

Grade 12 ADV Physics

UNITED ARAB EMIRATES
MINISTRY OF EDUCATION



الإمارات العربية المتحدة
وزارة التربية والتعليم

EOT1 Sample Questions

2025/2026 Exam coverage



MCQ Questions

LO:

Define quantities of light like luminous flux and illuminance, specifying their SI units.

EX:

Student Textbook

P:

5,6

Luminous flux:

With the ray model of light, a source that is brighter produces more light rays than a less bright source.

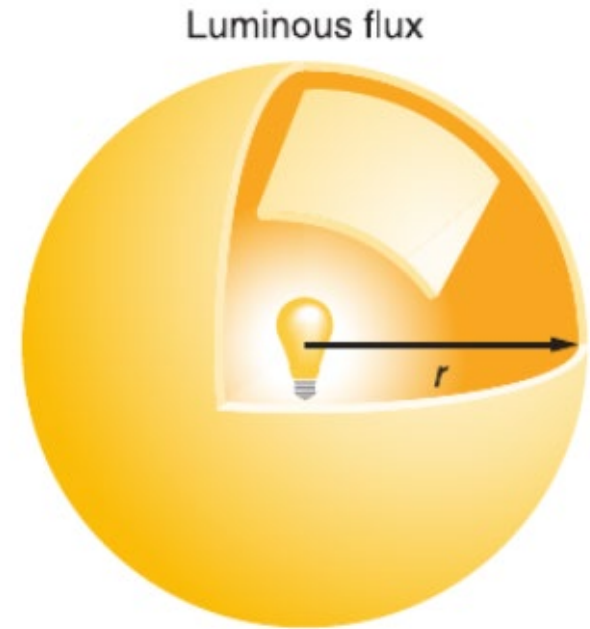
The **rate** at which the bulb, (a luminous source), produces light energy is called the **luminous flux (P)**

it can be measured by capturing all the light emitted by a source by constructing a surface that completely encloses the source, as in **Figure 5**.

Luminous flux: is the rate at which light rays are emitted from a luminous source.

Measured (Unit) is **lumens (lm)**.

The total amount of light that strikes the surface in a given unit of time depends only on the luminous flux of the source.

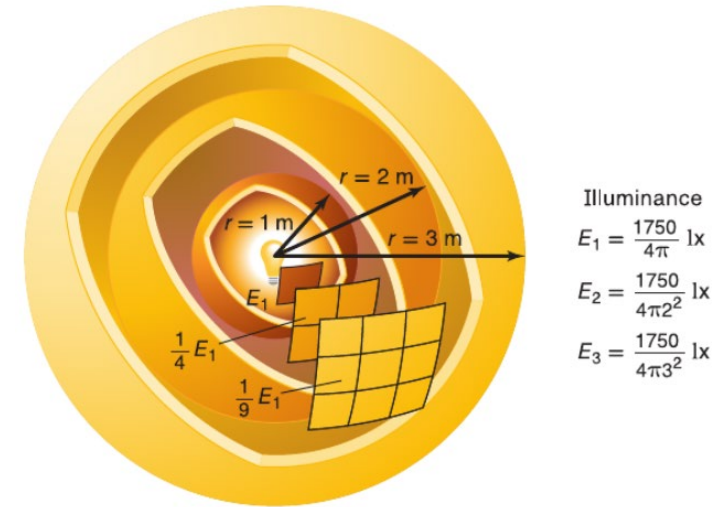


Illuminance:

Once you know the quantity of light being emitted by a luminous source, you can determine the amount of illumination the source provides to an object, such as a book.

illuminance (E): The luminous flux falling on a given surface area at any instant.

Unit: Lux $lx = \frac{lm}{m^2}$



Inverse-square relationship:

As the light rays spread out in straight lines in all directions from a point source, the number of light rays that illuminate a unit of area decreases as the **square of the distance** from the point source.

$$E = \frac{p}{4\pi r^2}$$

E : Illuminance

p : luminous flux

r : Distance the object is from the light source



السؤال (7)

The rate of incidence of light on the surface of a body is called?

معدل سقوط الضوء على سطح الجسم يسمى ؟

الاستضاءة

Illumination

التدفق الضوئي

Luminous flux

الاسفار

Travels

الاضاءه

Lighting





السؤال (3)

The two main factors that affect body lighting are?

العاملان الرئيسيان اللذان يؤثران على اضاءة الجسم هما ؟

اللون والسطوع .

Color and brightness

المسافة والصلابة.

Distance and hardness

الصلابة واللون.

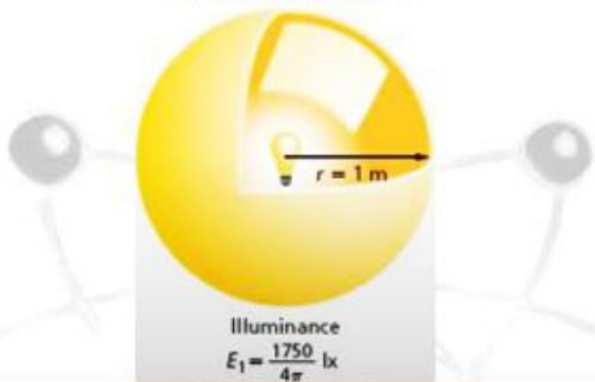
Hardness and color

المسافة والسطوع

Distance and
brightness





السؤال (6)	
In the adjacent figure, if (r) decreases to (0.25 m), what will be the total luminous flux striking the inside of the sphere?	في الشكل المجاور, اذا انخفض (r) الى (0.25 m) فماذا سيكون التدفق الضوئي الكلي الذي يضرب داخل الكرة ؟
Luminous flux $P = 1750 \text{ lm}$  Illuminance $E_1 = \frac{1750}{4\pi} \text{ lx}$	
438 lm	875 lm
7000 lm	1750 lm

Luminous flux doesn't depend on the distance





السؤال (9)

A model that describes how light interacts with matter?

نموذج يصف كيفيه تفاعل الضوء مع المادة ؟

نموذج الشعاع الضوئي

Light beam model

المصادر المضيئة

Luminous sources

النموذج الضوئي للضوء

Photometric model of light

النموذج الجسيمي للضوء

The particle model of light





Extra questions

1. The SI unit of luminous flux?

- a) Candela (Cd)
- b) Lux (Lx)
- c) Lumen (Lm)**
- d) Watt (W)

2. The illuminance on a surface is measured in?

- a) Candela (Cd)
- b) Lux (Lx)**
- c) Lumen (Lm)
- d) Watt (W)

3. The rate at which the bulb, produces light energy is called ?

- a) Luminous Intensity
- b) Illuminance
- c) Luminous Flux**
- d) Luminous Source

3. The Light energy falling on a given surface area at any instant.?

- a) Luminous Intensity
- b) Illuminance**
- c) Luminous Flux
- d) Luminous Source



LO:

Define diffraction as the bending of a wave as it passes the edge of a barrier.

EX:

Student Textbook

P:

12



Diffraction and the Wave Model

In 1665 Italian scientist Francesco Maria Grimaldi observed that the edges of shadows are not perfectly sharp. He introduced a narrow beam of light into a dark room and held a rod in front of the light such that it cast a shadow on a white surface. The shadow cast by the rod was wider than the shadow should have been if light traveled in a straight line past the edges of the rod. Grimaldi also noted that the shadow was bordered by colored bands. He determined that both of these observations could be explained if light bent slightly. He called the bending of light as it passes the edge of a barrier **diffraction**.

Huygens' principle In 1678 Dutch scientist Christiaan Huygens used a wave model to explain diffraction. According to Huygens' principle, all the points of a wavefront of light can be thought of as new sources of smaller waves.

These smaller waves, or wavelets, expand in every direction and are in step with one another. A flat, or plane, wavefront of light consists of an infinite number of point sources in a line. **Figure 12** illustrates Huygen's principle.

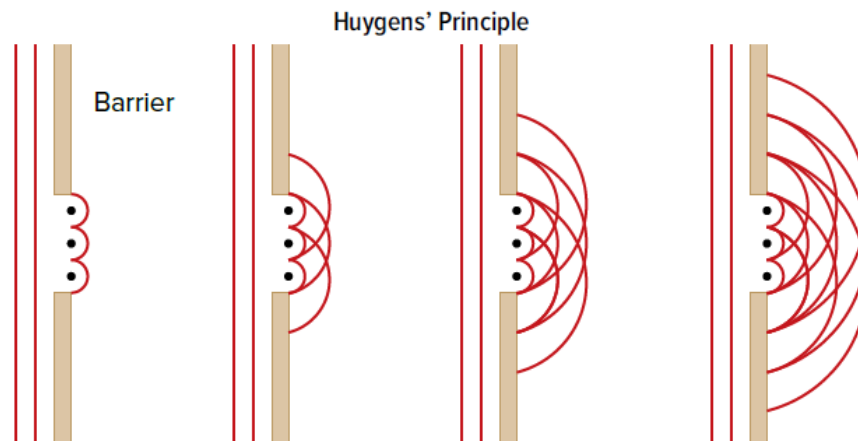


Figure 12 Huygens' wavelets combine to form a straight wavefront, except at the edges of the wave. The wavelets spread out in a circular manner when a barrier creates an edge.

1) Diffraction is best described as:

- a) The change in wave speed in a new medium.
- b) The bending of a wave as it passes the edge of a barrier.**
- c) The superposition of two waves meeting.
- d) The change in frequency due to motion.

2) Which phenomenon occurs when a water wave spreads out after passing through a narrow opening in a barrier?

- a) Refraction
- c) Diffraction**
- b) Reflection
- d) Dispersion

3) The bending of light around the edge of an obstacle is an example of:

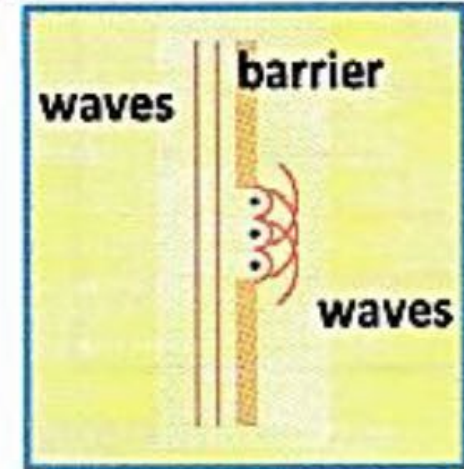
- a) Reflection
- c) Diffraction**
- b) Refraction
- d) Polarization





3- What is the name of the **phenomenon** of the waves after passing the barrier in the figure?

- ☐ reflection
- ☐ refraction
- ☒ diffraction
- ☐ polarization



LO:

- Describe that the color of light is related to its wavelength and frequency.
- Describe primary and secondary pigments and the effects of mixing pigments or dyes.

EX:

Student Textbook

P:

13 - 15



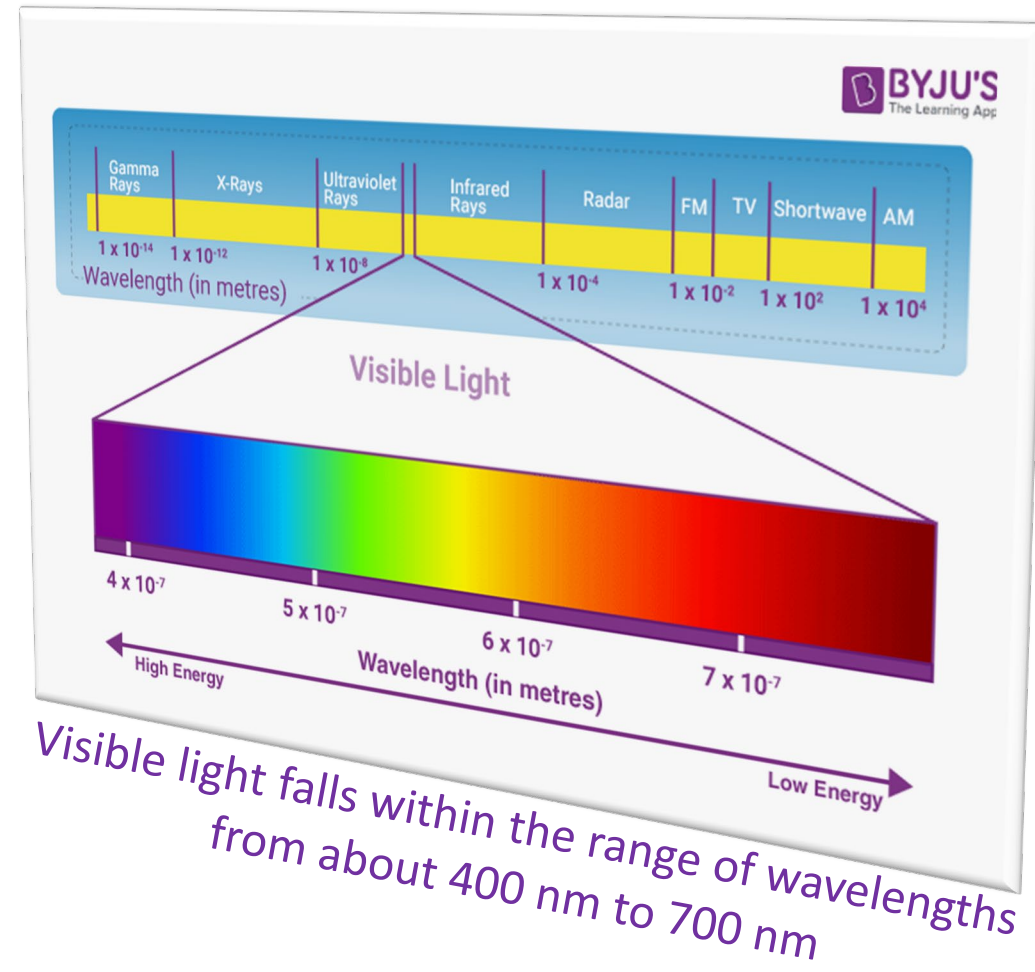
Can the wave model of light explain the colors?

For light to be a wave, it must have wavelength and frequency, and the color of light is **related to wavelength**.

As white light crosses the boundary from air into glass and back into air, its wave nature causes each different color of light to be bent at a different angle (**diffraction**).

The shorter the wavelength (**violet**), the more the light is bent.

This unequal bending of the different colors causes the white light to be spread into a spectrum.





Primary colors: (red, green, blue)

Colors that can be mixed in pairs to form three additional colors.

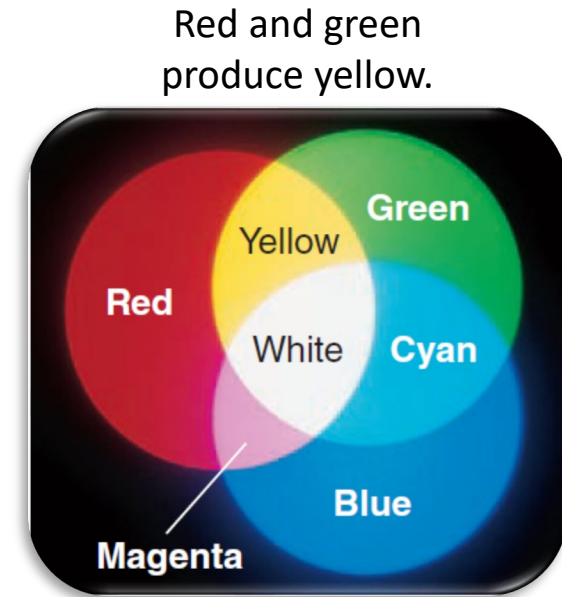
Secondary color: (yellow, cyan, magenta)

The colors resulted from mixing the primary colors.

Complementary colors: (yellow and blue), (Green and magenta), (cyan and Red)

Two colors of light that can be combined to produce white light.

If yellow light and blue light are projected onto a white screen with the correct intensities, the surface will appear to be white.



Red and green
produce yellow.

blue and green
produce cyan.

red and blue
produce magenta.





Color by subtraction of light:

Why objects have different colors?

- In nature objects can **reflect** and **transmit** light. They also can **absorb** light.
- The color of an object **depends on the wavelengths present in the light** that **illuminates** the object and also on which wavelengths are **absorbed** by the object and which wavelengths are **reflected**.
- The natural existence or artificial placement of **dyes** in the material of an object, or **pigments** on its surface, gives the object color.



Dyes:

a molecule that absorbs certain wavelengths of light and transmits or reflects others.

- used to color cloth, can be made from plant or insect extracts.
- A red shirt is red because the dyes in it reflect mostly red light to our eyes.

When **white** light falls on the **red** object shown in **(picture 1)**, the dye molecules in the object absorb most of the **blue** and **green** light and reflect mostly **red** light.

When only **blue** light falls on the **red** object shown in **(picture 2)**, very little light is reflected, and the object appears to be almost **black**.

When only **red** light falls on the **blue** or **green** object shown in **(picture 3)**, very little light is reflected, and the object appears to be almost **black**.



picture 1



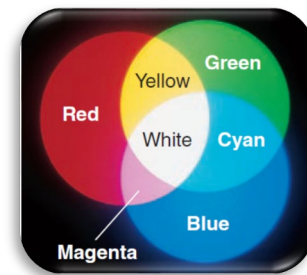
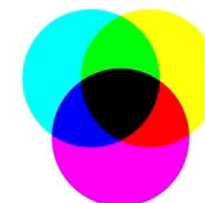
picture 2



picture 3

Pigments:

pigments usually are made of crushed minerals rather than plant or insect extracts.

Primary pigment	absorbs only one primary color and reflects two from white light. Yellow, cyan, magenta	Yellow pigment absorbs blue light and reflects red and green light. Cyan pigment absorbs red light and reflects blue and green light. Magenta pigment absorbs green light and reflects red and blue light.	
Secondary pigment	absorbs two primary colors and reflects one from white light red, green, blue	red (which absorbs green and blue light). green (which absorbs red and blue light). blue (which absorbs red and green light).	
Complementary pigment	are two colors of light that can be combined to produce black pigment.	(Yellow and blue) (Green and magenta) (cyan and Red)	



Note that the primary pigment colors are the secondary colors of light.

The secondary pigment colors are light's primary colors.



Question 16: What is a primary pigment defined as?

- A) A pigment that reflects only one primary color of light.
- B) A pigment that absorbs all primary colors of light.
- C) A pigment that absorbs only one primary color of light and reflects the other two.
- D) A pigment that produces white light when combined with another pigment.

Question 18: Which primary color of light does Cyan Pigment absorb?

- A) Green light
- B) Blue light
- C) Red light
- D) Yellow light





Question 15: What is the practical application mentioned for complementary colors?

- A) Mixing paints for art.
- B) Whitening yellowish laundry with a bluing agent.**
- C) Creating special effects in movies.
- D) Designing traffic lights.





Extra questions

1. When the primary pigments **yellow** and **cyan** are mixed.

yellow absorbs blue light.

cyan absorbs red light.

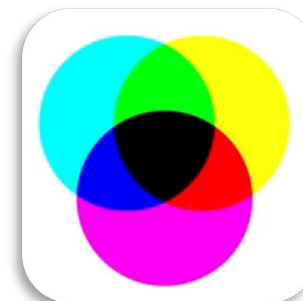
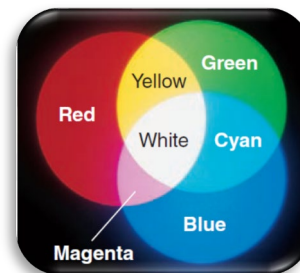
Thus, the combination make green pigment.

2. When the primary **cyan** pigment is mixed with the secondary pigment **red**

cyan absorbs red light.

red absorbs green and blue light.

Thus, the combination make black.





Extra questions

3. When the primary pigments **magenta** and **cyan** are mixed.

magenta absorbs green light.

cyan absorbs red light.

Thus, the combination make blue pigment.

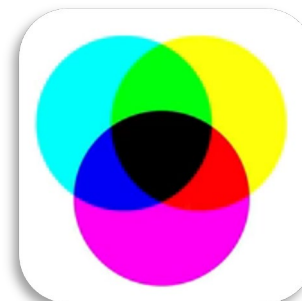
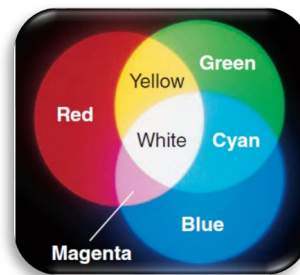


4. When the primary **yellow** pigment is mixed with the secondary pigment **blue**

yellow absorbs blue light.

blue absorbs green and red light.

Thus, the combination make black.





Extra questions

5. When the primary **magenta** pigment is mixed with the secondary pigment **green**

magenta absorbs green light.

green absorbs red and blue light.

Thus, the combination make black.

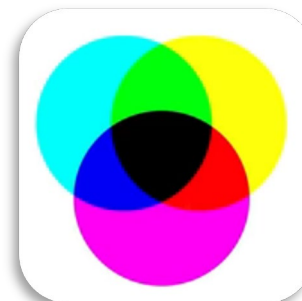
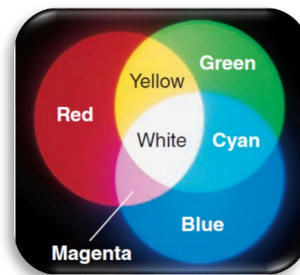


6. When the primary pigments **yellow** and **magenta** are mixed.

yellow absorbs blue light.

magenta absorbs green light.

Thus, the combination make red pigment.





Extra questions

7. Why the die that is **red** appears **red** in white light.

A **red** dye **absorb** **blue** and **green** light and **reflects** **red** light.

8. Why the die that is **blue** appears **black** in **red** light.

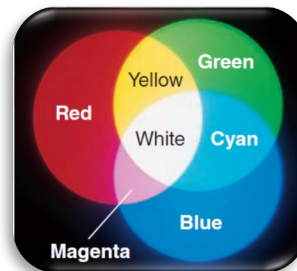
A **blue** dye **absorb** **red** and there is no other colors to reflect.

9. why the die that is **yellow** appears **red** in **red** light.

A **Yellow** dye **absorb** **blue** light and **reflects** **green** and **red** light.

10. In which color **blue** dye appears in **magenta** light.

magenta is the mix of **red** and **blue** the **blue** dye will absorb **red** and reflect **blue**. So, **blue** will appear **blue** in **magenta** light.



Extra questions

11. In which color **yellow** dye appears in **green** light.

Yellow is the mix of **red** and **green** the **Yellow** dye will reflect **red** (no red in this light) and **green**. So, **Yellow** will appear **green** in **green** light.

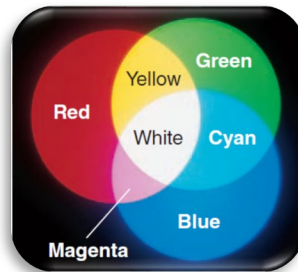
12. In which color **magenta** dye appears in **white** light.

magenta is the mix of **red** and **blue**. In **white** light **magenta** will reflect **red** and **blue** and appear **magenta**

13. In which color **yellow** dye appears in **magenta** light.

A **Yellow** dye **absorb** **blue** light and **reflects** **green** and **red** light,

Magenta is the mix of **red** and **blue**. In **magenta** light **Yellow** will reflect **red** and absorb **blue** and appear **red**.



LO:

Apply Malus's law to light filtered by polarizer and analyzer filters.

EX:

Student Textbook
Physics Challenge

P:

16, 17, 18



Malus's law:

Unpolarized light with intensity I_0 passes through the polarizer.

The intensity, I_1 , of the light that passes through the polarizer is given by:

$$I_1 = \frac{1}{2} I_0$$

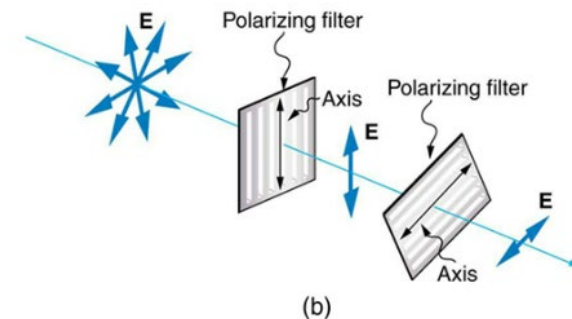
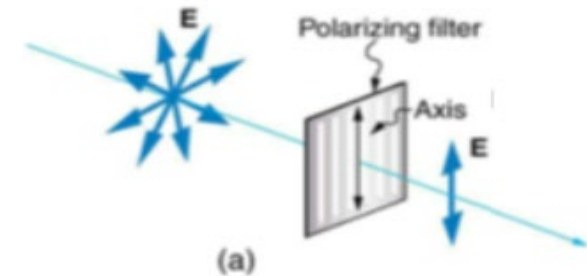
because the unpolarized light had equal contributions from the y- and z-components and only the y-components are transmitted by the polarizer. The factor $\frac{1}{2}$ applies only to the case of unpolarized light passing through a polarizer.

Let's insert another polarizer with a polarizing angle (θ).

After the light I_1 passes through the polarizer, the intensity, I_2 is given by:

$$I_2 = I_1 \cos^2 \theta$$

Malus's law



**Physics Challenge** (page 18)

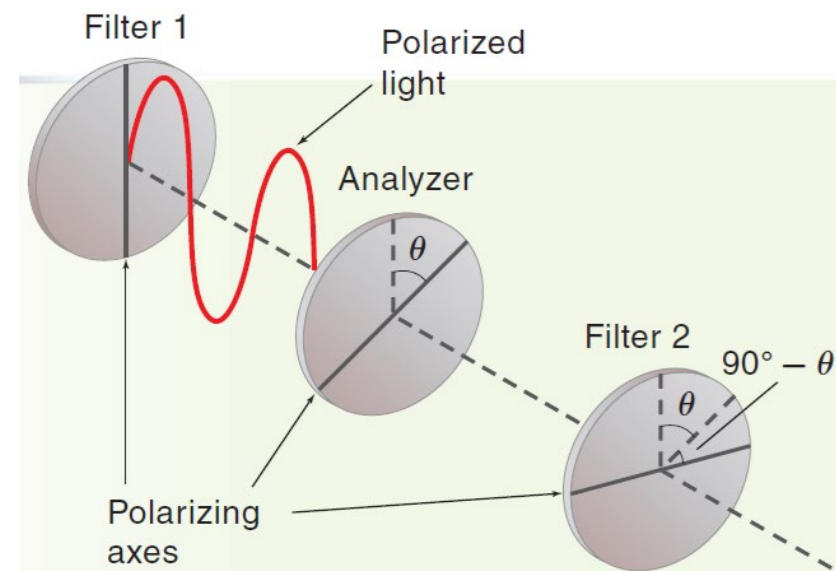
You place an analyzer filter between the two cross-polarized filters, such that its polarizing axis is not parallel to either of the two filters, as shown in the figure to the right.

1. You observe that some light passes through filter 2, though no light passed through filter 2 before you inserted the analyzer filter. Why does this happen?

The analyzer filter allows some light to pass through, since its polarizing axis is not perpendicular to the polarizing axis of the first filter. The last polarizing filter now can pass light from the analyzer filter, since the polarizing axis of the analyzer filter is not perpendicular to the polarizing axis of the last polarizing filter.

2. The analyzer filter is placed at an angle of θ relative to the polarizing axis of filter 1. Derive an equation for the intensity of light coming out of filter 2 compared to the intensity of light coming out of filter 1.

$$\left. \begin{aligned} I_{\text{analyzer}} &= I_1 \cos^2 \theta \\ I_2 &= I_{\text{analyzer}} \cos^2 (90^\circ - \theta) \end{aligned} \right\} I_2 = I_1 \cos^2 \theta \cos^2 (90^\circ - \theta)$$



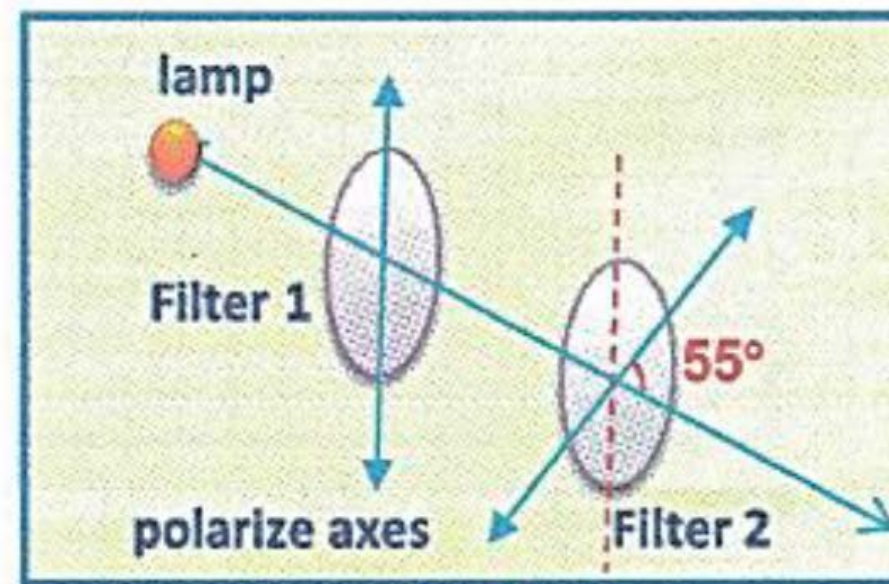


In the figure, the intensity of the polarized light coming out from the **first** polarizing filter is (75 W/m^2) .

19- Calculate the intensity of the polarized light coming out from filter 2 ?

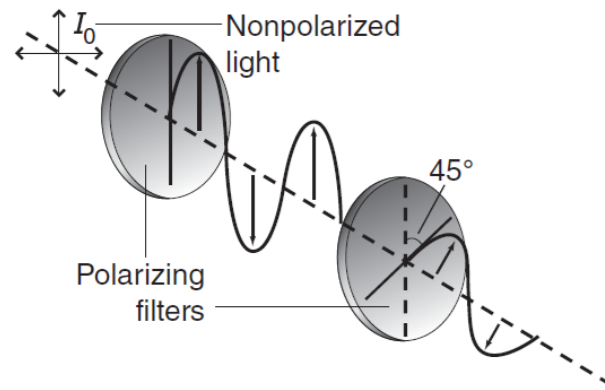
$$I_2 = I_1 \cos^2 \theta$$

$$I_2 = 75 \cos^2 (90 - 55) = 50.3 \text{ W/m}^2$$



**Extra questions**

10. Nonpolarized light of intensity I_0 is incident on a polarizing filter, and the emerging light strikes a second polarizing filter, as shown in the figure. What is the light intensity emerging from the second polarizing filter?



$$I_1 = \frac{1}{2} I_0 = \frac{1}{2} I_0$$

$$I_2 = I_1 \cos^2 \theta = \frac{1}{2} I_0 \cos^2 45^\circ = \frac{1}{4} I_0$$

LO:

-Apply mathematical equations to calculate unknown physical quantities (wavelengths, frequencies, or speeds) when light waves are doppler shifted based on the relative speed of the observer and the light source.

EX:

Student Textbook
Practice problems

P:

20



Doppler Effect:

Observed Light Frequency

The observed frequency of light from a source is equal to the actual frequency of the light generated by the source, times the quantity **1 plus or minus** the relative speed along the axis, divided by the speed of light, between the source and the observer.

$$f_{obs} = f \left(1 \pm \frac{v}{c} \right)$$

(+) source and the observer are moving toward each other.

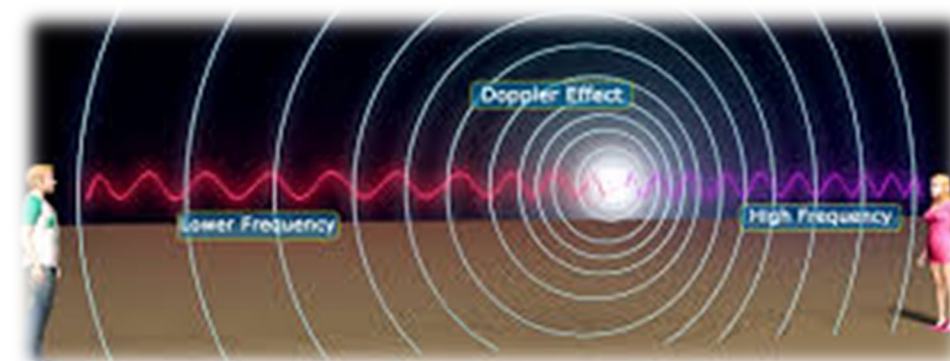
(-) source and the observer are moving away from each other.

(f_{obs}) observed frequency

(f) actual frequency

(v) relative speed along the axis

(c) speed of light ($3 \times 10^8 m/s$)



**PRACTICE PROBLEMS** (page20)

17. A hydrogen atom in a galaxy moving with a speed of $6.55 \times 10^6 m/s$ away from Earth emits light with a frequency of $6.16 \times 10^{14} Hz$. What frequency of light from that hydrogen atom would be observed by an astronomer on Earth?

(–) the atom moving away from Earth.

$$f_{obs} = f \left(1 - \frac{v}{c} \right)$$

$$f_{obs} = 6.16 \times 10^{14} \left(1 - \frac{6.55 \times 10^6}{3 \times 10^8} \right)$$

$$f_{obs} = 6.03 \times 10^{14} Hz$$



**Extra questions**

5. A galaxy is moving away at $5.8 \times 10^6 m/s$. Its light appears to observers to have a frequency of $5.6 \times 10^{14} Hz$. What is the emitted frequency of the light?

A. $1.1 \times 10^{13} Hz$

(-) the atom moving away from Earth.

B. $5.7 \times 10^{14} Hz$

$$f_{obs} = f \left(1 - \frac{v}{c} \right)$$

C. $5.5 \times 10^{14} Hz$

D. $6.2 \times 10^{14} Hz$

$$f = \frac{f_{obs}}{\left(1 - \frac{v}{c} \right)}$$

$$f = \frac{5.6 \times 10^{14}}{\left(1 - \frac{5.8 \times 10^6}{3 \times 10^8} \right)} = 5.7 \times 10^{14} Hz$$



Doppler Effect:

Doppler Shift

The difference between the observed wavelength of light and the actual wavelength of light generated by a source is equal to the actual wavelength of light generated by the source, times the relative speed of the source and observer, divided by the speed of light.

$$\Delta\lambda = (\lambda_{obs} - \lambda) = \pm \left(\frac{v}{c}\right) \lambda$$

(-) source and the observer are moving toward each other (blueshift).

(+) source and the observer are moving away from each other (redshifted).

wavelength is shorter

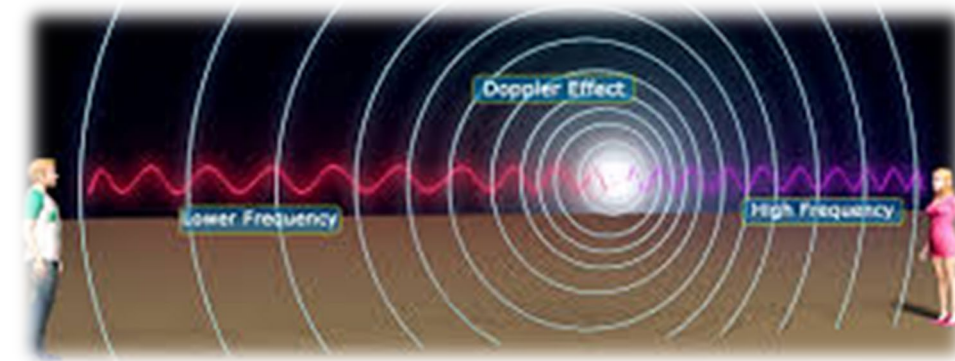
wavelength is longer

(λ_{obs}) observed wavelength

(λ) actual wavelength

(v) relative speed along the axis

(c) speed of light ($3 \times 10^8 m/s$)



**PRACTICE PROBLEMS** (page20)

18. A hydrogen atom in a galaxy moving with a speed of $6.55 \times 10^6 m/s$ away from Earth emits light with a wavelength of 486 nm . What wavelength would be observed on Earth from that hydrogen atom?

(+) the atom moving away from Earth.

$$(\lambda_{obs} - \lambda) = + \left(\frac{v}{c} \right) \lambda$$

$$\lambda_{obs} = 486 \times 10^{-9} \left(1 + \frac{6.55 \times 10^6}{3 \times 10^8} \right)$$

$$\lambda_{obs} = \lambda + \left(\frac{v}{c} \right) \lambda$$

$$\lambda_{obs} = 4.97 \times 10^{-7} m$$

$$\lambda_{obs} = \lambda \left(1 + \left(\frac{v}{c} \right) \right)$$



**PRACTICE PROBLEMS** (page20)

19. CHALLENGE An astronomer is looking at the spectrum of a galaxy and finds that it has an oxygen spectral line of 525 nm, while the laboratory value is measured at 513 nm. Calculate how fast the galaxy would be moving relative to Earth. Explain whether the galaxy is moving toward or away from Earth and how you know.

