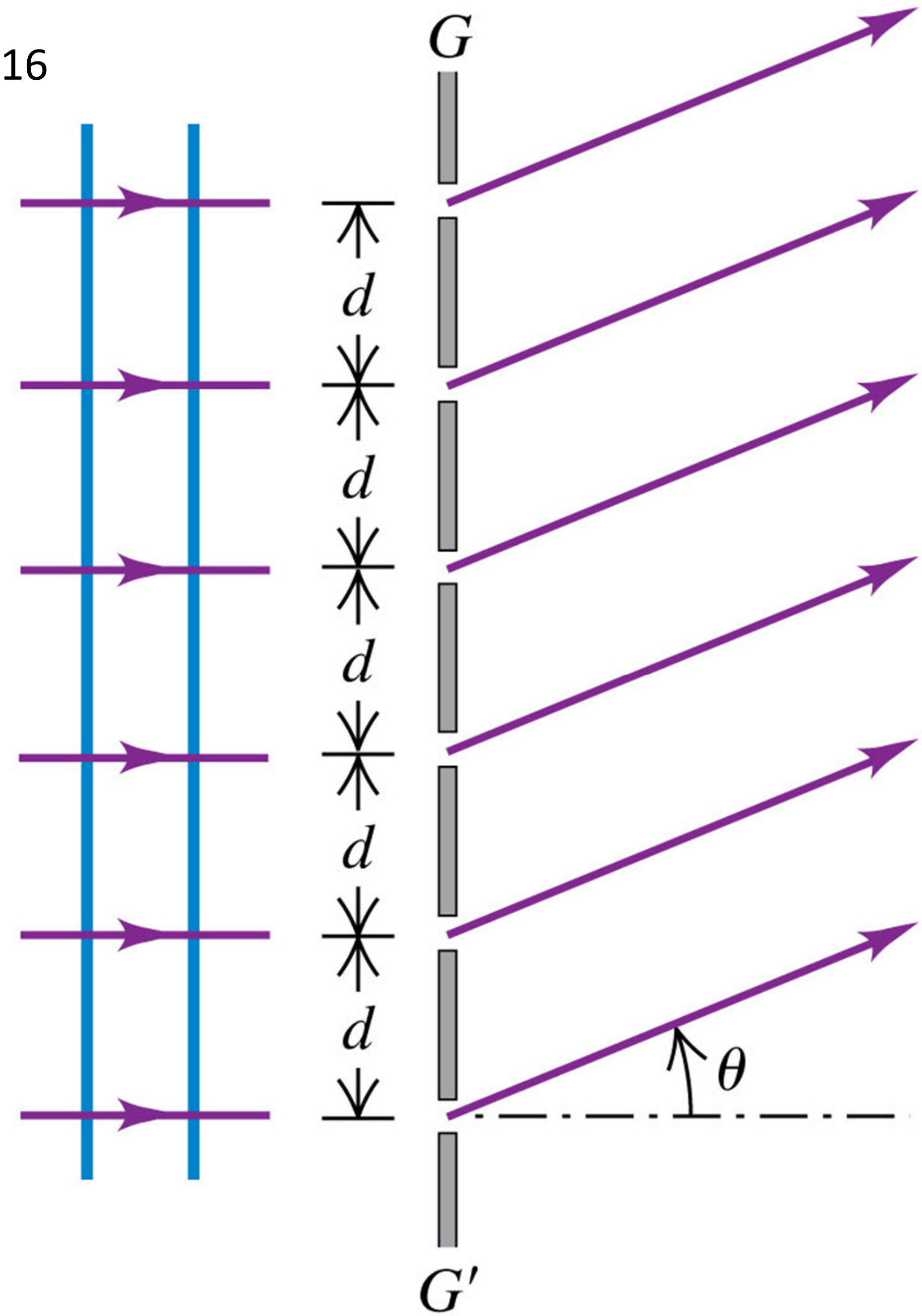
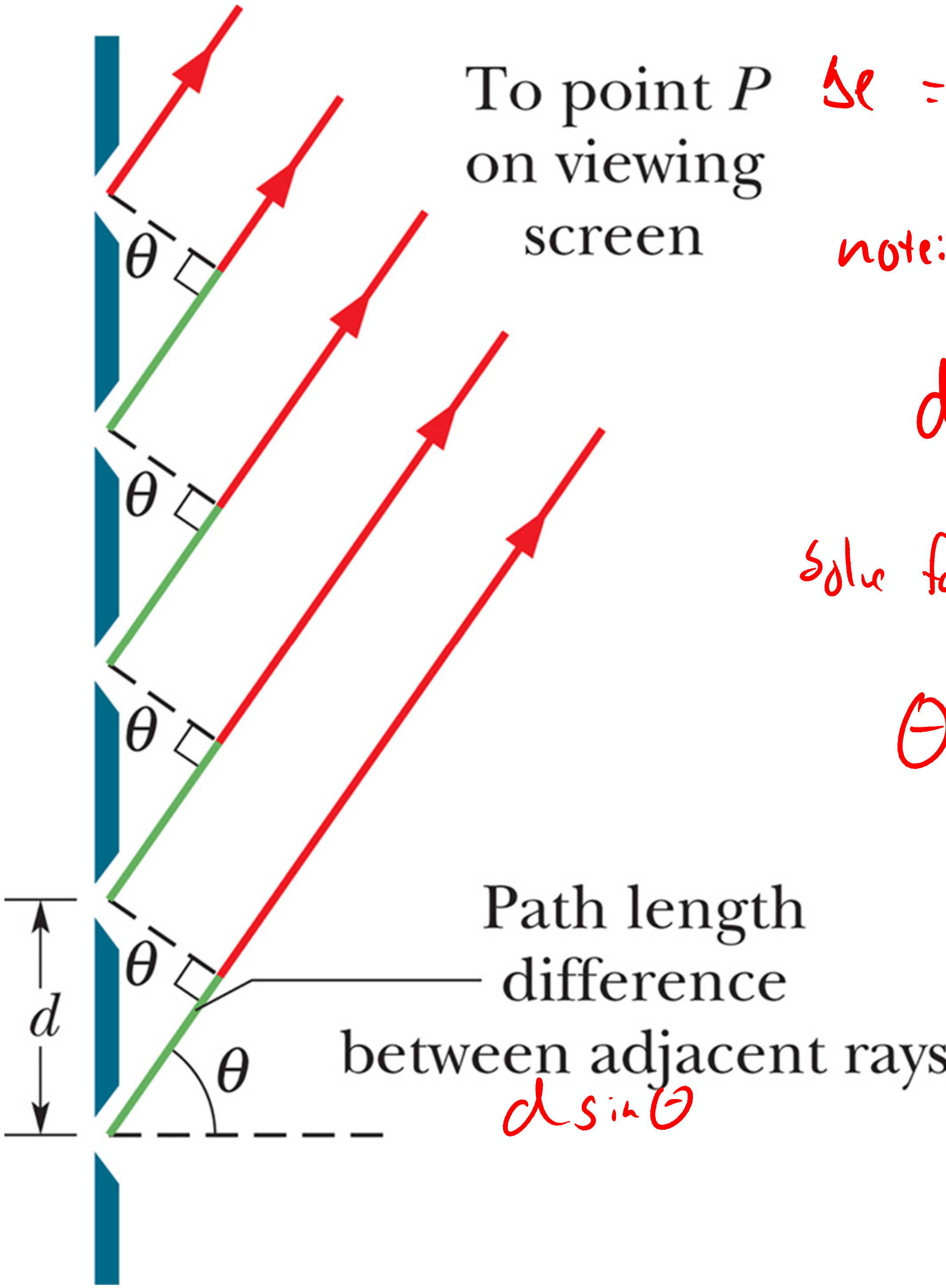


Fig.36.16





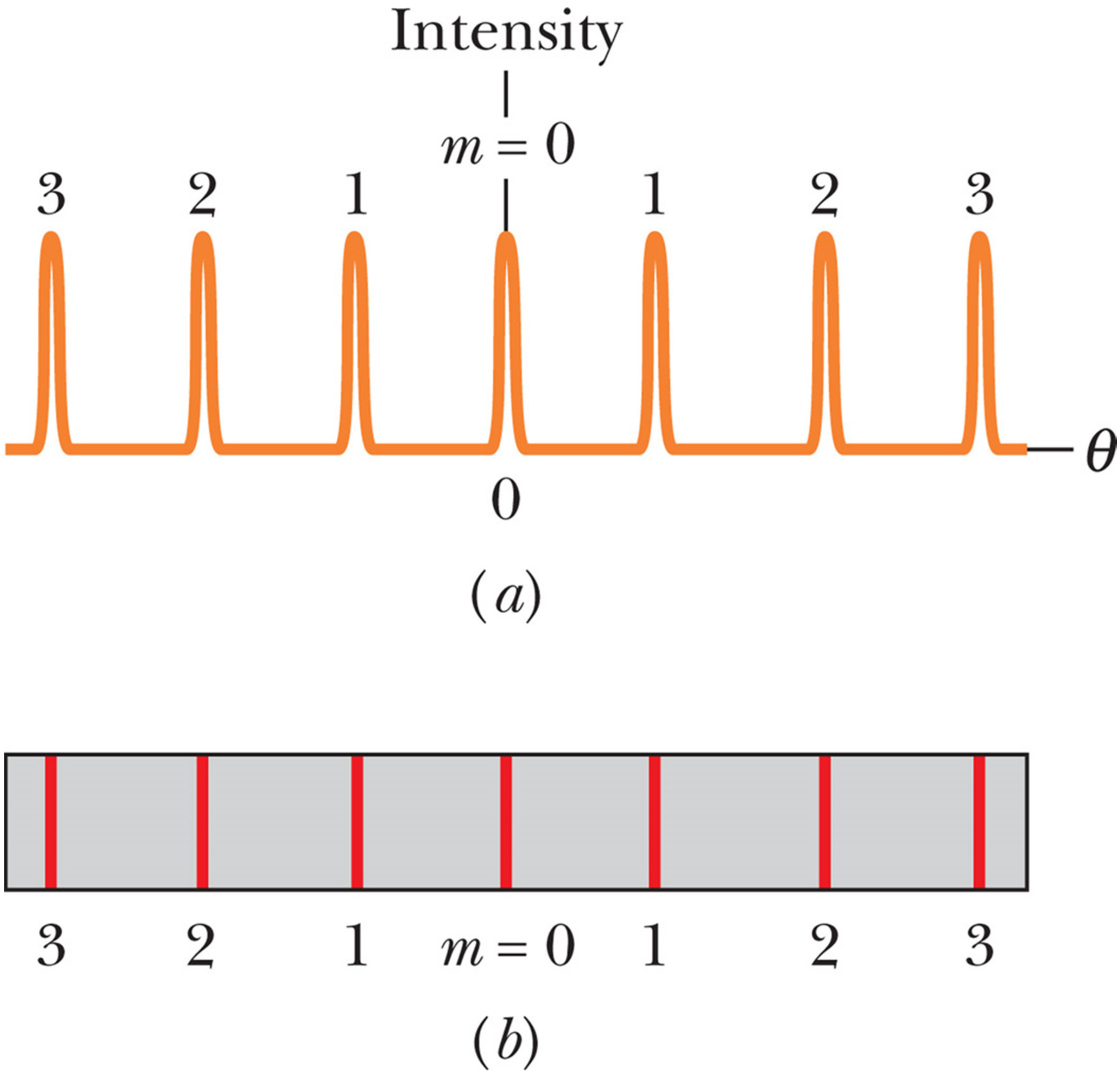
$$\delta\ell = m\lambda = d\sin\theta$$

note: "N lines per inch"

$$d = \frac{1}{N}$$

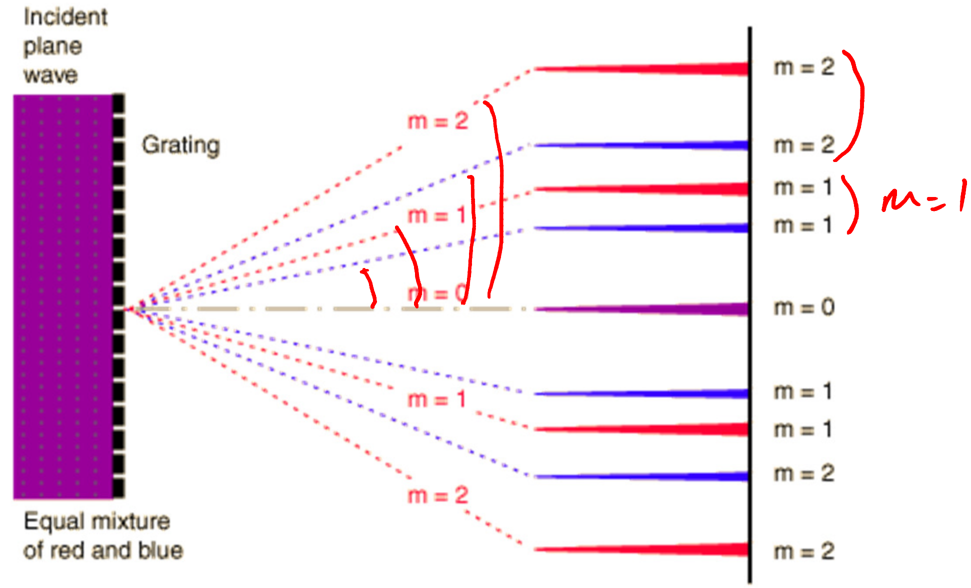
solve for $\theta = \sin^{-1}\left(\frac{m\lambda}{d}\right)$

$$\theta = \theta(\lambda)$$


Intensity
m = 0
3
2
1
1
2
3
θ
0
(a)
3
2
1
m = 0
1
2
3
(b)

(from http://hyperphysics.phy-astr.gsu.edu)

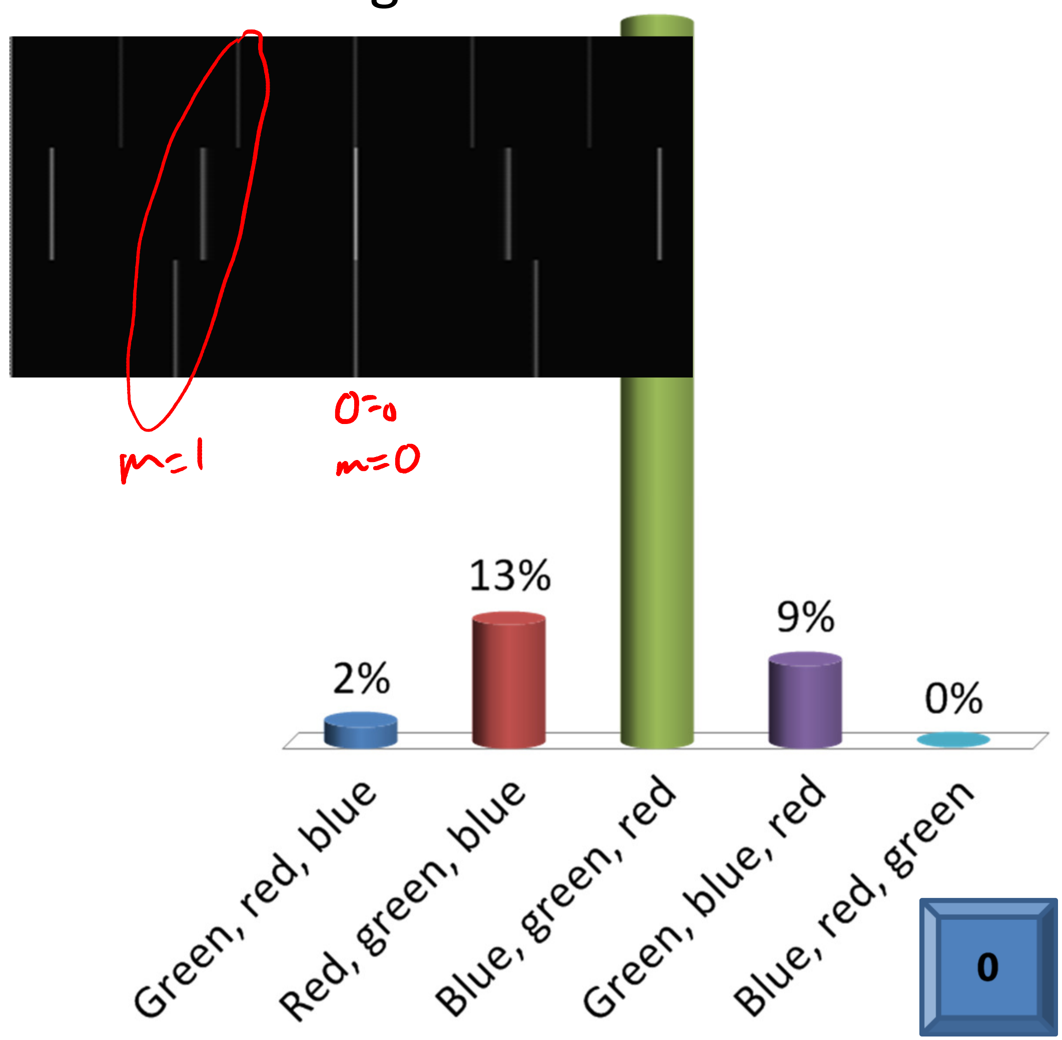
$d \sin\theta = m\lambda$

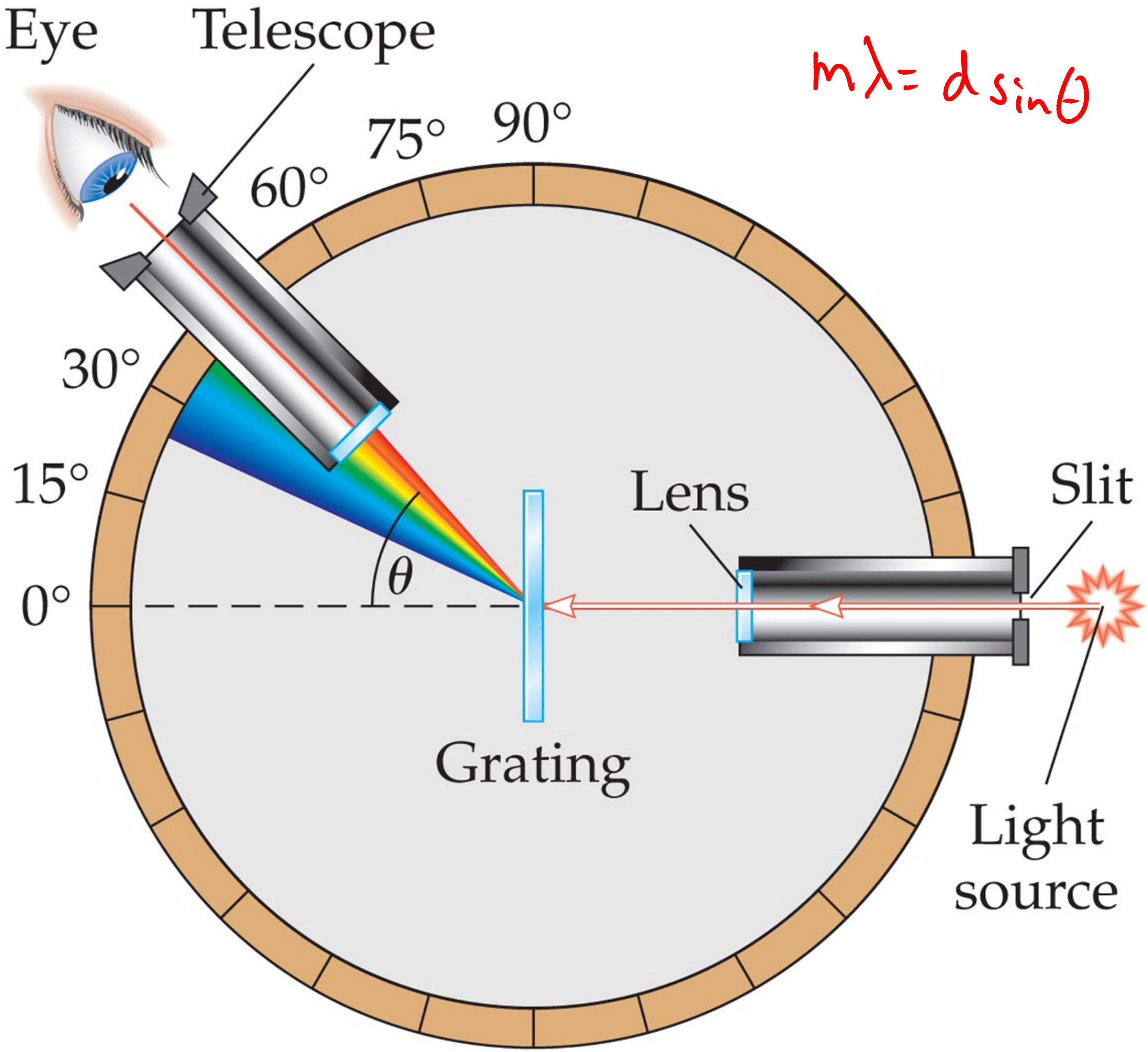


Three monochromatic light beams are directed at a diffraction grating. The resulting pattern (shown in greyscale) is observed on a screen 2 m from the grating. What is the correct order from top to bottom of the three light beams used?

