• PROGRAM OF "PHYSICS"

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ANALYTICAL PHYSICS 2B

03 credits (45 periods)

Chapter 1 Geometric Optics

Chapter 2 Wave Optics

Chapter 3 Relativity

Chapter 4 Quantum Physics

Chapter 5 Nuclear Physics

Chapter 6 The Standard Model of Particle Physics

References :

Young and Freedman, *University Physics*, Volume 2, 12th Edition, Pearson/Addison Wesley, San Francisco, 2007

Halliday D., Resnick R. and Merrill, J. (1988), *Fundamentals of Physics*, Extended third edition. John Willey and Sons, Inc.

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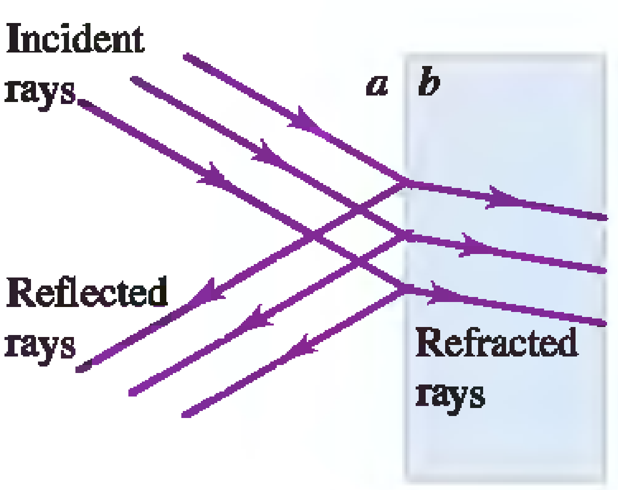
Chapter 1 Geometric Optics

1 Reflection of Light
2 The Law of Refraction
3 Thin Lenses and Optical Instruments

1. Reflection and Refraction

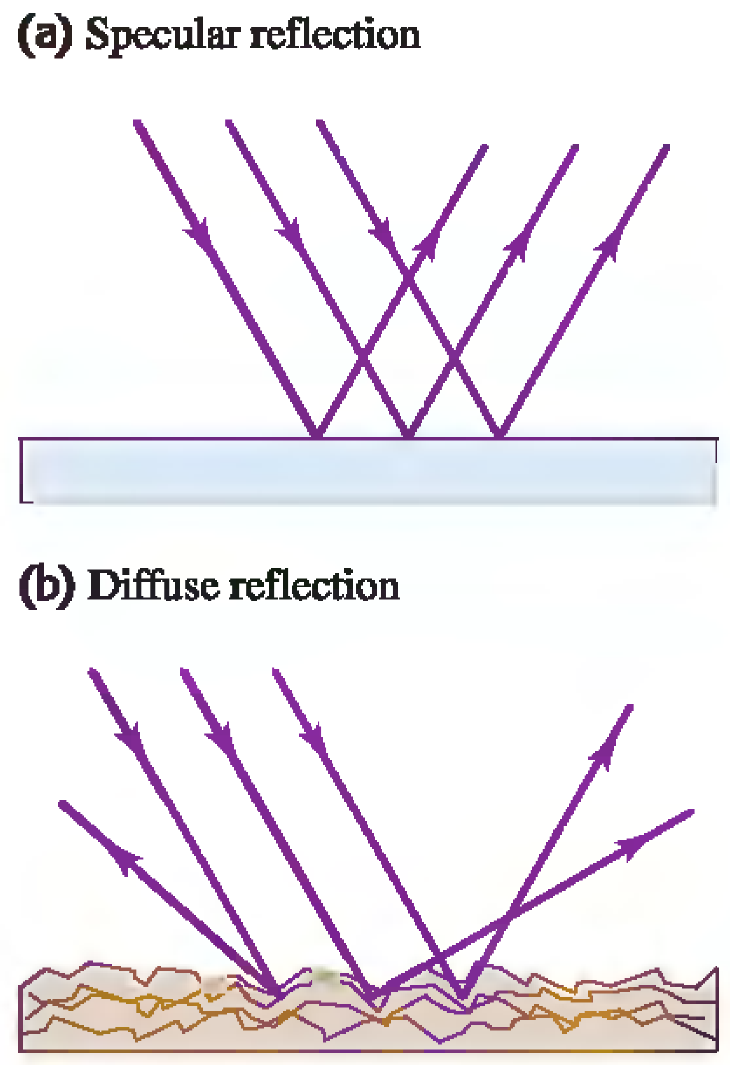
1.1 Basic notions

- When a light wave strikes a smooth interface separating two transparent materials (such as air and glass or water and glass), the wave is in general partly reflected and partly refracted (transmitted) into the second material



If the interface is rough, both the transmitted light and the reflected light are scattered in various directions

Reflection at a definite angle from a very smooth surface is called specular reflection (from the Latin word for "mirror"); scattered reflection from a rough surface is called diffuse reflection.



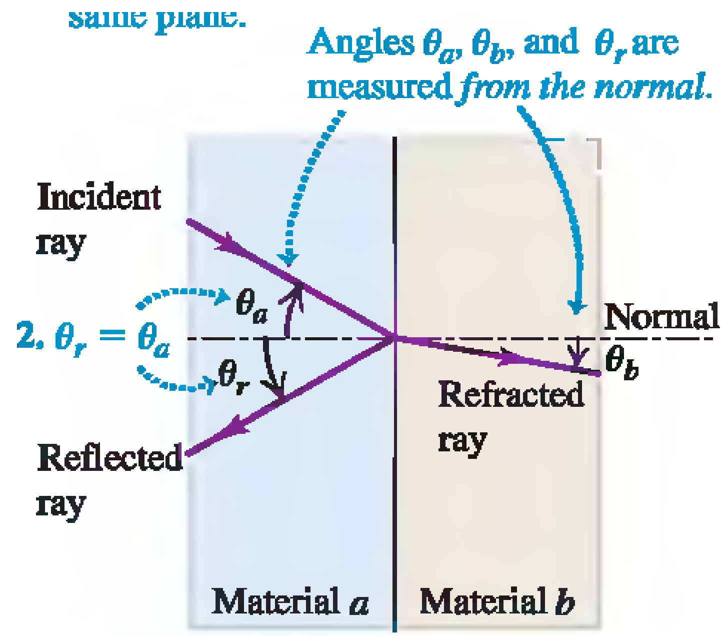
The directions of the incident, reflected, and refracted rays at a interface between two optical materials in terms of the angles they make with the normal (perpendicular) to the surface at the point of incidence

The index of refraction of an optical material (also called the refractive index), denoted by n.

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

(the ratio of the speed of light c in vacuum to the speed v in the material)

$$c \geq v \longrightarrow n \geq 1$$



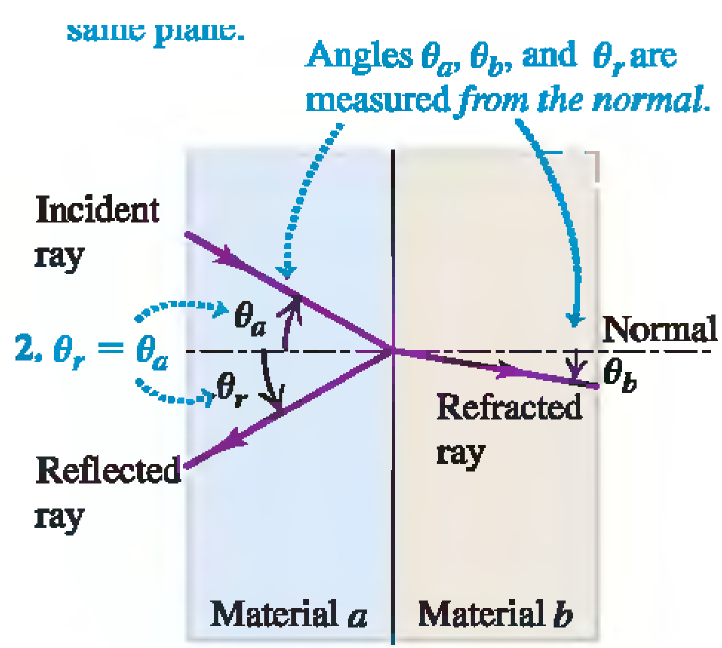
1.2 The Laws of Reflection and Refraction

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

• The angle of reflection is equal to the angle of incidence for all wavelengths and for any pair of materials.