The observed (apparent) wavelength appears to be longer than the known (actual) wavelength of the oxygen spectral line.

$$(\lambda_{obs} - \lambda) = + \left(\frac{v}{c} \right) \lambda$$

$$\frac{(\lambda_{obs} - \lambda)}{\lambda} = \left(\frac{v}{c} \right)$$

This means that the astronomer and the galaxy are moving away from each other. So use the positive form of the Doppler shift equation.

$$v = c \frac{(\lambda_{obs} - \lambda)}{\lambda}$$

$$v = (3 \times 10^8) \frac{(525 \times 10^{-9} - 513 \times 10^{-9})}{513 \times 10^{-9}} = 6.02 \times 10^6 \text{ m/s}$$



**Extra questions**

6. A celestial object is known to contain an element that emits light at a wavelength of 525 nm. The observed spectral line for this element is at 473 nm. Is the object approaching or receding, and at what speed?

$$(\lambda_{obs} - \lambda) = -\left(\frac{v}{c}\right)\lambda$$

observed wavelength is shorter

$$\frac{(\lambda_{obs} - \lambda)}{\lambda} = -\left(\frac{v}{c}\right)$$

(-) source and the observer are moving toward each other (blueshift).

$$v = -c \frac{(\lambda_{obs} - \lambda)}{\lambda}$$

$$v = -(3 \times 10^8) \frac{(473\text{nm} - 525\text{nm})}{525\text{nm}} = 2.9 \times 10^7 \text{m/s}$$

7. How fast is a galaxy moving relative to Earth if light from hydrogen's spectrum of 486 nm is redshifted to 491 nm?

$$(\lambda_{obs} - \lambda) = \left(\frac{v}{c}\right)\lambda$$

$$\frac{(\lambda_{obs} - \lambda)}{\lambda} = \left(\frac{v}{c}\right)$$

$$v = c \frac{(\lambda_{obs} - \lambda)}{\lambda}$$

$$v = (3 \times 10^8) \frac{(491\text{nm} - 486\text{nm})}{486\text{nm}} = 3.09 \times 10^6 \text{m/s}$$



**Extra questions**

8. Suppose that you are a traffic officer and you stop a driver for going through a red light. Further suppose that the driver draws a picture for you (Figure 29) and explains that the light looked green because of the Doppler effect when he went through it. Explain to him using the Doppler shift equation how fast he would have had to be going for the red light ($\lambda = 645 \text{ nm}$) to appear green ($\lambda = 545 \text{ nm}$).

$$(\lambda_{obs} - \lambda) = -\left(\frac{v}{c}\right)\lambda \quad (-) \text{ source and the observer are moving toward each other.}$$

$$\frac{(\lambda_{obs} - \lambda)}{\lambda} = -\left(\frac{v}{c}\right)$$

$$v = -c \frac{(\lambda_{obs} - \lambda)}{\lambda} = -(3 \times 10^8) \frac{(545 \times 10^{-9} - 645 \times 10^{-9})}{645 \times 10^{-9}} = 4.65 \times 10^7 \text{ m/s}$$

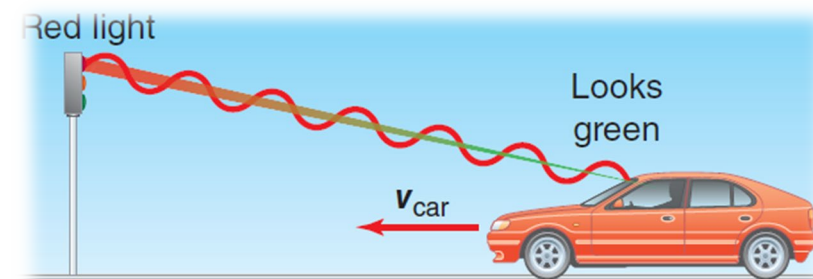


Figure 29



LO:

-Apply the law of reflection in drawing ray diagrams and solving numerical problems.

EX:

Student Textbook
Example problem1
Practice problems

P:

29,30,31

The Law of Reflection:

The angle that a reflected ray makes as measured from the normal to a reflective surface equals the angle that the incident ray makes as measured from the same normal.

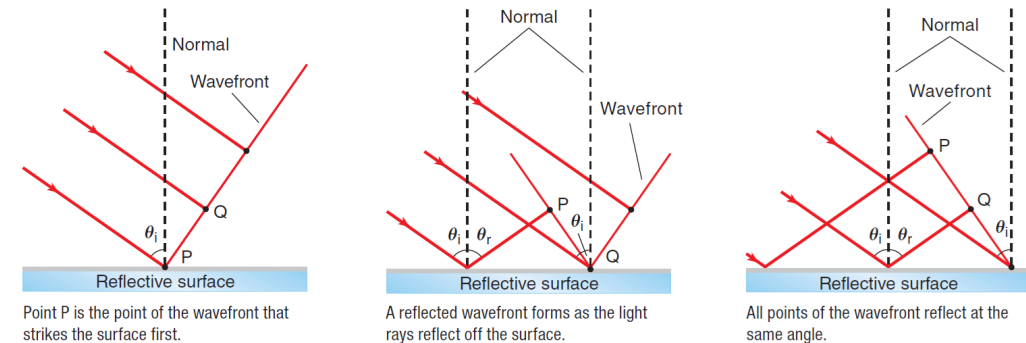
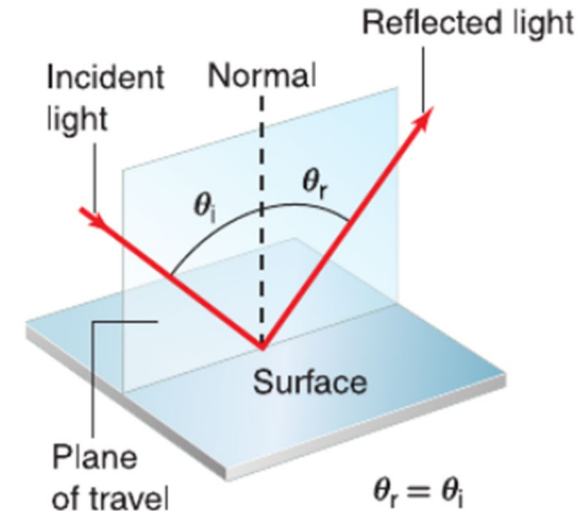
$$\theta_r = \theta_i$$

We can describe this law in terms of the wave model of light. **Figure 3** shows a wavefront of light approaching a reflective surface.

The wavefront is perpendicular to the light ray.

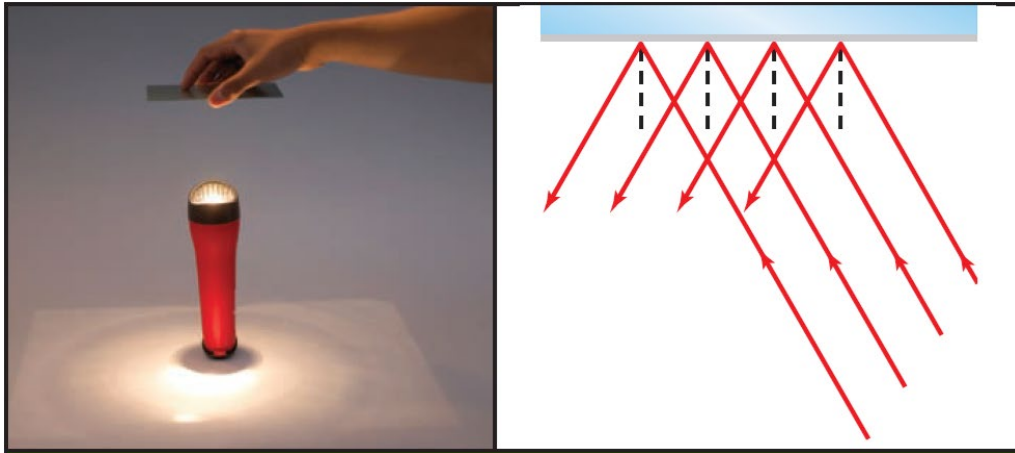
As each point along the wavefront reaches the surface; it reflects off that surface. Because all points are traveling at the same speed, they all travel the same total distance at the same time.

Thus, the wavefront as a whole leaves the surface at an angle equal to its incident angle.





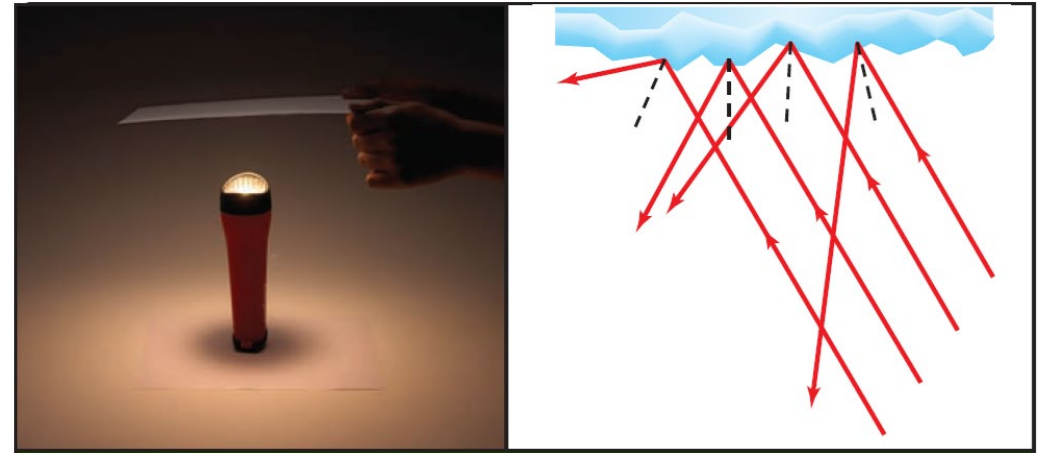
The Law of Reflection:



Smooth Surface: Specular Reflection

The reflected rays are parallel to each other

Specular reflection: in which parallel light rays reflect in parallel.



Rough Surface: Diffuse Reflection

The reflected rays are not parallel to each other

Diffuse reflection: The scattering of light off a rough surface.

The law of reflection applies to both smooth and rough surfaces. For a rough surface, the angle that each incident ray makes with the normal equals the angle that its reflected ray makes with the normal.

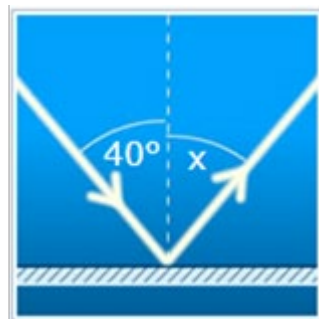




Extra questions

1. Diagrams show a light ray reflecting off a mirror. what is the value of angle 'X'.

$$x = \theta_r = \theta_i = 40^\circ$$



$$\theta_i = 90^\circ - 39^\circ = 51^\circ$$

$$x = \theta_r = \theta_i = 51^\circ$$



2. Diagrams show a light ray reflecting off a mirror. what is the value of angle 'X'.

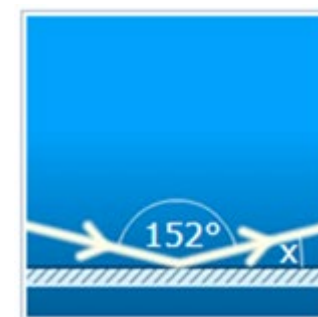
$$\theta_i = \frac{90^\circ}{2} = 45^\circ$$

$$x = 90^\circ - 45^\circ = 45^\circ$$



$$\theta_i = \frac{152^\circ}{2} = 76^\circ$$

$$x = 90^\circ - 76^\circ = 14^\circ$$





PRACTICE PROBLEMS (page 31)

1. Explain why the reflection of light off ground glass changes from diffuse to specular if you spill water on it.

Water fills in the rough areas and makes the surface smoother.

2. What is the angle of incidence of a light ray reflected off a plane mirror at an angle of 35° to the normal?

$$\theta_r = \theta_i = 35^\circ$$

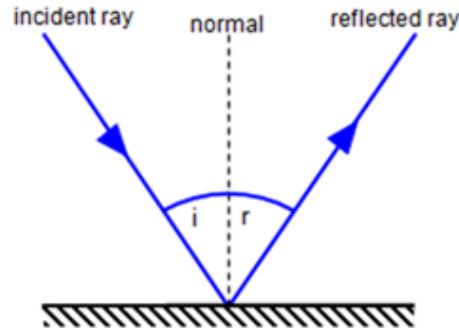


**PRACTICE PROBLEMS** (page 31)

3. Suppose the angle of incidence of a light ray is 42° .

a. What is the angle of reflection?

$$\theta_r = \theta_i = 42^\circ$$



b. What is the angle the incident ray makes with the mirror?

$$\theta_{i,mirror} = 90^\circ - \theta_i = 90^\circ - 42^\circ = 48^\circ$$

c. What is the angle between the incident ray and the reflected ray?

$$\theta_i + \theta_r = 2\theta_i = 84^\circ$$

4. Light from a laser strikes a plane mirror at an angle of 38° to the normal. If the angle of incidence increases by 13° , what is the new angle of reflection?

$$\theta_i = \theta_{i,initial} + 13^\circ$$

$$\theta_i = 38^\circ + 13^\circ = 51^\circ$$

$$\theta_r = \theta_i = 51^\circ$$





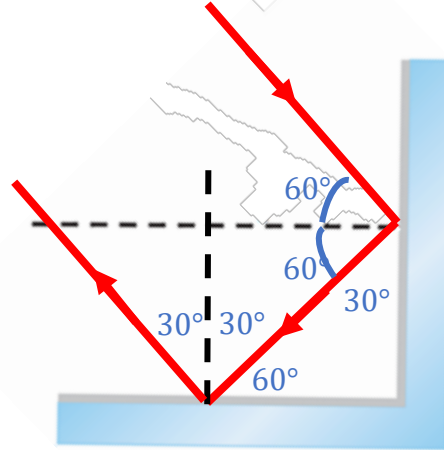
PRACTICE PROBLEMS (page 31)

5. You position two plane mirrors at right angles to each other. A light ray strikes one mirror at an angle of 60° to the normal and reflects toward the second mirror. What is its angle of reflection off the second mirror?

$$\theta_{r1} = \theta_{i1} = 60^\circ$$

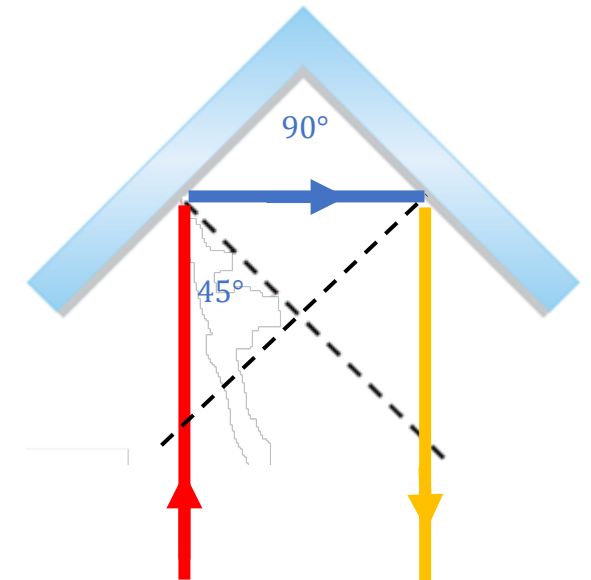
$$\theta_{i2} = 90^\circ - 60^\circ = 30^\circ$$

$$\theta_{r2} = \theta_{i2} = 30^\circ$$



6. **CHALLENGE** You are asked to design a retroreflector using two mirrors that will reflect a laser beam by 180° independent of the incident direction of the beam. What should be the angle between the two mirrors?

90°



EXAMPLE PROBLEM 1 (page 31)

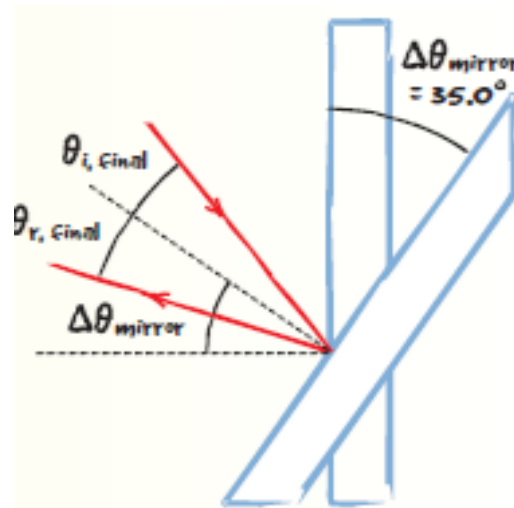
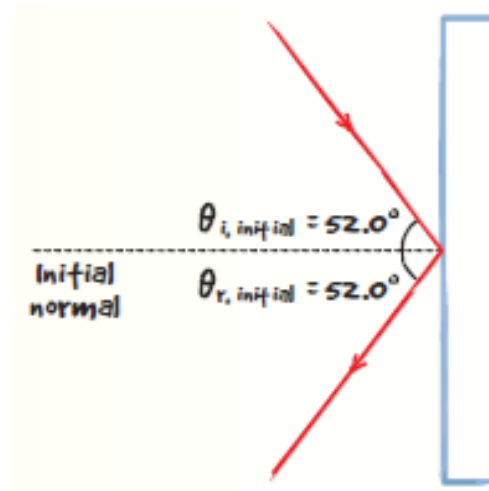
CHANGING THE ANGLE OF INCIDENCE

A light ray strikes a plane mirror at an angle of 52.0° to the normal.

The mirror then rotates 35.0° around the point where the ray strikes the mirror so that the angle of incidence of the light ray decreases.

The axis of rotation is perpendicular to the plane of the incident and the reflected rays.

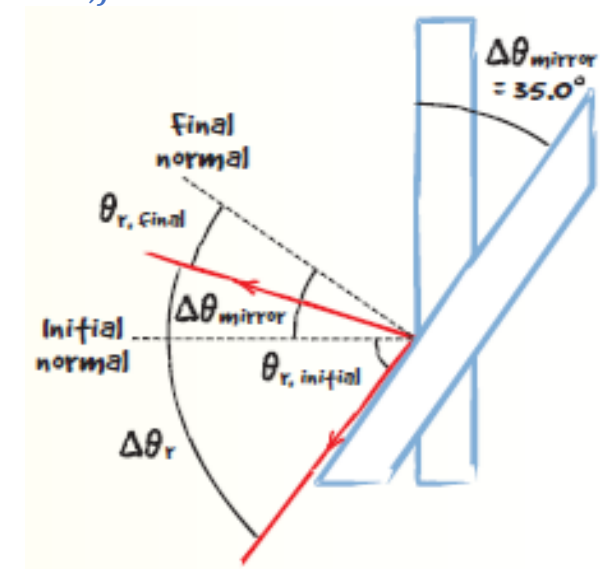
What is the angle between the initial and final reflected ray?



$$\theta_{i, \text{final}} = \theta_{i, \text{initial}} - \Delta\theta_{\text{mirror}}$$

$$\theta_{i, \text{final}} = 52^\circ - 35^\circ = 17^\circ$$

$$\theta_{r, \text{final}} = \theta_{i, \text{final}} = 17^\circ$$

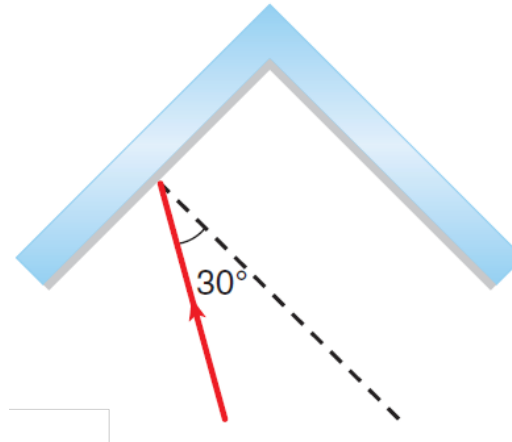


$$\Delta\theta_r = \theta_{r, \text{initial}} + \Delta\theta_{\text{mirror}} - \theta_{r, \text{final}}$$

$$\Delta\theta_r = 52^\circ + 35^\circ - 17^\circ = 70^\circ$$

**Extra questions**

3. Two adjacent plane mirrors form a right angle, as shown. A light ray is incident upon one of the mirrors at an angle of 30° to the normal. What is the angle at which the light ray is reflected from the other mirror?



Reflection from the first mirror:

$$\theta_{r1} = \theta_{i1} = 30^\circ$$

Reflection from the second mirror:

$$\theta_{i2} = 90^\circ - \theta_{r1}$$

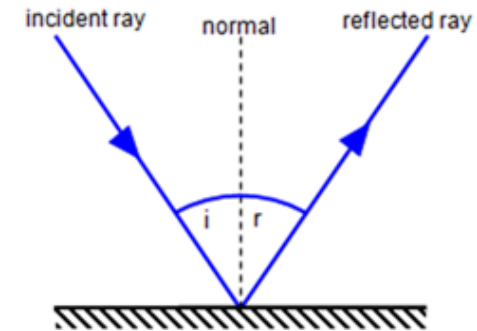
$$\theta_{i2} = 90^\circ - 30^\circ = 60^\circ$$

$$\theta_{r2} = \theta_{i2} = 60^\circ$$

4. A light ray strikes a mirror at an angle of 53° to the normal.

A- What is the angle of reflection?

$$\theta_r = \theta_i = 53^\circ$$



B- What is the angle between the incident ray and the reflected ray?

$$\theta = \theta_r + \theta_i = 53^\circ$$

$$\theta = 53^\circ + 53^\circ = 106^\circ$$





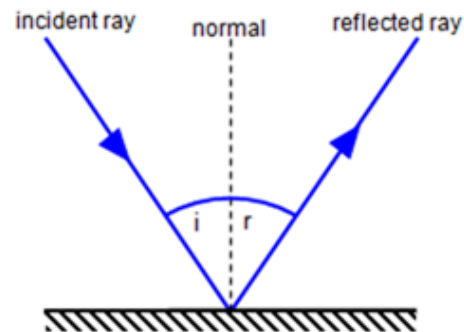
Check Your Progress (page 33)

7. Reflection A light ray strikes a flat, smooth, reflecting surface at an angle of 80° to the normal. What angle does the reflected ray make with the surface of the mirror?

$$\theta_r = \theta_i = 80^\circ$$

$$\theta_{r, \text{mirror}} = 90^\circ - \theta_r$$

$$\theta_{r, \text{mirror}} = 90^\circ - 80^\circ = 10^\circ$$



9. Law of Reflection Explain how the law of reflection applies to diffuse reflection.

The law of reflection applies to individual rays of light.

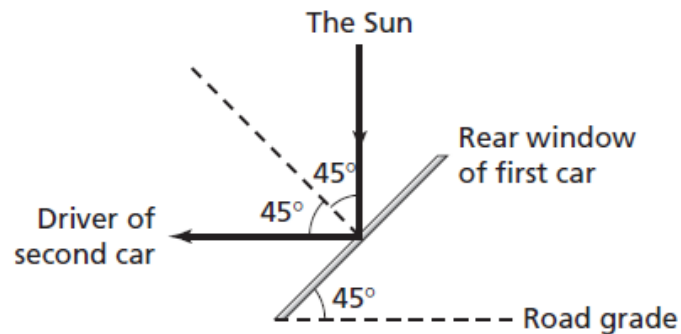
Rough surfaces make the light rays reflect in many different directions.





Check Your Progress (page33)

10. Image Diagram A car is following another car along a straight road. The first car has a rear window tilted at 45° to the horizontal. Draw a ray diagram showing the position of the Sun that would cause sunlight to reflect into the eyes of the driver of the second car.



The Sun's position directly overhead would likely reflect light into the driver's eyes, according to the law of reflection.

11. Critical Thinking Explain how diffuse reflection of light off an object enables you to see that object from any angle.

The incoming light reflects off the surface of the object in all directions.

This enables you to view the object from any location.



**Extra questions**

5. A light ray strikes a mirror at an angle of 60° to the normal. The mirror is then rotated 18° clockwise, as shown. What is the angle that the reflected ray makes with the mirror?

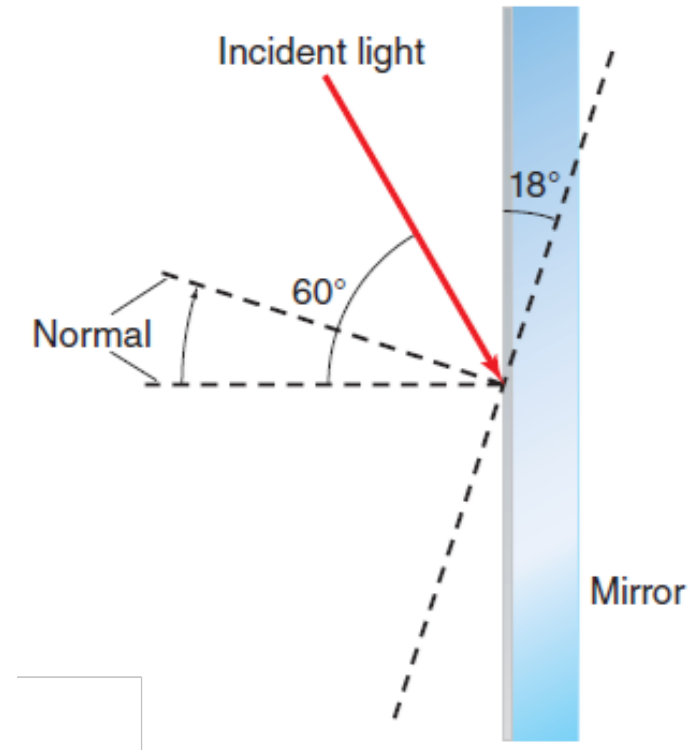
$$\theta_i = \theta_{i,old} - 18^\circ$$

$$\theta_i = 60^\circ - 18^\circ = 42^\circ$$

$$\theta_r = \theta_i = 42^\circ$$

$$\theta_{r,mirror} = 90^\circ - \theta_r$$

$$\theta_{r,mirror} = 90^\circ - 42^\circ = 48^\circ$$





Extra questions

6. Two plane mirrors are connected at their sides so that they form a 45° angle between them. A light ray strikes one mirror at an angle of 30° to the normal and then reflects off the second mirror. Calculate the angle of reflection of the light ray off the second mirror.

Reflection from the first mirror:

$$\theta_{r,1} = \theta_{i,1} = 30^\circ$$

The angle the ray forms with the mirror is thus:

$$90^\circ - 30^\circ = 60^\circ$$

Because the two mirrors form a 45° angle, the angle the ray reflecting off the first mirror forms with the second mirror is:

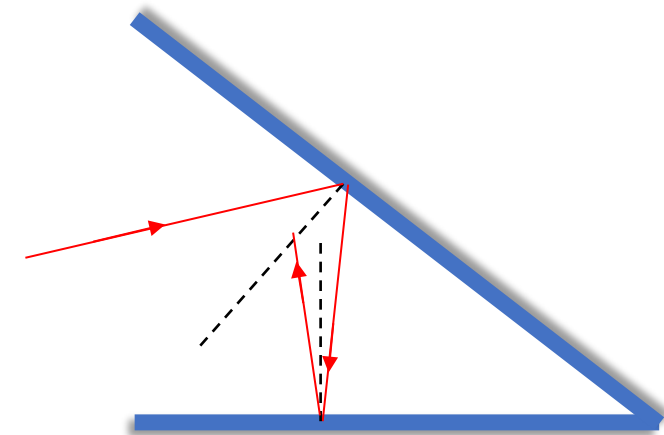
$$180^\circ - 60^\circ - 45^\circ = 75^\circ$$

The angle the ray forms with the second mirror is thus:

$$\theta_{i,2} = 90^\circ - 75^\circ = 15^\circ$$

The angle of reflection from the second mirror is:

$$\theta_{r,2} = \theta_{i,2} = 15^\circ$$



LO:

- Draw a ray diagram to locate the position of an image formed by a plane mirror, showing its properties.
- Represent mathematically the relation between image position and object position, as well as the image height and object height for a plane mirror.

EX:

Student Textbook
Check your progress

P:

32, 33,33



Properties of Plane-Mirror Images:

Looking at the reflection of the person in the mirror

- The image appears to be at the **same distance** behind the mirror as the person are in front of the mirror.

$$x_i = -x_o$$

The negative sign indicates that the image is behind the mirror (and therefore virtual).

- The image matches your size (**same height**).

$$h_i = h_o$$

- The image is **vertically oriented** (left is right and right is left- **reversed front-to-back**) as you are.



Get It?

Summarize the properties of plane mirror image.

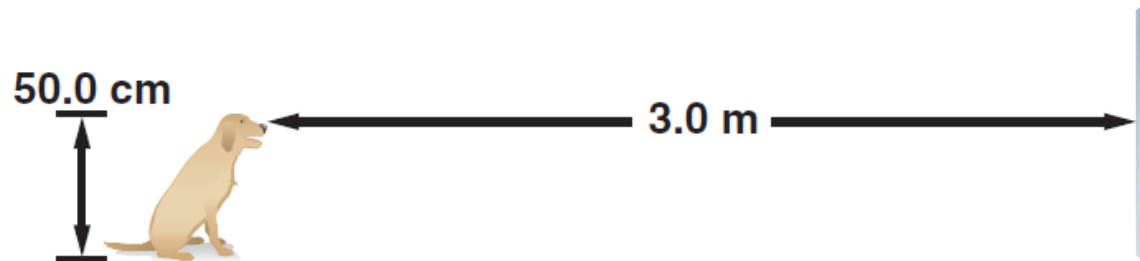
Images formed by a plane mirror are **virtual**, the **same size** as the object, the **same distance** from the mirror as the object's distance from the mirror, and are **reversed front-to-back**.





Check Your Progress (page33)

8. Image Properties A dog looks at its image, as shown in Figure 9. What is the image position, height, and type of image?



$$x_i = -3 \text{ m}$$

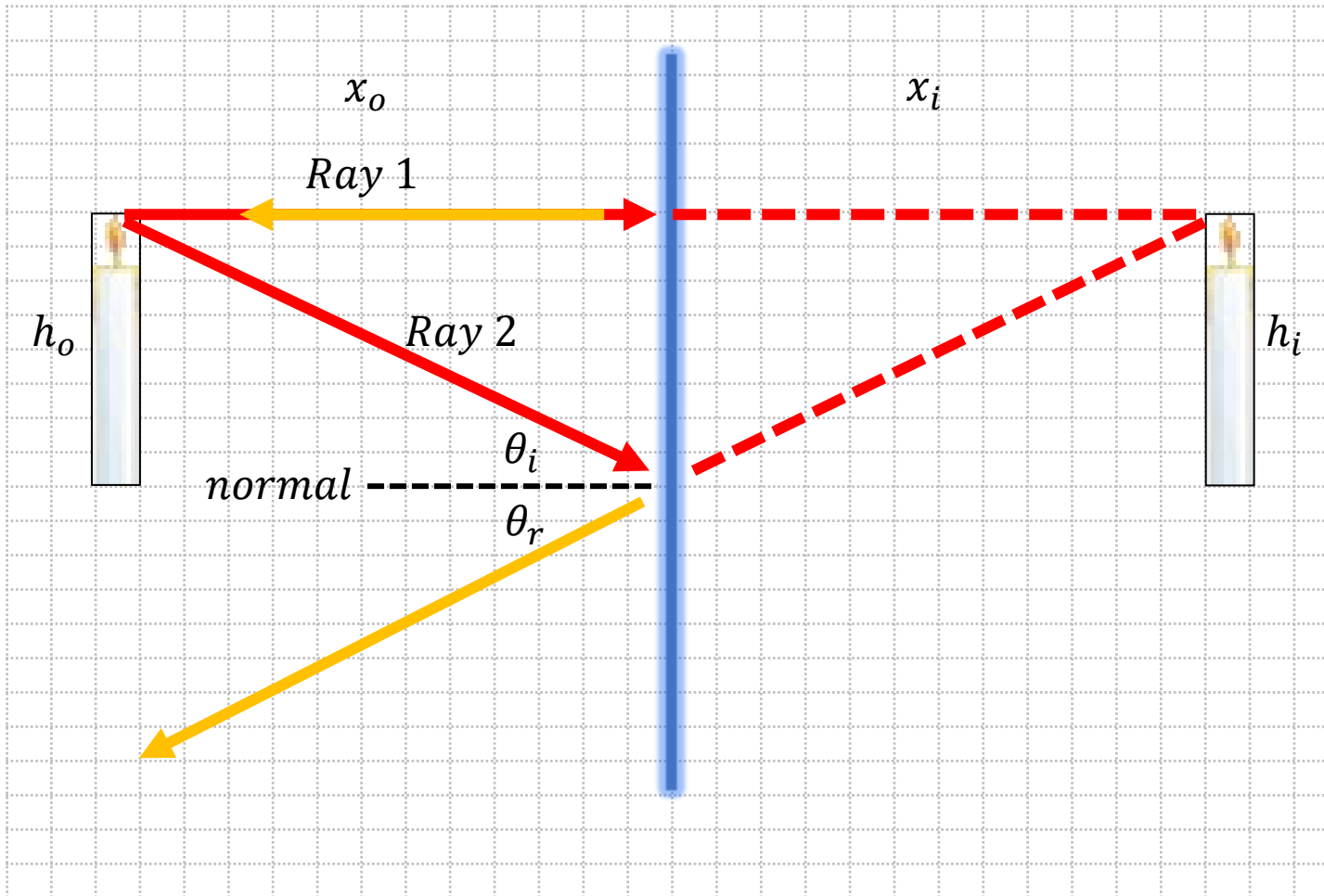
$$h_i = 50 \text{ cm}$$

The image is virtual





Drawing the image in Plane-Mirrors:



1- Draw ray 1 (strait line to the mirror $\theta_i = 0^\circ$).

This ray will reflect back on itself ($\theta_i = \theta_r$)

2- Draw ray 2 (at any point in the mirror).

This ray will reflect according to the law of reflection ($\theta_i = \theta_r$)

3- Draw an extend for the reflected rays behind the mirror as dashed lines.

The point where the lines converge (meet to gather) is the image position.





Extra questions

1. A student believes that very sensitive photographic film can detect a virtual image. The student puts photographic film at the location of a virtual image. Does this attempt succeed? Explain.

No, the rays do not converge at a virtual image.

No image forms and the student would not get a picture.

Some virtual images are behind the mirror.

2. **Picture in a Mirror** Penny wishes to take a picture of her image in a plane mirror, as shown in in the Figure. If the camera is 1.2 m in front of the mirror, at what distance should the camera lens be focused?

The image is 1.2 m behind the mirror, so the camera lens should be set to 2.4 m.



LO:

- Describe defects in concave mirrors, such as curved aberration, and how they can be corrected.
- List some of the uses of concave and mirrors

EX:

Student Textbook

P:

35, 39

Defects in concave mirrors:

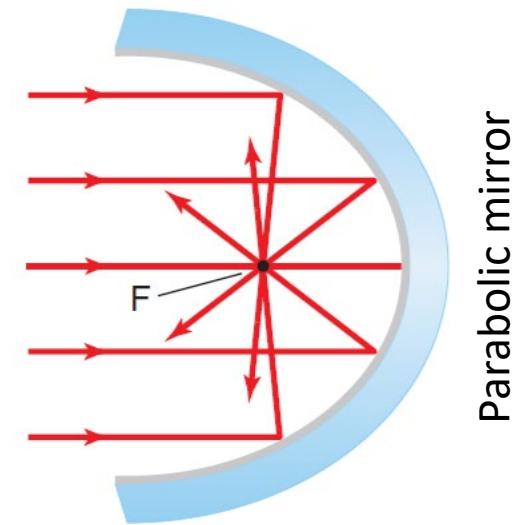
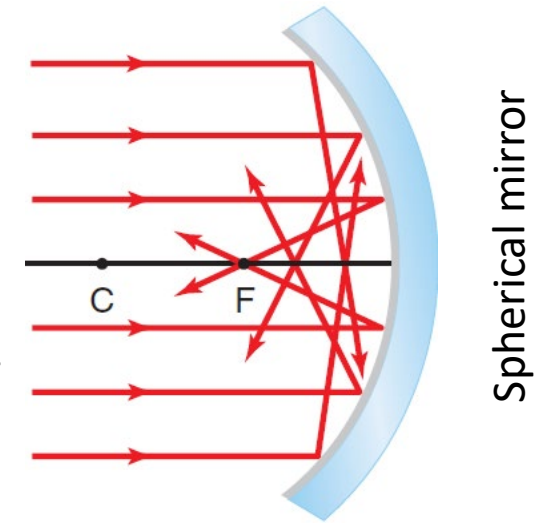
In diagramming rays, you used a vertical line to represent the mirror. In reality, light rays reflect off the mirror itself, as shown in **Figure 17**.

Only parallel rays that are close to the principal axis reflect through the focal point. Other rays converge at points closer to the mirror.

This defect, called **spherical aberration**, occurs because the light rays do not converge at a focal point, which makes an image look fuzzy.

A mirror ground to the shape of a parabola, as in **Figure 17**, suffers no spherical aberration.

Large, **parabolic glass mirrors are expensive to manufacture**; so, many telescopes use spherical mirrors and **smaller, specially-designed secondary mirrors or lenses to correct for spherical aberration**. We can also reduce spherical aberration by **reducing the ratio of the mirror's diameter to its radius of curvature**.



Properties of curved mirrors:

Concave Mirror (inwardly curving reflective surface)

Principal Axis: line perpendicular to the mirror's surface that divides the mirror in half.

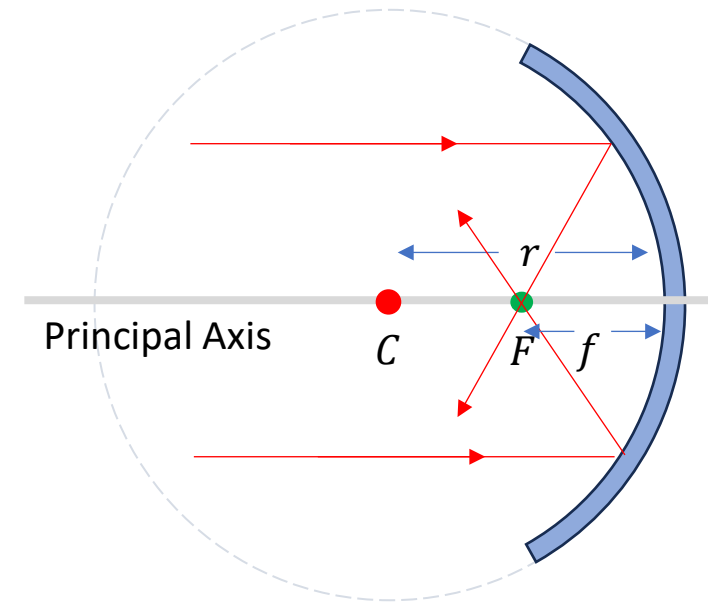
C: geometric center

r: radius of curvature

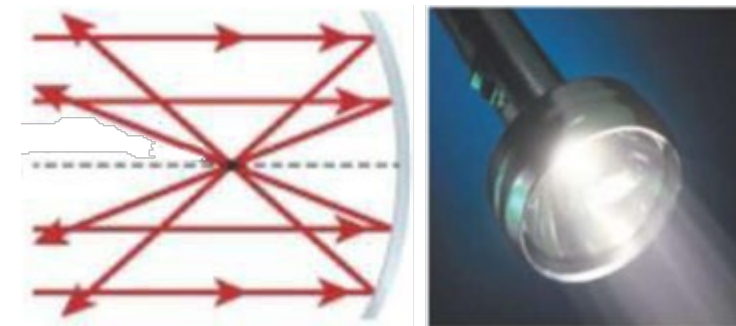
Focal Point (F): Incident light rays that are **parallel** to the principal axis are reflected and intersect the principal axis at a point halfway between C and M.