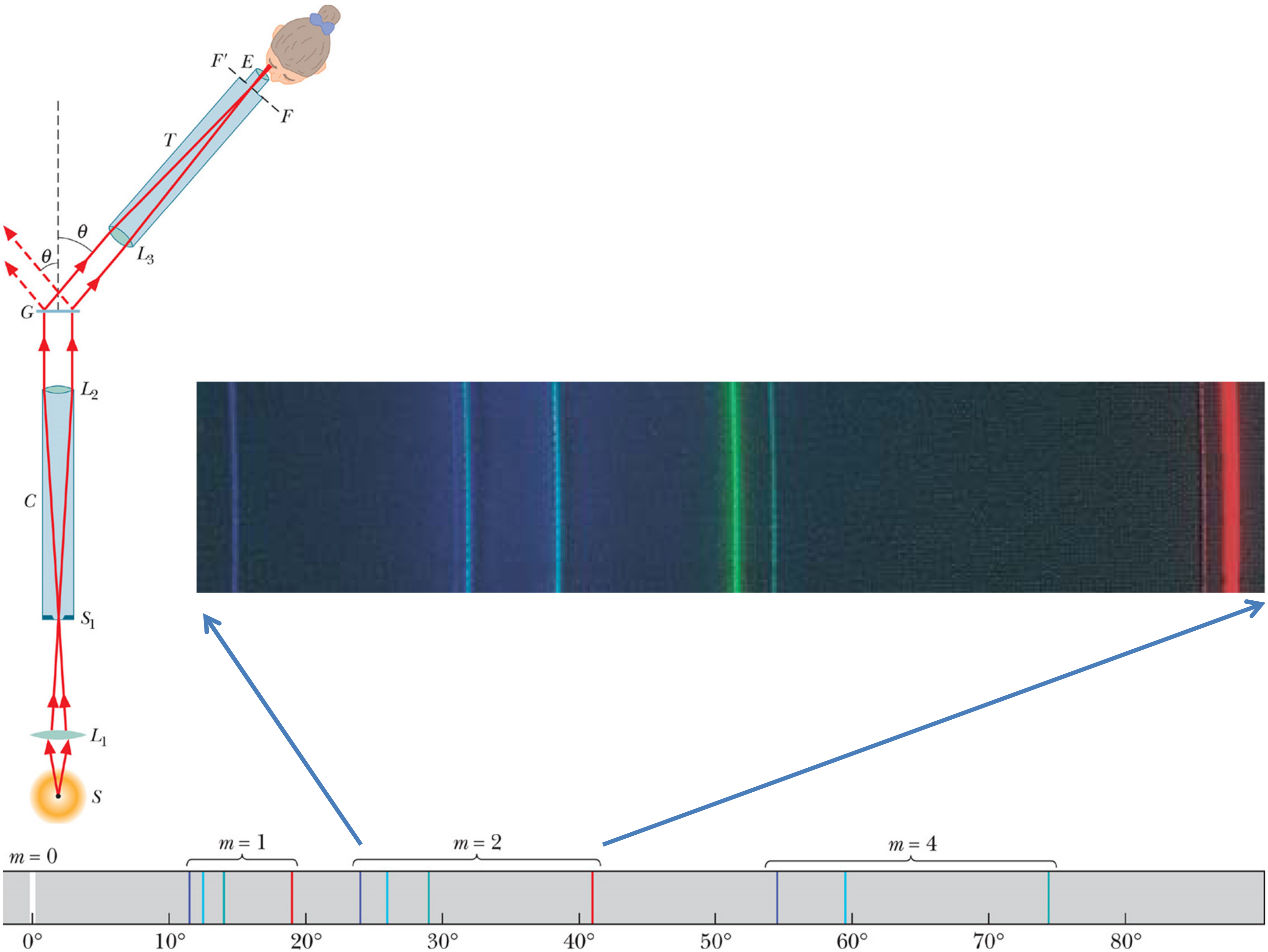
1. Green, red, blue
2. Red, green, blue
3. Blue, green, red
4. Green, blue, red
5. Blue, red, green

$m\lambda = d\sin\theta$



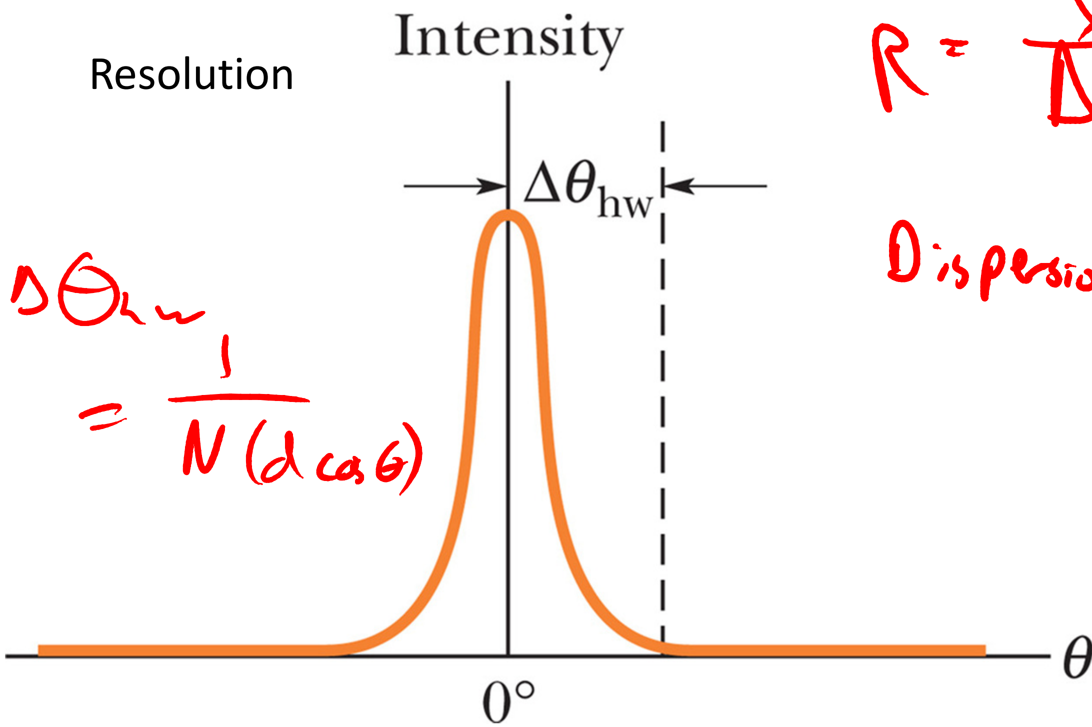


$m\lambda = d\sin\theta$



F′
E
F
T
θ
θ
L3
G
L2
C
S1
L1
S
m = 0
m = 1
m = 2
m = 4
0°
10°
20°
30°
40°
50°
60°
70°
80°

Resolution



$$R = \frac{\lambda}{\Delta\lambda} \qquad \lambda \propto \theta$$

$$\Delta\theta_{hw} = \frac{1}{N(d\cos\theta)}$$

Dispersion $D = \frac{\Delta\theta}{\Delta\lambda} = \frac{d\theta}{d\lambda}$

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

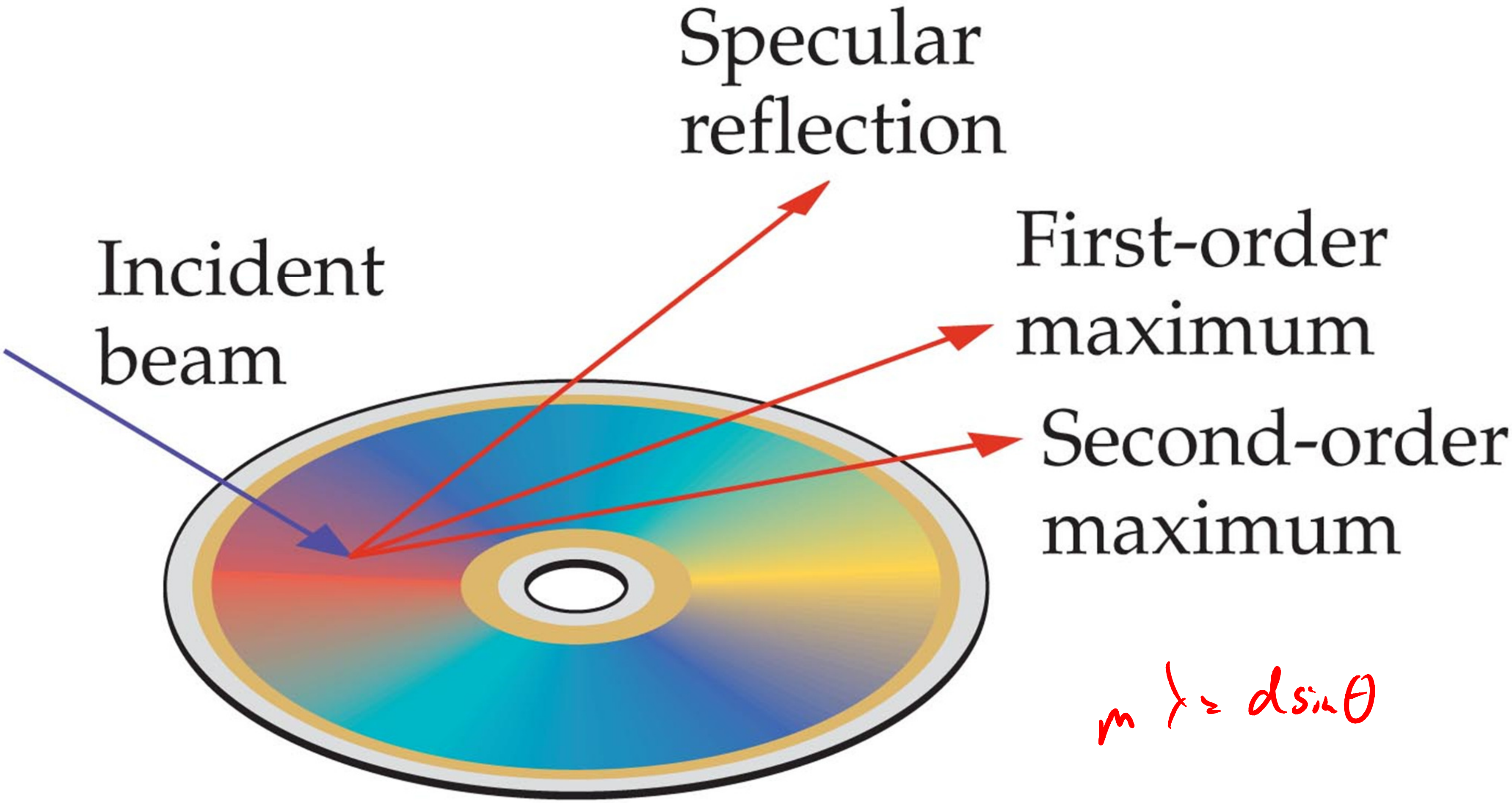
$$d(\cos\theta)\,d\theta = m\,d\lambda$$

$$\frac{d\theta}{d\lambda} = \frac{m}{d(d\cos\theta)} = D$$

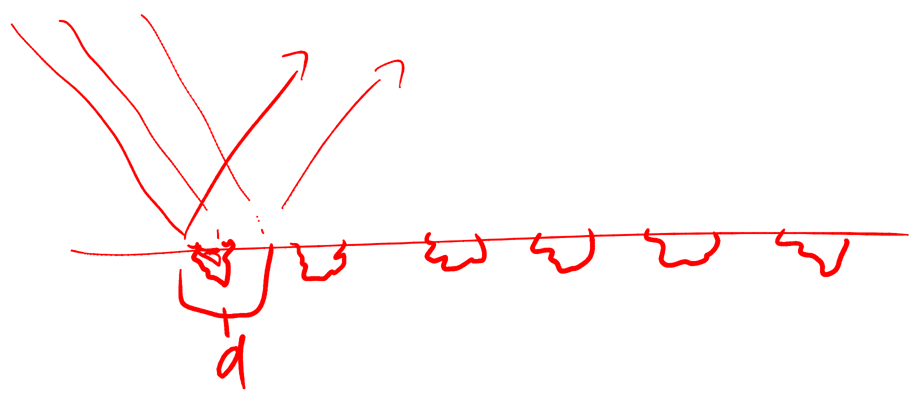
$$\frac{\lambda}{N\frac{(d\cos\theta)}{d\lambda}} = \frac{m}{(d\cos\theta)}$$

$$\frac{\lambda}{N} = m\,d\lambda$$

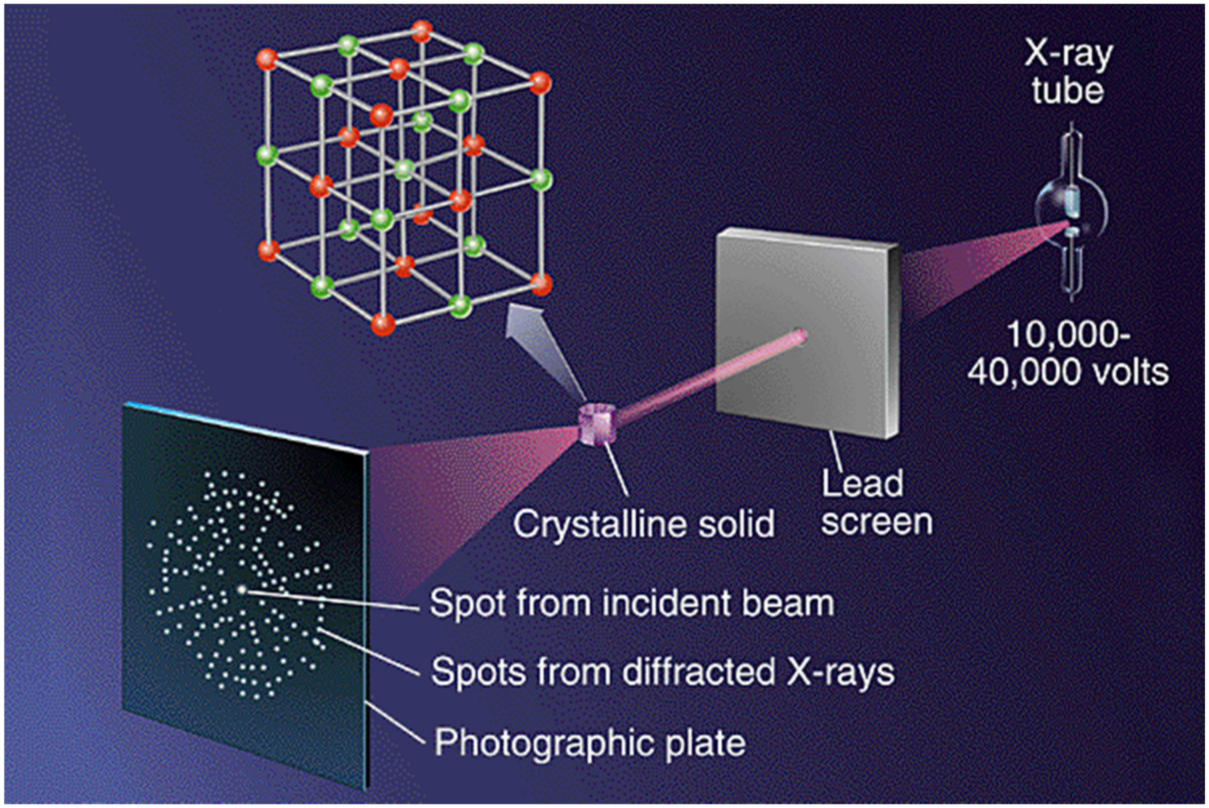
so $R = \frac{\lambda}{\Delta\lambda} = N \cdot m$



$m\lambda = d\sin\theta$



(from http://www.scienceiscool.org)



(from Crain's Petrophysical Handbook)

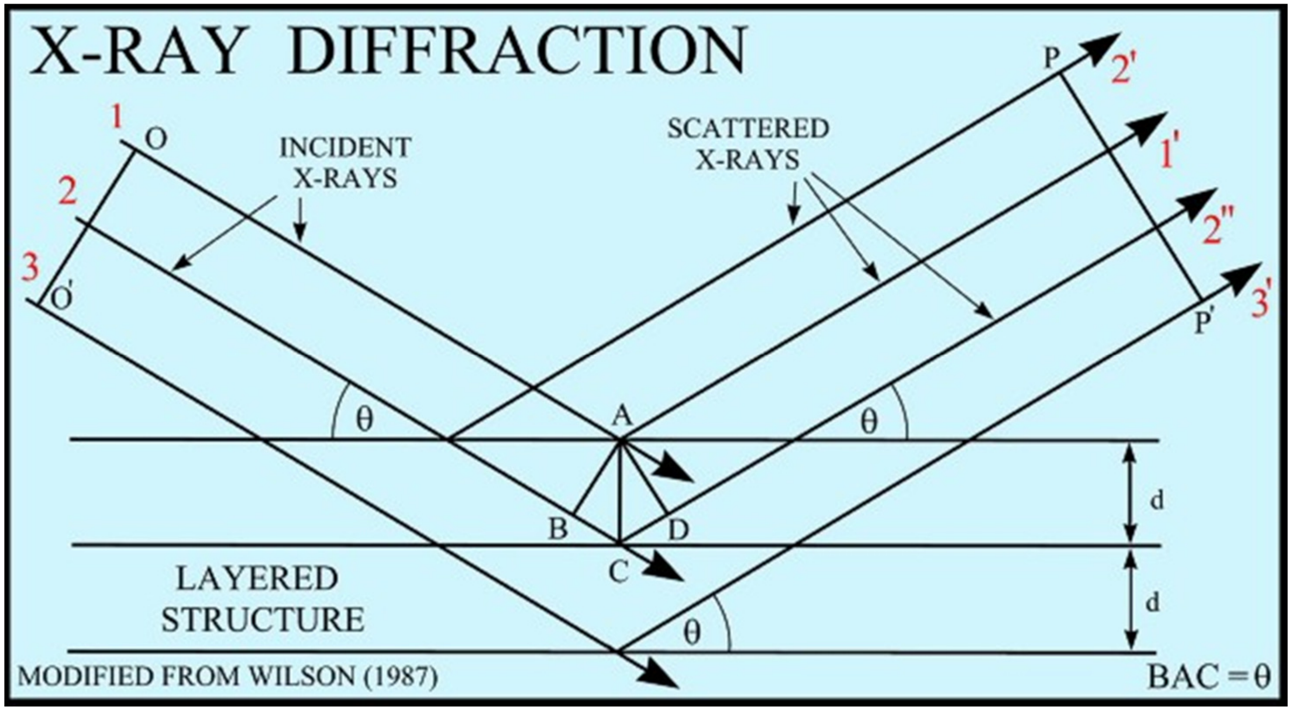
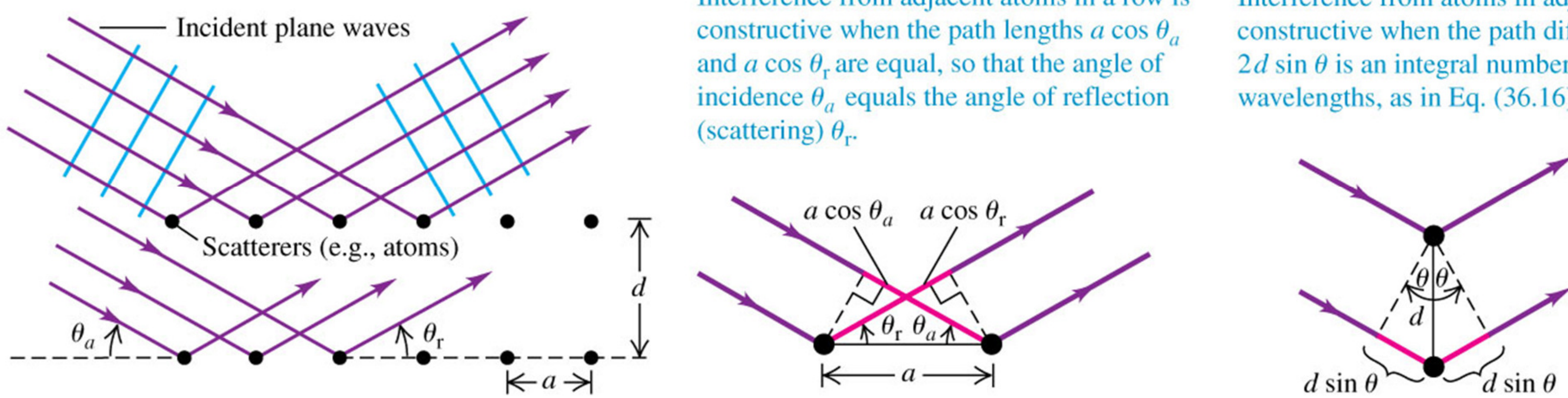