$$\boxed{\theta_a = \theta_b}$$

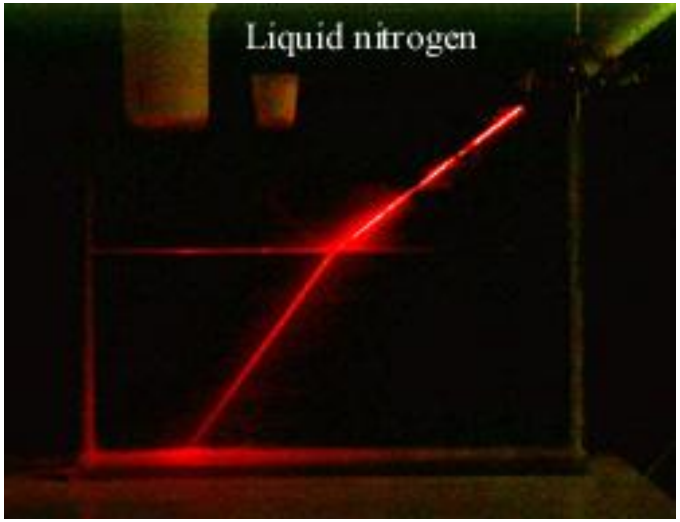
(law of reflection)

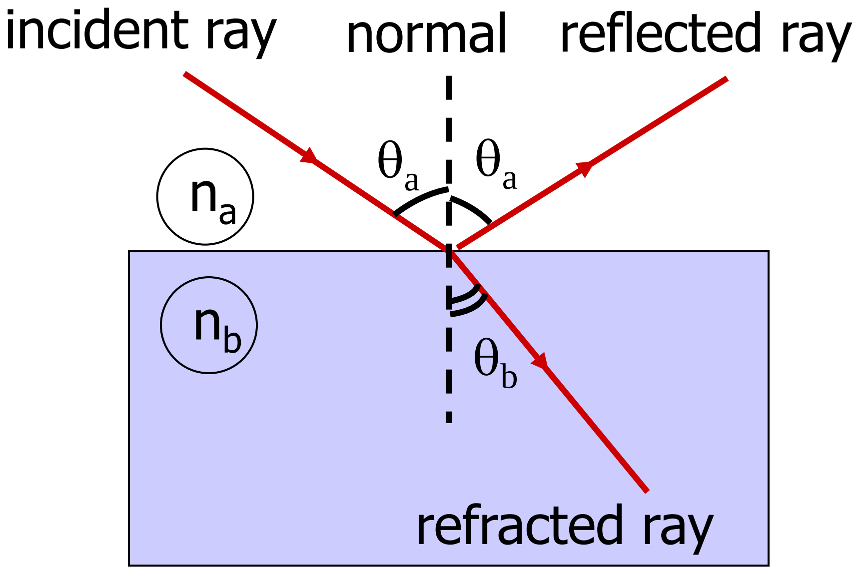


- For monochromatic light and for a given pair of materials, *a* and *b*, on opposite sides of the interface, the ratio of the sins of the angles θ_a and θ_b, is equal to the inverse ratio of the two indexes of refraction:

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

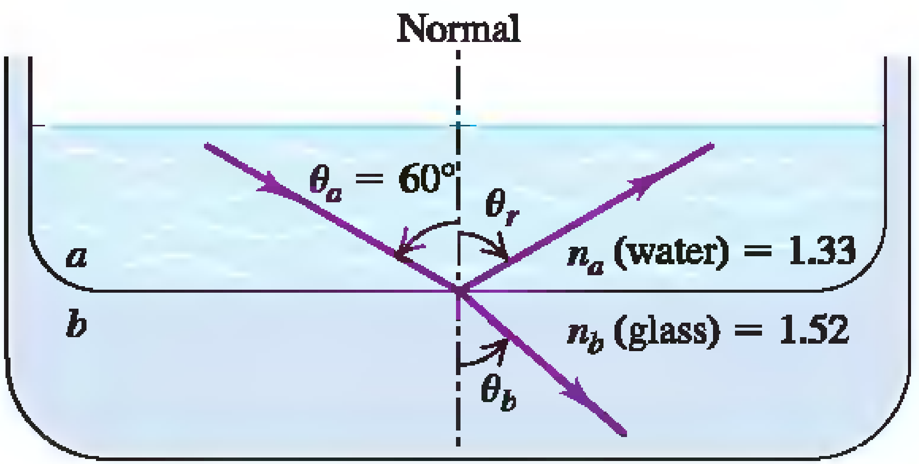
(law of refraction - Snell's law)





PROBLEM 1 In the figure, material *a* is water and material is a glass with index of refraction 1.52. If the incident ray makes an angle of 60^0 with the normal, find the directions of the reflected and refracted rays.

SOLUTION



$$\theta_r = \theta_a = 60.0°.$$

$$n_a \sin\theta_a = n_b \sin\theta_b$$

$$\sin\theta_b = \frac{n_a}{n_b}\sin\theta_a = \frac{1.33}{1.52}\sin 60.0° = 0.758$$

$$\theta_b = 49.3°$$

PROBLEM 2 The wavelength of the red light from a helium-neon laser is 633 μm in air but 474 μm in the aqueous humor inside your eye-ball. Calculate the index of refraction of the aqueous humor and the speed and frequency of the light in this substance.

SOLUTION

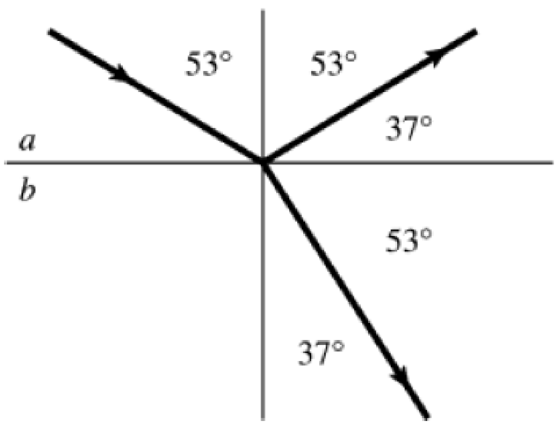
$$\lambda = \frac{\lambda_0}{n} \qquad n = \frac{\lambda_0}{\lambda} = \frac{633\ \text{nm}}{474\ \text{nm}} = 1.34$$

$$v = \frac{c}{n} = \frac{3.00 \times 10^8\ \text{m/s}}{1.34} = 2.25 \times 10^8\ \text{m/s}$$

$$f = \frac{v}{\lambda} = \frac{2.25 \times 10^8\ \text{m/s}}{474 \times 10^{-9}\ \text{m}} = 4.74 \times 10^{14}\ \text{Hz}$$

PROBLEM 3 Light traveling in water strikes a glass plate at an angle of incidence of 53.0^0; part of the beam is reflected and part is refracted. If the reflected and refracted portions make an angle of 90.0^0 with each other, what is the index of refraction of the glass?

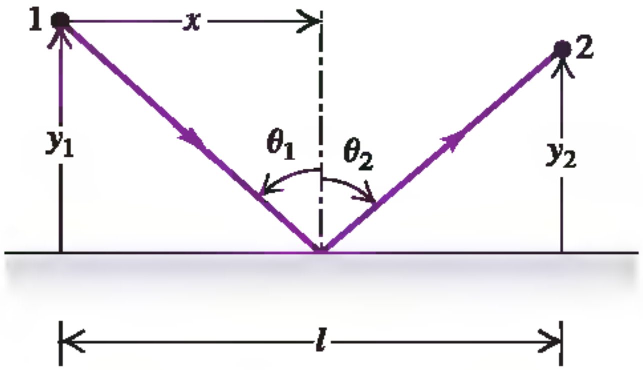
SOLUTION



From the figure, $\theta_b = 37.0^\circ$ and $n_b = n_a \dfrac{\sin\theta_a}{\sin\theta_b} = 1.33\,\dfrac{\sin 53^\circ}{\sin 37^\circ} = 1.77.$

PROBLEM 4 A ray of light traveling with speed *c* leaves point 1 shown in the figure and is reflected to point 2. The ray strikes the reflecting surface a horizontal distance x from point 1. (a) What is the time *t* required for the light to travel from 1 to 2 ? (b) When does this time reaches its minimum value ?

SOLUTION



(a) The distance traveled by the light ray

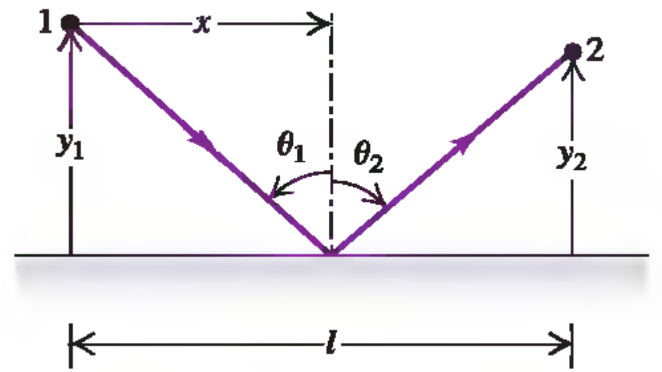
$$d = (x^2 + y_1^2)^{1/2} + ((l - x)^2 + y_2^2)^{1/2}$$

$$t = \frac{d}{c} = \frac{(x^2 + y_1^2)^{1/2} + ((l - x)^2 + y_2^2)^{1/2}}{c}$$

PROBLEM 4 A ray of light traveling with speed c leaves point 1 shown in the figure and is reflected to point 2. The ray strikes the reflecting surface a horizontal distance x from point 1. (a) What is the time t required for the light to travel from 1 to 2 ? (b) When does this time reaches its minimum value ?

