

Pearson Physics Level 30
Unit VII Electromagnetic Radiation: Chapter 13
Solutions

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Concept Check

Infrared radiation is observed by the human body through the sensing of temperature. In a way similar to visible light, infrared radiation can be reflected; so it can be observed both directly and indirectly.

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Concept Check

1. In the context of EMR, the wave model of light and the particle model of light are used to simplify a complex entity or process. In both cases, a model is used to explain many of the observed behaviours of EMR. For example, a particle and a wave can both reflect in a similar fashion to that of light and EMR in general.
2. In the particle model, a particle is considered to be analogous to a photon of light, inferring that EMR will have the behavioural characteristics of a particle. In the wave model, a wave is considered to be analogous to a photon of light, inferring that EMR will behave similarly to mechanical waves. Other examples of models are the Rutherford, Dalton, and Bohr models of the atom.
3. The EMR spectrum is based on wavelength and frequency. As the frequency of the EMR increases, so does the associated energy.

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Concept Check

1. Drawing a path to connect two opposite electric field vectors reveals that there must be a change in direction of the electric field along a square path. The changing electric field will produce a magnetic field according to **Faraday's Law**: The circulation of the electric field around a closed path determines the rate of change of the magnetic field that passes through this closed path.
2. A conductor is not required for EMR to propagate since a changing electric field exists in the region near an accelerating charge. In turn the changing electric field induces a changing magnetic field that also propagates as a region of influence in empty space.
3. A changing electric field exists in the region near any accelerating charge. Therefore, if a charge accelerates, a changing electric field is present, which induces a changing magnetic field, propagating outwards from the source at the speed of light.

13.1 Check and Reflect

Knowledge

1. EMR can be detected directly from the source, or indirectly after being reflected.
2. EMR spectrum should be similar to Figure 13.4. The spectrum is organized by wavelength and/or frequency.
3. Definitions of EMR
 - a) particle model – describes EMR as a stream of tiny particles radiating out from a source
 - b) wave model - describes EMR as a stream of transverse waves radiating out from a source
 - c) quantum model – describes EMR as discrete bundles of energy, each of which is a particle that has wavelike characteristics.
4. Young's two slit experiment produced a pattern of light with varying intensity after light passed through two small slits. This pattern is similar to two-source interference patterns in water waves, as seen in section 8.3. Therefore, Young's experiment presented strong evidence for the wave model of light.
5. Hertz used his apparatus to produce a rapidly changing electric field (observed as a spark) which induced a current in a nearby antenna. This observation supports Maxwell's theory that a changing electric field will induce a changing magnetic field, both varying over time and traveling outward from the source. When the changing electric and magnetic field reached the antenna, an induced current was observed.
6. Maxwell's study of capacitors helped him understand that an electric field could exist in the absence of medium or conductor. This led to an explanation of why EMR can travel in empty space.
7. If the electric field were constant, like one existing between two stationary point charges, then no electromagnetic radiation would be produced.

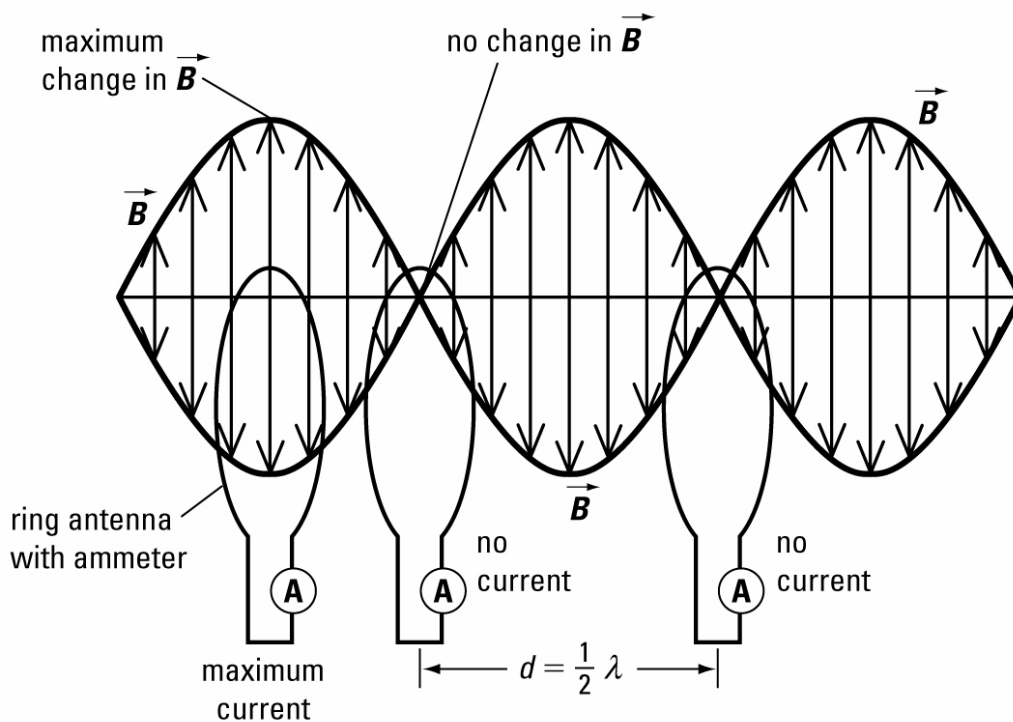
Applications

8. The frequency of the changing electric field at the spark gap was 2.5×10^3 Hz. Therefore, the frequency of the EMR observed at an antenna located nearby would also be 2.5×10^3 Hz.
9. EMR that is incident on a radio receiver will induce a current flow, therefore, the antenna must be a good conductor.
10. A changing magnetic field is required to produce a changing electric field. If the magnetic field lines held within a closed path are constant and unchanging, there will not be an electric field along the closed path.
11. If an electric charge is not moving, there is no acceleration or changing electric field, therefore it will not produce a magnetic field.
12. X rays are at a high enough frequency and energy to cause biological damage. Repeated exposure could cause cancer and other health side effects, therefore technicians who work in this environment must either wear protective clothing (to block the X rays) or leave the room (to avoid the X rays).
13. When an electromagnetic wave contacts a conductor, such as an antenna, the changing electric and magnetic fields will induce a current flow in the conductor or antenna.

14. EMR could be produced by an oscillating voltage or potential, which accelerates electrons back and forth at a known frequency along a conductor. Other methods could involve an electron collision, causing a rapidly changing electric field to produce EMR.

Extensions

15. In a standing wave pattern for EMR there will be regions of maximum change (antinodes) and regions of no change (nodes) in the magnetic field. At the antinodes the maximum change in magnetic field will induce the maximum current in the ring antenna, which could be measured with an ammeter. In a similar way, at the nodes, there will be no change in the magnetic field and therefore no current induced in the ring antenna. By moving the ring antenna along the standing wave, the distance separating adjacent nodes or antinodes can be determined. Doubling the distance between the antinodes or nodes reveals the wavelength.



16. Schematics will vary, but should include the following connections:
 Encoded data is sent to the satellite from a ground based station using EMR (in digital form). The satellite amplifies the signal and transmits it to ground based receivers (dish). The ground based receiver decodes the digital signal and transmits it via conduction to the television.

Example 13.1 Practice Problems

1. **Given**

12 sides / 1 rotation

$d = 6.00 \times 10^4 \text{ m}$

$v = 2.88 \times 10^8 \text{ m/s}$

Required

frequency of rotation (f) (rot/s = Hz)

Analysis and Solution

$$\frac{\text{rot}}{\text{side}} \times \frac{\mu\text{m}}{\text{s}} \times \frac{1}{\mu\text{m}} = \frac{\text{rot}}{\text{s}} = \text{Hz}$$

$$\frac{1 \text{ rot}}{12 \text{ side}} \times \frac{2.88 \times 10^8 \mu\text{m}}{1 \text{ s}} \times \frac{1}{6.00 \times 10^4 \mu\text{m}} = 400 \frac{\text{rot}}{\text{s}}$$

$$f = 400 \text{ Hz}$$

Paraphrase and Verify

If the speed of light is 2.88×10^8 m/s and it has to travel a total of 60.0 km from the rotating mirror to the fixed mirror and back, the rotating mirror must spin at 400 Hz in order for the light to successfully travel from the source to the observer.

2. Given

8 sides / 1 rotation

$$d = 3.00 \times 10^4 \text{ m}$$

$$v = 3.00 \times 10^8 \text{ m/s}$$

Required

frequency of rotation (f) (rot /s = Hz)

Analysis and Solution

$$\frac{\text{rot}}{\text{side}} \times \frac{\mu\text{m}}{\text{s}} \times \frac{1}{\mu\text{m}} = \frac{\text{rot}}{\text{s}} = \text{Hz}$$

$$\frac{1 \text{ rot}}{8 \text{ side}} \times \frac{3.00 \times 10^8 \mu\text{m}}{1 \text{ s}} \times \frac{1}{3.00 \times 10^4 \mu\text{m}} = 1250 \frac{\text{rot}}{\text{s}}$$

$$f = 1.25 \times 10^3 \text{ Hz}$$

Paraphrase and Verify

If the speed of light is 3.00×10^8 m/s and it has to travel a total of 30.0 km, the rotating mirror must spin at 1.25×10^3 Hz in order for the light to successfully travel from the source to the observer.

3. Given

8 sides / 1 rotation

$$f = 500 \text{ rot /s (Hz)}$$

$$d = 7.20 \times 10^4 \text{ m}$$

Required

speed of light (c)

Analysis and Solution

The round trip distance is 7.20×10^4 m.

The travel time Δt is one eighth of the period of rotation.

$$T = \frac{1}{f} \quad \Delta t = \frac{1}{8}T \quad c = \frac{\Delta d}{\Delta t}$$

$$T = \frac{1}{500 \text{ Hz}} \quad \Delta t = \frac{1}{8}(2.00 \times 10^{-3} \text{ s}) \quad c = \frac{7.20 \times 10^4 \text{ m}}{2.50 \times 10^{-4} \text{ s}}$$

$$T = 2.00 \times 10^{-3} \text{ s} \quad \Delta t = 2.50 \times 10^{-4} \text{ s} \quad c = 2.88 \times 10^8 \text{ m/s}$$

Paraphrase

The speed of light in air was found to be 2.88×10^8 m/s.

13.2 Check and Reflect

Knowledge

1. In Galileo's original experiment, the light travelled between two relatively close observers so quickly that accurate measurements of the time taken could not be made.
2. The orientation of the mirrors in a Michelson-type experiment has to be very precise in order for the light to be reflected directly toward the observation point. If the rotating mirror is not turning such that the light is reflected at the precise angle needed, the light will be scattered at various angles and will not reach the observer.
3. When the moon Io emerges from behind Jupiter it can be observed when the light reflected from its surface reaches Earth. The light travels at a constant, finite speed and the time it takes to reach Earth depends on the distance separating Io and Earth. Since the distance between Io and Earth is constantly changing as they rotate around the Sun, the moon Io appeared to be eclipsed later when the separation distance is great and earlier when the separation distance is small.

Applications

4. Given

$$d = 3.0 \times 10^{11} \text{ m}$$

$$t = 24 \text{ min} \left(\frac{60 \text{ s}}{1 \text{ min}} \right)$$

Required

speed of light, (c)

Analysis and Solution

$$c = \frac{\Delta d}{\Delta t}$$

$$c = \frac{3.0 \times 10^{11} \text{ m}}{24 \text{ min} \left(\frac{60 \text{ s}}{1 \text{ min}} \right)}$$

$$c = 2.08 \times 10^8 \frac{\text{m}}{\text{s}}$$

$$= 2.1 \times 10^8 \frac{\text{m}}{\text{s}}$$

Paraphrase

The speed of light in this experiment is $2.1 \times 10^8 \text{ m/s}$.