Fig.36.22

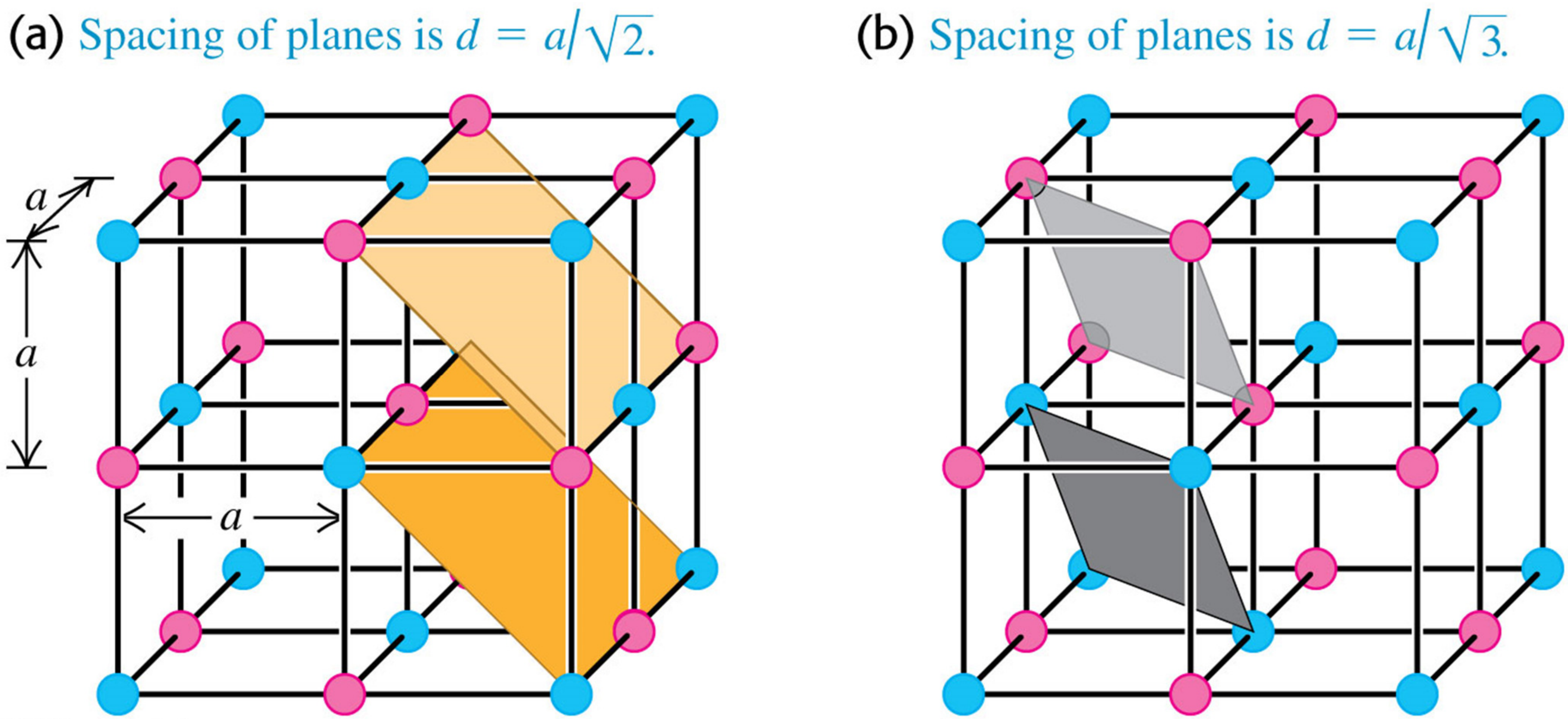


(a) Scattering of waves from a rectangular array

(b) Scattering from adjacent atoms in a row
Interference from adjacent atoms in a row is constructive when the path lengths $a \cos \theta_a$ and $a \cos \theta_r$ are equal, so that the angle of incidence θ_a equals the angle of reflection (scattering) θ_r.

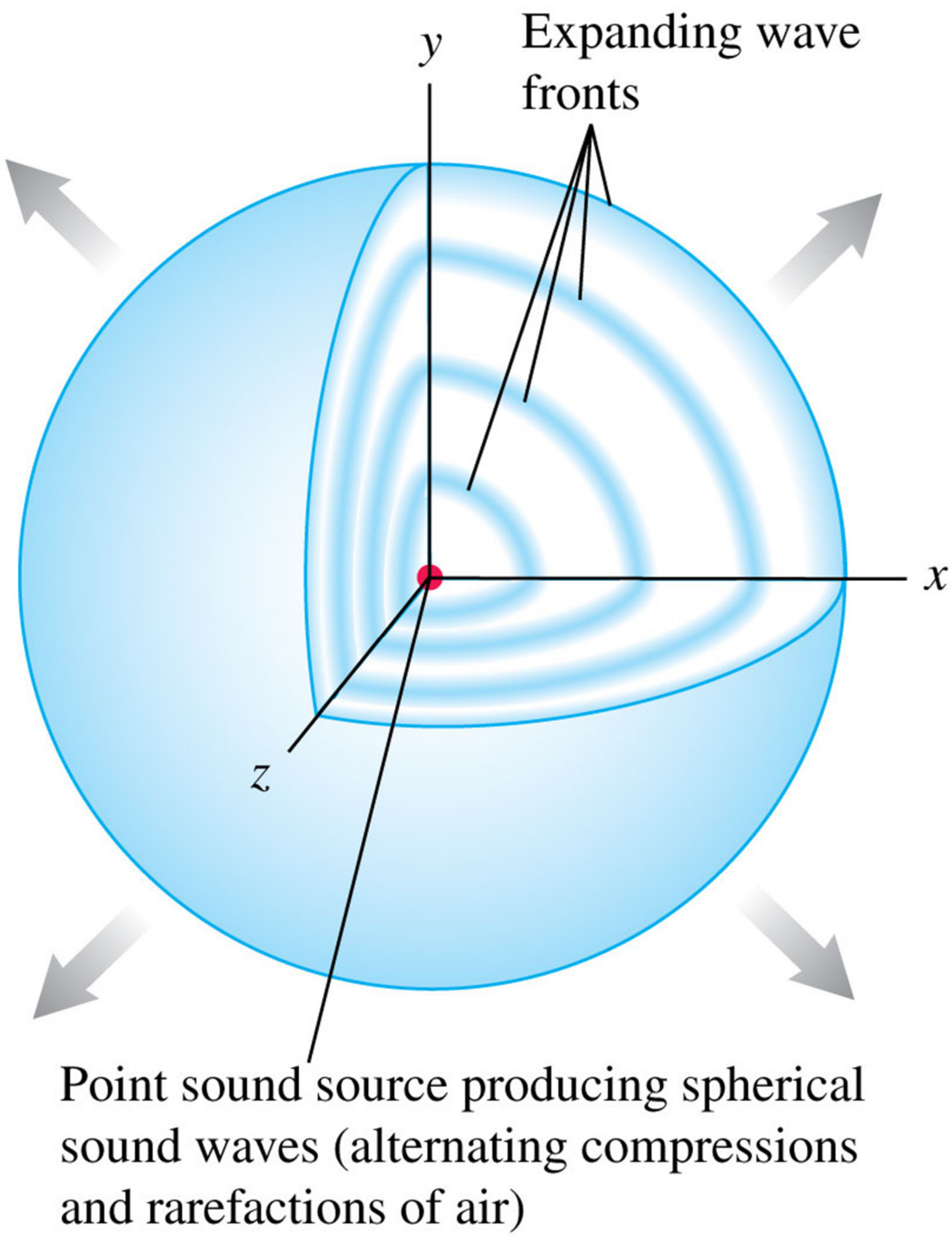
(c) Scattering from atoms in adjacent rows
Interference from atoms in adjacent rows is constructive when the path difference $2d \sin \theta$ is an integral number of wavelengths, as in Eq. (36.16).

Fig.36.23

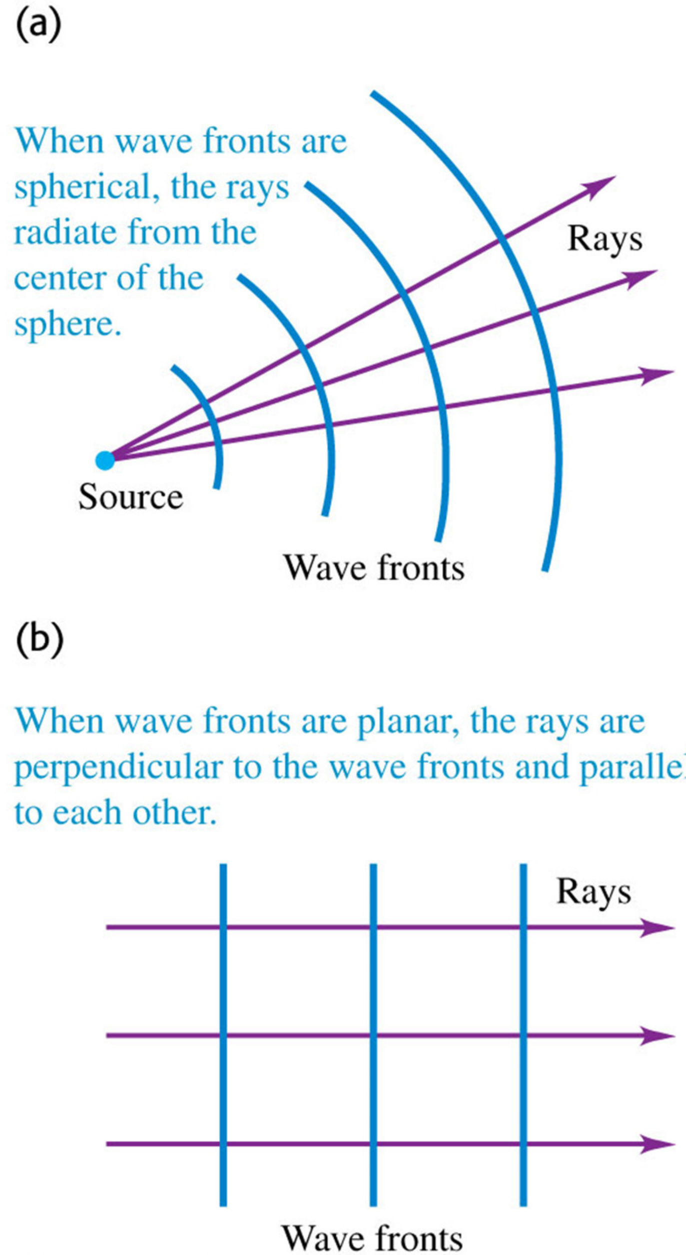


(a) Spacing of planes is $d = a/\sqrt{2}$.
a
a
a
(b) Spacing of planes is $d = a/\sqrt{3}$.

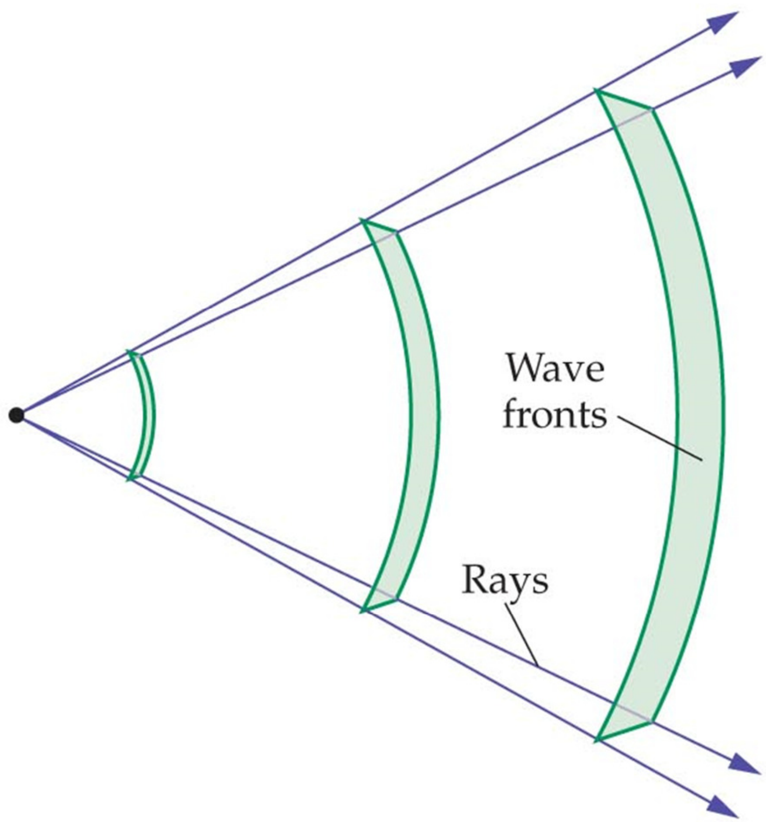
End of diffraction, start of Geometric Optics



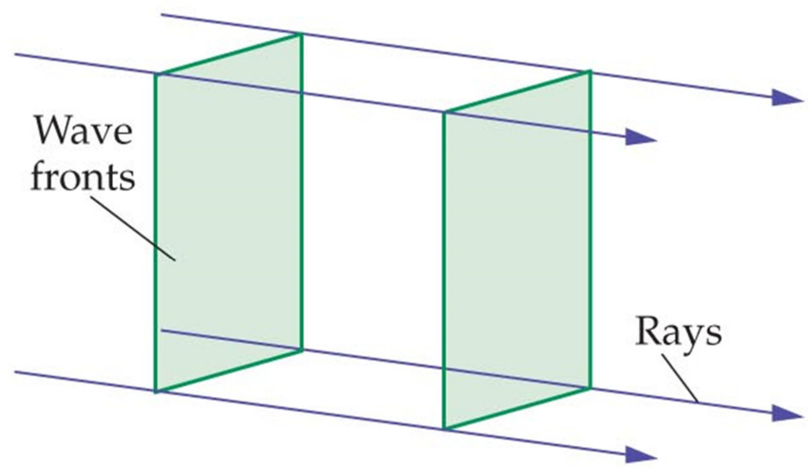
y
Expanding wave fronts
x
z
Point sound source producing spherical sound waves (alternating compressions and rarefactions of air)



(a)
When wave fronts are spherical, the rays radiate from the center of the sphere.
Rays
Source
Wave fronts
(b)
When wave fronts are planar, the rays are perpendicular to the wave fronts and parallel to each other.
Rays
Wave fronts



(a) Spherical wave fronts



(b) Planar wave fronts

Huygen's Principle

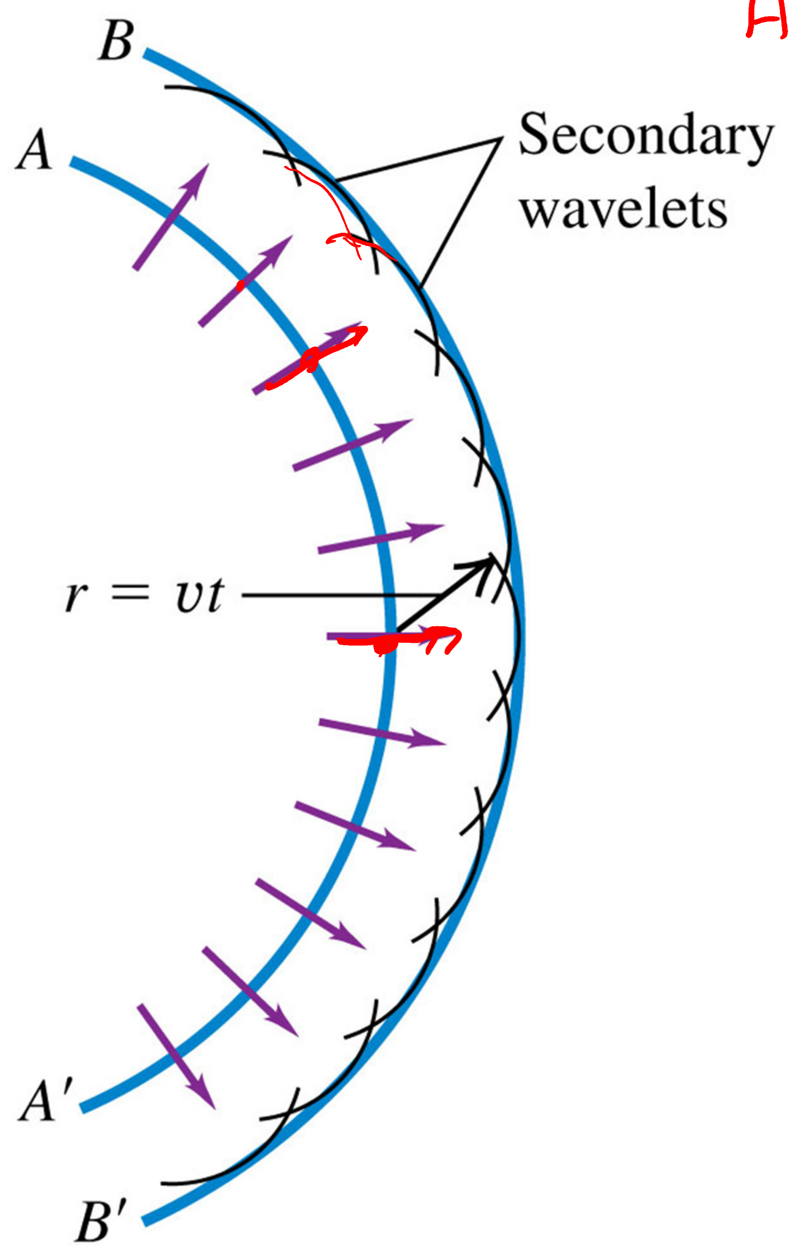


Fig.37.3

"Camera Obscura" (pinhole camera)

"Magnification"