Focal length (f): is the distance between the mirror and the focal point and can be expressed as $\left(f = \frac{r}{2}\right)$.

Concave mirrors are placed behind the lightbulbs in theater spotlights and in car headlights. It is a concave mirror that allows the light from a spotlight to be focused into a spot.



Concave Mirror is a Converging mirror



Properties of curved mirrors:

Convex Mirror (outwardly curving reflective surface)

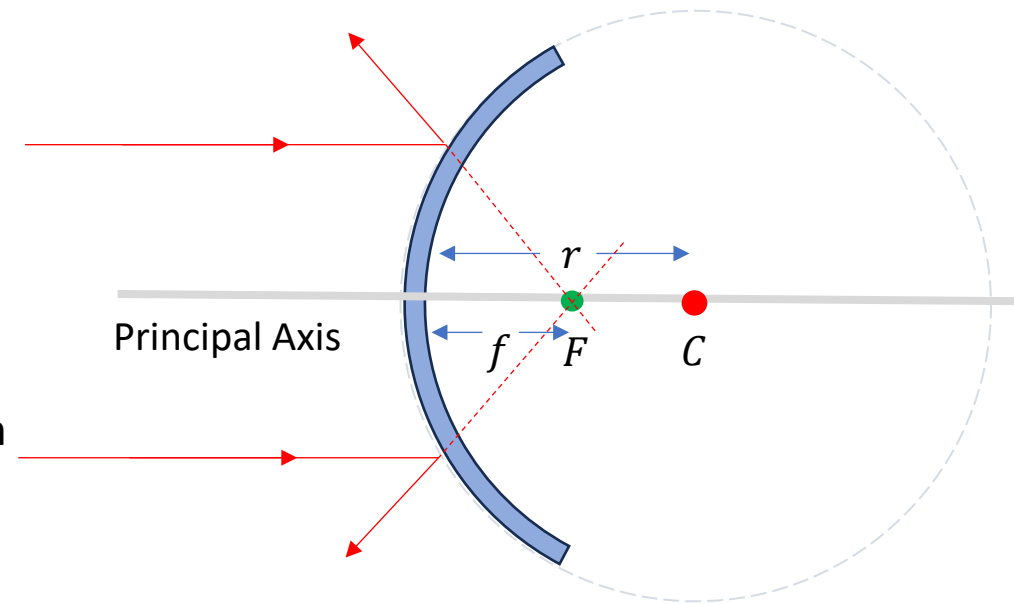
Geometric center and focal point are behind the mirror.

Incident light rays that are **parallel** to the principal axis are reflected away from the mirror in a path (if extended behind the mirror would pass through the focal point).

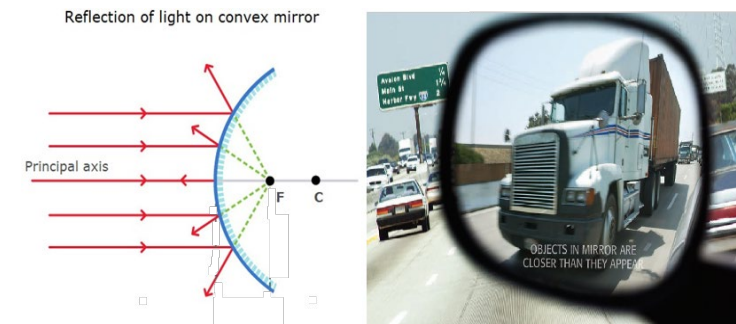
images formed by convex mirror are smaller than the objects. And by forming smaller images, convex mirrors **enlarge the area** that an observer sees, which is called the field of view. (reducing the image size makes the objects appear **farther away** than they really are).

Also, the image is visible from a large range of angles; thus, the field of view is visible from a wide perspective.

Convex mirrors are used as store security mirrors and many side-view mirrors on cars are convex mirrors.



Convex Mirror is a diverging mirror





Concave mirror



Testing of teeth by concave mirror



burning mirror



convave mirron in torch light



Solar cooker



head light of a car

Concave mirror that allows the light from a spotlight to be focused into a spot.

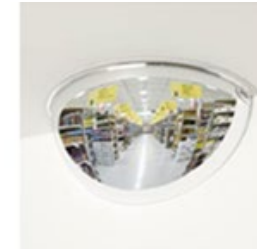
Convex mirror



Security Mirror



Traffic Mirror



Dome Mirror



Automobile Side Mirror



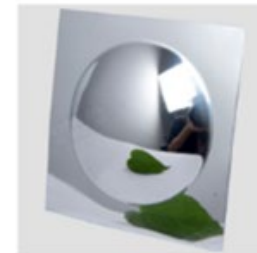
ATM Convex Mirror



Wall Art Decoration



Under car Inspection Mirror



Education Application

The image is visible from a large range of angles; thus, the field of view is visible from a wide perspective





1) What is the primary cause of spherical aberration in a concave spherical mirror?

- a) Different colors of light focus at different points
- b) Marginal rays focus at a different point than paraxial rays**
- c) The mirror absorbs too much light
- d) The image becomes magnified unevenly

2) How can spherical aberration in concave mirrors be corrected?

- a) By using a parabolic mirror instead of a spherical one**
- b) By placing a convex lens in front of the mirror
- c) By silvering the mirror surface
- d) By increasing the mirror's focal length

3) Which statement best describes spherical aberration?

- a) Light rays parallel to the principal axis converge at a single point
- b) The mirror produces multiple images of a single object
- c) The mirror focuses parallel rays to different points, creating a blurred image**
- d) The mirror changes the color of the reflected light

Ex. Why are convex mirrors used as rearview mirrors?

Convex mirrors are used as rearview mirrors because they allow for a wide range of view, allowing the driver to see a much larger area than is afforded by ordinary mirrors.





4) Which application typically uses a concave mirror?

- a) Car side-view mirrors
- b) Security mirrors in stores
- c) Shaving/makeup mirrors
- d) Rear-view mirrors in vehicles

5) Where would you most commonly find a convex mirror being used?

- a) In astronomical telescopes
- b) In dental examination tools
- c) In vehicle side-view mirrors
- d) In flashlight reflectors

6) What makes concave mirrors suitable for use in solar cookers?

- a) They create virtual, erect images
- b) They provide a wide field of view
- c) They diverge light rays
- d) They converge sunlight to a focal point

Ex. Rearview Mirrors The outside rearview mirrors of cars often carry the warning “Objects in the mirror are closer than they appear.” What kind of mirrors are these, and what advantage do they have?

convex mirrors

It provides a wider field of view.





Extra questions

12. You have to order a large concave mirror for a high-quality telescope. Should you order a spherical mirror or a parabolic mirror? Explain.

You should order a parabolic mirror to eliminate spherical aberrations

Worksheet on LMS:

State one advantage, weakness and one possible use of a convex mirror in our daily lives.

The image is visible from a large range of angles

Convex mirrors are used as store security mirrors and many side-view mirrors on cars are convex mirrors

images formed by convex mirror are smaller than the objects. And by forming smaller images, convex mirrors enlarge the area that an observer sees, which is called the field of view. (reducing the image size makes the objects appear farther away than they really are.



LO:

22	-Draw a ray diagram to find the image of an object formed by a curved mirror and determine the properties of the formed image. -Apply the mirror equation to calculate the image distance, the object distance, or the focal length of a spherical mirror using appropriate algebraic signs for focal length and corresponding distances. -Calculate the magnification produced by a spherical mirror.	Student Textbook Example problem2,3 Practice problems	36-38 41,42
----	--	---	----------------

EX:

P:

LO:

-Draw a ray diagram to find the image of an object formed by a curved mirror and determine the properties of the formed image.

EX:

Student Textbook

P:

36 - 38

Ray Diagrams for Concave Mirrors:

In concave mirrors light rays coming from the object to the mirror should follow these rules:

Ray 1: parallel to the principal axis.

This ray will reflect passing through the focal point.

Ray 2: passing through the focal point.

This ray will reflect parallel to the principal axis.

Ray 3: passing through the geometrical center.

This ray will reflect-back on itself.

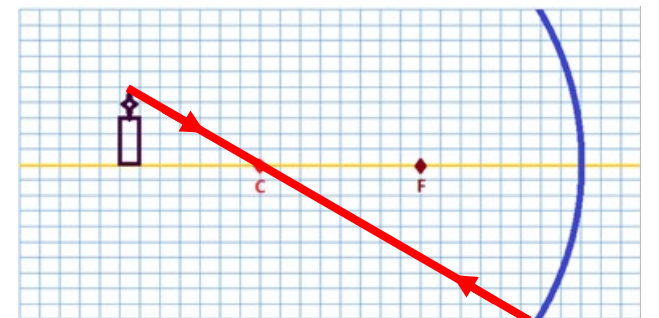
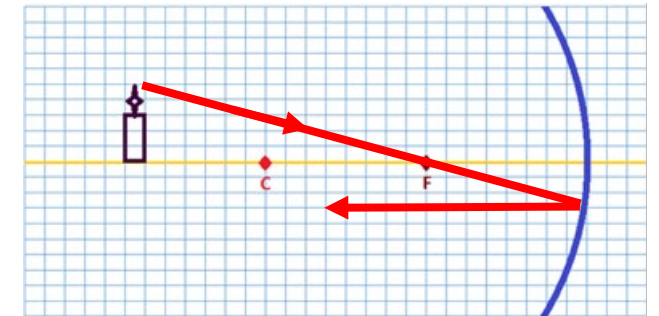
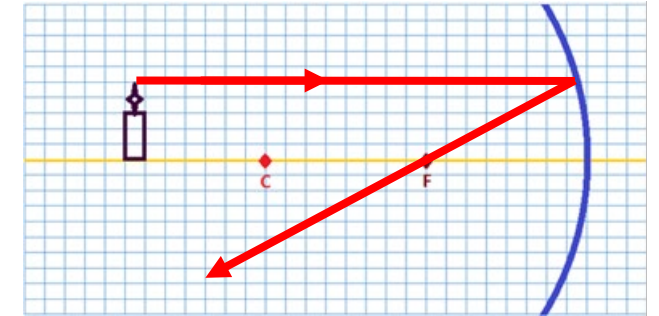
To sketch a ray diagram, you need only two of the three rays.

Image properties in concave mirror depend on:

The object's position

Image type	Real	OR	Virtual
Orientation	Upright	OR	Inverted
Size	Enlarged	OR	Reduced

Or No image



Concave mirrors

Draw a ray diagram to find the image of an object located at a distance greater than twice the focal length of a concave mirror and determine the properties of the formed image.

Position 1: object located at a distance greater than twice the focal length.

Ray 1: from the top of the object parallel to the principal axis.

This ray will reflect passing through the focal point.

Ray 2: from the top of the object passing through the focal point.

This ray will reflect parallel to the principal axis.

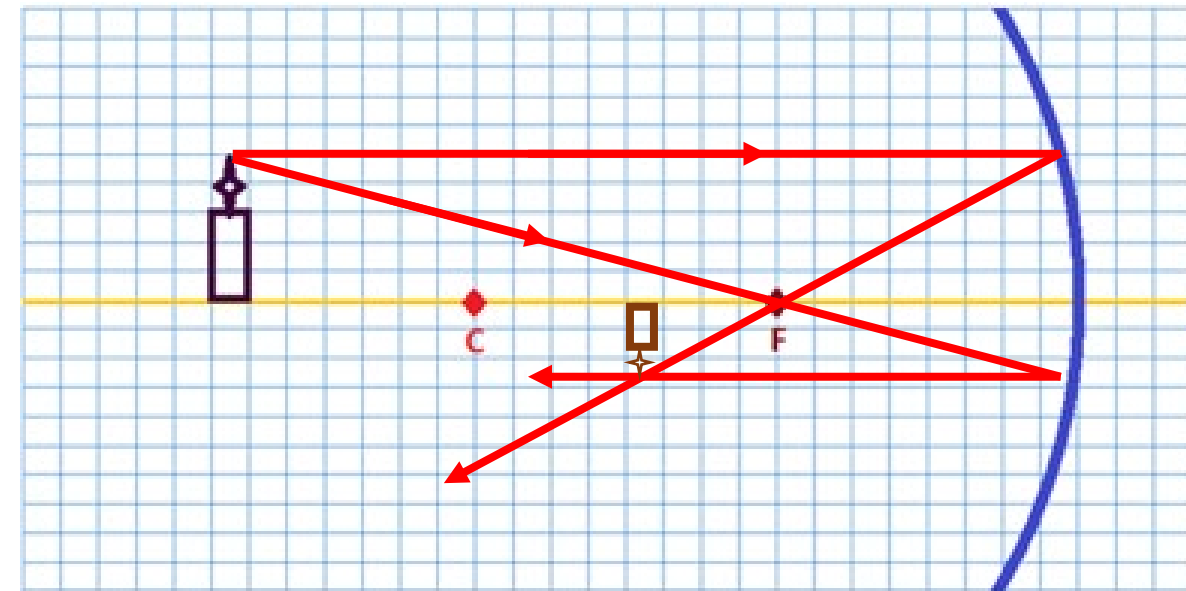
The point where the reflected rays converge represent the point where the light rays came from, use it to draw the object image.

Based on the diagram, What are the image properties:

Real	OR	Virtual
Upright	OR	Inverted
Enlarged	OR	Reduced in size

Its real because there is an actual light rays converged together.
Real images are always inverted.

$x_0 > 2F$ The object is behind the center



Concave mirrors

Draw a ray diagram to find the image of an object located between the focal length and twice the focal length of a concave mirror and determine the properties of the formed image.

Position 2: object located at a distance equal to twice the focal length.

Ray 1: from the top of the object parallel to the principal axis.

This ray will reflect passing through the focal point.

Ray 2: from the top of the object passing through the focal point.

This ray will reflect parallel to the principal axis.

The point where the reflected rays converge represent the point where the light rays came from, use it to draw the object image.

Based on the diagram, What are the image properties:

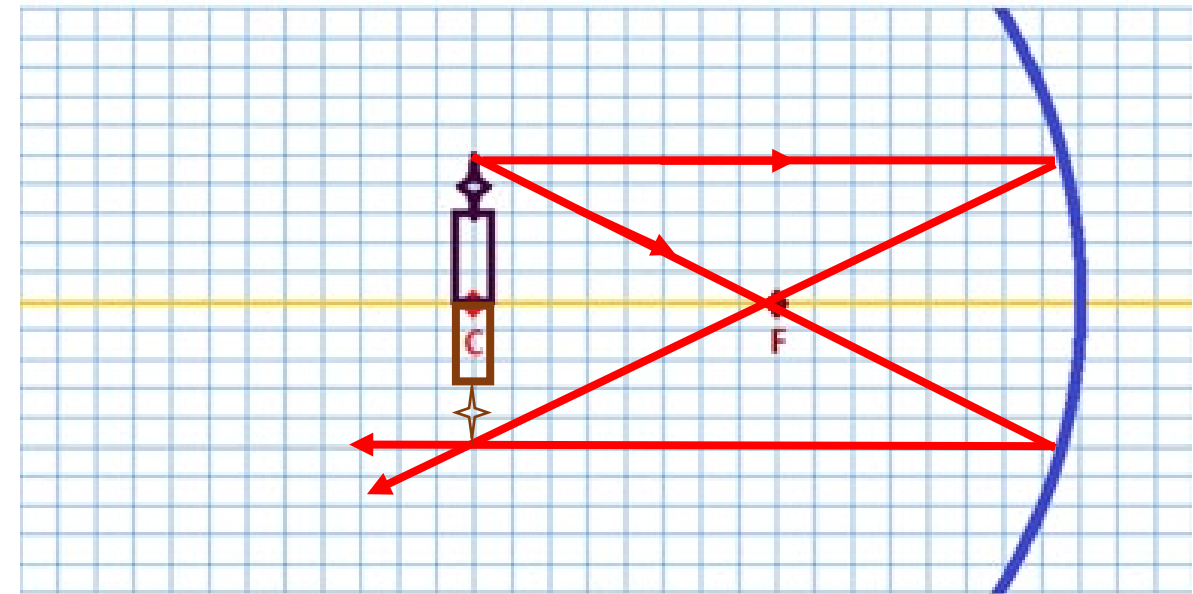
Real	OR	Virtual
Upright	OR	Inverted
Enlarged	OR	Reduced in size

Its real because there is an actual light rays converged together.

Real images are always inverted.

Same size as the object.

$x_0 = 2F$ The object is at the center



Concave mirrors

Draw a ray diagram to find the image of an object located between the focal length and twice the focal length of a concave mirror and determine the properties of the formed image.

Position 3: object located at a distance greater than the focal length and less than twice the focal length.

Ray 1: from the top of the object parallel to the principal axis.

This ray will reflect passing through the focal point.

Ray 2: from the top of the object passing through the focal point.

This ray will reflect parallel to the principal axis.

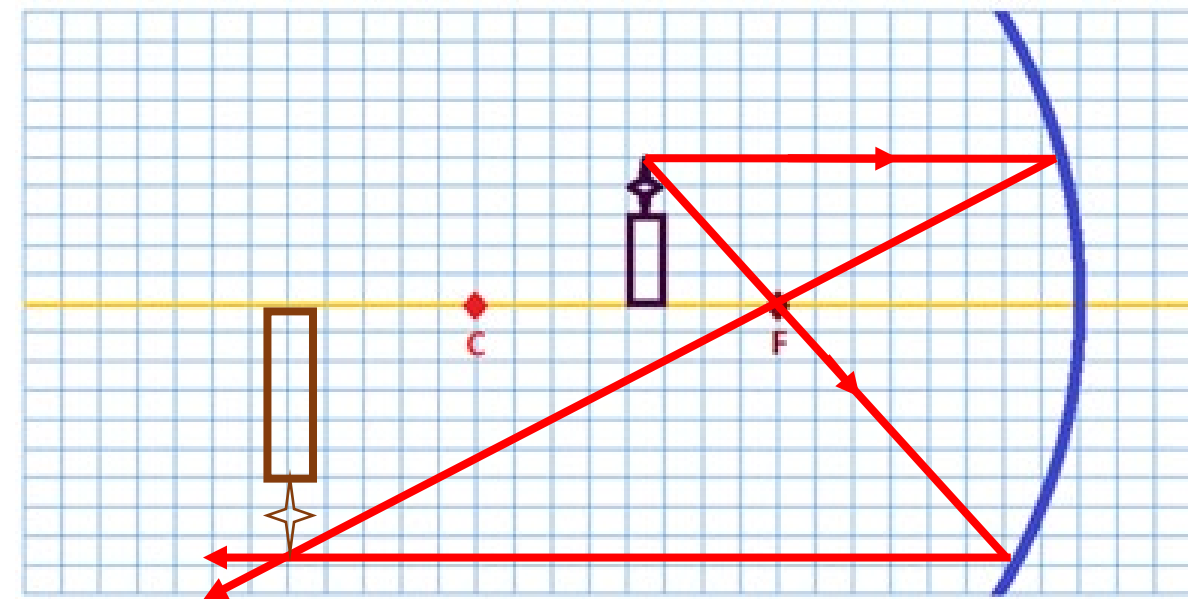
The point where the reflected rays converge represent the point where the light rays came from, use it to draw the object image.

Based on the diagram, What are the image properties:

Real	OR	Virtual
Upright	OR	Inverted
Enlarged	OR	Reduced in size

Its real because there is an actual light rays converged together.
Real images are always inverted.

$2F > x_0 > F$ the object is between the center and the focal





Concave mirrors

Describe that no image is formed when an object is placed at the focal point of a concave mirror.

Position 4: object located at the focal length.

Ray 1: from the top of the object parallel to the principal axis.

This ray will reflect passing through the focal point.

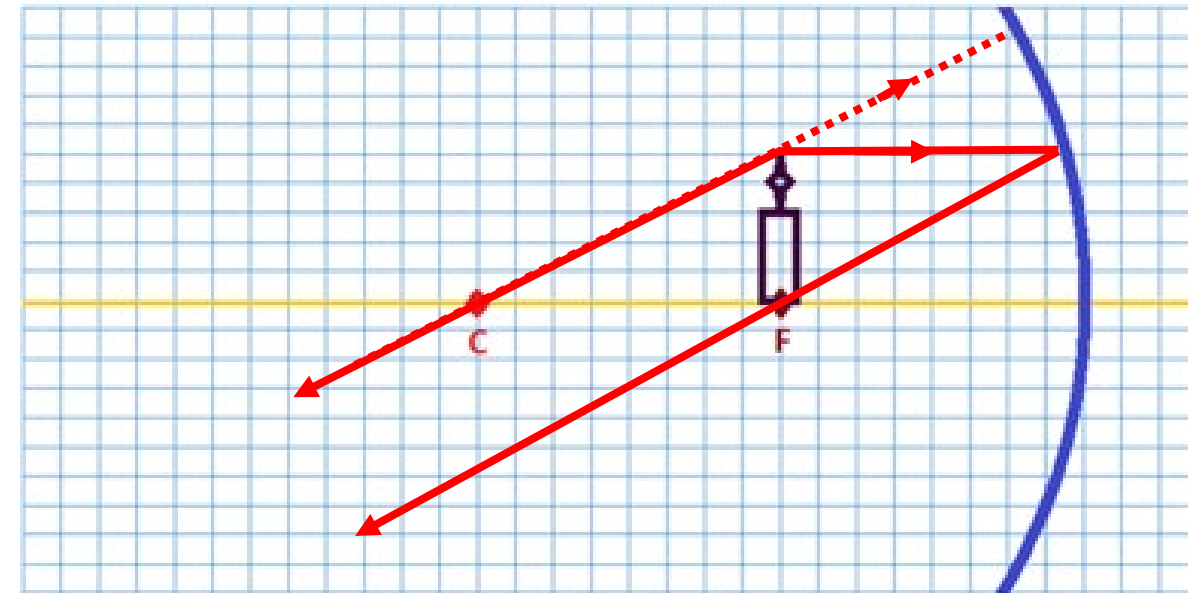
Ray 2: from the top of the object passing through geometrical center.

This ray will reflect-back on itself.

The reflected rays will not converge (light rays are parallel to each other)

No image formed.

$x_0 = F$ the object is at the focal



Concave mirrors

Draw a ray diagram to find the image of an object located at a distance smaller than the focal length of a concave mirror and determine the properties of the formed image.

Position 5: object located at a distance less than the focal length.

Ray 1: from the top of the object parallel to the principal axis.

This ray will reflect passing through the focal point.

Ray 2: from the top of the object passing through the focal point.

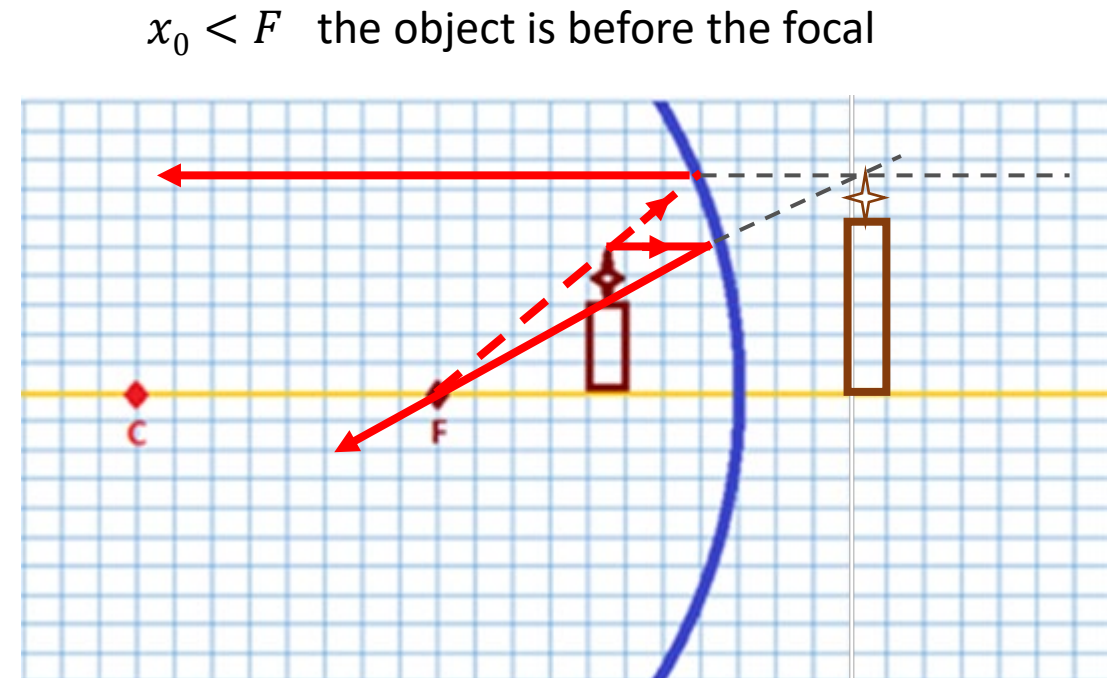
This ray will reflect parallel to the principal axis.

The two rays will not converge in front of the mirror, but if you extend the two rays behind the mirror the extended lines will converge. Then you can draw the image.

Based on the diagram, What are the image properties:

Real	OR	Virtual
Upright	OR	Inverted
Enlarged	OR	Reduced in size

It's virtual because there is no actual light rays converged together.



Ray Diagrams for Convex Mirrors:

In convex mirrors the object is always Infront of the mirror (one position) and the light rays always diverge.

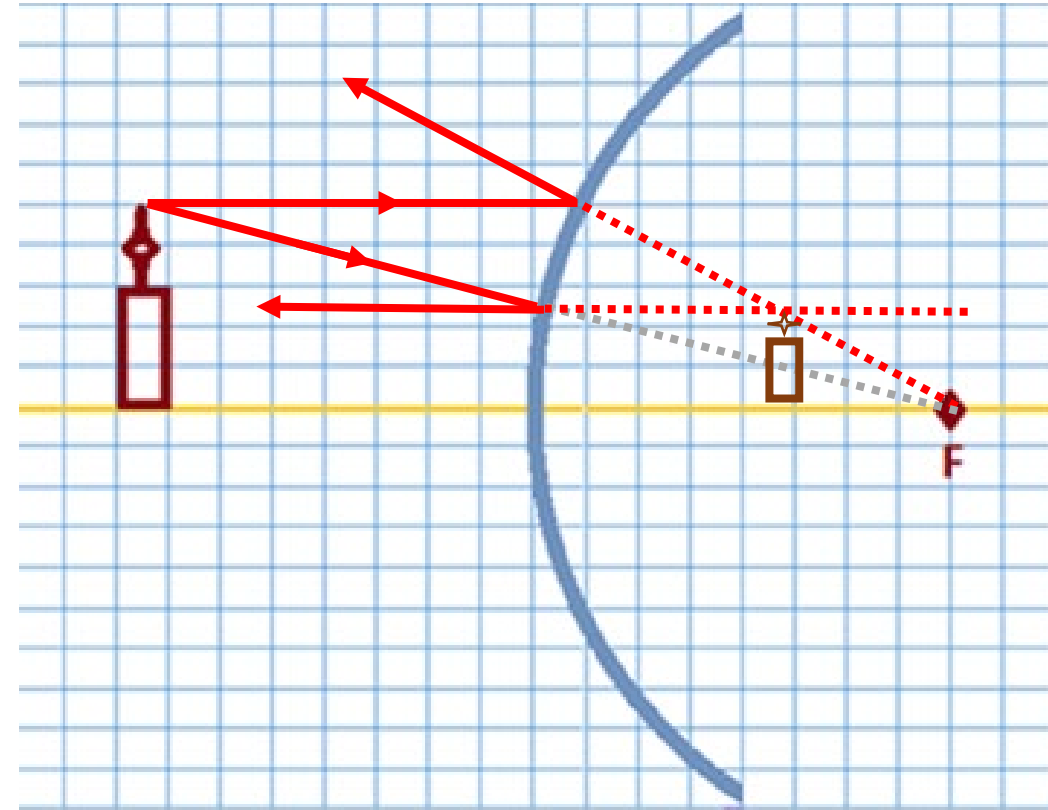
Ray 1: parallel to the principal axis.

This ray will reflect as if its coming from the focal point.

Ray 2: as if its passing through the focal point.

This ray will reflect parallel to the principal axis.

The tow rays will not converge Infront of the mirror, but if you extend the tow rays behind the mirror the extended lines will converge. Then you can draw the image.



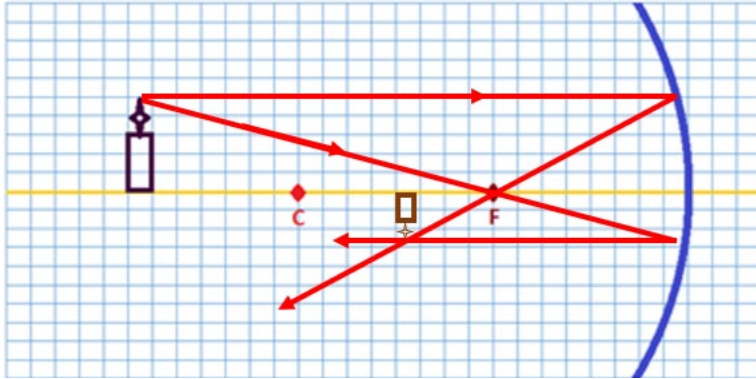
Based on the diagram, What are the image properties:

Real	OR	Virtual
Upright	OR	Inverted
Enlarged	OR	Reduced in size

Its virtual because there is no actual light rays converged together.

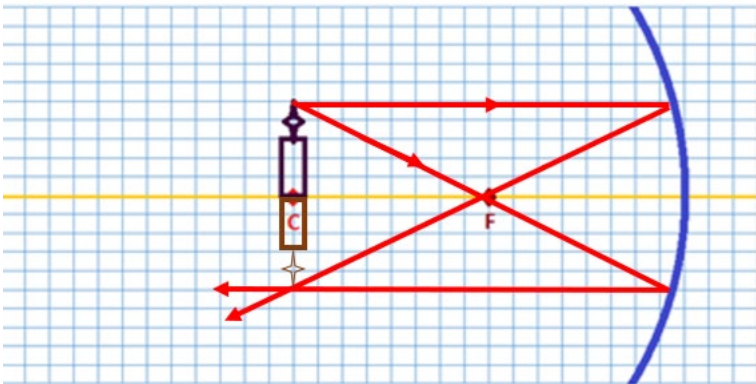


$x_0 > 2F$ The object is behind the center



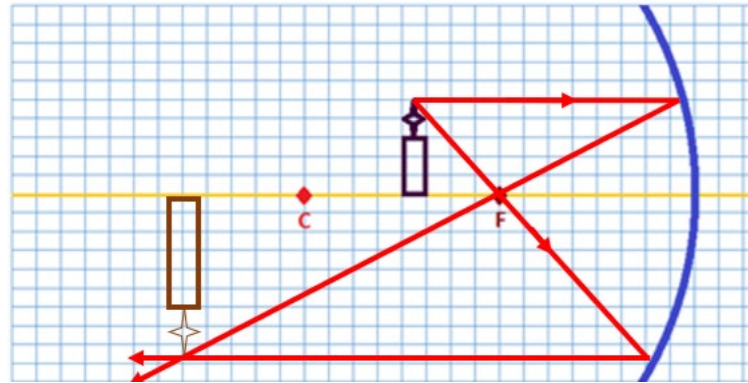
Real, inverted , reduced

$x_0 = 2F$ The object is at the center



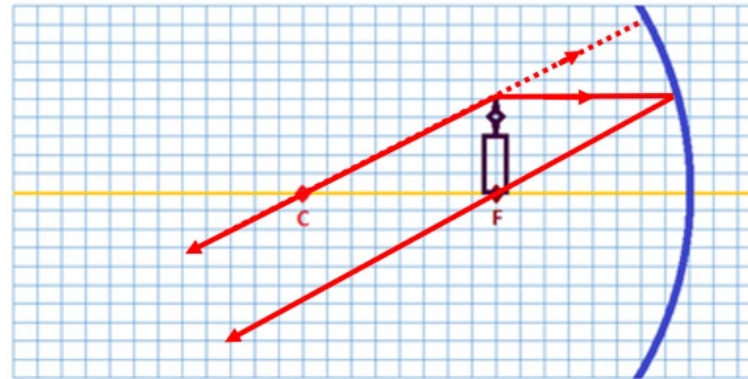
Real, inverted , Same size

$2F > x_0 > F$ the object is between the center and the focal



Real, inverted , Enlarged

$x_0 = F$ the object is at the focal



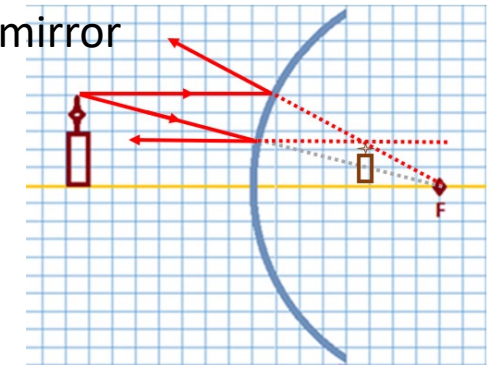
No image

$x_0 < F$ the object is before the focal



Virtual, Upright , Enlarged

convex mirror



Virtual, Upright , Reduced in size





Worksheet on LMS:

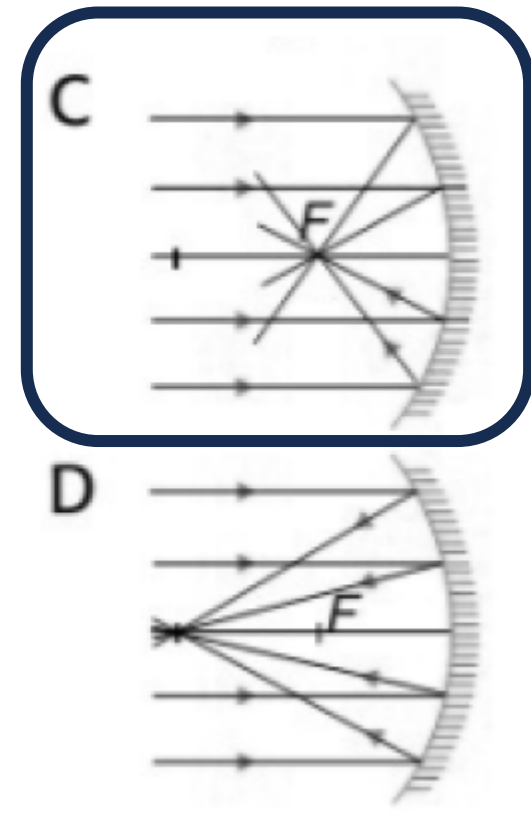
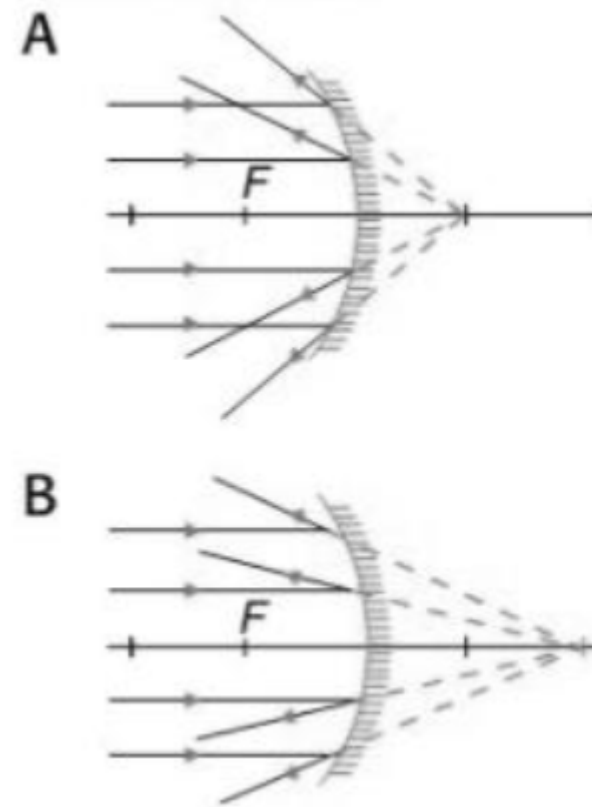
In which of the following mirrors are images always virtual and diminished?

- a. A convex mirror
- b. A plane mirror
- c. A concave mirror

4. How does the light ray travel along the principal axis of a concave mirror reflect?

This ray will reflect passing through the focal point.

3. Which of the following shows the reflection of light from a concave mirror?





Worksheet on LMS:

5. The focal length of a convex mirror is 10cm. What are the characteristics of the image of an object placed 20cm away from the mirror?

$x_o = 2F$ The object is at the center

Real, inverted, Same size

6. A concave mirror has a focal length of (f). An object is placed at a distance of (U) from the mirror. Which of the conditions below will form an image which is virtual, upright and enlarged and at infinity?

a) $U > 2F$ The object is behind the center

b) $U = 2F$ The object is at the center

c) $2F > U > F$ object is between the center and the focal

d) $U = F$ the object is at the focal

e) $U < F$ the object is before the focal





Worksheet on LMS:

10. Mirror X can be used to form a real or virtual image. X is a .

A concave mirror

11. Laterally inverted images are :

- a. Upright and virtual
- b. Upright and real
- c. Inverted and virtual
- ☒ d. Inverted and real

8. An object is placed 40cm from a concave mirror. The image formed is **inverted, real and same size** as the object. The focal length of the mirror is :

- a. < 20cm
- ☒ b. 20cm
- c. Between 20 cm and 40 cm
- d. 40 cm

An object is placed at a distance of 20cm in front of a concave mirror. A sharp image is formed on the **screen next to the object**. What is the focal length of the concave mirror?

- | | |
|--|---------|
| a. 5cm | c. 15cm |
| ☒ b. 10cm | d. 20cm |





Extra questions

1. Why is it impossible for a convex mirror to form a real image?

The light ray will always diverge

2. An object produces a virtual image in a concave mirror. Where is the object located?

Object must be located between F and the mirror.

