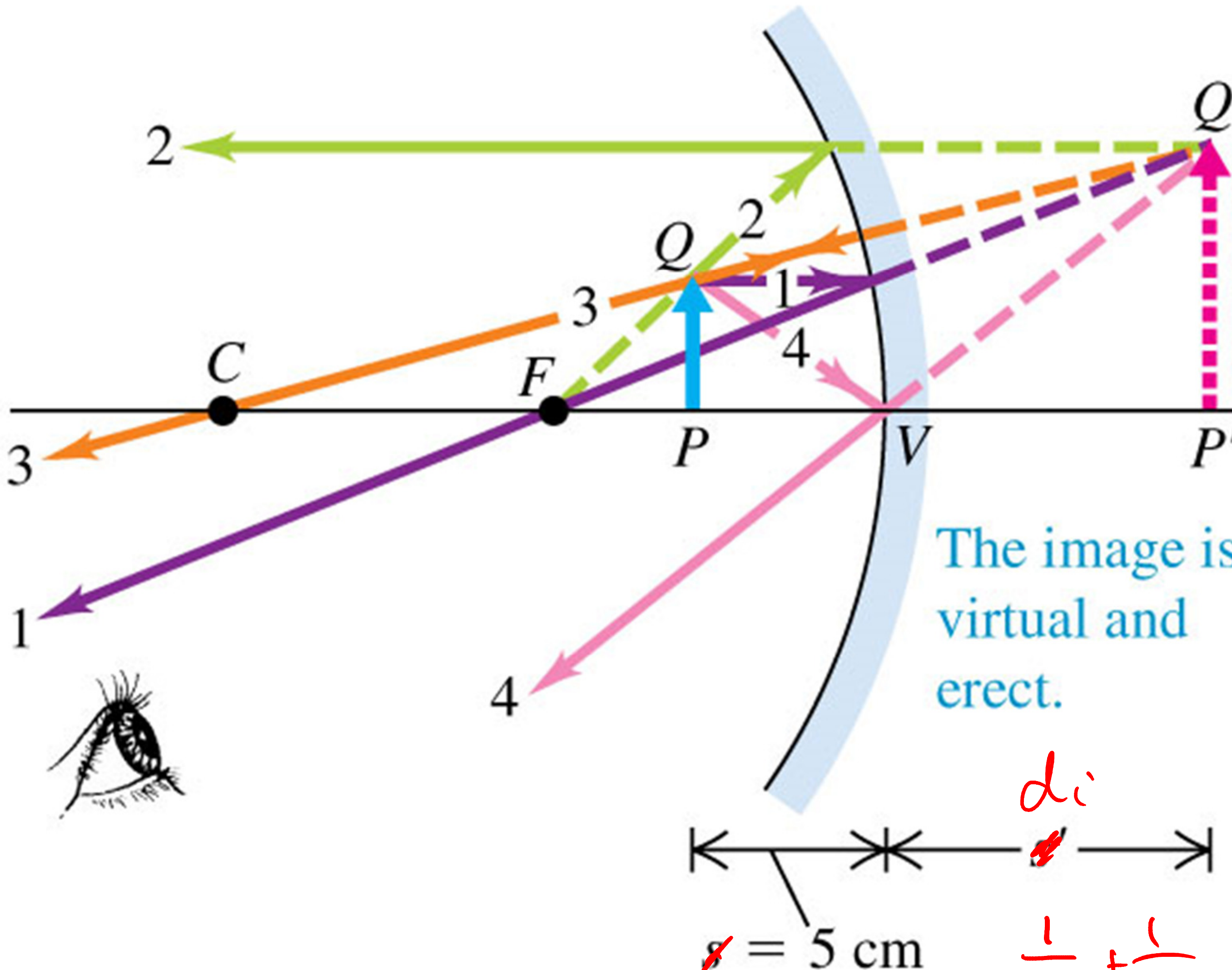
(d) Construction for ~~s~~ d_o = 5 cm

r =20 cm, so f=10 cm



Solve for $d_i = -10 \text{cm}$

$m = -\frac{d_i}{d_o} = +2$

$\frac{1}{d_i} + \frac{1}{d_o} = \frac{1}{f}$

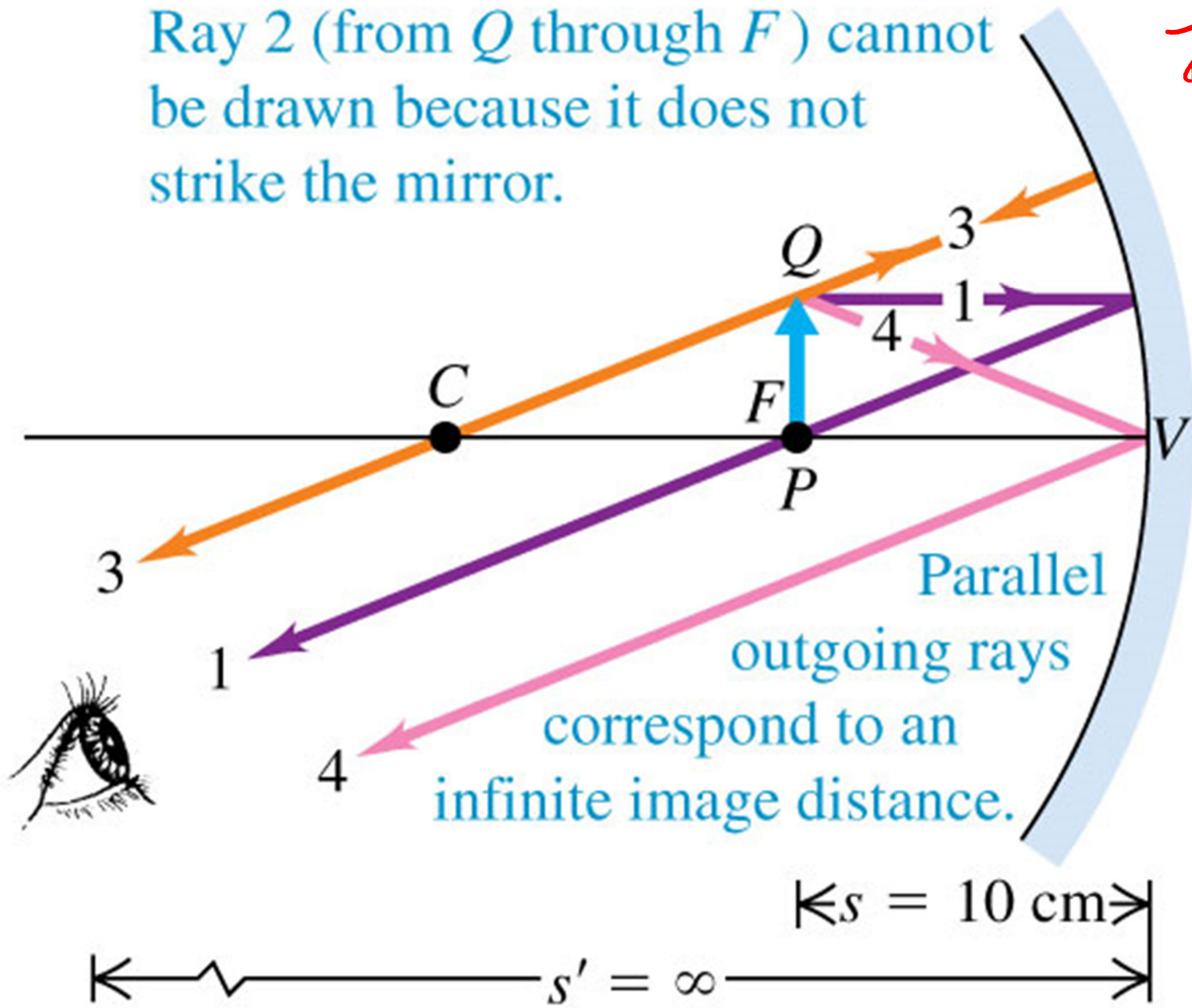
(c) Construction for ~~s~~ d_o = 10 cm

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$\frac{1}{10} + \frac{1}{d_i} = \frac{1}{10}$$

$$\frac{1}{d_i} = 0$$

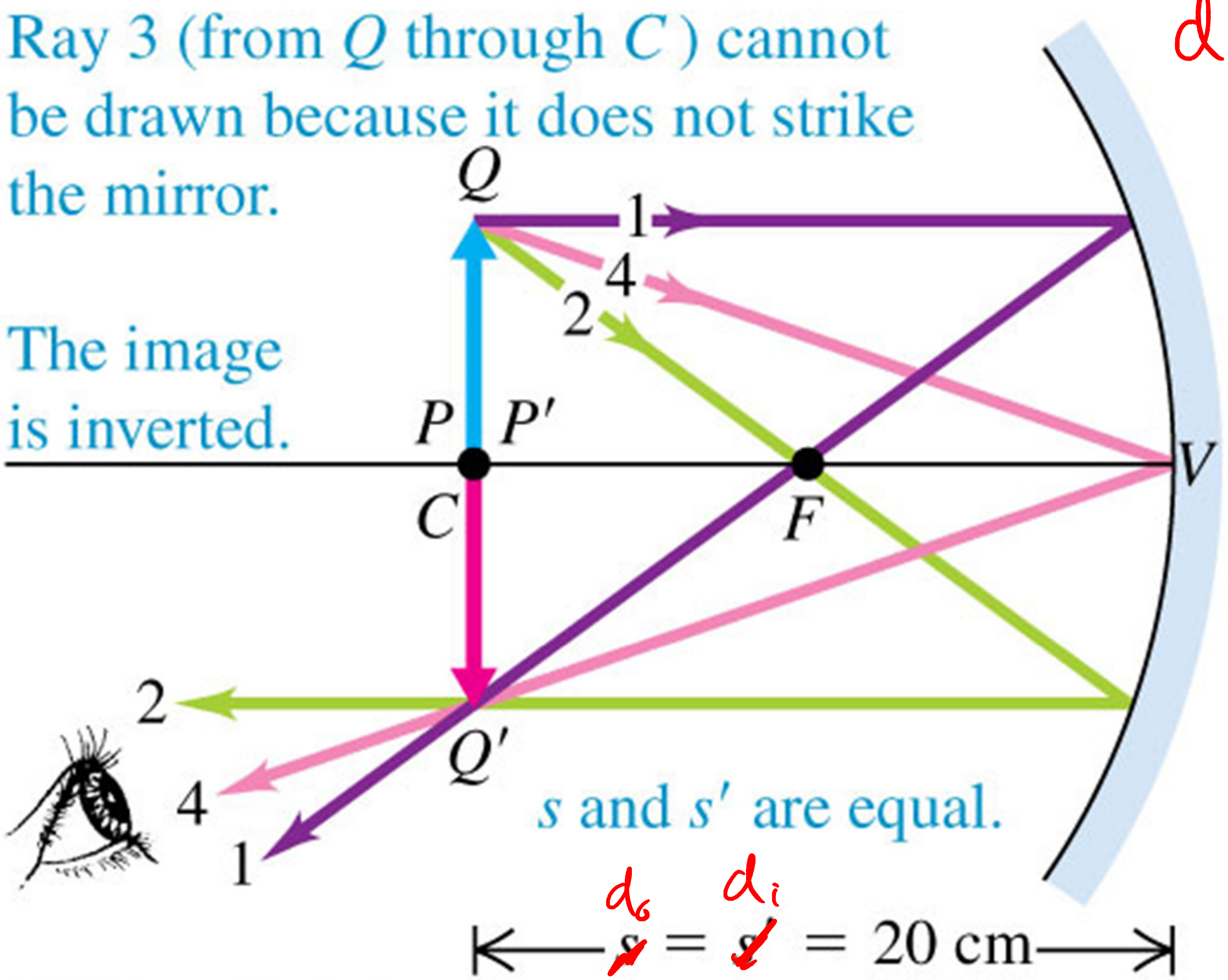
$$d_i = \infty$$



(b) Construction for s = 20 cm (d_o)

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

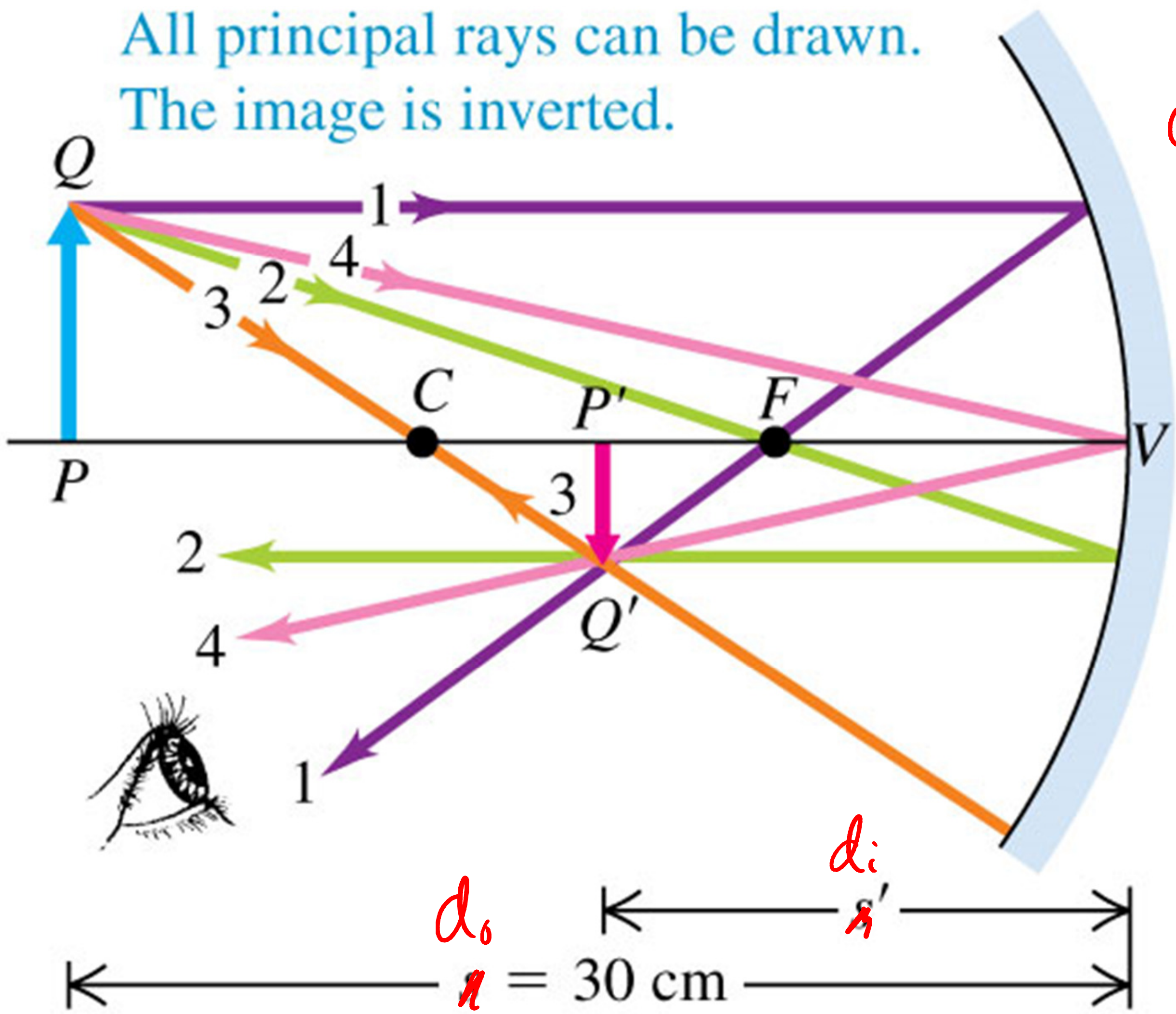
$d_i = 20\,cm$



(a) Construction for d_o = 30 cm

$$\frac{1}{d_i}+\frac{1}{d_o}=\frac{1}{f}$$

d_i = 15 cm



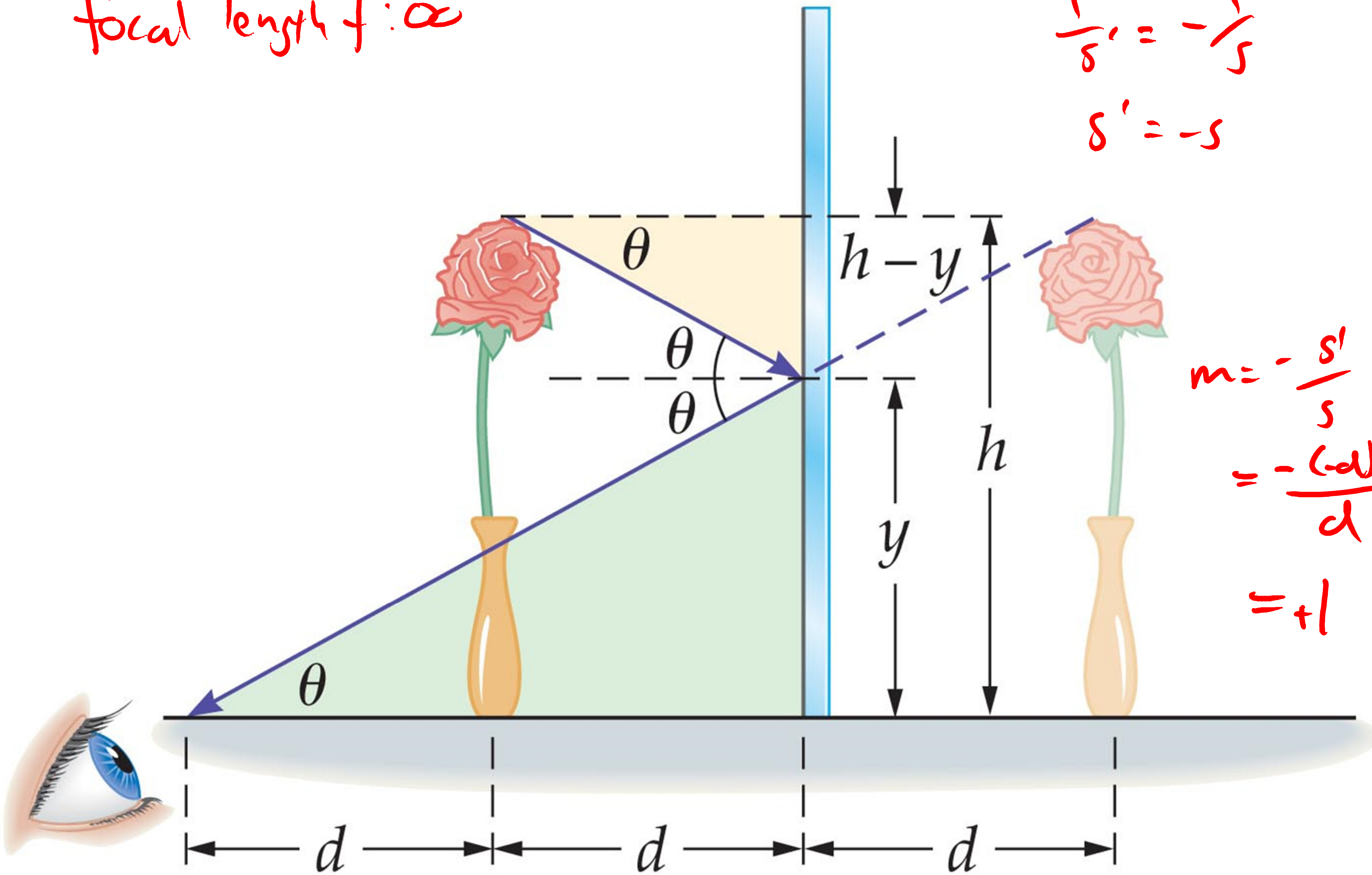
radius of curv: ∞

focal length f: ∞

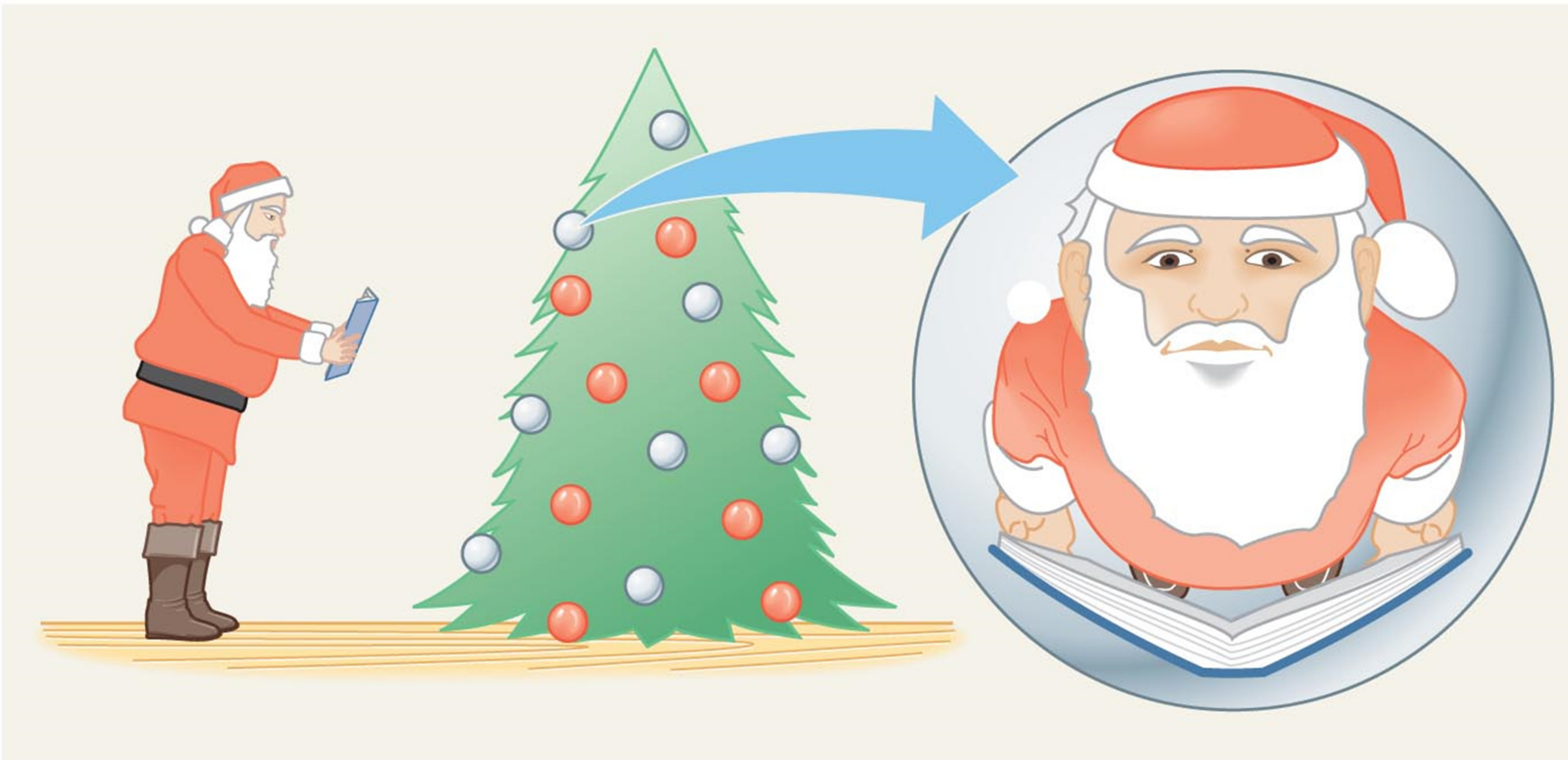
$$\frac{1}{s'} = \frac{1}{f}^{\to 0} - \frac{1}{s}$$