$M=h_i/h_o$

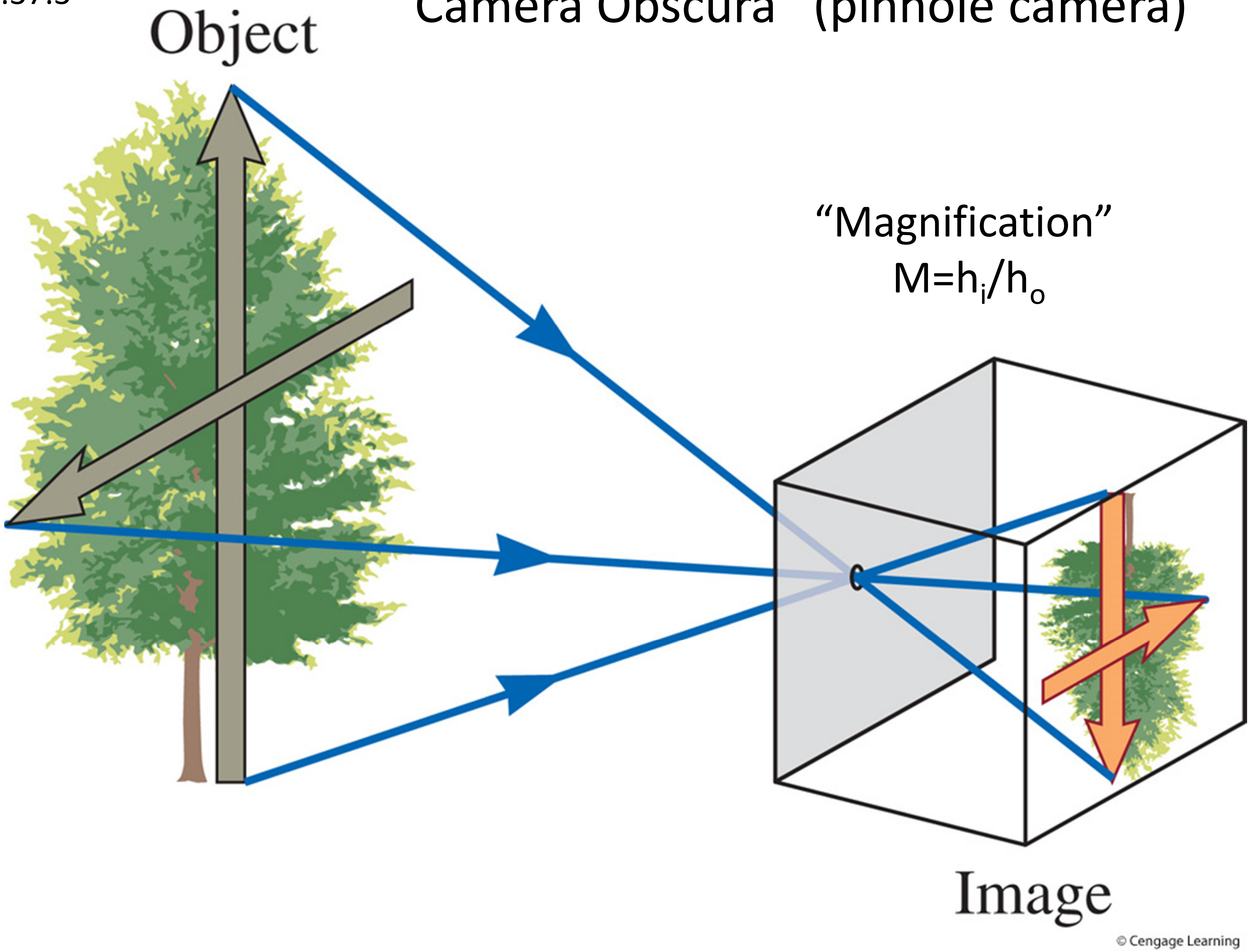
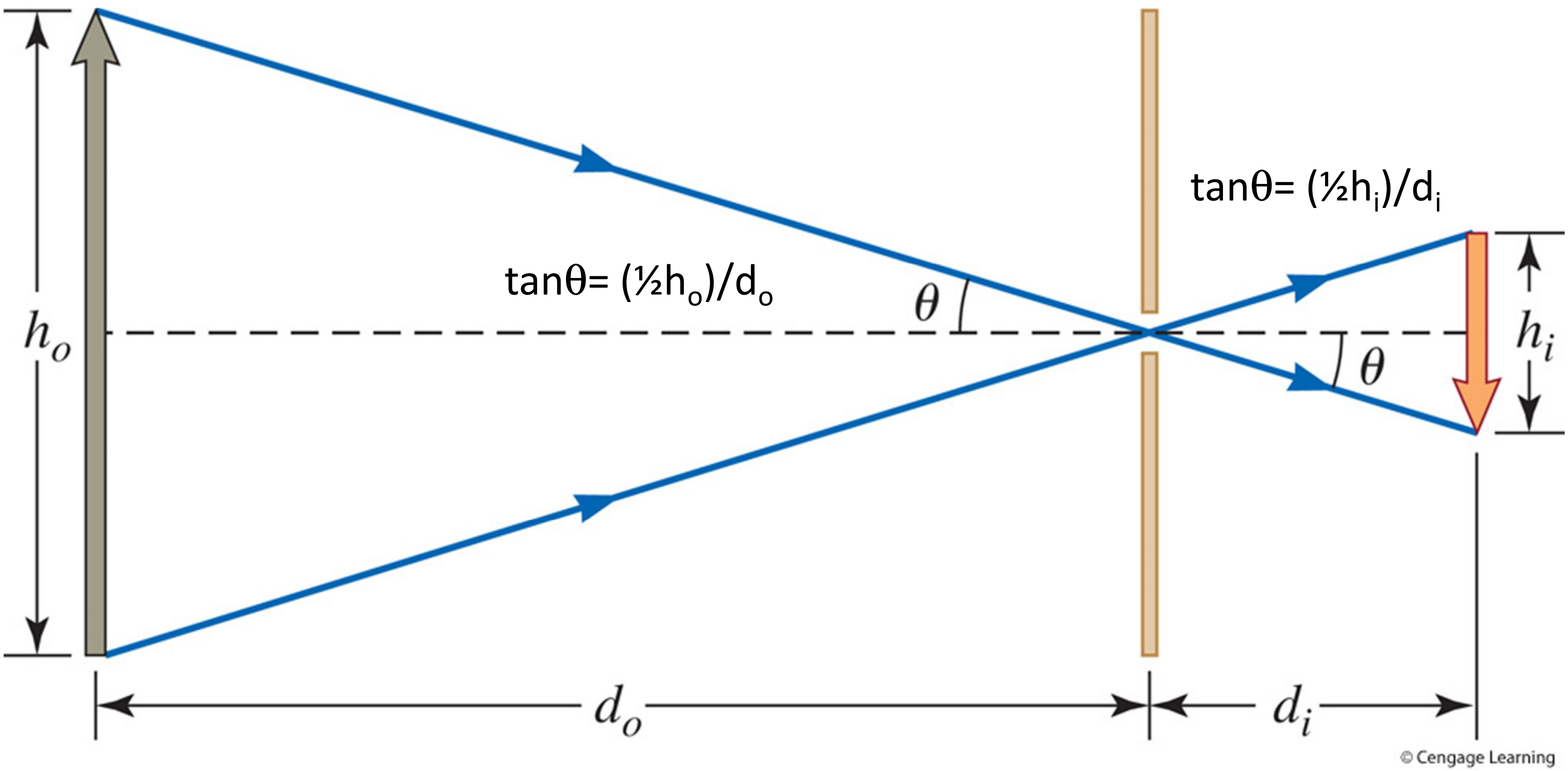
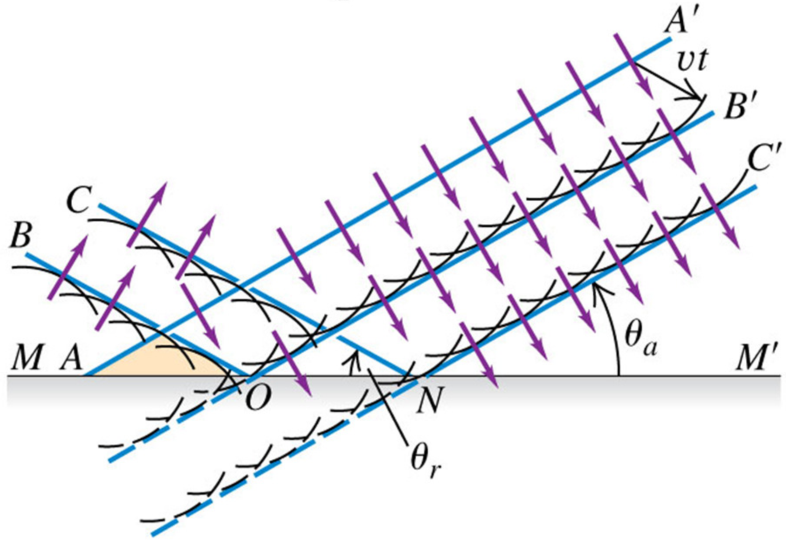


Fig.37.3

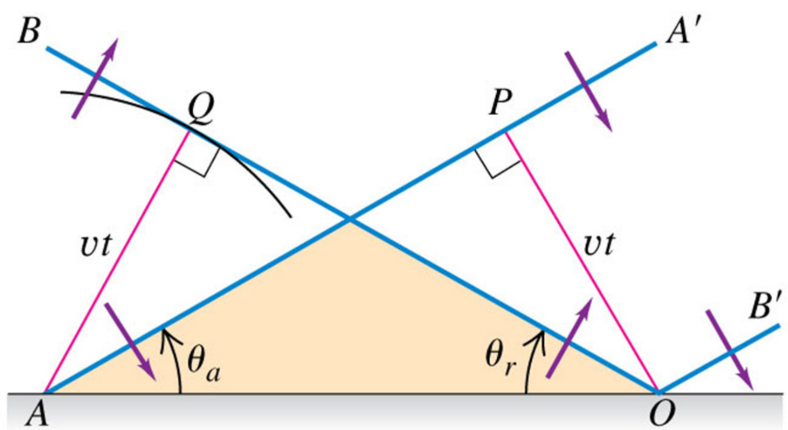


Combine the two equations, get $M=h_i/h_o = -d_i/d_o$
Why negative? Negative M means upside down

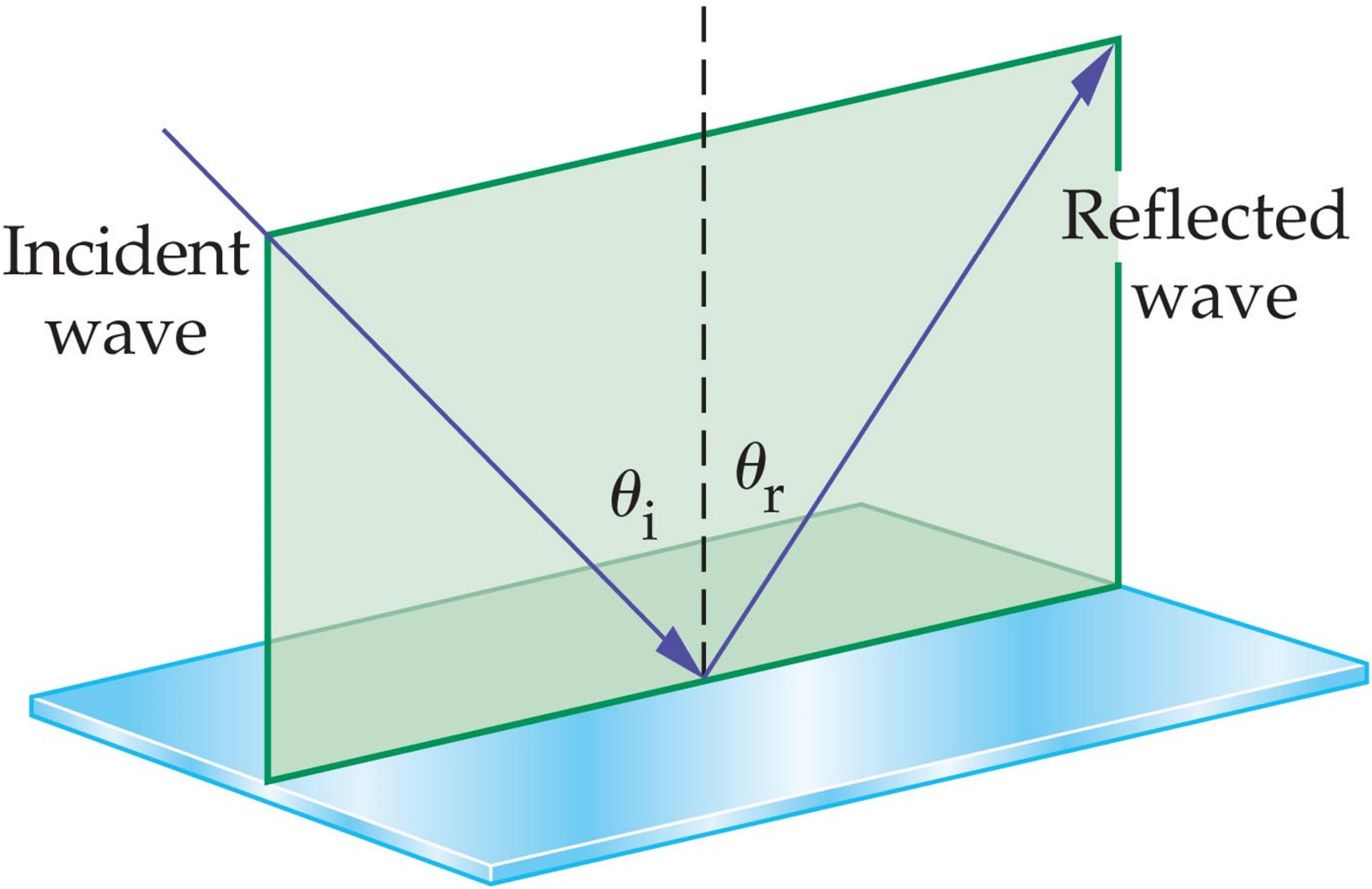
(a) Successive positions of a plane wave AA' as it is reflected from a plane surface



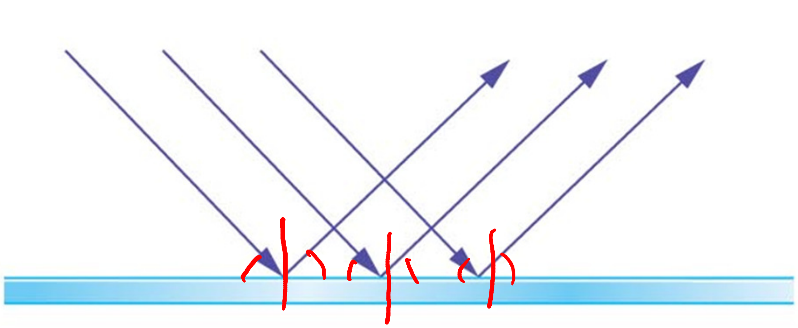
(b) Magnified portion of **(a)**



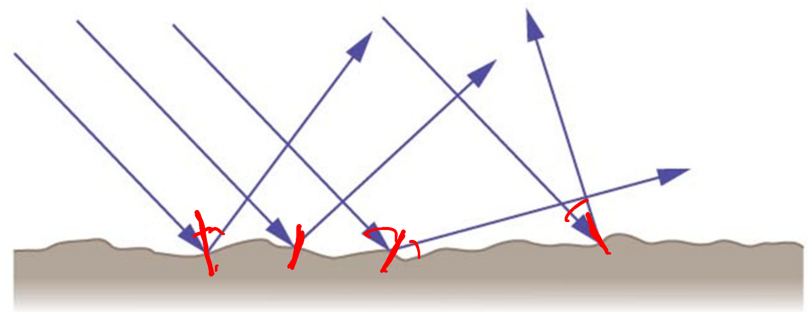
$\theta_i = \theta_R$



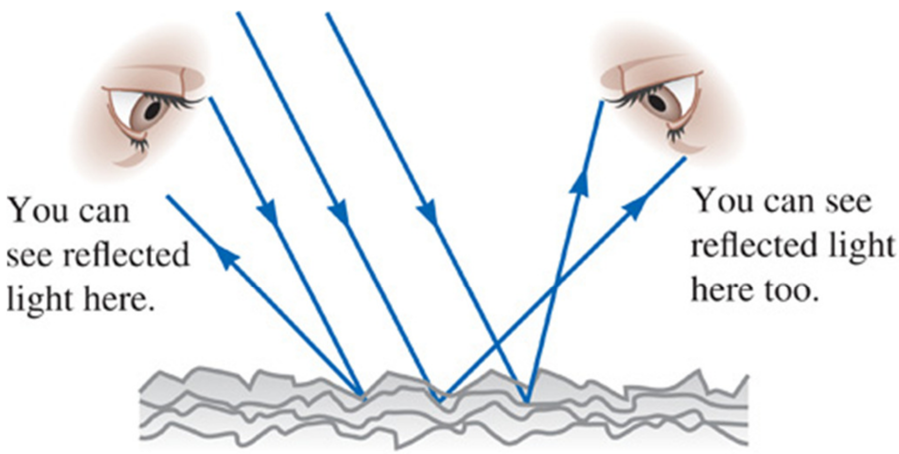
Law of reflection still applies for each ray…