3. What is the defect that all concave spherical mirrors have, and what causes it?

Rays parallel to the axis that strike the edges of a concave spherical mirror are not reflected through the focal point. This effect is called spherical aberration.

4. What is the relationship between the radius of curvature and the focal length of a concave mirror?

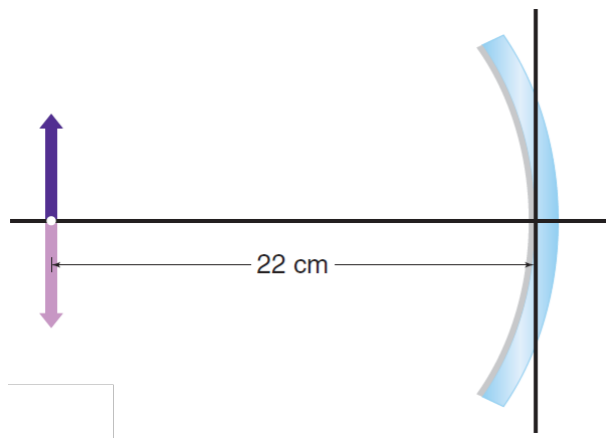
The radius of curvature is twice the focal length





Extra questions

8. Analyze and Conclude The object in the Figure is located **22 cm** from a concave mirror. What is the focal length of the mirror?



The object located at a distance equal to twice the focal length.

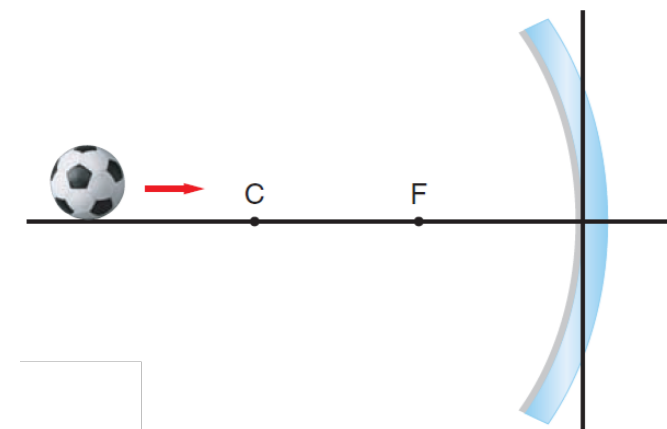
$$f = \frac{r}{2} = \frac{22}{2} = 11 \text{ cm}$$

9. Apply Concepts The ball in the Figure slowly rolls toward the concave mirror on the right. Describe how the size of the ball's image changes as it rolls along.

Beyond C, the image is smaller than the ball. As the ball rolls toward the mirror, the image size increases.

The image is the same size as the ball when the ball is at C.

The image size continues to increase until there is no image when the ball is at F. Past F, the size of the image decreases until it equals the ball's size when the ball touches the mirror.



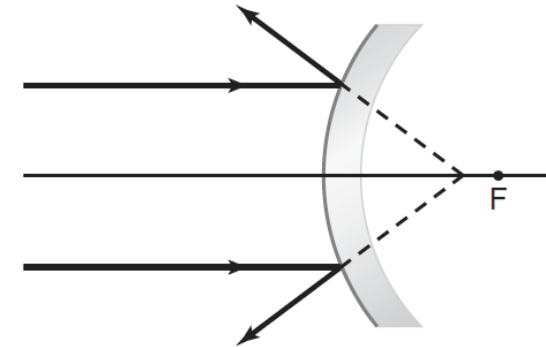


Extra questions

10. Where is the object located if the image that is produced by a concave mirror is smaller than the object?

- A. at the mirror's focal point
- B. between the mirror and the focal point
- C. between the focal point and center of curvature
- D. past the center of curvature**

11. The light rays in the illustration below do not properly focus at the focal point. This problem occurs with



- A. all spherical mirrors.**
- B. all parabolic mirrors.
- C. only defective spherical mirrors.
- D. only defective parabolic mirrors.



LO:

-Apply the mirror equation to calculate the image distance, the object distance, or the focal length of a spherical mirror using appropriate algebraic signs for focal length and corresponding distances

EX:

Example problem^{2,3}
Practice problems

P:

41,42



Calculating Image Position:

We can use the spherical mirror model to develop a simple equation for spherical mirrors.

You must use the paraxial ray approximation, which states that only rays that are close to and almost parallel with the principal axis are used to form an image.

Using this, in combination with the law of reflection, leads to the mirror equation, relating the focal length (f), object position (x_o), and image position (x_i) of a spherical mirror.

MIRROR EQUATION

The reciprocal of the focal length of a spherical mirror is equal to the sum of the reciprocals of the image position and the object position.

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

f : focal length

x_i : image position

x_o : object position

(−) for convex mirror

(+) for concave mirror

When virtual images are formed, the image position (x_i) has a negative value, indicating that it is located behind the mirror.





Calculating Image Position:

Magnification (m), which is the ratio of the image height to the object height. By using similar-triangle geometry, you can also rewrite this ratio in terms of image and object positions.

MAGNIFICATION

The magnification of an object by a spherical mirror, defined as the image height divided by the object height, is equal to the negative of the image position, divided by the object position.

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

m : magnification

h_i : image height

h_o : object height

(m) has a negative value, indicating that the image is inverted.

($m > 1$) Image larger than object (enlarged)

($m = 1$) Image is the same size as the object

($m < 1$) Image smaller than object (reduced)



**EXAMPLE PROBLEM 2** (page 41)

REAL IMAGE FORMATION BY A CONCAVE MIRROR A concave mirror has a radius of curvature of **20.0 cm**. You place a **2.0 cm** tall object **30.0 cm** from the mirror. What are the image position and image height?

$$f = \frac{r}{2} = \frac{20}{2} = 10 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{10} = \frac{1}{x_i} + \frac{1}{30}$$

$$\frac{1}{x_i} = \frac{1}{10} - \frac{1}{30}$$

$$\frac{1}{x_i} = \frac{3}{30} - \frac{1}{30}$$

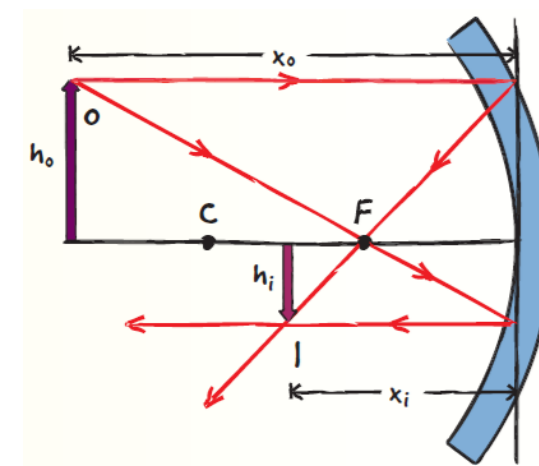
$$\frac{1}{x_i} = \frac{2}{30}$$

$$x_i = \frac{30}{2} = 15 \text{ cm}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{h_i}{2} = -\frac{15}{30}$$

$$h_i = -\frac{(15)(2)}{30} = -1 \text{ cm} \quad \text{inverted, and real}$$



**EXAMPLE PROBLEM 3** (page 42)

IMAGE IN A SECURITY MIRROR A **convex** security mirror in a warehouse has a **-0.50 m** focal length. A **2.0 m** tall forklift is **5.0 m** from the mirror. What are the image position and image height?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{-0.5} = \frac{1}{x_i} + \frac{1}{5}$$

$$\frac{1}{x_i} = -\frac{1}{0.5} - \frac{1}{5}$$

$$\frac{1}{x_i} = -\frac{10}{5} - \frac{1}{5}$$

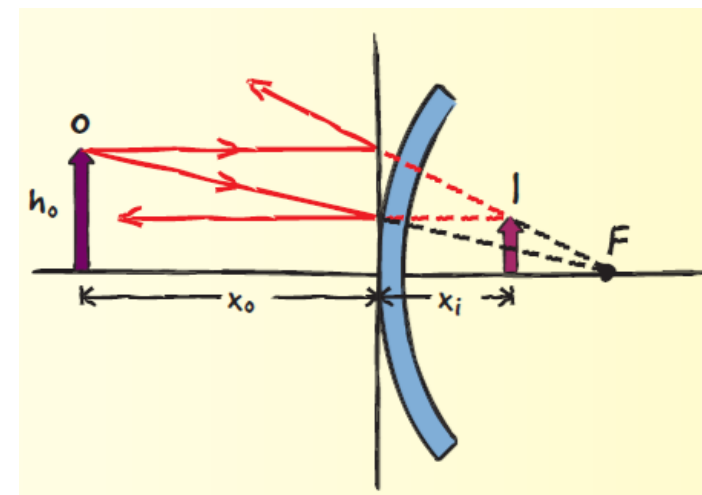
$$\frac{1}{x_i} = -\frac{11}{5}$$

$$x_i = -\frac{5}{11} = -0.45 \text{ cm}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{h_i}{2} = -\frac{-0.45}{5}$$

$$h_i = \frac{(0.45)(2)}{5} = 0.18 \text{ cm}$$

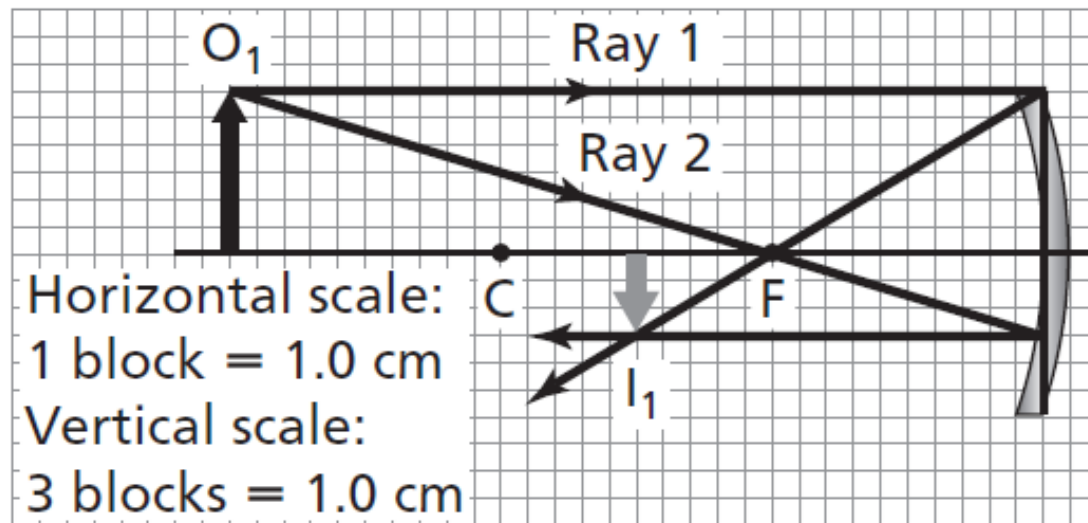


Upright, smaller, virtual



**PRACTICE PROBLEMS** (page 41)

12. Use a ray diagram, drawn to scale, to solve Example Problem 2.



13. You place an object **36.0 cm** in front of a **concave** mirror with a **16.0 cm** focal length. Determine the image position.

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{16} = \frac{1}{x_i} + \frac{1}{36}$$

$$\frac{1}{x_i} = \frac{1}{16} - \frac{1}{36}$$

$$\frac{1}{x_i} = \frac{36}{576} - \frac{16}{576}$$

$$\frac{1}{x_i} = \frac{20}{576}$$

$$x_i = \frac{576}{20} = 28.7 \text{ cm}$$



**PRACTICE PROBLEMS** (page 41)

14. You place a 3.0 cm tall object 20.0 cm from a 16.0 cm radius concave mirror. Determine the image position and image height.

$$f = \frac{r}{2} = \frac{16}{2} = 8 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{8} = \frac{1}{x_i} + \frac{1}{20}$$

$$\frac{1}{x_i} = \frac{1}{8} - \frac{1}{20}$$

$$\frac{1}{x_i} = \frac{5}{40} - \frac{2}{40}$$

$$\frac{1}{x_i} = \frac{3}{40}$$

$$x_i = \frac{40}{3} = 13.3 \text{ cm}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{h_i}{3} = -\frac{13.3}{20}$$

$$h_i = -\frac{(13.3)(3)}{20} = -1.995 \text{ cm}$$



**PRACTICE PROBLEMS** (page 41)

15. A **concave** mirror has a **7.0 cm** focal length. You place a **2.4 cm** tall object **16.0 cm** from the mirror. Determine the image height.

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{7} = \frac{1}{x_i} + \frac{1}{16}$$

$$\frac{1}{x_i} = \frac{1}{7} - \frac{1}{16}$$

$$\frac{1}{x_i} = \frac{16}{112} - \frac{7}{112}$$

$$\frac{1}{x_i} = \frac{9}{112}$$

$$x_i = \frac{112}{9} = 12.4 \text{ cm}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{h_i}{2.4} = -\frac{12.4}{16}$$

$$h_i = -\frac{(12.4)(2.4)}{16} = -1.86 \text{ cm}$$



**PRACTICE PROBLEMS** (page 41)

16. CHALLENGE You place an object near a **Concave** mirror with a **10.0 cm** focal length. The image is **3.0 cm** tall, **inverted**, and **16.0 cm** from the mirror. What are the object position and object height?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{10} = \frac{1}{16} + \frac{1}{x_o}$$

$$\frac{1}{x_o} = \frac{1}{10} - \frac{1}{16}$$

$$\frac{1}{x_o} = \frac{16}{160} - \frac{10}{160}$$

$$\frac{1}{x_o} = \frac{6}{160}$$

$$x_o = \frac{160}{6} = 26.7 \text{ cm}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{-3}{h_o} = -\frac{16}{26.7}$$

$$\frac{h_o}{3} = \frac{26.7}{16}$$

$$h_i = \frac{(26.7)(3)}{16} = 5 \text{ cm}$$

(h_i) has a negative value, indicating that the image is inverted, and real.



PRACTICE PROBLEMS (page 42)

17. You place an object **20.0 cm** in front of a **convex** mirror with a **-15.0 cm** focal length. Find the image position using both a scale diagram and the mirror equation.

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

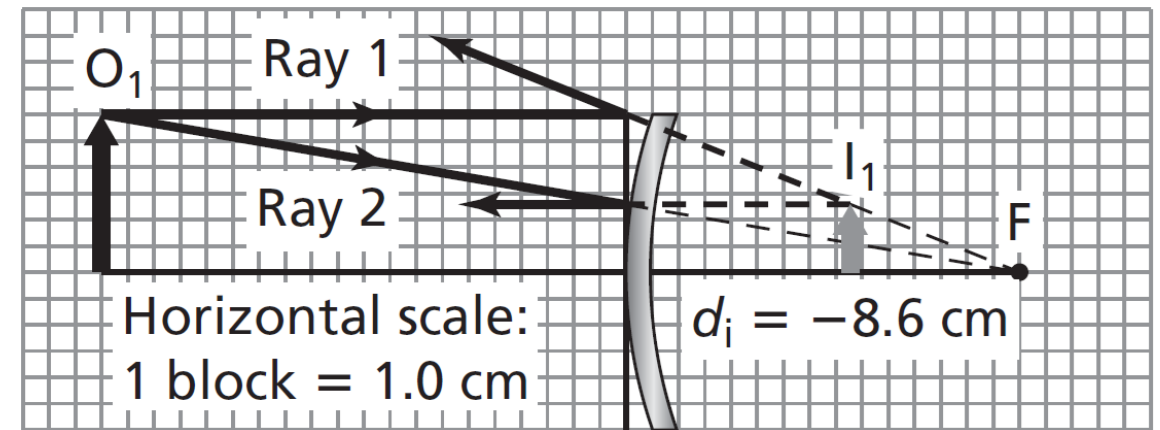
$$\frac{1}{-15} = \frac{1}{x_i} + \frac{1}{20}$$

$$\frac{1}{x_i} = -\frac{1}{15} - \frac{1}{20}$$

$$\frac{1}{x_i} = -\frac{4}{60} - \frac{3}{60}$$

$$\frac{1}{x_i} = -\frac{7}{60}$$

$$x_i = -\frac{60}{7} = -8.571 \text{ cm}$$



**PRACTICE PROBLEMS** (page 42)

18. A **convex** mirror has a focal length of **-13.0 cm**. You place a **6.0 cm** diameter lightbulb **60.0 cm** from that mirror. What is the lightbulb's image position and diameter?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{-13} = \frac{1}{x_i} + \frac{1}{60}$$

$$\frac{1}{x_i} = -\frac{1}{13} - \frac{1}{60}$$

$$\frac{1}{x_i} = -\frac{60}{780} - \frac{13}{780}$$

$$\frac{1}{x_i} = -\frac{73}{780}$$

$$x_i = -\frac{780}{73} = -10.68 \text{ cm}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{h_i}{6} = -\frac{-10.68}{60}$$

$$h_i = \frac{(10.68)(6)}{60} = 1.068 \text{ cm}$$



**PRACTICE PROBLEMS** (page42)

19. A 7.6 cm diameter ball is located 22.0 cm from a convex mirror with a radius of curvature of 60.0 cm. What are the ball's image position and diameter?

$$f = \frac{r}{2} = \frac{60}{2} = 30 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{-30} = \frac{1}{x_i} + \frac{1}{22}$$

$$\frac{1}{x_i} = -\frac{1}{30} - \frac{1}{22}$$

$$\frac{1}{x_i} = -\frac{22}{660} - \frac{30}{660}$$

$$\frac{1}{x_i} = -\frac{52}{660}$$

$$x_i = -\frac{660}{52} = -12.7 \text{ cm}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{h_i}{7.6} = -\frac{-12.7}{22}$$

$$h_i = \frac{(12.7)(7.6)}{22} = 4.4 \text{ cm}$$



**PRACTICE PROBLEMS** (page 42)

20. A 1.8 m tall girl stands 2.4 m from a store's security mirror. Her image appears to be 0.36 m tall.

a. What is the image's distance?

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{0.36}{1.8} = -\frac{x_i}{2.4}$$

$$x_i = -\frac{(0.36)(2.4)}{1.8} = -0.48 \text{ cm}$$

b. What is the focal length of the mirror?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{f} = -\frac{1}{0.48} + \frac{1}{2.4}$$

$$\frac{1}{f} = -\frac{2.4}{1.152} + \frac{0.48}{1.152}$$

$$\frac{1}{f} = -\frac{1.92}{1.152}$$

$$f = -\frac{1.152}{1.92} = -0.6 \text{ cm}$$



**PRACTICE PROBLEMS** (page 42)

21. CHALLENGE A **convex** mirror is needed to produce an image that is **three-fourths** the size of an object and located **24 cm** behind the mirror.

a. What is the object's distance?

$$m = -\frac{x_i}{x_o}$$

$$\frac{3}{4} = -\frac{-24}{x_o}$$

$$x_o = \frac{(4)(24)}{3} = 32 \text{ cm}$$

b. What focal length should be specified?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{f} = -\frac{1}{24} + \frac{1}{32}$$

$$\frac{1}{f} = -\frac{32}{768} + \frac{24}{768}$$

$$\frac{1}{f} = -\frac{8}{768}$$

$$f = -\frac{768}{8} = -96 \text{ cm}$$



Check Your Progress (page 43)

22. Image Properties If you know the focal length of a concave mirror, where should you place an object so that its image is upright and larger compared to the object? Will this produce a real or virtual image?

You should place the object between the mirror and the focal point. The image will be virtual.

23. Magnification You place an object **20.0 cm** in front of a **concave** mirror with a focal length of **9.0 cm**. What is the magnification of the image?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{9} = \frac{1}{x_i} + \frac{1}{20}$$

$$\frac{1}{x_i} = \frac{1}{9} - \frac{1}{20}$$

$$\frac{1}{x_i} = \frac{20}{180} - \frac{9}{180}$$

$$\frac{1}{x_i} = \frac{11}{180}$$

$$x_i = \frac{180}{11} = 16.36 \text{ cm}$$

$$m = -\frac{x_i}{x_o}$$

$$m = -\frac{16.36}{20} = -0.818$$



Check Your Progress (page43)

24. Object Position The placement of an object in front of a **concave** mirror with a focal length of **12.0 cm** forms a real image that is **22.3 cm** from the mirror. What is the object position?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{x_o} = \frac{22.3}{267.6} - \frac{12}{267.6}$$

$$\frac{1}{12} = \frac{1}{22.3} + \frac{1}{x_o}$$

$$\frac{1}{x_o} = \frac{10.3}{267.6}$$

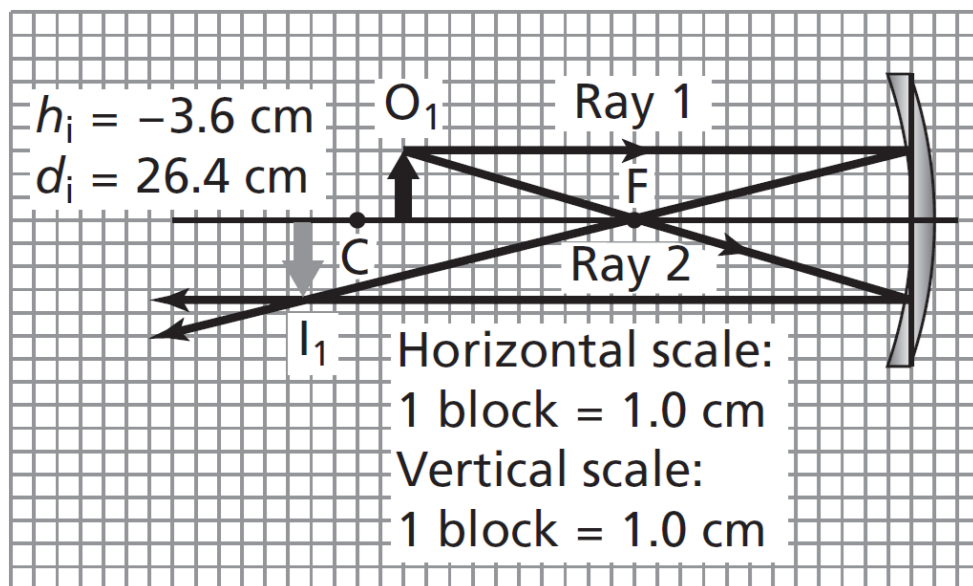
$$\frac{1}{x_o} = \frac{1}{12} - \frac{1}{22.3}$$

$$x_o = \frac{267.6}{10.3} = 26 \text{ cm}$$



Check Your Progress (page 43)

25. Image Position and Height You place a **3.0 cm** tall object **22.0 cm** in front of a **concave** mirror that has a focal length of **12.0 cm**. Find the image position and height by drawing a ray diagram to scale. Verify your answer using the mirror and magnification equations.



$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{12} = \frac{1}{x_i} + \frac{1}{22}$$

$$\frac{1}{x_i} = \frac{1}{12} - \frac{1}{22}$$

$$\frac{1}{x_i} = \frac{22}{264} - \frac{12}{264}$$

$$\frac{1}{x_i} = \frac{10}{264} \Rightarrow x_i = \frac{264}{10} = 26.4 \text{ cm}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

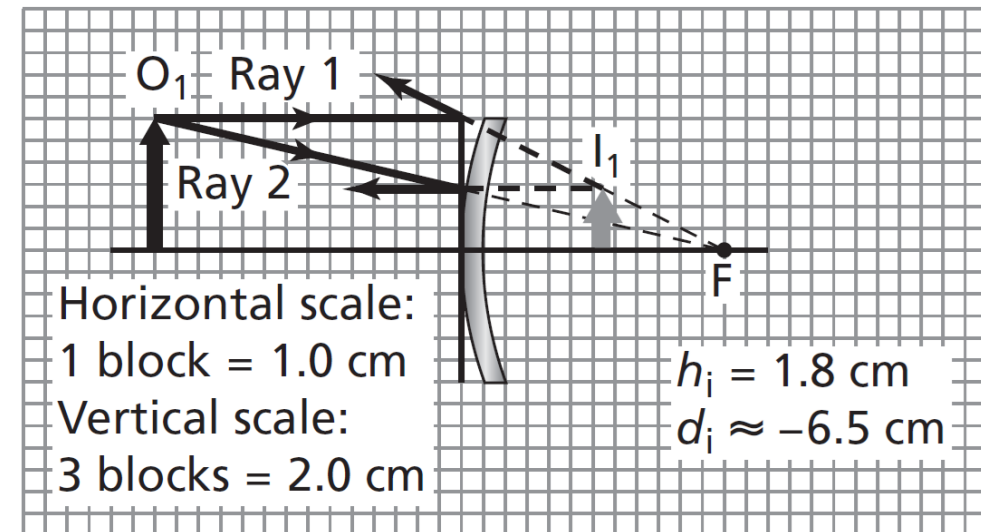
$$\frac{h_i}{3} = -\frac{26.4}{22}$$

$$h_i = -\frac{(26.4)(3)}{22} = -3.6 \text{ cm}$$



Check Your Progress (page 43)

26. Ray Diagram You place a **4.0 cm** tall object **14.0 cm** from a **convex** mirror with a focal length of **-12.0 cm**. Draw a scale ray diagram showing the image position and height. Verify your answer using the mirror and magnification equations.



$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{-12} = \frac{1}{x_i} + \frac{1}{14}$$

$$\frac{1}{x_i} = -\frac{1}{12} - \frac{1}{14}$$

$$\frac{1}{x_i} = -\frac{14}{168} - \frac{12}{168}$$

$$\frac{1}{x_i} = -\frac{26}{168} \Rightarrow x_i = -\frac{168}{26} = -6.46 \text{ cm}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{h_i}{4} = -\frac{-6.46}{14}$$

$$h_i = \frac{(6.46)(4)}{14} = 1.86 \text{ cm}$$

Check Your Progress (page 43)

27. Radius of Curvature You place a 6.0 cm tall object 16.4 cm from a convex mirror. If the image of the object is 2.8 cm tall, what is the mirror's radius of curvature?

$$\frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{2.8}{6} = -\frac{x_i}{16.4}$$

$$x_i = -\frac{(2.8)(16.4)}{6} = -7.7 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{f} = -\frac{1}{7.7} + \frac{1}{16.4}$$

$$\frac{1}{f} = -\frac{16.4}{126.28} + \frac{7.7}{126.28}$$

$$\frac{1}{f} = -\frac{8.7}{126.28}$$

$$f = -\frac{126.28}{8.7}$$

$$f = -14.5 \text{ cm}$$

$$r = 2f$$

$$r = 2(14.5) = 29 \text{ cm}$$



Check Your Progress (page 43)

28. Focal Length A **convex** mirror is used to produce an image that is **two-thirds** the size of an object and located **12 cm** behind the mirror. What is the focal length of the mirror?

$$m = -\frac{x_i}{x_o}$$

$$\frac{2}{3} = -\frac{-12}{x_o}$$

$$x_o = \frac{(12)(3)}{2} = 18 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{f} = \frac{1}{-12} + \frac{1}{18}$$

$$\frac{1}{f} = -\frac{3}{36} + \frac{2}{36} = -\frac{1}{36}$$

$$f = -\frac{36}{1} = -36 \text{ cm}$$

29. Critical Thinking Would spherical aberration be less for a mirror whose height, compared to its radius of curvature, is small or large? Explain.

It would be less for a mirror whose height is relatively small compared to its radius of curvature; diverging light rays from an object that strike the mirror are more paraxial so they converge more closely to create an image that is not blurred.



**Extra questions**

5. A **convex** mirror is needed to produce an image one **half the size** of an object and located **36 cm** behind the mirror. What focal length should the mirror have?

$$m = -\frac{x_i}{x_o}$$

$$\frac{1}{2} = -\frac{-36}{x_o}$$

$$x_o = \frac{(2)(36)}{1} = 72 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{f} = \frac{1}{-36} + \frac{1}{72}$$

$$\frac{1}{f} = -\frac{2}{72} + \frac{1}{72} = -\frac{1}{72}$$

$$f = -\frac{72}{1} = -72 \text{ cm}$$



**Extra questions**

6. A dentist uses a small mirror with a radius of curvature of 40 mm to locate a cavity in a patient's tooth. If the mirror is concave and is held 16 mm from the tooth, what is the magnification of the image?

$$f = \frac{r}{2} = \frac{40}{2} = 20 \text{ mm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{20} = \frac{1}{x_i} + \frac{1}{16}$$

$$\frac{1}{x_i} = \frac{1}{20} - \frac{1}{16}$$

$$\frac{1}{x_i} = \frac{16}{320} - \frac{20}{320}$$

$$\frac{1}{x_i} = -\frac{4}{320}$$

$$x_i = -\frac{320}{4} = -80 \text{ mm}$$

$$m = -\frac{x_i}{x_o}$$

$$m = -\frac{-80}{16} = 5$$



**Extra questions**

7. Challenge A ball is positioned **22 cm** in front of a spherical mirror and forms a **virtual** image. If the spherical mirror is replaced with a plane mirror, the image appears **12 cm** closer to the mirror. What kind of spherical mirror was used?

The object position for both mirrors is 22 cm. So, the image position for the plane mirror is 22 cm.

Because the spherical mirror forms a virtual image, the image is located behind the mirror.

Thus, the image position for the spherical mirror is negative.

$$x_{o-sph} = x_{o-plan} - 12$$

$$x_{o-sph} = -22 - 12 = -34 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{f} = \frac{1}{-34} + \frac{1}{22}$$

$$\frac{1}{f} = -\frac{22}{748} + \frac{34}{748}$$

$$\frac{1}{f} = \frac{12}{704}$$

$$f = \frac{748}{12} = -62 \text{ cm}$$

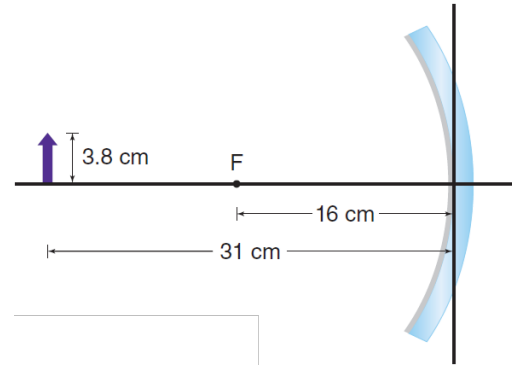
The focal length is positive, so the spherical mirror is a concave mirror.





Extra questions

8. Find the image position and height for the object shown in the figure.



$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{x_i} = \frac{15}{496}$$

$$\frac{1}{16} = \frac{1}{x_i} + \frac{1}{31}$$

$$x_i = \frac{496}{15} = 33.6 \text{ cm}$$

$$\frac{1}{x_i} = \frac{1}{16} - \frac{1}{31}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{1}{x_i} = \frac{31}{496} - \frac{16}{496}$$

$$\frac{h_i}{3.8} = -\frac{33.6}{31}$$

$$h_i = -\frac{(33.6)(3.8)}{31} = -4.1 \text{ cm}$$

9. A jeweler inspects a watch with a diameter of 3.0 cm by placing it 8.0 cm in front of a concave mirror of 12.0 cm focal length. Where is the watch's image? What is the image's diameter?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{x_i} = -\frac{1}{24}$$

$$\frac{1}{12} = \frac{1}{x_i} + \frac{1}{8}$$

$$x_i = -\frac{24}{1} = -24 \text{ cm}$$

$$\frac{1}{x_i} = \frac{1}{12} - \frac{1}{8}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{1}{x_i} = \frac{2}{24} - \frac{3}{24}$$

$$\frac{h_i}{3} = -\frac{-24}{8}$$

$$h_i = 9 \text{ cm}$$



**Extra questions**

10. You place an object 30.0 cm from a concave mirror of 15.0 cm focal length. The object is 1.8 cm tall. Use the mirror equation to find the image position. What is the image height?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{15} = \frac{1}{x_i} + \frac{1}{30}$$

$$\frac{1}{x_i} = \frac{1}{15} - \frac{1}{30}$$

$$\frac{1}{x_i} = \frac{2}{30} - \frac{1}{30}$$

$$\frac{1}{x_i} = \frac{1}{30}$$

$$x_i = \frac{30}{1} = 30 \text{ cm}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{h_i}{1.8} = -\frac{30}{30}$$

$$h_i = -\frac{(30)(1.8)}{30} = -1.8 \text{ cm}$$



**Extra questions**

11. You place a 3.0 cm tall object 22.4 cm from a concave mirror. If the mirror has a radius of curvature of 34.0 cm, what are the image position and height?

$$f = \frac{r}{2} = \frac{34}{2} = 17 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{17} = \frac{1}{x_i} + \frac{1}{22.4}$$

$$\frac{1}{x_i} = \frac{1}{17} - \frac{1}{22.4}$$

$$\frac{1}{x_i} = \frac{22.4}{380.8} - \frac{17}{380.8}$$

$$\frac{1}{x_i} = \frac{5.4}{380.8}$$

$$x_i = \frac{380.8}{5.4} = 70.5 \text{ cm}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{h_i}{3} = -\frac{70.5}{22.4}$$

$$h_i = -\frac{(70.5)(3)}{22.4} = -9.44 \text{ cm}$$



**Extra questions**

12. Shiny spheres that are placed on pedestals on a lawn are **convex** mirrors. One such sphere has a diameter of **40.0 cm**. A **12 cm** tall robin sits in a tree that is **1.5 m** from the sphere. Where is the image of the robin, and how tall is the image?

$$f = \frac{r}{2} = \frac{(40 \div 2)}{2} = 10 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{-10} = \frac{1}{x_i} + \frac{1}{150}$$

$$\frac{1}{x_i} = -\frac{1}{10} - \frac{1}{150}$$

$$\frac{1}{x_i} = -\frac{15}{150} - \frac{1}{150}$$

$$\frac{1}{x_i} = -\frac{16}{150}$$

$$x_i = -\frac{150}{16} = -9.4 \text{ cm}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{h_i}{12} = -\frac{-9.4}{150}$$

$$h_i = \frac{(9.4)(12)}{150} = 0.75 \text{ cm}$$



**Extra questions**

13. A **concave** mirror has a radius of curvature of **26.0 cm**. An object that is **2.4 cm** tall is placed **30.0 cm** from the mirror. Where is the image position? What is the image height?

$$f = \frac{r}{2} = \frac{(26)}{2} = 13 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{13} = \frac{1}{x_i} + \frac{1}{30}$$

$$\frac{1}{x_i} = -\frac{1}{13} - \frac{1}{30}$$

$$\frac{1}{x_i} = \frac{30}{390} - \frac{13}{390}$$

$$\frac{1}{x_i} = \frac{17}{390}$$

$$x_i = \frac{390}{17} = 22.9 \text{ cm}$$

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{h_i}{2.4} = -\frac{22.9}{30}$$

$$h_i = -\frac{(2.4)(22.9)}{30} = -1.83 \text{ cm}$$



**Extra questions**

14. What is the radius of curvature of a **concave** mirror that magnifies an object by a **factor of +3.2** when the object is placed **20.0 cm** from the mirror?

$$m = -\frac{x_i}{x_o}$$

$$3.2 = -\frac{x_i}{20}$$

$$x_i = -(3.2)(20) = -64 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{f} = \frac{1}{-64} + \frac{1}{20}$$

$$\frac{1}{f} = -\frac{20}{1280} + \frac{64}{1280} = \frac{44}{1280}$$

$$f = \frac{1280}{44} = 29 \text{ cm}$$

$$r = 2f$$

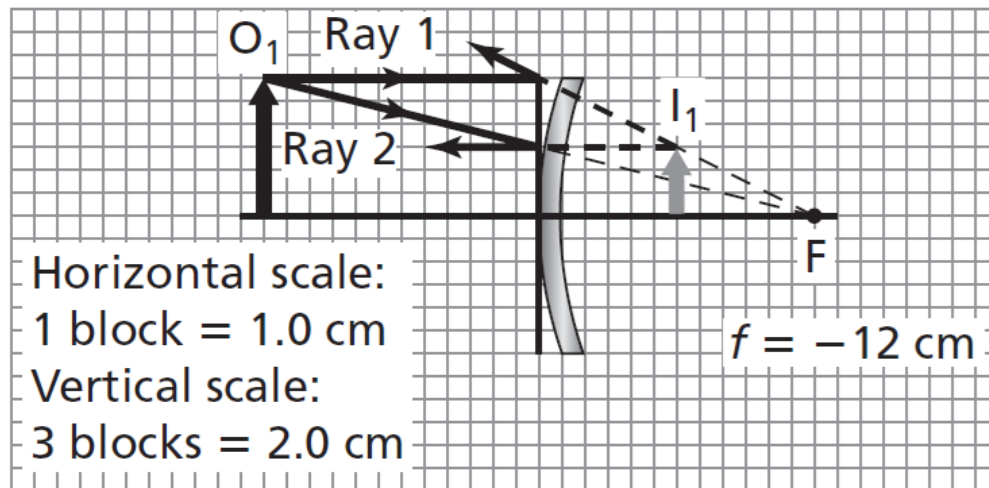
$$r = 2(29) = 58 \text{ cm}$$





Extra questions

15. A 4.0 cm tall object is placed 12.0 cm from a convex mirror. If the image of the object is 2.0 cm tall and the image is located at -6.0 cm, what is the focal length of the mirror? Draw a ray diagram to answer the question. Use the mirror equation and to verify your answer.



$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{f} = \frac{1}{-6} + \frac{1}{12}$$

$$\frac{1}{f} = -\frac{2}{12} + \frac{1}{12}$$

$$\frac{1}{f} = -\frac{1}{12}$$

$$f = -\frac{12}{1} = -12 \text{ cm}$$



**Extra questions**

16. A convenience store uses a surveillance mirror to monitor the store's aisles. Each mirror has a radius of curvature of **3.8 m**.

a. What is the image position of a customer who stands **6.5 m** in front of the mirror?

$$f = \frac{r}{2} = \frac{-3.8}{2} = -1.9 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{-1.9} = \frac{1}{x_i} + \frac{1}{6.5}$$

$$\frac{1}{x_i} = -\frac{1}{1.9} - \frac{1}{6.5}$$

$$\frac{1}{x_i} = -\frac{6.5}{12.35} - \frac{1.9}{12.35}$$

$$\frac{1}{x_i} = -\frac{8.4}{12.35}$$

$$x_i = -\frac{12.35}{8.4} = -1.47 \text{ cm}$$

b. What is the image height of a customer who is **1.7 m** tall?