$$\frac{1}{s'} = -\frac{1}{s}$$

$$s' = -s$$

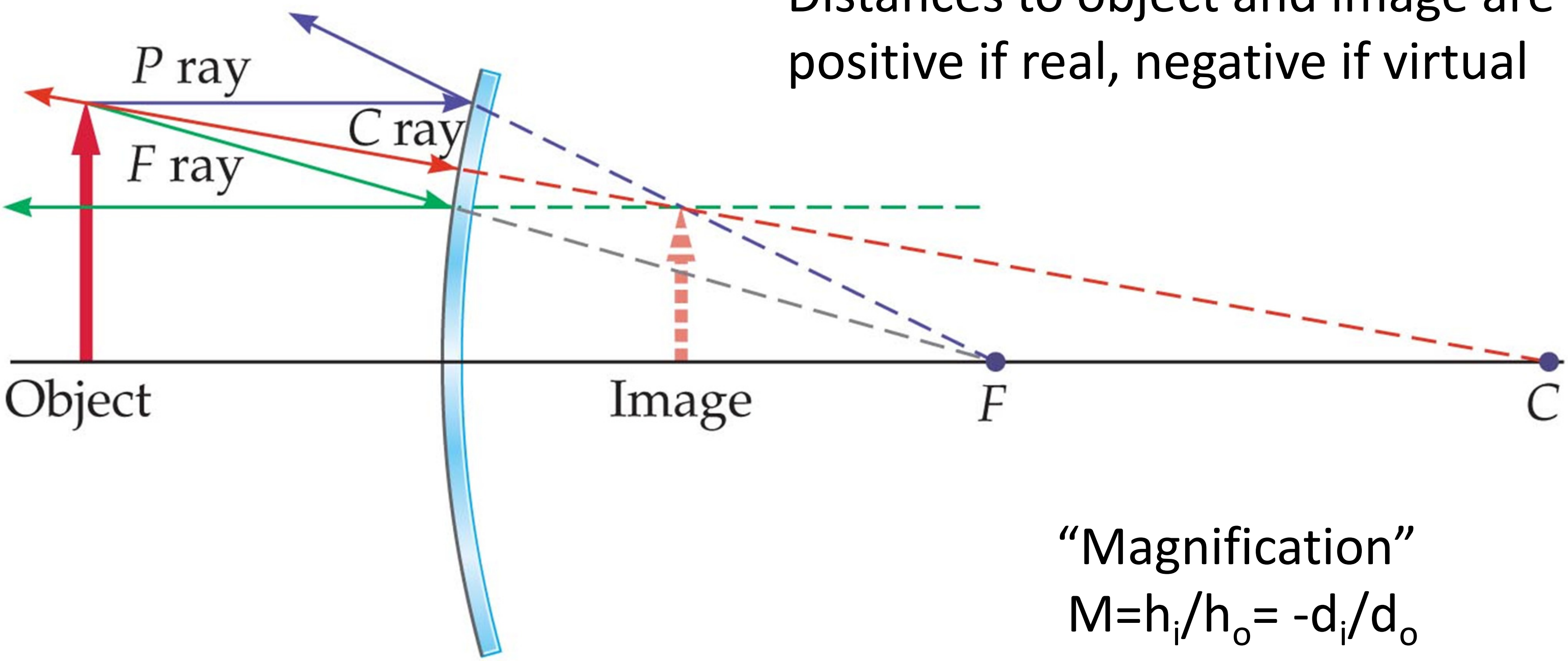


$$m = -\frac{s'}{s} = -\frac{(-d)}{d} = +1$$



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

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

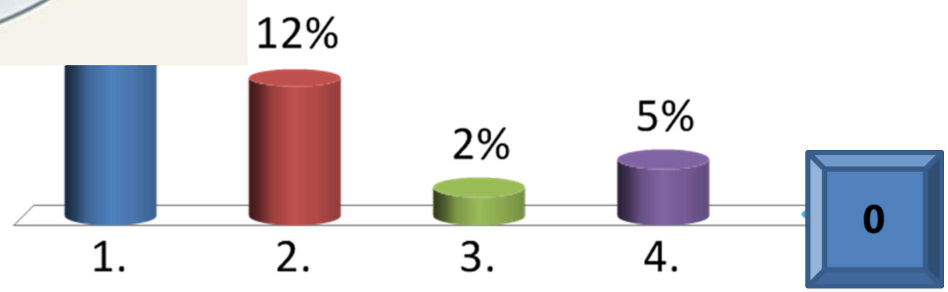


"Magnification"

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

Santa is standing in front of a security mirror at the mall. His image is 4x smaller than he is, and he's 2.0m away. What's the focal length of the mirror?

1. 0.67 m ✓
2. 1.3 m
3. 2.0 m
4. 4.0 m
5. 6.0 m



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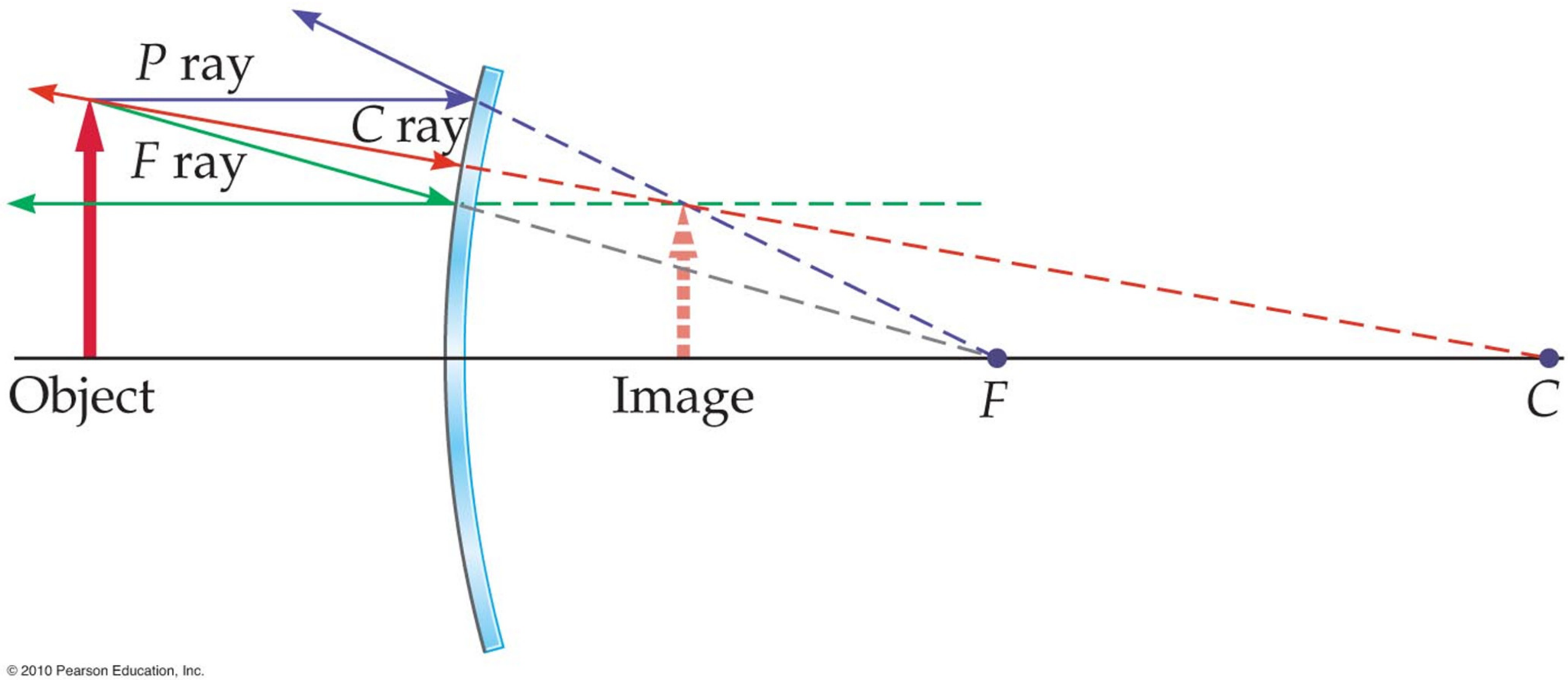
Draw it out first…



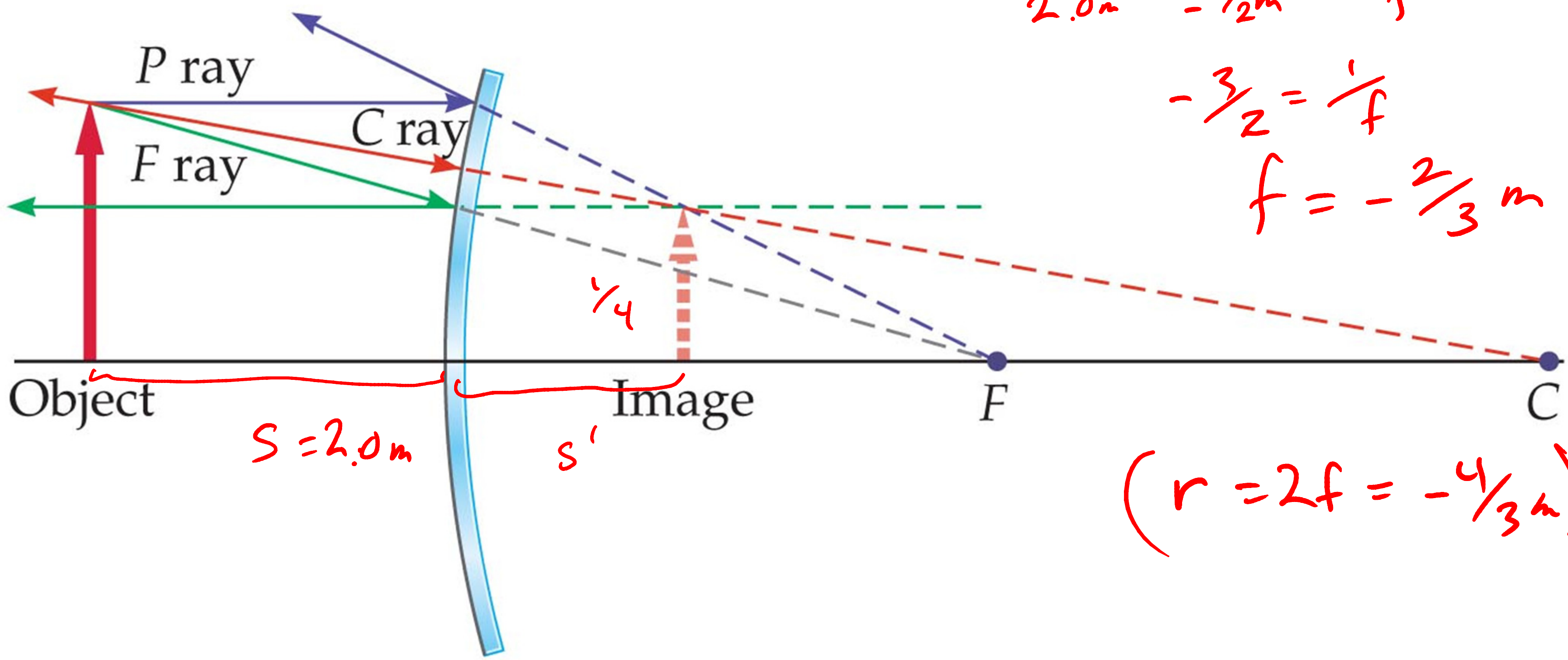
Draw it out first…

$$m = +\tfrac{1}{4} = -\tfrac{s'}{s} = \frac{-s'}{2.0\,m} \Rightarrow s' = -\tfrac{1}{2}\,m$$

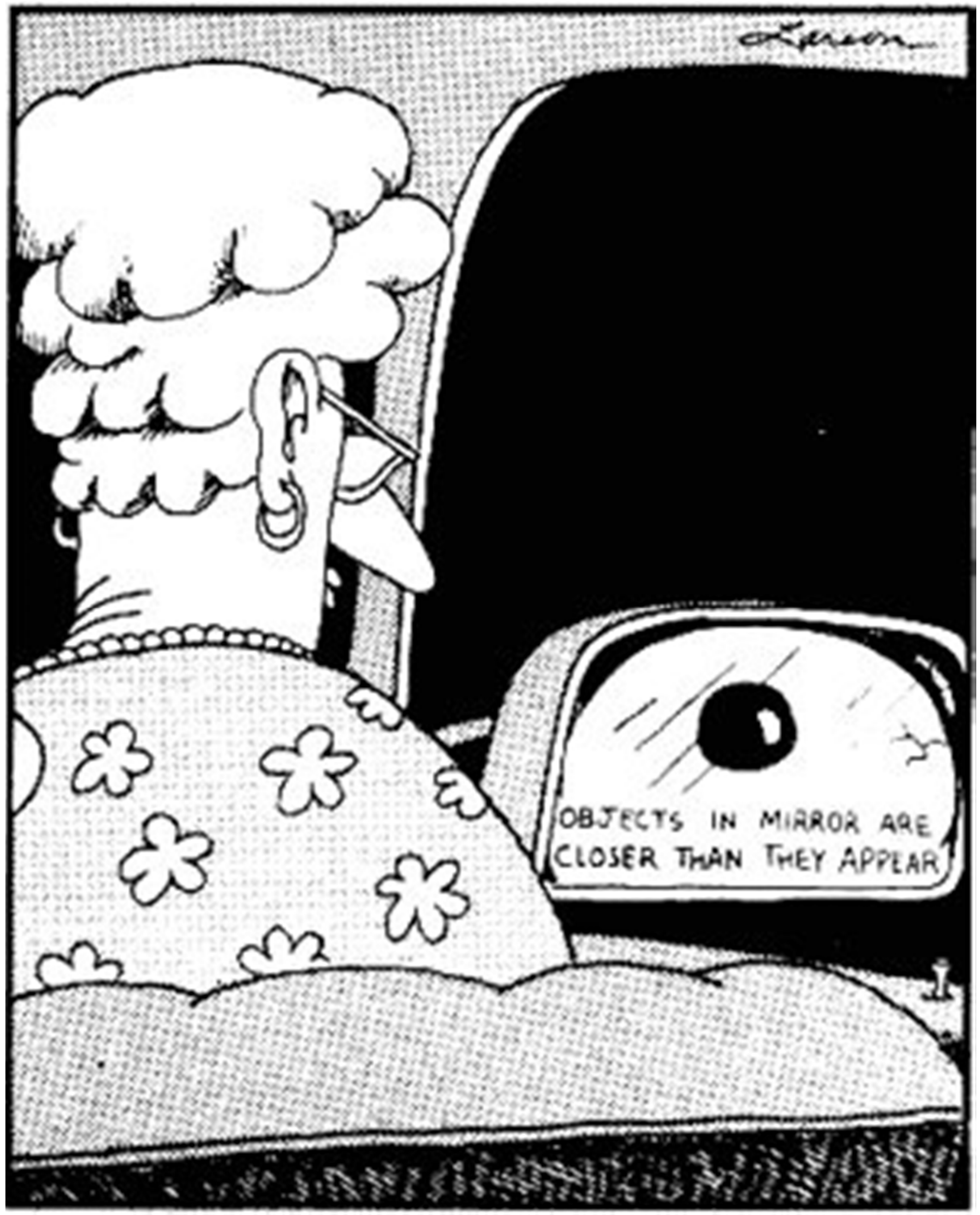
$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f} = \frac{1}{2.0\,m} + \frac{1}{-\tfrac{1}{2}m} = \frac{1}{f}$$

$$-\tfrac{3}{2} = \tfrac{1}{f}$$

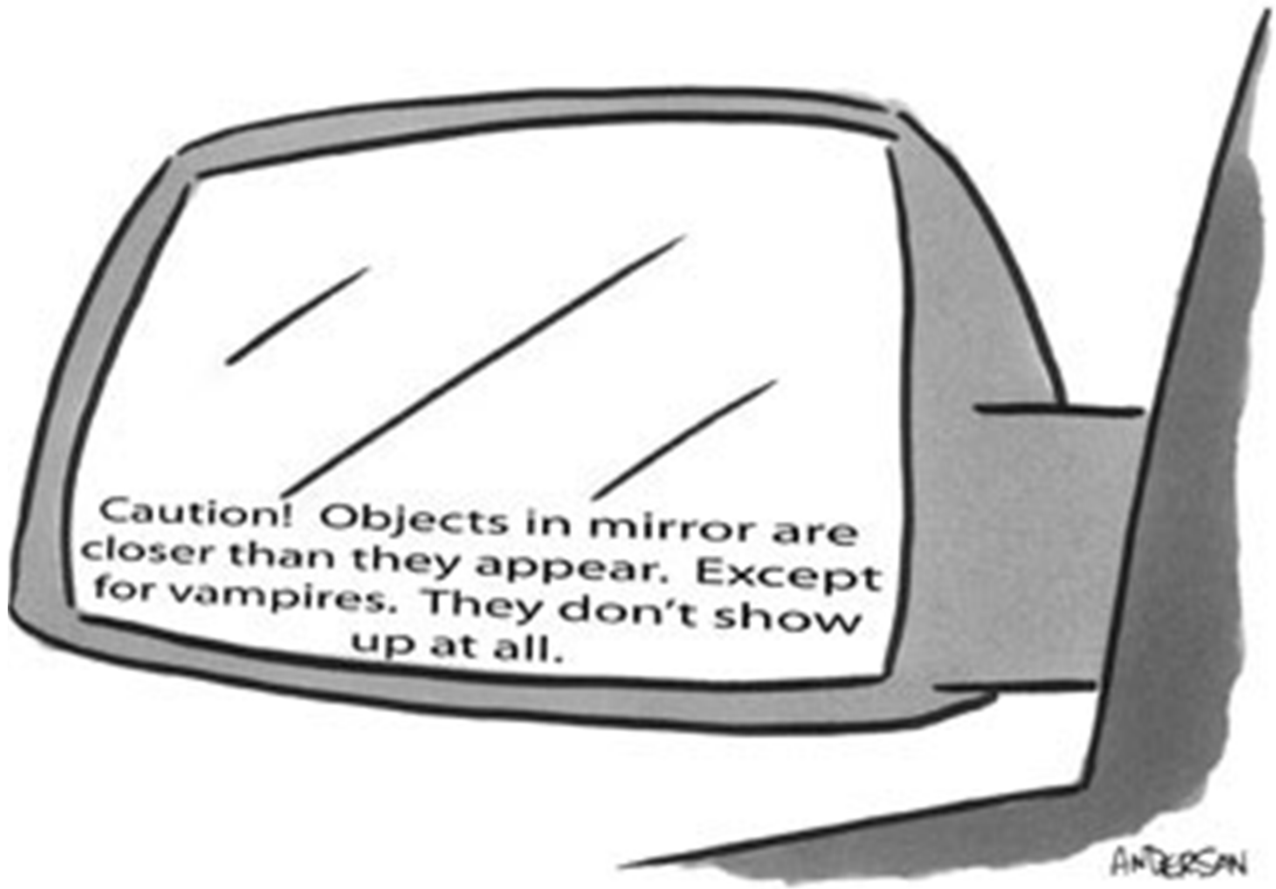
$$f = -\tfrac{2}{3}\,m$$



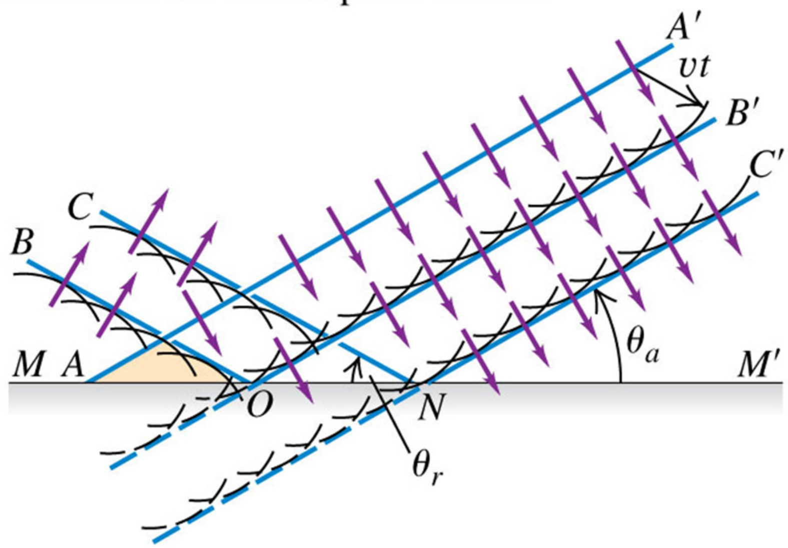
$$\left(r = 2f = -\tfrac{4}{3}\,m\right)$$