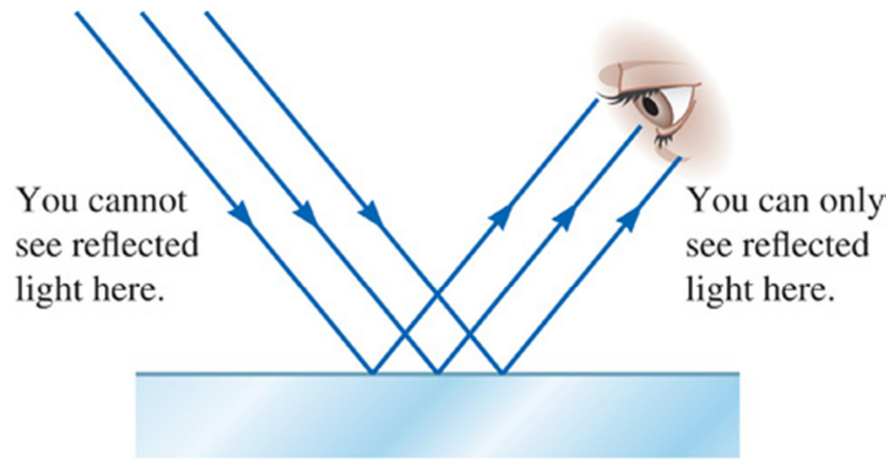
(a) Specular reflection



(b) Diffuse reflection

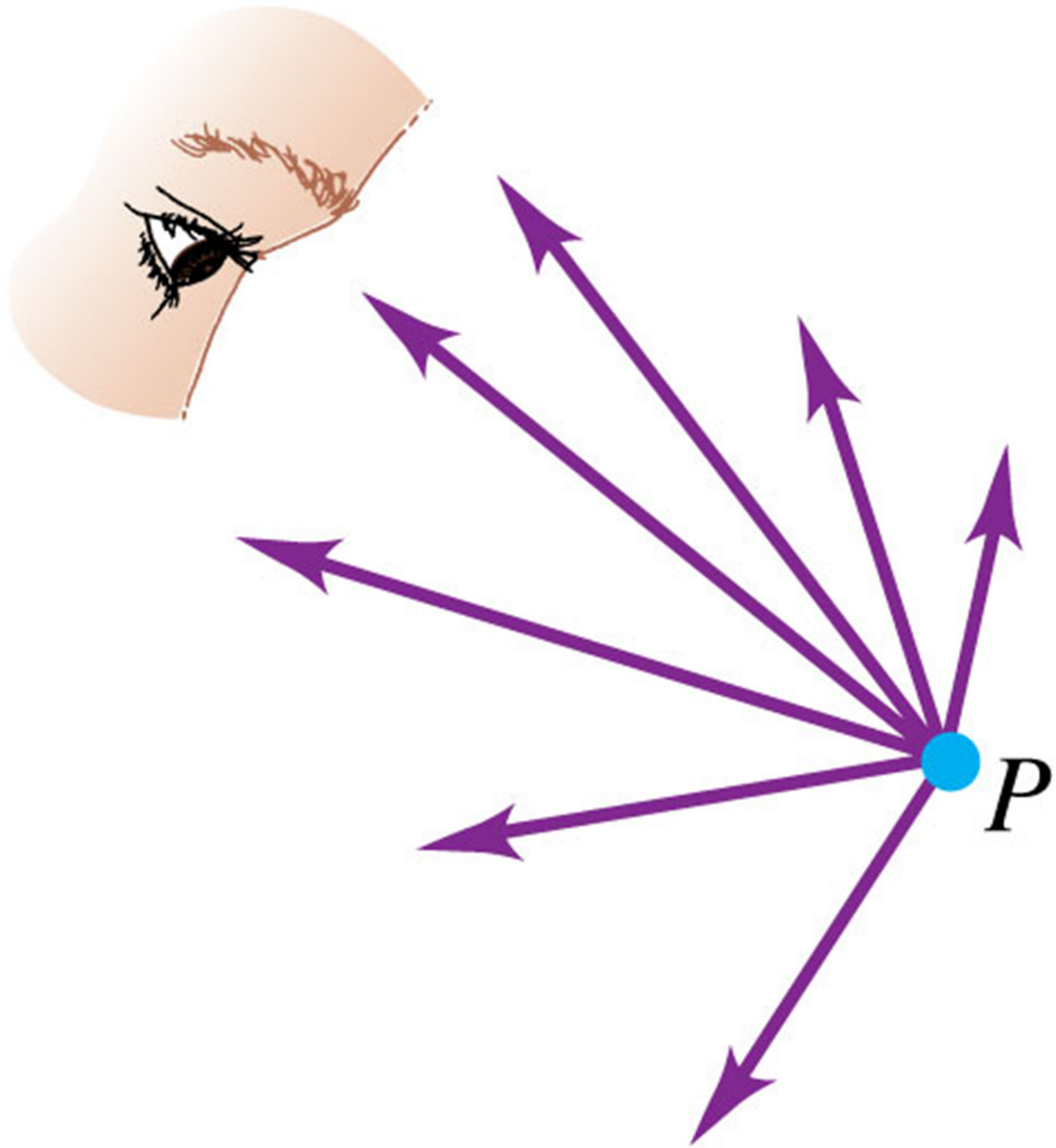


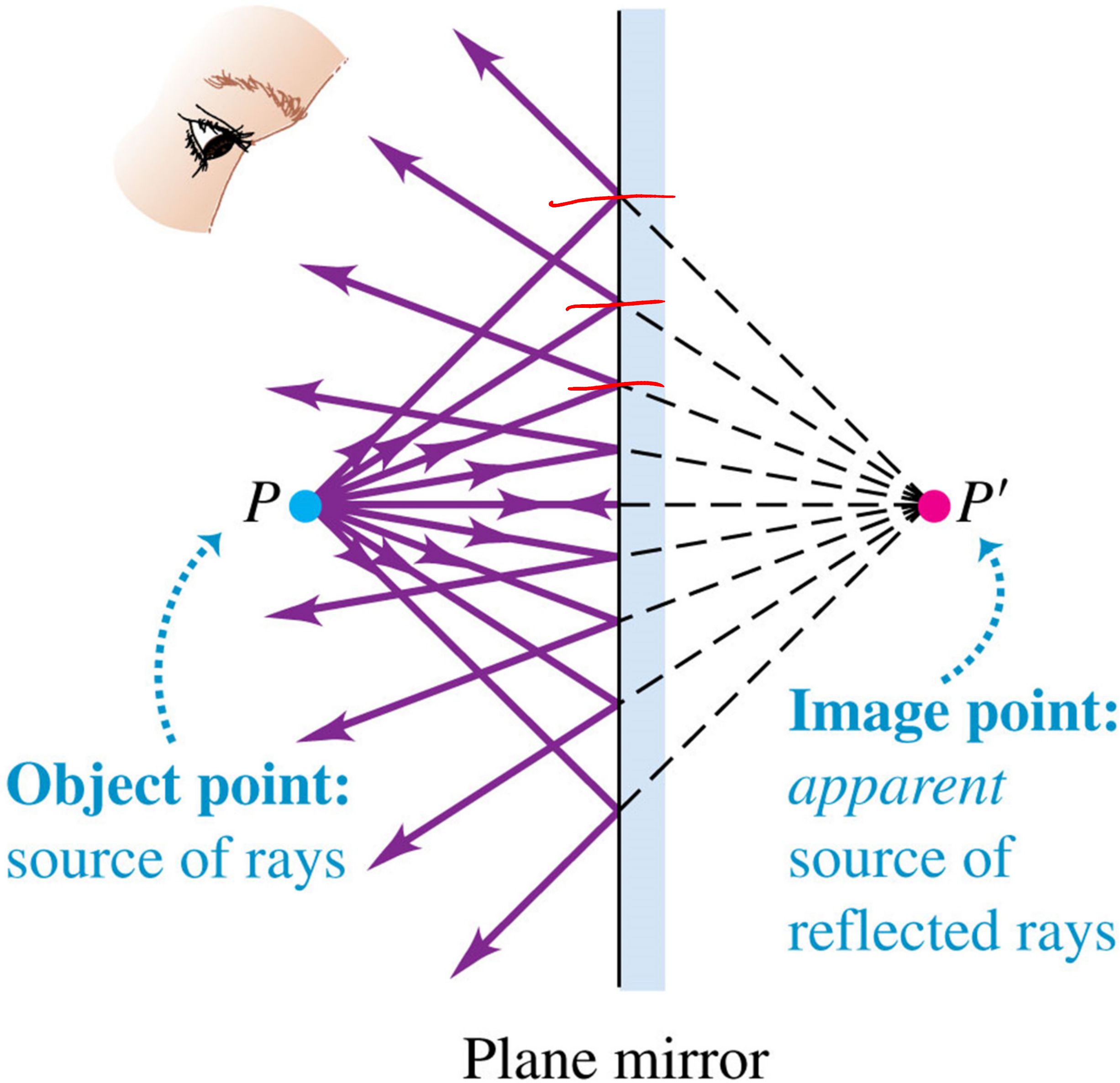
A. Diffuse reflection



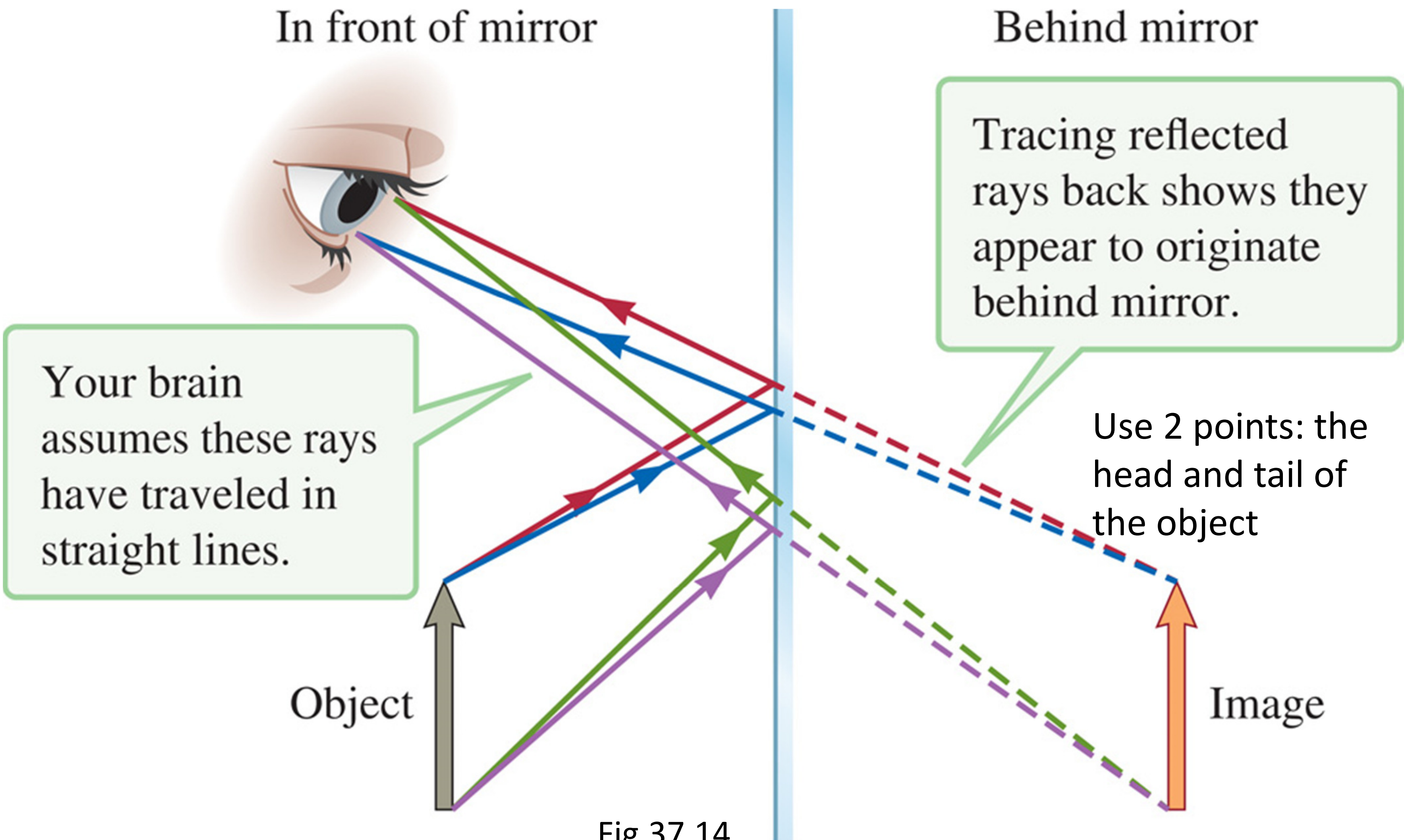
B. Specular reflection

Fig.37.14


P

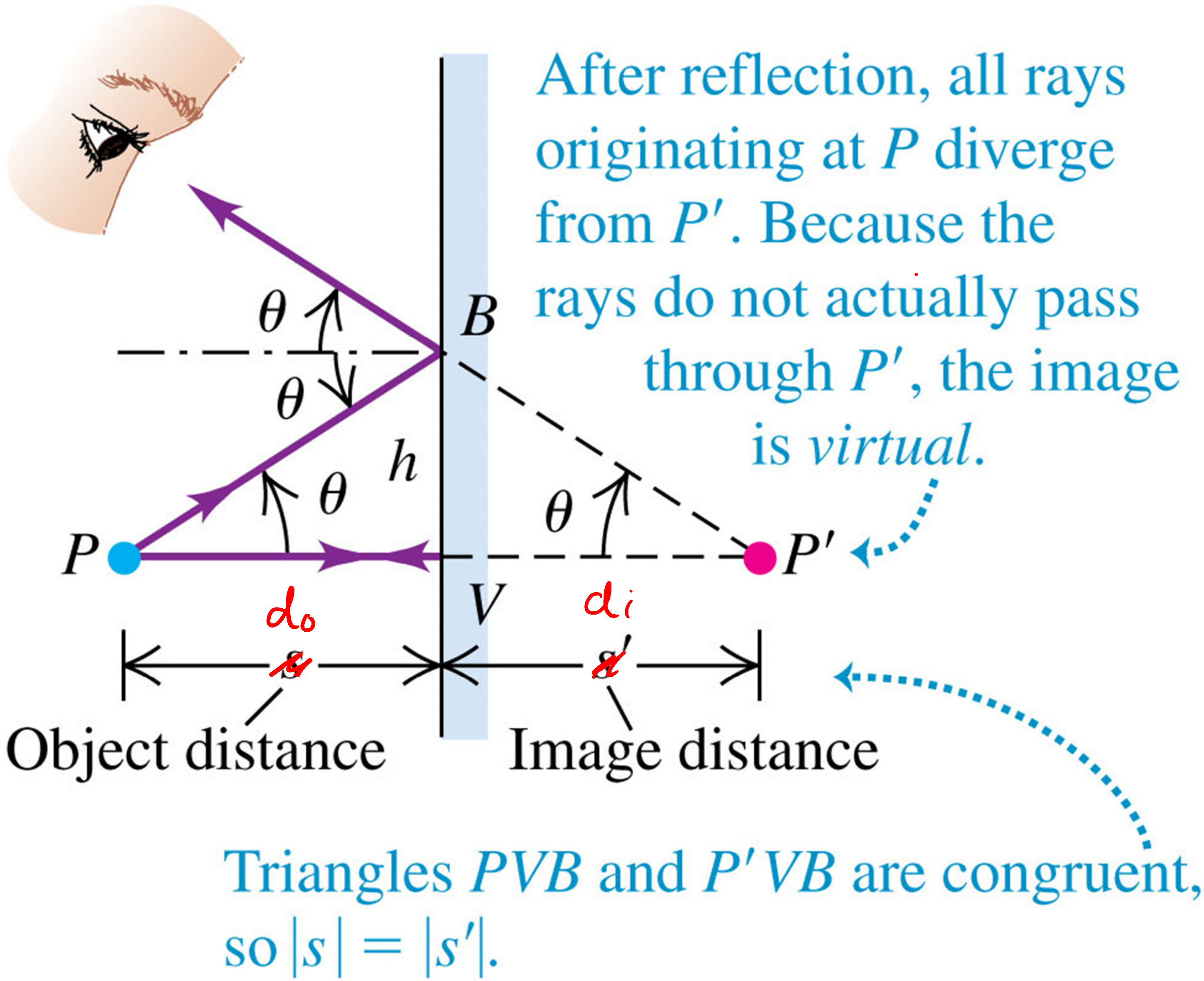

P
P′
Image point:
apparent
source of
reflected rays
Object point:
source of rays
Plane mirror

How does this work for non-point objects?



Use 2 points: the head and tail of the object

Fig.37.14


After reflection, all rays originating at P diverge from P′. Because the rays do not actually pass through P′, the image is *virtual*.
θ
θ
θ
θ
B
h
P
P′
V
d_o
d_i
s
s′
Object distance
Image distance
Triangles *PVB* and *P′VB* are congruent, so $|s| = |s'|$.

Two Types of Images

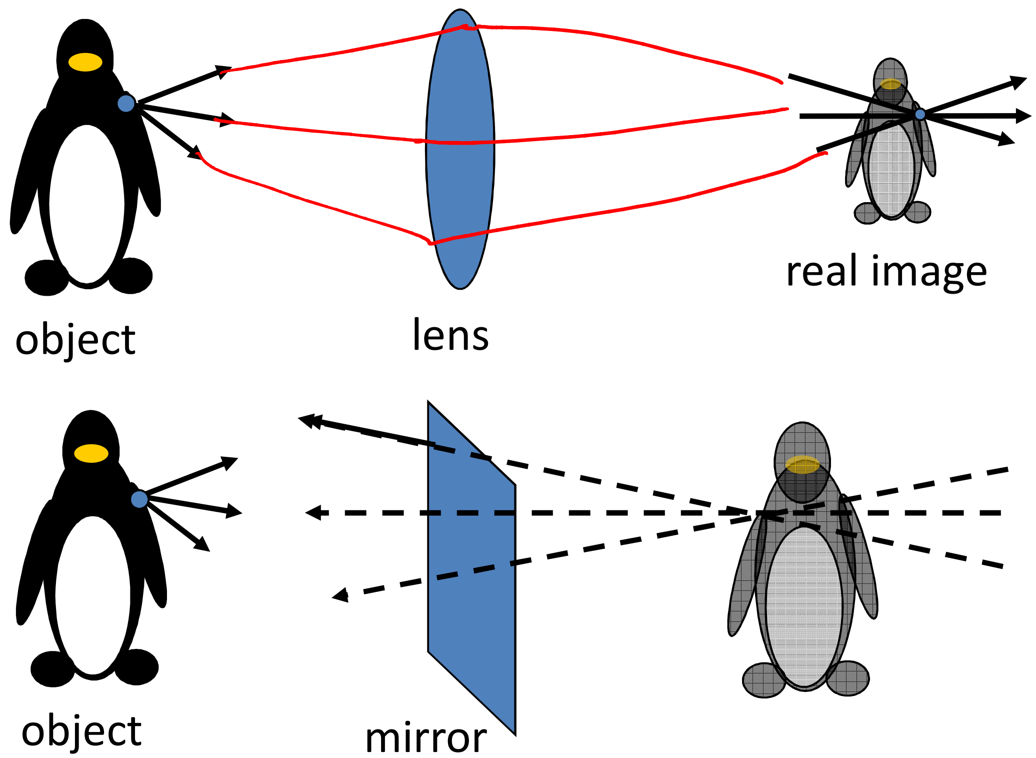
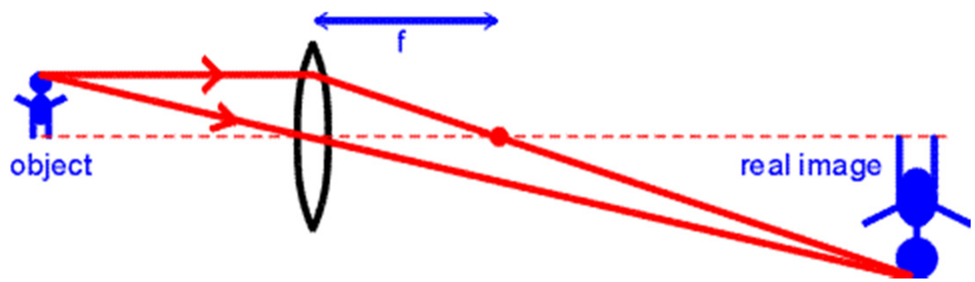


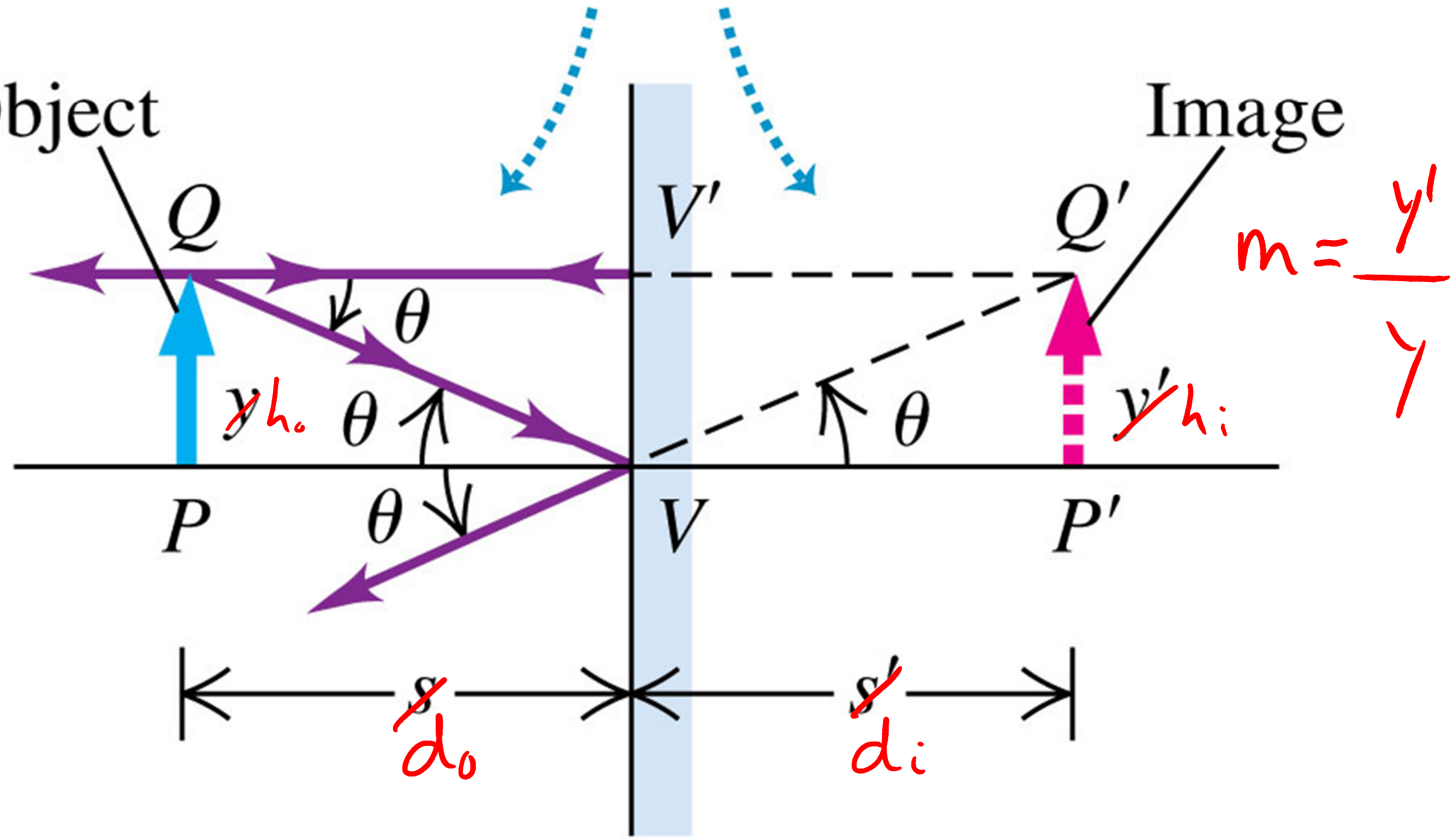
Image: A reproduction derived from light.

Real Image: Light rays actually pass through image, really exist in space (or on a screen for example) whether you are looking or not.

Virtual Image: No light rays actually pass through image. Only appear to be coming from image. Image only exists when rays are traced back to perceived location of source.


f
object
real image

For a plane mirror, PQV and $P'Q'V$ are congruent, so $y = y'$ and the object and image are the same size (the lateral magnification is 1).