5. Given

$$d = 2.00 \times 10^7 \text{ m}$$

$$c = 3.00 \times 10^8 \frac{\text{m}}{\text{s}}$$

Required

time for signal travel (t)

Analysis and Solution

$$c = \frac{\Delta d}{\Delta t}$$

$$\Delta t = \frac{\Delta d}{c} = \frac{2.00 \times 10^7 \text{ m}}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}$$

$$\Delta t = 6.67 \times 10^{-2} \text{ s}$$

Paraphrase

The signal reaches the satellite in $6.67 \times 10^{-2} \text{ s}$.

6. Given

$$\frac{1 \text{ rotation}}{64 \text{ sides}}$$

$$c = 3.00 \times 10^8 \frac{\text{m}}{\text{s}}$$

$$d = 1.60 \times 10^4 \text{ m}$$

Required

frequency of rotation (f)

Analysis and Solution

$$\begin{aligned} f &= \frac{\text{rot}}{\text{side}} \times \frac{\cancel{\text{m}}}{\text{s}} \times \frac{1}{\cancel{\text{m}}} = \frac{\text{rot}}{\text{s}} \\ &= \frac{1 \text{ rot}}{64 \text{ side}} \times \frac{3.00 \times 10^8 \text{ m}}{1 \text{ s}} \times \frac{1}{1.60 \times 10^4 \cancel{\text{m}}} \\ &= \frac{293 \text{ rot}}{\text{s}} \end{aligned}$$

$$f = 293 \text{ Hz}$$

Paraphrase

The speed of light can be measured when the rotating mirror spins at a frequency of 293 Hz.

7. Given

$$\frac{1 \text{ rotation}}{16 \text{ sides}}$$

$$c = 3.00 \times 10^8 \frac{\text{m}}{\text{s}}$$

$$d = 7.00 \times 10^3 \text{ m}$$

Required

frequency of rotation (f)

Analysis and Solution

$$\begin{aligned} f &= \frac{\text{rot}}{\text{side}} \times \frac{\cancel{\text{m}}}{\text{s}} \times \frac{1}{\cancel{\text{m}}} = \frac{\text{rot}}{\text{s}} \\ &= \frac{1 \text{ rot}}{16 \text{ side}} \times \frac{3.00 \times 10^8 \cancel{\text{m}}}{1 \text{ s}} \times \frac{1}{7.00 \times 10^3 \cancel{\text{m}}} \\ &= \frac{2679 \text{ rot}}{\text{s}} \end{aligned}$$

$$f = 2.7 \times 10^3 \text{ Hz}$$

Paraphrase

The speed of light can be measured when the rotating mirror spins at a frequency of $2.7 \times 10^3 \text{ Hz}$.

8. Given

$$\frac{1 \text{ rotation}}{8 \text{ sides}}$$

$$c = 3.00 \times 10^8 \frac{\text{m}}{\text{s}}$$

$$f = 545 \text{ Hz}$$

Required

distance (d)

Analysis and Solution

$$d = \frac{\cancel{\text{rot}}}{\text{side}} \times \frac{\text{m}}{\cancel{\text{s}}} \times \frac{\cancel{\text{s}}}{\cancel{\text{rot}}}$$

$$d_{\text{total}} = \frac{1 \text{ rot}}{8 \text{ side}} \times \frac{3.00 \times 10^8 \text{ m}}{1 \text{ s}} \times \frac{1 \text{ s}}{545 \text{ rot}}$$

$$d_{\text{total}} = 68807 \text{ m}$$

$$d = \frac{68807 \text{ m}}{2} = 3.44 \times 10^4 \text{ m}$$

Paraphrase

The fixed mirror should be placed $3.44 \times 10^4 \text{ m}$ from the rotating mirror.

9. Given

$$\frac{1 \text{ rotation}}{16 \text{ sides}}$$

$$c = 2.97 \times 10^8 \frac{\text{m}}{\text{s}}$$

$$d = 1.00 \times 10^4 \text{ m}$$

Required

frequency of rotation (f)

Analysis and Solution

$$f = \frac{\text{rot}}{\text{side}} \times \frac{\cancel{\text{m}}}{\text{s}} \times \frac{1}{\cancel{\text{m}}} = \frac{\text{rot}}{\text{s}}$$

$$= \frac{1 \text{ rot}}{16 \text{ side}} \times \frac{2.97 \times 10^8 \cancel{\text{m}}}{1 \text{ s}} \times \frac{1}{1.00 \times 10^4 \cancel{\text{m}}}$$

$$= \frac{1856 \text{ rot}}{\text{s}}$$

$$f = 1.86 \times 10^3 \text{ Hz}$$

Paraphrase

The mirror was rotating at $1.86 \times 10^3 \text{ Hz}$.

10. Given

$$\frac{1 \text{ rot}}{8 \text{ side}}$$

$$f = 1.00 \times 10^3 \text{ Hz}$$

$$d = 3.50 \times 10^4 \text{ m}$$

Requiredspeed of light (c)**Analysis and Solution**

$$T = \frac{1}{f} \quad c = \frac{\Delta d}{\Delta t}$$

$$T = \frac{1}{1.00 \times 10^3 \text{ Hz}} = 1.00 \times 10^{-3} \text{ s}$$

$$\Delta t = \frac{1}{8} T$$

$$\Delta t = \frac{1}{8} (1.00 \times 10^{-3} \text{ s})$$

$$\Delta t = 1.25 \times 10^{-4} \text{ s}$$

$$c = \frac{3.50 \times 10^4 \text{ m}}{1.25 \times 10^{-4} \text{ s}}$$

$$c = 2.80 \times 10^8 \frac{\text{m}}{\text{s}}$$

ParaphraseBased on the student's observations, the speed of light is 2.80×10^8 m/s.**11. Given**

$$\frac{1 \text{ rot}}{64 \text{ side}}$$

$$f = 3.40 \times 10^2 \text{ Hz}$$

$$d = 1.31 \times 10^4 \text{ m}$$

Requiredspeed of light (c)**Analysis and Solution**

$$T = \frac{1}{f} \quad c = \frac{\Delta d}{\Delta t}$$

$$T = \frac{1}{3.40 \times 10^2 \text{ Hz}} = 2.9412 \times 10^{-3} \text{ s}$$

$$\Delta t = \frac{1}{64} T$$

$$\Delta t = \frac{1}{64} (2.9412 \times 10^{-3} \text{ s})$$

$$\Delta t = 4.59558 \times 10^{-5} \text{ s}$$

$$c = \frac{1.31 \times 10^4 \text{ m}}{4.59558 \times 10^{-5} \text{ s}}$$

$$c = 2.85 \times 10^8 \frac{\text{m}}{\text{s}}$$

ParaphraseThe speed of light is 2.85×10^8 m/s.

Extensions

12. a) The exact distance between the satellite and receiver can be determined by comparing the time values on the receiver to the time the satellite sent the signal. The difference in time equals the time the signal took to travel between the satellite and receiver. Using this time and the speed of light, the distance can be determined.
- b) Once the receiver determines the distance to three or more satellites, it can calculate its exact position using a process called trilateration. In this process, three spheres are produced, each with a radius equal to the distance between one satellite and the receiver. The point where all three spheres intersect is the exact location of the receiver.

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Concept Check

1. If $\frac{1}{d_o}$ is zero, the mirror equation becomes $\frac{1}{f} = \frac{1}{d_i}$; therefore, the image distance is equal to the focal length, so the image will appear at the focal point.
2. If $\frac{1}{f} = 0$, the mirror equation becomes:

$$-\frac{1}{d_i} = \frac{1}{d_o} \text{ indicating that the image and object distances are equal in magnitude.}$$

The negative image distance indicates that the image is virtual and on the opposite side of the mirror.

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Example 13.2 Practice Problems

1. Given

$$d_o = +20.0 \text{ cm}$$

$$f = -10.0 \text{ cm (diverging mirror has a negative focal length)}$$

Required

image distance (d_i)

magnification (m)

Analysis and Solution

Location of the image:

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

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

$$\frac{1}{d_i} = \frac{1}{-10.0 \text{ cm}} - \frac{1}{+20.0 \text{ cm}}$$

$$d_i = -6.67 \text{ cm}$$

Magnification of the image:

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$m = \frac{-d_i}{d_o} = \frac{-(-6.67\text{cm})}{+20.0\text{cm}} = 3.33 \times 10^{-1} \times$$

Paraphrase

The image forms 6.67 cm from the mirror. It is magnified by 3.33×10^{-1} times, and it is a virtual image, indicated by the negative image distance.

2. a) Given

$$d_o = +6.0 \text{ cm}$$

$$f = +12.0 \text{ cm}$$

Required

image distance (d_i)

magnification (m)

image attributes

Analysis and Solution

Location of the image:

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

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

$$\frac{1}{d_i} = \frac{1}{+12.0 \text{ cm}} - \frac{1}{+6.0 \text{ cm}}$$

$$d_i = -12 \text{ cm}$$

Magnification of the image:

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$m = \frac{-d_i}{d_o} = \frac{-(-12 \text{ cm})}{+6.0 \text{ cm}} = 2.0 \times$$

Paraphrase

The image forms 12 cm from the mirror. It is magnified 2.0 times and it is virtual, erect, and enlarged.

b) Given

$$d_o = +10.0 \text{ cm}$$

$$f = -5.00 \text{ cm}$$

Required

image distance (d_i)

magnification (m)

image attributes

Analysis and Solution

Location of the image:

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

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

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

$$d_i = -3.33 \text{ cm}$$

Magnification of the image:

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$m = \frac{-d_i}{d_o} = \frac{-(-3.33 \text{ cm})}{+10.0 \text{ cm}} = 0.333 \times$$

Paraphrase and Verify

The image forms 3.33 cm from the mirror. It is magnified 0.333 times and it is virtual, upright, and diminished.

c) Given

$$d_o = +2.0 \text{ cm}$$

$$f = -10.0 \text{ cm}$$

Required

image distance (d_i)

magnification (m)

image attributes

Analysis and Solution

Location of the image:

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

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

$$\frac{1}{d_i} = \frac{1}{-10.0 \text{ cm}} - \frac{1}{+2.0 \text{ cm}}$$

$$d_i = -1.7 \text{ cm}$$

Magnification of the image:

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$m = \frac{-d_i}{d_o} = \frac{-(-1.667 \text{ cm})}{+2.0 \text{ cm}} = 0.83 \times$$

Paraphrase and Verify

The image forms 1.7 cm from the mirror. It is magnified 0.83 times and it is virtual, upright, and diminished.

3. Given

$$h_o = 5.0 \text{ cm}$$

$$d_o = 2.0 \text{ cm}$$

$$m = -4 \times$$

Requiredimage distance (d_i) imagefocal length (f)**Analysis and Solution**

Location of the image:

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

$$d_i = -md_o$$

$$d_i = -(-4)(2.0 \text{ cm}) = 8.0 \text{ cm}$$

$$d_i = 8 \text{ cm}$$

focal length:

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

$$\frac{1}{f} = \frac{1}{2.0 \text{ cm}} + \frac{1}{8.0 \text{ cm}}$$

$$f = 1.6 \text{ cm}$$

Paraphrase and Verify

The image forms 8 cm from the mirror and the focal length of the mirror is 1.6 cm.

4. Given

$$h_o = 4.0 \text{ cm}$$

$$d_o = 15.0 \text{ cm}$$

$$f = 5.0 \text{ cm}$$

Requiredimage distance (d_i)image height (h_i)magnification (m)

image attributes

Analysis and Solution

Location of the image:

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

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

$$\frac{1}{d_i} = \frac{1}{5.0 \text{ cm}} - \frac{1}{15.0 \text{ cm}}$$

$$d_i = 7.5 \text{ cm}$$

Magnification and height of the image:

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

$$m = -\frac{d_i}{d_o} = -\frac{7.5 \text{ cm}}{15.0 \text{ cm}} = -0.50 \times$$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = mh_o$$

$$h_i = (-0.5)(4.0 \text{ cm}) = -2.0 \text{ cm}$$

Paraphrase and Verify

The image forms 7.5 cm from the mirror, it is magnified -0.50 times and it is 2.0 cm high. It is real, inverted, and diminished.