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{h_i}{1.7} = -\frac{-1.47}{6.5}$$

$$h_i = \frac{(1.7)(1.47)}{6.5} = 0.38 \text{ cm}$$



**Extra questions**

17. A production-line inspector wants a mirror that produces an image that is **upright** with a magnification of **7.5** when it is located **14.0 mm** from a machine part.

a. What kind of mirror would do this job?

An enlarged, upright image results only from a concave mirror, with the object inside the focal length.

b. What is its radius of curvature?

$$m = -\frac{x_i}{x_o}$$

$$7.5 = -\frac{x_i}{14}$$

$$x_i = -(7.5)(14) = -105 \text{ mm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{f} = \frac{1}{-105} + \frac{1}{14} = \frac{91}{1470}$$

$$f = 16 \text{ mm}$$

$$r = 2f = 32 \text{ mm}$$



**Extra questions**

18. A 1.6 m tall girl stands 3.2 m from a convex mirror. What is the focal length of the mirror if her image appears to be 0.28 m tall?

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{0.28}{1.6} = -\frac{x_i}{3.2}$$

$$x_i = -\frac{(0.28)(3.2)}{1.6} = -0.56 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{f} = \frac{1}{-0.56} + \frac{1}{3.2}$$

$$\frac{1}{f} = -\frac{3.2}{1.792} + \frac{0.56}{1.792}$$

$$\frac{1}{f} = -\frac{2.64}{1.792}$$

$$f = \frac{1.792}{2.64} = -0.68 \text{ cm}$$





Extra questions

19. A **convex** mirror is used to produce an image that is **three-fourths** the size of an object and located **8.4 cm** behind the mirror. What is the focal length of the mirror?

A. -34 cm

B. -11 cm

C. -6.3 cm

D. -4.8 cm

$$m = -\frac{x_i}{x_o}$$

$$\frac{3}{4} = -\frac{-8.4}{x_o}$$

$$x_o = \frac{(8.4)(4)}{3}$$

$$x_o = 11.2 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{f} = \frac{1}{-8.4} + \frac{1}{11.2}$$

$$\frac{1}{f} = -\frac{11.2}{94} + \frac{8.4}{94}$$

$$f = -\frac{94}{2.8} = -33.57 \text{ cm}$$

20. A **concave** mirror produces an **inverted** image that is **8.5 cm** tall, located **34.5 cm** in front of the mirror. If the focal point of the mirror is **24.0 cm**, then what is the height of the object?

A. 2.3 cm

B. 3.5 cm

C. 14 cm

D. 19 cm

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{24} = \frac{1}{34.5} + \frac{1}{x_o}$$

$$\frac{1}{x_o} = \frac{1}{24} - \frac{1}{34.5}$$

$$x_o = \frac{828}{10.5} = 78.9 \text{ cm}$$

$$\frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$\frac{8.5}{h_o} = -\frac{34.5}{78.9}$$

$$h_o = -\frac{(8.5)(78.9)}{34.5}$$

$$x_o = -19.9 \text{ cm}$$





Extra questions

21. A cup sits 17 cm from a concave mirror. The image of the cup appears 34 cm in front of the mirror. What are the magnification and orientation of the cup's image?

A. 0.5, inverted

B. 0.5, upright

C. 2.0, inverted

D. 2.0, upright

$$m = -\frac{x_i}{x_o}$$

$$m = -\frac{34}{17} = -2 \text{ cm}$$

22. What is the focal length of a concave mirror that magnifies, by a factor of +3.2, an object that is placed 30 cm from the mirror?

A. 23 cm

B. 32 cm

C. 44 cm

D. 46 cm

$$m = -\frac{x_i}{x_o}$$

$$3.2 = -\frac{x_i}{20}$$

$$x_i = -(3.2)(20)$$

$$x_i = -64 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{f} = \frac{1}{-64} + \frac{1}{20}$$

$$\frac{1}{f} = -\frac{30}{2880} + \frac{96}{2880} = \frac{66}{2880}$$

$$f = \frac{2880}{66} = 43.6 \text{ cm}$$





Extra questions

23. An object is placed 21 cm in front of a concave mirror with a focal length of 14 cm. What is the image position?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

A. 242 cm

B. 28.4 cm

C. 8.4 cm

D. 42 cm

$$\frac{1}{21} = \frac{1}{x_i} + \frac{1}{14}$$

$$\frac{1}{x_i} = \frac{1}{21} - \frac{1}{14}$$

$$\frac{1}{x_i} = \frac{14}{294} - \frac{21}{294} = -\frac{7}{294}$$

$$x_i = -\frac{294}{7} = -42\text{cm}$$

24. A concave mirror with a focal length of 16.0 cm produces an image located 38.6 cm from the mirror. What is the distance of the object from the front of the mirror?

A. 2.4 cm

B. 11.3 cm

C. 22.6 cm

D. 27.3 cm

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$\frac{1}{16} = \frac{1}{38.6} + \frac{1}{x_o}$$

$$\frac{1}{x_o} = \frac{1}{16} - \frac{1}{38.6}$$

$$\frac{1}{x_o} = \frac{38.6}{617.6} - \frac{16}{617.6} = \frac{22.6}{617.6}$$

$$x_o = \frac{617.6}{22.6} = 27.3\text{cm}$$



LO:

Infer the type, orientation, and size of an image from the magnitude and algebraic sign of magnification.

EX:

Student Textbook

P:

35



Calculating Image Position:

Magnification (m), which is the ratio of the image height to the object height. By using similar-triangle geometry, you can also rewrite this ratio in terms of image and object positions.

MAGNIFICATION

The magnification of an object by a spherical mirror, defined as the image height divided by the object height, is equal to the negative of the image position, divided by the object position.

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

m : magnification

h_i : image height

h_o : object height

(m) has a negative value, indicating that the image is inverted.

($m > 1$) Image larger than object (enlarged)

($m = 1$) Image is the same size as the object

($m < 1$) Image smaller than object (reduced)





1) A spherical mirror produces an image with a magnification of -2.0. What can be concluded about the image?

- a) Virtual, upright, and diminished
- b) Virtual, upright, and magnified
- c) Real, inverted, and diminished
- d) Real, inverted, and magnified**

2) What does a magnification value of +0.5 indicate about the image?

- a) Real, inverted, and twice the size of the object
- b) Virtual, upright, and half the size of the object**
- c) Real, upright, and half the size of the object
- d) Virtual, inverted, and twice the size of the object

3) An optical system forms an image with a magnification of -0.8. Which statement correctly describes the image?

- a) The image is virtual and larger than the object
- b) The image is real and smaller than the object**
- c) The image is virtual and inverted
- d) The image is real and upright



LO:

Compare and contrast plane, concave, and convex mirrors regarding the properties of images formed and the algebraic

EX:

Student Textbook

P:

43



Mirror Comparison:

Table 1 Single-Mirror System Properties

Mirror Type	f	x_o	x_i	m	Image
Plane	∞	$x_o > 0$	$ x_i = x_o$ (negative)	same size	virtual
Concave	+	$x_o > r$	$r > x_i > f$	reduced, inverted	real
		$r > x_o > f$	$x_i > r$	enlarged, inverted	real
		$f > x_o > 0$	$ x_i > x_o$ (negative)	enlarged	virtual
Convex	-	$x_o > 0$	$ f > x_i > 0$ (negative)	reduced	virtual





1) Which type of mirror can form a real, inverted image that is larger than the object?

- a) Plane mirror
- b) Concave mirror**
- c) Convex mirror
- d) Both b and c

2) For which mirror type is the image always virtual, upright, and the same size as the object?

- a) Plane mirror**
- b) Concave mirror
- c) Convex mirror
- d) Both a and c

3) Which statement about algebraic signs for image distance (x) is correct?

- a) For convex mirrors, x is always positive
- b) For concave mirrors forming real images, x is negative
- c) For virtual images (all mirrors), x is positive
- d) For virtual images (all mirrors), x is negative**



LO:

Describe refraction of light (or a wave) as it crosses the boundary between two different mediums and represent that in a ray diagram.

EX:

Student Textbook

P:

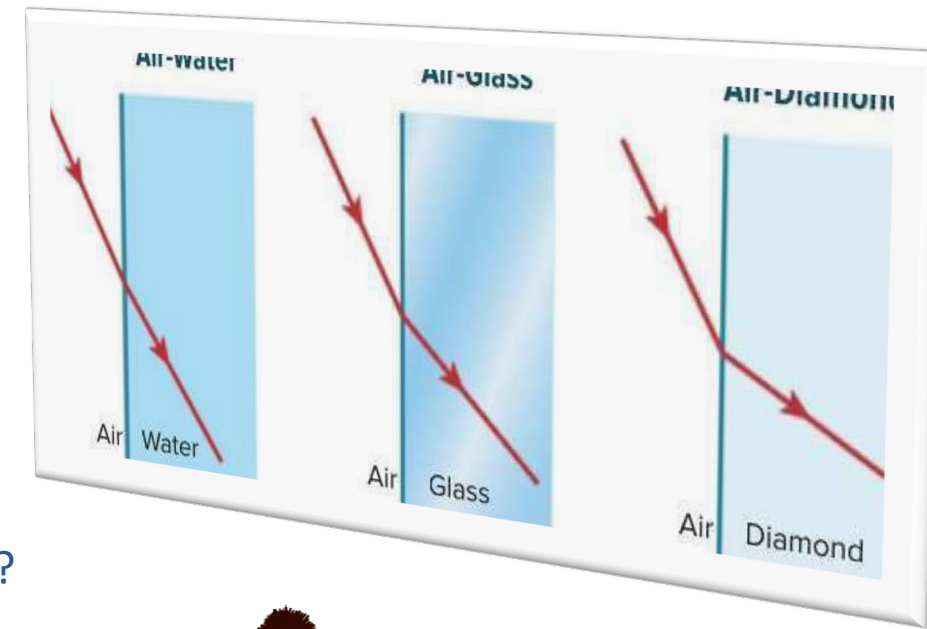
44, 45



Light and boundary:

Refraction: is the bending of light as it crosses the boundary between two mediums.

The picture is showing identical rays of light start in air and pass into three different mediums: water, glass, and diamond and hits the surface of each medium at the same angle.



 - What do you notice about the light rays after they cross the boundaries?
The light rays bend as they cross the boundaries.

 - What difference do you notice between the three mediums shown?
The light rays bend more when traveling from air to diamond than from air to water or air to glass.

 - The angle that the light bends with depends on:
The properties of the mediums that the light rays are traveling from and into.



What do you think the relationship is between the angle of the light as it crosses the boundary between mediums and refraction?



Snell's Law of Refraction:

The product of the index of refraction of the first medium and the sine of the angle of incidence is equal to the product of the index of refraction of the second medium and the sine of the angle of refraction.

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

n_1 : index of refraction for the first medium

θ_1 : angle of incidence

n_2 : index of refraction for the second medium

θ_2 : angle of refraction

Index of refraction

Snell found that when light passed from air into a transparent medium, the sines of the angles were related. This **index of refraction** (n) determines the angle of refraction of light as it crosses the boundary between two mediums. Properties of the mediums light is traveling through determine indices of refraction. Values of n for several mediums are listed in **Table 1**.

Table 1	
Indices of Refraction for Yellow Light ($\lambda = 589 \text{ nm}$ in vacuum)	
Medium	n
Vacuum	1.00
Air	1.0003*
Water	1.33
Ethanol	1.36
Float glass	1.52
Quartz	1.54
Flint glass	1.62
Diamond	2.42

$$n_1 > n_2$$

$$\sin \theta_1' < \sin \theta_2'$$

$$\theta_1' < \theta_2'$$

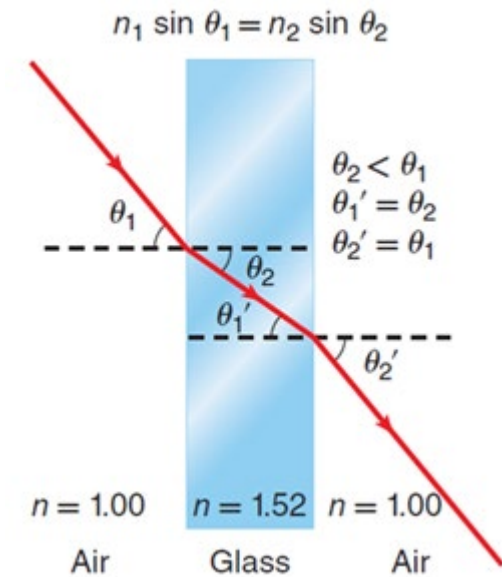
light is bent away from the normal.

$$n_1 < n_2$$

$$\sin \theta_1 > \sin \theta_2$$

$$\theta_1 < \theta_2$$

Light bends toward the normal



Note the direction of the ray when it leaves the glass. It is the same as before it struck the glass, $\theta_1 < \theta_2'$.

This is because the boundaries are between the same two mediums.





1) What is the best description of refraction?

- a) The bouncing of light off a surface
- b) The bending of light as it passes from one medium to another**
- c) The spreading of light around obstacles
- d) The change in light's speed in a vacuum

2) In a ray diagram showing light passing from air into glass, how does the ray behave at the boundary?

- a) It bends away from the normal
- b) It bends toward the normal**
- c) It continues straight without bending
- d) It reflects back into the air

3) When drawing a refraction ray diagram, what must be included at the point where the ray crosses the boundary between two media?

- a) A dotted line showing the original path
- b) A label showing the wavelength change
- c) A normal line perpendicular to the boundary**
- d) An arrow showing the speed increase



Check Your Progress (page50)

35. Index of refraction You notice that when a light ray enters a certain liquid from water, it is bent toward the normal, but when it enters the same liquid from float glass, it is bent away from the normal. What can you conclude about the liquid's index of refraction?

$$n_{\text{water}} < n_{\text{liquid}} < n_{\text{glass}}$$

therefore, n_{liquid} must be between 1.33 and 1.52.





Extra questions

1. What factor determine whether the light will bend toward or away from the normal.

The relative values of the refractive index

2. Although the light coming from the Sun is refracted while passing through Earth's atmosphere, the light is not separated into its spectrum. What does this indicate about the speeds of different colors of light traveling through air?

The speeds of the different colors of light traveling through air are the same.





Extra questions

6. How does the angle of incidence compare with the angle of refraction when a light ray passes from air into glass at a nonzero angle?

The angle of incidence is larger than the angle of refraction, because air has a smaller index of refraction.

7. How does the angle of incidence compare with the angle of refraction when a light ray leaves glass and enters air at a nonzero angle?

The angle of incidence is smaller than the angle of refraction, because glass has a larger index of refraction.



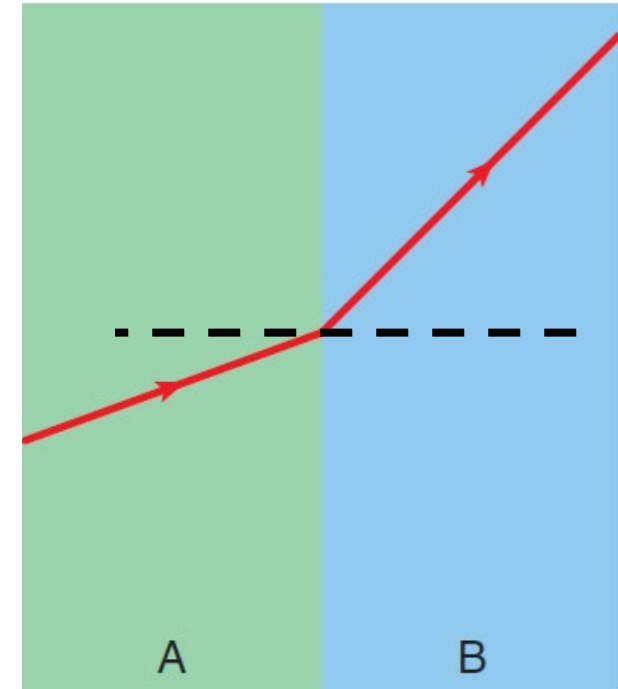


Extra questions

12. Which medium, A or B, in **Figure 34** has a larger index of refraction? Explain.

The light ray refracted away from the normal line, so it moved from a material with high refractive index to a material with low refractive index

$$n_A > n_B$$





Extra questions

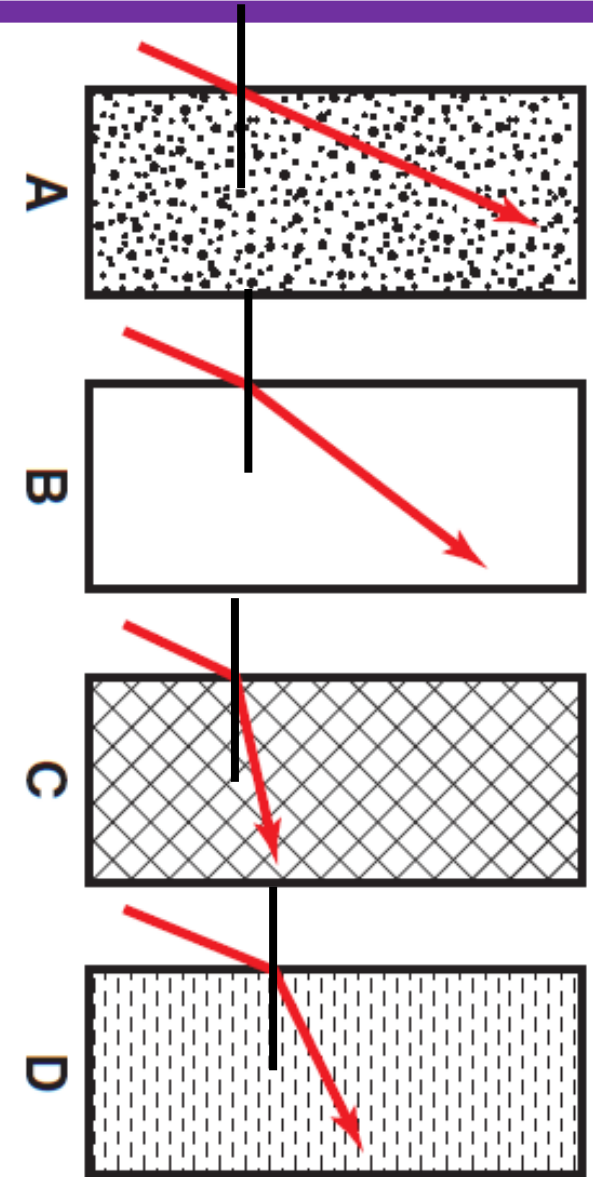
16. Ranking Task Figure 29 depicts a ray of light traveling from air into several mediums. Rank the mediums according to index of refraction from **greatest to least**. Specifically indicate any ties.

$$n_{air} \sin \theta_{air} = n_r \sin \theta_r$$

$$\sin \theta_r = \frac{n_{air} \sin \theta_{air}}{n_r}$$

When the index of refraction increase
 $\sin \theta_r$ decrease (θ_r) decrease.

$$C > D > B > A$$



LO:

-Define the index of refraction of a medium and relate it to the properties of the medium.

EX:

Student Textbook

P:

45

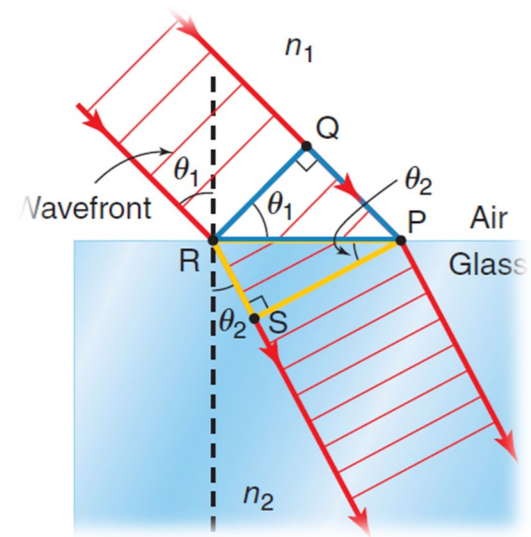


The Meaning of the Index of Refraction:

The index of refraction describes how much light bends as it enters a medium.

Wave model of light:

light **interacts with atoms** in such a way that it **moves more slowly** through a medium than it does through a vacuum.



$$\lambda = \frac{c}{f}$$

In vacuum

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

Other mediums

When light cross the boundary between vacuum and other medium
The velocity of the light decrease, the wavelength decrease, but frequency
remain the same

Index of Refraction :

The index of refraction of a medium is equal to the speed of light in a vacuum divided by the speed of light in the medium.

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





1) How is the index of refraction (n) of a medium defined?

- a) The speed of light in the medium multiplied by the speed of light in a vacuum
- b) The speed of light in a vacuum divided by the speed of light in the medium**
- c) The wavelength of light in the medium divided by its wavelength in a vacuum
- d) The frequency of light in the medium divided by its frequency in a vacuum

2) A medium with a higher index of refraction will cause light to:

- a) Travel faster and bend less
- b) Travel slower and bend more**
- c) Travel faster and bend more
- d) Travel slower and bend less

3) Which material typically has the highest index of refraction?

- a) Air
- b) Water
- c) Glass
- d) Diamond**



LO:

- Describe some applications of total internal reflection
- Explain some natural phenomena, such as the formation of mirage or rainbows or others, which involve optical phenomena like reflection, refraction, total internal reflection, or dispersion of light.

EX:

Student Textbook

P:

48, 49



Total Internal Reflection:

Total internal reflection:

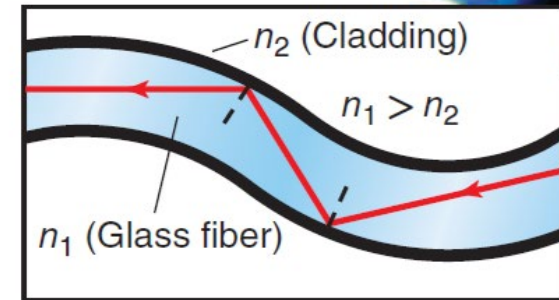
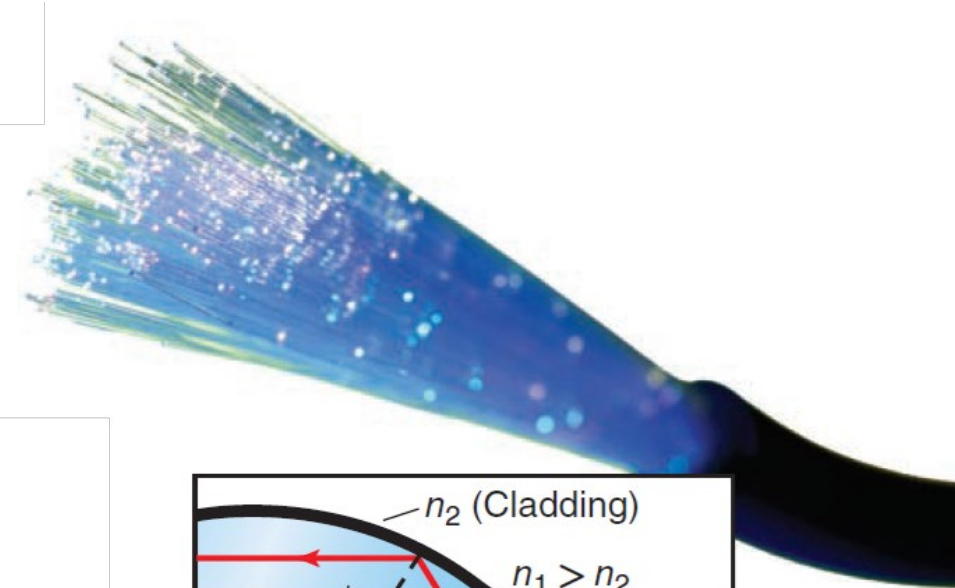
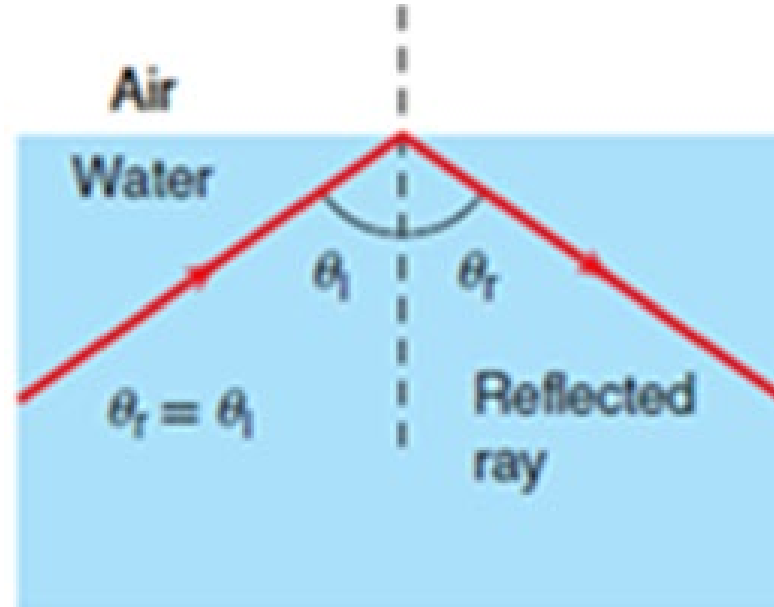
occurs when light traveling from a region of a higher index of refraction to a region of a lower index of refraction strikes the boundary at an **angle greater than the critical angle** such that all light **reflects back** into the region of the higher index of refraction.

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

$$\theta_1 > \theta_c$$

$$\sin \theta_2 > 1$$

Total internal reflection



REAL-WORLD
PHYSICS





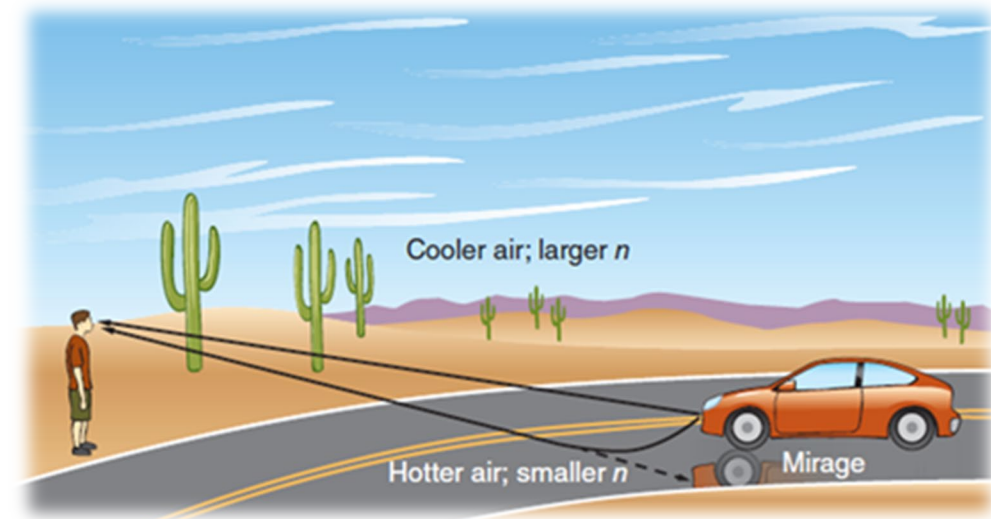
Mirages:

As you drive down a road, you see what appears to be the reflection of an oncoming car in a pool of water.

The pool, however, disappears as you approach it.



The **mirage** is the result of the Sun heating the road.





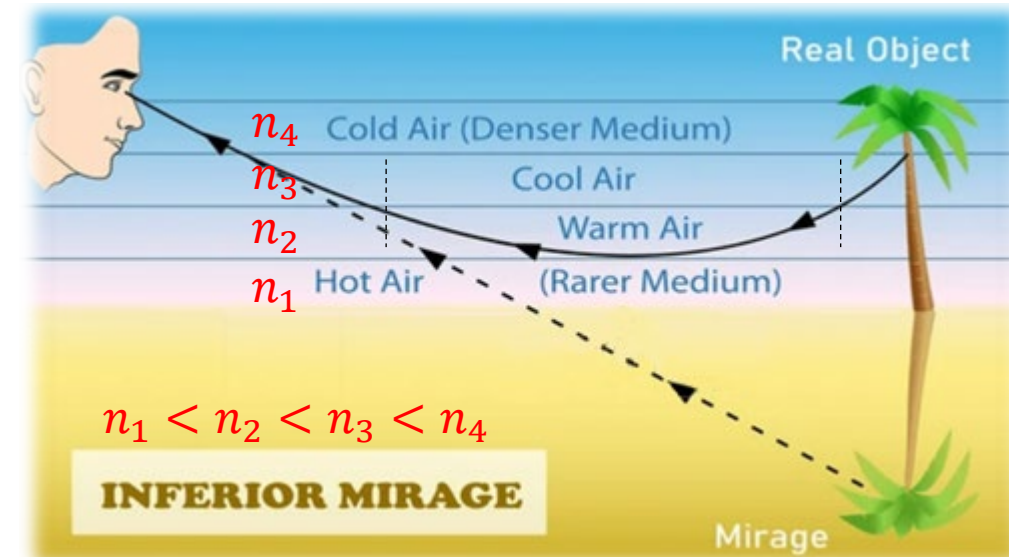
Mirages:

The hot road heats the air above it and produces a thermal layering of air, causing light traveling toward the road from the tree to gradually bend upward ($n_3 > n_2$) light is bent away from the normal.

This makes the light appear to be coming from a reflection in a pool.

As light from a distant object travels downward toward the road, the index of refraction of the air decreases as the air gets hotter, but the temperature change is gradual. Recall that light wavefronts are comprised of Huygens' wavelets.

In the case of a mirage, the Huygens' wavelets closer to the ground travel faster than those higher up, causing the wavefronts to gradually turn upward ($n_1 < n_2$) Light bends toward the normal.



The speed of light, and therefore, the index of refraction, for a gaseous medium can change slightly with temperature.





Rainbows:

A prism is not the only means of dispersing light.

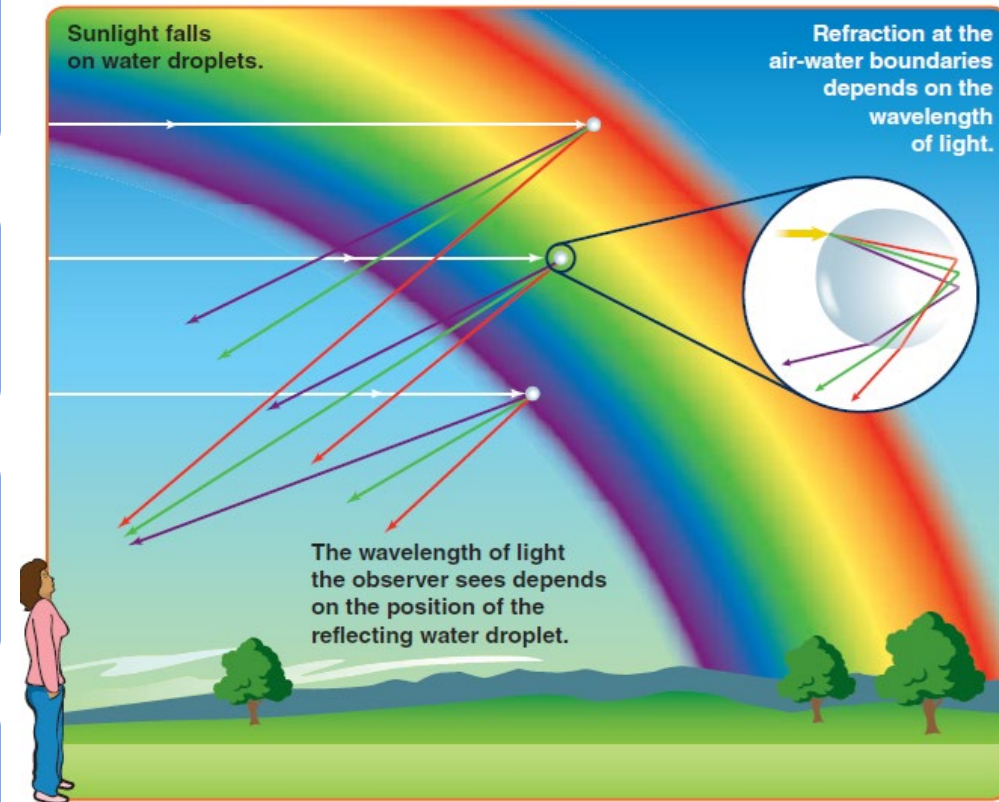
A rainbow is a spectrum formed when sunlight is dispersed by water droplets in the atmosphere.

Sunlight that falls on a water droplet is refracted. Since each color has a different wavelength, it is refracted at a slightly different angle, as shown in **Figure 8**, resulting in dispersion.

At the back surface of the droplet, some of the light undergoes internal reflection. On the way out of the droplet, the light once again is refracted and dispersed.

Although each droplet produces a complete spectrum, an observer positioned between the Sun and the rain will see only a certain wavelength of light from each droplet.

The wavelength observed depends on the relative positions of the Sun, the droplet, and the observer, as shown in **Figure 8**.





1) Which of the following devices operates primarily based on total internal reflection?

- a) Convex lens
- b) Plane mirror
- c) Optical fiber**
- d) Concave mirror

2) In binoculars and single-lens reflex (SLR) cameras, what optical component is used to redirect light through 90 degrees using total internal reflection?

- a) Concave lens
- b) Prism**
- c) Diffraction grating
- d) Convex mirror

3) Why are diamonds often cut to have many facets?

- a) To decrease their refractive index
- b) To maximize the light that undergoes total internal reflection, increasing brilliance**
- c) To minimize reflection and increase transparency
- d) To spread light out and reduce its intensity





4) The formation of a rainbow primarily involves:

- a) Reflection and diffraction only
- b) Refraction and total internal reflection only
- c) Refraction, dispersion, and internal reflection within water droplets**
- d) Polarization and interference of sunlight

5) A mirage, such as the appearance of water on a hot road, is caused by:

- a) Reflection from a hot surface
- b) Total internal reflection in cool air layers
- c) The refraction of light in layers of air with different densities and temperatures**
- d) The dispersion of light into its component colors





6) The "green flash" sometimes seen just as the sun sets over the ocean is an atmospheric phenomenon caused primarily by:

- a) Diffraction of sunlight
- b) Refraction and dispersion of sunlight in the atmosphere
- c) Total internal reflection in clouds
- d) Polarization of light by water molecules



LO:

Define dispersion and explain the dispersion of light through a prism.

EX:

Student Textbook

P:

49, 50

Dispersion of Light:

Dispersion of light is the separation of white light into a spectrum of colors.

- White light is made up from a spectrum of colors that have different wavelength and different frequencies.



Speed of light



The speed of light in a medium is determined by interactions between the light and the atoms that make up the medium.



The speed of light and the index of refraction for a solid or liquid medium vary for different wavelengths of light.



The speed of light and index of refraction also change slightly with temperature for a gaseous medium.
This is due to the effects of temperature on the energy of particles at the atomic level.

	V	B	G	Y	O	R	
							
Color	Wavelength (nm)	Frequency (THz)	Photon energy (eV)				
 violet	380–450	670–790	2.75–3.26				
 blue	450–485	620–670	2.56–2.75				
 cyan	485–500	600–620	2.48–2.56				
 green	500–565	530–600	2.19–2.48				
 yellow	565–590	510–530	2.10–2.19				
 orange	590–625	480–510	1.98–2.10				
 red	625–750	400–480	1.65–1.98				

Dispersion of Light:

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

Lower speed
higher index of
refraction

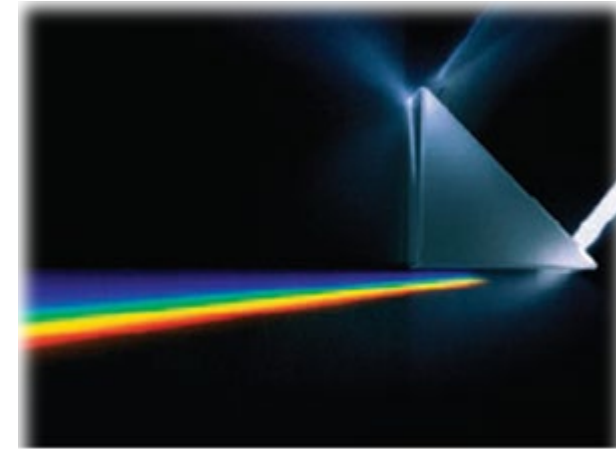
The speed of **violet** light through glass is **less** than the speed of **red** light through glass.

This results in **glass** having a **slightly higher index** of refraction for **violet** light than it has for **red** light.

$$\sin \theta_{air} = \frac{n_{Glass} \sin \theta_{Glass}}{n_{air}}$$

This **higher index of refraction** for **violet** make the angle of refraction larger for **violet** light than it has for **red** light.

The result is the separation of white light into a spectrum of colors.



Color	Wavelength (nm)	Frequency (THz)	Photon energy (eV)
violet	380–450	670–790	2.75–3.26
blue	450–485	620–670	2.56–2.75
cyan	485–500	600–620	2.48–2.56
green	500–565	530–600	2.19–2.48
yellow	565–590	510–530	2.10–2.19
orange	590–625	480–510	1.98–2.10
red	625–750	400–480	1.65–1.98

LO:

- Distinguish between a convex (converging) lens and a concave (diverging) lens.
- Compare and contrast convex and concave lenses regarding the properties of images formed and the algebraic signs for different quantities involved.

EX:

Student Textbook
Check your progress 50

P:

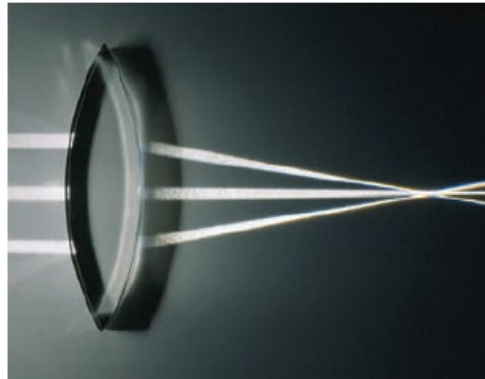
51, 54,60



A **lens** is a piece of transparent material, such as glass or plastic, that is used to focus light and form an image.