SOLUTION

$$t = \frac{d}{c} = \frac{(x^2 + y_1^2)^{1/2} + ((l -}{c}$$



(b) Taking the derivative with respect t

$$\frac{dt}{dx} = \frac{1}{c}\frac{d}{dt}\left[(x^2 + y_1^2)^{1/2} + \left((l-x)^2 + y_2^2\right)\right]$$

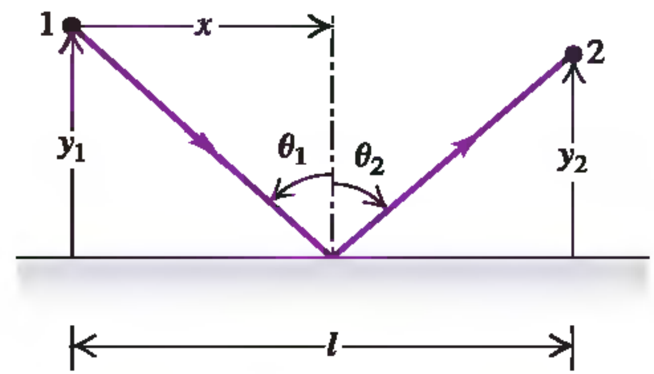
$$= \frac{1}{c}\left[x(x^2 + y_1^2)^{-1/2} - (l-x)\left((l-x)^2 + y_2^2\right)^{-1/2}\right] = 0$$

$$\frac{x}{\sqrt{x^2 + y_1^2}} = \frac{(l-x)}{\sqrt{(l-x)^2 + y_2^2}}, \quad \sin\theta_1 = \sin\theta_2 \text{ and } \theta_1 = \theta_2.$$

PROBLEM 4 A ray of light traveling with speed c leaves point 1 shown in the figure and is reflected to point 2. The ray strikes the reflecting surface a horizontal distance x from point 1. (a) What is the time t required for the light to travel from 1 to 2 ? (b) When does this time reaches its minimum value ?

SOLUTION

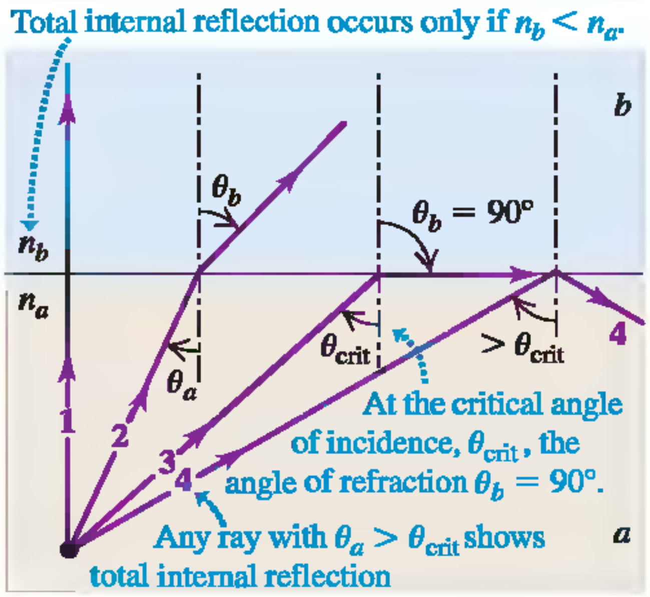
$$\theta_1 = \theta_2 .$$



(The law of reflection corresponding to the actual path taken by the light)

Fermat's Principle of Least Time : among all possible paths between two points, the one actually taken by a ray of light is that for which the time of travel is a minimum.

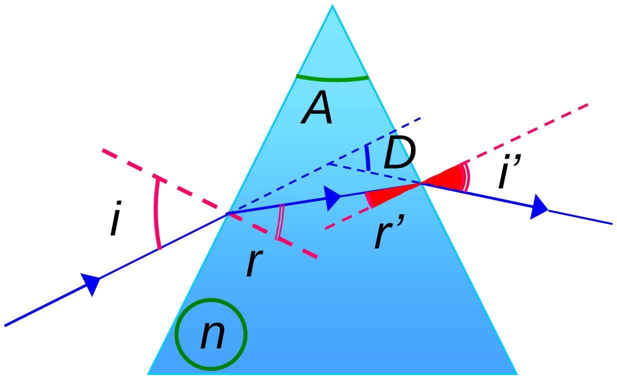
- **Total Internal Reflection**



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

$$\sin\theta_{crit} = \frac{n_b}{n_a} \qquad \text{(critical angle for total internal reflection)}$$

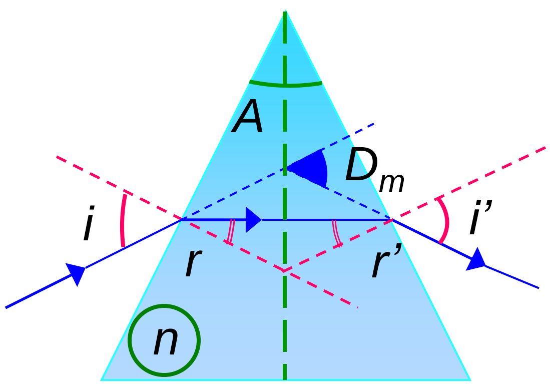
• Prism



$$\boxed{\sin i = n \sin r\,;} \qquad \boxed{\sin i' = n \sin r'\,;}$$

$$\boxed{A = r + r'\,;}$$

$$\boxed{D = i + i' - A}$$



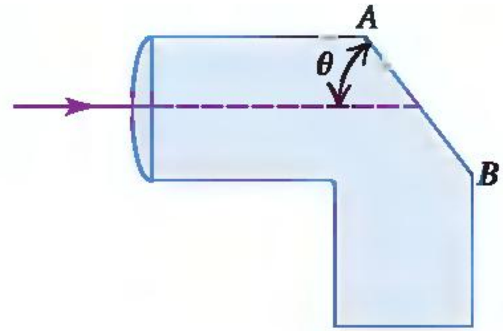
- Minimum deflection :

$$\boxed{i' = i\,;} \qquad \boxed{r = r' = \frac{A}{2}\,;}$$

$$\boxed{D_m = 2i - A}$$

PROBLEM 5 Light enters a solid pipe made of plastic having an index of refraction of 1.60. The light travels parallel to the upper part of the pipe. You want to cut the face AB so that all the light will reflect back into the pipe after it first strikes that face. (a) What is the largest that θ can be if the pipe is in air? (b) If the pipe is immersed in water of refractive index 1.33, what is the largest that θ can be?

SOLUTION



(a) $(1.60)\sin\theta_a = (1.00)\sin 90^\circ$

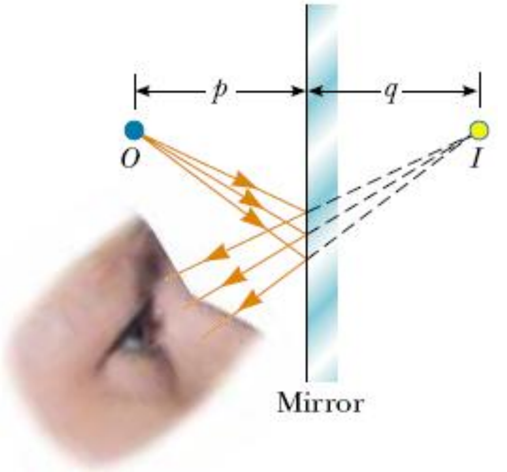
$\theta_a = 38.7^\circ$. $\theta = 90^\circ - \theta_a = 51.3^\circ$

(b) $(1.60)\sin\theta_a = (1.333)\sin 90^\circ$

$\theta_a = 56.4^\circ$. $\theta = 90^\circ - \theta_a = 33.6^\circ$

2. Mirrors

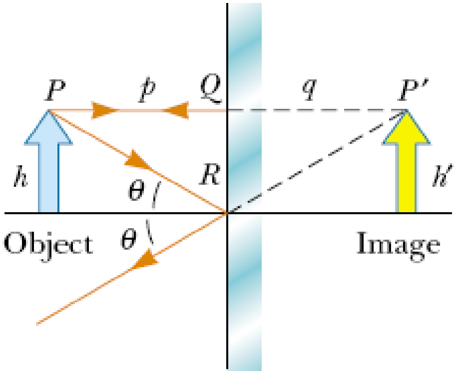
2.1 Flat mirrors



The distance p is called the object distance.

The distance q is called the image distance.