5. The object distance is assumed to be infinite; therefore the image distance is equal to the focal length of the mirror (45.0 cm). The image is real, inverted, and diminished.

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13.3 Check and Reflect

Knowledge

1. In Figure 13.27 the boundary is not flat and the normal line is always drawn perpendicular to the surface of the boundary.
2. Concept maps vary but should show similar connections:
 - principal axis (PA) – an imaginary line drawn through the vertex, perpendicular to the surface of the curved mirror at this point
 - focal point (F) – the point where light rays that are parallel to the principal axis converge, or appear to diverge from, after being reflected
 - centre of curvature (C) – the point on the principal axis that would represent the centre of the sphere from which the curved mirror was cut
3. In specular or regular reflection, parallel rays that are incident on a flat, smooth, reflecting surface, such as a mirror, are reflected as parallel rays. In diffuse reflection parallel rays that are incident on a rough, irregular shaped reflecting surface are scattered in many different directions.
4. A virtual image is one that forms when light rays appear to be coming from an image which does not exist. A real image is one that can be formed on a diffusely reflecting surface, such as a piece of paper, where rays actually converge.
5. A converging mirror is a concave reflecting surface that causes parallel light rays to converge after being reflected. A diverging mirror is a convex reflecting surface that causes parallel light rays to spread out or diverge after being reflected.
6. Incident Ray 1 is parallel to the principal axis and will reflect through the focal point on a converging mirror, or appear to have originated from the focal point on a diverging mirror. Incident Ray 2 travels through the focal point on a converging mirror, or is directed at the focal point on a diverging mirror and will be reflected back parallel to the principal axis. Incident Ray 3 travels through the centre of curvature on a converging mirror, or is directed at the centre of curvature on a diverging mirror, and is reflected directly back along the incident path.
7. A diverging mirror causes parallel light rays to spread out, or diverge after being reflected. To the observer, the reflected rays that diverge appear to originate from a focal point that is behind the mirror. This focal point does not exist, but only appears to exist based on the direction of the reflected rays.

Applications

8. Given

$$h_i = 5.0 \text{ cm}$$

$$d_o = 10.0 \text{ cm}$$

$$h_o = 4.0 \text{ cm}$$

Required

focal length (f)

Analysis and Solution

$$\frac{h_i}{h_o} = -\frac{d_i}{d_o} \quad \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = -\frac{h_i d_o}{h_o}$$

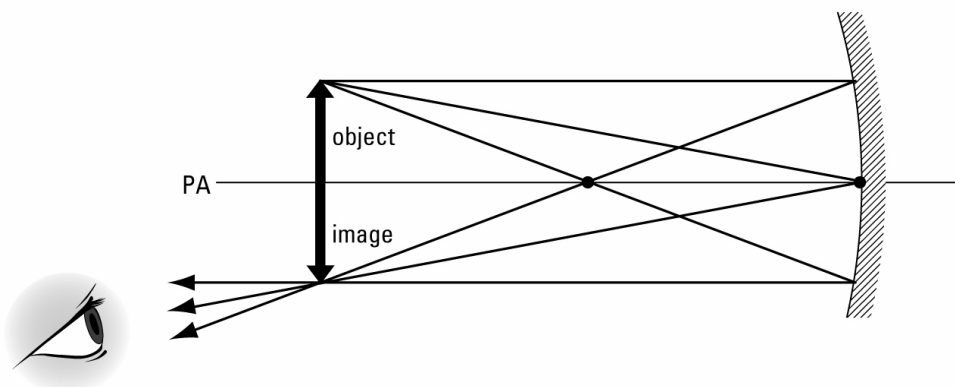
$$d_i = -\frac{(5.0 \text{ cm})(10.0 \text{ cm})}{4.0 \text{ cm}} = -12.5 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{10.0 \text{ cm}} - \frac{1}{12.5 \text{ cm}}$$

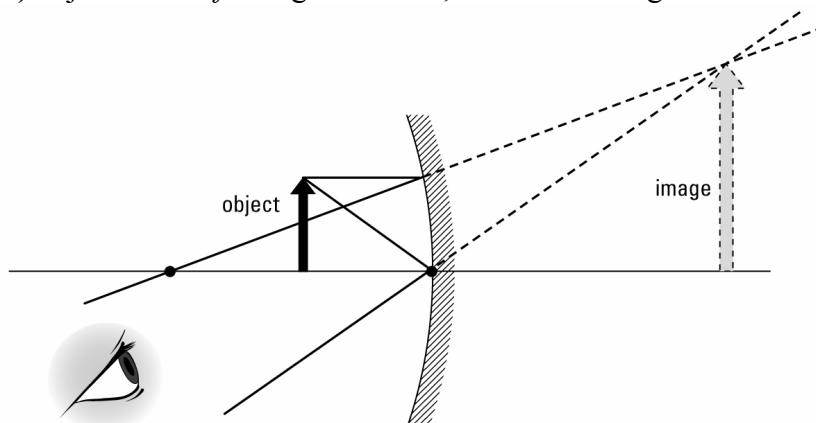
$$f = 50 \text{ cm}$$

Paraphrase: The focal length of the mirror is 50 cm.

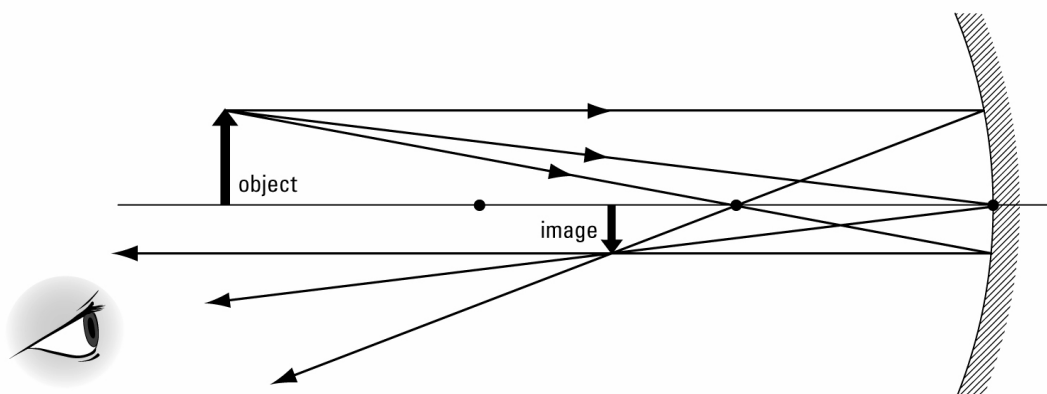
9. a) object at $2.0 f$: image is real, inverted and same size as object



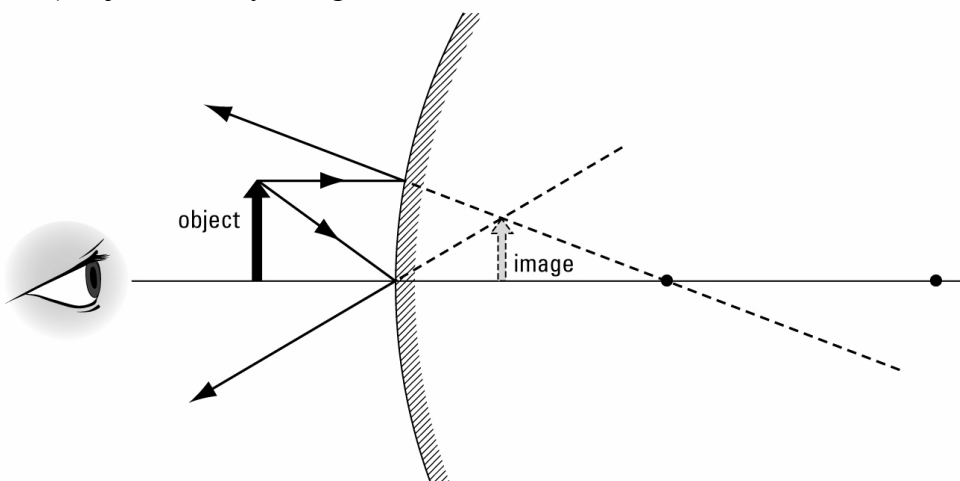
- b) object at $0.50 f$: image is virtual, erect and enlarged.



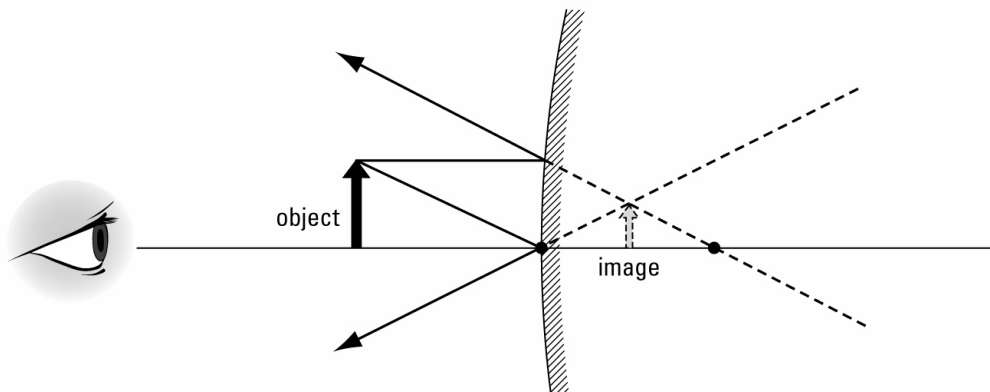
c) object at $3.0f$: image is real, inverted and diminished.



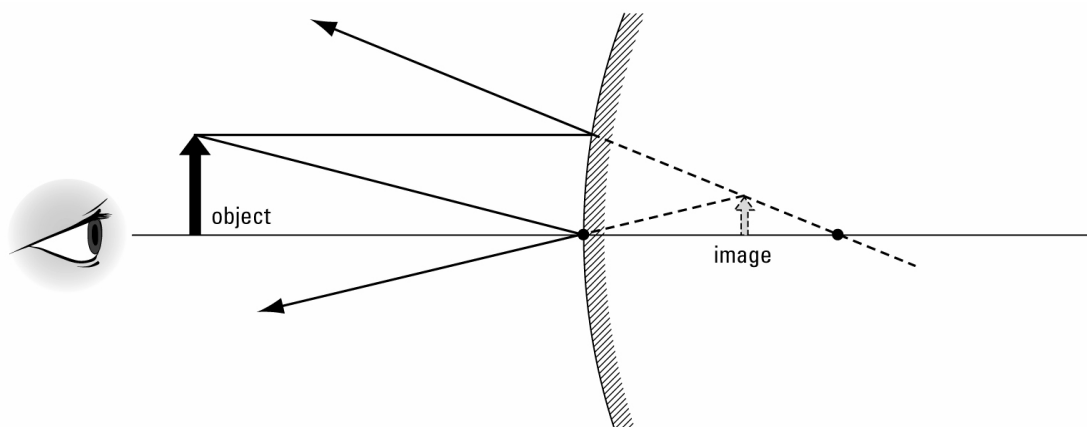
10. a) object at $0.50f$: image is virtual, erect and diminished.