Convex Lens

A lens that is thicker at the center than at the edges

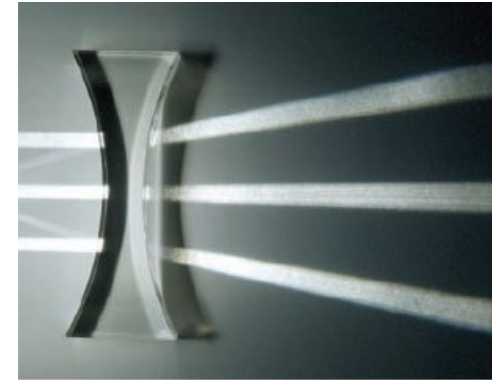


When it is surrounded by material with a lower index of refraction, such as air, it refracts parallel light rays so that they all pass through a common point, called the focal point, after going through the lens.

For this reason, a convex lens is often called a **converging lens**.

Concave Lens

A lens that is thinner in the middle than at the edges



When surrounded by material with a lower index of refraction, rays passing through it spread out.

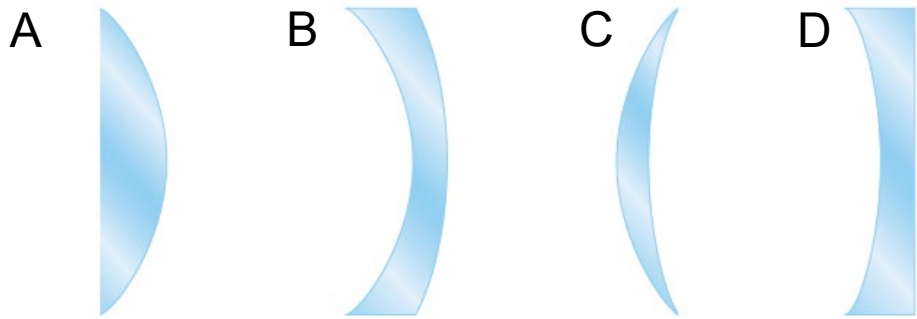
For this reason, a concave lens is often called a **diverging lens**.





Check Your Progress (page60)

50. Types of Lenses The cross sections of four different thin lenses are shown in Figure 38.



a. Which of these lenses, if any, are convex, or converging, lenses?

Lenses a and c are converging.

b. Which of these lenses, if any, are concave, or diverging, lenses?

Lenses b and d are diverging.



LO:

Explain defects in spherical lenses such as spherical aberration and chromatic aberration and how they can be corrected.

EX:

Student Textbook

P:

56



Defects of Spherical Lenses:

In reality, spherical lenses, have **intrinsic defects (aberration)** caused by their **spherical design** or the **dispersion** of light through the lens **and it affects the focus and color of images.**

Spherical aberration

- When drawing ray diagram, we assume that all parallel rays focus at the same position.
- In reality, parallel rays that pass through the edges of a spherical lens focus at positions different from those of parallel rays that pass through the center.

This inability of a spherical lens to focus all parallel rays to a single point is called spherical aberration.



The effects are shown in the **Figure**. In reality, most lenses have a slightly different shape to address this, but the spherical approximation works well enough for our purposes. In high-precision instruments, many lenses, often five or more, are used to form sharp, well-defined images.





Defects of Spherical Lenses:

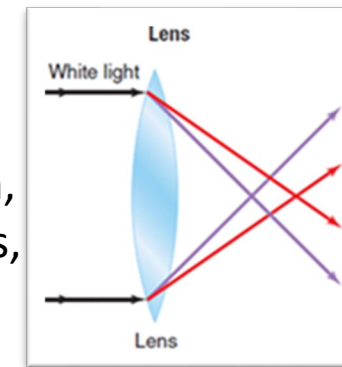


Light that passes through a lens is **slightly dispersed**, especially near the edges, causing an effect called **chromatic aberration**. This is seen as an **apparent ring of color** around an object viewed through a lens.



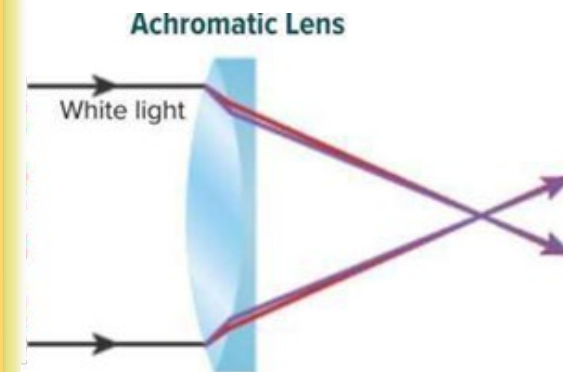
Chromatic aberration

Because the index of refraction of a medium depends on wavelength, different wavelengths of light are refracted at slightly different angles, as you can see in **the Figure**.



Chromatic aberration is always present when a single lens is used. However, this defect can be greatly reduced by an **achromatic lens**, which is a system of two or more lenses, such as a convex lens with a concave lens, that have different indices of refraction. Such a combination of lenses is shown in **Figure 17**.

Both lenses in the figure disperse light, but the dispersion caused by the convex lens is almost canceled by the dispersion caused by the concave lens. The index of refraction of the convex lens is chosen so that the combination of lenses still converges the light at the desired location.





Check Your Progress (page60)

53. Chromatic Aberration All simple lenses have chromatic aberration. Infer why you do not see this effect when you look through a microscope. which has two convex lenses.

All precision optical instruments use a combination of lenses, called an achromatic lens, to minimize chromatic aberration.

52. Thin Lens Approximation what is the thin lens approximation and why is it used?

All parallel rays focus at the same position (focal).

Used for drawing rays through spherical lenses





1) What is the primary cause of spherical aberration in a simple spherical lens?

- a) Different colors of light focus at different points.
- b) Marginal rays and paraxial rays focus at different points along the principal axis.
- c) The lens material absorbs too much light.
- d) The image becomes distorted due to lens curvature.

2) Chromatic aberration in lenses occurs because:

- a) Light rays strike the edges of the lens at different angles.
- b) The lens has an irregular surface.
- c) The refractive index of the lens material varies with the wavelength of light.
- d) The lens fails to reflect certain colors properly.





3) How can chromatic aberration in optical instruments be effectively corrected?

a) By using a lens with a shorter focal length.

b) By combining lenses made of different types of glass (an achromatic doublet).

c) By using a diaphragm to block marginal rays.

d) By silvering the surface of the lens.



LO:

- Define nearsightedness (Myopia) and farsightedness (Hyperopia).
- Describe the formation of image in case of nearsightedness and farsightedness and how defects in vision are corrected using concave and convex lenses.

EX:

Student Textbook
Check your progress 57

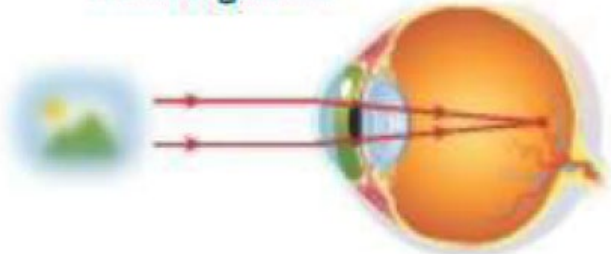
P:

58, 60

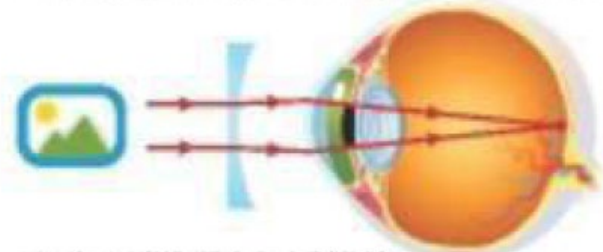


Nearsightedness (myopia):

Nearsighted



A nearsighted eye focuses images at a point in front of the retina, making distant images blurry.



A concave lens corrects nearsightedness by increasing the focal length.



- The focal length of the eye is **too short** to focus light on the retina.



- Images are formed in **front** of the retina.



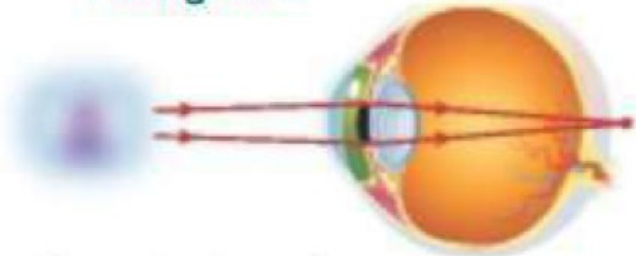
- A **concave lenses** correct this by diverging light, thereby increasing images' distances from the lens and forming images on the retina.



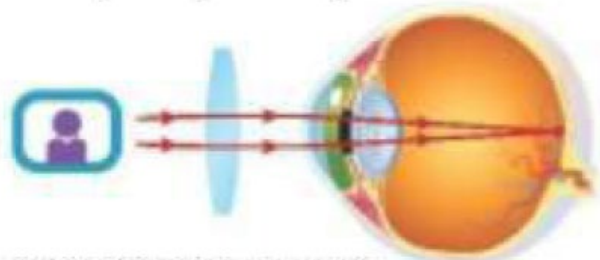


Farsighted (hyperopia):

Farsighted



A farsighted eye focuses images at a point behind the retina, making nearby images blurry.



A convex lens corrects farsightedness by reducing the focal length.



- The focal length of the eye is **too long**. Images are therefore not formed on the retina.

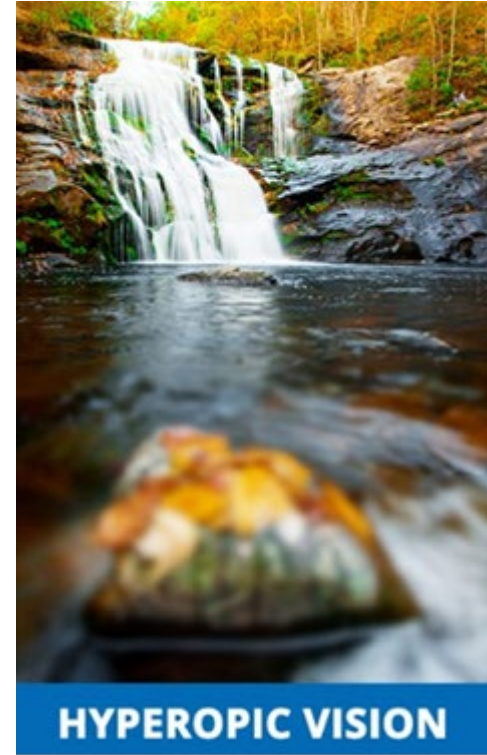


- Images are formed **behind** the retina.

A similar result is caused by the increasing rigidity of the lenses in the eyes of people who are more than about 45 years old.



- A **convex lenses** correct this by produce virtual images farther from the eye than the associated objects, . The images then become the objects for the eye lens and can be focused on the retina.



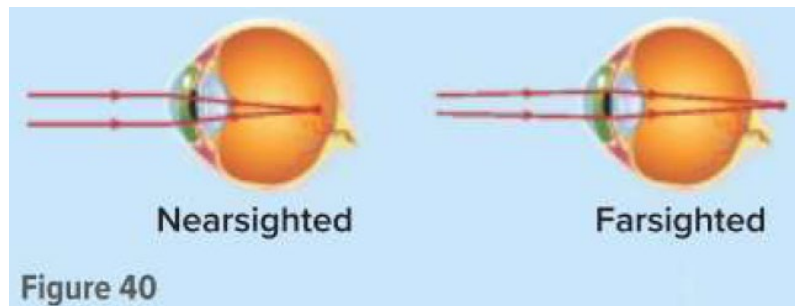
HYPEROPIC VISION





Check Your Progress (page60)

57. Eyeglass Lenses Which type of lens, convex or concave, should a nearsighted person use? See **Figure 40**. Explain.



concave lenses





1) What is the primary cause of nearsightedness (Myopia)?

a) The eyeball is too short, causing the image to focus behind the retina.

b) The eyeball is too long, causing the image to focus in front of the retina.

c) The lens of the eye becomes too weak with age.

d) The cornea becomes irregularly shaped.

2) A person with farsightedness (Hyperopia) has difficulty seeing:

a) Distant objects clearly

b) Both near and far objects

c) Near objects clearly

d) Objects in low light conditions

3) Which statement correctly describes hyperopia?

a) The focal point is in front of the retina

b) It is corrected using a diverging lens

c) The eyeball is typically shorter than normal

d) It improves naturally with age





4) In a myopic eye, where does the image of a distant object form?

- a) On the retina
- b) Behind the retina
- c) In front of the retina**
- d) Not formed at all

5) What type of lens is used to correct hyperopia and why?

- a) Concave lens to diverge light rays before they enter the eye
- b) Convex lens to converge light rays before they enter the eye**
- c) Cylindrical lens to correct asymmetric curvature
- d) Plane glass to reduce light intensity

6) How does a concave lens help correct myopia?

- a) It converges light rays to move the focal point forward
- b) It diverges light rays to move the focal point backward onto the retina**
- c) It magnifies the image to make it clearer
- d) It reduces chromatic aberration in the eye



LO:

Describe the optical systems and formation of images in common optical instruments.

EX:

Student Textbook

P:

59



Refracting Telescopes:



An astronomical refracting telescope uses lenses to magnify distant objects.



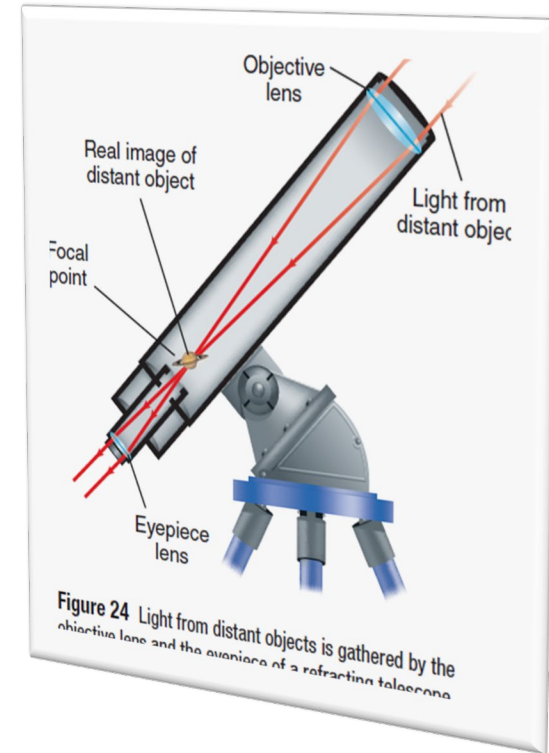
- Light from stars and other astronomical objects comes from so far away that the incoming rays can be considered parallel.
- These rays enter the objective convex lens, which focuses them as a real image at the focal point of the objective lens.
- The image is inverted compared to the object. This image then becomes the object for the convex lens of the eyepiece.



Notice that the eyepiece lens is positioned so that the focal point of the objective lens is between the eyepiece lens and its focal point. This means a **virtual** image is produced that is **upright** and **larger** than the first image.

However, because the first image was already inverted, the final image is still inverted.

In a telescope, the convex lens of the eyepiece is almost always an **achromatic lens**.



Cameras:



- As light enters the camera through the aperture, it passes through an **achromatic** lens.

This lens system refracts the light much like a single convex lens would, forming an image that is inverted on the reflex mirror.

The image is reflected upward to a prism that inverts and redirects the light to the viewfinder.



- When the person holding the camera takes a photograph, he or she presses the shutter-release button, which briefly raises the mirror.

The light, instead of being diverted upward to the prism, then travels along a straight path to form an image on the sensor.

The image sensor, which is often a charge-coupled device (CCD), captures a two-dimensional image that corresponds to the image projected onto it.

The image information is collected on the photoactive region of the CCD as electric charge proportional to the light intensity. The CCD then processes the charge and transfers the information to a storage device.

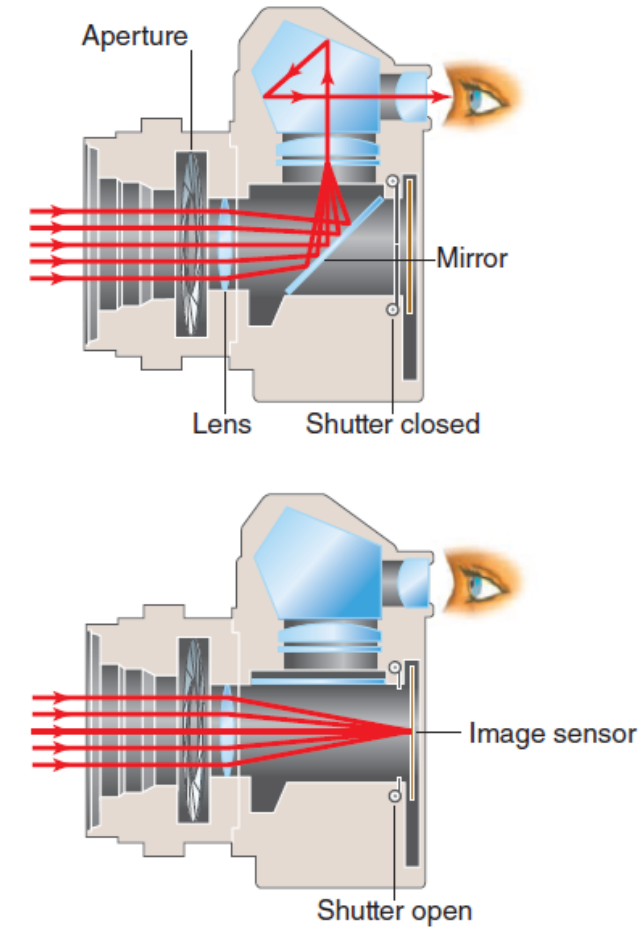


Figure 25 The lens of a camera can be adjusted to focus an image on the image sensor. When the shutter is closed, a mirror diverts the image to the viewer's eye.



1) In a simple camera, what type of image is formed on the film or sensor?

- a) Virtual, upright, and magnified
- b) Real, inverted, and diminished**
- c) Virtual, inverted, and diminished
- d) Real, upright, and magnified

2) What is the primary function of the eyepiece lens in a compound microscope?

- a) To form a real, inverted image of the object
- b) To magnify the real image formed by the objective lens**
- c) To reduce chromatic aberration in the system
- d) To illuminate the specimen being viewed

3) In an astronomical refracting telescope, the final image seen by the eye is:

- a) Real and inverted
- b) Virtual and inverted**
- c) Real and upright
- d) Virtual and upright



FRQ Questions

Q1

LO:

21	-Apply the equation for illuminance of a point source to numerical problems. -Relate luminous intensity to illuminance.	Student Textbook	6-8
		Example problem1	9
		Practice problems	
		Check your progress	11

EX:

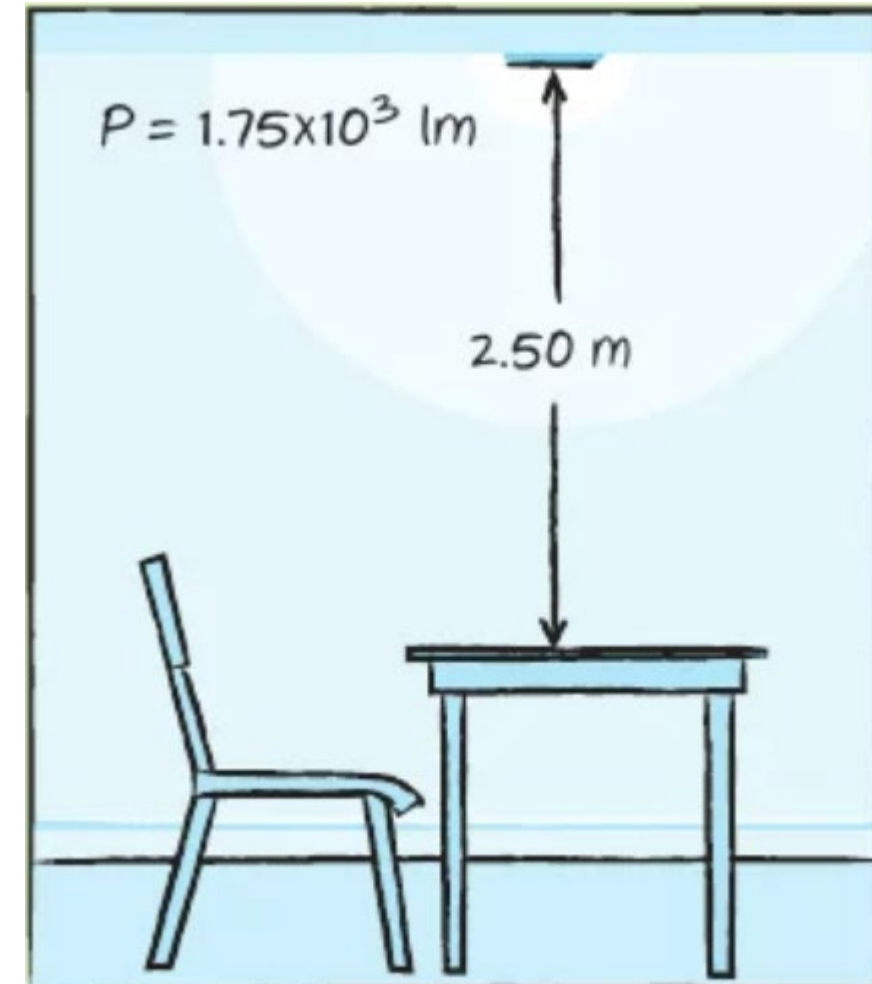
P:

**EXAMPLE PROBLEM 1** (page9)

ILLUMINATION OF A SURFACE What is the illuminance on your desktop if it is lit by a **1750 lm** lamp that is **2.50 m** above your desk?

$$E = \frac{p}{4\pi r^2}$$

$$E = \frac{1750}{4\pi(2.5)^2} = 22.3 \text{ lx}$$



**PRACTICE PROBLEMS** (page 9)

5. What is the illumination on a surface that is 3.0 m below a 150-W incandescent lamp that emits a luminous flux of 2275 lm?

$$E = \frac{p}{4\pi r^2}$$

$$E = \frac{2275}{4\pi(3)^2} = 20.11 \text{ lx}$$

6. A public school law requires a minimum illuminance of 160 lx at the surface of each student's desk. An architect's specifications call for classroom lights to be located 2.0 m above the desks. What is the minimum luminous flux that the lights must produce?

$$E = \frac{p}{4\pi r^2}$$

$$P = 4\pi r^2 E$$

$$P = 4\pi(2)^2(160) = 8042.477 \text{ lm}$$



**PRACTICE PROBLEMS** (page 9)

7. CHALLENGE Your local public library is planning to remodel the computer lab.

The contractors have purchased fluorescent lamps with a rated luminous flux of **1750 lm**.

The desired illumination on the keyboard surfaces is **175 lx**.

Assume a single lamp illuminates each keyboard.

A- What distance above the surface should the lights be placed to achieve the desired illumination?

$$E = \frac{p}{4\pi r^2}$$

$$r^2 = \frac{p}{4\pi E}$$

$$r = \sqrt{\frac{p}{4\pi E}} = \sqrt{\frac{1750}{4\pi(175)}} = 0.892m$$



**PRACTICE PROBLEMS** (page 9)

7. CHALLENGE Your local public library is planning to remodel the computer lab.

The contractors have purchased fluorescent lamps with a rated luminous flux of **1750 lm**.

The desired illumination on the keyboard surfaces is **175 lx**.

Assume a single lamp illuminates each keyboard.

B- If the contractors had also already purchased fixtures to hold the lights that when installed would be **1.5 m** above the keyboard surface, would the desired illuminance be achieved? If not, would the illuminance be greater or less than desired?

$$E = \frac{p}{4\pi r^2} = \frac{1750}{4\pi(1.5)^2} = 61.89 \text{ lx} \quad \text{less than desired}$$

C- What change in the lamp's luminous flux would be required to achieve the desired illuminance?

$$E = \frac{p}{4\pi r^2}$$

$$P = 4\pi r^2 E$$

$$P = 4\pi(1.5)^2(175) = 4948 \text{ lm}$$



**PRACTICE PROBLEMS** (page9)

1. A lamp is moved from 30 cm to 90 cm above the pages of a book. Compare the illumination on the book before and after the lamp is moved.

$$\frac{E_1}{E_2} = \frac{\frac{p}{4\pi r_1^2}}{\frac{p}{4\pi r_2^2}}$$

$$\frac{E_1}{E_2} = \frac{r_2^2}{r_1^2}$$

$$\frac{E_1}{E_2} = \frac{90^2}{30^2} = 9$$

$$E_1 = 9E_2$$



Check Your Progress (page11)

12. Distance of a Light Source A lightbulb illuminating your computer keyboard provides only **half the illuminance** that it should. If it is currently **1.0 m** away, how far should it be to provide the correct illuminance?

$$E_{\text{now}} = \frac{1}{2} E_{\text{need}}$$

$$r_{\text{need}}^2 = \frac{r_{\text{now}}^2}{2}$$

$$\frac{\cancel{p}}{4\pi r_{\text{now}}^2} = \frac{1}{2} \frac{\cancel{p}}{4\pi r_{\text{need}}^2}$$

$$r_{\text{need}} = \sqrt{\frac{r_{\text{now}}^2}{2}}$$

$$\frac{1}{r_{\text{now}}^2} = \frac{1}{2r_{\text{need}}^2}$$

$$r_{\text{need}} = \sqrt{\frac{(1)^2}{2}} = 0.71\text{m}$$





PRACTICE PROBLEMS (page9)

2. Draw a graph of the illuminance produced by a lamp with a luminous flux of 2275 lm at distances from 0.50 m and 5.0 m.

$$E = \frac{p}{4\pi r^2}$$

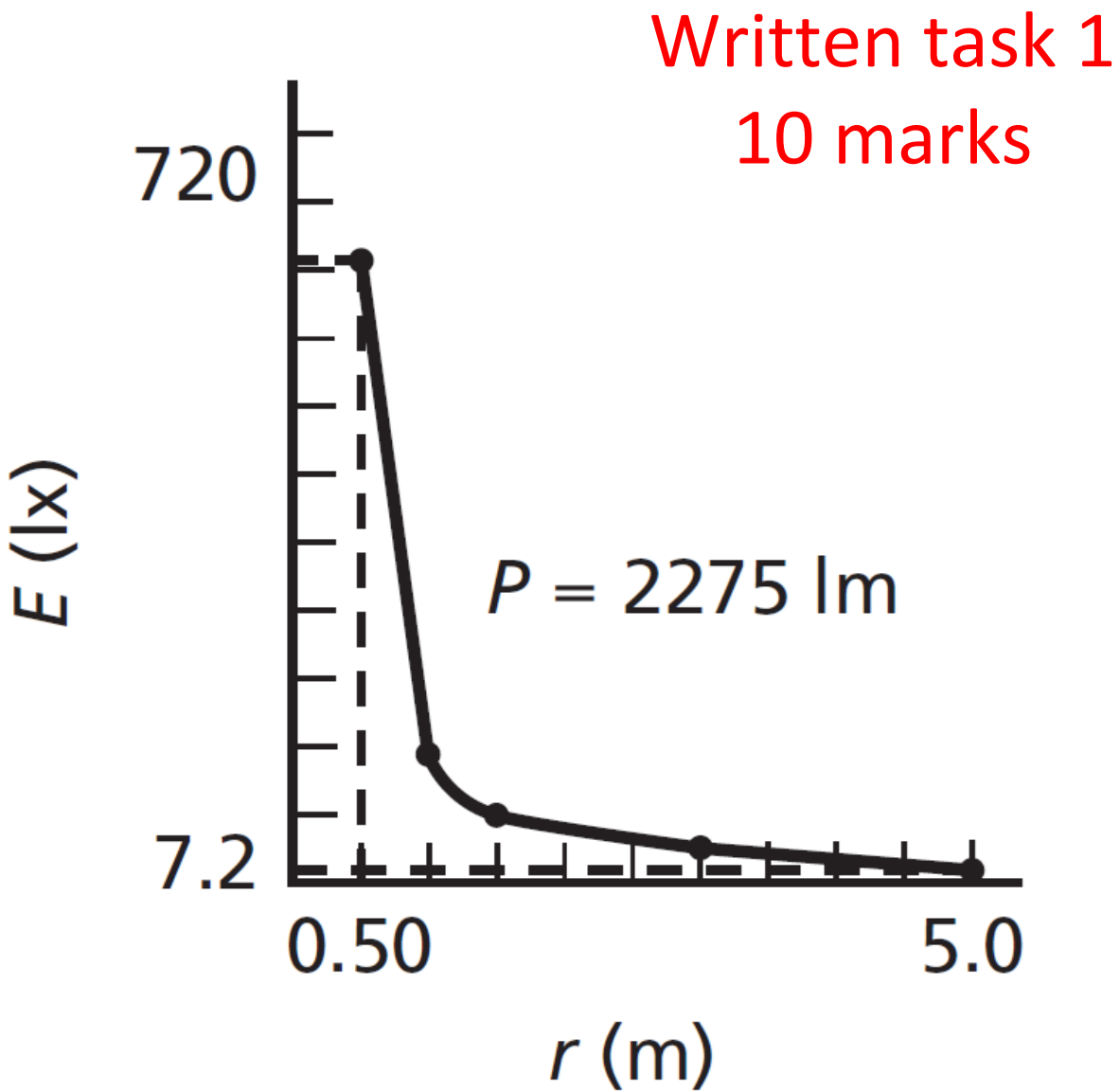
$$E_1 = \frac{2275}{4\pi(0.5)^2} = 724.15 \text{ lx}$$

$$E_2 = \frac{2275}{4\pi(1)^2} = 181.04 \text{ lx}$$

$$E_3 = \frac{2275}{4\pi(1.5)^2} = 80.46 \text{ lx}$$

•
•
•

Distance (m)	Illumination (lx)
0.5	
1	
1.5	
2	
2.5	
3	
3.5	
4	
4.5	
5	



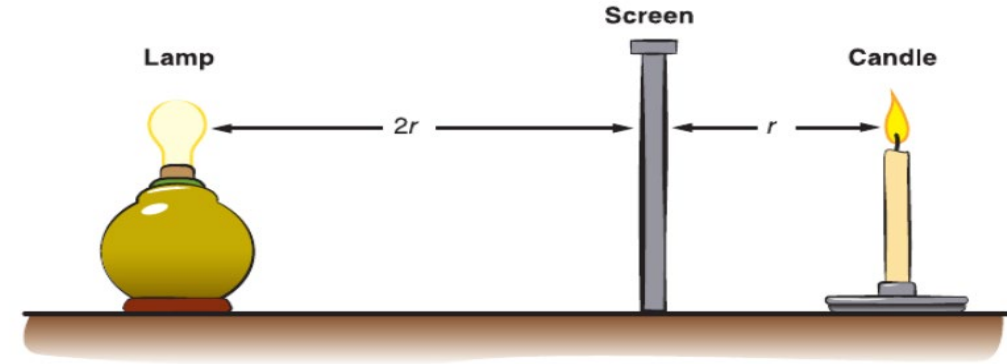


Luminous intensity:

Some luminous sources are specified in candelas (cd). A candela is not a measure of luminous flux but of luminous intensity.

The luminous intensity of a point source is the luminous flux that falls on 1 m^2 of the inside of a 1 m radius sphere.

$$\text{luminous intensity}(I) = \frac{\text{luminous flux}(p)}{4\pi}$$



For the bulb to provide the same illuminance on its side of the screen as the candle does on the candle side of the screen, the bulb would have to be **four times brighter** than the candle.

The lightbulb's luminous intensity, therefore, would have to be four times the candle's luminous intensity.

If both sources in **Figure 7** had the same luminous intensity, the source at $2r$ would only provide one-quarter the illuminance to the screen. This is consistent with the inverse-square relationship we just developed.



**PRACTICE PROBLEMS** (page 9)

3. A 64-cd point source of light is 3.0 m away from a painting. What is the illumination on the painting in lux?

$$E = \frac{p}{4\pi r^2}$$

$$E = \left(\frac{p}{4\pi}\right) \left(\frac{1}{r^2}\right)$$

luminous intensity (I)

$$E = \frac{I}{r^2}$$

$$E = \frac{64}{3^2} = 7.11 \text{ Lx}$$

4. A screen is placed between two lamps so that they illuminate the screen equally, as shown in Figure 9. The first lamp emits a luminous flux of 1445 lm and is 2.5 m from the screen.

What is the distance of the second lamp from the screen if the luminous flux is 2375 lm?

$$E_1 = E_2$$

$$r_2^2 = p_2 \frac{r_1^2}{p_1}$$

$$\frac{p_1}{4\pi r_1^2} = \frac{p_2}{4\pi r_2^2}$$

$$\frac{p_1}{r_1^2} = \frac{p_2}{r_2^2}$$

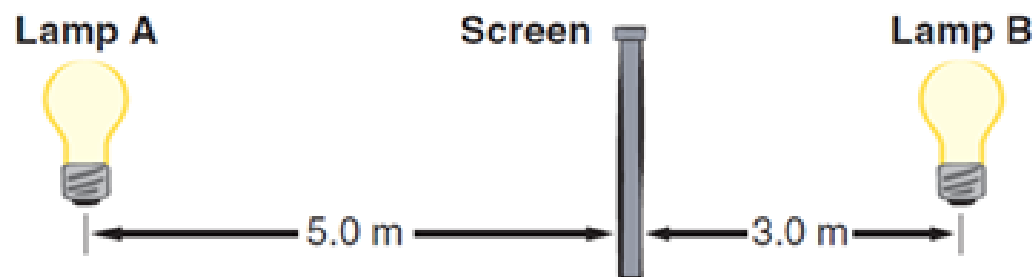
$$r_2 = \sqrt{p_2 \frac{r_1^2}{p_1}}$$

$$r_2 = \sqrt{(2375) \frac{(2.5)^2}{(1445)}} = 3.2 \text{ m}$$



Check Your Progress (page 11)

11. Luminous Intensity Two lamps illuminate a screen equally from distances shown in **Figure 11**. If lamp A is rated 75 cd, what is lamp B rated?



$$E_1 = E_2$$

$$\frac{I_1}{r_1^2} = \frac{I_2}{r_2^2}$$

$$I_2 = I_1 \frac{r_2^2}{r_1^2}$$

$$I_2 = \sqrt{(75) \frac{(3)^2}{(5)^2}} = 27 \text{ cd}$$



Check Your Progress (page11)

10. Illuminance Does one lightbulb provide more or less illuminance than two identical lightbulbs at twice the distance? Explain.

$$\frac{E_1}{E_2} = \frac{\frac{\cancel{p}}{4\pi\cancel{r_1}^2}}{\frac{2\cancel{p}}{4\pi(2\cancel{r_1})^2}}$$

$$\frac{E_1}{E_2} = \frac{1}{2}$$

$$\frac{E_1}{E_2} = 2$$

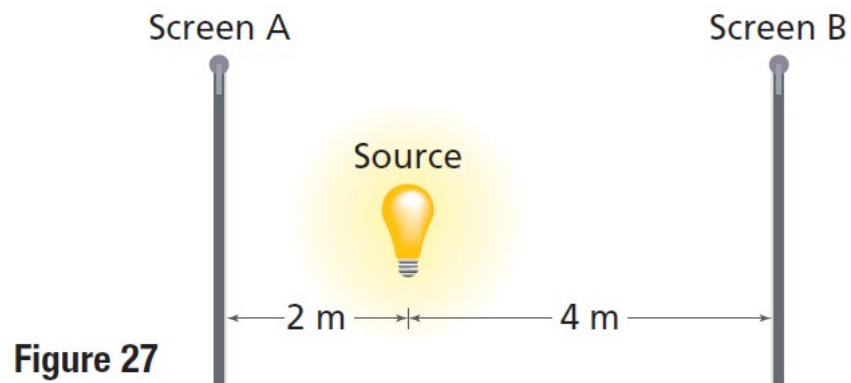
$$E_1 = 2E_2$$

One lightbulb provides an illuminance that is two times larger than two of the same lightbulb at twice the distance, because $E \propto \frac{p}{d^2}$



**Extra questions**

4. A point source of light is **2.0 m** from screen A and **4.0 m** from screen B, as shown in **Figure 27**. How does the illuminance at screen B compare with the illuminance at screen A?



$$\frac{E_A}{E_B} = \frac{\cancel{p} \frac{p}{4\pi r_A^2}}{\cancel{p} \frac{p}{4\pi r_B^2}}$$

$$\frac{E_A}{E_B} = \frac{r_B^2}{r_A^2}$$

$$\frac{E_A}{E_B} = \frac{4^2}{2^2} = 4$$

$$E_A = 4E_B$$

Illumination at screen A is four times the illumination on screen B





السؤال (1)

If the luminous flux of a lamp is (1750 lm), what is the illumination of the surface at a distance of (2 m) from the light source?

إذا كان التدفق الضوئي لمصباح (1750 lm) ، فما هو اناره السطح على بعد (2m) ، من مصدر الضوء ؟

13 lx

28 lx

35 lx

140 lx

$$E = \frac{p}{4\pi r^2}$$

$$E = \frac{1750}{4\pi(2)^2} = 34.81 \text{ lx}$$





السؤال (2)

An architect is designing lighting for a school. The lighting in the classrooms must be at least 37 illuminants. In students' desks, if the light shining on each desk has a luminous flux of 4200 lm, what is the maximum distance from which the lights can be placed?

مهندس معماري يقوم بتصميم الاضاءه لمدرسة , يجب ان تكون الاضاءه في الفصول الدراسية (37 lx) على الأقل في مكاتب الطلاب , اذا كان الضوء الساطع على كل مكتب له تدفق ضوئي قدره (4200 lm) , فما اقصى مسافة يمكن وضع الأضواء فوقها ؟

4 m

3 m

2 m

1 m

$$E = \frac{p}{4\pi r^2}$$

$$r^2 = \frac{p}{4\pi E}$$

$$r = \sqrt{\frac{p}{4\pi E}} = \sqrt{\frac{2400}{4\pi(37)}} = 2.27m$$





السؤال (5)

In the adjacent figure, if (r) decreases to (0.25 m), what is the illuminance of the ball?