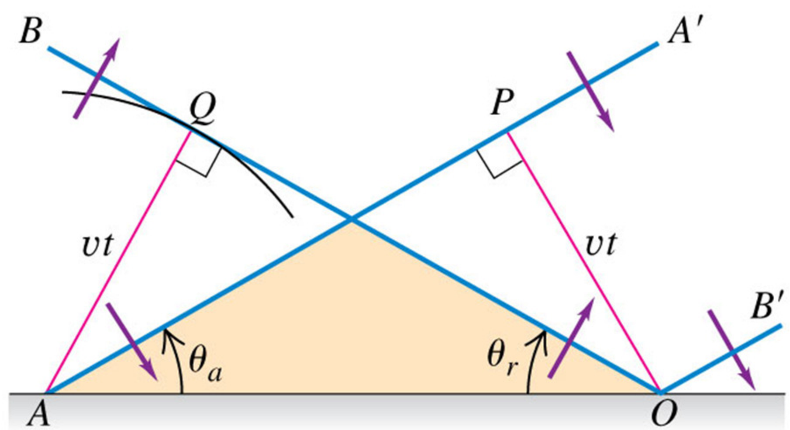
A classic “Far Side”
By Gary Larson

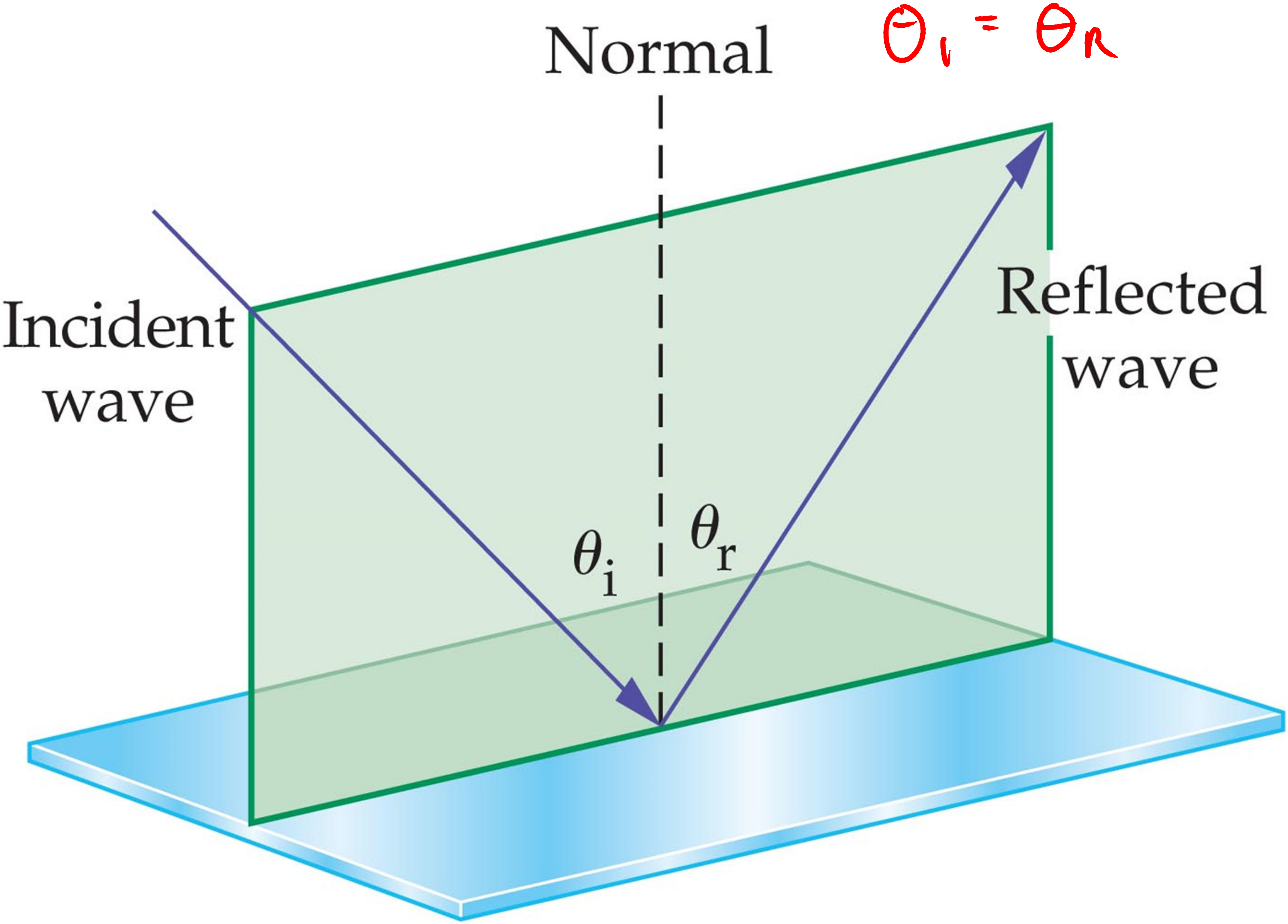

Caution! Objects in mirror are closer than they appear. Except for vampires. They don't show up at all.
ANDERSON

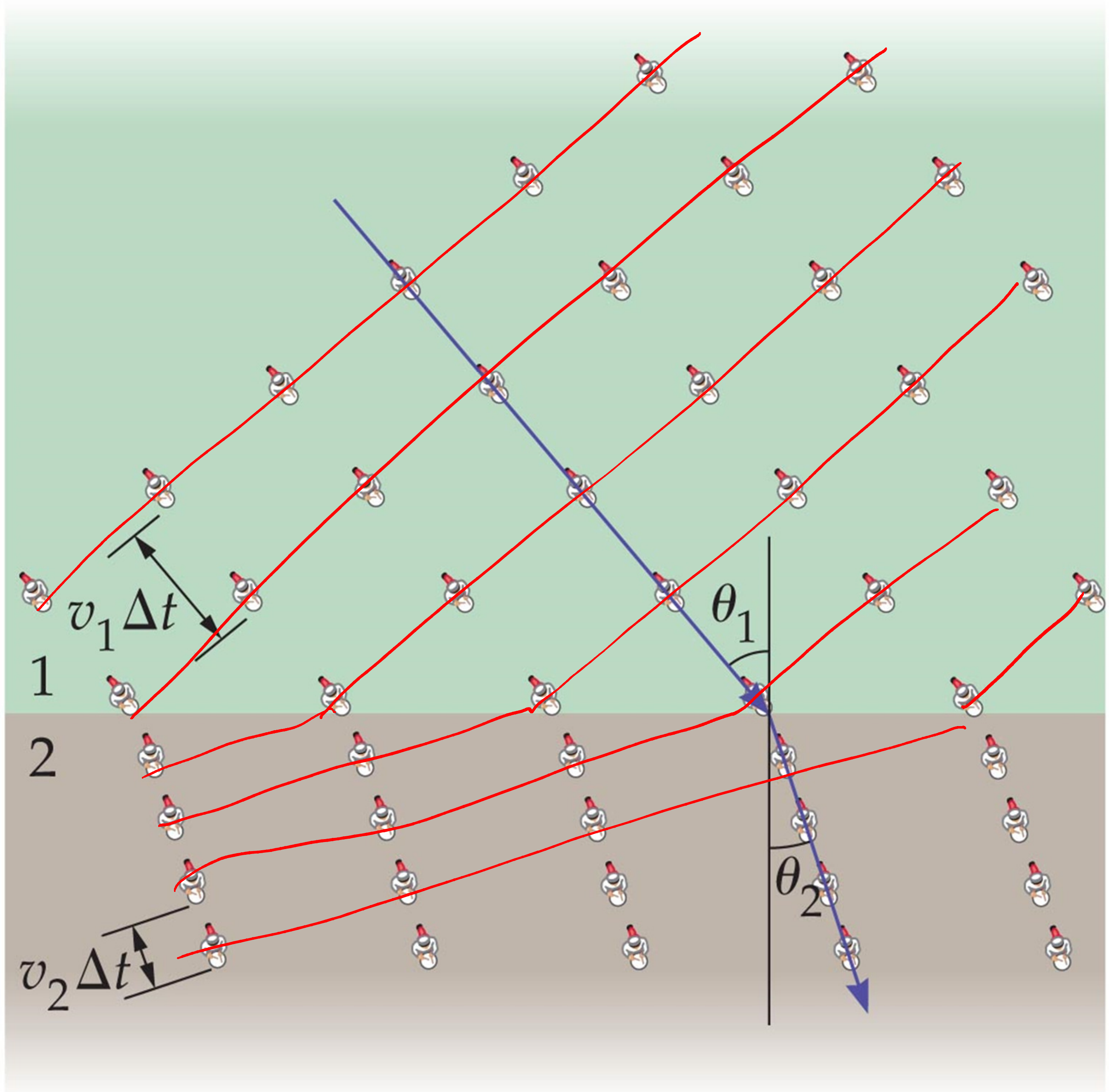
(a) Successive positions of a plane wave AA' as it is reflected from a plane surface



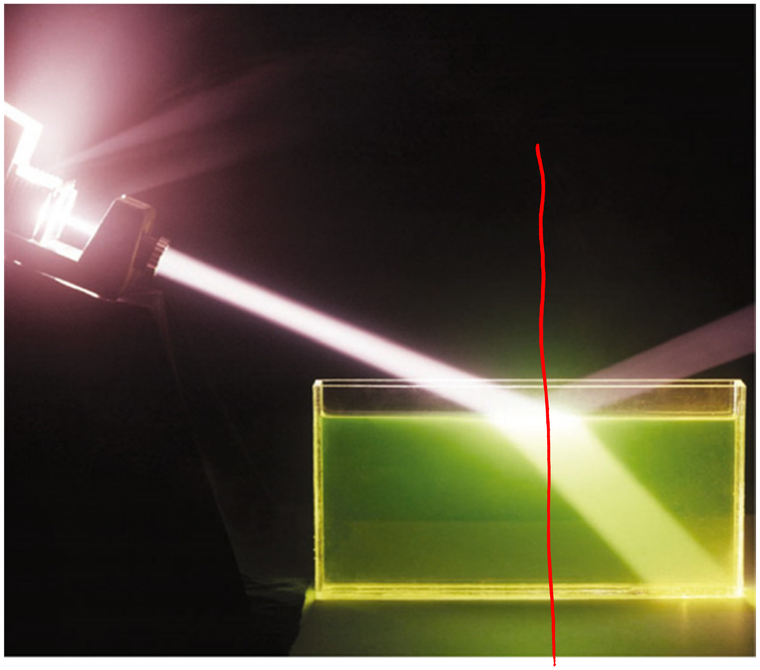
(b) Magnified portion of (a)



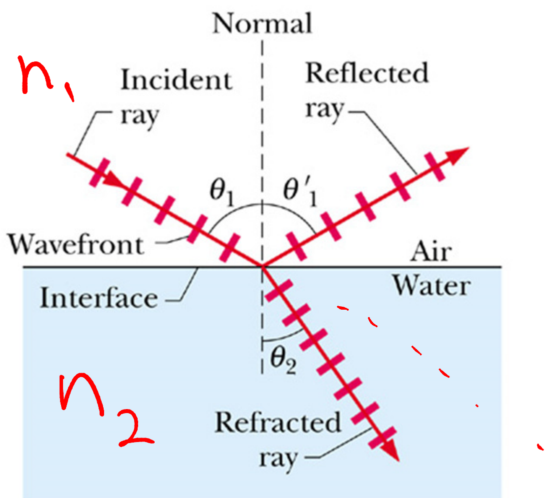

Normal
Incident wave
Reflected wave
θ_i
θ_r



$v_1 \Delta t$
1
2
θ_1
θ_2
$v_2 \Delta t$



(a)



(b)

Law of Reflection:

$$\theta_1 = \theta_2$$

Snell's Law of Refraction:

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

n = index of refraction

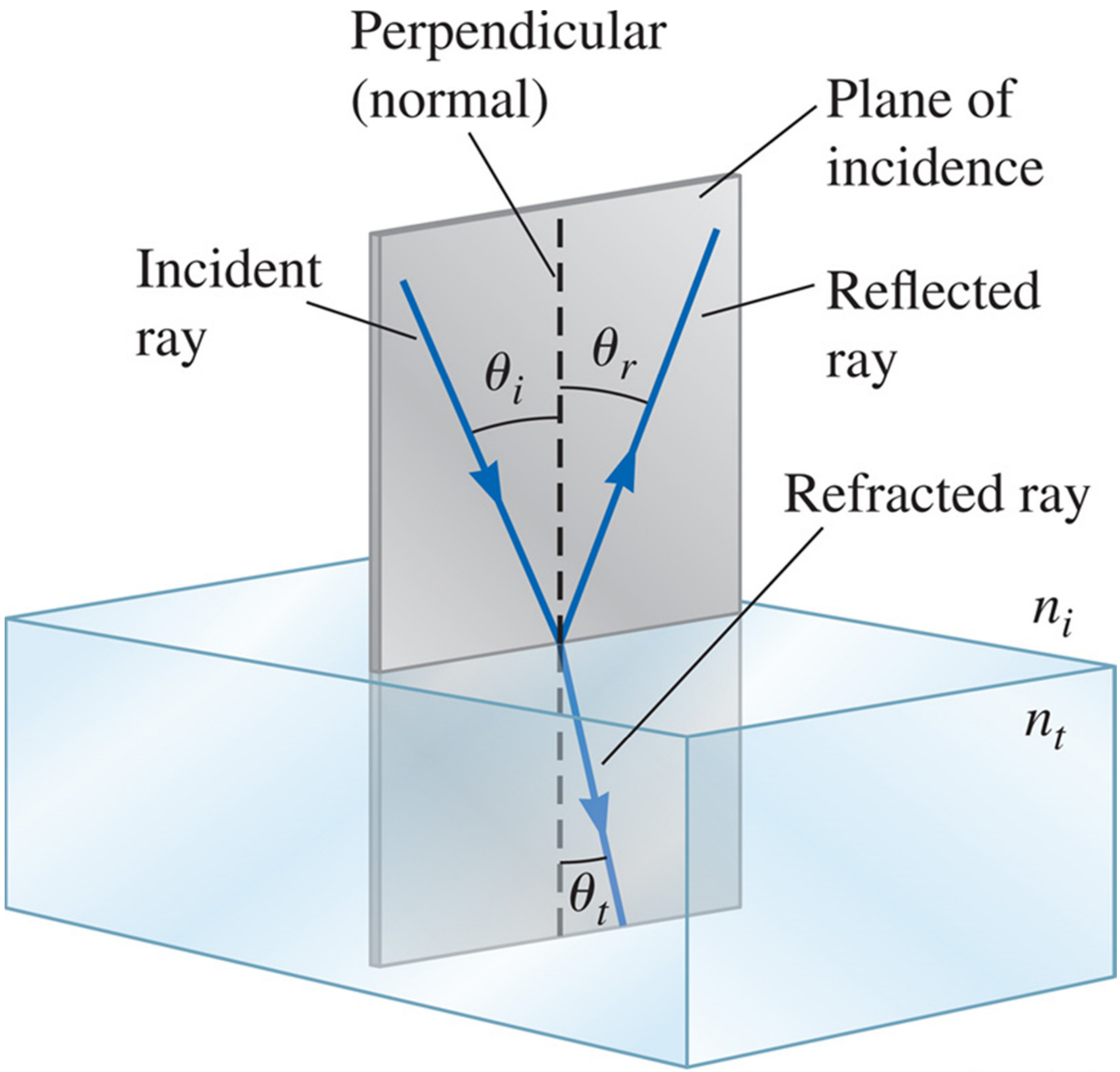
Speed of light in stuff is slow:

$$= c/n$$

Vacuum: $n=1$ air $n=1.00029$

water: 1.33 glass ~ 1.5

Fig.38.1



Perpendicular
(normal)
Plane of
incidence
Incident
ray
Reflected
ray
θ_i
θ_r
Refracted ray
n_i
n_t
θ_t
© Cengage Learning

n is factor speed slows down by

$v = c/n$

$v = f\lambda$

$E = hf$

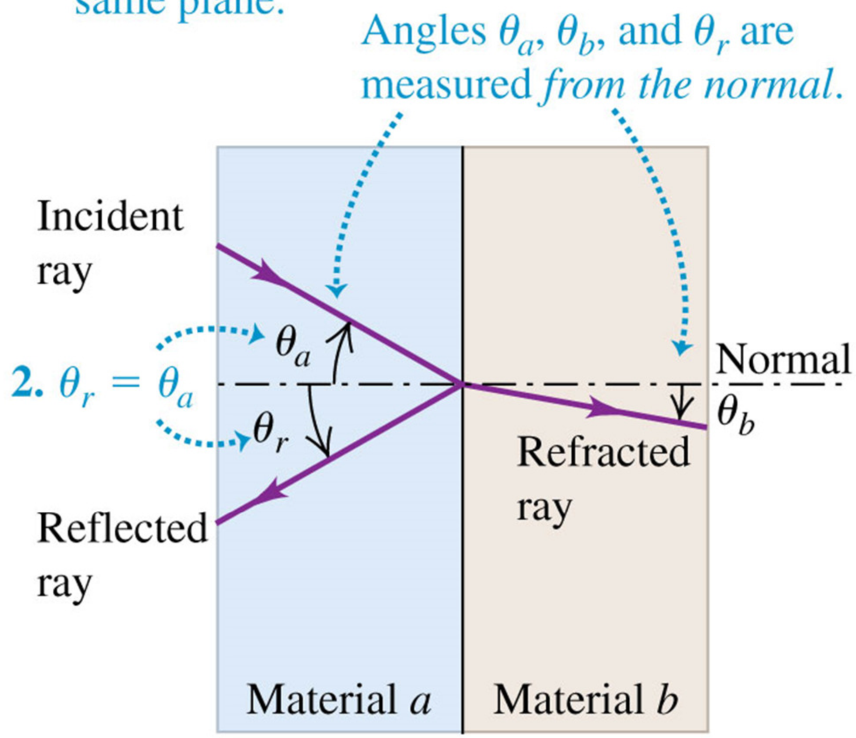
$\lambda_n = \frac{\lambda}{n}$

$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$

Table 33.1 Index of Refraction for Yellow Sodium Light, λ_0 = 589 nm

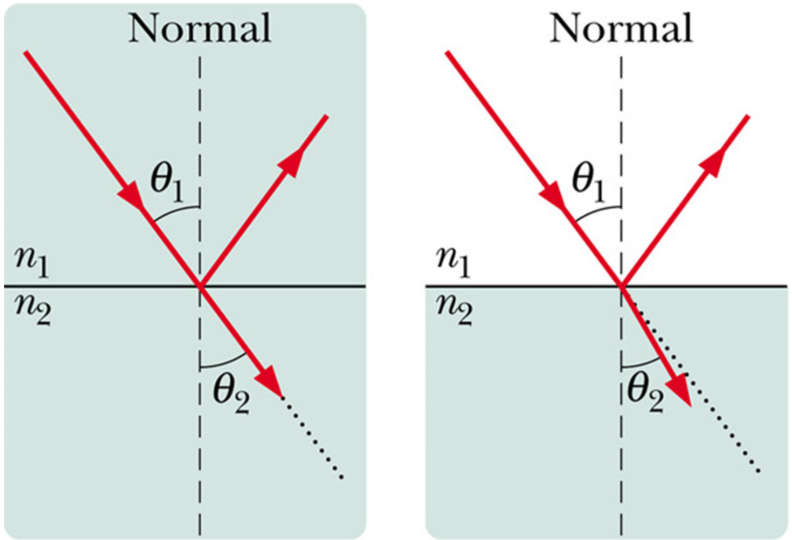
Substance	Index of Refraction, *n*
Solids	
Ice (H_2O)	1.309
Fluorite (CaF_2)	1.434
Polystyrene	1.49
Rock salt (NaCl)	1.544
Quartz (SiO_2)	1.544
Zircon ($ZrO_2 \cdot SiO_2$)	1.923
Diamond (C)	2.417
Fabulite ($SrTiO_3$)	2.409
Rutile (TiO_2)	2.62
Glasses (typical values)	
Crown	1.52
Light flint	1.58
Medium flint	1.62
Dense flint	1.66
Lanthanum flint	1.80
Liquids at 20°C	
Methanol (CH_3OH)	1.329
Water (H_2O)	1.333
Ethanol (C_2H_5OH)	1.36
Carbon tetrachloride (CCl_4)	1.460
Turpentine	1.472
Glycerine	1.473
Benzene	1.501
Carbon disulfide (CS_2)	1.628

1. The incident, reflected, and refracted rays and the normal to the surface all lie in the same plane.



3. When a monochromatic light ray crosses the interface between two given materials *a* and *b*, the angles θ_a and θ_b are related to the indexes of refraction of *a* and *b* by

$$\frac{\sin\theta_a}{\sin\theta_b} = \frac{n_b}{n_a}$$



$n_2 = n_1$

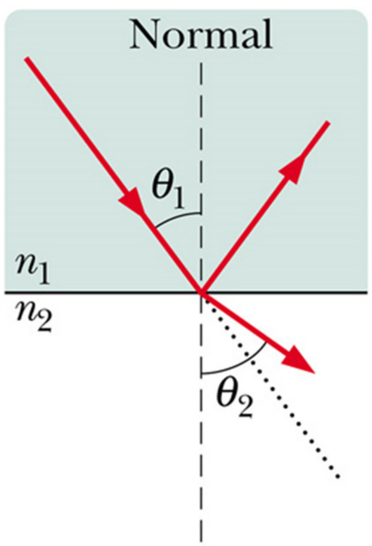
(*a*)

$n_2 > n_1$

(*b*)

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

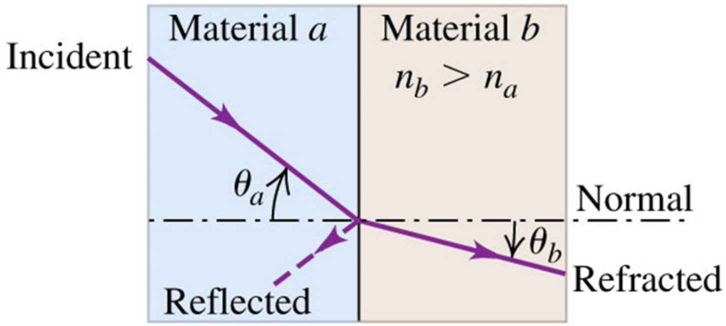
$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2}\sin\theta_1\right)$$



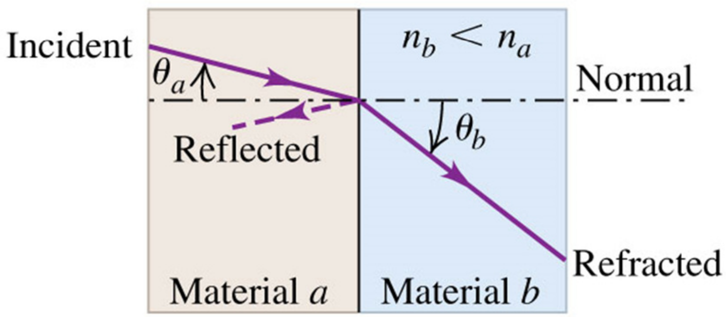
$n_2 < n_1$

(*c*)

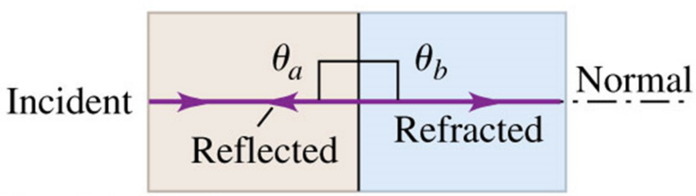
(a) A ray entering a material of *larger* index of refraction bends *toward* the normal.