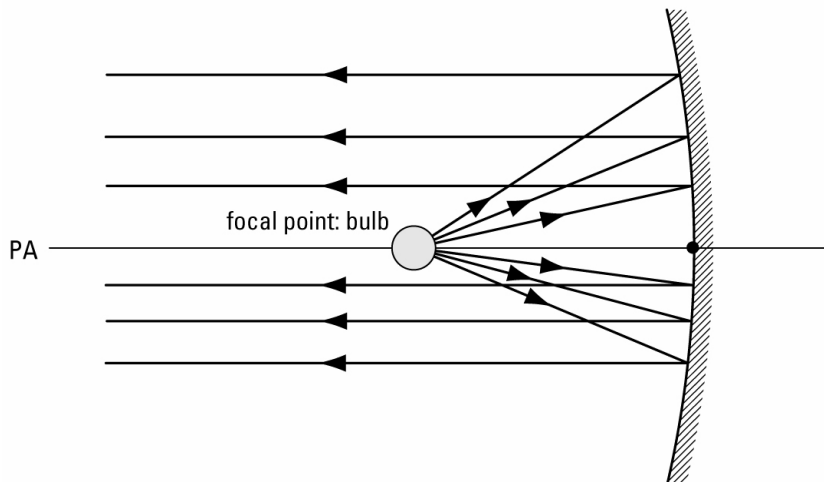
b) object at $1.0f$: image is virtual, erect and diminished.



c) object at $1.5f$: image is virtual, erect and diminished.



11. Any incident ray which originates at the focal point will be reflected parallel to the principal axis. In the case of a flashlight or headlight, most of the rays originate or pass through the focal point and are reflected parallel to the principal axis.



Extension

12. For assessment of students' performance in this research activity, you may wish to use Generic Rubric GR 11. Research Report. You might hand out this rubric at the time that you assign the exercise, so that students know what is expected of them.

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Example 13.3 Practice Problems

1. *Given*

$$\theta_2 = 25^\circ$$

$$n_1 = 2.42$$

$$n_2 = 1.00$$

Requiredangle of incidence (θ_1)**Analysis and Solution**

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}$$

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

$$\theta_1 = \sin^{-1} \left(\frac{(1.00)(\sin 25)}{2.42} \right)$$

$$\theta_1 = 10^\circ$$

ParaphraseThe angle of incidence as the light exits the diamond is 10° **2. Given**

$$\theta_1 = 20^\circ$$

$$\theta_2 = 17^\circ$$

$$n_1 = 1.00$$

Requiredindex of refraction of transparent material (n_2)**Analysis and Solution**

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}$$

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

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

$$n_2 = \left(\frac{(1.00)(\sin 20)}{(\sin 17)} \right)$$

$$n_2 = 1.2$$

Paraphrase

The transparent material has an index of refraction equal to 1.2.

3. Given

$$\theta_1 = 15^\circ$$

$$n_1 = 1.00$$

$$n_2 = 1.54$$

Requiredangle of refraction (θ_2)**Analysis and Solution**

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}$$

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

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

$$\theta_2 = \sin^{-1} \left(\frac{(1.00)(\sin 15)}{1.54} \right)$$

$$\theta_2 = 9.7^\circ$$

Paraphrase

The angle of refraction is 9.7° .

4. Given

$$\theta_1 = 20^\circ$$

$$\theta_2 = 15^\circ$$

$$n_1 = 1.00$$

Required

index of refraction (n_2)

Analysis and Solution

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}$$

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

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

$$n_2 = \left(\frac{(1.00)(\sin 20)}{(\sin 15)} \right)$$

$$n_2 = 1.3$$

Paraphrase and Verify

The unknown material has an index of refraction equal to 1.3.

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Example 13.4 Practice Problems

1. Given

The refractive index of each material:

water: 1.33

ethanol: 1.37

ruby: 1.54

crown glass: 1.52

The speed of light in air = 3.00×10^8 m/s

Required

speed of light (c) in each material:

Analysis and Solution

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

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

$$v_{\text{water}} = \frac{c}{n} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{1.33} = 2.26 \times 10^8 \frac{\text{m}}{\text{s}}$$

$$v_{\text{ethanol}} = \frac{c}{n} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{1.37} = 2.19 \times 10^8 \frac{\text{m}}{\text{s}}$$

$$v_{\text{ruby}} = \frac{c}{n} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{1.54} = 1.95 \times 10^8 \frac{\text{m}}{\text{s}}$$

$$v_{\text{crown glass}} = \frac{c}{n} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{1.52} = 1.97 \times 10^8 \frac{\text{m}}{\text{s}}$$

Paraphrase and Verify

The speed of light is different in each material, travelling slower in materials with a higher index of refraction.

2. Given

$$\theta_1 = 25.0^\circ$$

$$n_1 = 1.00$$

$$n_2 = 1.47$$

$$\lambda_1 = 737 \text{ nm}$$

Required

angle of refraction (θ_2)

wavelength (λ_2)

Analysis and Solution

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}$$

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

$$\frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$$

$$\lambda_2 = \frac{\lambda_1 n_1}{n_2}$$

$$\theta_2 = \sin^{-1} \left(\frac{n_1 \sin \theta_1}{n_2} \right) \quad \lambda_2 = \frac{\lambda_1 n_1}{n_2}$$

$$\theta_2 = \sin^{-1} \left(\frac{(1.00) \sin(25)}{1.47} \right) \quad \lambda_2 = \frac{(737 \text{ nm})(1.00)}{1.47}$$

$$\theta_2 = 16.7^\circ \quad \lambda_2 = 501 \text{ nm}$$

Paraphrase

The angle of refraction is 16.7° and the wavelength in the quartz glass is 501 nm.

3. Given

$$\lambda_1 = 500 \text{ nm}$$

$$\lambda_2 = 450 \text{ nm}$$

$$n_1 = 1.00$$

Requiredrefractive index (n_2)**Analysis and Solution**

$$\frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$$

$$n_2 = \frac{\lambda_1 n_1}{\lambda_2}$$

$$n_2 = \frac{\lambda_1 n_1}{\lambda_2}$$

$$n_2 = \frac{(500\text{nm})(1.00)}{(450\text{nm})}$$

$$n_2 = 1.11$$

Paraphrase

The refractive index of the unknown material is 1.11.

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Concept Check

1. Light is refracted *toward* the normal line when passing from a medium with a low refractive index like air, into a medium with a high refractive index like water.
2. Total internal reflection cannot occur when light travels from a low index medium like air, into a high index medium like water since the light will always be bent toward the normal line and away from the boundary.

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Example 13.5 Practice Problems**1. Given**

Refractive index of:

water = 1.33

diamond = 2.42

air = 1.00

Requiredcritical angle for water/air interface, (θ_{critical})critical angle for diamond /air interface, (θ_{critical})critical angle for diamond/water interface, (θ_{critical})**Analysis and Solution**

$$n_2 \sin \theta_{\text{critical}} = n_1 \sin 90^\circ$$

$$\theta_{\text{critical}} = \sin^{-1} \left(\frac{n_1 \sin 90^\circ}{n_2} \right)$$

$$\begin{aligned} \text{(a) } \theta_{\text{critical water/air}} &= \sin^{-1}\left(\frac{1.00 \sin 90^\circ}{1.33}\right) \\ \theta_{\text{critical water/air}} &= 48.8^\circ \\ \text{(b) } \theta_{\text{critical diamond/air}} &= \sin^{-1}\left(\frac{1.00 \sin 90^\circ}{2.42}\right) \\ \theta_{\text{critical diamond/air}} &= 24.4^\circ \\ \text{(c) } \theta_{\text{critical diamond/water}} &= \sin^{-1}\left(\frac{1.33 \sin 90^\circ}{2.42}\right) \\ \theta_{\text{critical diamond/water}} &= 33.3^\circ \end{aligned}$$

Paraphrase

The critical angle for a water/air boundary is 48.8° : for a diamond/air boundary it is 24.4° : for a diamond water boundary it is 33.3° .

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Example 13.6 Practice Problems

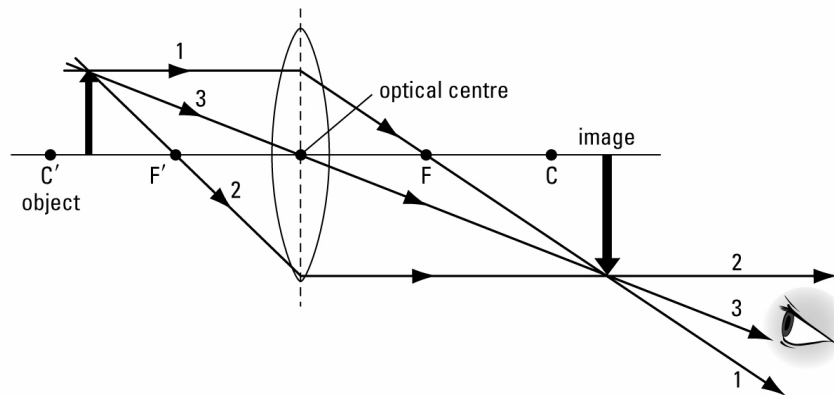
1. a) Given

an object located between C' and F' relative to a converging lens

Required

image attributes

Analysis and Solution



Paraphrase

Image is beyond C , real, inverted, and enlarged.

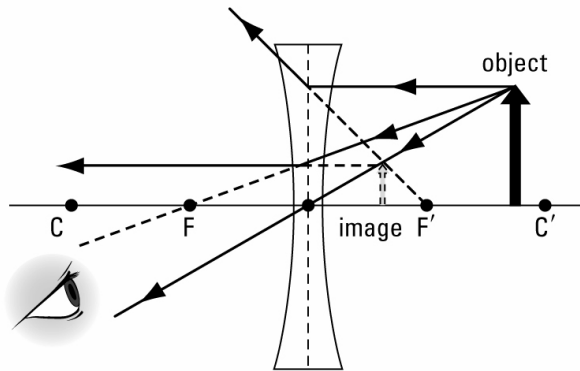
b) Given

an object located between C' and F' relative to a diverging lens

Required

image attributes

Analysis and Solution



Paraphrase

Image is between the lens and F, virtual, erect, and diminished.

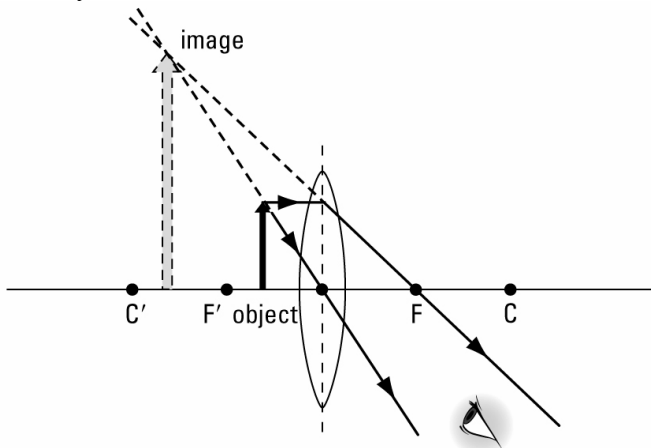
c) Given

an object located between F' and a converging lens

Required

image attributes

Analysis and Solution



Paraphrase

Image is between F' and C', virtual, erect, and enlarged.

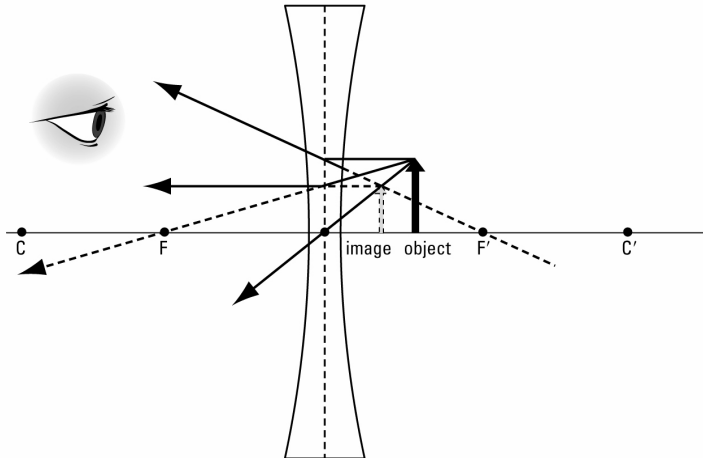
d) Given

an object located between F' and the lens of a diverging lens

Required

image attributes

Analysis and Solution



Paraphrase

Image is between the lens and F, virtual, erect, and diminished

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Example 13.7 Practice Problems

1. Given

$$h_o = 3.00 \text{ cm}$$

$$d_o = 15.0 \text{ cm}$$

$$f = 10.0 \text{ cm}$$

Required

image distance (d_i)

image height (h_i)

image attributes

Analysis and Solution

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \quad m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} \quad h_i = -\frac{d_i h_o}{d_o}$$

$$\frac{1}{d_i} = \frac{1}{10.0 \text{ cm}} - \frac{1}{15.0 \text{ cm}} \quad h_i = -\frac{(30.0\text{cm})(3.00 \text{ cm})}{15.0 \text{ cm}}$$

$$d_i = 30.0 \text{ cm} \quad h_i = -6.00 \text{ cm}$$

Paraphrase

The image forms 30.0 cm from the lens with a height of -6.00 cm. The image is real, inverted, and enlarged.