في الشكل المجاور، اذا انخفض (r) الى (0.25 m) فما هو اناره الكره ؟

Luminous flux $P = 1750 \text{ lm}$



Illuminance
 $E_1 = \frac{1750}{4\pi} \text{ lx}$

2224 lx

556 lx

8.69 lx

139 lx

$$E = \frac{p}{4\pi r^2}$$

$$E = \frac{1750}{4\pi(0.25)^2} = 2228 \text{ lx}$$





السؤال (13)

A light source has a luminous intensity of (64 cd) and is located at a height of (3 m) above a plate. What is the luminous intensity in lux?

مصدر ضوئي شدة اضاءته (64 cd) ويقع على ارتفاع (3m) فوق لوحة , ما مقدار شدة الاستضاءة بوحدة اللوكس ؟

$$8.2 \times 10^{-2} \text{ lx}$$

$$5.1 \text{ lx}$$

$$5.6 \times 10^{-1} \text{ lx}$$

$$7.1 \text{ lx}$$

$$E = \frac{I}{r^2}$$

$$E = \frac{64}{3^2} = 7.11 \text{ Lx}$$

A 64-cd point source of light is 3.0 m away from a painting.
What is the illumination on the painting in lux?





You shine an $8.0 \times 10^2 \text{ lm}$ light bulb onto a person who is standing 2.0 m away. What is the illuminance of the light on the person?

$$E = \frac{p}{4\pi r^2}$$

$$E = \frac{8.0 \times 10^2}{4\pi(2)^2} = 15.9 \text{ lx}$$





A candle has a luminous flux of $p_1=1500$ lm and is placed at a distance of $r=0.34$ m from a screen. It produces the same illuminance as a lamp with luminous flux $p_2=2500$ lm, placed at a distance d from the screen.

(a) Find the distance d .

$$E_1 = E_2$$

$$\frac{p_1}{4\pi r_1^2} = \frac{p_2}{4\pi r_2^2}$$

$$\frac{p_1}{r_1^2} = \frac{p_2}{r_2^2}$$

$$r_2^2 = p_2 \frac{r_1^2}{p_1}$$

$$r_2 = \sqrt{p_2 \frac{r_1^2}{p_1}}$$

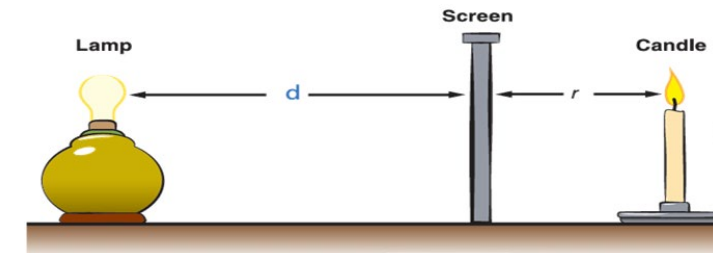
$$r_2 = \sqrt{(2500) \frac{(0.34)^2}{(1500)}}$$

$$r_2 = 0.439 \text{ m}$$

(b) If the lamp is moved closer to the screen so that its distance becomes 0.31 m, find the ratio of the new illuminance to the previous one.

$$\frac{E_A}{E_B} = \frac{\cancel{p} / 4\pi r_A^2}{\cancel{p} / 4\pi r_B^2}$$

$$\frac{E_A}{E_B} = \frac{r_B^2}{r_A^2}$$



$$\frac{E_A}{E_B} = \frac{(0.31)^2}{(0.439)^2} = 0.5$$

$$E_A = 0.5 E_B$$



LO:

23	-Calculate the refractive index of a medium using a suitable mathematical representation ($n = c/v$). -State and apply Snell's law of refraction. -Calculate the critical angle using Snell's law.	Practice problems Student Textbook	46 47,48
----	---	---------------------------------------	-------------

EX:

P:

**EXAMPLE PROBLEM 4** (page 46)

ANGLE OF REFRACTION A beam of light in air hits a sheet of float glass at an angle of 30.0° . What is the angle of refraction of the light ray?

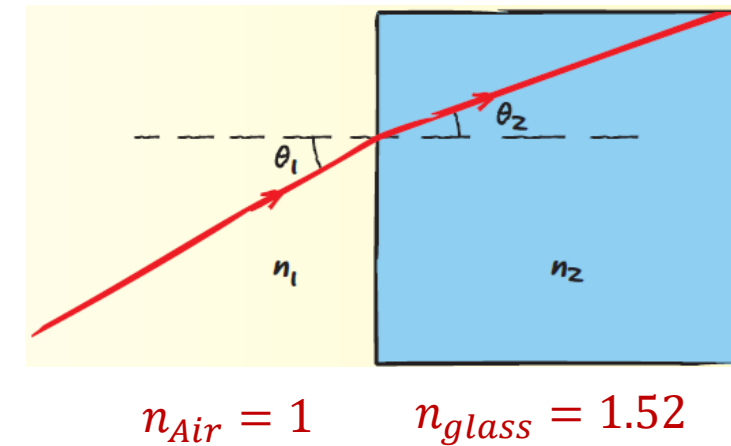
$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\sin \theta_2 = \frac{n_1 \sin \theta_1}{n_2}$$

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

$$\theta_2 = \sin^{-1} \left(\frac{(1) \sin 30}{1.52} \right)$$

$$\theta_2 = 19.2^\circ$$



**PRACTICE PROBLEMS** (page 46)

30. A laser beam in air enters ethanol at an angle of incidence of 37.0° . What is the angle of refraction?

$$n_{\text{ethanol}} = 1.36$$

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

$$\sin \theta_2 = \frac{n_1 \sin \theta_1}{n_2}$$

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

$$\theta_2 = \sin^{-1} \left(\frac{(1) \sin 37}{1.36} \right) = 26.3^\circ$$

31. As light travels from air into water, the angle of refraction is 25.0° to the normal. Find the angle of incidence.

$$n_{\text{water}} = 1.33$$

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

$$\sin \theta_1 = \frac{n_2 \sin \theta_2}{n_1}$$

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

$$\theta_1 = \sin^{-1} \left(\frac{(1.33) \sin 25}{1} \right) = 34.2^\circ$$



**PRACTICE PROBLEMS** (page 46)

32. Light in air enters a diamond facet at 45.0° .
What is the angle of refraction?

$$n_{\text{diamond}} = 2.42$$

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

$$\sin \theta_2 = \frac{n_1 \sin \theta_1}{n_2}$$

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

$$\theta_2 = \sin^{-1} \left(\frac{(1) \sin 45}{2.42} \right) = 17^\circ$$

33. A block of unknown material is submerged in water. Light in the water enters the block at an angle of incidence of 31° . The angle of refraction of the light in the block is 27° . What is the index of refraction of the material of the block?

$$n_{\text{water}} = 1.33$$

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

$$n_2 = \frac{n_1 \sin \theta_1}{\sin \theta_2}$$

$$n_2 = \frac{(1.33) \sin 31}{\sin 27} = 1.5$$



**PRACTICE PROBLEMS** (page 46)

34. CHALLENGE Light travels from air into another medium. The angle of incidence is 45.0° and the angle of refraction is 27.7° . What is the other medium?

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

$$n_2 = \frac{n_1 \sin \theta_1}{\sin \theta_2}$$

$$n_2 = \frac{(1) \sin 45}{\sin 27.7} = 1.52$$

From the table in the book
the material is float glass



Check Your Progress (page 50)

35. Index of refraction You notice that when a light ray enters a certain liquid from water, it is bent toward the normal, but when it enters the same liquid from float glass, it is bent away from the normal. What can you conclude about the liquid's index of refraction?

$$n_{\text{water}} < n_{\text{liquid}} < n_{\text{glass}}$$

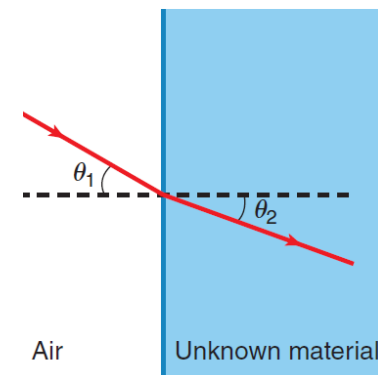
therefore, n_{liquid} must be between 1.33 and 1.52.

23. Index of refraction A ray of light in air has an angle of incidence of 30.0° on a block of unknown material and an angle of refraction of 20.0° , as shown in **Figure 10**. What is the index of refraction of the material?

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

$$n_2 = \frac{n_1 \sin \theta_1}{\sin \theta_2}$$

$$n_2 = \frac{(1) \sin 30}{\sin 20} = 1.46$$



**Check Your Progress** (page50)

37. Angle of Refraction A beam of light passes from water into polyethylene with $n = 1.50$. If $\theta_1 = 57.5^\circ$, what is the angle of refraction in the polyethylene?

$$n_{\text{water}} = 1.33$$

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

$$\sin \theta_2 = \frac{n_1 \sin \theta_1}{n_2}$$

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

$$\theta_2 = \sin^{-1} \left(\frac{(1.33) \sin 57.5}{1.5} \right) = 48.4^\circ$$





Extra questions

1. What factor determine whether the light will bend toward or away from the normal.

The relative values of the refractive index

2. Although the light coming from the Sun is refracted while passing through Earth's atmosphere, the light is not separated into its spectrum. What does this indicate about the speeds of different colors of light traveling through air?

The speeds of the different colors of light traveling through air are the same.



**Extra questions**

3. Aquarium Tank A thick sheet of plastic, $n = 1.5$, is used as the side of an aquarium tank. Light reflected from a fish in the water $n=1.33$ has an angle of incidence of 35.0° . At what angle does the light enter the air?

$$n_w \sin \theta_w = n_p \sin \theta_p$$

$$\sin \theta_p = \frac{n_w \sin \theta_w}{n_p}$$

$$\theta_p = \sin^{-1} \left(\frac{n_w \sin \theta_w}{n_p} \right)$$

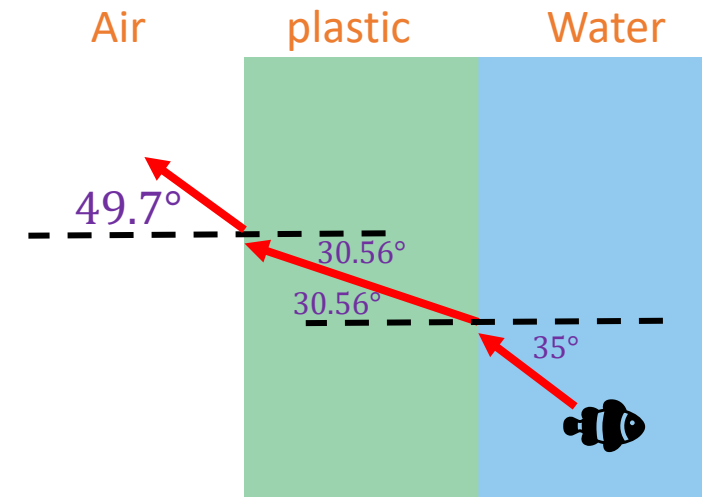
$$\theta_p = \sin^{-1} \left(\frac{(1.33) \sin 35}{1.5} \right) = 30.56^\circ$$

$$n_p \sin \theta_p = n_A \sin \theta_A$$

$$\sin \theta_A = \frac{n_p \sin \theta_p}{n_A}$$

$$\theta_A = \sin^{-1} \left(\frac{n_p \sin \theta_p}{n_A} \right)$$

$$\theta_A = \sin^{-1} \left(\frac{(1.5) \sin 30.56}{1} \right) = 49.7^\circ$$



**Extra questions**

8. Light travels from flint glass into ethanol. The angle of refraction in the ethanol is 25.0° . What is the angle of incidence in the glass?

$$n_{\text{glass}} = 1.62$$

$$n_{\text{ethanol}} = 1.36$$

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

$$\sin \theta_1 = \frac{n_2 \sin \theta_2}{n_1}$$

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

$$\theta_1 = \sin^{-1} \left(\frac{(1.36) \sin 25}{1.62} \right) = 20.8^\circ$$

9. A flashlight beam is directed at a swimming pool in the dark at an angle of 46° with respect to the normal to the surface of the water. What is the angle of refraction of the beam in the water? (The refractive index for water is 1.33)

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

A. 18° B. 30° C. 33° D. 44°

$$\sin \theta_2 = \frac{n_1 \sin \theta_1}{n_2}$$

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

$$\theta_1 = \sin^{-1} \left(\frac{(1) \sin 46}{1.33} \right) = 32.7^\circ$$





Extra questions

10. A beam of light strikes the flat, glass side of a waterfilled aquarium at an angle of 40.0° to the normal. For glass, $n = 1.50$, for water $n=1.33$.

a. At what angle does the beam enter the glass?

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

$$\sin \theta_2 = \frac{n_1 \sin \theta_1}{n_2}$$

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

$$\theta_2 = \sin^{-1} \left(\frac{(1) \sin 40}{1.5} \right) = 25.4^\circ$$

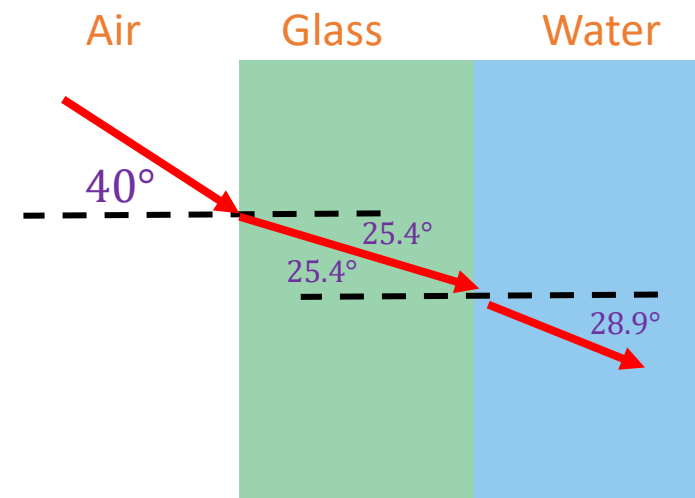
b. At what angle does the beam enter the water?

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

$$\sin \theta_2 = \frac{n_1 \sin \theta_1}{n_2}$$

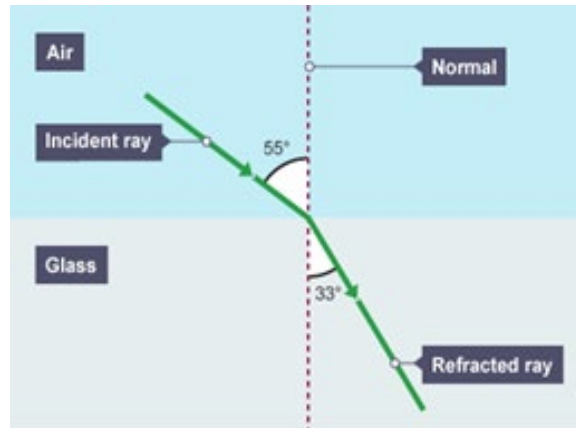
$$\theta_2 = \sin^{-1} \left(\frac{n_1 \sin \theta_1}{n_2} \right)$$

$$\theta_2 = \sin^{-1} \left(\frac{(1.5) \sin 25.4}{1.33} \right) = 28.9^\circ$$



Extra questions

13. A beam of light hits a glass block if the angle of incidence in air is 55° and the angle of refraction inside the block is 33° calculate the refractive index for the glass?



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

$$n_2 = \frac{n_1 \sin \theta_1}{\sin \theta_2}$$

$$n_2 = \frac{(1) \sin 55}{\sin 33} = 1.5$$

14. The diagram shows what happens to a ray of light as it meets the boundary between air and water. The refractive index of the water is 1.3 . Calculate the angle of refraction r

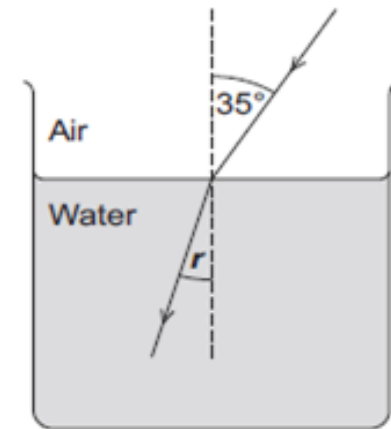
$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

$$\sin \theta_2 = \frac{n_1 \sin \theta_1}{n_2}$$

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

$$\theta_2 = \sin^{-1} \left(\frac{(1) \sin 35}{1.3} \right) = 26.1^\circ$$

Figure 2



**Extra questions**

15. The light ray shown in the figure below makes an angle of 20.0° with the normal line at the boundary of linseed oil and water. Determine the angles θ_1 , and θ_2 . Note that $n = 1.48$ for linseed oil.

$$n_1 \sin \theta_1 = n_{oil} \sin \theta_{oil}$$

$$\sin \theta_1 = \frac{n_{oil} \sin \theta_{oil}}{n_1}$$

$$\theta_1 = \sin^{-1} \left(\frac{n_{oil} \sin \theta_{oil}}{n_1} \right)$$

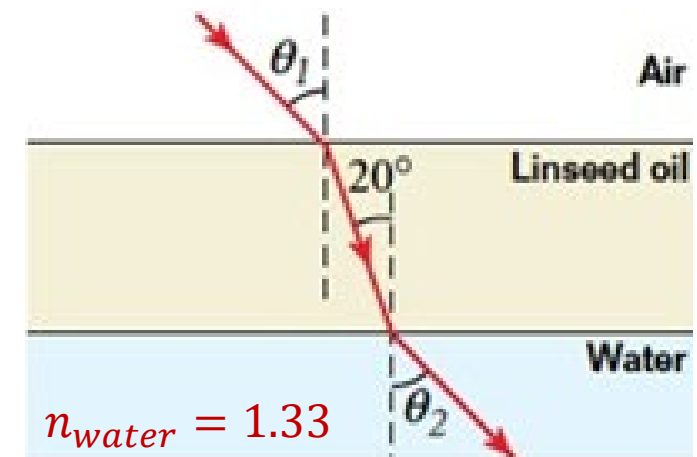
$$\theta_1 = \sin^{-1} \left(\frac{(1.48) \sin 20}{1} \right) = 30.41^\circ$$

$$n_{oil} \sin \theta_{oil} = n_2 \sin \theta_2$$

$$\sin \theta_2 = \frac{n_{oil} \sin \theta_{oil}}{n_2}$$

$$\theta_2 = \sin^{-1} \left(\frac{n_{oil} \sin \theta_{oil}}{n_2} \right)$$

$$\theta_2 = \sin^{-1} \left(\frac{(1.48) \sin 20}{1.33} \right) = 22.37^\circ$$



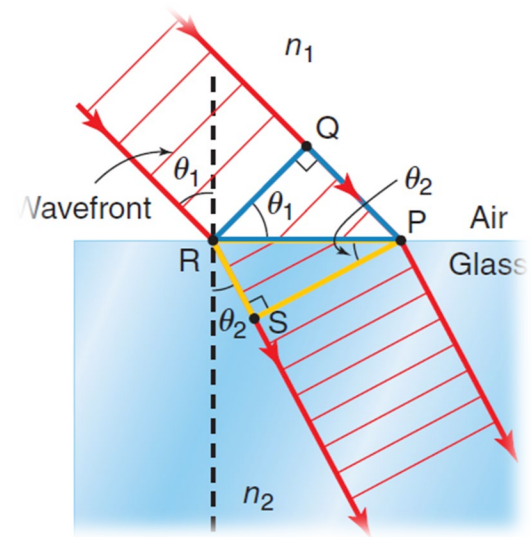


The Meaning of the Index of Refraction:

The index of refraction describes how much light bends as it enters a medium.

Wave model of light:

light **interacts with atoms** in such a way that it **moves more slowly** through a medium than it does through a vacuum.



$$\lambda = \frac{c}{f} \quad \text{In vacuum}$$

$$\lambda = \frac{v}{f} \quad \text{Other mediums}$$

When light cross the boundary between vacuum and other medium
The velocity of the light decrease, the wavelength decrease, but frequency
remain the same

Index of Refraction :

The index of refraction of a medium is equal to the speed of light in a vacuum divided by the speed of light in the medium.

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





Check Your Progress (page50)

38. Speed of Light What is the speed of light in chloroform ($n = 1.51$)?

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

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

$$v = \frac{3 \times 10^8}{1.51} = 1.98 \times 10^8 \text{ m/s}$$



**Extra questions**

1. The speed of light in diamond is $1.24 \times 10^8 \text{ m/s}$. What is the index of refraction of diamond?

A. 0.0422

B. 0.413

C. 1.24

D. 2.42

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

$$n = \frac{3 \times 10^8}{1.254 \times 10^8} = 2.42$$

2. Find the speed of light in antimony trioxide if it has an index of refraction of 2.35.

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

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

$$v = \frac{3 \times 10^8}{2.35} = 1.27 \times 10^8 \text{ m/s}$$



**Extra questions**

3. The speed of light in clear plastic is $1.9 \times 10^8 \text{ m/s}$. A ray of light strikes the plastic at an angle of 22.0° . At what angle is the ray refracted?

$$n_{\text{plastic}} = \frac{c}{v}$$

$$n_{\text{plastic}} = \frac{3 \times 10^8}{1.9 \times 10^8} = 1.58$$

$$n_{\text{air}} \sin \theta_{\text{air}} = n_{\text{plastic}} \sin \theta_{\text{plastic}}$$

$$\sin \theta_{\text{plastic}} = \frac{n_{\text{air}} \sin \theta_{\text{air}}}{n_{\text{plastic}}}$$

$$\theta_{\text{plastic}} = \sin^{-1} \left(\frac{n_{\text{air}} \sin \theta_{\text{air}}}{n_{\text{plastic}}} \right)$$

$$\theta_{\text{plastic}} = \sin^{-1} \left(\frac{(1) \sin 22}{1.58} \right) = 13.7^\circ$$



**Extra questions**

4. The index of refraction of float glass is 1.53 for violet light, and it is 1.51 for red light. What is the speed of violet light in float glass? What is the speed of red light in float glass?

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

$$v_{\text{violet}} = \frac{c}{n_{\text{violet}}}$$

$$v_{\text{violet}} = \frac{3 \times 10^8}{1.53} = 1.96 \times 10^8 \text{ m/s}$$

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

$$v_{\text{red}} = \frac{c}{n_{\text{red}}}$$

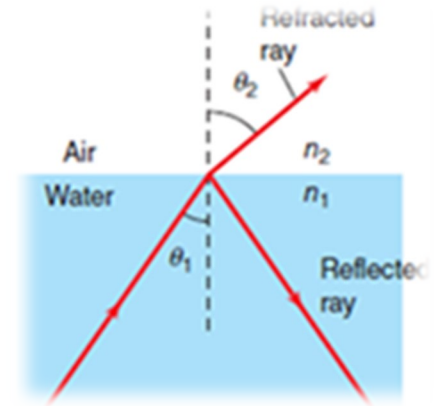
$$v_{\text{red}} = \frac{3 \times 10^8}{1.51} = 1.98 \times 10^8 \text{ m/s}$$



Critical angle:

When light strikes a transparent boundary, some of the light is (transmitted –refracted) and some is reflected.

As light travels from a medium of higher (n) to one of lower (n), the angle of refraction (θ_2) is larger than the angle of incidence (θ_1).



If the incident angle (θ_1) increase what will happen to the angle of refraction (θ_2).

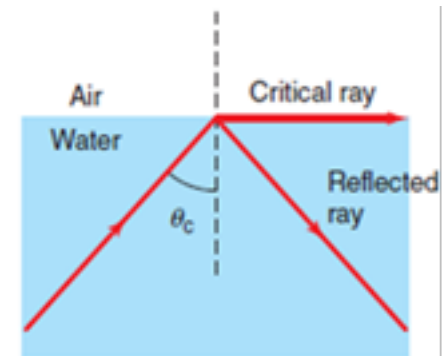
It will increase.

Critical angle:

This leads to an interesting phenomenon. At a certain angle of incidence known as the **critical angle** (θ_c), the refracted light ray lies along the boundary of the two mediums.

When $\theta_1 = \theta_c$ then, $\sin \theta_2 = 1$ and, $\theta_2 = 90^\circ$

$$\sin \theta_c = \frac{n_2}{n_1}$$



A ray refracted along the boundary of the medium forms the critical angle.



Total Internal Reflection:

Total internal reflection:

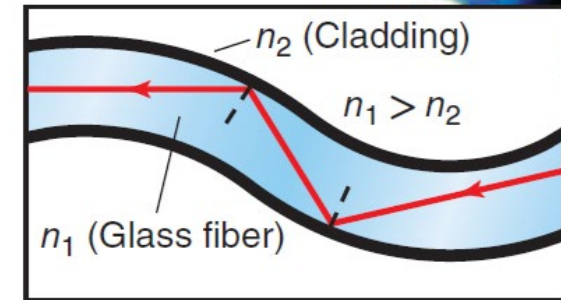
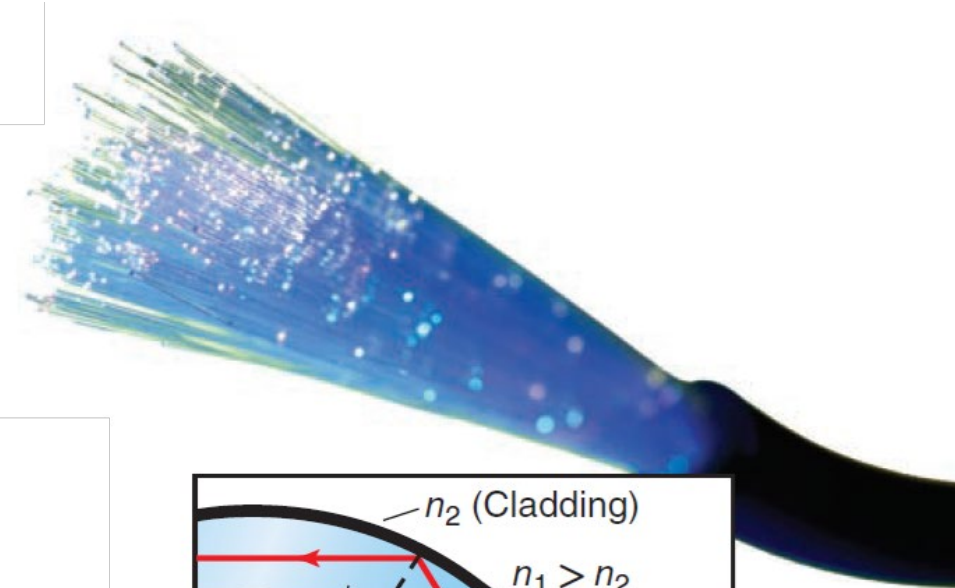
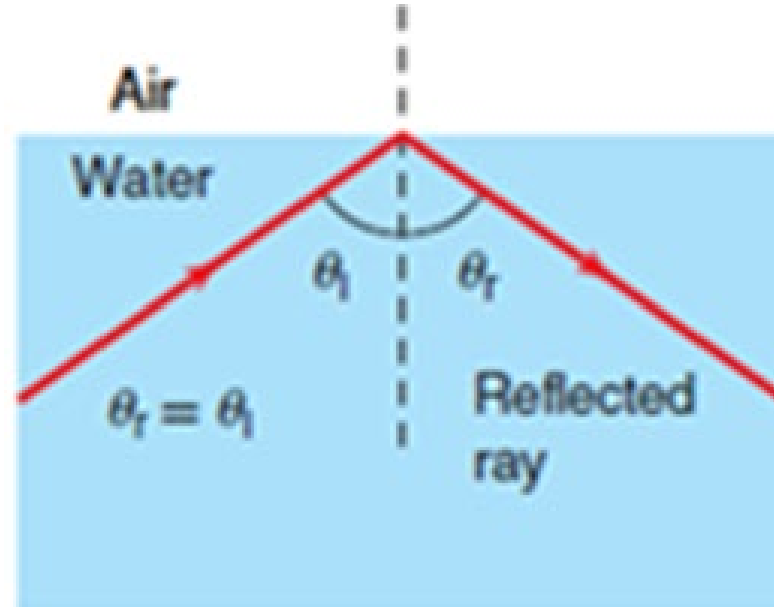
occurs when light traveling from a region of a higher index of refraction to a region of a lower index of refraction strikes the boundary at an **angle greater than the critical angle** such that all light **reflects back** into the region of the higher index of refraction.

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

$$\theta_1 > \theta_c$$

$$\sin \theta_2 > 1$$

Total internal reflection



REAL-WORLD
PHYSICS





Extra questions

1. A light ray enters a block of float glass ($n=1.52$), as illustrated in the **Figure**. Use a ray diagram to trace the path of the ray until it leaves the glass.

From air to the glass

$$n_a \sin \theta_a = n_g \sin \theta_g$$

$$\sin \theta_g = \frac{n_a \sin \theta_a}{n_g}$$

$$\theta_g = \sin^{-1} \left(\frac{(1) \sin 45}{1.52} \right)$$

$$\theta_g = 28^\circ$$

From glass to air

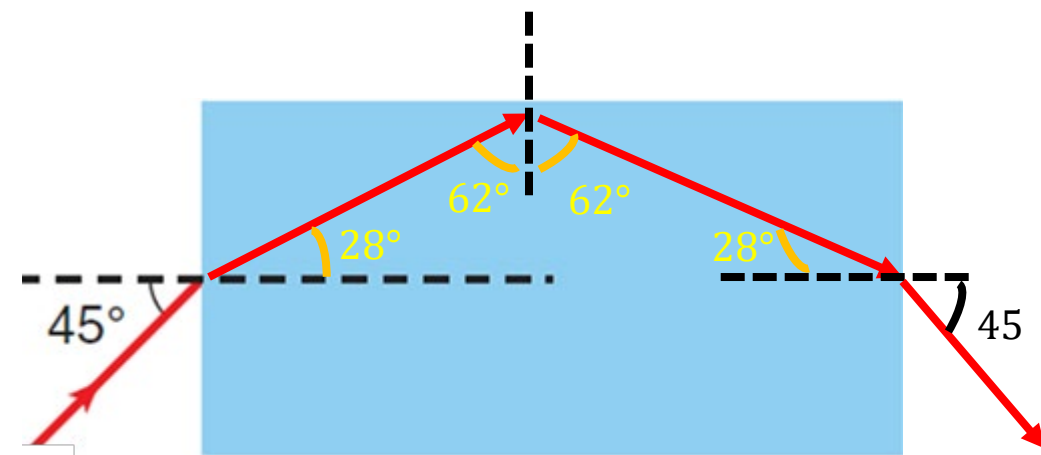
$$n_g \sin \theta_g = n_a \sin \theta_a$$

$$\theta_a = \sin^{-1} \left(\frac{(1.52) \sin 62}{1} \right)$$

$$\theta_a = \sin^{-1}(1.34)$$

The value $\sin^{-1}(1.34)$ is not defined.

Therefore, total internal reflection occurs.



From glass to air

$$n_g \sin \theta_g = n_a \sin \theta_a$$

$$\theta_a = \sin^{-1} \left(\frac{(1.52) \sin 28}{1} \right)$$

$$\theta_a = 45^\circ$$



**Extra questions**

2. Find the critical angle for a diamond ($n=2.42$) in air.

$$\sin \theta_c = \frac{n_2}{n_1}$$

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

$$\theta_c = \sin^{-1} \left(\frac{1}{2.42} \right) = 24.4^\circ$$

3. A ray of light in water has an angle of incidence of 55.0° . What is the angle of refraction in air?

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

$$\sin \theta_2 = \frac{n_1 \sin \theta_1}{n_2}$$

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

$$\theta_2 = \sin^{-1} \left(\frac{(1.33) \sin 55}{1} \right)$$

$$\theta_2 = \sin^{-1}(1.09)$$

The value $\sin^{-1}(1.09)$ is not defined.

Therefore, total internal reflection occurs.



**Extra questions**

4. The critical angle for a special glass in air is 41.0° . What is the critical angle if the glass is immersed in water?

$$\sin \theta_c = \frac{n_a}{n_g}$$

$$n_g = \frac{n_a}{\sin \theta_c}$$

$$n_g = \frac{1}{\sin(41)} = 1.524$$

$$\sin \theta_c = \frac{n_w}{n_g}$$

$$\theta_c = \sin^{-1} \left(\frac{n_w}{n_g} \right)$$

$$\theta_c = \sin^{-1} \left(\frac{1.33}{1.524} \right) = 60.8^\circ$$

5. How does the size of the critical angle change as the index of refraction of the medium the ray is traveling into increases?

The critical angle decreases as the index of refraction increases.



**Extra questions**

6. A critical angle of 45.0° is found for light traveling through a block of float glass ($n=1.52$) into another medium. What is the index of refraction for the medium the light is traveling into?

$$\sin \theta_c = \frac{n_{\text{medium}}}{n_{\text{glass}}}$$

$$n_{\text{medium}} = (n_{\text{glass}})(\sin \theta_c)$$

$$n_{\text{medium}} = (1.52)(\sin(45)) = 1.07$$

7. The critical angle for total internal reflection at a diamond-air boundary is 24.4° . What is the angle of refraction in the air if light enters the boundary at an angle of 20.0° ?

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

$$n_{\text{diamond}} = 2.42$$

$$\sin \theta_2 = \frac{n_1 \sin \theta_1}{n_2}$$

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

$$\theta_2 = \sin^{-1} \left(\frac{(2.42) \sin 20}{1} \right) = 55.86$$



**Extra questions**

8. What is the critical angle for total internal reflection when light travels from glass ($n = 1.52$) to water ($n = 1.33$)?

A. 29.0°

$$\sin \theta_c = \frac{n_{\text{water}}}{n_{\text{glass}}}$$

B. 41.2°

C. 48.8°

$$\theta_c = \sin^{-1} \left(\frac{n_{\text{water}}}{n_{\text{glass}}} \right)$$

D. 61.0°

$$\theta_c = \sin^{-1} \left(\frac{1.33}{1.524} \right) = 60.8^\circ$$



LO:

24	-Draw a ray to find the image of an object located at different distances from a lens and determine the location and properties of the formed image. -Apply the thin lens equation to calculate the image distance, the object distance, or the focal length of a convex or a concave lens using appropriate algebraic signs for focal length and corresponding distances -Calculate the magnification produced by a thin convex or concave lens.	Student Textbook	52,53
		Example problem5	
		Practice problems	55
		Check your progress	60
		45,55,51,55,56	

EX:

P:



Ray Diagrams for Convex lenses:

In convex lenses light rays coming from the object to the lens should follow these rules:

Ray 1: parallel to the principal axis.

This ray will refract passing through the focal point.

Ray 2: passing through the focal point.

This ray will refract parallel to the principal axis.

Ray 3: passing through the geometrical center of the lens.

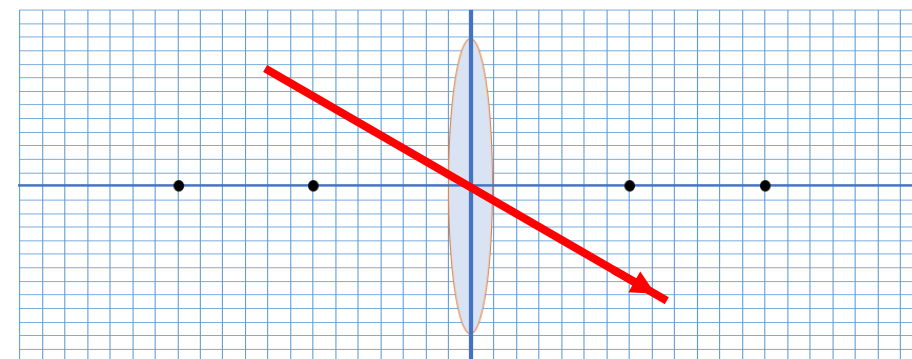
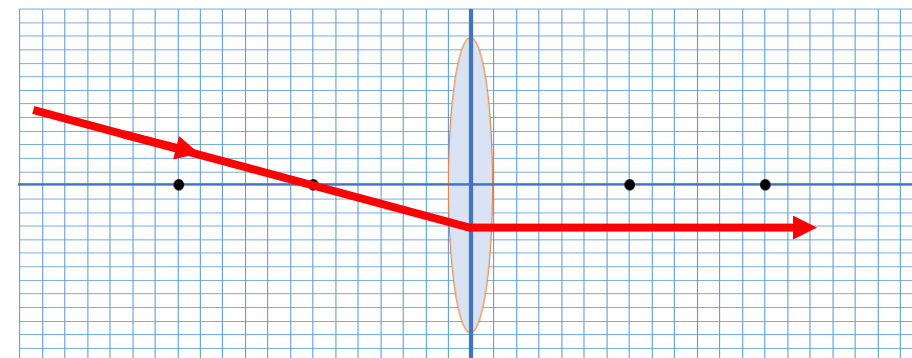
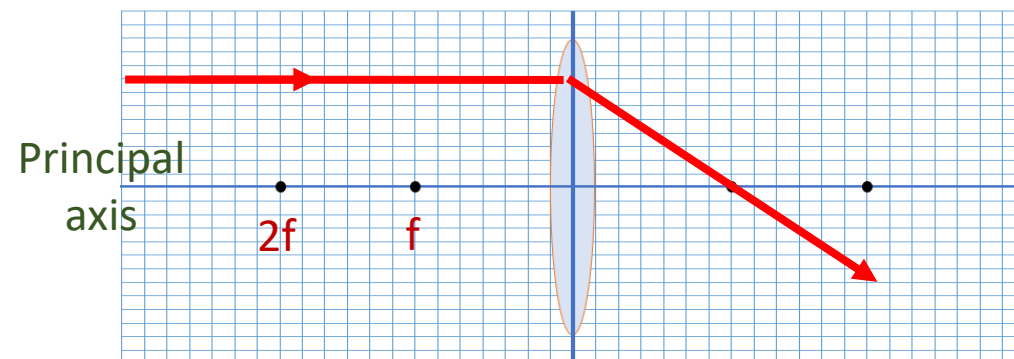
This ray will continue without refraction

To sketch a ray diagram, you need only two of the three rays.