(b) A ray entering a material of *smaller* index of refraction bends *away from* the normal.

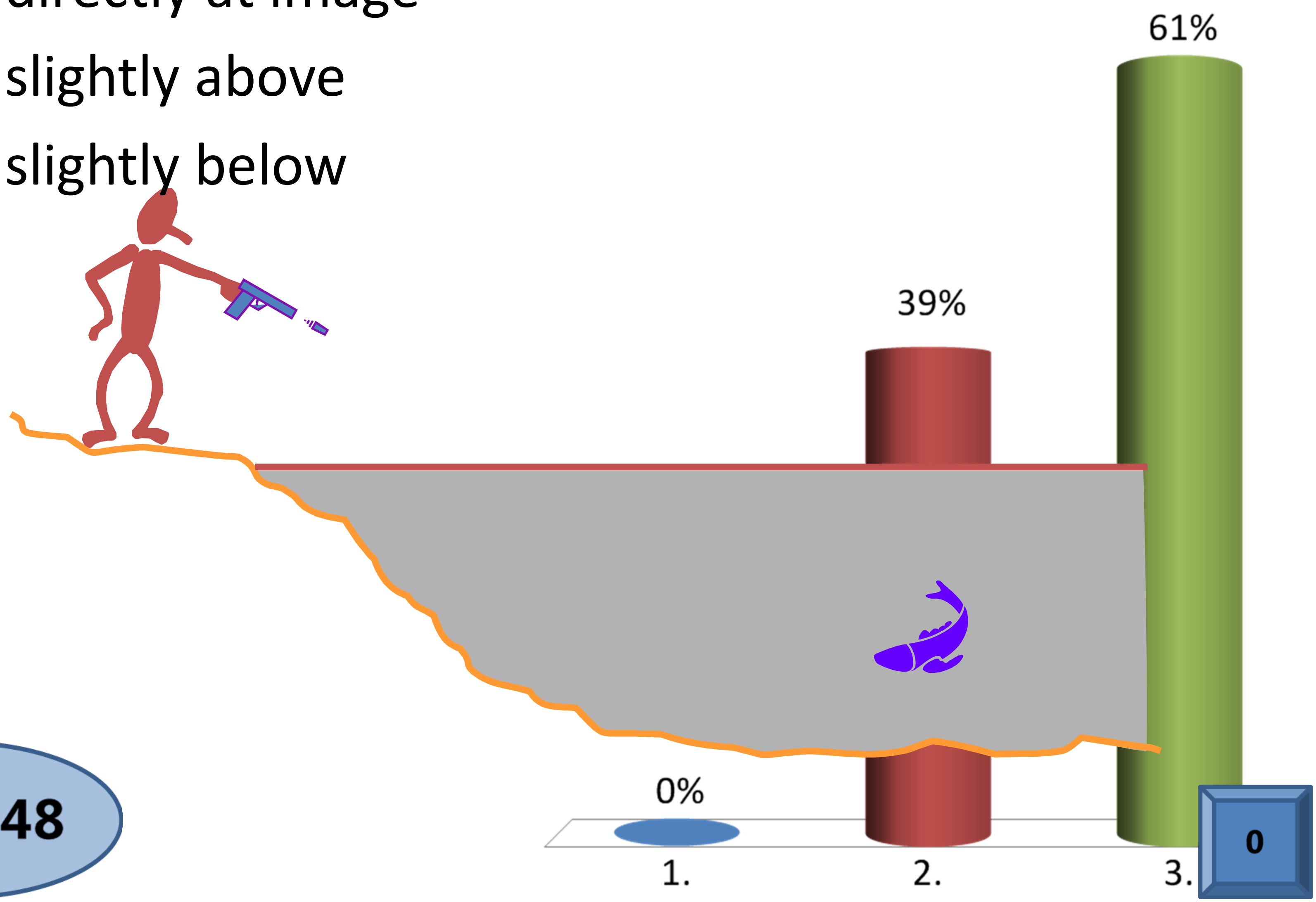


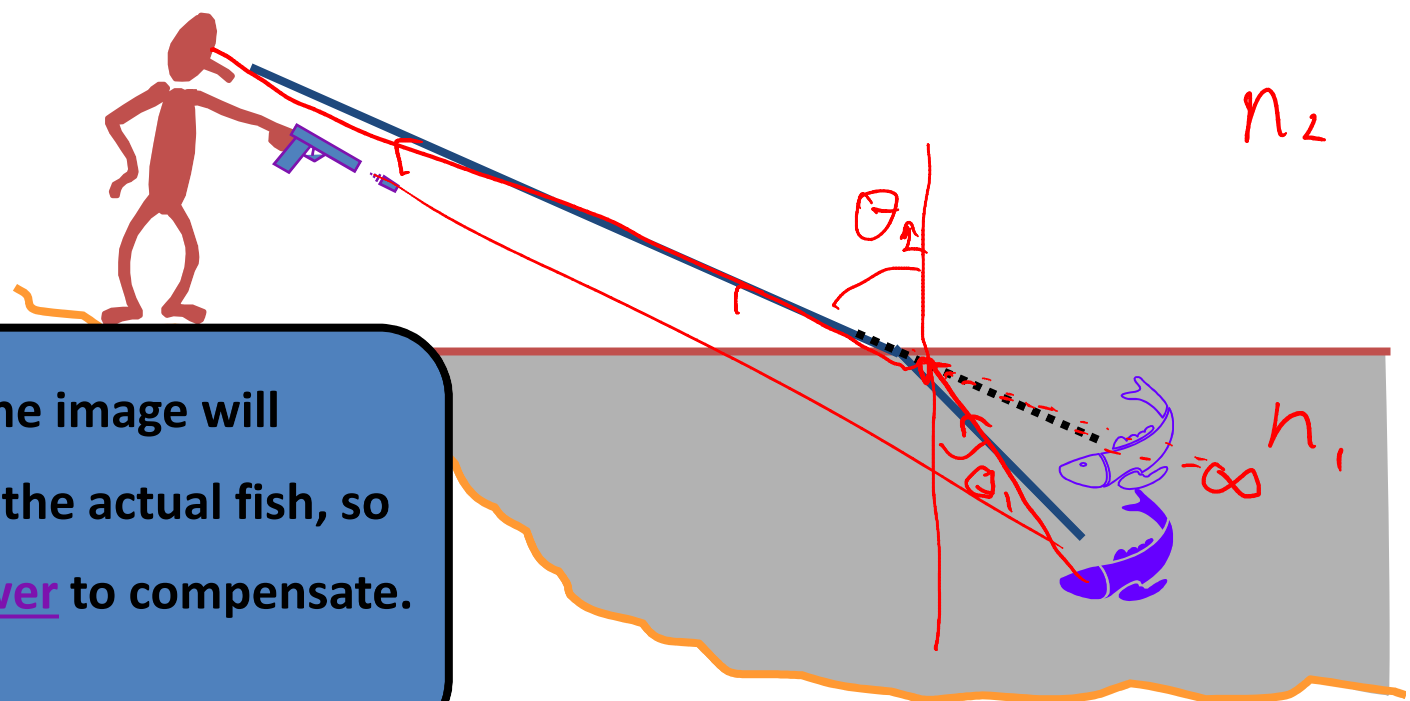
(c) A ray oriented along the normal does not bend, regardless of the materials.



To shoot a fish with a gun, should you aim directly at the image, slightly above, or slightly below?

1. Aim directly at image
2. Aim slightly above
3. ✓ Aim slightly below

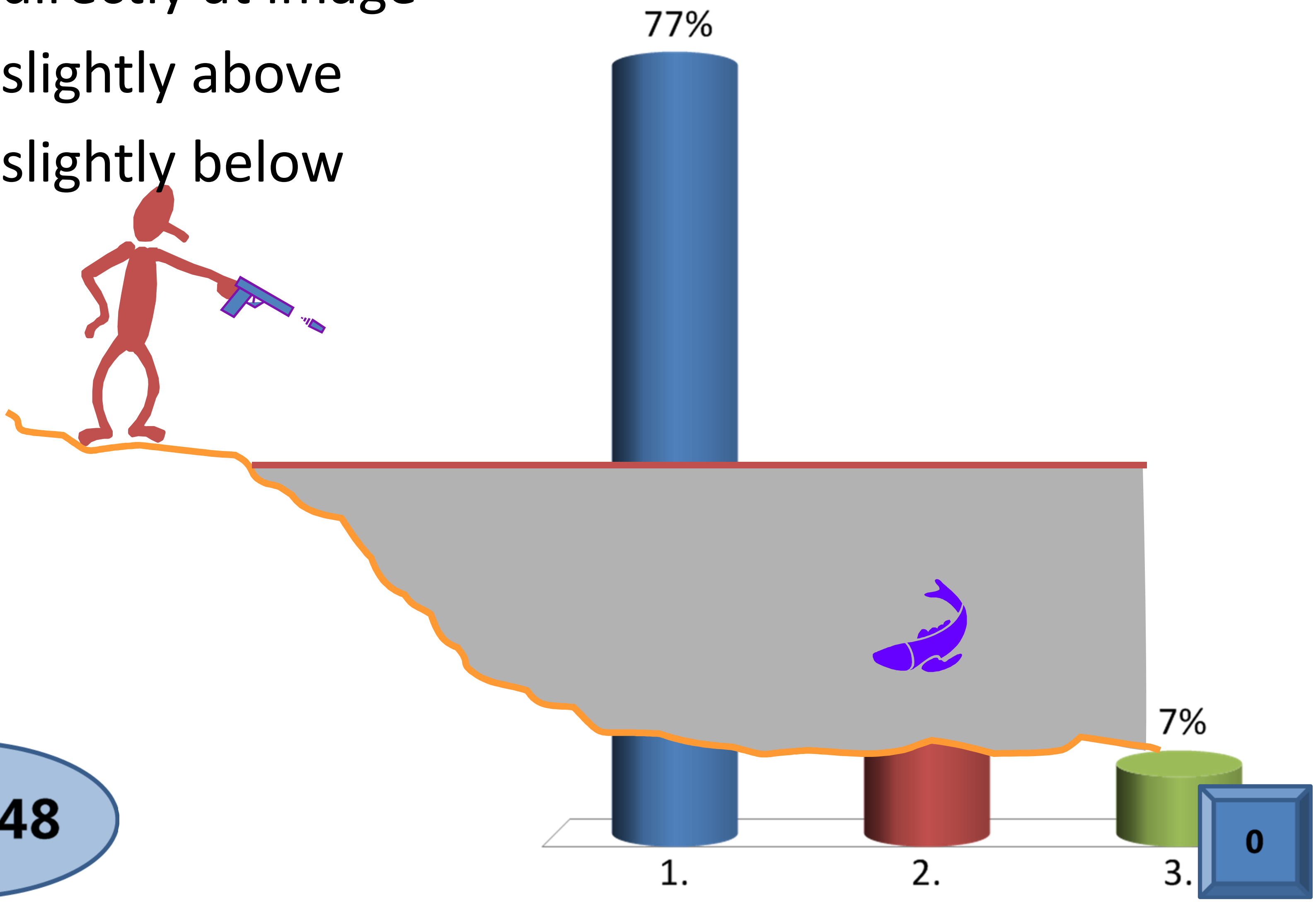




Due to refraction, the image will appear higher than the actual fish, so you have to aim <u>lower</u> to compensate.

To shoot a fish with a *laser gun*, should you aim directly at the image, slightly above, or slightly below?

1. Aim directly at image ✔
2. Aim slightly above
3. Aim slightly below



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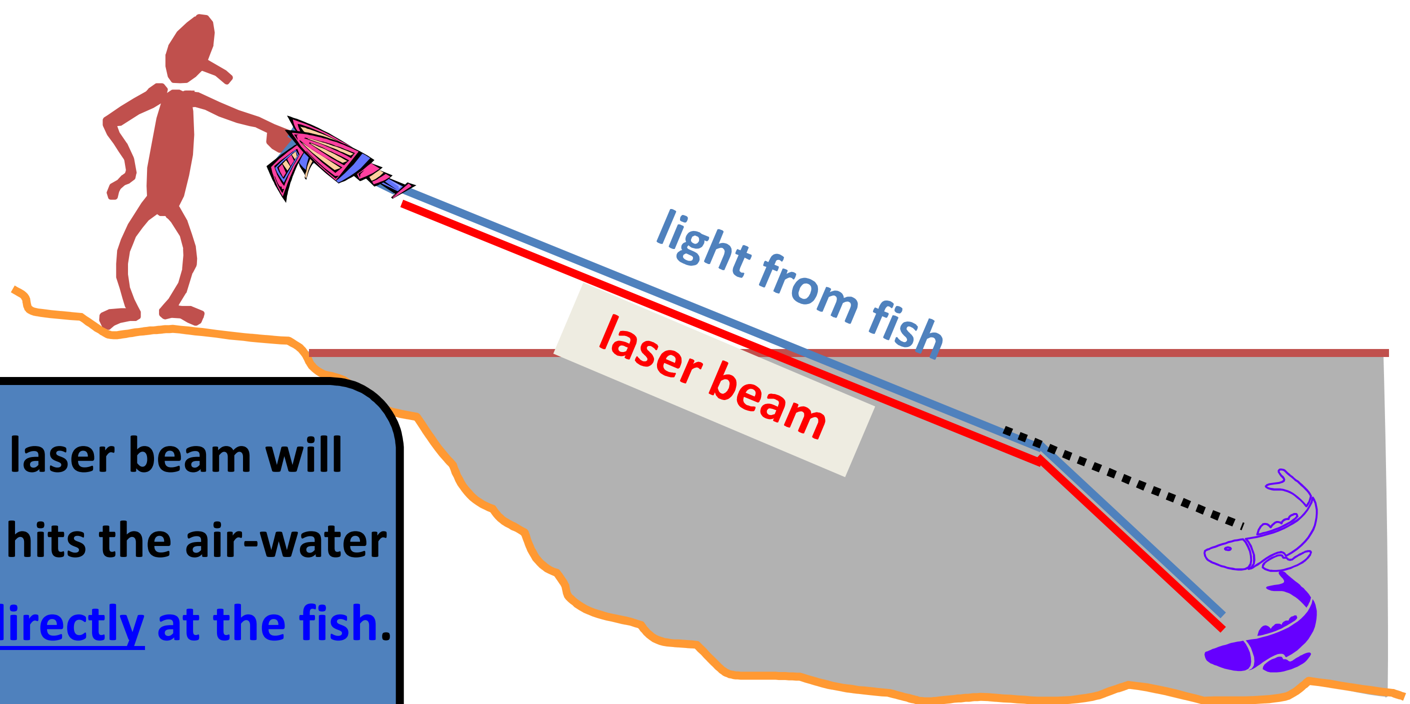
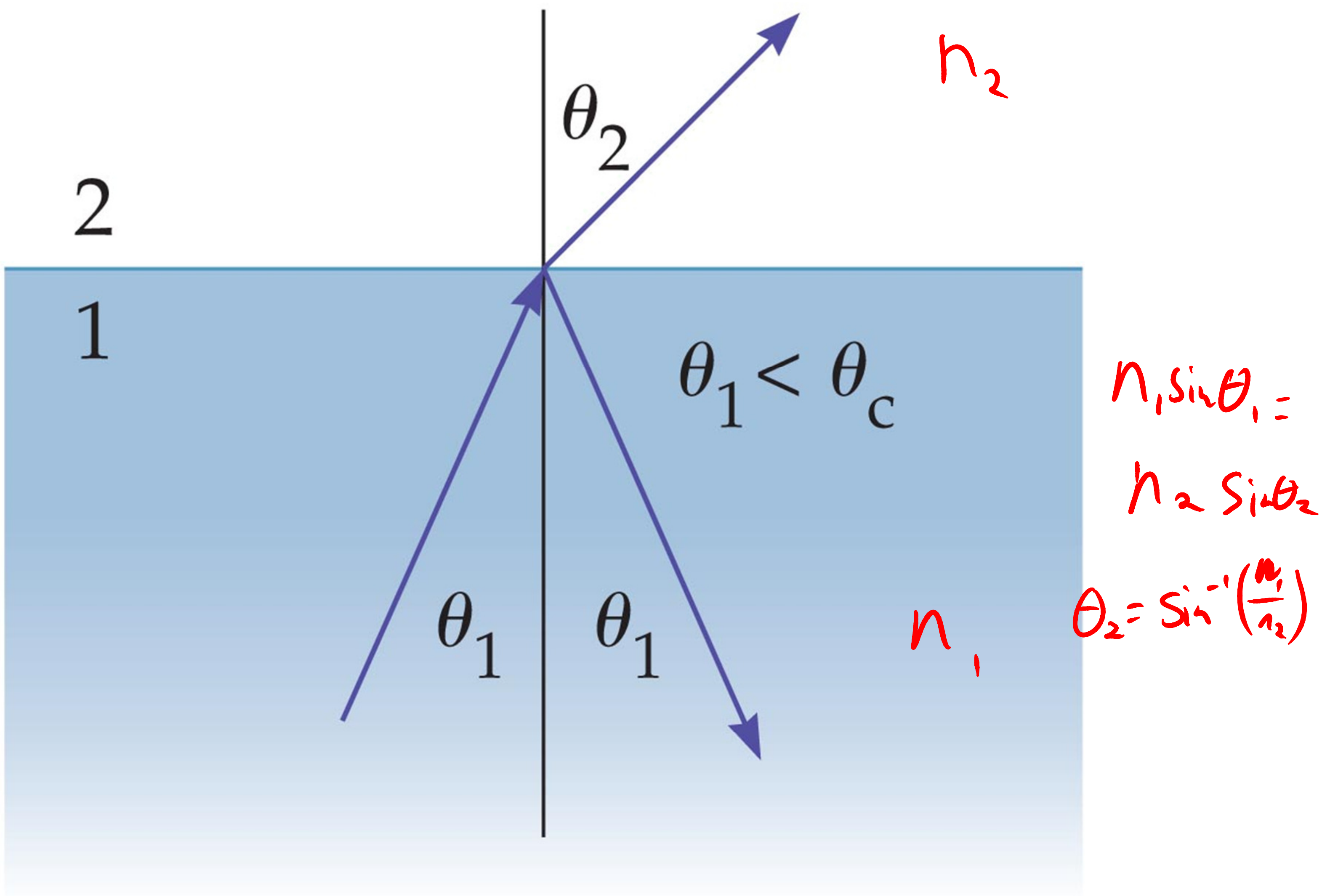
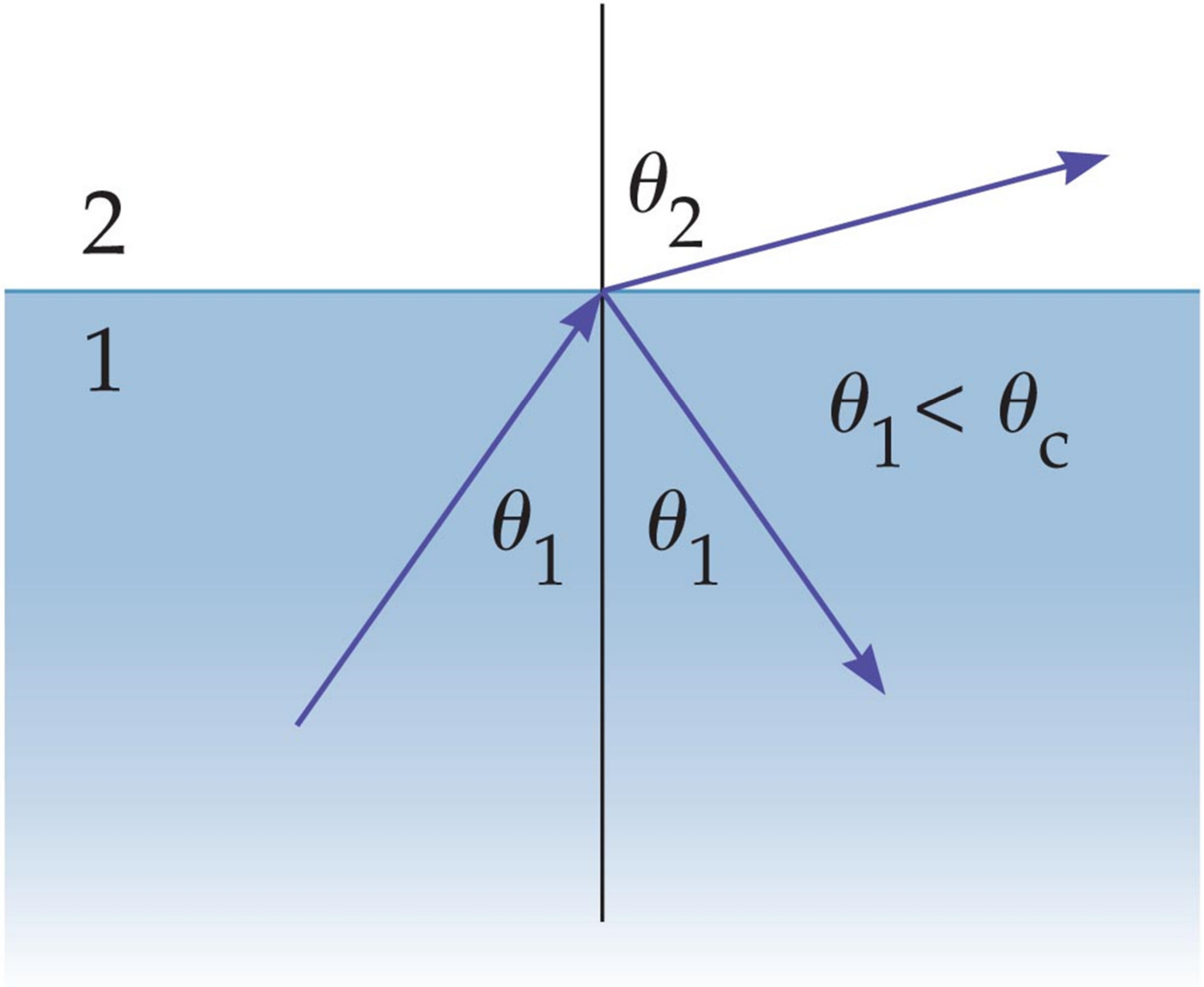