2. Given

$$h_o = 10.0 \text{ cm}$$

$$d_o = 100.0 \text{ cm}$$

$$f = -25.0 \text{ cm}$$

Requiredimage distance, (d_i)image height (h_i)

image type

Analysis and Solution

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \quad m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} \quad h_i = -\frac{d_i h_o}{d_o}$$

$$\frac{1}{d_i} = \frac{1}{-25.0 \text{ cm}} - \frac{1}{100.0 \text{ cm}} \quad h_i = \frac{-(-20.0 \text{ cm})(10.0 \text{ cm})}{100.0 \text{ cm}}$$

$$d_i = -20.0 \text{ cm} \quad h_i = 2.00 \text{ cm}$$

Paraphrase

The image forms 20.0 cm from the lens with a height of 2.00 cm. Since the image distance is negative it is a virtual image.

3. Given

$$d_o = 7.50 \text{ cm}$$

$$d_i = 500 \text{ cm}$$

Requiredfocal length (f)magnification (m)**Analysis and Solution**

$$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o} \quad m = -\frac{d_i}{d_o}$$

$$\frac{1}{f} = \frac{1}{500 \text{ cm}} + \frac{1}{7.50 \text{ cm}} \quad m = -\frac{(500 \text{ cm})}{7.50 \text{ cm}}$$

$$f = 7.39 \text{ cm} \quad m = -66.7 \times$$

Paraphrase

The projector lens has a focal length of 7.39 cm and the image is magnified -66.7 times.

Student Book page 683**13.4 Check and Reflect****Knowledge**

1. Light is bent towards the normal line when it passes from a low index medium to a high index medium.
2. The index of refraction can be measured by observing the change in speed, direction, or wavelength of the EMR as it enters the new medium.
3. Concept maps may vary, but should include the following connections: The angle of incidence is the angle between the incident ray and the normal line. The angle of refraction is the angle between the refracted ray and the normal line.
4. The simple form of Snell's Law assumes that the first medium has an index of refraction equal to one. Therefore, Snell's constant and the index of refraction for the

second medium are one and the same thing. In the general form of Snell's law, the first medium can have an index of refraction greater than or equal to one.

5. Place a semi-circular block of Lucite® on the centre of a sheet of polar coordinate paper. Direct a light ray towards the curved surface of the block, (directly at the centre of the polar coordinate paper). Slowly increase the angle of incidence until the light ray internally reflects. The smallest possible angle of reflection will be equal to the critical angle.
6.
 - economically less expensive than copper wire of equivalent length
 - thinner, more flexible, and made of non-flammable materials
 - able to handle a higher data-carrying capacity based on the fibre bundle diameter
 - less signal degradation and interference between multiple signals on the same fibre as compared to copper networks
 - the glass fibres are highly transparent so that repeaters (amplifiers) can be many kilometres apart, as opposed to coaxial cable repeaters that must be less than 1 km apart
7. Incident light with a smaller, shorter wavelength will slow down and refract to a greater extent than light with a larger, longer wavelength. As each wavelength of light refracts at a slightly different angle, the wavelengths will separate, producing a continuous spectrum.
8. When light enters a new medium, like glass, the wavelength is reduced but the frequency is unchanged. According to the universal wave equation, ($v = f\lambda$) if the speed of the wave is reduced, so too is the wavelength. Therefore, the index of refraction is related to both the speed of a wave, and its wavelength. Dispersion is caused by the fact that the index of refraction is different for each wavelength in the visible spectrum, causing each wavelength to refract at a slightly different angle.

Applications

9. Given

$$n_{\text{water}} = 1.33$$

$$c = 3.00 \times 10^8 \frac{\text{m}}{\text{s}}$$

Required

speed of light in water (v_{water})

Analysis and Solution

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

$$v = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{1.33}$$

$$v = 2.26 \times 10^8 \frac{\text{m}}{\text{s}}$$

Paraphrase

The speed of light in water is 2.26×10^8 m/s.

10. Given

$$n_{\text{quartz glass}} = 1.47$$

$$\theta_{\text{incident}} = 35.0^\circ$$

Requiredangle of refraction ($\theta_{\text{refraction}}$)**Analysis and Solution**

$$\frac{\sin \theta_{\text{incident}}}{\sin \theta_{\text{refraction}}} = \frac{n_2}{n_1}$$

$$\theta_{\text{refraction}} = \sin^{-1} \left(\frac{(\sin \theta_{\text{incident}})(n_1)}{n_2} \right)$$

$$\theta_{\text{refraction}} = \sin^{-1} \left(\frac{(\sin 35.0^\circ)(1.00)}{1.47} \right)$$

$$\theta_{\text{refraction}} = 23.0^\circ$$

ParaphraseThe angle of refraction is 23.0° when the light enters the quartz glass at 35.0° .**11. Given**

$$n_{\text{water}} = 1.33$$

$$n_{\text{Lucite}} = 1.52$$

$$\theta_{\text{refraction}} = 28.0^\circ$$

Requiredangle of incidence ($\theta_{\text{incidence}}$)**Analysis and Solution**

$$\frac{\sin \theta_{\text{incidence}}}{\sin \theta_{\text{refraction}}} = \frac{n_2}{n_1}$$

$$\theta_{\text{incidence}} = \sin^{-1} \left(\frac{(\sin \theta_{\text{refraction}})(n_2)}{n_1} \right)$$

$$\theta_{\text{incidence}} = \sin^{-1} \left(\frac{(\sin 28.0^\circ)(1.52)}{1.33} \right)$$

$$\theta_{\text{incidence}} = 32.4^\circ$$

ParaphraseThe light ray is incident on the Lucite® block at an angle of 32.4° .**12. Given**

$$n_{\text{air}} = 1.00$$

$$n_{\text{Lucite}} = 1.52$$

$$\theta_{\text{refraction}} = 90^\circ$$

Requiredcritical angle (θ_{critical})

Analysis and Solution

$$\frac{\sin \theta_{\text{critical}}}{\sin 90^\circ} = \frac{n_2}{n_1}$$

$$\theta_{\text{critical}} = \sin^{-1} \left(\frac{(\sin 90^\circ)(n_2)}{n_1} \right)$$

$$\theta_{\text{critical}} = \sin^{-1} \left(\frac{(\sin 90^\circ)(1.00)}{1.52} \right)$$

$$\theta_{\text{critical}} = 41.1^\circ$$

Paraphrase

The critical angle for an air-Lucite interface is 41.1° . If the angle of incidence is larger than the critical angle the light will internally reflect.

13. Given

$$n_{\text{air}} = 1.00$$

$$n_{\text{water}} = 1.33$$

$$\theta_{\text{refraction}} = 90^\circ$$

Required

critical angle (θ_{critical})

Analysis and Solution

$$\frac{\sin \theta_{\text{critical}}}{\sin 90^\circ} = \frac{n_2}{n_1}$$

$$\theta_{\text{critical}} = \sin^{-1} \left(\frac{(\sin 90^\circ)(n_2)}{n_1} \right)$$

$$\theta_{\text{critical}} = \sin^{-1} \left(\frac{(\sin 90^\circ)(1.00)}{1.33} \right)$$

$$\theta_{\text{critical}} = 48.8^\circ$$

Paraphrase

Since the angle of incidence is larger than the critical angle, the light will internally reflect at the water-air interface and remain in the water.

14. Given

$$n_{\text{ruby}} = 1.54$$

$$n_{\text{air}} = 1.00$$

$$\theta_{\text{incident}} = 25.0^\circ$$

$$\lambda_1 = 540 \text{ nm}$$

Required

angle of refraction ($\theta_{\text{refraction}}$)

wavelength of light in ruby (λ_2)

Analysis and Solution

$$\frac{\sin \theta_{\text{incident}}}{\sin \theta_{\text{refraction}}} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$$

$$\theta_{\text{refraction}} = \sin^{-1} \left(\frac{(\sin \theta_{\text{incident}})(n_1)}{n_2} \right)$$

$$\lambda_2 = \frac{n_1 \lambda_1}{n_2}$$

$$\theta_{\text{refraction}} = \sin^{-1} \left(\frac{(\sin 25.0^\circ)(1.00)}{1.54} \right)$$

$$\theta_{\text{refraction}} = 15.9^\circ$$

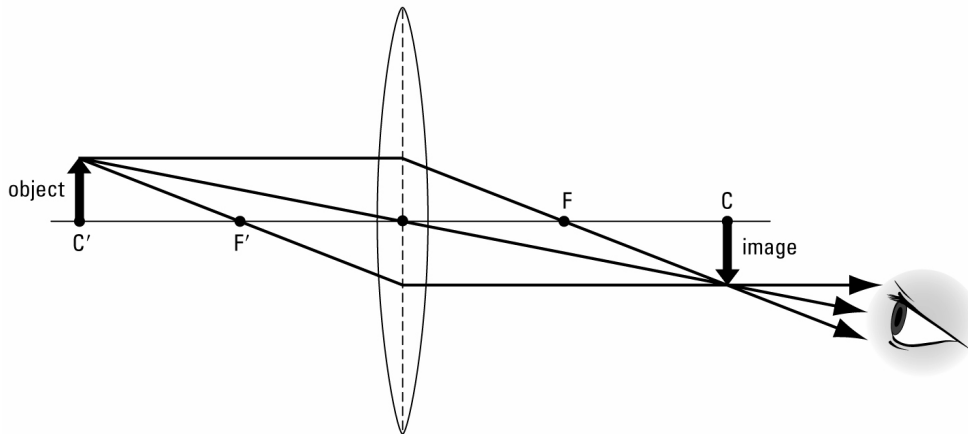
$$\lambda_2 = \frac{(1.00)(540\text{nm})}{1.54}$$

$$\lambda_2 = 351\text{nm}$$

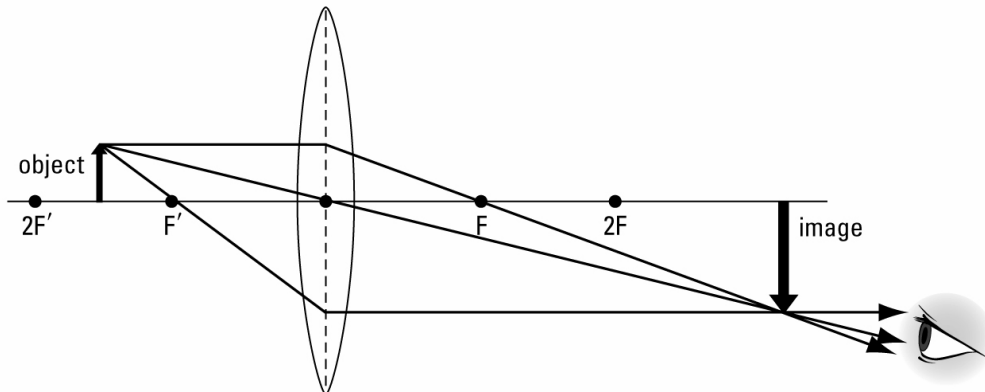
Paraphrase

The angle of refraction is 15.9° and the light has a wavelength of 351 nm in the ruby.