Real object $\rightarrow$ Virtual image



$$|p| = |q| \text{ and } h = h'.$$

Lateral magnification

$$M \equiv \frac{\text{Image height}}{\text{Object height}} = \frac{h'}{h}$$

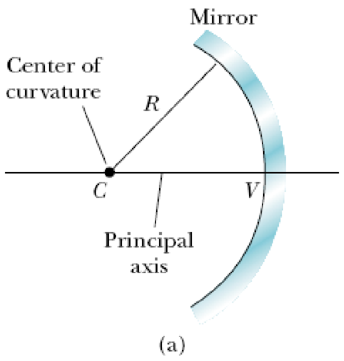
$$M = 1 \text{ because } h' = h.$$

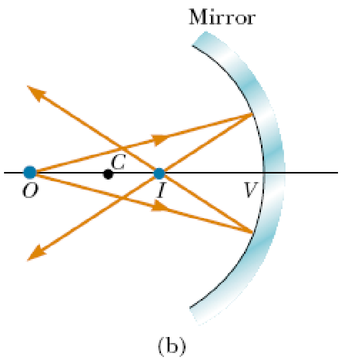
2. Mirrors

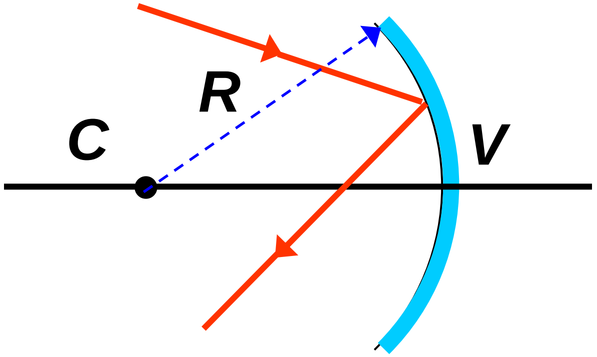
2.2 Spherical mirrors

A spherical mirror has the shape of a section of a sphere.

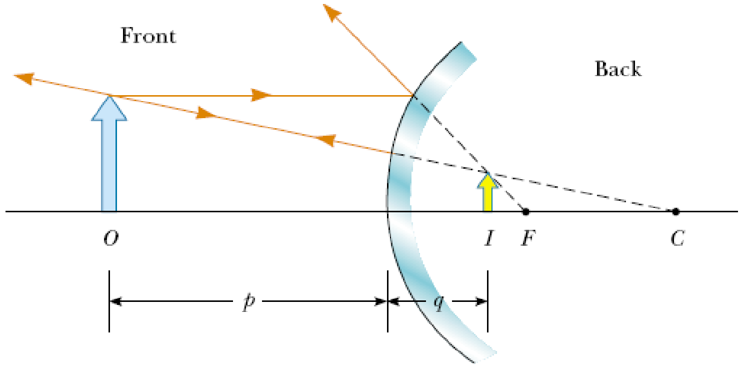
Light reflected from the inner (concave surface): concave mirror.

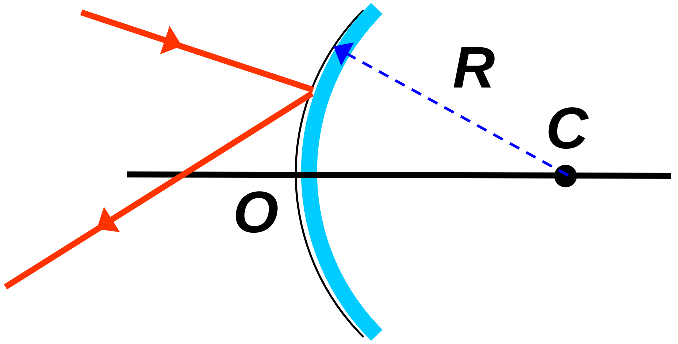


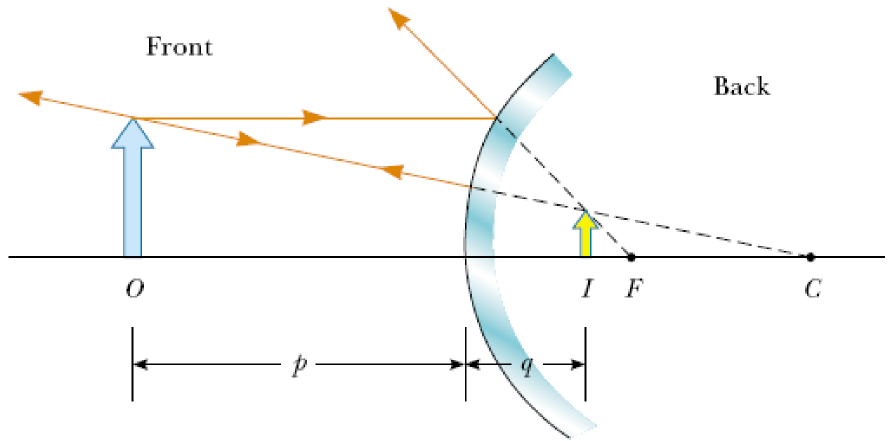




Light reflected from the outer (convex surface) : convex mirror.

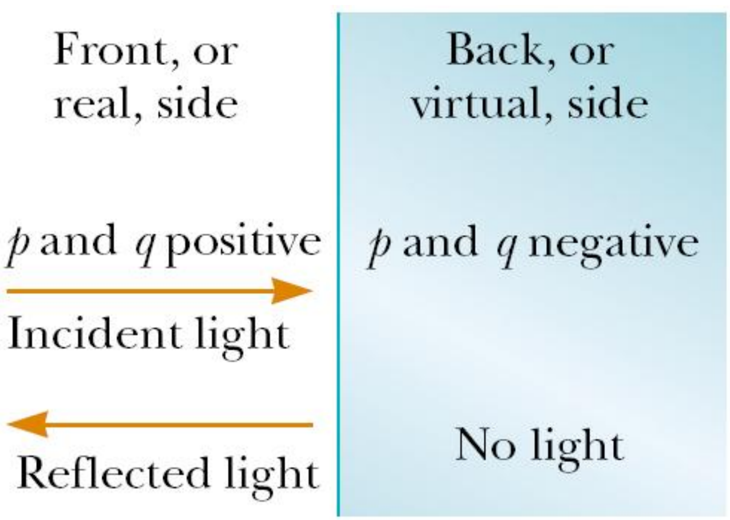






F : focal point ; *f* : focal length

Mirror equation : $$\boxed{\frac{1}{p}+\frac{1}{q}=\frac{1}{f}} \qquad f=\frac{R}{2}$$



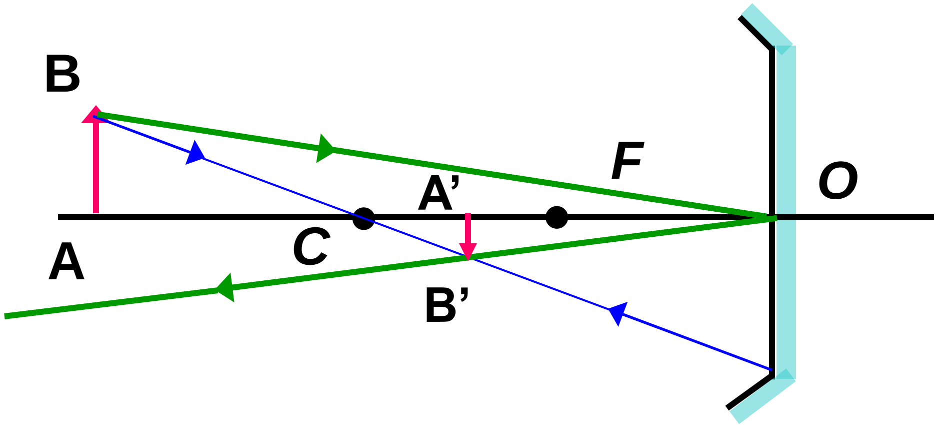
Real object $\leftrightarrow$ $p > 0$

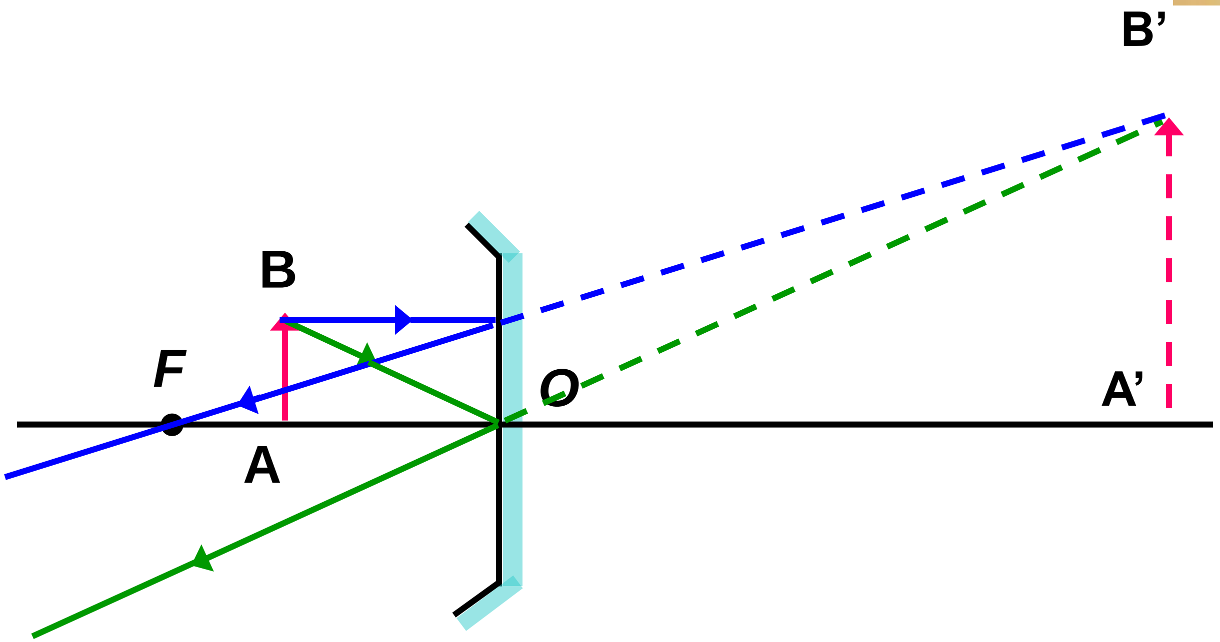
Virtual object $\leftrightarrow$ $p < 0$