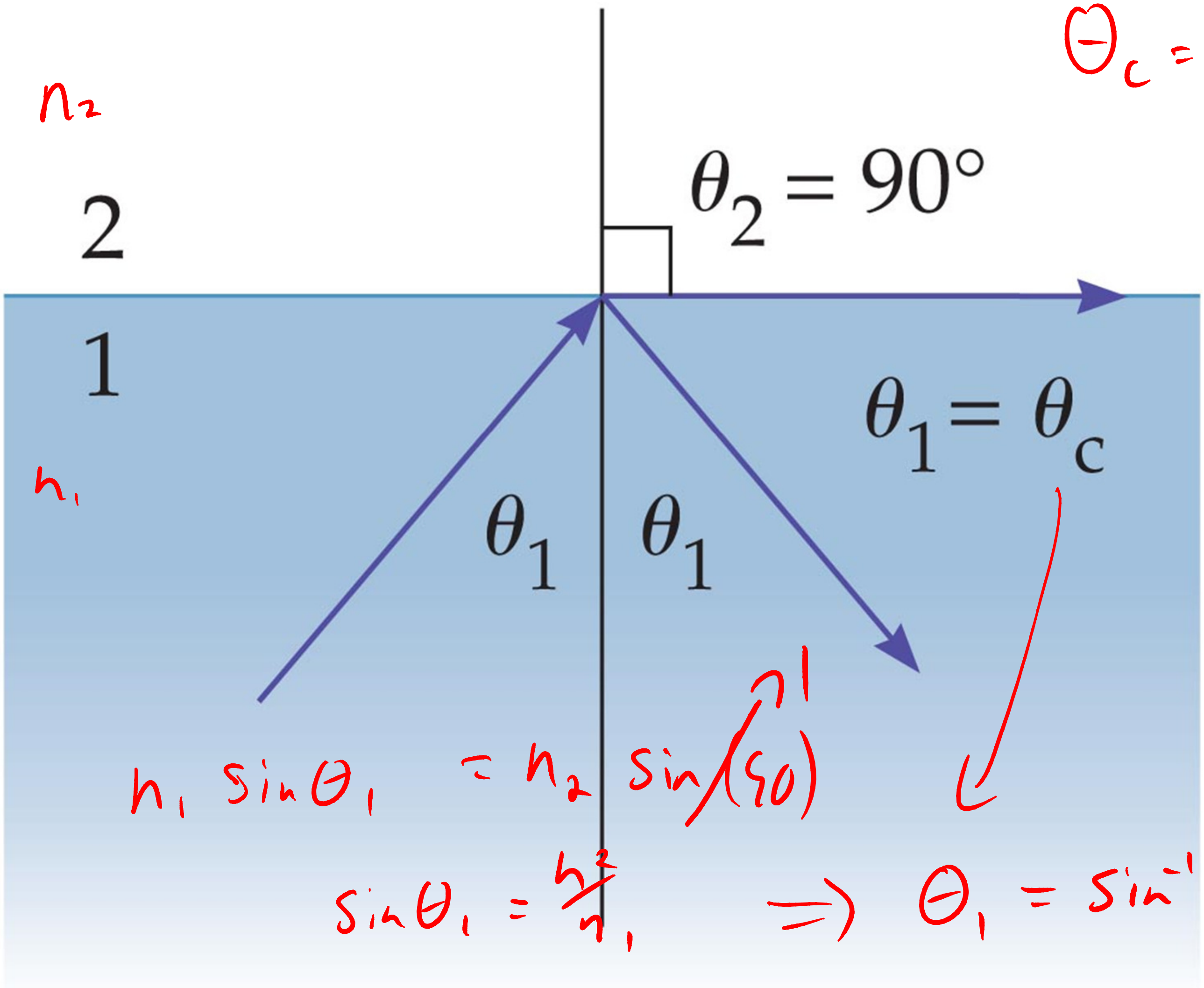
The light from the laser beam will also bend when it hits the air-water interface, so aim <u>directly</u> at the fish.



(a) Small angle of incidence



(b) Larger angle of incidence



n_2

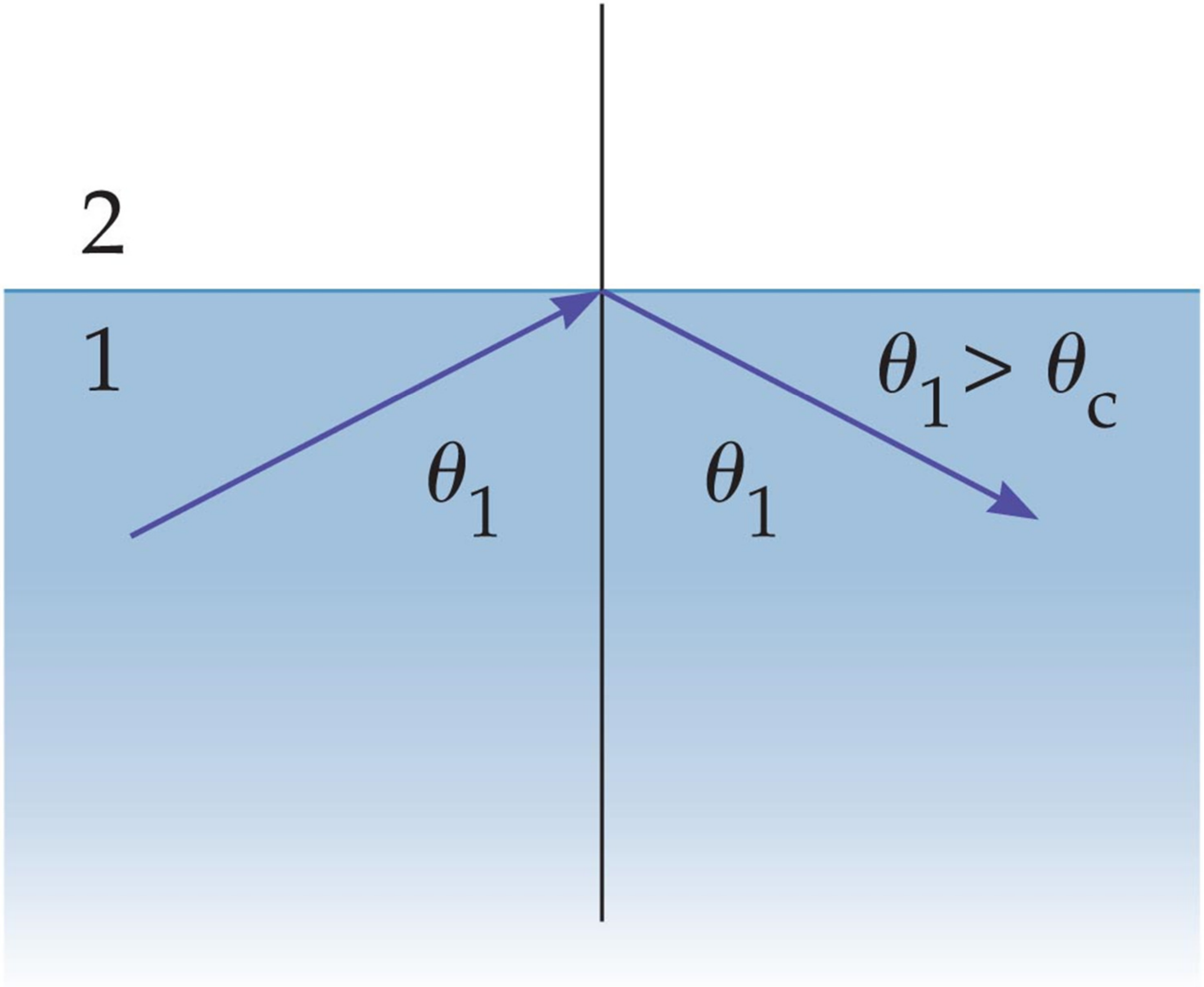
n_1

θ_c = "critical angle"

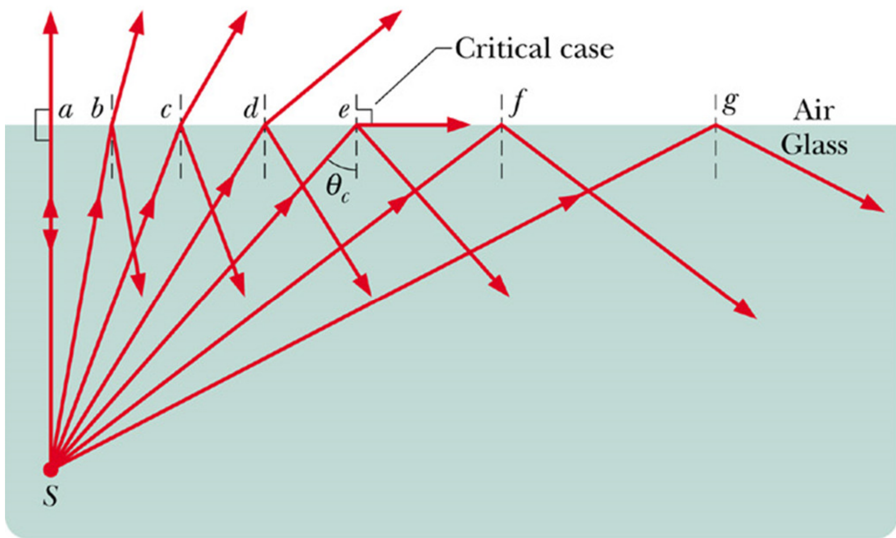
$$n_1 \sin\theta_1 = n_2 \sin(90) \quad [\sin(90) \to 1]$$

$$\sin\theta_1 = \frac{n_2}{n_1} \Rightarrow \theta_1 = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

(c) Refracted beam parallel to interface

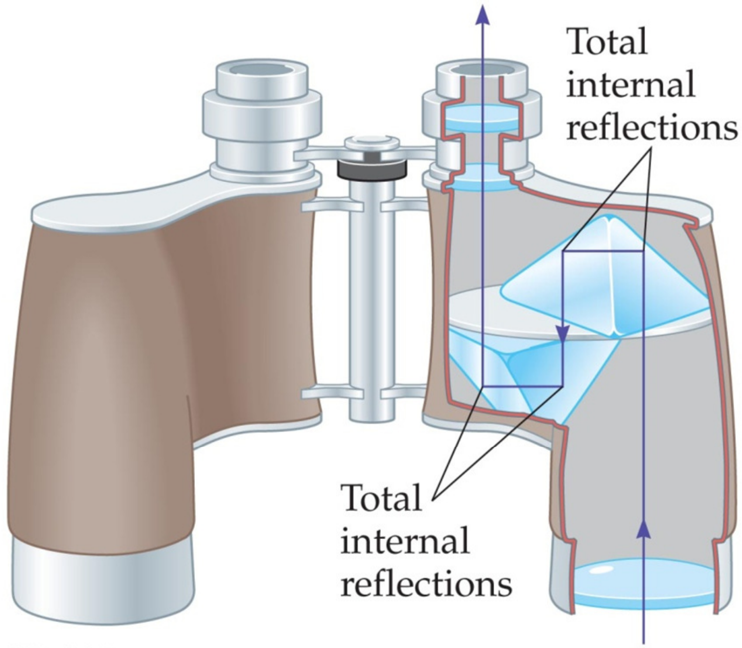


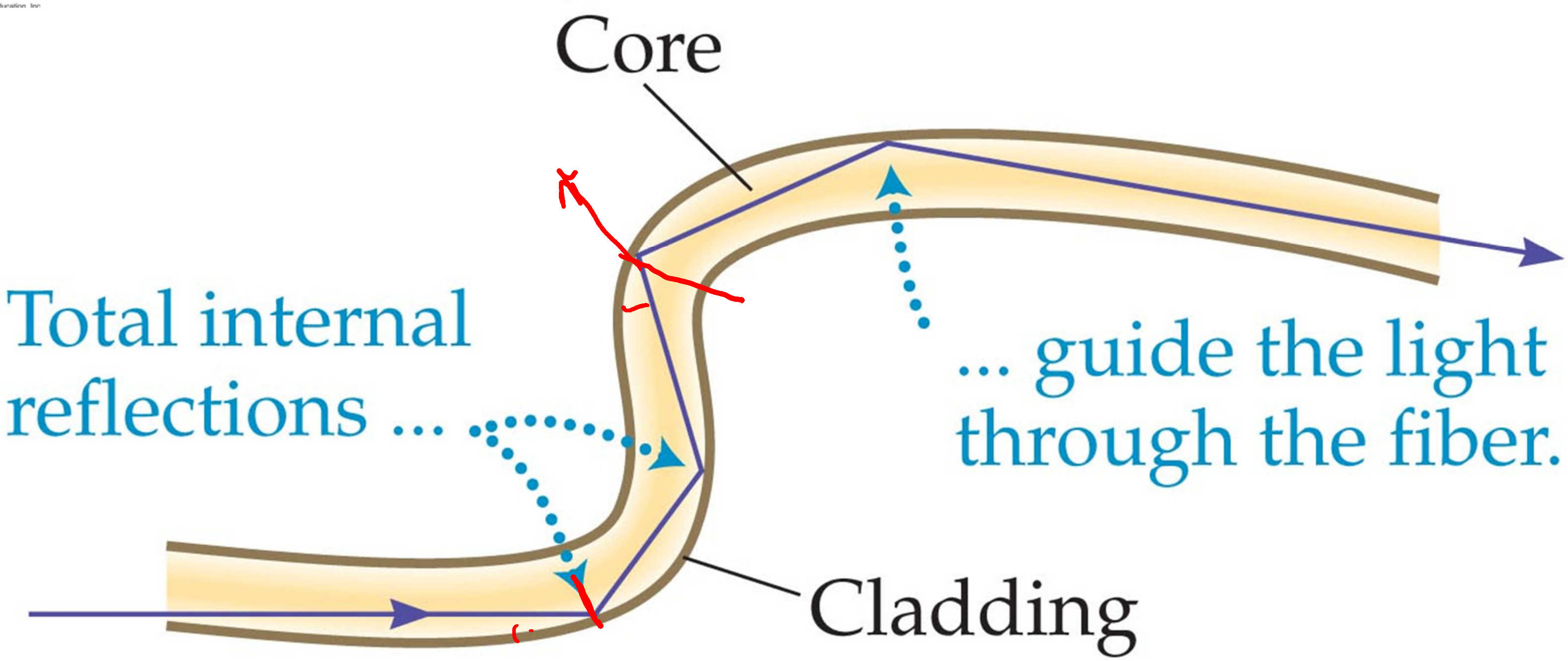
(d) Total internal reflection

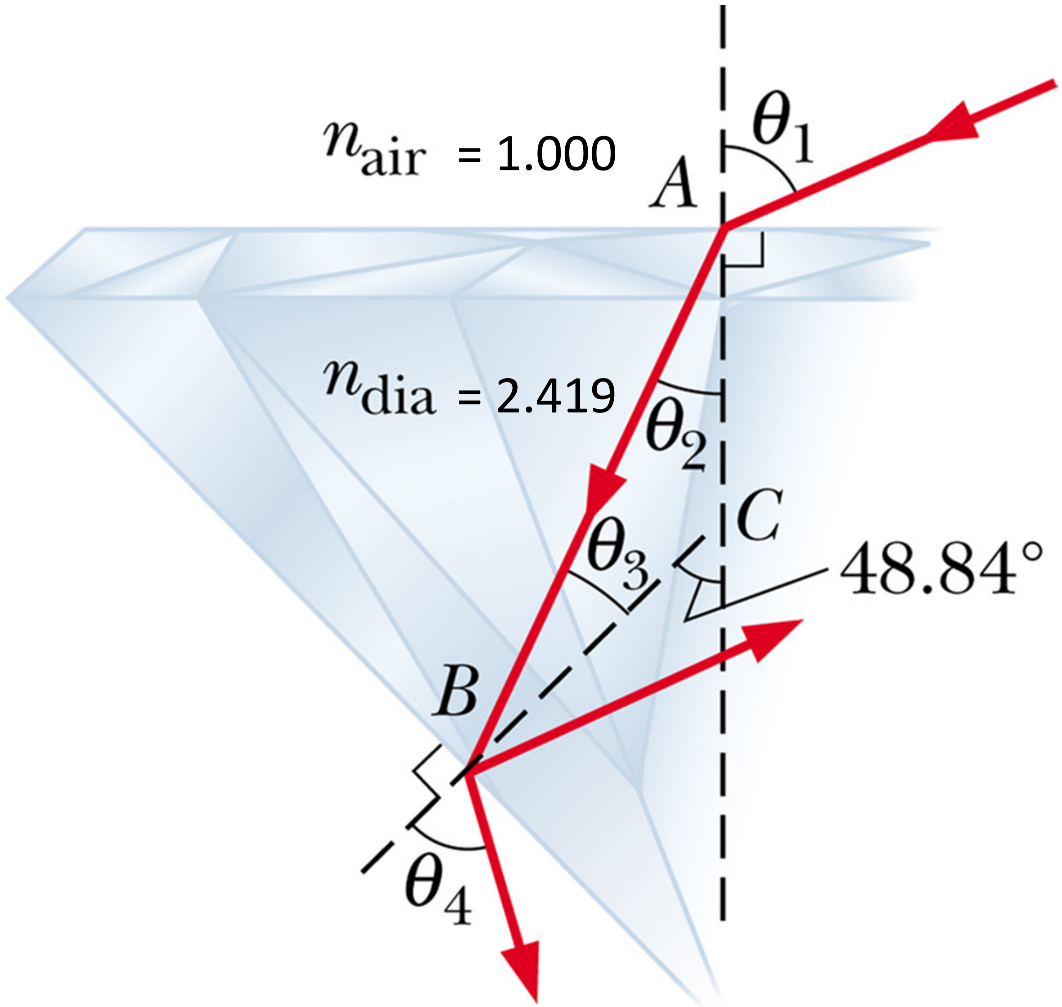


(a)

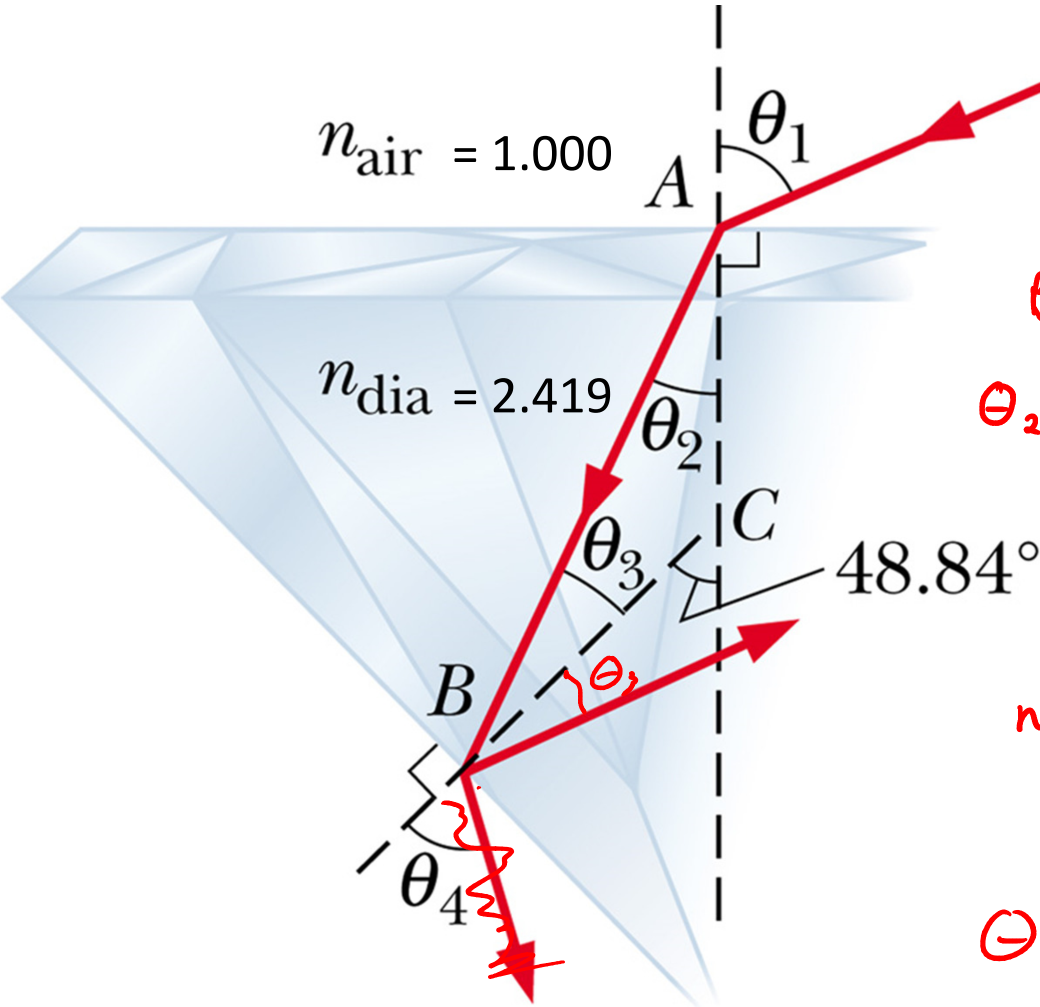
(b)



Total
internal
reflections
Total
internal
reflections


Core
Total internal
reflections ...
... guide the light
through the fiber.
Cladding



Student problem: Given θ_1 is 40 degrees (just one possibility)
Find θ_2 then θ_3, and determine is θ_3 greater than the critical angle that gives total internal reflection? Make sure you can explain the condition



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

so $\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2} \sin\theta_1\right) = 15.41°$

But how to find θ_3?