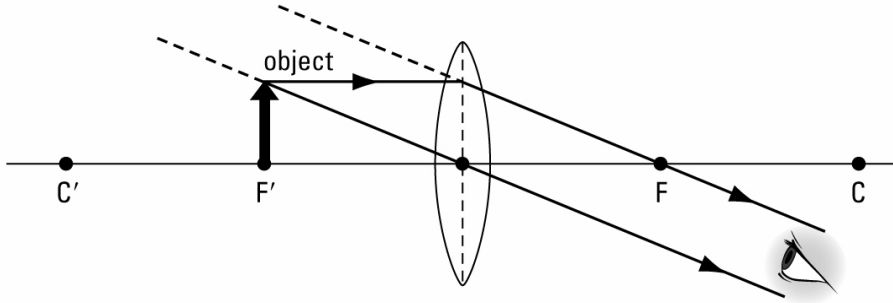
15. a) image is real, inverted, and the same size as the object .



b) image is real, inverted, and enlarged



c) no image forms since the refracted rays are parallel.



16. Given

$$f = 4.50\text{cm} = 4.50 \times 10^{-2}\text{m}$$

$$h_o = 25.0\text{m}$$

$$d_o = 50.0\text{m}$$

Required

image height (h_i)

image attitude

Analysis and Solution

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

$$m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

$$\frac{1}{d_i} = \frac{1}{4.50 \times 10^{-2}\text{m}} - \frac{1}{50.0\text{m}}$$

$$d_i = 4.50 \times 10^{-2}\text{m}$$

$$h_i = -\frac{(4.50 \times 10^{-2}\text{m})(25.0\text{m})}{50.0\text{m}}$$

$$h_i = -2.25 \times 10^{-2}\text{m}$$

Paraphrase

The image is $2.25 \times 10^{-2}\text{m}$ high and the negative height indicates that it is inverted.

17. Incident light with a smaller, shorter wavelength will slow down and refract to a greater extent than light with a larger, longer wavelength. Therefore, the blue light is refracted at a larger angle than the red light.

18. a) Given

$$f = 8.00\text{cm}$$

$$d_o = 8.10\text{cm}$$

Required

image distance (d_i)

Analysis and Solution

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

$$\frac{1}{d_i} = \frac{1}{8.00\text{cm}} - \frac{1}{8.10\text{cm}}$$

$$d_i = 648\text{cm}$$

Paraphrase

The screen must be placed 648 cm from the lens in order to produce a clear image.

b) Given

$$h_o = 1.75\text{cm}$$

$$d_o = 8.10\text{cm}$$

$$d_i = 648\text{cm}$$

Required

Image height (h_i)

Analysis and Solution

$$-\frac{d_i}{d_o} = \frac{h_i}{h_o}$$

$$h_i = -\frac{d_i h_o}{d_o}$$

$$h_i = -\frac{(648\text{cm})(1.75\text{cm})}{8.10\text{cm}}$$

$$h_i = -140\text{cm}$$

Paraphrase

The image on the screen is 140 cm. The negative height indicates that it is inverted relative to the object.

c) Given

$$f = 8.00\text{cm}$$

$$d_i = 648\text{cm} - 300\text{cm} = 348\text{cm}$$

Required

object distance (d_o)

Analysis and Solution

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

$$\frac{1}{d_o} = \frac{1}{8.00\text{cm}} - \frac{1}{348\text{cm}}$$

$$d_o = 8.19\text{cm}$$

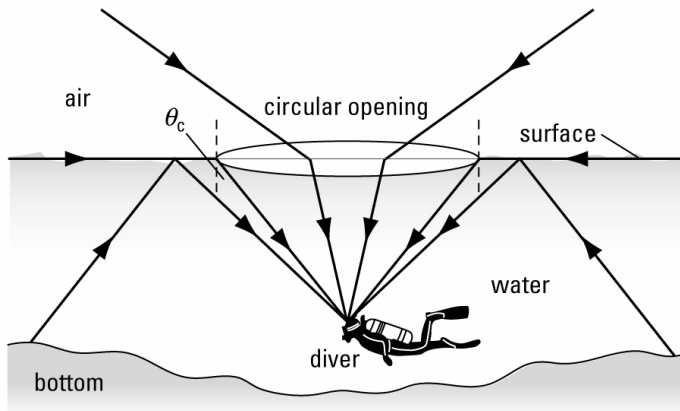
Paraphrase

If the screen is moved 3.0 m closer to the projector then the object must be positioned 8.19 cm from the lens.

Extensions

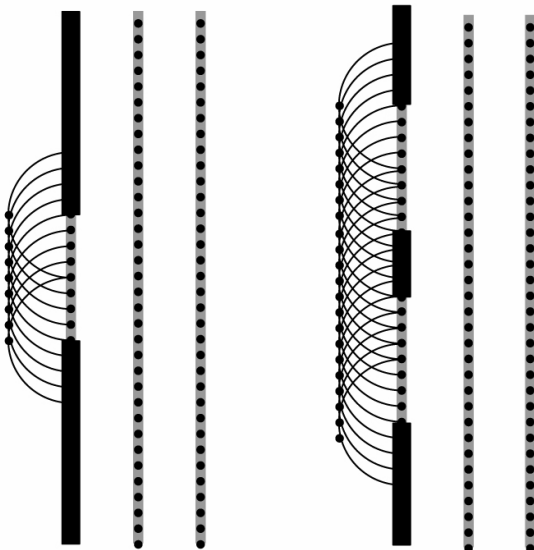
19. The sparkle and glitter associated with diamonds is caused by total internal reflection. The diamond's high index of refraction in combination with the shape of the surface both reflects and focusses the light. We observe this effect as sparkles.

20. A magnifying glass is a converging lens. When multiple rays of EMR energy converge at the focal point of the lens, there can be sufficient energy to ignite combustible material.
21. If a diver is underwater and looks up, a circular “hole” appears on the surface of the water, which otherwise appears to be a mirror. This is caused by total internal reflection. Light rays which are in the water and are incident on the surface at an angle of 49° (critical angle for a water-air interface), or larger, are internally reflected.



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Concept Check



As the secondary wavelets emerge from the opening(s), they form a new wavefront travelling outward with curved edges. An interference pattern is produced as multiple wavelets overlap and interfere with one another.

Example 13.8 Practice Problems**1. Given**

$$d = 2.0 \times 10^{-4} \text{ m}$$

$$n = 2$$

$$\theta = 0.26^\circ$$

Requiredwavelength (λ)**Analysis and Solution**

$$\lambda = \frac{d \sin \theta}{n}$$

$$\lambda = \frac{(2.0 \times 10^{-4} \text{ m})(\sin 0.26^\circ)}{2}$$

$$\lambda = 4.5 \times 10^{-7} \text{ m}$$

ParaphraseThe light has a wavelength of $4.5 \times 10^{-7} \text{ m}$.**2. Given**

$$d = 5.5 \times 10^{-4} \text{ m}$$

$$n = 3$$

$$\lambda = 4.60 \times 10^{-7} \text{ m}$$

Requiredangle of diffraction (θ)**Analysis and Solution**

$$\lambda = \frac{d \sin \theta}{n}$$

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

$$\theta = \sin^{-1} \left(\frac{(4.60 \times 10^{-7} \text{ m})(3)}{5.5 \times 10^{-4} \text{ m}} \right)$$

$$\theta = 0.14^\circ$$

ParaphraseThe angle of diffraction to the third antinode is 0.14° .**3. Given**

$$d = 4.0 \times 10^{-4} \text{ m}$$

$$n = 2$$

$$\theta = 0.095^\circ$$

Requiredwavelength (λ)

Analysis and Solution

$$\lambda = \frac{d \sin \theta}{n - \frac{1}{2}}$$

$$\lambda = \frac{(4.0 \times 10^{-4} \text{ m})(\sin 0.095^\circ)}{2 - \frac{1}{2}}$$

$$\lambda = 4.4 \times 10^{-7} \text{ m}$$

Paraphrase

The wavelength of light producing this pattern is 4.4×10^{-7} m and this corresponds to the colour violet.

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Example 13.9 Practice Problems

1. Given

$$d = 1.5 \times 10^{-4} \text{ m}$$

$$L = 5.0 \text{ m}$$

$$x = 4.50 \times 10^{-2} \text{ m}$$

$$n = 3$$

Required

wavelength (λ)

Analysis and Solution

$$\lambda = \frac{xd}{\left(n - \frac{1}{2}\right)L}$$

$$\lambda = \frac{(4.50 \times 10^{-2} \text{ m})(1.5 \times 10^{-4} \text{ m})}{\left(3 - \frac{1}{2}\right)(5.0 \text{ m})}$$

$$\lambda = 5.4 \times 10^{-7} \text{ m}$$

Paraphrase

The wavelength of light is 5.4×10^{-7} m.

2. Given

$$d = 3.00 \times 10^{-5} \text{ m}$$

$$L = 1.50 \text{ m}$$

$$x = 3.10 \times 10^{-2} \text{ m}$$

$$n = 1$$

Required

wavelength (λ)

Analysis and Solution

$$\lambda = \frac{xd}{nL}$$
$$\lambda = \frac{(3.10 \times 10^{-2} \text{ m})(3.00 \times 10^{-5} \text{ m})}{(1)(1.50 \text{ m})}$$

$$\lambda = 6.20 \times 10^{-7} \text{ m}$$

Paraphrase

The wavelength of light producing this pattern $6.20 \times 10^{-7} \text{ m}$ and this corresponds to the colour red.

3. Given

$$x = 1.00 \times 10^{-1} \text{ m}$$

$$L = 1.20 \text{ m}$$

$$\lambda = 5.00 \times 10^{-7} \text{ m}$$

$$n = 3$$

Required

slit distance (d)

Analysis and Solution

$$\lambda = \frac{xd}{\left(n - \frac{1}{2}\right)L}$$
$$d = \frac{\lambda \left(n - \frac{1}{2}\right)L}{x}$$
$$d = \frac{(5.00 \times 10^{-7} \text{ m}) \left(3 - \frac{1}{2}\right)(1.20 \text{ m})}{(1.00 \times 10^{-1} \text{ m})}$$

$$d = 1.5 \times 10^{-5} \text{ m}$$

Paraphrase

The two slits are separated by $1.5 \times 10^{-5} \text{ m}$.

Example 13.10 Practice Problems

1. Given

$$d = \frac{1 \text{ cm}}{2500 \text{ lines}} = 4.000 \times 10^{-4} \text{ cm}$$

$$d = 4.000 \times 10^{-6} \text{ m}$$

$$n = 3$$

$$x = 2.00 \times 10^{-1} \text{ m}$$

$$L = 5.00 \times 10^{-1} \text{ m}$$

Requiredwavelength (λ)**Analysis and Solution**

$$\lambda = \frac{xd}{\left(n - \frac{1}{2}\right)L}$$

$$\lambda = \frac{(2.00 \times 10^{-1} \text{ m})(4.000 \times 10^{-6} \text{ m})}{\left(3 - \frac{1}{2}\right)(5.00 \times 10^{-1} \text{ m})}$$

$$\lambda = 6.40 \times 10^{-7} \text{ m}$$

ParaphraseThe wavelength of the light is $6.40 \times 10^{-7} \text{ m}$.**2. Given**

$$n = 3$$

$$x = 5.00 \times 10^{-2} \text{ m}$$

$$L = 6.0 \times 10^{-1} \text{ m}$$

$$\lambda = 5.00 \times 10^{-7} \text{ m}$$

Requirednumber of lines per cm. $\left(\frac{1}{d}\right)$ **Analysis and Solution**

$$\lambda = \frac{xd}{\left(n - \frac{1}{2}\right)L}$$

$$d = \frac{\lambda \left(n - \frac{1}{2}\right)L}{x}$$

$$d = \frac{(5.00 \times 10^{-7} \text{ m}) \left(3 - \frac{1}{2}\right) (6.0 \times 10^{-1} \text{ m})}{(5.00 \times 10^{-2} \text{ m})}$$

$$d = 1.5 \times 10^{-5} \text{ m}$$

$$\frac{\text{lines}}{\text{metre}} = \frac{1}{1.5 \times 10^{-5} \text{ m}} = 6.7 \times 10^4 \frac{\text{lines}}{\text{metre}}$$

$$\frac{6.7 \times 10^4 \text{ lines}}{1 \cancel{\text{m}}} \times \frac{1 \cancel{\text{m}}}{100 \text{ cm}} = 6.7 \times 10^2 \frac{\text{lines}}{\text{cm}}$$

ParaphraseThere are 6.7×10^2 lines/cm in the diffraction grating.