Real image $\leftrightarrow$ $q > 0$

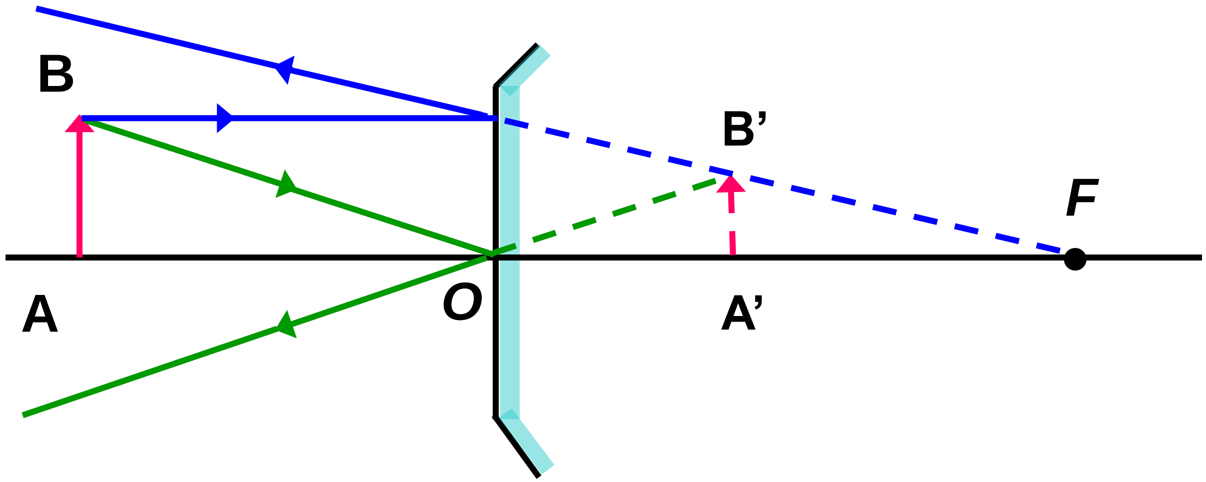
Virtual image $\leftrightarrow$ $q < 0$

Concave mirror :





Convex mirror :



PROBLEM 6 Assume that a certain spherical mirror has a focal length of 10.0 cm. Locate and describe the image for object distances of (a) 25.0 cm, (b) 10.0 cm, and (c) 5.00 cm.

SOLUTION

(a)

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

$$\frac{1}{25.0\text{ cm}} + \frac{1}{q} = \frac{1}{10.0\text{ cm}}$$

$$q = \boxed{16.7\text{ cm}}$$

$$M = -\frac{q}{p} = -\frac{16.7\text{ cm}}{25.0\text{ cm}} = -0.668$$

PROBLEM 7 Assume that a certain spherical mirror has a focal length of 10.0 cm. Locate and describe the image for object distances of (a) 25.0 cm, (b) 10.0 cm, and (c) 5.00 cm.

SOLUTION

(b)

$$\frac{1}{10.0\text{ cm}} + \frac{1}{q} = \frac{1}{10.0\text{ cm}} \qquad q = \boxed{\infty}$$

(c)

$$\frac{1}{5.00\text{ cm}} + \frac{1}{q} = \frac{1}{10.0\text{ cm}}$$

$$q = \boxed{-10.0\text{ cm}}$$

$$M = -\frac{q}{p} = -\left(\frac{-10.0\text{ cm}}{5.00\text{ cm}}\right) = 2.00$$

PROBLEM 8 A woman who is 1.5 m tall is located 3.0 m from an antishoplifting mirror. The focal length of the mirror is 0.25 m. Find the position of her image and the magnification.

SOLUTION

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} = \frac{1}{-0.25\text{ m}}$$

$$\frac{1}{q} = \frac{1}{-0.25\text{ m}} - \frac{1}{3.0\text{ m}}$$

$$q = \boxed{-0.23\text{ m}}$$

The magnification is

$$M = -\frac{q}{p} = -\left(\frac{-0.23\text{ m}}{3.0\text{ m}}\right) = \boxed{0.077}$$

3. Thin Lenses

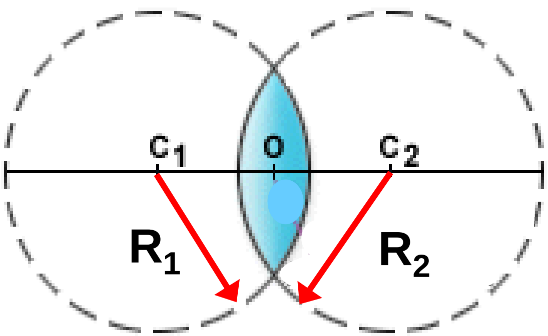
3.1 Notions

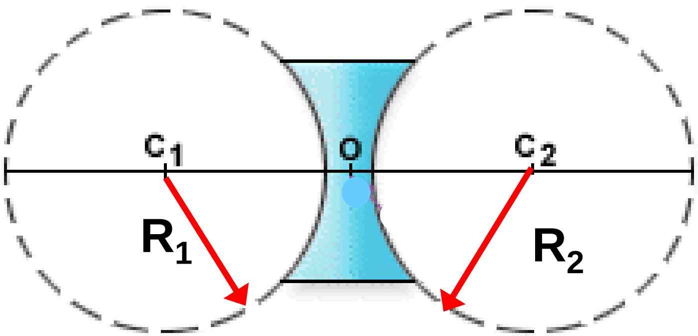
A lens is an optical system with two refracting surfaces. If two spherical surfaces close enough together that we can neglect the distance between them (the thickness of the lens) : **thin lens**.

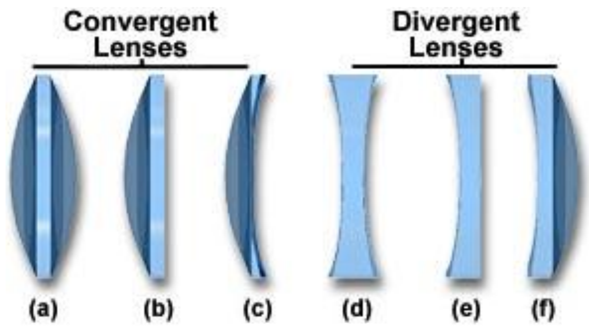
The focal length *f* :

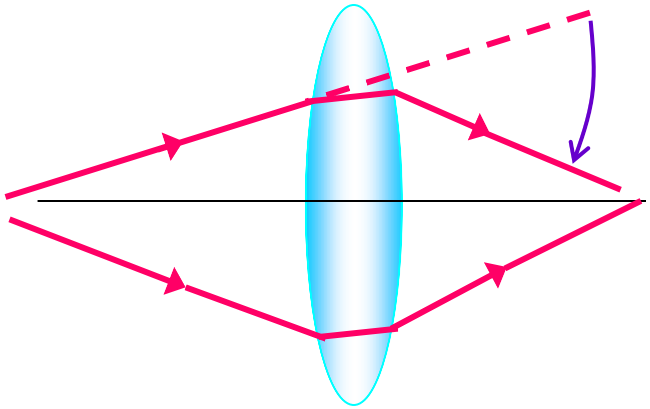
$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

(lens makers' equation)