$\theta_2 + \theta_3 + (180 - 48.84) = 180$

$\theta_2 + \theta_3 = 48.84$

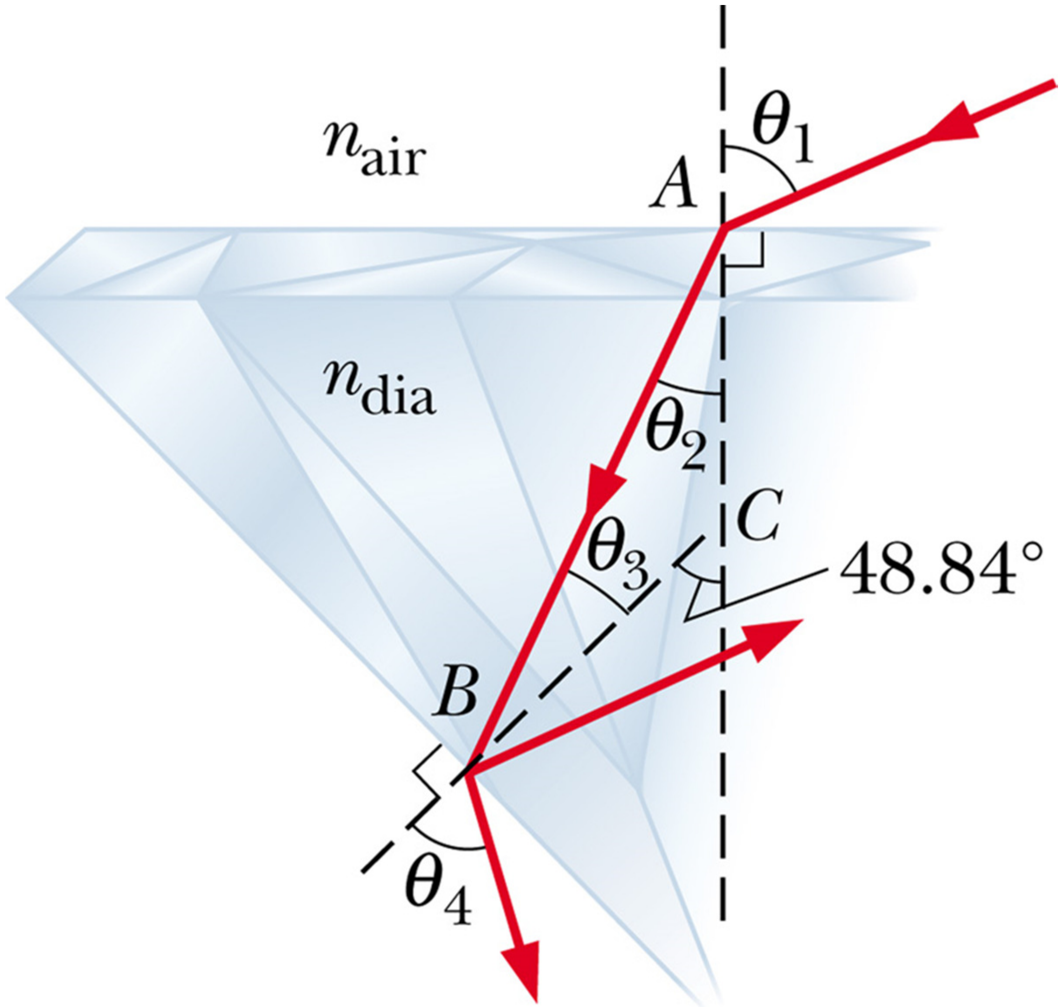
$\theta_3 = 33.43°$

$n_d \sin\theta_d = n_a \sin(90)$ 1

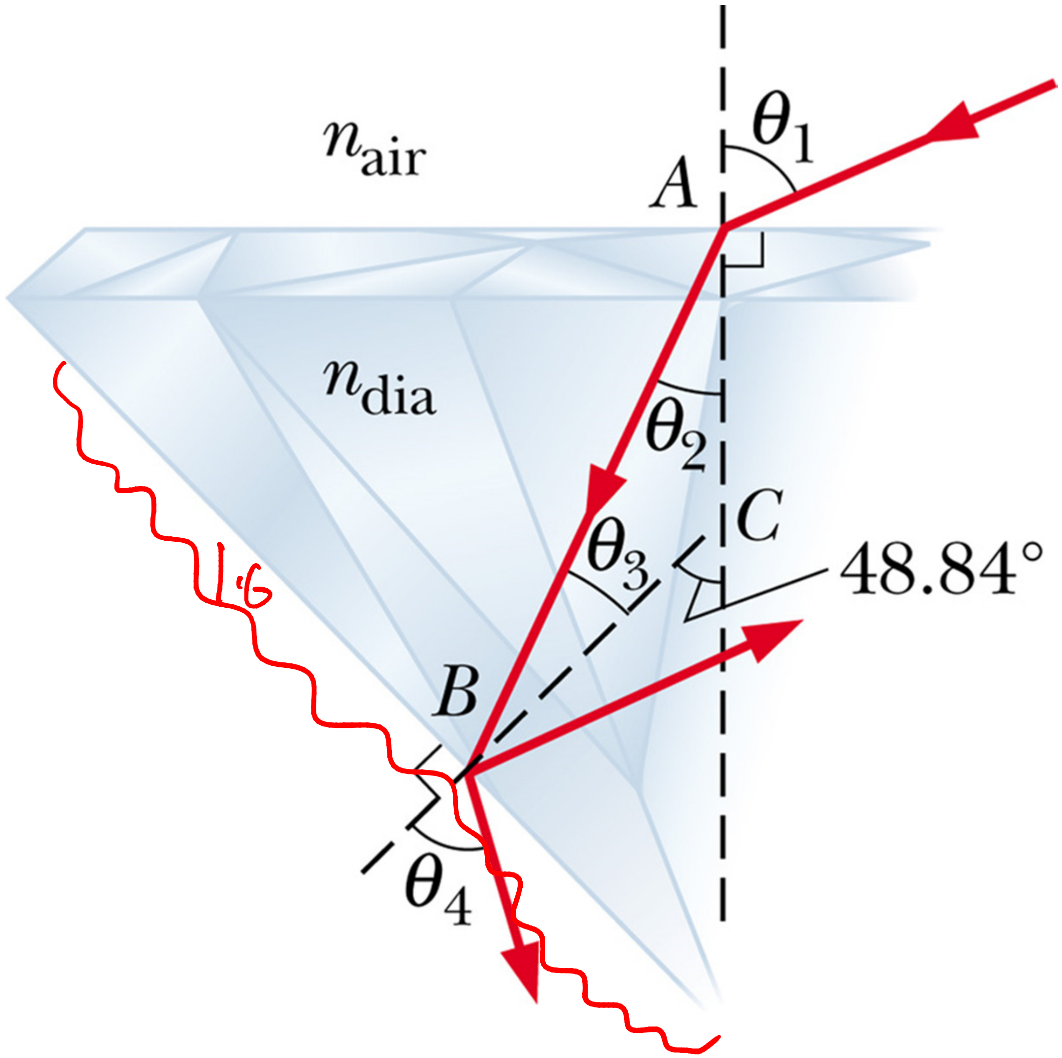
$\left(\theta_d = \sin^{-1}\left(\frac{n_a}{n_d}\right)\right)$

$\theta_c = \sin^{-1}\left(\frac{1.00}{2.419}\right) = 24.40°$

Student problem: Given θ_1 is 40 degrees (just one possibility)
Find θ_2 then θ_3, and determine is θ_3 greater than the critical angle that gives total internal reflection? Make sure you can explain the condition

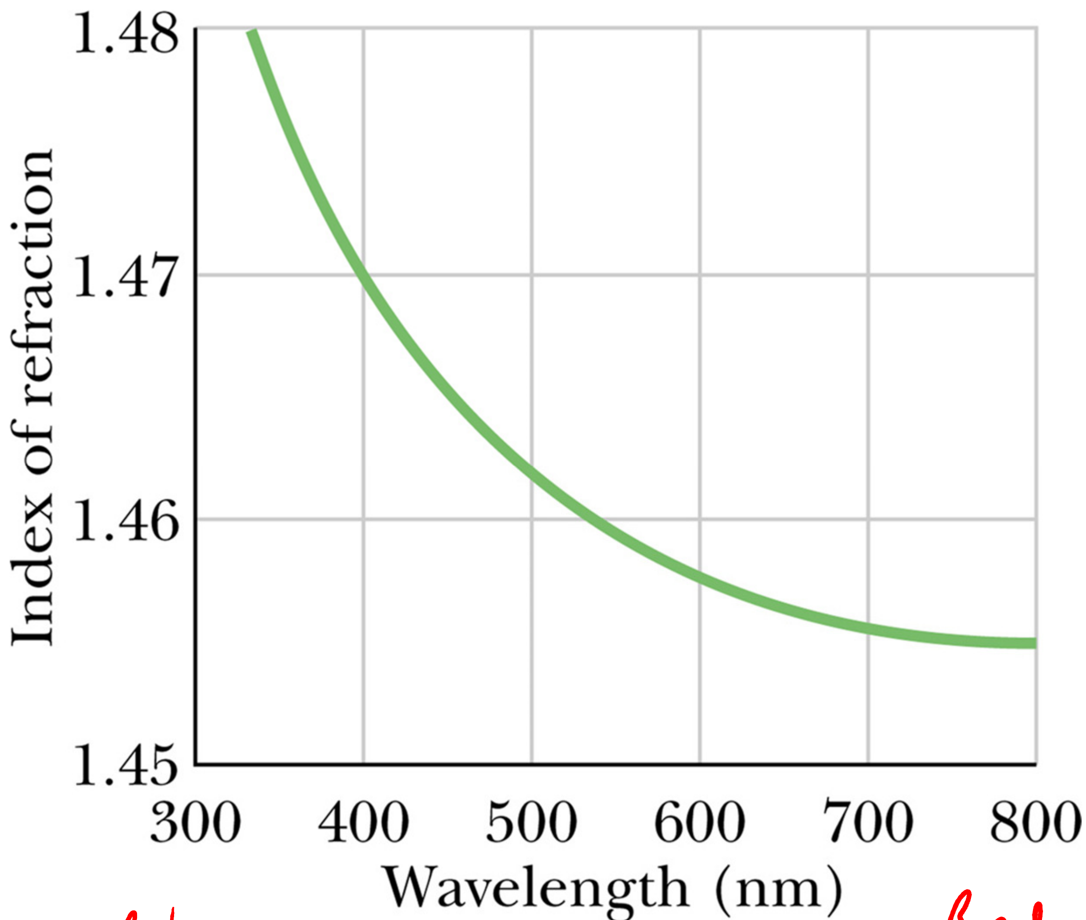


Student problem: What if it's not air behind the diamond at point B, but rather grease from your finger with n=1.6? Is diamond still sparkly?



here, θ_c @ point B is new: $\theta_c = \sin^{-1}\left(\frac{1.6}{2.419}\right) = 41°$

Student problem: What if it's not air behind the diamond at point B, but rather grease from your finger with n=1.6? Is diamond still sparkly?



n

Blue

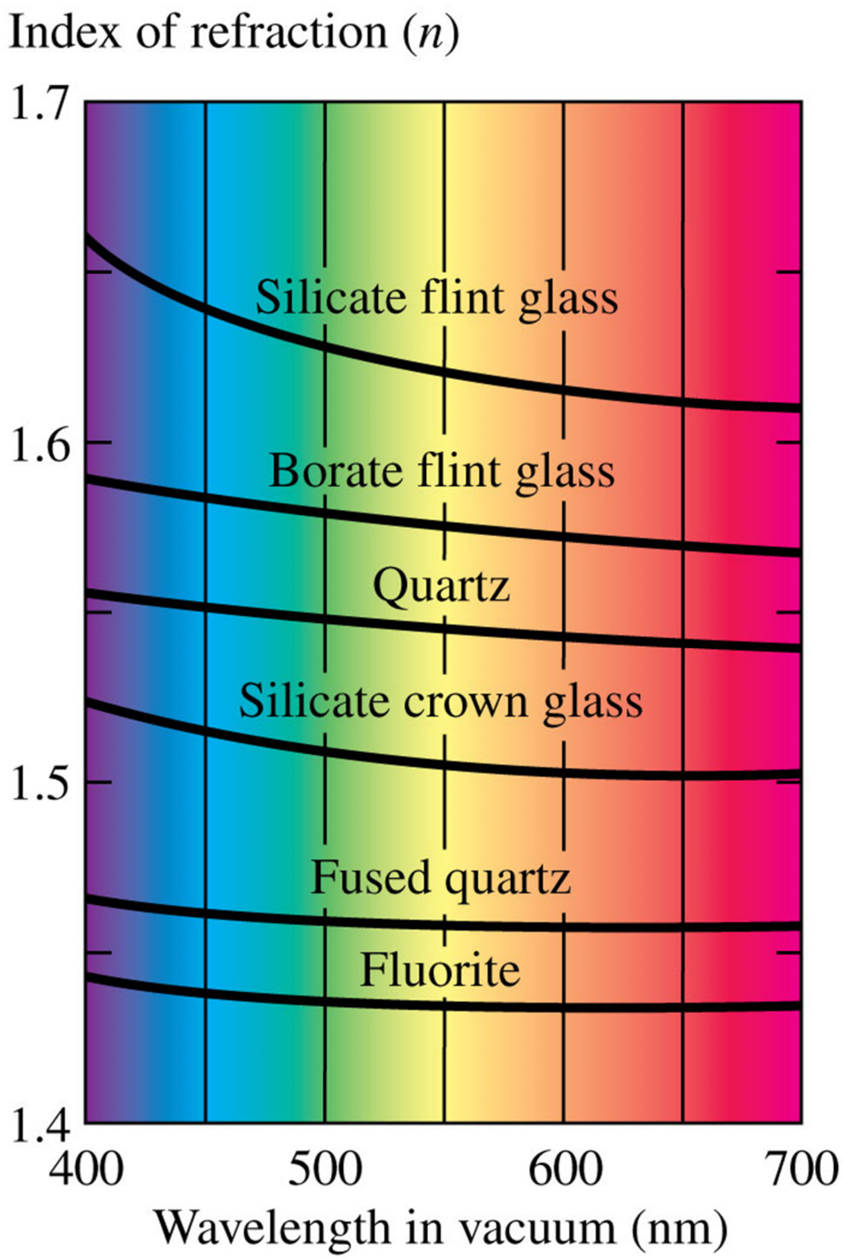
Red

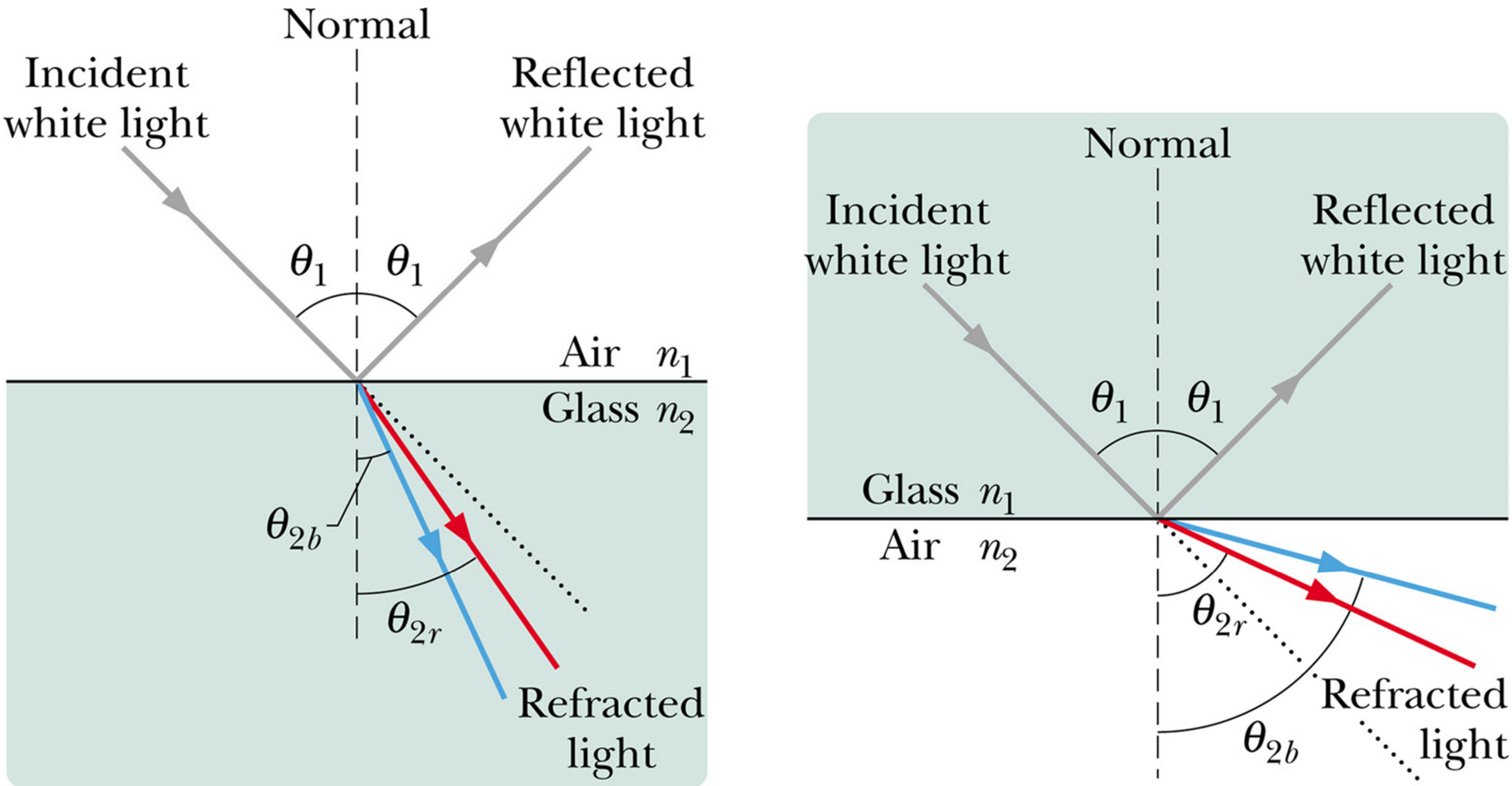
dispersion

↓

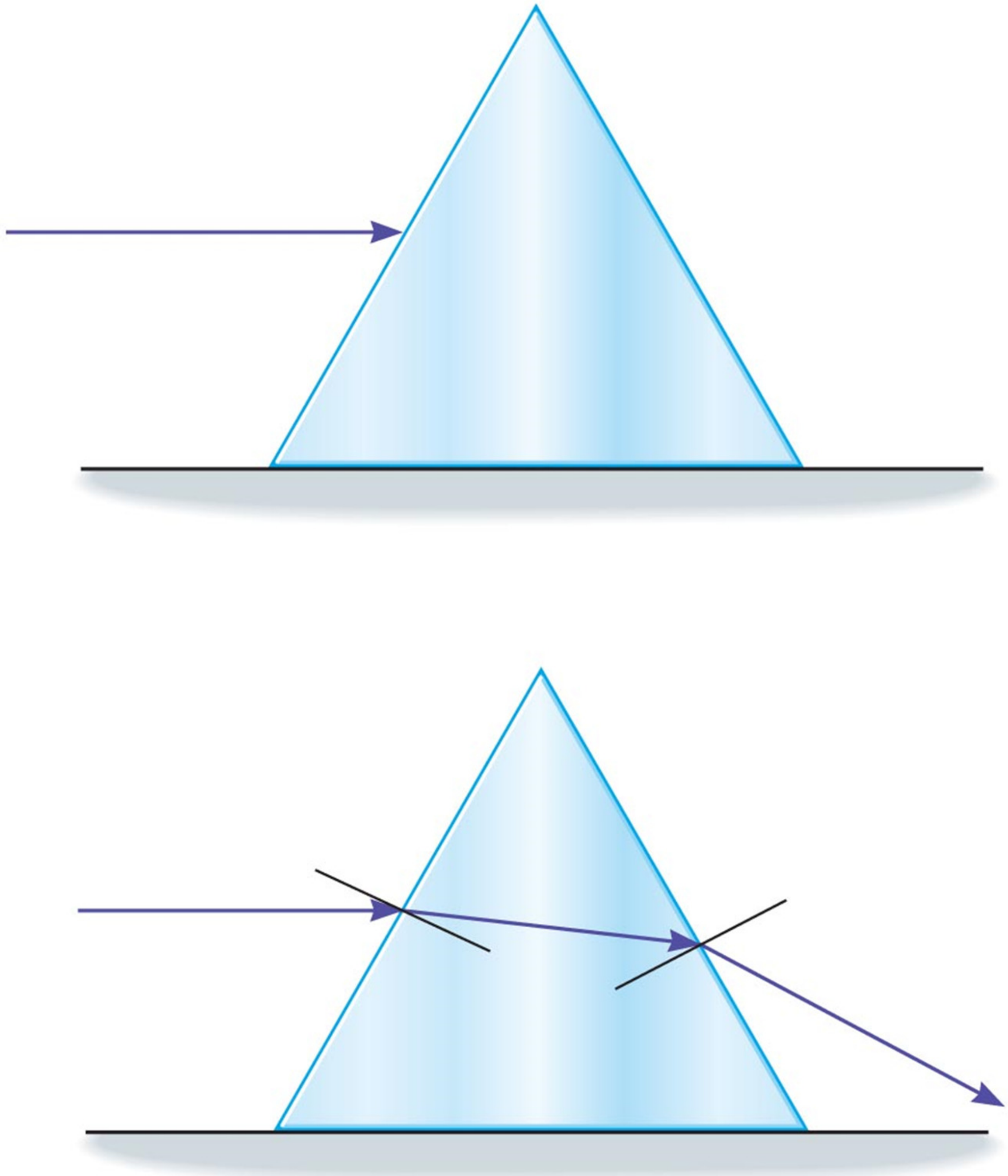
$$\frac{dn}{d\lambda}$$

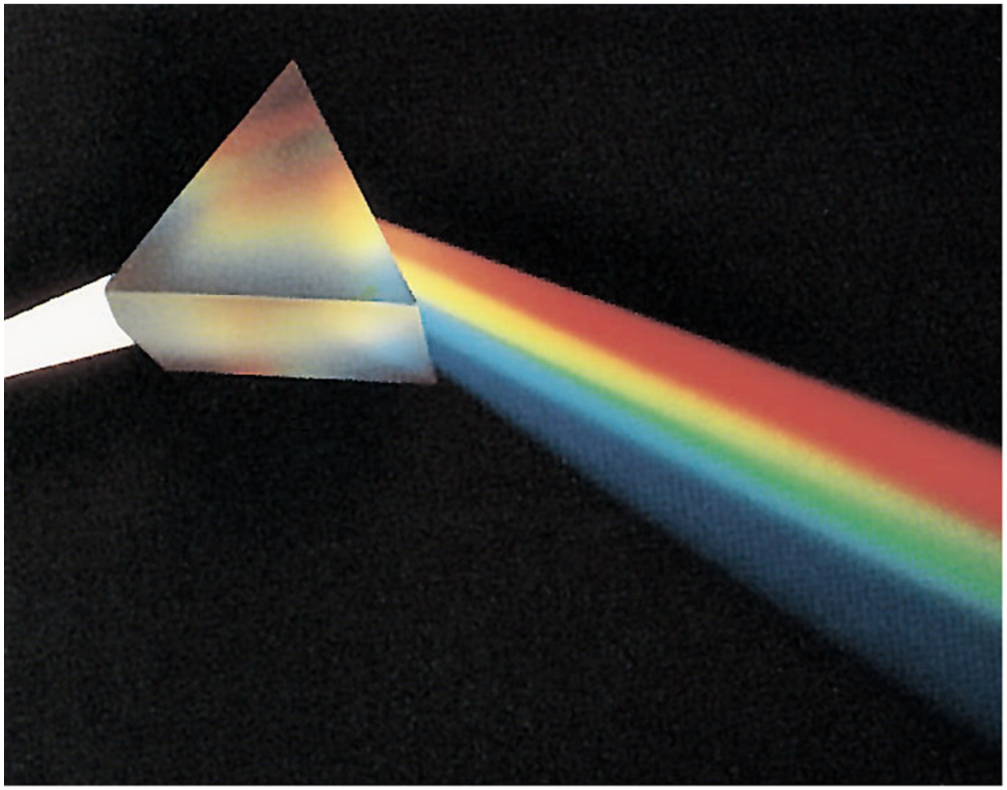
$n(\lambda)$


Index of refraction (n)
1.7
1.6
1.5
1.4
Silicate flint glass
Borate flint glass
Quartz
Silicate crown glass
Fused quartz
Fluorite
400
500
600
700
Wavelength in vacuum (nm)