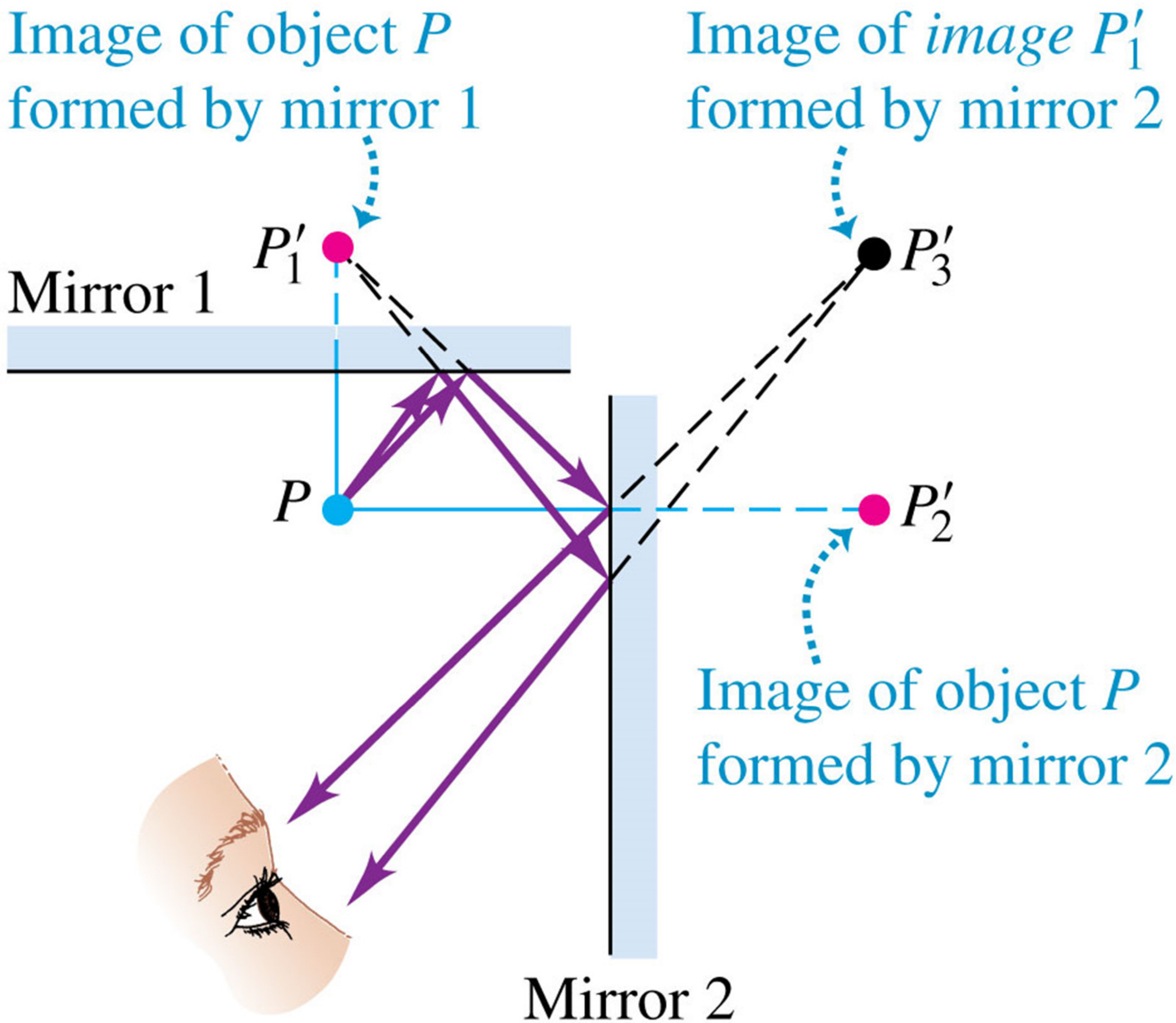
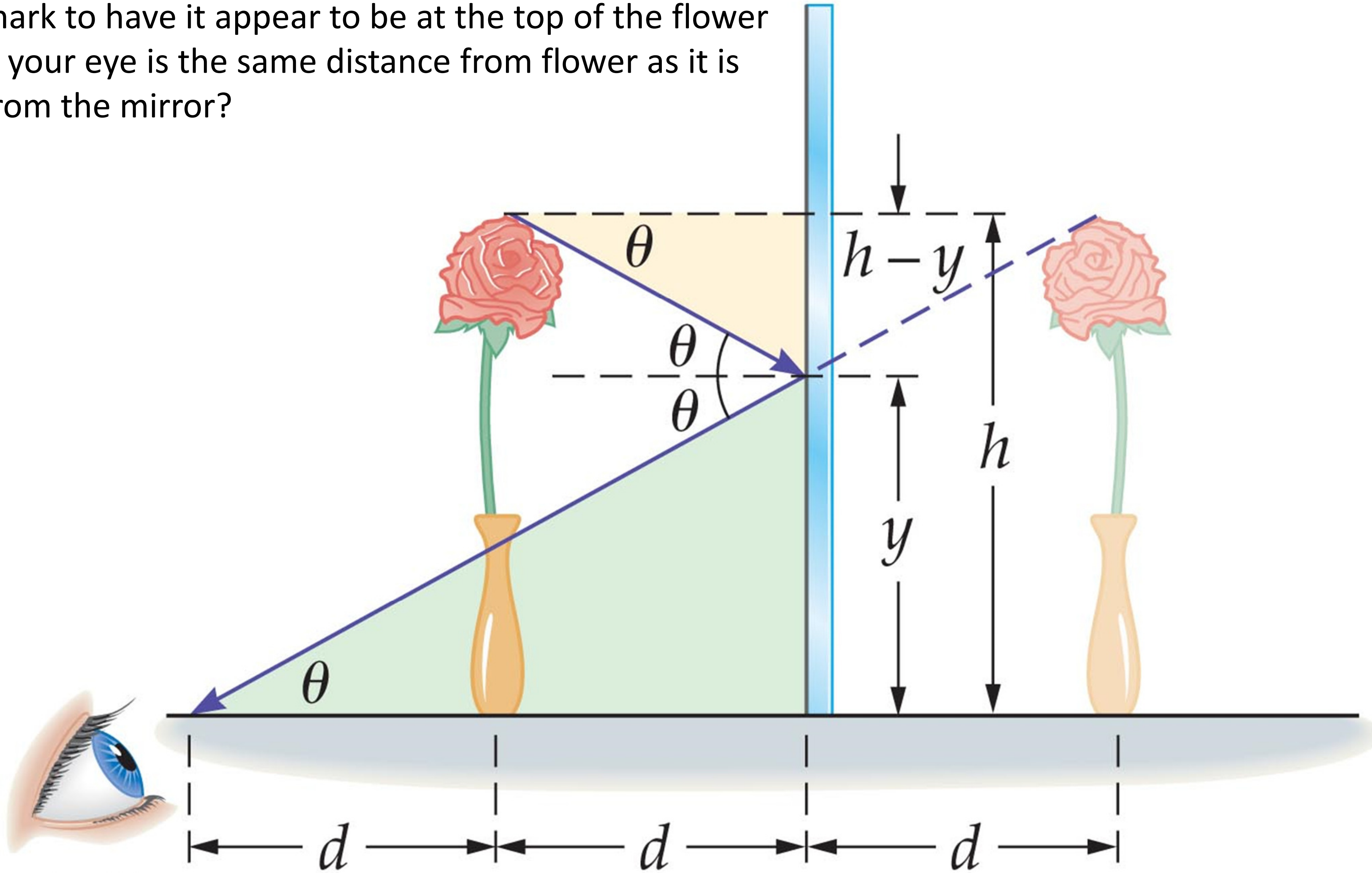


Image of object P formed by mirror 1
Image of *image* P_1' formed by mirror 2
P_1'
P_3'
Mirror 1
P
P_2'
Image of object P formed by mirror 2
Mirror 2

How high up on the mirror (y) would you make a mark to have it appear to be at the top of the flower if your eye is the same distance from flower as it is from the mirror?



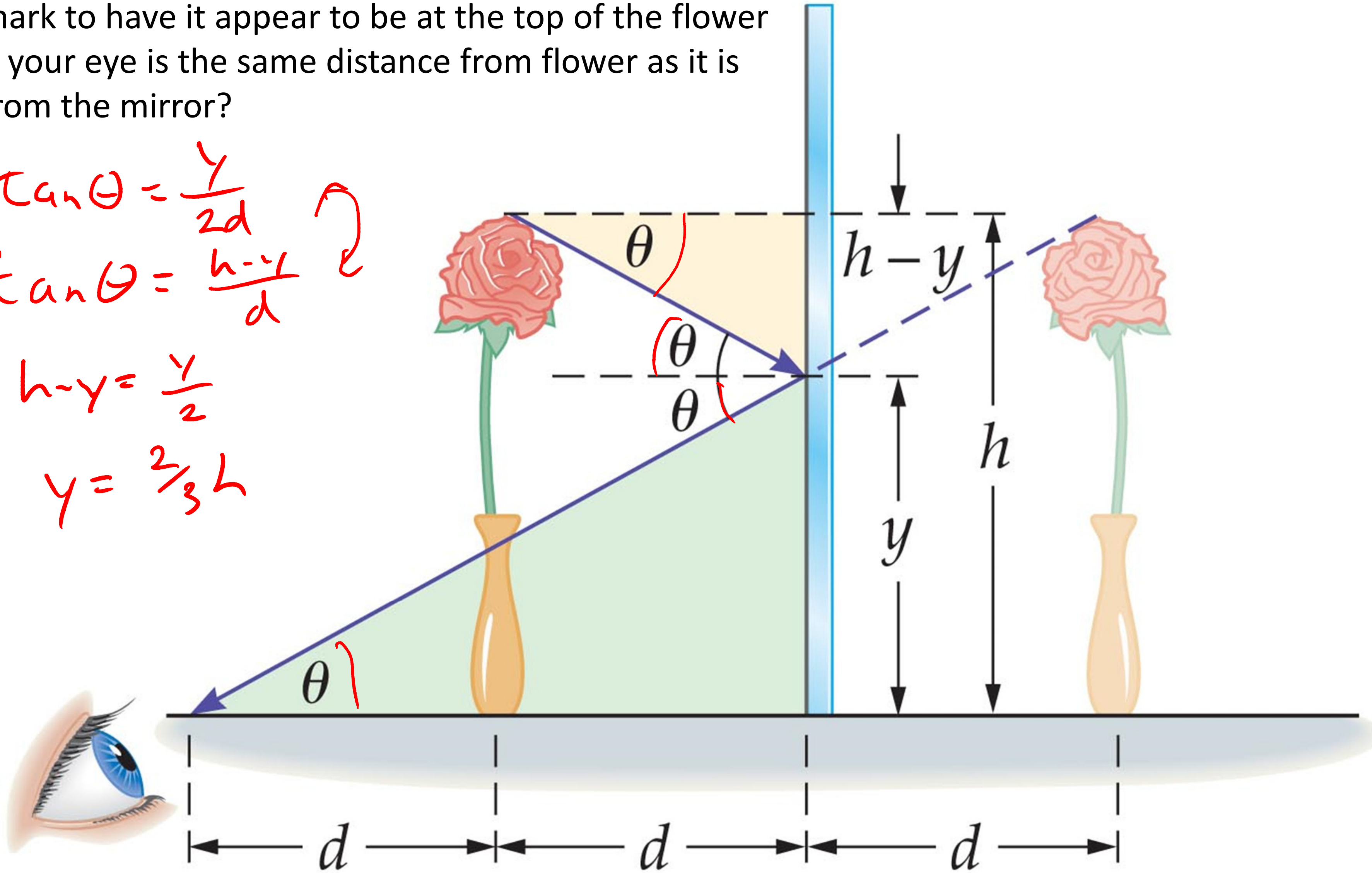
How high up on the mirror (y) would you make a mark to have it appear to be at the top of the flower if your eye is the same distance from flower as it is from the mirror?

$\tan\theta = \frac{y}{2d}$

$\tan\theta = \frac{h-y}{d}$

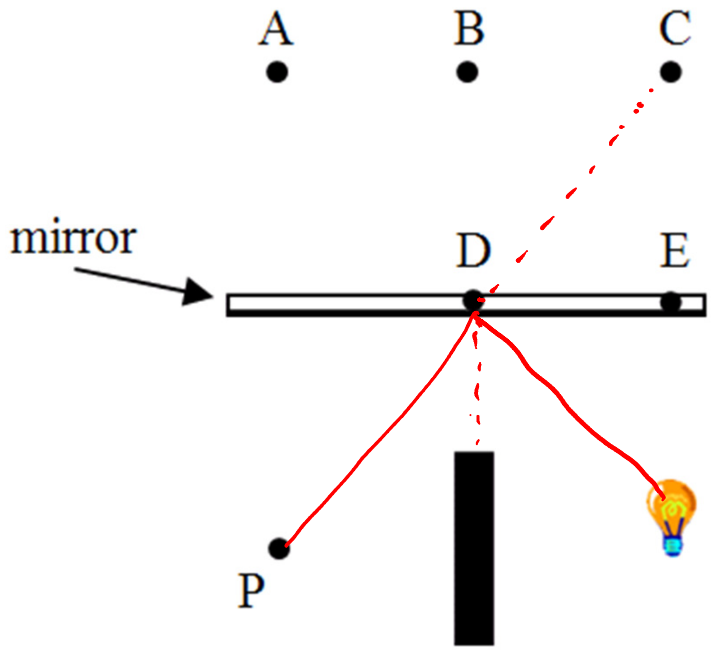
$h - y = \frac{y}{2}$

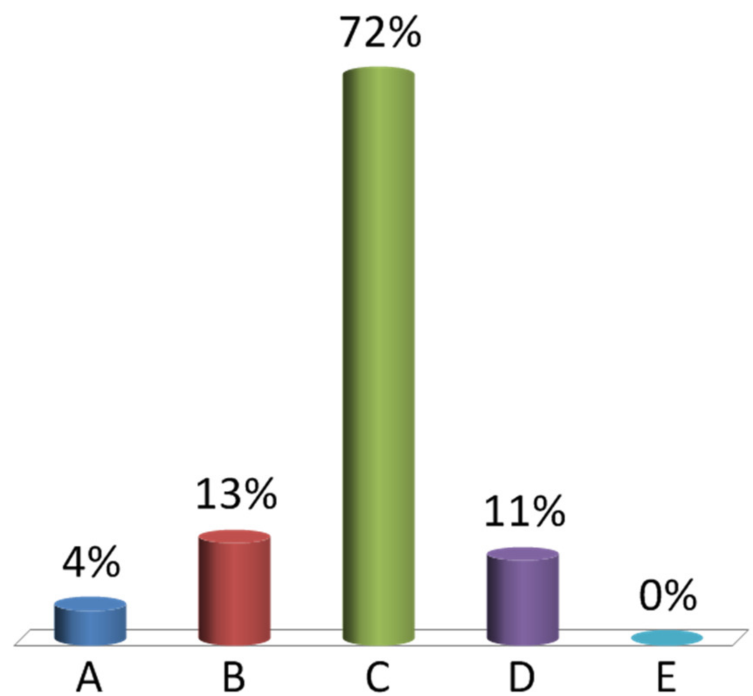
$y = \frac{2}{3}h$



You are standing in front of a mirror at the point P shown. There is a light bulb behind a screen that you cannot see directly. As you look in the mirror, where does the image of the light bulb appear?

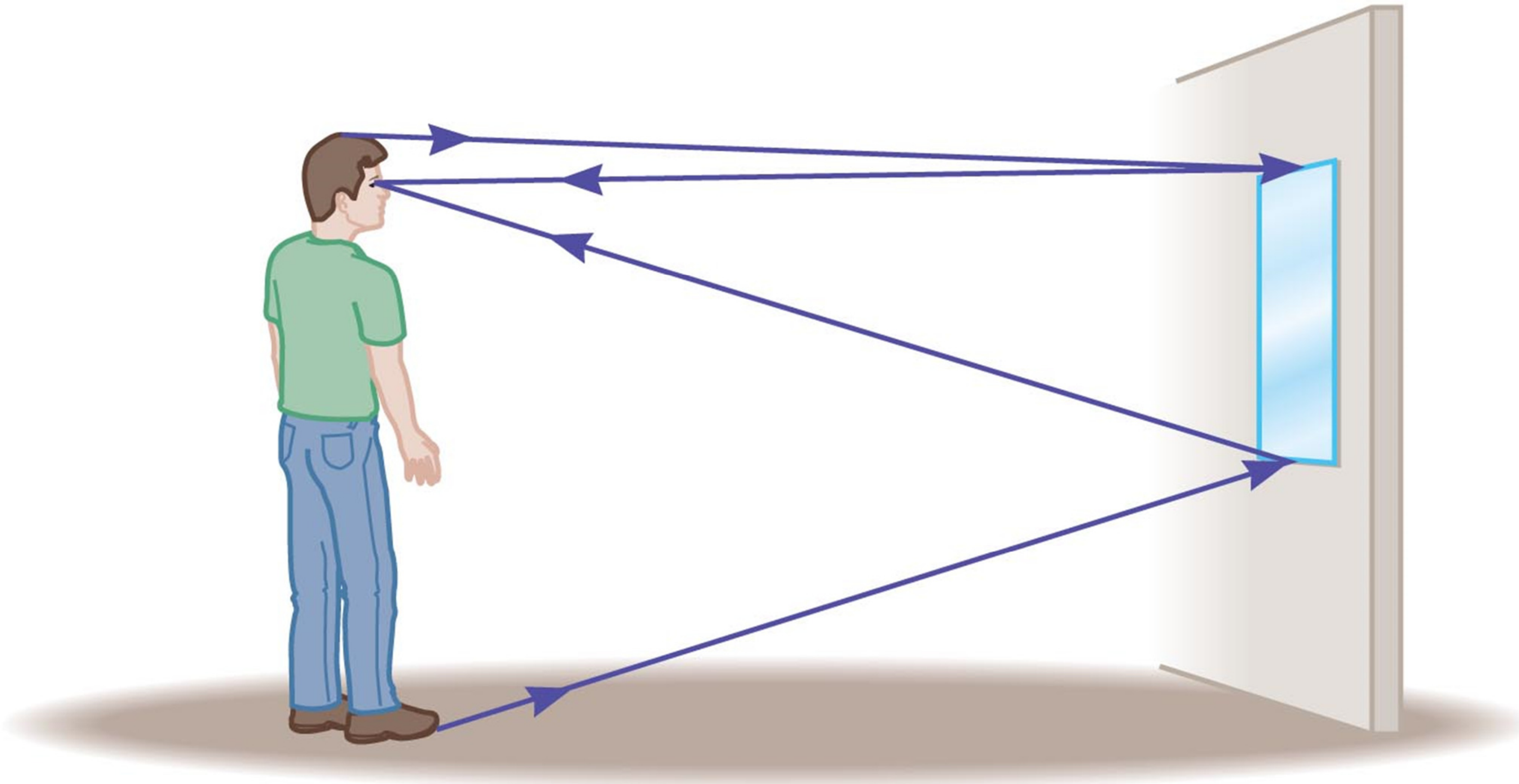
1. A
2. B
3. C ✓
4. D
5. E



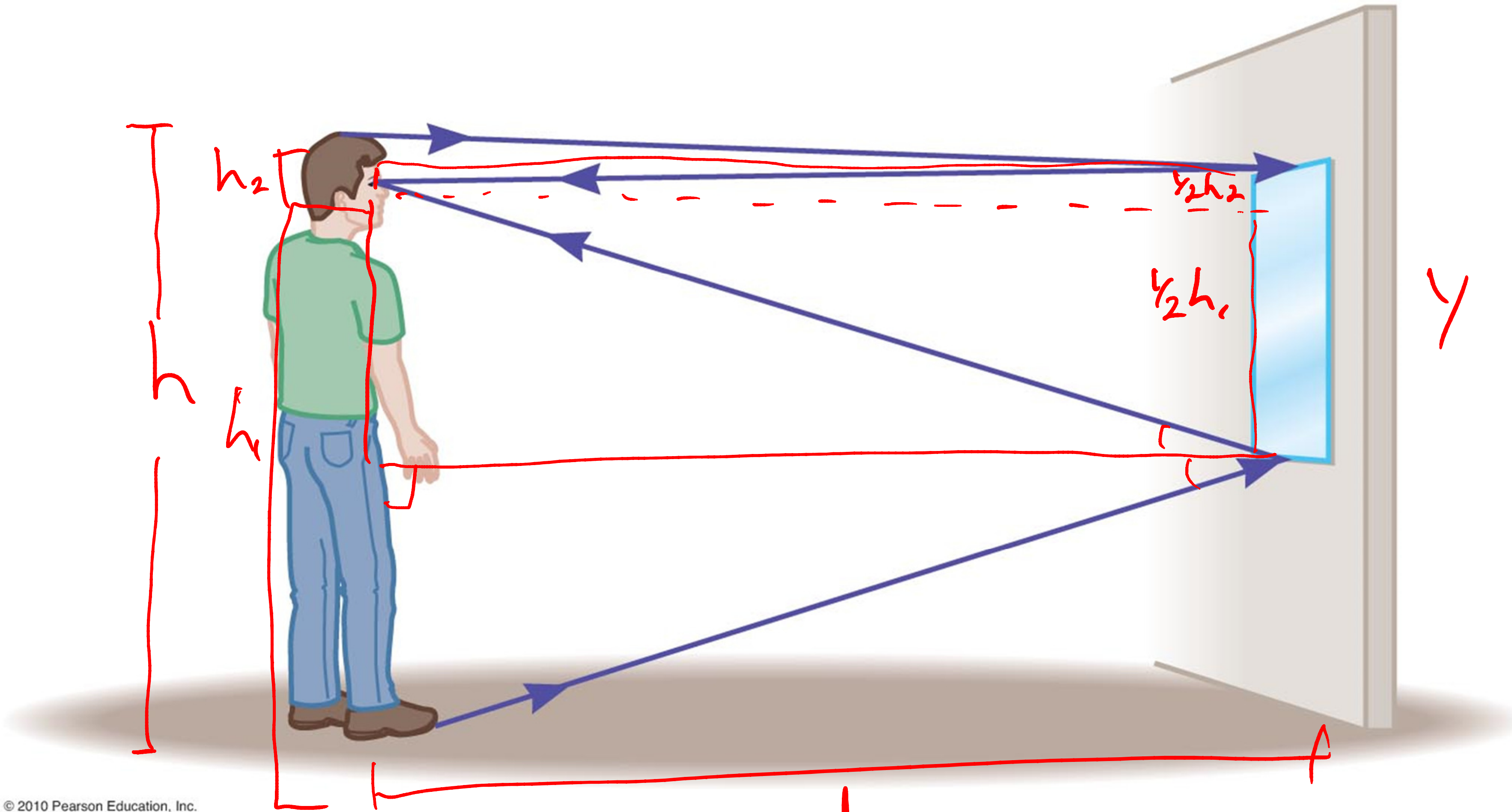


0

For a guy who is *h* meters tall, what's the smallest height mirror he could buy that would let him see his whole self from top of hair to bottom of shoes?