3. Given

$$d = \frac{1 \text{ cm}}{1000 \text{ lines}} = 1.000 \times 10^{-3} \text{ cm}$$

$$d = 1.000 \times 10^{-5} \text{ m}$$

$$\lambda = 7.50 \times 10^{-7} \text{ m}$$

$$n = 1$$

$$L = 3.0 \text{ m}$$

Required

separation distance (x)

Analysis and Solution

$$\lambda = \frac{xd}{nL}$$

$$x = \frac{\lambda nL}{d}$$

$$x = \frac{(7.50 \times 10^{-7} \text{ m})(1)(3.0 \text{ m})}{1.000 \times 10^{-5} \text{ m}}$$

$$x = 2.25 \times 10^{-1} \text{ m}$$

$$x = 22.5 \text{ cm}$$

$$x = 23 \text{ cm}$$

Paraphrase

The bright antinodes are separated by a distance of 23 cm.

13.5 Check and Reflect

Knowledge

1. According to Huygens' Principle, a straight wavefront will take on a semi-circular shape as it emerges from the opening.
2. When a straight wavefront is incident on two narrow openings, each opening acts as a point source (wavelet), with a circular wavefront emerging. Since the wavelets or point sources have the same wavelength, the circular waves emerge in phase and interfere depending on the length of the path difference to any point p .
3. Incandescent white lights emit light waves in random bursts, out of phase with any second light source which could be placed nearby. In addition, the emitted waves have a variety of wavelengths making up all the colours in the spectrum. Therefore, the interference pattern would not be constant, but would vary rapidly over time, making any observation of the pattern impossible.
4. Young needed to have two sources of light that were coherent (in phase) and separated by a very small distance so that an interference pattern could be observed. He did this by splitting a small sunbeam using a card that was slightly smaller than the diameter of the sunbeam.
5. Concept maps will vary but should include the following connections: When the path length of two identical waves is different by a whole number of $\frac{1}{2}$ wavelengths they

are out of phase and destructive interference occurs, producing a nodal fringe. When the path lengths are different by a whole number of wavelengths they are in phase and constructive interference will occur to produce an antinodal fringe.

Applications

6. Given

$$n = 3$$

$$\lambda = 6.50 \times 10^{-7} \text{ m}$$

$$\theta = 20^\circ$$

Required

slit separation (d)

Analysis and Solution

$$\lambda = \frac{d \sin \theta}{n}$$

$$d = \frac{n\lambda}{\sin \theta}$$

$$d = \frac{(3)(6.50 \times 10^{-7} \text{ m})}{\sin 20}$$

$$d = 5.7 \times 10^{-6} \text{ m}$$

Paraphrase

The two slits are 5.7×10^{-6} m apart.

7. Given

$$d = 6.00 \times 10^{-6} \text{ m}$$

$$n = 2$$

$$\lambda = 4.25 \times 10^{-7} \text{ m}$$

Required

angle of diffraction (θ)

Analysis and Solution

$$\lambda = \frac{d \sin \theta}{n - \frac{1}{2}}$$

$$\theta = \sin^{-1} \left(\frac{\lambda \left(n - \frac{1}{2} \right)}{d} \right)$$

$$\theta = \sin^{-1} \left(\frac{(4.25 \times 10^{-7} \text{ m}) \left(2 - \frac{1}{2} \right)}{6.00 \times 10^{-6} \text{ m}} \right)$$

$$\theta = 6.10^\circ$$

Paraphrase

The angle of diffraction to the 2nd node is 6.10° .

8. Given

$$d = \frac{1 \text{ cm}}{5.00 \times 10^3 \text{ lines}} = 2.00 \times 10^{-4} \text{ cm}$$

$$d = 2.00 \times 10^{-6} \text{ m}$$

$$\lambda = 7.00 \times 10^{-7} \text{ m}$$

$$n = 1$$

$$L = 1.00 \text{ m}$$

Required

distance between 1st and central antinodes (x)

Analysis and Solution

$$\lambda = \frac{xd}{nL}$$

$$x = \frac{\lambda n L}{d}$$

$$x = \frac{(7.00 \times 10^{-7} \text{ m})(1)(1.00 \text{ m})}{2.00 \times 10^{-6} \text{ m}}$$

$$x = 0.350 \text{ m}$$

$$x = 35.0 \text{ cm}$$

Paraphrase

The distance between the 1st and central antinodes is 35.0 cm.

9. Given

$$d = \frac{1 \text{ cm}}{60 \text{ lines}} = 1.66667 \times 10^{-2} \text{ cm}$$

$$d = 1.66667 \times 10^{-4} \text{ m}$$

$$f = 5.75 \times 10^{14} \text{ Hz}$$

$$\lambda = \frac{v}{f} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{5.75 \times 10^{14} \text{ Hz}}$$

$$\lambda = 5.21739 \times 10^{-7} \text{ m}$$

$$n = 3 - 2 = 1$$

$$L = 1.20 \text{ m}$$

Required

distance between 2nd and 3rd dark fringes (x)

Analysis and Solution

$$\lambda = \frac{xd}{nL}$$

$$x = \frac{\lambda n L}{d}$$

$$x = \frac{(5.21739 \times 10^{-7} \text{ m})(1)(1.20 \text{ m})}{1.66667 \times 10^{-4} \text{ m}}$$

$$x = 3.76 \times 10^{-3} \text{ m}$$

Paraphrase

The distance between the 2nd and 3rd dark fringes is 3.76×10^{-3} m.

10. Given

$$d = \frac{1 \text{ m}}{6.00 \times 10^4 \text{ lines}}$$

$$n = 1$$

$$x = 5.50 \times 10^{-2} \text{ m}$$

$$L = 1.50 \text{ m}$$

Required

wavelength (λ)

frequency (f)

Analysis and Solution

$$\lambda = \frac{xd}{nL}$$

$$v = f\lambda$$

$$\lambda = \frac{(5.50 \times 10^{-2} \text{ m}) \left(\frac{1 \text{ m}}{6.00 \times 10^4 \text{ lines}} \right)}{(1)(1.50 \text{ m})}$$

$$\lambda = 6.11 \times 10^{-7} \text{ m}$$

$$f = \frac{v}{\lambda} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{6.11 \times 10^{-7} \text{ m}}$$

$$f = 4.91 \times 10^{14} \text{ Hz}$$

Paraphrase

The unknown light source has a wavelength of 6.11×10^{-7} m and a frequency of 4.91×10^{14} Hz.

11. Given

$$d = \frac{0.01 \text{ m}}{5.00 \times 10^2 \text{ lines}}$$

$$n = 1$$

$$x = 3.10 \times 10^{-2} \text{ m}$$

$$L = 1.50 \text{ m}$$

Required

wavelength (λ)

frequency (f)

Analysis and Solution

$$\lambda = \frac{xd}{nL}$$

$$v = f\lambda$$

$$\lambda = \frac{(3.10 \times 10^{-2} \text{ m}) \left(\frac{0.01 \text{ m}}{5.00 \times 10^2 \text{ lines}} \right)}{(1)(1.50 \text{ m})}$$

$$\lambda = 4.13 \times 10^{-7} \text{ m}$$

$$f = \frac{v}{\lambda} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{4.13333 \times 10^{-7} \text{ m}}$$

$$f = 7.26 \times 10^{14} \text{ Hz}$$

Paraphrase

The unknown light source has a wavelength of $4.13 \times 10^{-7} \text{ m}$ and a frequency of $7.26 \times 10^{14} \text{ Hz}$.

Extensions

12. Experimental designs will vary but should be based on the following:
1. the unknown light source is incident on a diffraction grating which produces an interference pattern on a nearby screen.
 2. The distances between each visible antinode and the central antinode (x) are measured and recorded.
 3. Slit separation (d) is determined from the grating, and the distance between the grating and the screen (L) is measured and recorded.
 4. For each antinode, the wavelength is calculated using $\lambda = xd/nL$. An average value for the wavelength is then determined.

Materials may include a diffraction grating, screen, ruler, metre-stick and light source.

13. X rays have a much shorter wavelength than visible light rays. Comparing the diffraction pattern produced by visible light and X rays that are incident on the same diffraction grating, one would notice that the separation between antinodes (x) would be smaller for X rays, based on:

$$x = \lambda(nL/d), \text{ where } (nL/d) \text{ is constant.}$$

14. Crystal lattices and structures too small to be seen with visible light have openings which can be thought of as small slits. Using X rays or other, shorter, wavelengths which can diffract in these small openings, the size and shape of the crystal lattice can be inferred. This inference is based on the interference pattern produced on photographic film, which is sensitive to the type of EMR that is incident on the crystal.