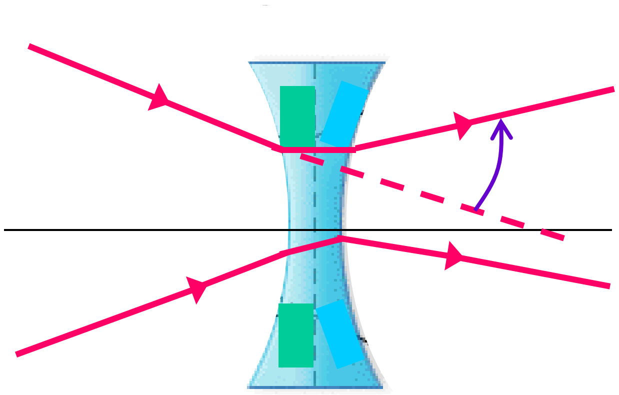




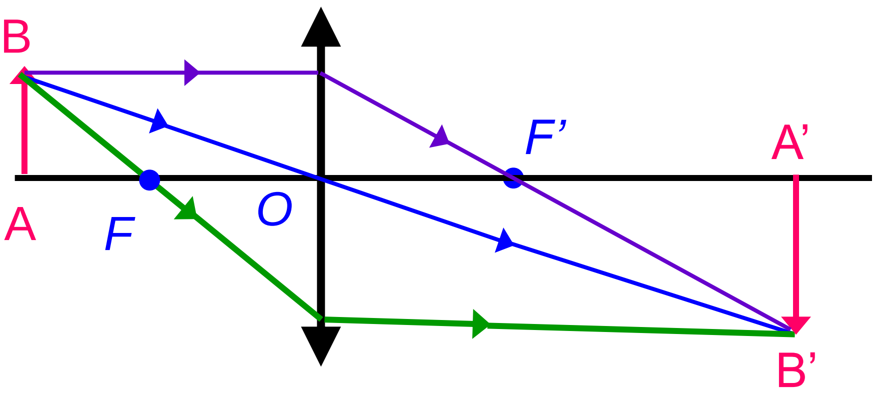




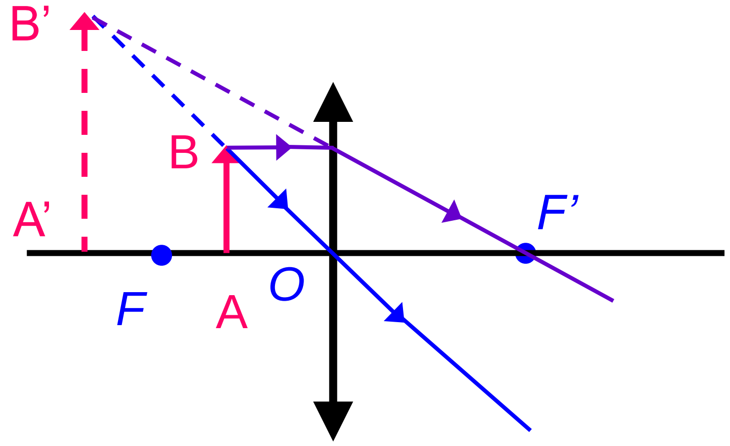
Convergent lens

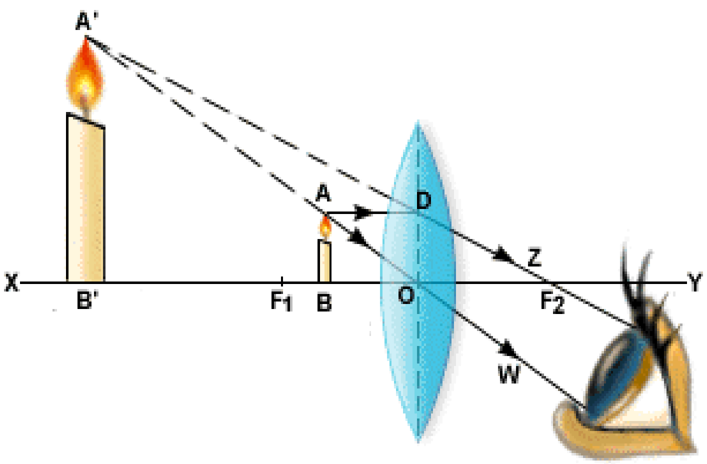


Divergent lens

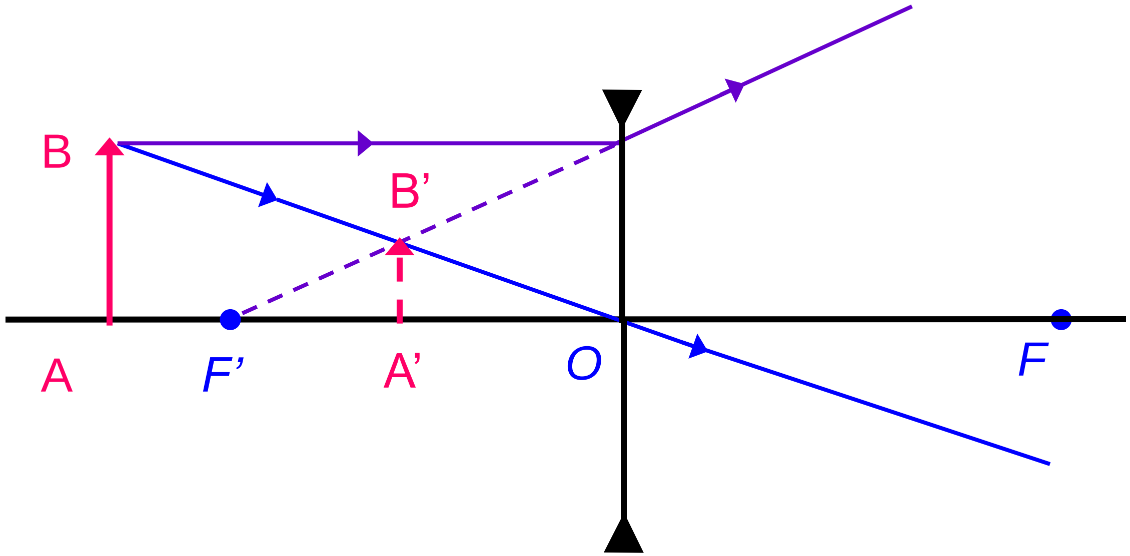


Real object, real image

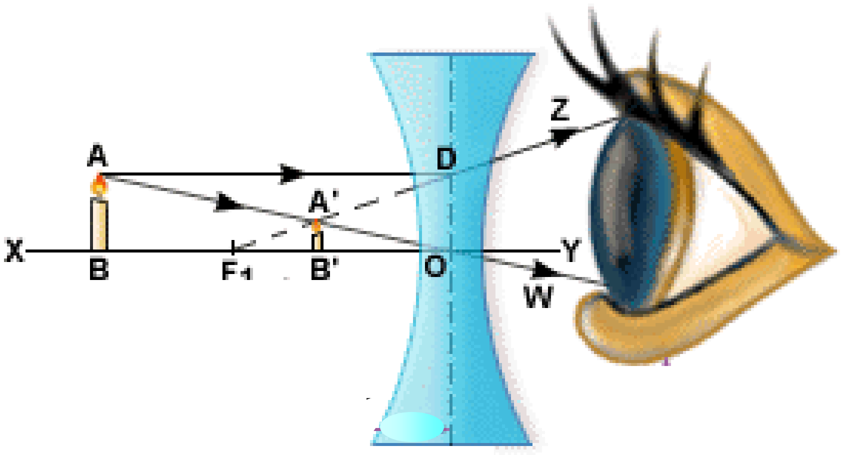




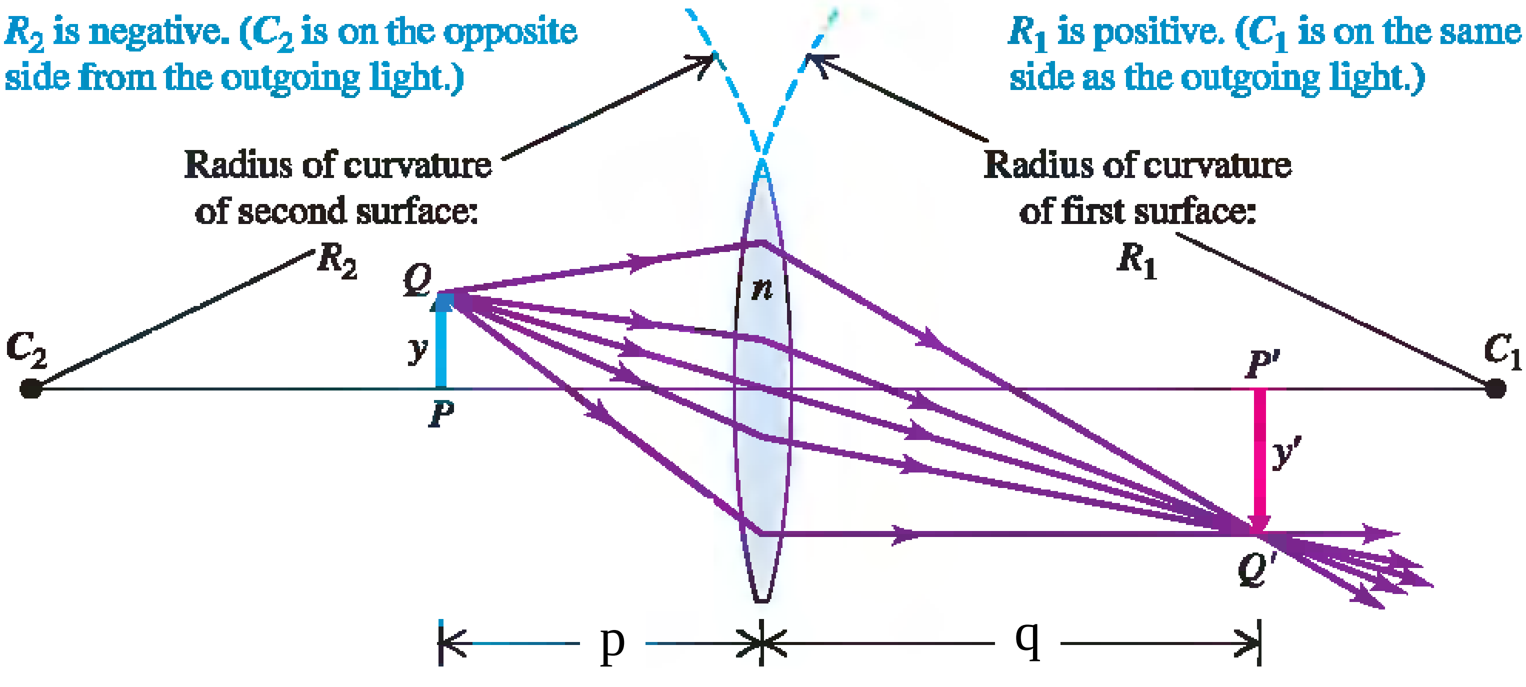
Real object, virtual image



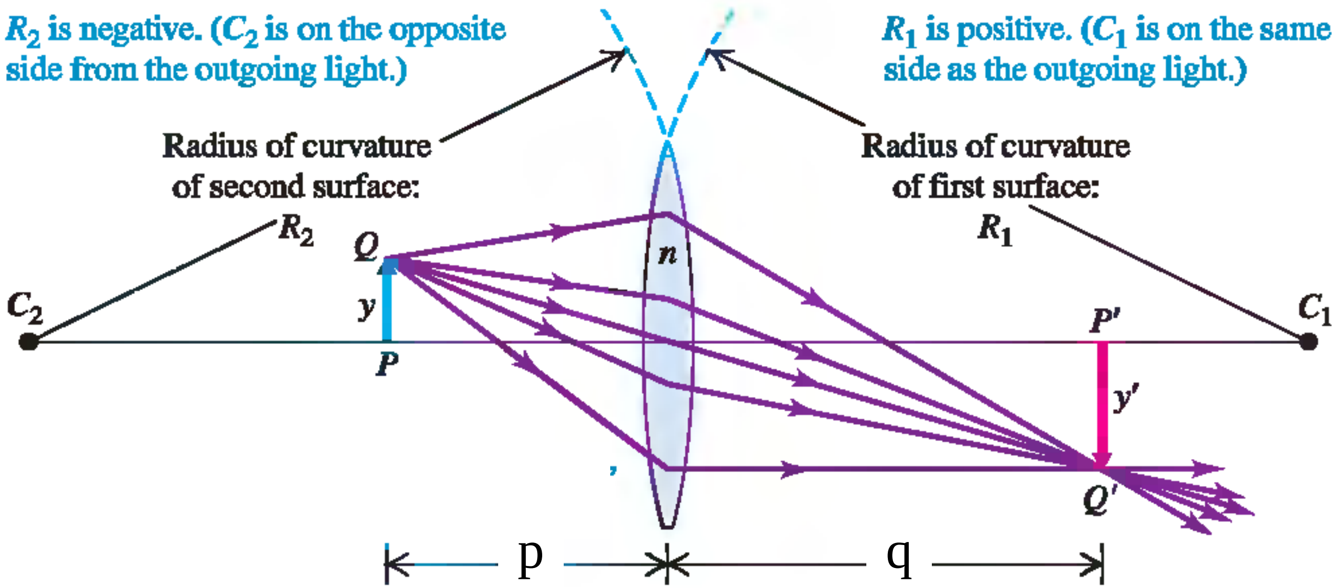
Real object, virtual image



$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$ **(lens makers' equation)**

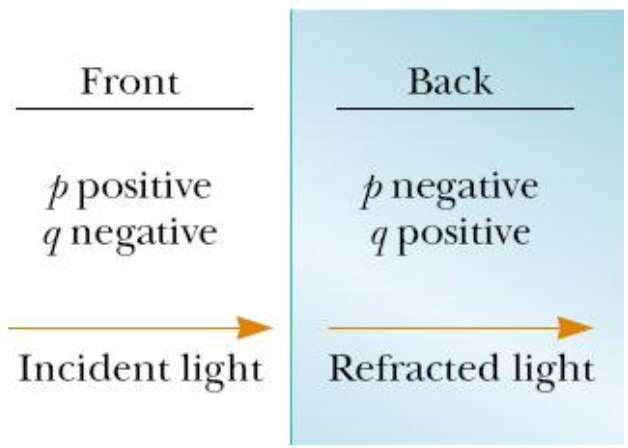


f is **positive** if the lens is **converging.**
f is **negative** if the lens is **diverging.**



Thin-lens equation :

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



Lateral magnification :

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

Real object $\leftrightarrow$ $p > 0$ Virtual object $\leftrightarrow$ $p < 0$

Real image $\leftrightarrow$ $q > 0$ Virtual image $\leftrightarrow$ $q < 0$

PROBLEM 9 A diverging lens has a focal length of 20.0 cm. An object 2.00 cm tall is placed 30.0 cm in front of the lens. Locate the image. Determine both the magnification and the height of the image.