For a guy who is *h* meters tall, what's the smallest height mirror he could buy that would let him see his whole self from top of hair to bottom of shoes?

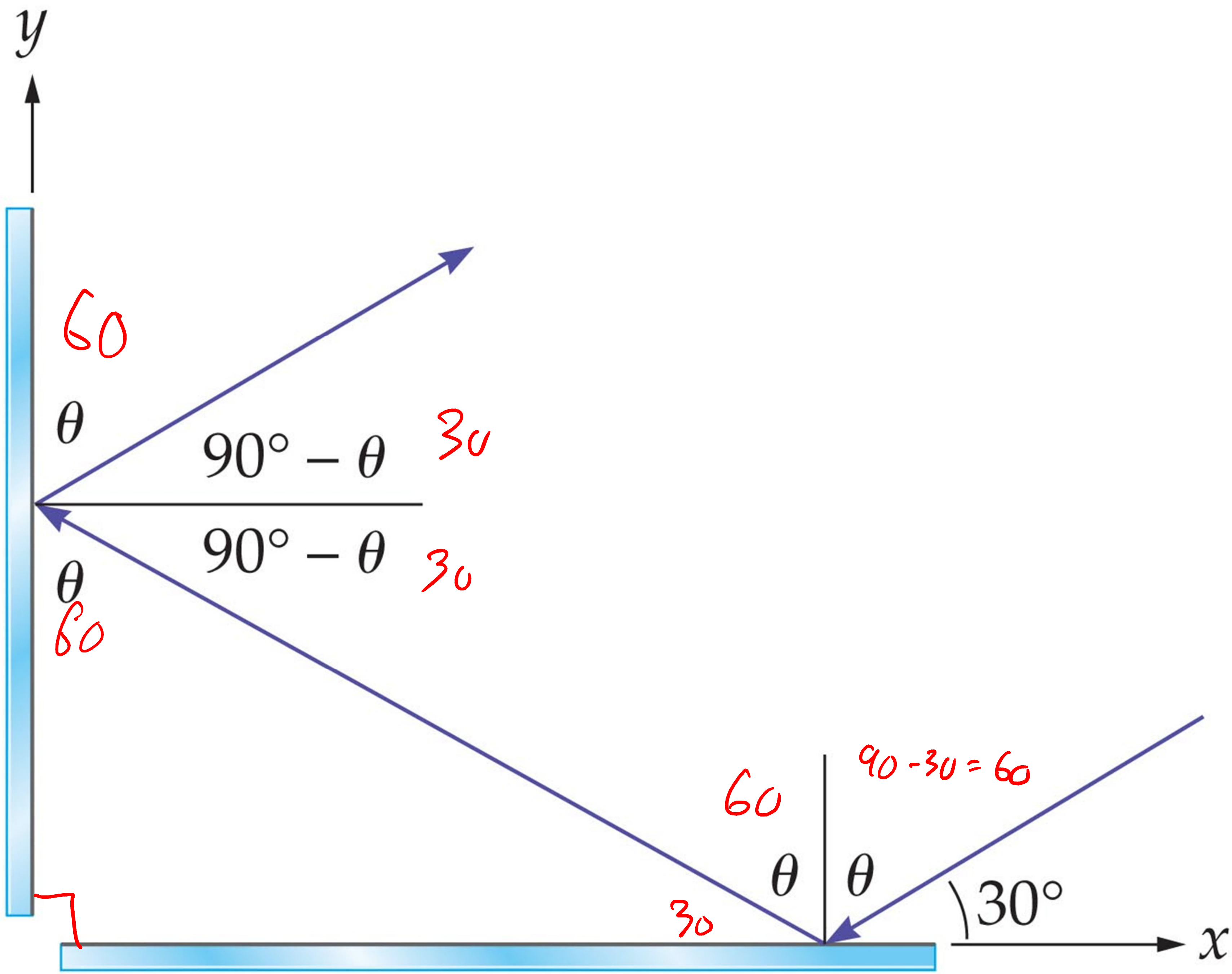


$h = h_2 + h_1$

$y = \frac{1}{2}h_1 + \frac{1}{2}h_2$

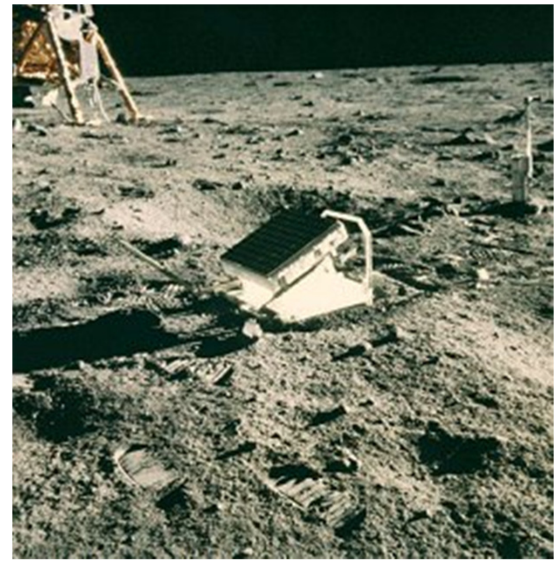
$\frac{1}{2}(h_1 + h_2)$

$\frac{1}{2}h$



y
60
θ
90° − θ
30
90° − θ
30
θ
60
90-30=60
60
θ
θ
30
30°
x

Apollo 11 lunar laser ranging retroreflector



The round-trip travel time pinpoints the moon's distance with
staggering precision: better than a few centimeters out of 385,000 km, typically.
(see link to NASA site on class “links” page)

Fig.37.16

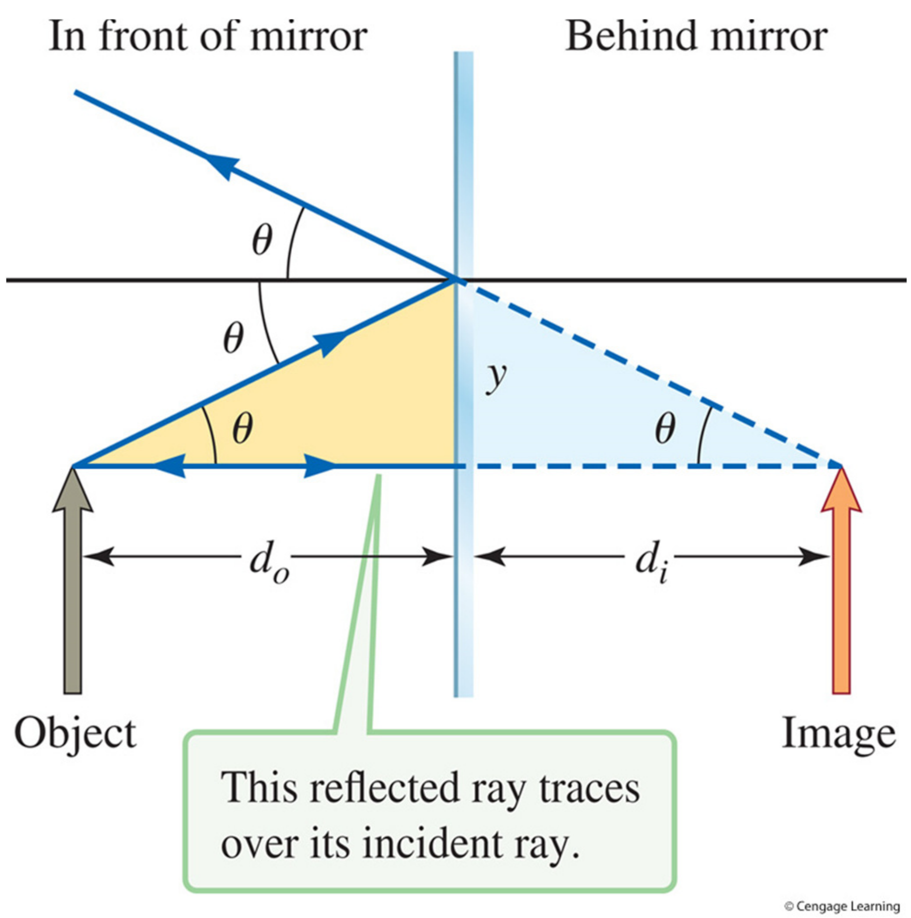
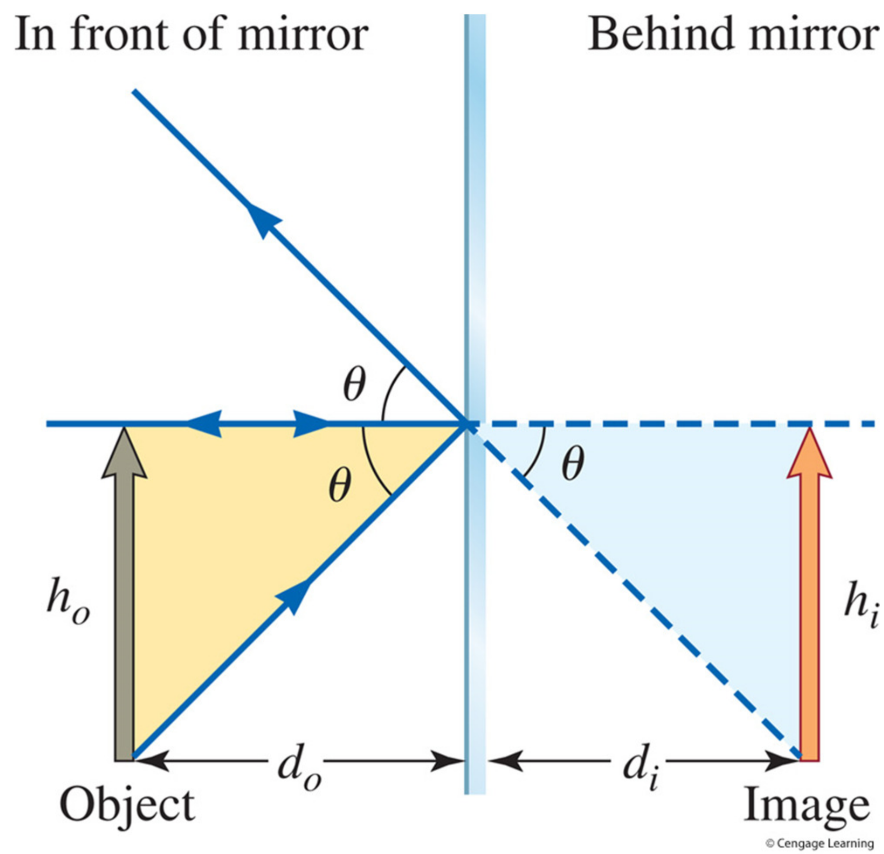


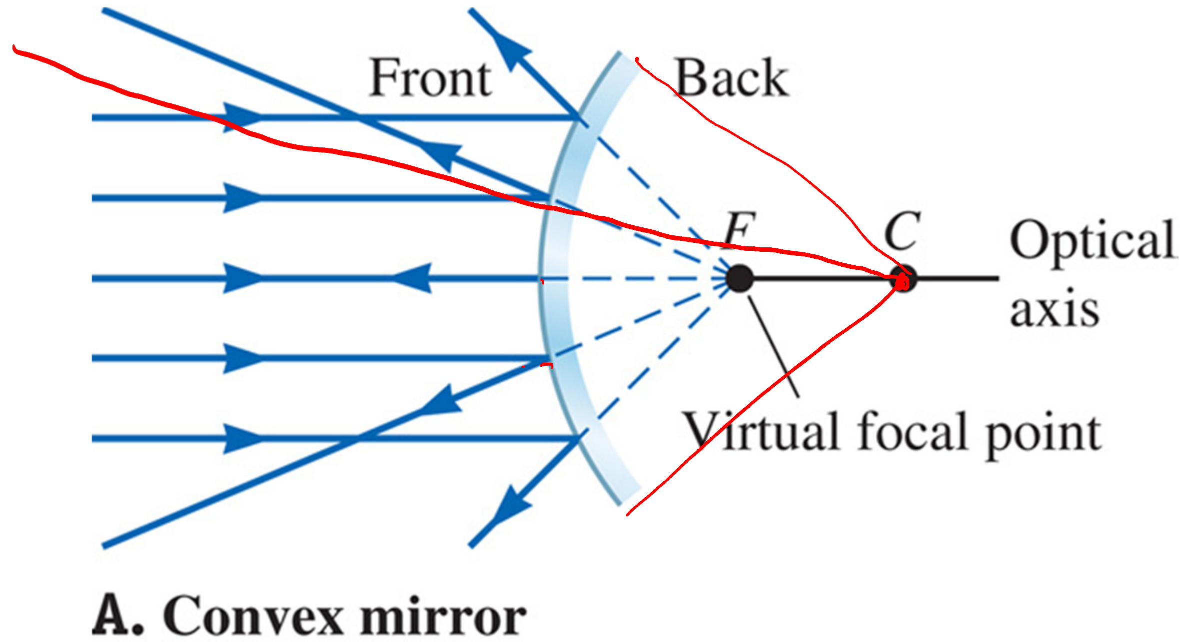
Fig.37.17



Similar triangles
show that $d_i = d_o$…

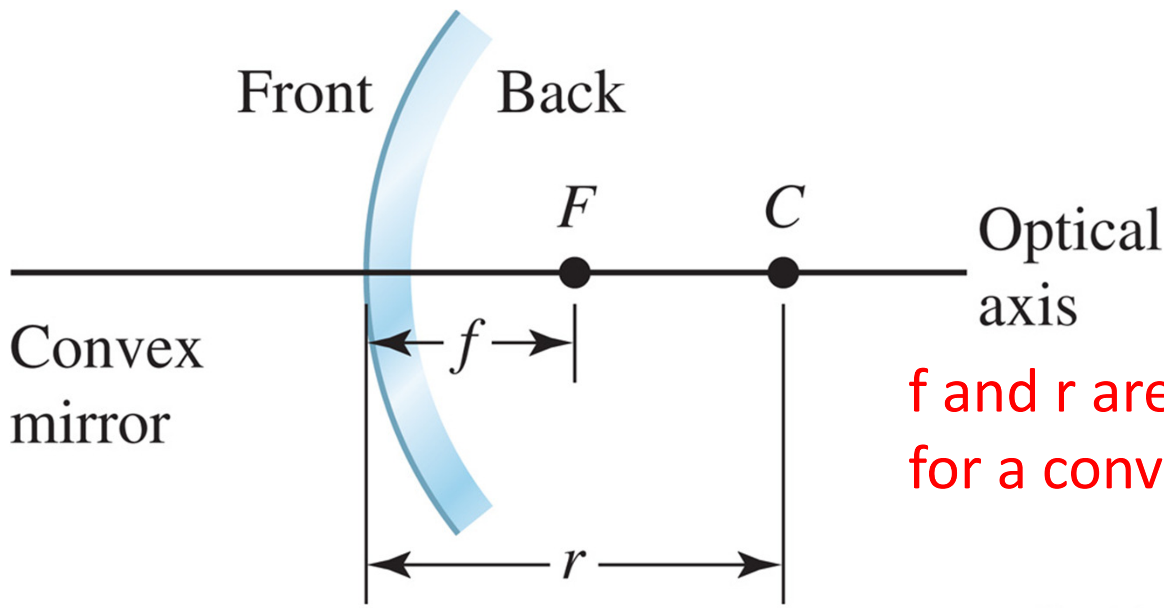
…so $h_i = -h_o$
and M = 1

Fig.37.28a



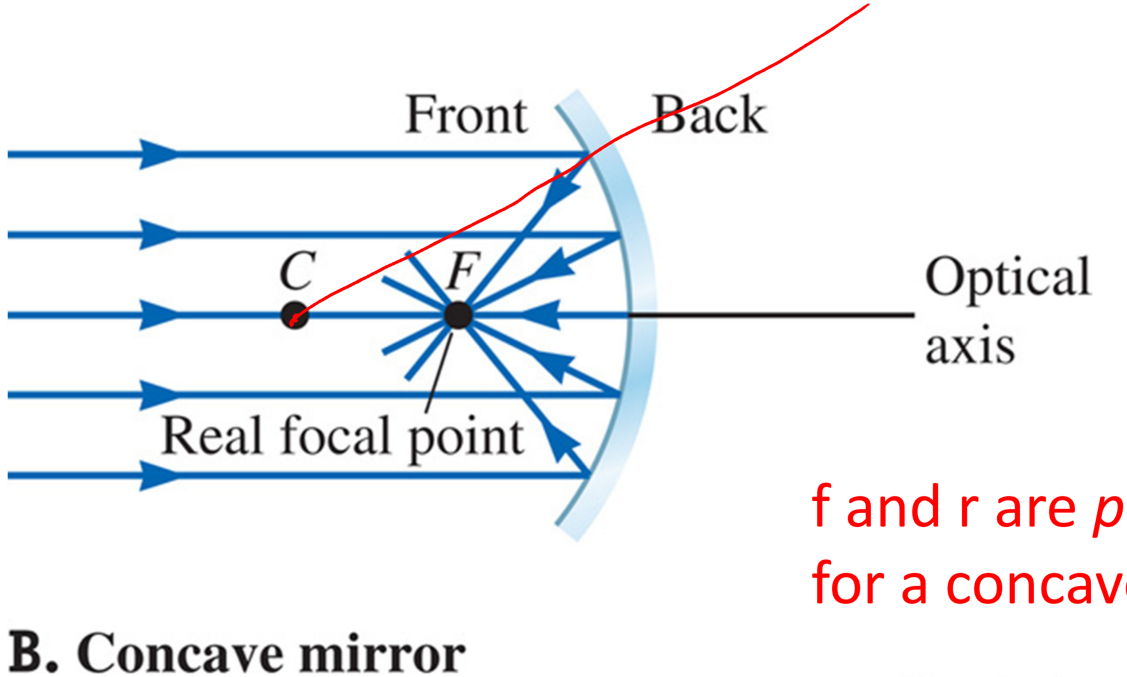
For a spherical mirror, focal length f is ½ of radius of curvature r