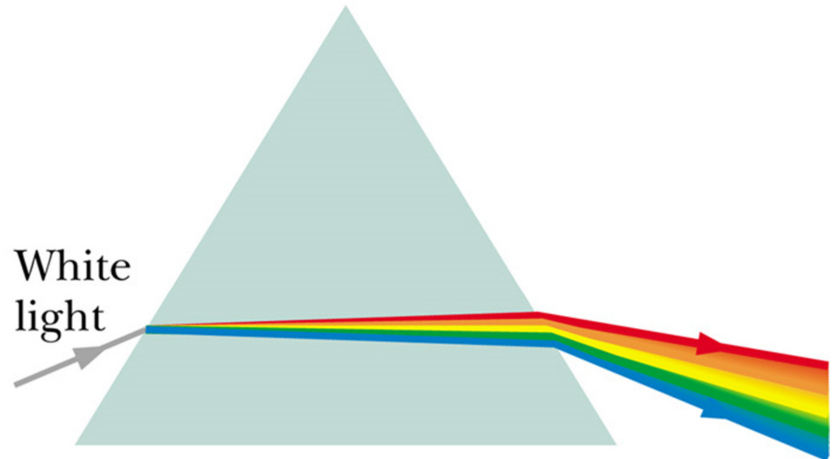

Normal
Incident white light
Reflected white light
θ_1
θ_1
Air n_1
Glass n_2
θ_{2b}
θ_{2r}
Refracted light
Normal
Incident white light
Reflected white light
θ_1
θ_1
Glass n_1
Air n_2
θ_{2r}
θ_{2b}
Refracted light

(*a*) (*b*)

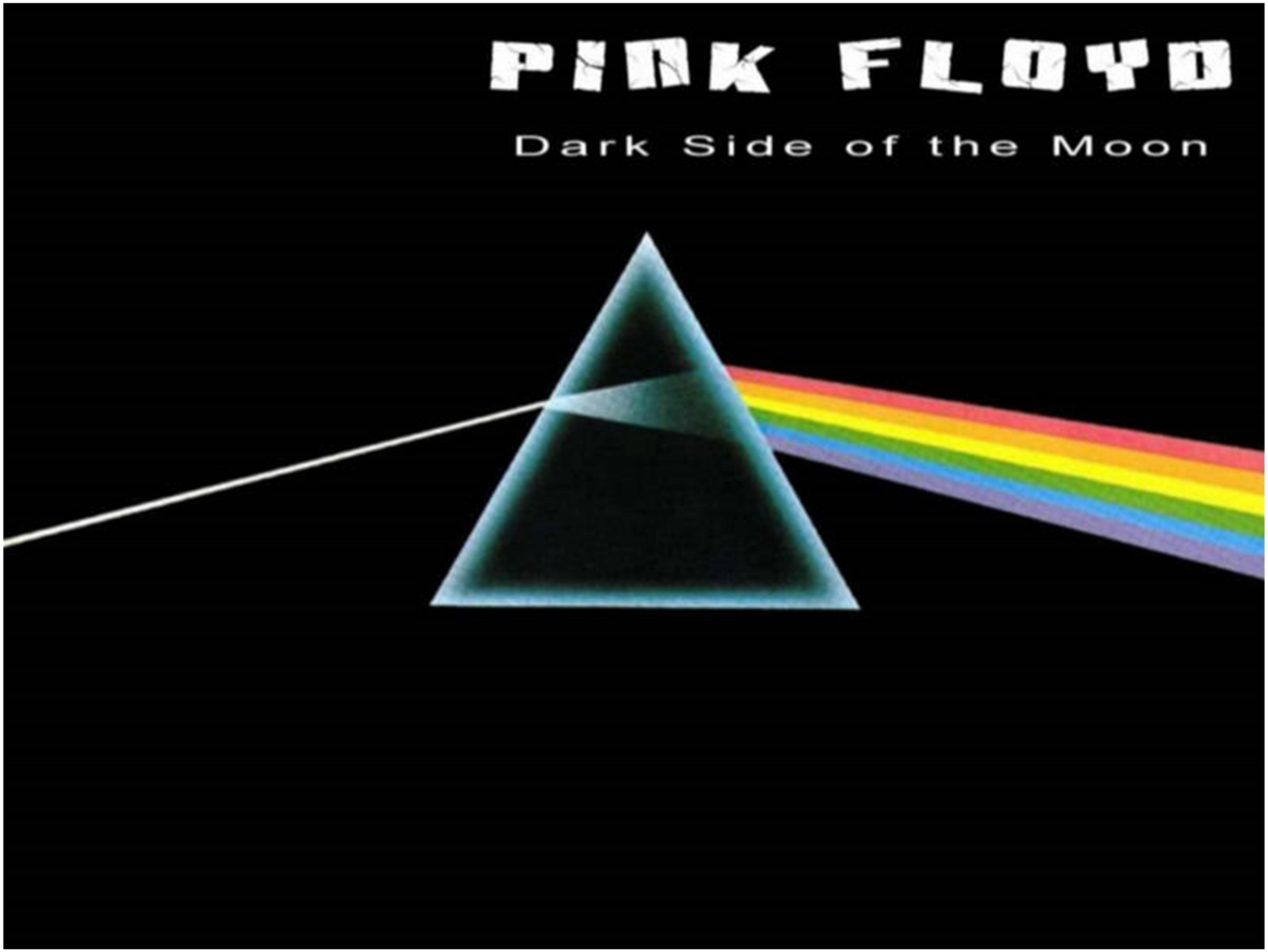


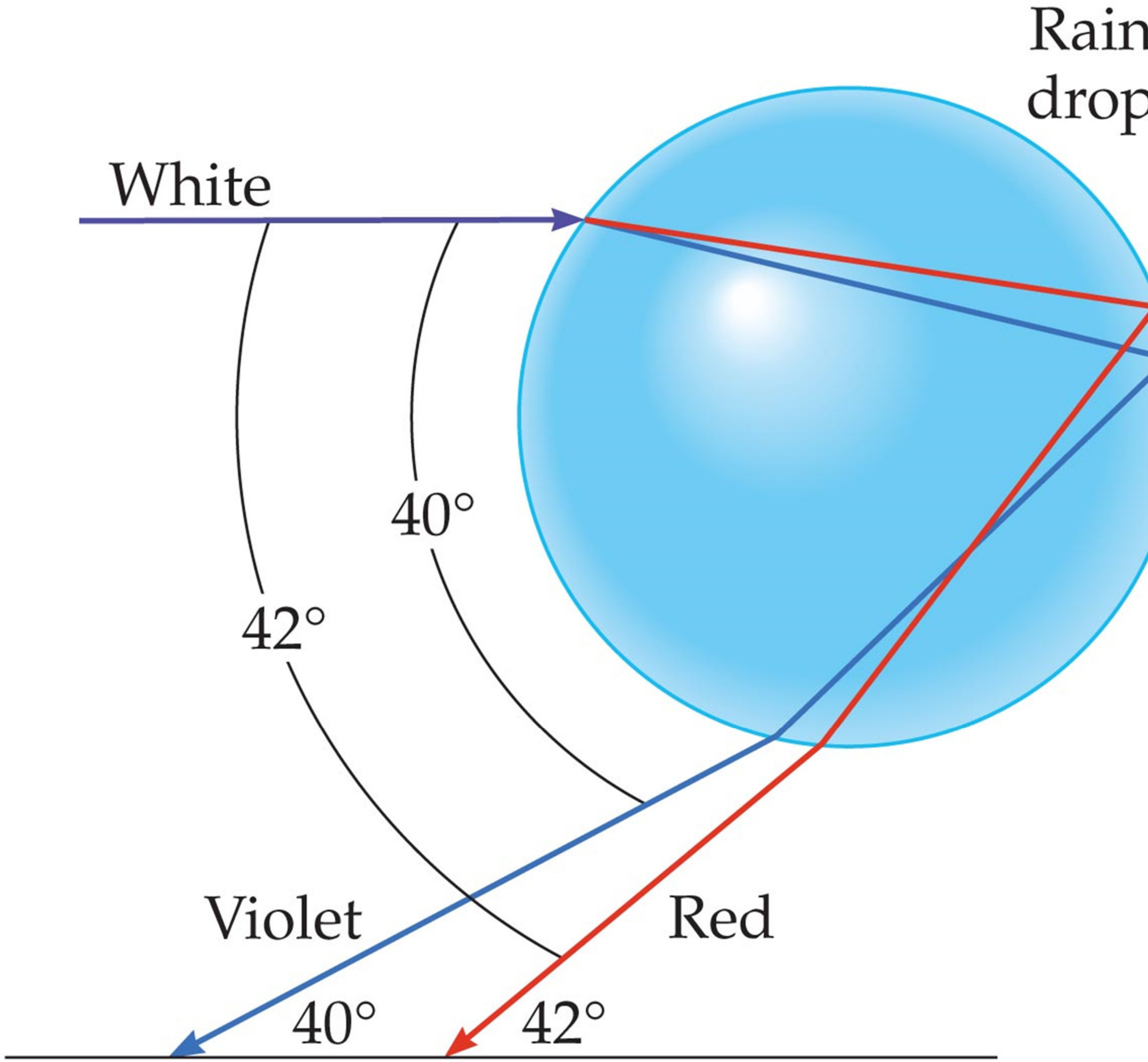


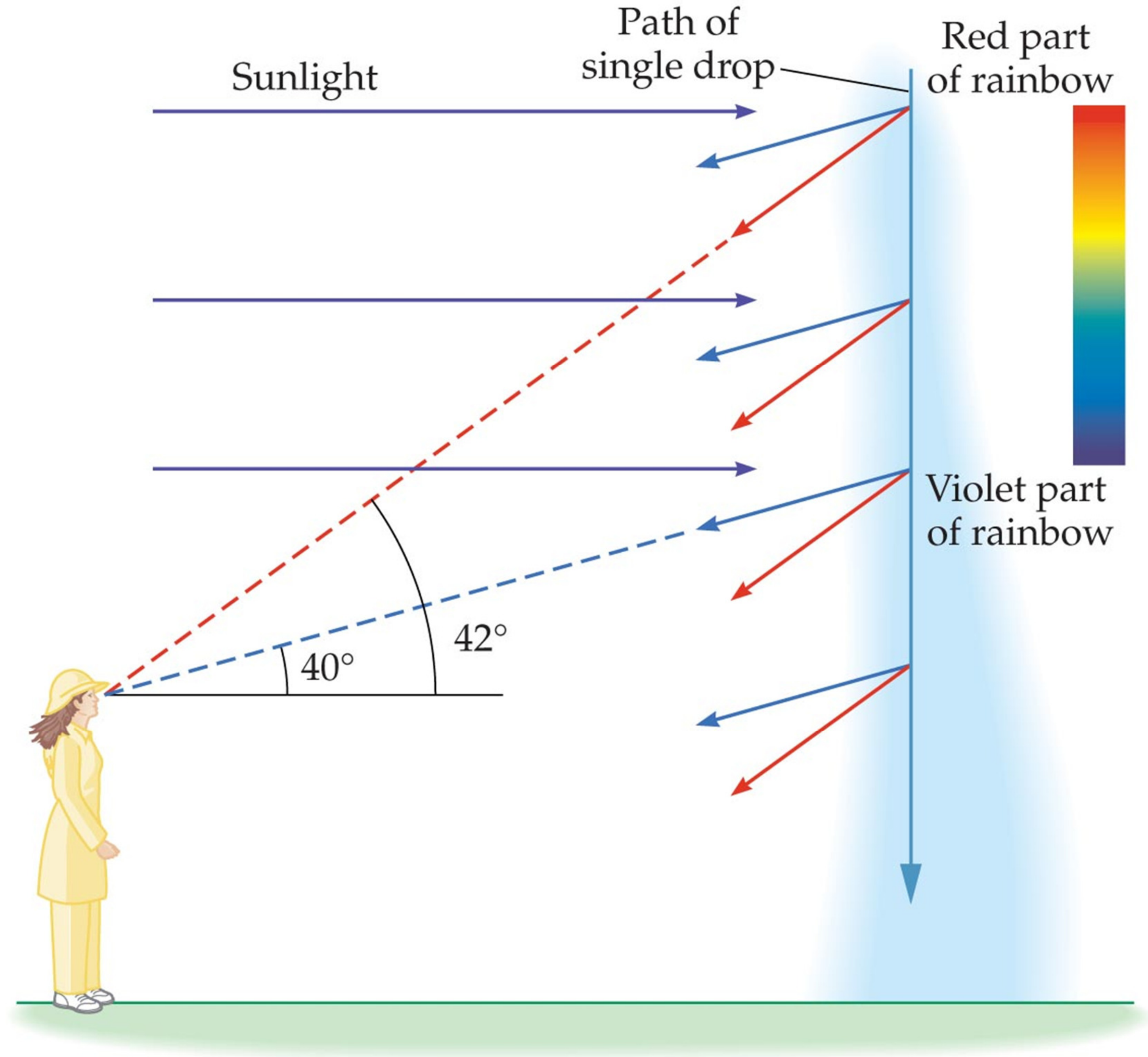
(*a*)

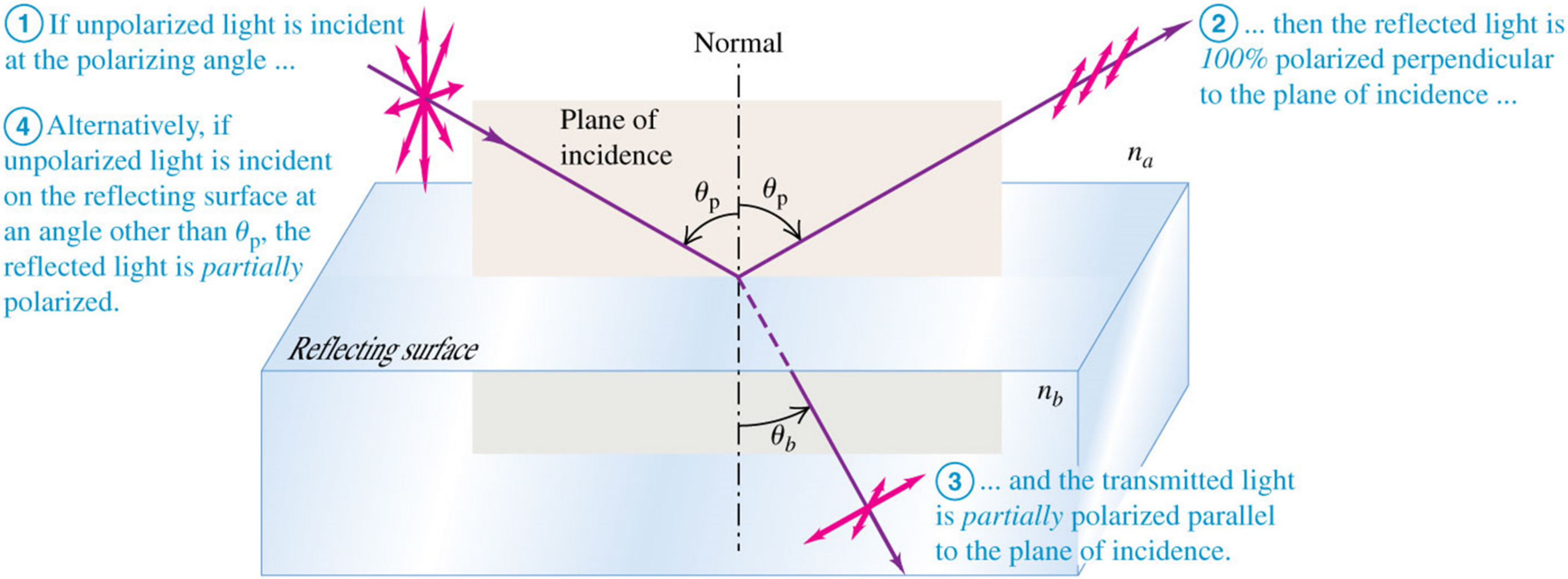


(*b*)


PINK FLOYD
Dark Side of the Moon


Rain
drop
White
40°
42°
Violet
Red
40°
42°

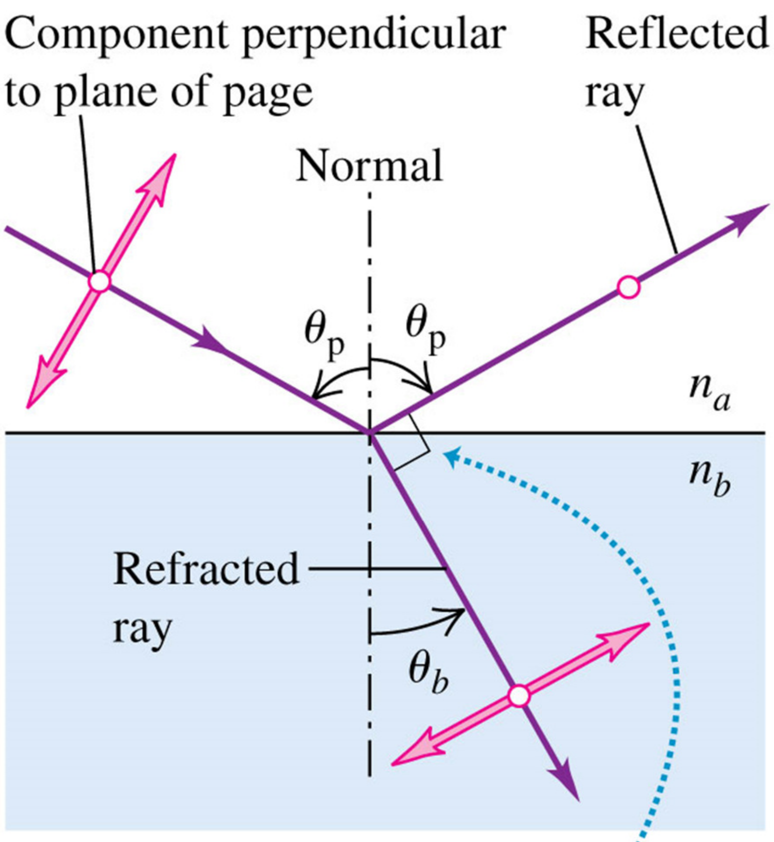

Path of
single drop
Red part
of rainbow
Sunlight
Violet part
of rainbow
42°
40°



$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

$$c_{water} = \frac{1}{\sqrt{\varepsilon \mu}}$$

Note: This is a side view of the situation shown in Fig. 33.27.