Image properties in convex lens depend on:

The object's position

Image type	Real	OR	Virtual
Orientation	Upright	OR	Inverted
Size	Enlarged	OR	Reduced



Position 1 : object located at a distance greater than twice the focal length.

Ray 1: from the top of the object parallel to the principal axis.

This ray will refract passing through the focal point.

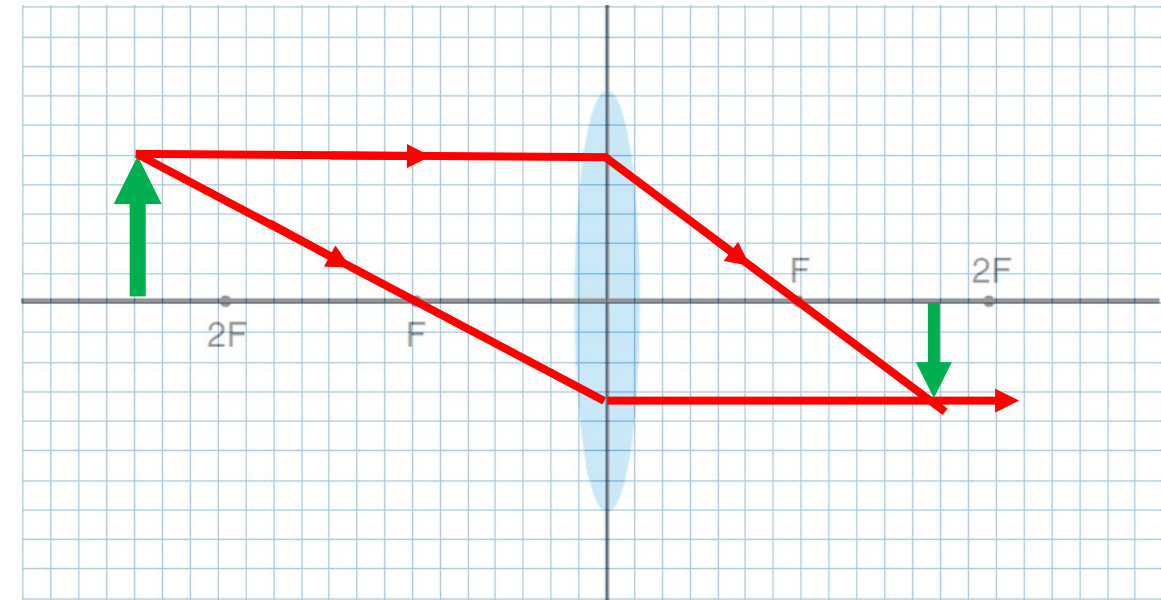
Ray 2: from the top of the object passing through the focal point.

This ray will refract parallel to the principal axis.

The point where the refracted rays converge represent the point where the light rays came from, use it to draw the object image.

Based on the diagram, What are the image properties:

$x_0 > 2F$ The object is behind the center



Real	OR	Virtual
Upright	OR	Inverted
Enlarged	OR	Reduced in size



Position 2: object located at a distance equal to twice the focal length.

Ray 1: from the top of the object parallel to the principal axis.

This ray will refract passing through the focal point.

Ray 2: from the top of the object passing through the focal point.

This ray will refract parallel to the principal axis.

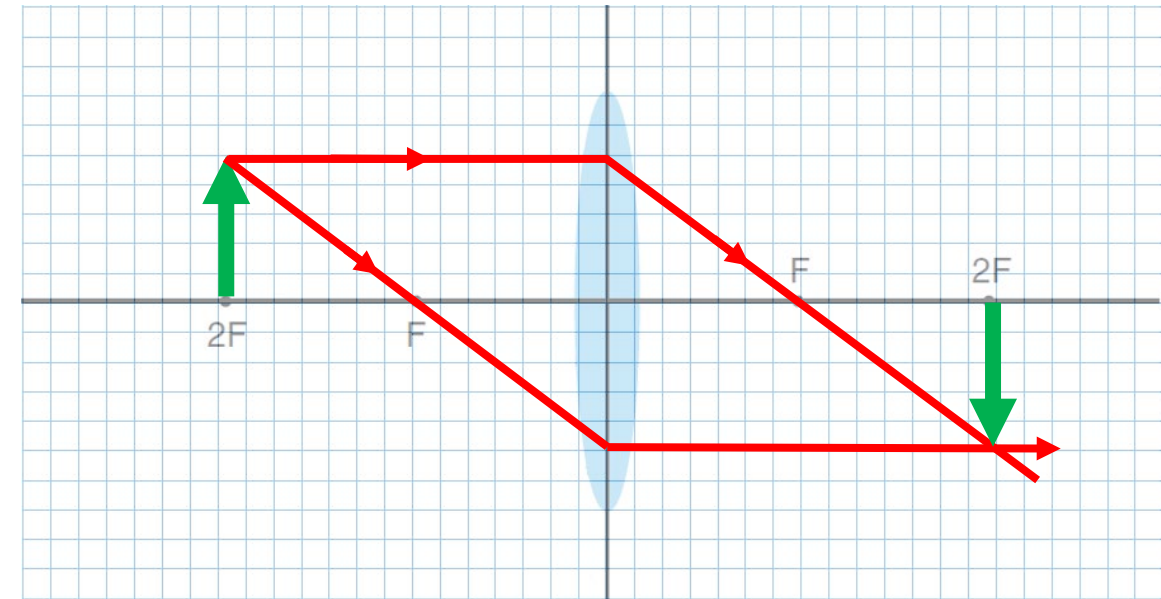
The point where the refracted rays converge represent the point where the light rays came from, use it to draw the object image.

Based on the diagram, What are the image properties:

Real	OR	Virtual
Upright	OR	Inverted
Enlarged	OR	Reduced in size

Same size as the object.

$x_0 = 2F$ The object is at the center



Position 3: object located at a distance greater than the focal length and less than twice the focal length.

Ray 1: from the top of the object parallel to the principal axis.

This ray will refract passing through the focal point.

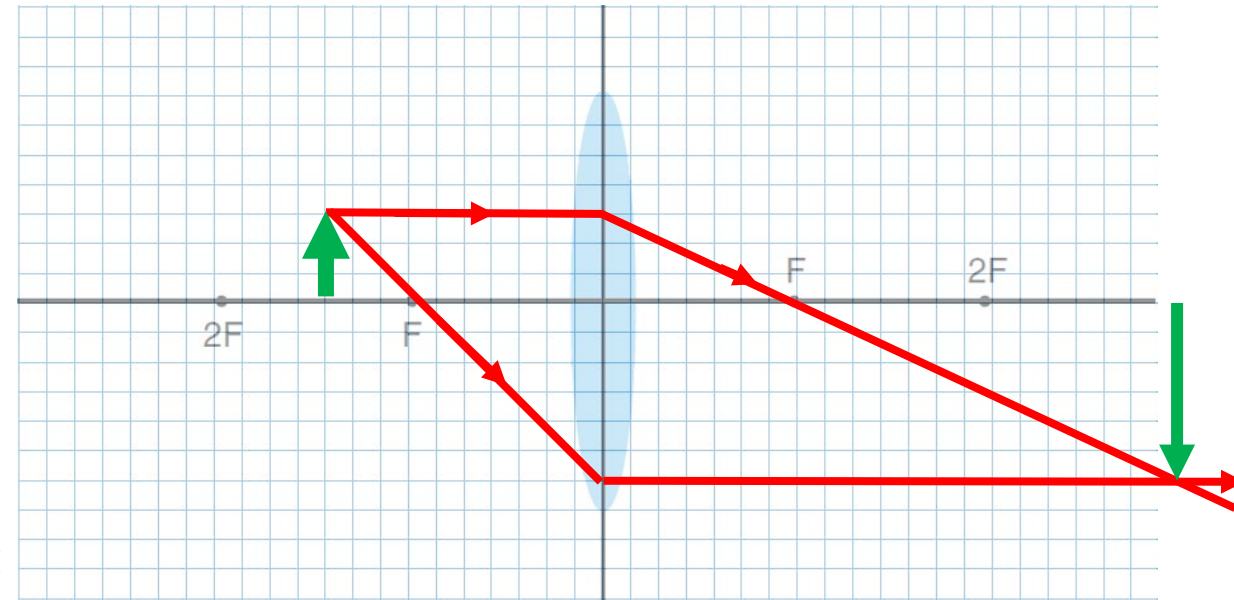
Ray 2: from the top of the object passing through the focal point.

This ray will refract parallel to the principal axis.

The point where the refracted rays converge represent the point where the light rays came from, use it to draw the object image.

Based on the diagram, What are the image properties:

$2F > x_0 > F$ the object is between the center and the focal



Real	OR	Virtual
Upright	OR	Inverted
Enlarged	OR	Reduced in size



Position 4: object located at the focal length.

Ray 1: from the top of the object parallel to the principal axis.

This ray will refract passing through the focal point.

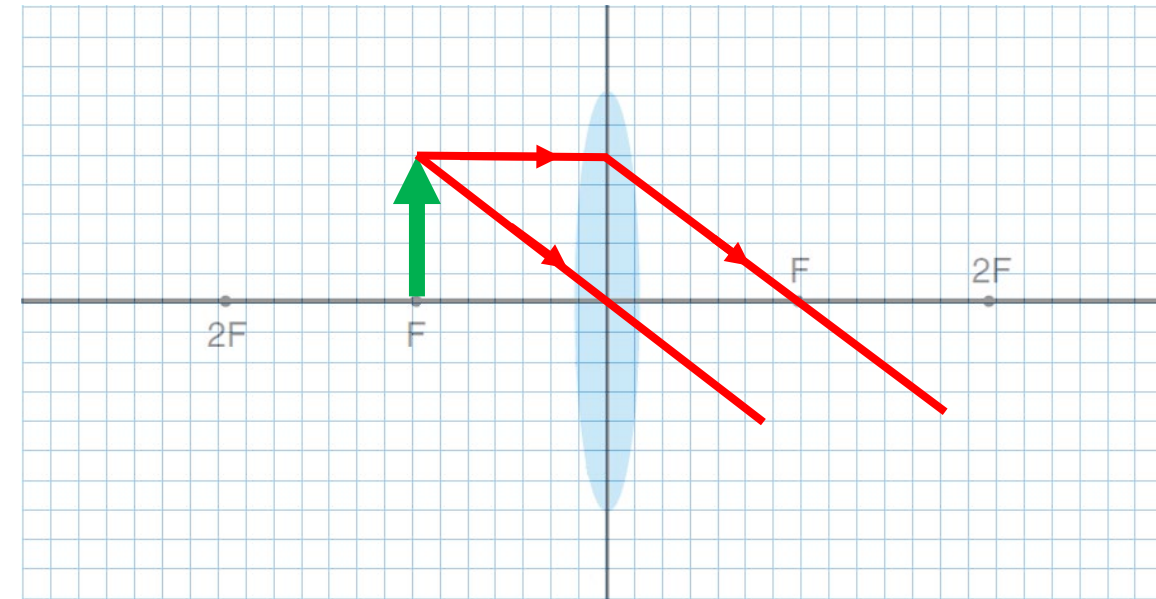
Ray 2: from the top of the object passing through the focal point.

This ray will refract parallel to the principal axis.

The reflected rays will not converge (light rays are parallel to each other)

No image formed.

$x_0 = F$ the object is at the focal



Position 5: object located at a distance less than the focal length.

Ray 1: from the top of the object parallel to the principal axis.

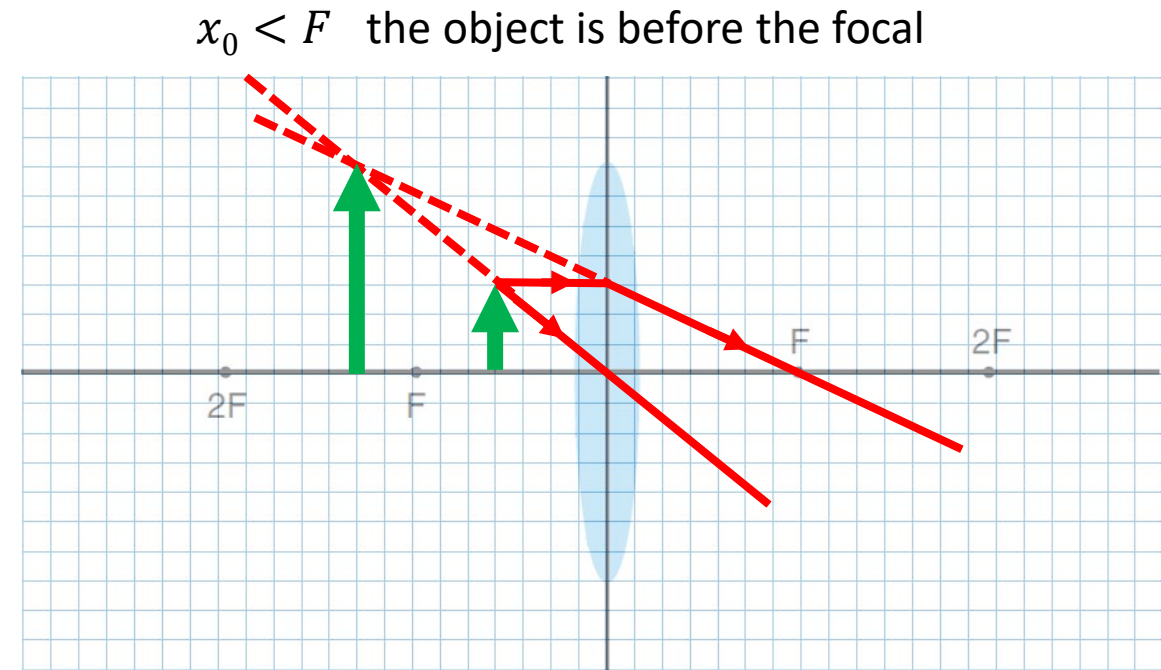
This ray will refract passing through the focal point.

Ray 2: from the top of the object passing through the center of the lens.

This ray will not refract.

The two rays will not converge, but if you extend the two rays the extended lines will converge. Then you can draw the image.

Based on the diagram, What are the image properties:



Real	OR	Virtual
Upright	OR	Inverted
Enlarged	OR	Reduced in size

Ray Diagrams for Concave lenses:

In concave lenses the light rays always diverge.

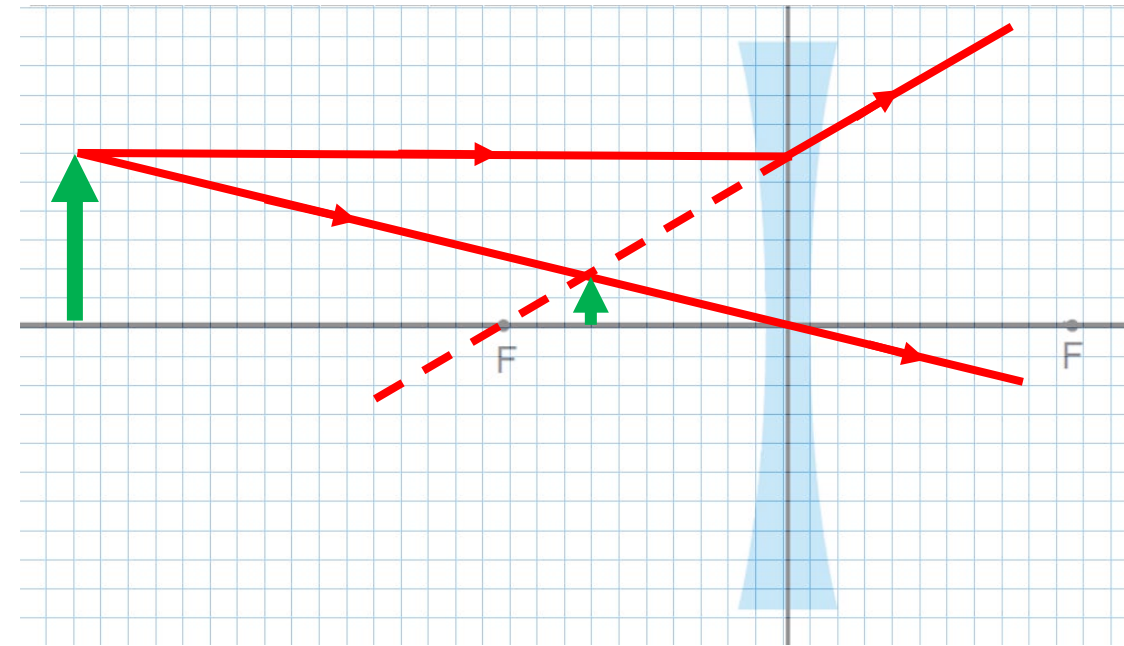
Ray 1: parallel to the principal axis.

This ray will reflect away, and its extension is coming from the focal point.

Ray 2: as if its passing through center of the lens.

This ray will not reflect.

The extension of ray 1 and the second ray will converge as shown. Then you can draw the image.

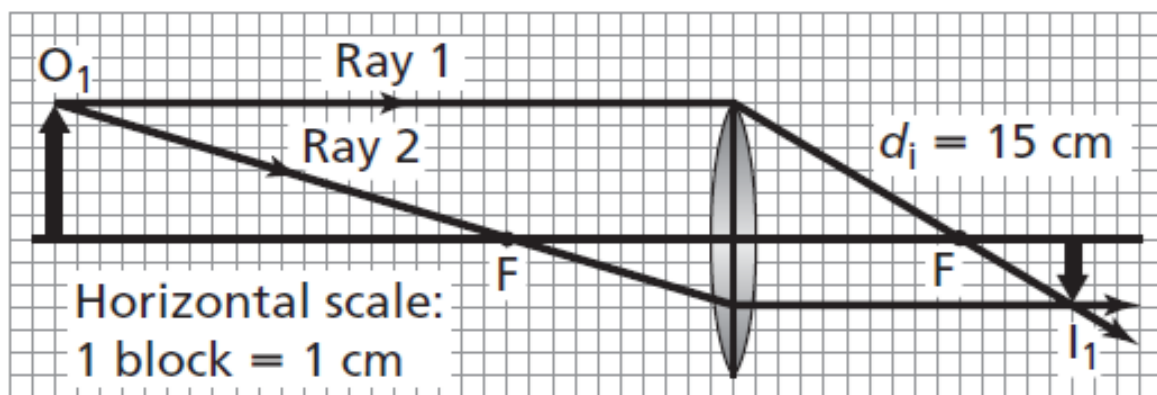


Based on the diagram, What are the image properties:

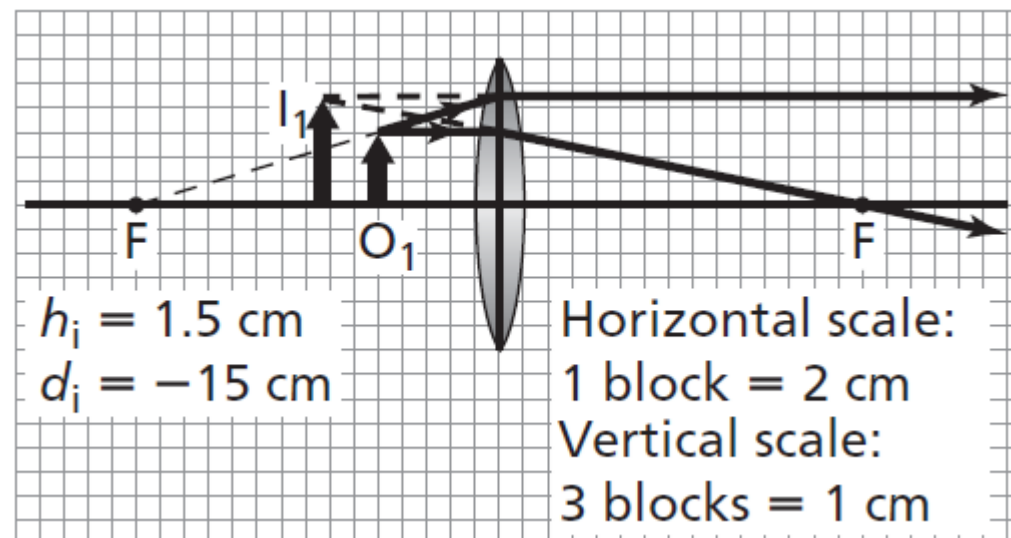
Real	OR	Virtual
Upright	OR	Inverted
Enlarged	OR	Reduced in size

**PRACTICE PROBLEMS** (page 55)

47. Use a scale ray diagram to find the image position of an object that is 30 cm to the left of a convex lens with a 10 cm focal length.



48. **CHALLENGE** A magnifier with a focal length of 30 cm is used to view a 1 cm tall object. Use a ray diagram to determine the location and size of the image when the magnifier is positioned 10 cm from the object.



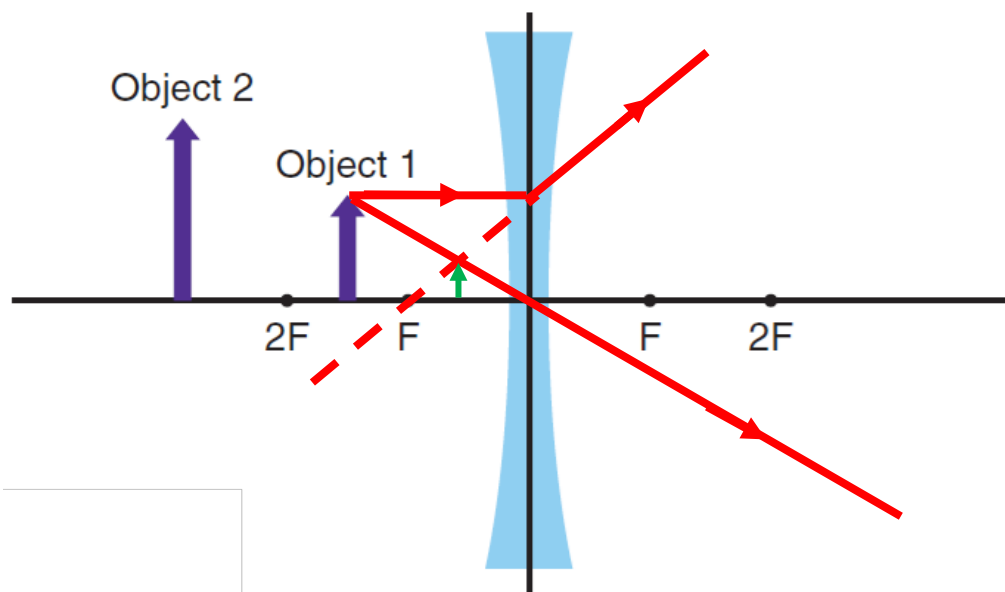
The location should be about 15 cm on the same side of the lens (15 cm) and the image should be upright and about 1.5 cm tall.



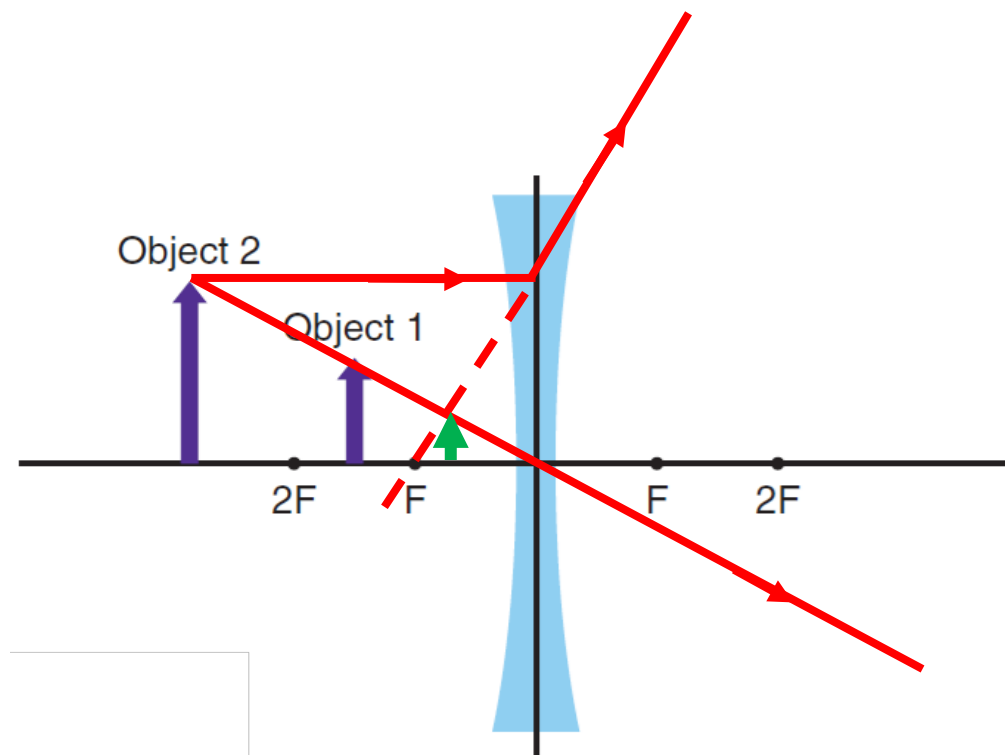


Check Your Progress (page60)

54. Type of Image Use the ray diagram in **Figure 39** to determine whether the image for object 1 will be reduced or enlarged, inverted or upright, and real or virtual. Do the same for object 2.



reduced , upright, virtual



reduced , upright, virtual



Thin lens equation:

Lenses can be constructed with a variety of shapes, but in this book, you will only consider thin lenses, with faces having spherical curvatures.

For lenses, **virtual images** are always on the same side of the lens as the object, which means the image position is **negative**.

Notice that a **concave lens produces only virtual images**, whereas a convex lens can produce real images or virtual images.

THIN LENS EQUATION

The inverse of the focal length of a spherical lens is equal to the sum of the inverses of the image position and the object position.

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

f : focal length

x_i : image position

x_o : object position

(+) for convex lens

(-) for concave lens

When virtual images are formed, the image position (x_i) has a negative value.



Thin lens equation:

Magnification (m), A property of spherical thin lenses that measures how much larger or smaller the image is than the object is magnification.

MAGNIFICATION

The magnification of an object by a spherical lens, defined as the image height divided by the object height, is equal to the negative of the image position divided by the object position.

$$m = \frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

m : magnification

h_i : image height

h_o : object height

(m) has a negative value, indicating that the image is inverted.

($m > 1$) Image larger than object (enlarged)

($m = 1$) Image is the same size as the object

($m < 1$) Image smaller than object (reduced)



EXAMPLE PROBLEM 5 (page 55)

AN IMAGE FORMED BY A CONVEX LENS

An object is placed 32.0 cm from a convex lens that has a focal length of 8.0 cm.

a. Where is the image?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$x_i = \frac{f x_o}{x_o - f}$$

$$x_i = \frac{(8)(32)}{32 - 8} = 11 \text{ cm}$$

b. If the object is 3.0 cm high, how tall is the image?

$$\frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

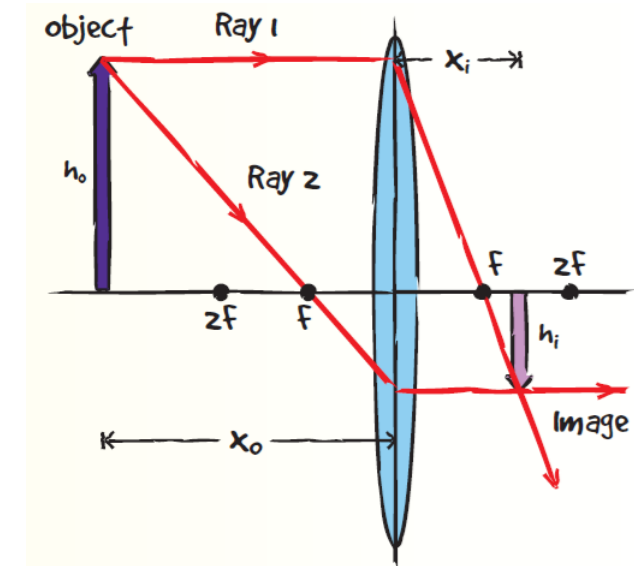
$$h_i = -\frac{h_o x_i}{x_o}$$

$$h_i = -\frac{(11)(3)}{(32)} = -1 \text{ cm}$$

c. What is the orientation of the image?

$$h_i = -1 \text{ cm}$$

inverted



**PRACTICE PROBLEMS** (page 55)

43. A 2.25 cm tall object is 8.5 cm to the left of a Convex lens of 5.5 cm focal length. Find the image position and height.

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$x_i = \frac{f x_o}{x_o - f}$$

$$x_i = \frac{(5.5)(8.5)}{8.5 - 5.5}$$

$$x_i = 15.6 \text{ cm}$$

$$\frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$h_i = -\frac{h_o x_i}{x_o}$$

$$h_i = -\frac{(15.6)(2.25)}{(8.5)}$$

$$h_i = -4.1 \text{ cm}$$

44. An object near a convex lens produces a 1.8 cm tall real image that is 10.4 cm from the lens and inverted. If the focal length of the lens is 6.8 cm, what are the object position and height?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$x_o = \frac{f x_i}{x_i - f}$$

$$x_o = \frac{(6.8)(10.4)}{10.4 - 6.8}$$

$$x_o = 19.6 \text{ cm}$$

$$\frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$h_o = -\frac{h_i x_o}{x_i}$$

$$h_o = -\frac{(-1.8)(-19.6)}{(10.4)}$$

$$h_o = -3.4 \text{ cm}$$



**PRACTICE PROBLEMS** (page 55)

45. An object is placed to the left of a **convex** lens with a **25 mm** focal length so that its **image is the same size as the object**. What are the image and object positions?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o} \quad x_i = x_o \quad \text{image is the same size as the object}$$

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

$$x_i = 2f$$

$$x_i = 2(25) = 50 \text{ mm}$$

46. Calculate the image position and height of a **2.0 cm** tall object located **25 cm** from a **convex** lens with a focal length of **5.0 cm**. What is the orientation of the image?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$x_i = \frac{f x_o}{x_o - f}$$

$$x_i = \frac{(5)(25)}{25 - 5}$$

$$x_i = 6.2 \text{ cm}$$

$$\frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$h_i = -\frac{h_o x_i}{x_o}$$

$$h_i = -\frac{(2)(6.2)}{(25)}$$

$$h_i = -0.5 \text{ cm}$$



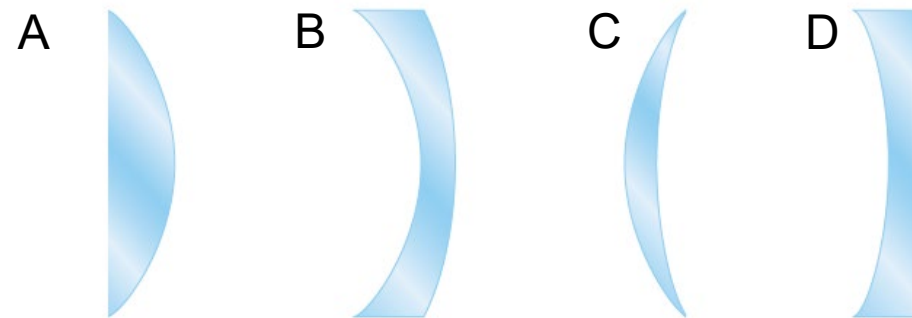


Check Your Progress (page 60)

49. lenses normally are used to produce images that are larger than the related objects, but they also can produce images that are smaller than the related objects. Explain.

If the object is located farther than twice the focal length from the lens, the size of the image is smaller than the size of the object.

50. Types of Lenses The cross sections of four different thin lenses are shown in Figure 38.



a. Which of these lenses, if any, are convex, or converging, lenses?

Lenses a and c are converging.

b. Which of these lenses, if any, are concave, or diverging, lenses?

Lenses b and d are diverging.



Check Your Progress (page60)

51. Image Position and Height An object is placed **1.5 m** from a **convex** lens with a focal length of **1.0 m**. Use the thin lens equation to determine the distance of the image from the lens. If the object height is **2.0 m**, what is the image height? Is the image real or virtual? Is the image inverted or upright?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$x_i = \frac{f x_o}{x_o - f}$$

$$x_i = \frac{(1)(1.5)}{1.5 - 1} = 3cm$$

$$\frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$h_i = -\frac{h_o x_i}{x_o}$$

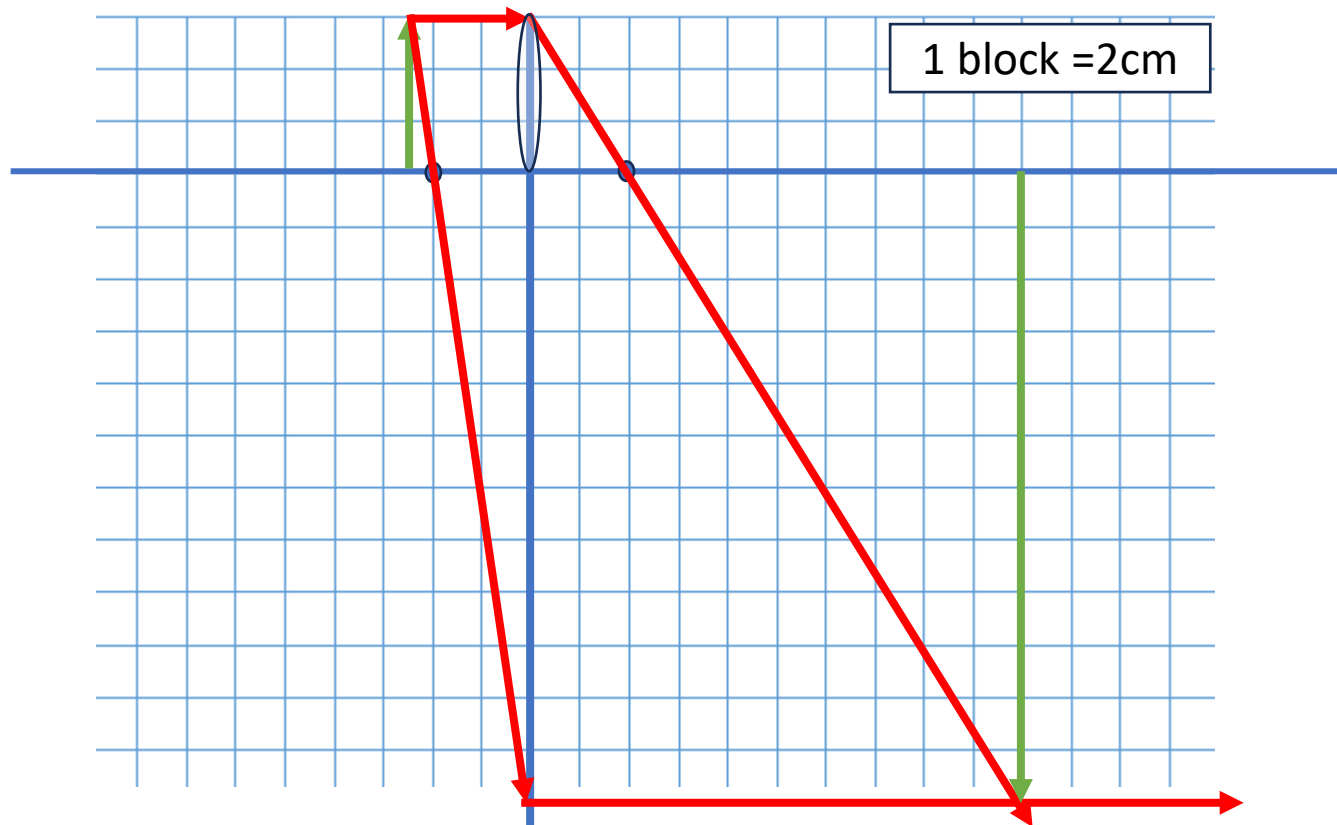
$$h_i = -\frac{(2)(3)}{(1.5)} = -4cm$$

real
inverted



Check Your Progress (page60)

55. Image Position and Height A 6.0 cm tall object is placed 5.0 cm from a convex lens with a focal length of 4.0 cm. Draw a ray diagram to determine the image location and size. Confirm your results using the thin lens equation and the magnification equation.



$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$x_i = \frac{f x_o}{x_o - f}$$

$$x_i = \frac{(4)(5)}{5 - 4}$$

$$x_i = 20\text{cm}$$

$$\frac{h_i}{h_o} = -\frac{x_i}{x_o}$$

$$h_i = -\frac{h_o x_i}{x_o}$$

$$h_i = -\frac{(6)(20)}{(5)}$$

$$h_i = -24\text{ cm}$$



Check Your Progress (page 60)

56. Diverging Lens A 6.5 cm tall salt shaker is viewed through a diverging lens with a focal length of 5.0 cm.

a. If the shaker is 6.0 cm from the lens, what is the image distance from the lens? Is the image virtual or real?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$x_i = \frac{f x_o}{x_o - f}$$

$$x_i = \frac{(-5)(6)}{6 - (-5)} = -2.7 \text{ cm}$$

b. What is the magnification? Is the image smaller or larger than the object?

$$m = -\frac{x_i}{x_o}$$

$$m = -\frac{-2.7}{6} = 0.45 \quad \text{smaller}$$

c. the salt shaker is moved to 4 cm from the lens, what is the distance of the image from the lens?

What is the magnification? Is the image now smaller or larger than the object?

$$\frac{1}{f} = \frac{1}{x_i} + \frac{1}{x_o}$$

$$x_i = \frac{f x_o}{x_o - f}$$

$$x_i = \frac{(-5)(4)}{4 - (-5)} = -2.2 \text{ cm}$$

$$m = -\frac{x_i}{x_o}$$

$$m = -\frac{-2.2}{4} = -0.55$$

smaller





Check Your Progress (page60)

58. Critical Thinking An air lens constructed of two watch glasses is placed in a tank of water. Copy **Figure 41** and draw the effect of this lens on parallel light ray's incident on the lens.

The light rays will diverge.

When light travels from a high to a low index of refraction, it speeds up, bends away from the normal line