SOLUTION

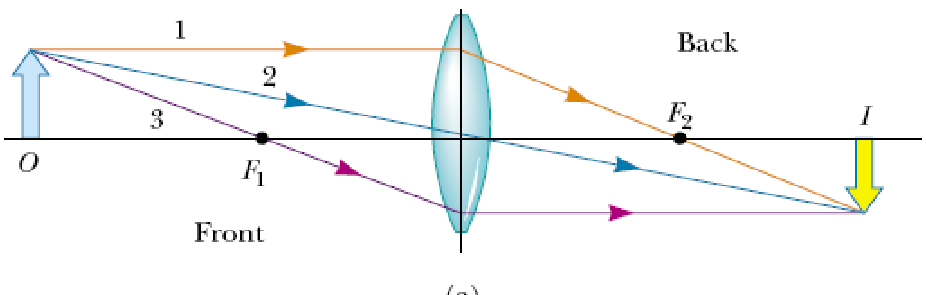
$$\frac{1}{30.0 \text{ cm}} + \frac{1}{q} = \frac{1}{-20.0 \text{ cm}}$$

$$q = \boxed{-12.0 \text{ cm}}$$

$M = 0.400$; $h' = 0.800$ cm.

PROBLEM 10 A converging lens of focal length 10.0 cm forms an image of each of three objects placed (a) 30.0 cm, (b) 10.0 cm, and (c) 5.00 cm in front of the lens. In each case, find the image distance and describe the image.

SOLUTION (a)



(a)

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

$$\frac{1}{30.0\text{ cm}} + \frac{1}{q} = \frac{1}{10.0\text{ cm}}$$

$$q = \boxed{15.0\text{ cm}}$$

The positive sign indicates that the image is in back of the lens and real. The magnification is

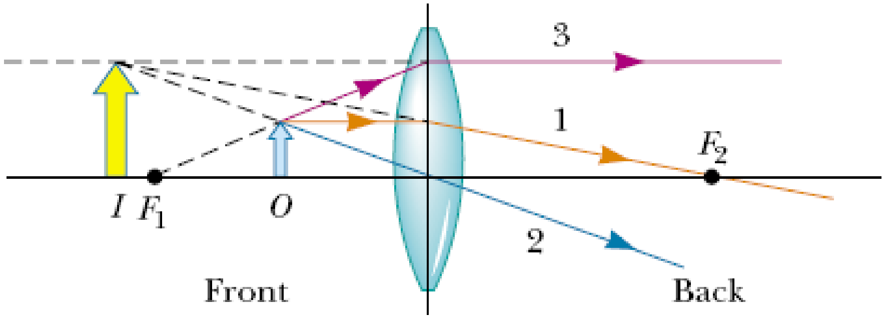
$$M = -\frac{q}{p} = -\frac{15.0\text{ cm}}{30.0\text{ cm}} = \boxed{-0.500}$$

PROBLEM 10 A converging lens of focal length 10.0 cm forms an image of each of three objects placed (a) 30.0 cm, (b) 10.0 cm, and (c) 5.00 cm in front of the lens. In each case, find the image distance and describe the image.

SOLUTION (b)

When the object is placed at the focal point, the image is formed at infinity.