Fig.37.29



f and r are *negative* for a convex mirror

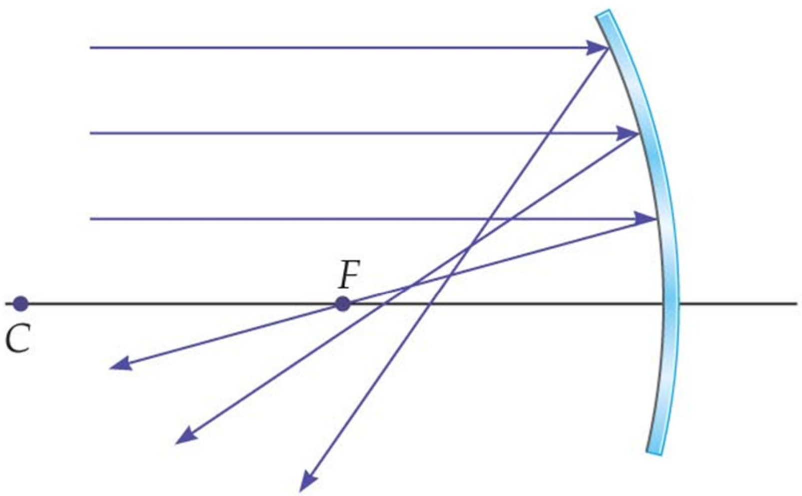
Fig.37.28b



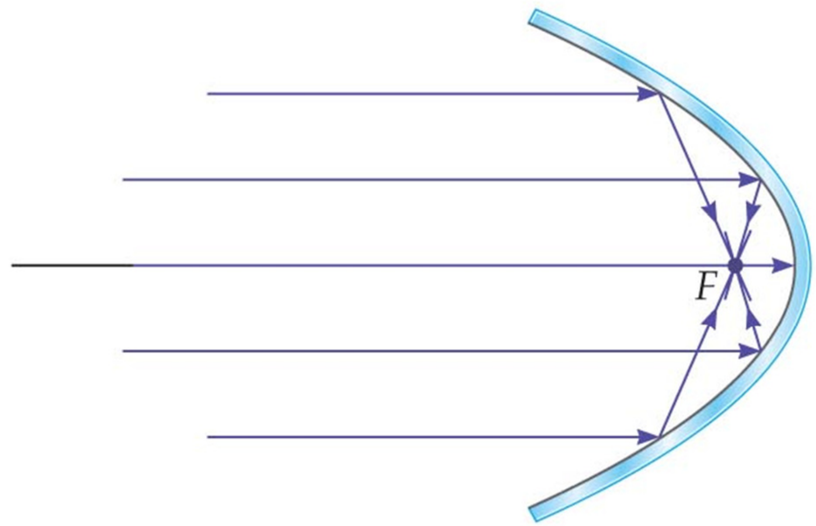
f and r are *positive* for a concave mirror

For a spherical mirror, focal length f is ½ of radius of curvature r

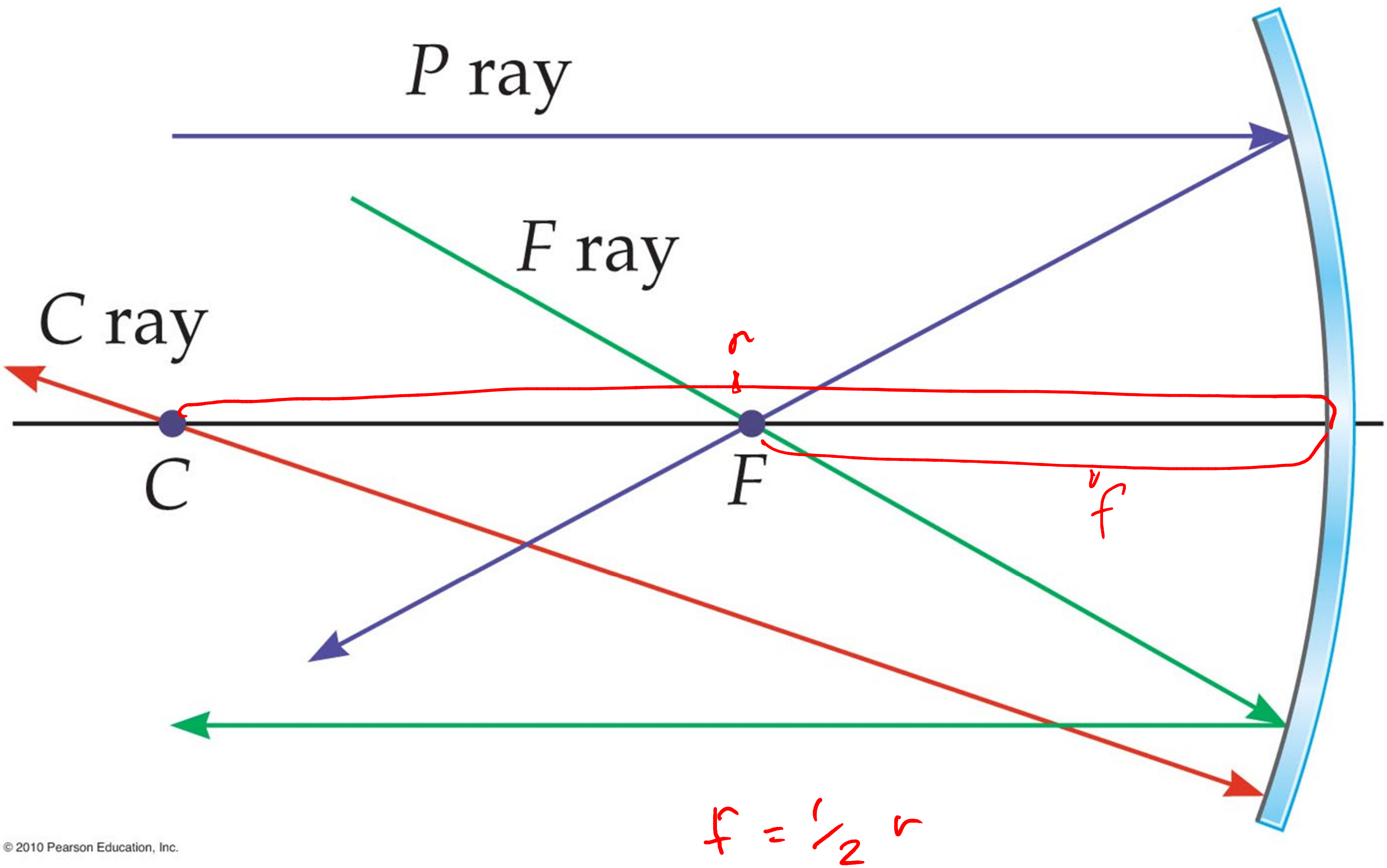
Spherical aberration



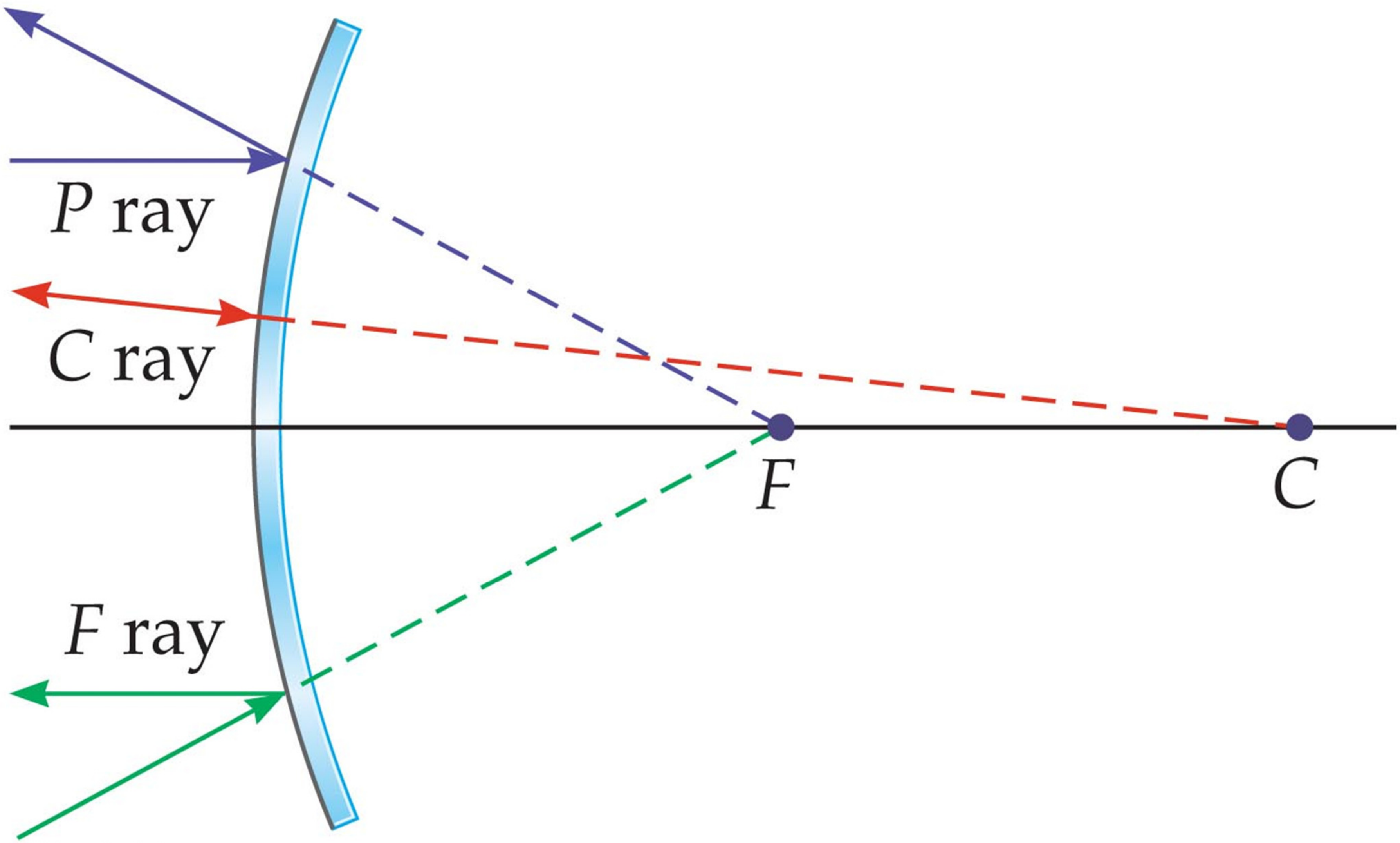
(a) A spherical mirror blurs the focus



(b) A parabolic mirror has a single focal point

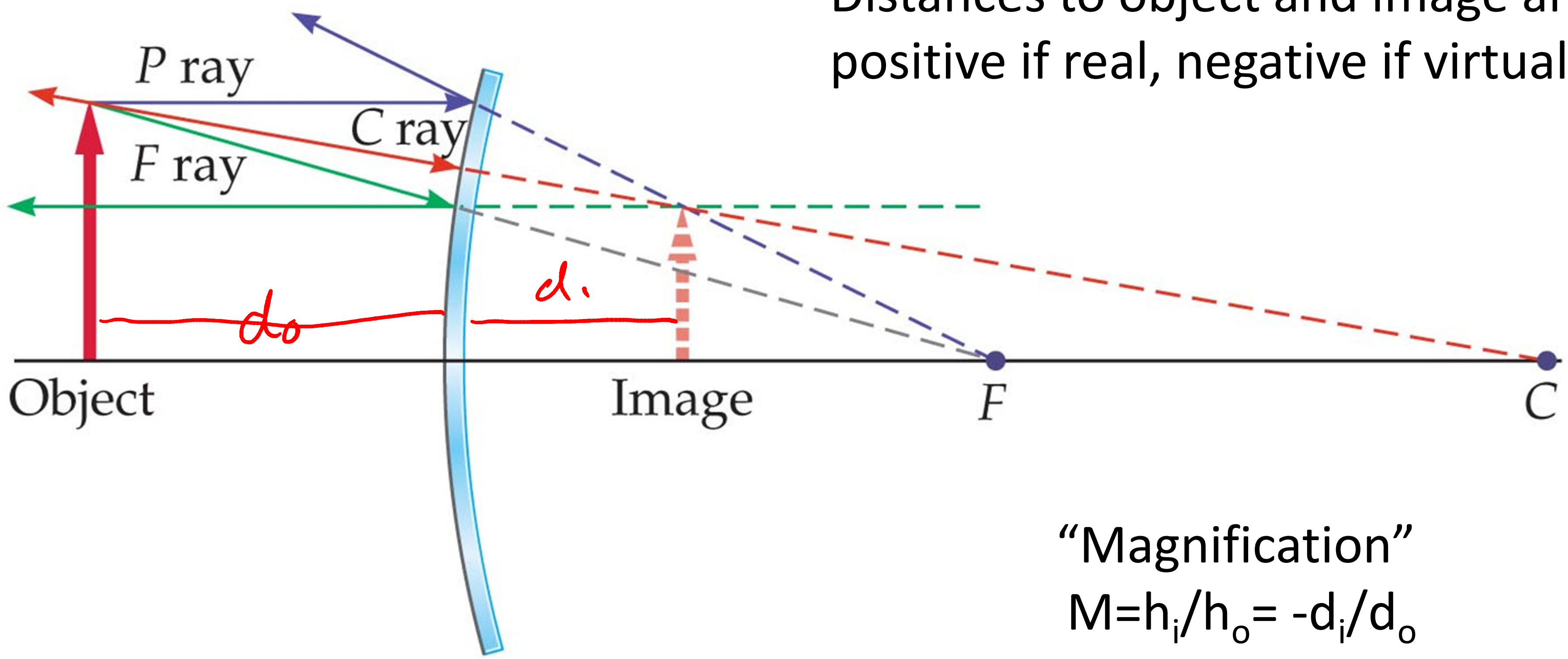


P ray
F ray
C ray
C
F
r
f
f = 1/2 r


P ray
C ray
F ray
F
C

$1/d_o + 1/d_i = 1/f$

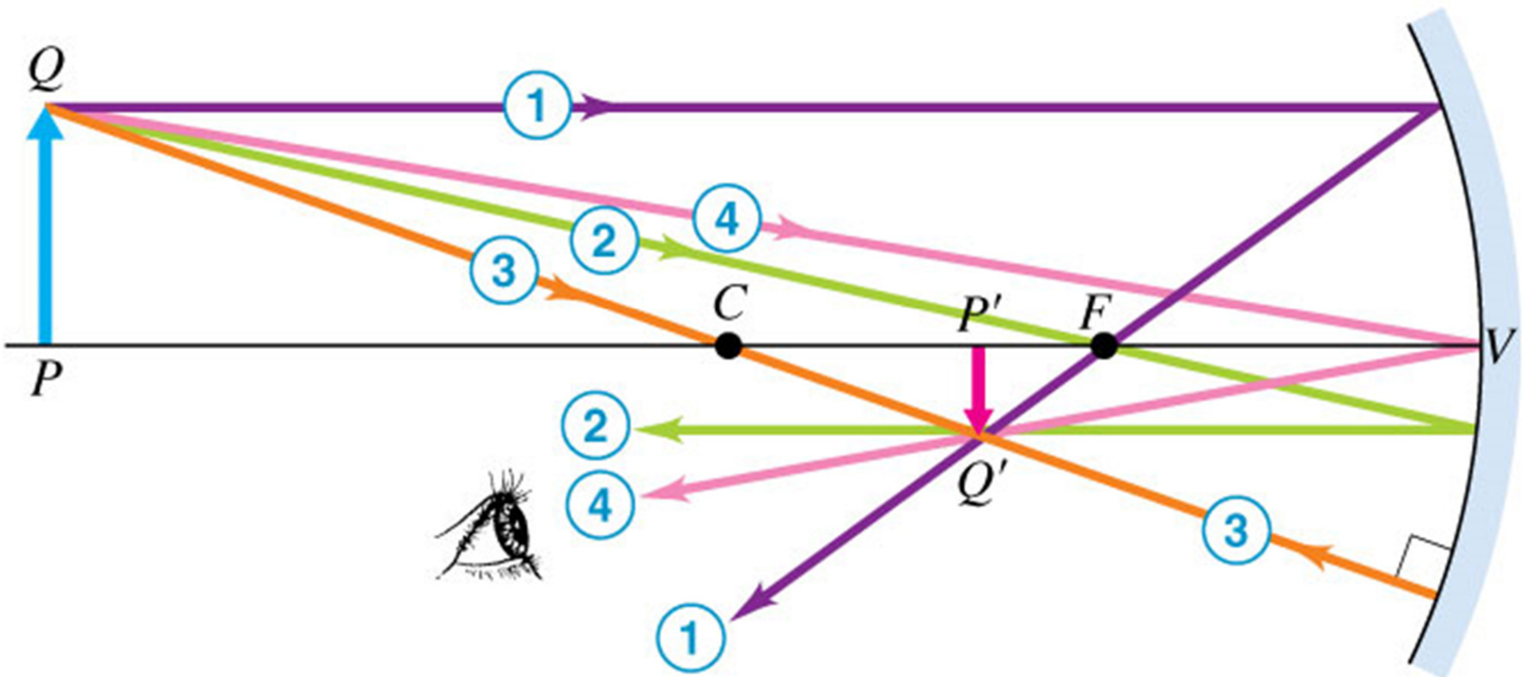
Distances to object and image are positive if real, negative if virtual



"Magnification"

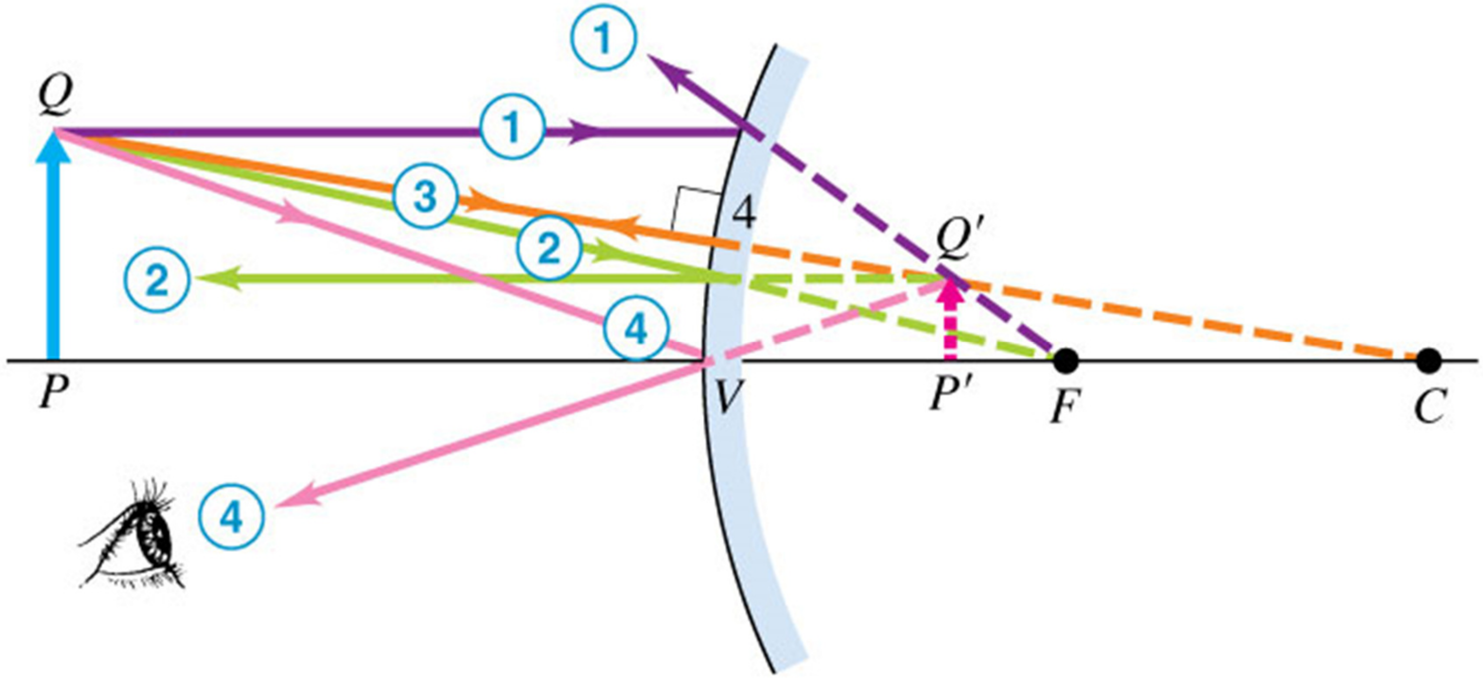
$M = h_i/h_o = -d_i/d_o$

(a) Principal rays for concave mirror



1. Ray parallel to axis reflects through focal point. P-ray
2. Ray through focal point reflects parallel to axis. F-ray
3. Ray through center of curvature intersects the surface normally and reflects along its original path. C-ray
4. Ray to vertex reflects symmetrically around optic axis.

(b) Principal rays for convex mirror



1 Reflected parallel ray appears to come from focal point.

2 Ray toward focal point reflects parallel to axis.

3 As with concave mirror: Ray radial to center of curvature intersects the surface normally and reflects along its original path.

4 As with concave mirror: Ray to vertex reflects symmetrically around optic axis.