When light strikes a surface at the polarizing angle, the reflected and refracted rays are perpendicular to each other and

$$\tan \theta_p = \frac{n_b}{n_a}$$

$$180^\circ = \theta_p + 90^\circ + \theta_b$$

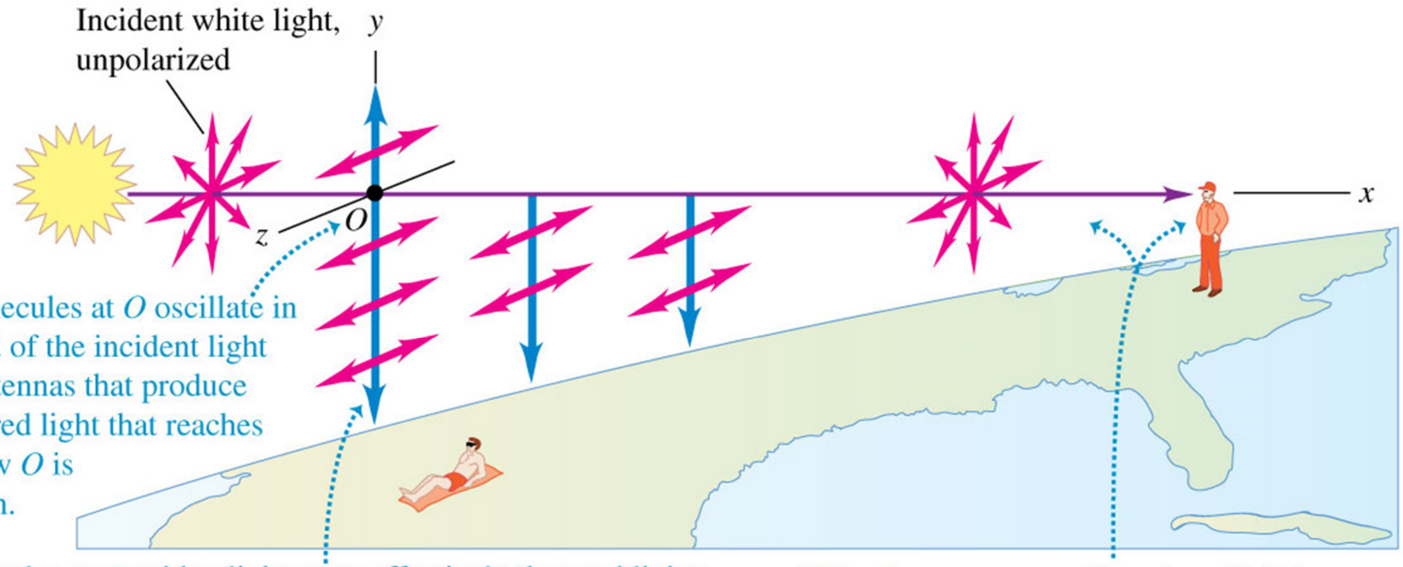
$$\theta_b = 90^\circ - \theta_p$$

$$n_a \sin \theta_p = n_b \sin \theta_b$$

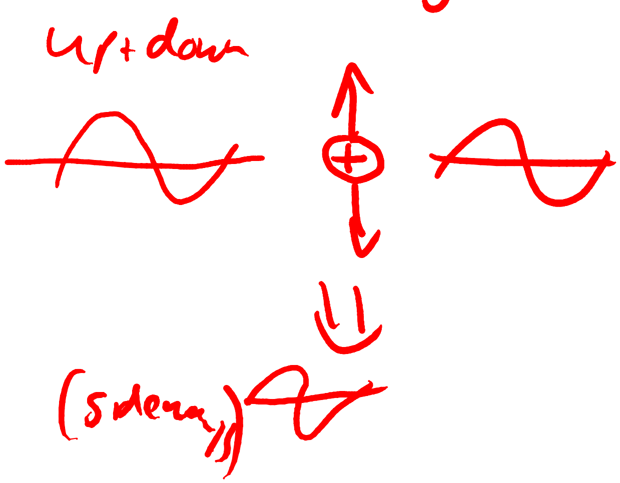
$$n_a \sin \theta_p = n_b \sin(90 - \theta_p)$$

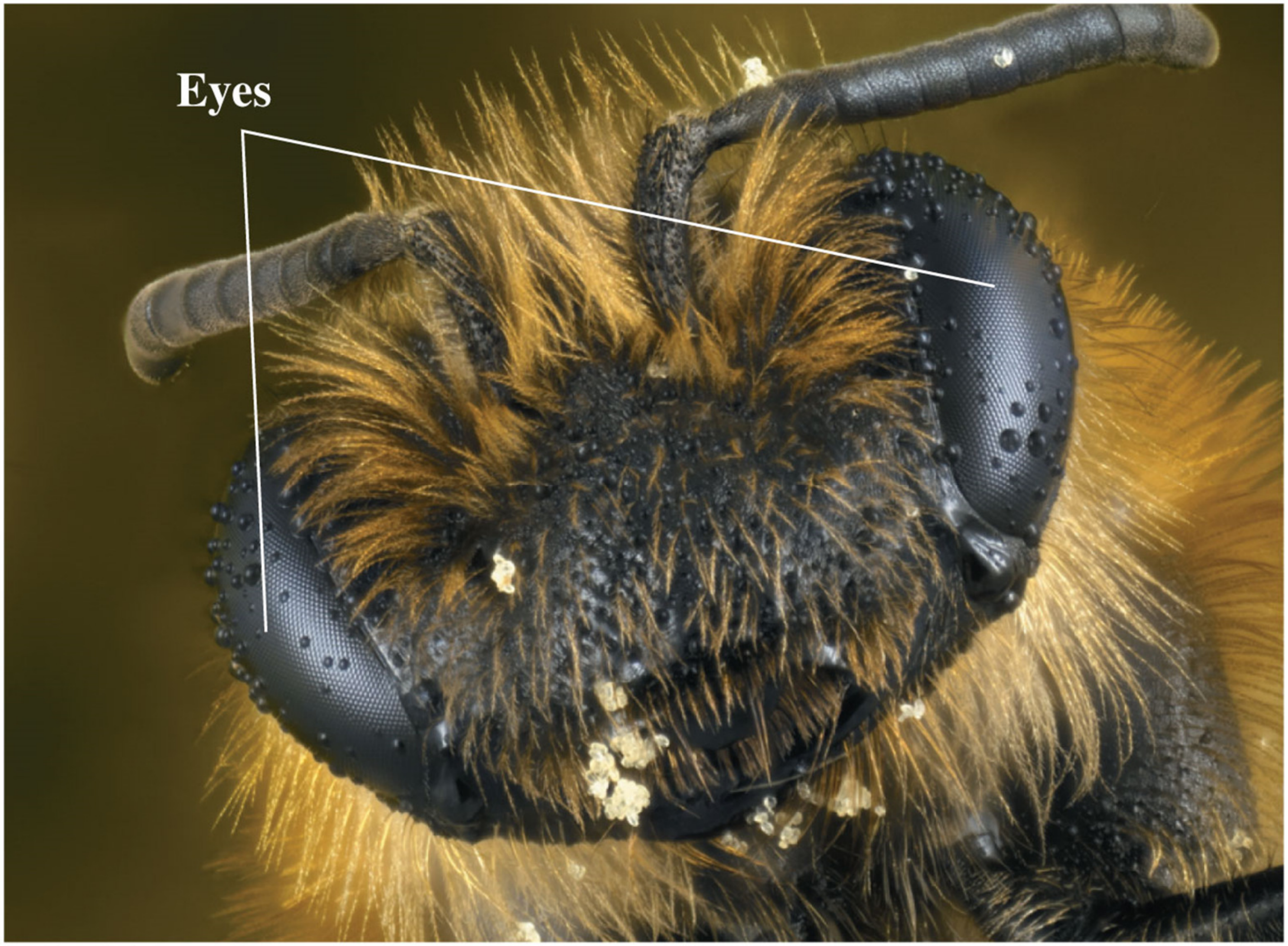
$$n_a \sin \theta_p = n_b \cos(\theta_p)$$

$$\tan \theta_p = \frac{n_b}{n_a}$$



Rayleigh Scattering $\propto \frac{1}{\lambda^4}$

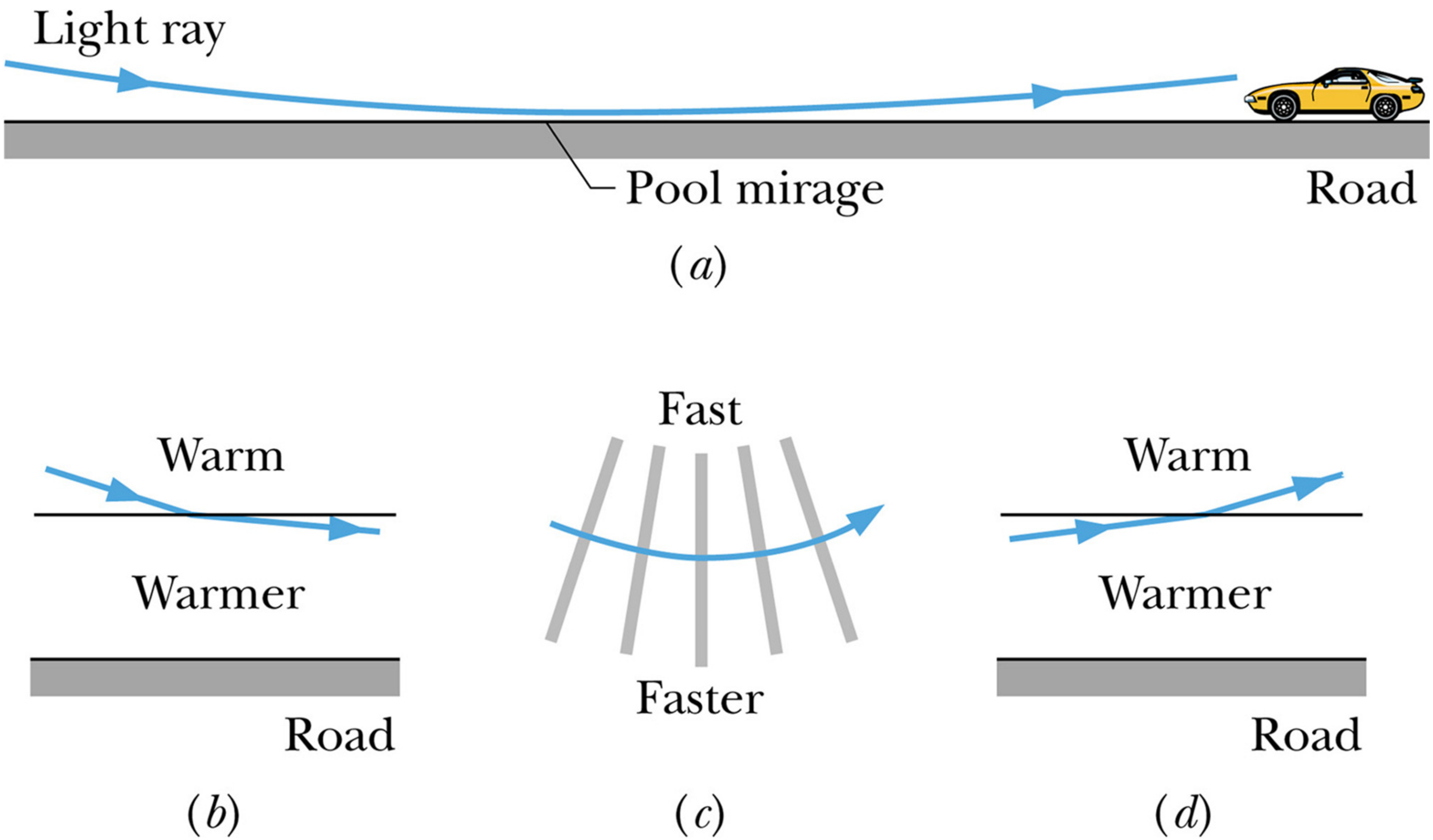


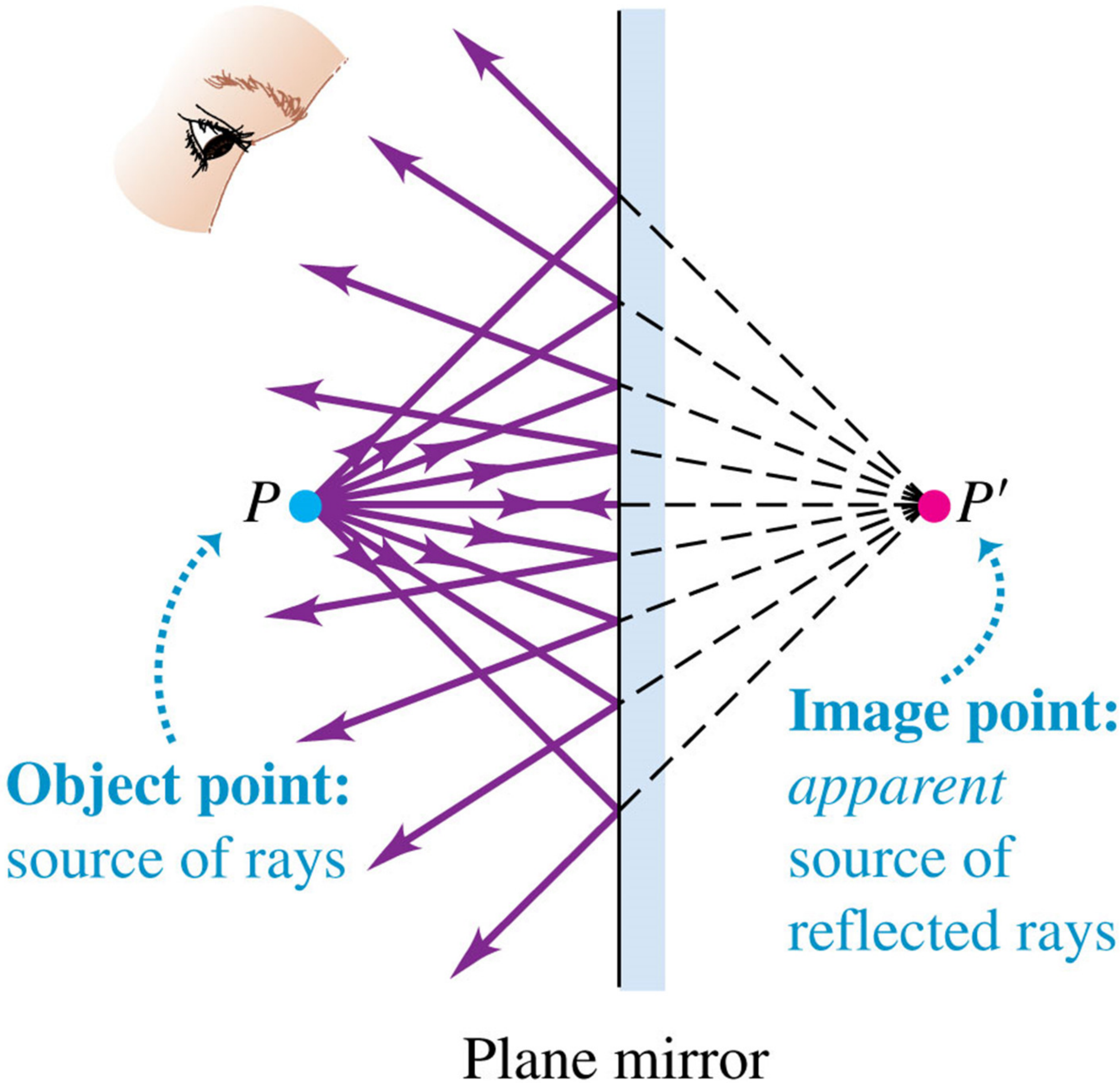


Even through clouds, light from Sun's direction unpolarized; light from away from sun polarized. Bees can see this.

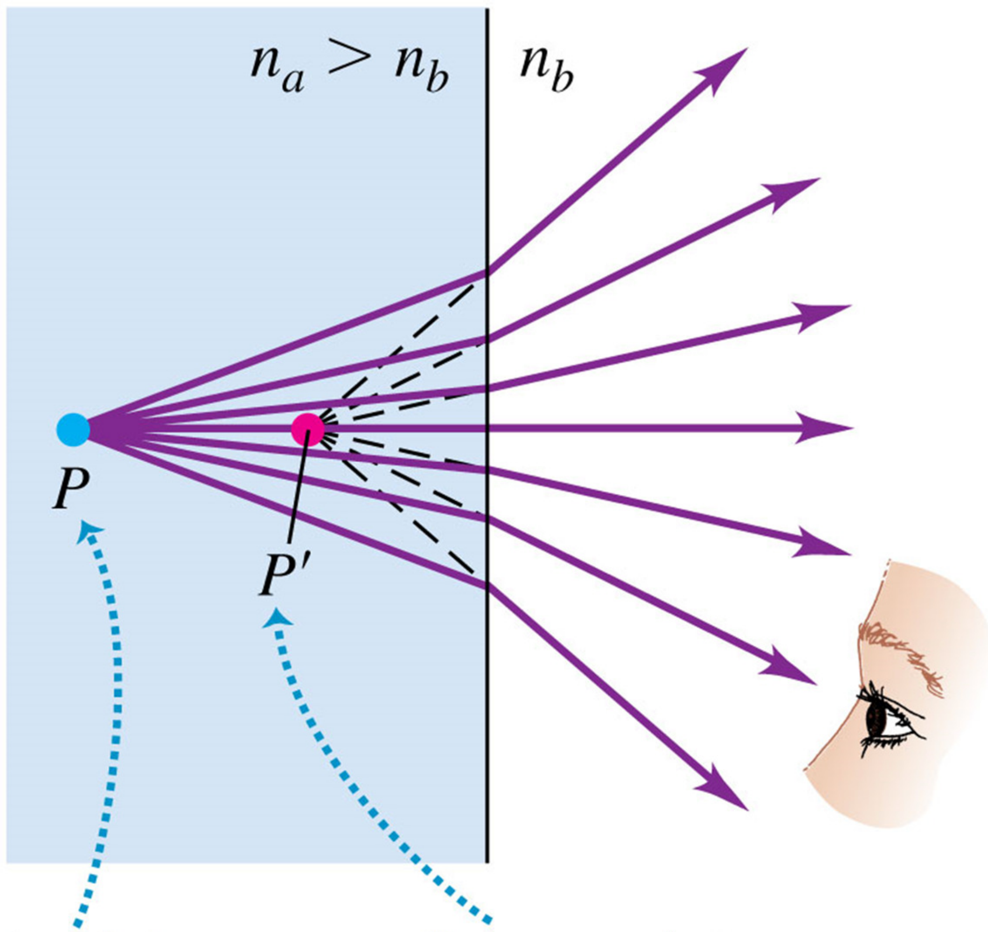
Iceland spar calcite crystals are polarizers: dramatized in The “Vikings” TV show, recent archaeology is backing up these “sunstones”

Image swiped from Wikipedia's "Mirage" article


Light ray
Pool mirage
Road
(a)
Warm
Warmer
Road
(b)
Fast
Faster
(c)
Warm
Warmer
Road
(d)

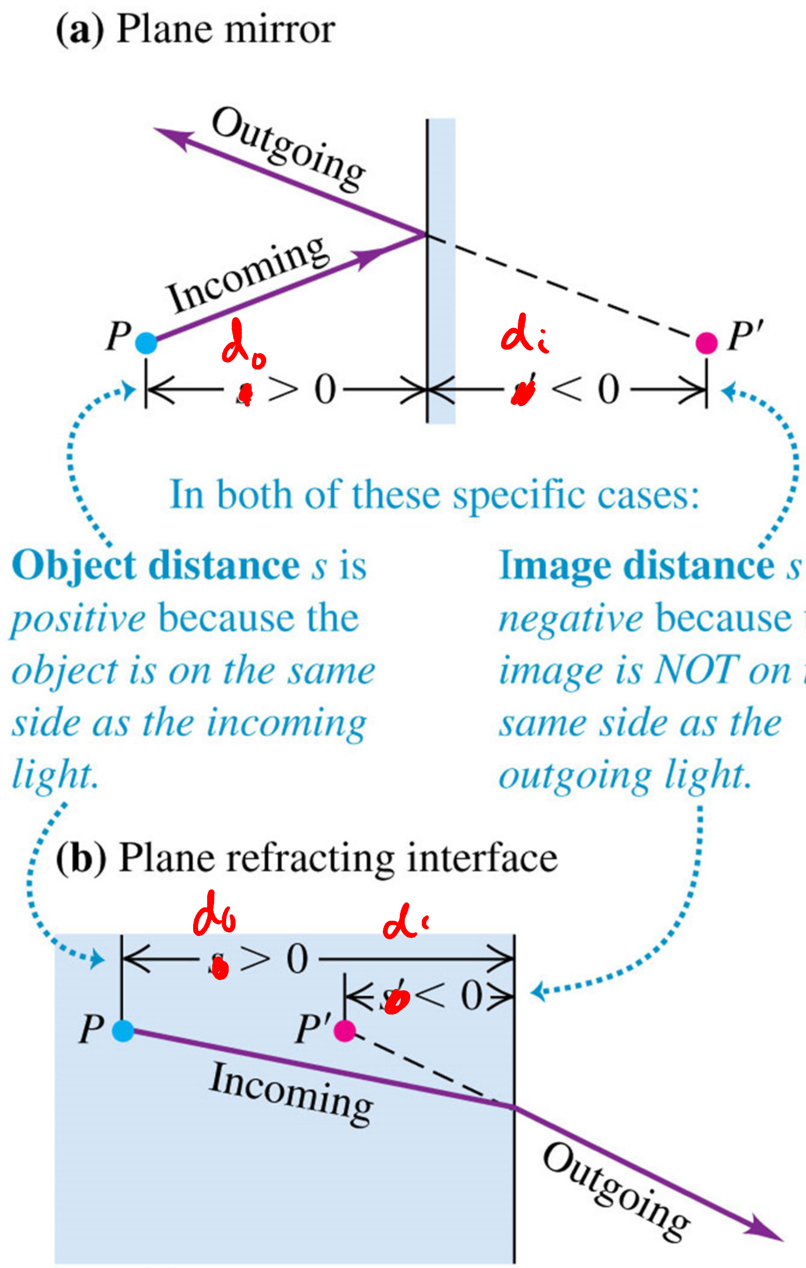

P
P′
Object point:
source of rays
Image point:
apparent
source of
reflected rays
Plane mirror

When $n_a > n_b$, P' is closer to the surface than P; for $n_a < n_b$, the reverse is true.



Object point: source of rays

Image point: apparent source of refracted rays


(a) Plane mirror
Outgoing
Incoming
P
P′
d_o
d_i
s > 0
s′ < 0
In both of these specific cases:
Object distance s is positive because the object is on the same side as the incoming light.
Image distance s′ is negative because the image is NOT on the same side as the outgoing light.
(b) Plane refracting interface
d_o
d_i
s > 0
s′ < 0
P
P′
Incoming
Outgoing