(c)



(b)

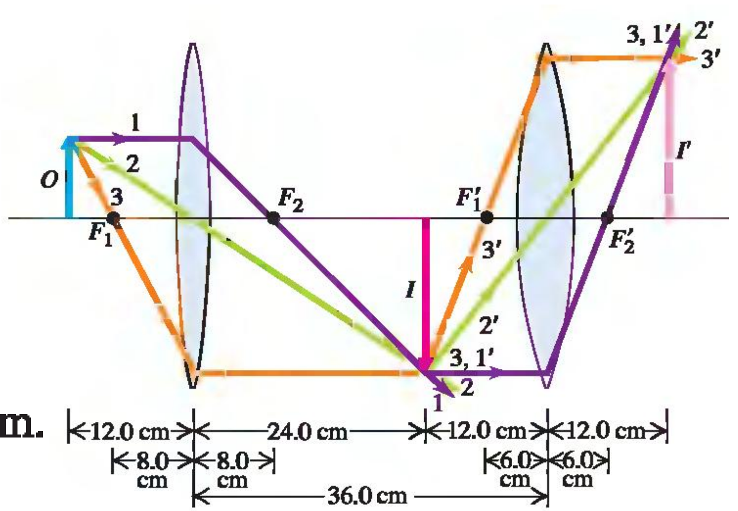
$$\frac{1}{5.00\text{ cm}} + \frac{1}{q} = \frac{1}{10.0\text{ cm}}$$

$$q = \boxed{-10.0\text{ cm}}$$

$$M = -\frac{q}{p} = -\left(\frac{-10.0\text{ cm}}{5.00\text{ cm}}\right) = \boxed{2.00}$$

PROBLEM 11 An object 8.0 cm high is placed 12.0 cm to the left of a converging lens of focal length 8.0 cm. A second converging lens of focal length 6.0 cm is placed 36.0 cm to the right of the first lens. Both lenses have the same optic axis. Find the position, size, and orientation of the image produced by the two lenses in combination.

SOLUTION



$$\frac{1}{12.0\text{ cm}} + \frac{1}{s_1'} = \frac{1}{8.0\text{ cm}} \qquad s_1' = +24.0\text{ cm}$$

$$m_1 = -(24.0\text{ cm})/(12.0\text{ cm}) = -2.00,$$

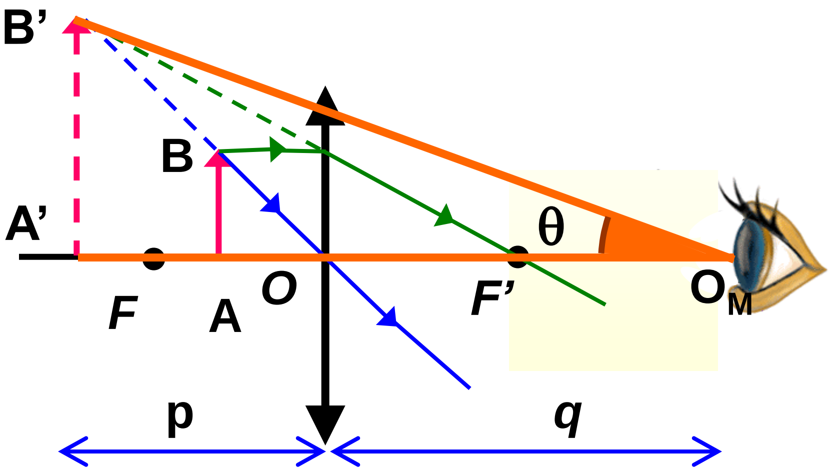
height of the first image is $(-2.0)(8.0\text{ cm}) = -16.0\text{ cm}$.

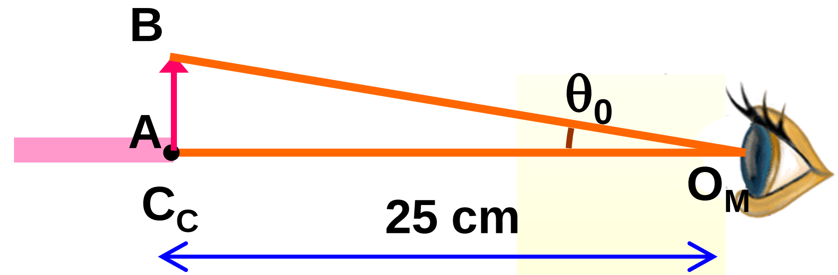
$$\frac{1}{12.0\text{ cm}} + \frac{1}{s_2'} = \frac{1}{6.0\text{ cm}} \qquad s_2' = +12.0\text{ cm}$$

$$m_2 = -(12.0\text{ cm})/(12.0\text{ cm}) = -1.0.$$

3. Thin Lenses

3.2 Simple magnifier





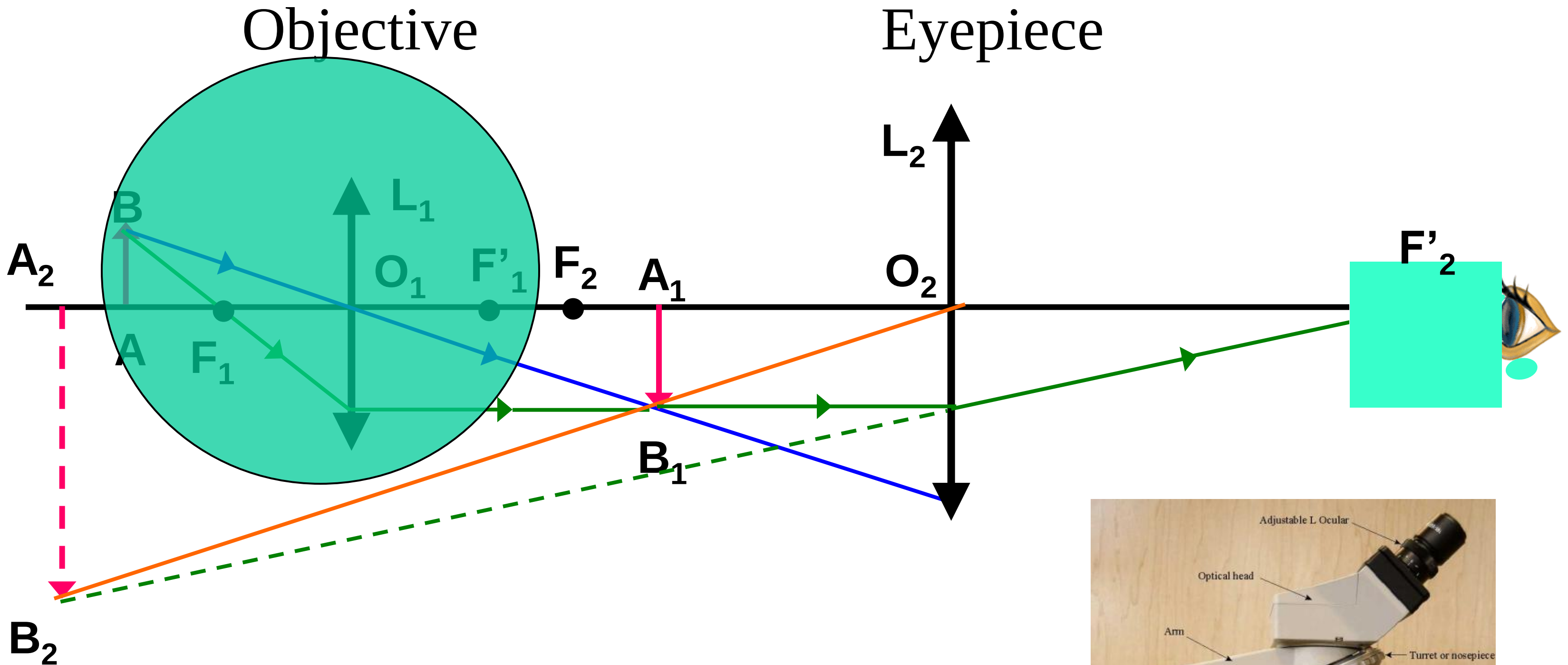
The simple magnifier consists of a single converging lens : this device increases the apparent size of an object.

Angular magnification:

$$m \equiv \frac{\theta}{\theta_0}$$

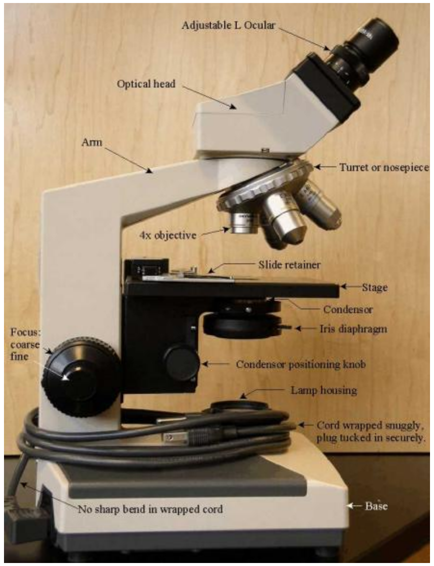
3. Thin Lenses

3.3 The compound microscope



The *objective* has a very short focal length

The *eyepiece* has a focal length of a few centimeters.



3. Thin Lenses

3.4 The Telescope