Chapter 13 Review

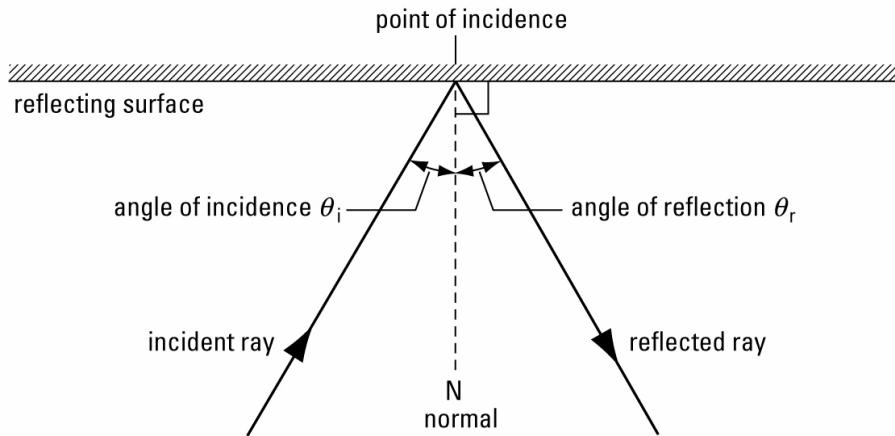
Knowledge

1. Table should be similar to Table 13.1 with additional notes related to common uses for each type of radiation.

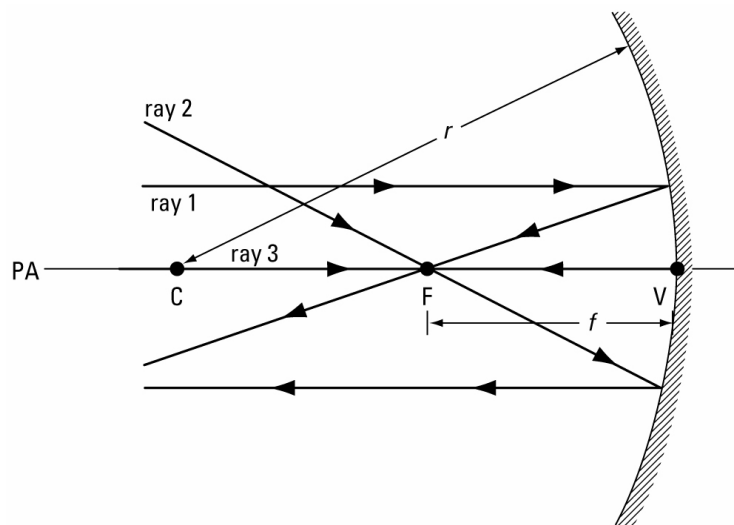
2. The particle model describes EMR as a stream of tiny particles radiating out from a source. The wave model describes EMR as a stream of transverse waves radiating out from a source.
3. Two critical insights understood by Maxwell were: A moving electric charge (or a changing electric field) produces a magnetic field; and, a changing magnetic field produces an electric field that can cause electric charges to move.
4. Drawing a path to connect these two electric field vectors reveals that there must be a change in direction of the electric field along this square path. According to Faraday's Law, there must be a perpendicular magnetic field that exists within the closed path of the changing electric field.
5. The changing electric field produced by a capacitor will produce a changing magnetic field in the same manner that a moving charge in a conductor does. Therefore, a conductor is not necessary for the production and propagation of perpendicular magnetic and electric fields.
6.
 - a) electromagnetic waves are produced whenever an electric charge is accelerating. Therefore, as an electric charge oscillates, electrical energy will be lost, and an equivalent amount of energy will be radiated outward in the form of oscillating electric and magnetic fields.
 - b) When the electric charge is accelerated in periodic motion, the frequency of oscillation of the charge will correspond exactly to the frequency of the electromagnetic wave that is produced.
 - c) All electromagnetic waves, including radio, infrared, visible light, and X rays, will travel at a speed of 3.00×10^8 m/s in a vacuum and obey the universal wave equation ($c = f\lambda$) relating speed, frequency, and wavelength
 - d) The oscillating electric and magnetic fields will always be perpendicular to each other and perpendicular to the direction of propagation of the wave.
 - e) Electromagnetic waves should show all the phenomena associated with transverse waves: interference, diffraction, refraction, and polarization.
7. When a changing electromagnetic field encounters a metal antenna, it will induce current flow, which can be measured. The induced current in the antenna will fluctuate in such a way as to match the frequency of the changing electric and magnetic fields in the wave. In Hertz's experiment, when the receiver was tuned to the same frequency as the radiator, the induced current flow in the antenna oscillated at a frequency identical to that of the changing electric field in the radiator. This was conclusive evidence that Hertz's device had indeed produced the electromagnetic radiation that was being observed at his antenna.
8. The eclipse of Io occurs at regular intervals based on its constant period of rotation around Jupiter. Astronomical observations showed that the timing of the eclipse appeared to vary by as much as 22 min depending on the relative positions of Jupiter and Earth. Christian Huygens reasoned that the variance in time was due to the extra distance (Earth's orbital diameter, estimated as 3.0×10^{11} m) that the light needed to travel when Jupiter and Earth were at their maximum distance of separation. His calculations produced a value of 2.3×10^8 m/s when he divided the estimated orbital diameter of Earth (3.0×10^{11} m) by the 22 min (1320 s) time variance.
9. In Fizeau's water experiment, light travelled through two water tubes, which had water flowing in opposite directions. The speed of the light was indeed influenced by

the motion of the water, and the light arrived out of phase at an exit point, as would be expected if light has wavelike characteristics. An interferometer was used to observe the resulting interference pattern, which provided strong support for the wave model of light.

10.



11.

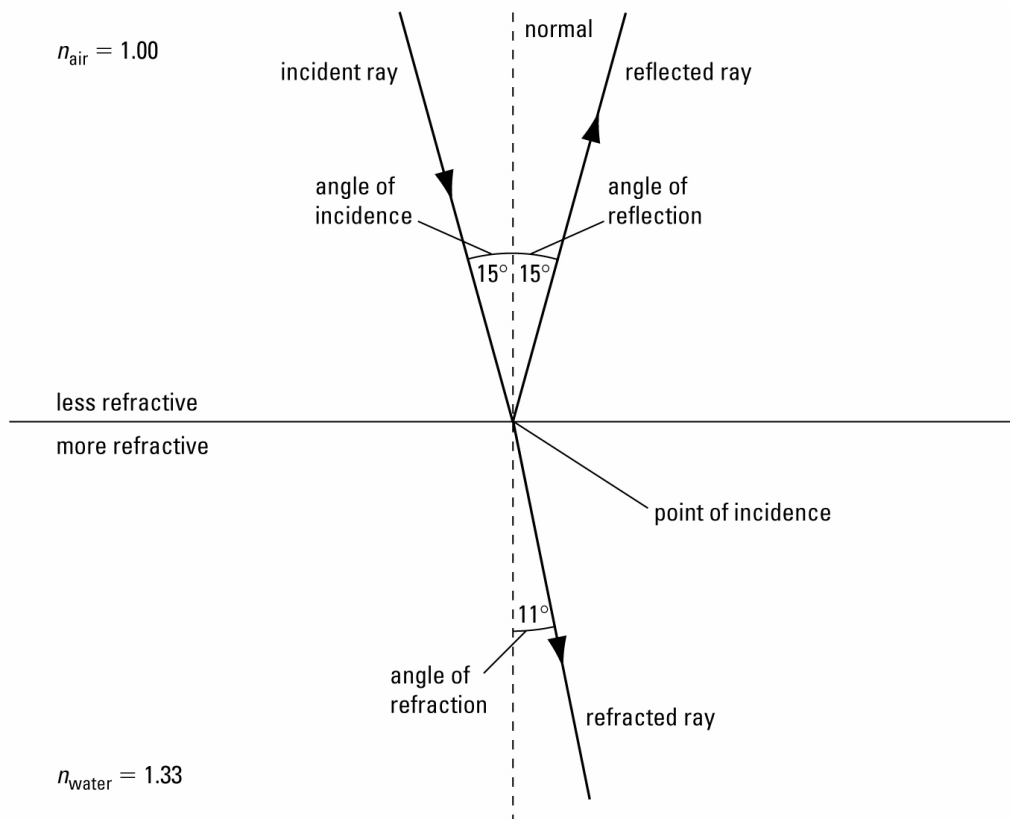


- **centre of curvature (C)** – the point in space that would represent the centre of the sphere from which the curved mirror was cut
- **radius of curvature (r)** – the distance from the centre of curvature to the mirror surface
- **vertex (V)** – the geometric centre of the curved mirror surface
- **principal axis (PA)** – an imaginary line drawn through the vertex, perpendicular to the surface of the curved mirror at this point
- **principal focal point (F)** – the point where light rays that are parallel to and close to the principal axis converge, or appear to diverge from, after being reflected

- **focal length (f)** – the distance from the vertex to the focal point, measured along the principal axis.

12. A real image forms where multiple rays converge or cross. In the case of a diverging mirror, all the reflected rays diverge and only appear to have originated from a single point, thus providing a virtual image. A real image can never form since the reflected rays never converge or cross.

13.



[Angle measurements are not exact here, but indicate the relationship between angles of incidence and refraction.]

14. When light passes from a medium with a high refractive index to one with a low refractive index the light is bent away from the normal line.

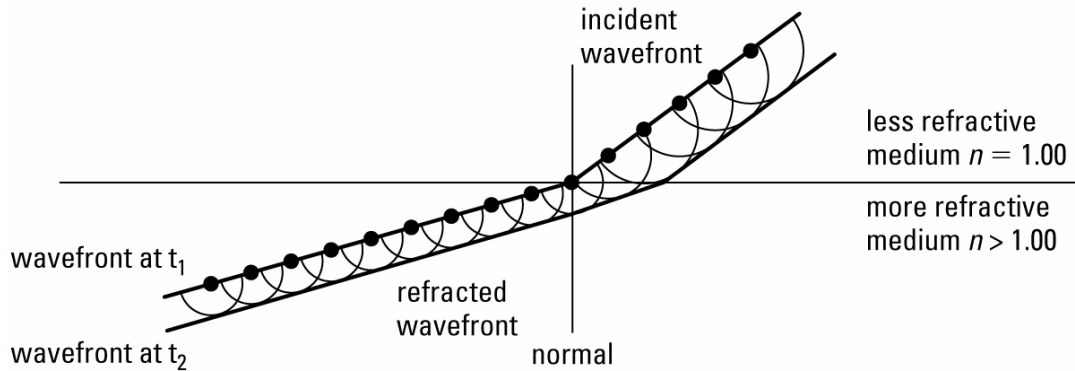
15. The simple form of Snell's Law, $\frac{\sin \theta_{\text{air}}}{\sin \theta_r} = n$ applies whenever the first medium has

an index of refraction equal to 1.0 (i.e. the medium is air or a vacuum). It can be used to determine the refractive index of any material when light passes from air or a vacuum into that material. The general form of Snell's Law, $n_1 \sin \theta_1 = n_2 \sin \theta_2$, can be applied in all cases, regardless of the indexes of refraction of the media and/or the direction in which the light travels.

16. Dispersion is the separation of white light into a continuous spectrum of colours - each defined by its wavelength. Two different methods of separating all the colours in white light are as follows. In a prism, the refractive index varies for each wavelength (or colour) and so the amount of refraction is different for each colour. This causes the colours to be separated as they exit the prism. In diffraction, dispersion can be

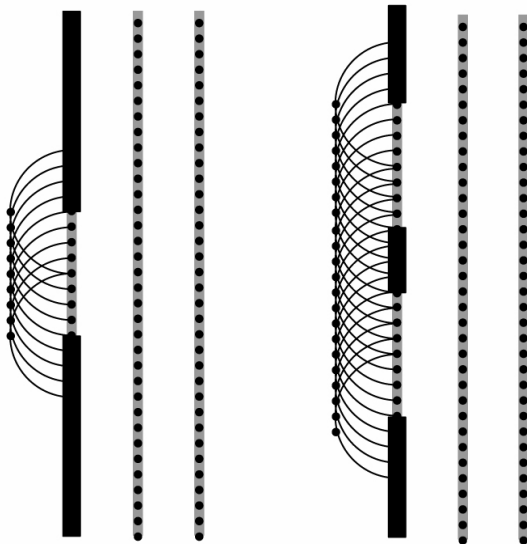
observed in the interference pattern because the path lengths which create destructive and constructive interference are defined by the wavelength of each colour in the visible spectrum. Since the wavelengths are different, the location of constructive and destructive interference for each wavelength is different – causing the colours to be dispersed or separated in the interference pattern.

17.



According to Huygens' Principle the straight wave front is composed of many small wavelets, with the line tangent to all wavelets forming the wave front. The wavelets travel faster in the less refractive medium, causing the wavefront to travel a greater distance during the t_1-t_2 time interval. This is illustrated by the larger radius of the wavelets in the less refractive medium. Therefore, the process of refraction can be explained using Huygens' Principle. This supports the wave model of light.

18.



Interference will occur as the wavelets overlap, causing areas of constructive interference and areas of destructive interference.

19. Incandescent lights emit light in random bursts, not necessarily in phase with one another, and with a variety of wavelengths making up all the colours in the spectrum. In this situation, the interference pattern would not be constant, but would vary rapidly over time, making any observation of a pattern impossible.

20. Electromagnetic waves can be blocked by two **polarizing filters** held at right angles to one another. This evidence can be explained by considering electromagnetic radiation as a transverse wave with perpendicular magnetic and electric fields.
21. Each antinode appears as a full spectrum when white light is incident on a diffraction grating because the differences in path lengths which create destructive and constructive interference are defined by the wavelength of each colour in the visible spectrum. Since the wavelengths are different, location of constructive and destructive interference for each wavelength is different – causing the colours to be dispersed or separated in the interference pattern.
22. Incident light which contacts the edge of a circular disc is diffracted inwards. A tracing of the path of all the diffracted light around the edge of the disc forms a geometric cone. Since the path length from the disc edge to the tip of the cone is identical for all the diffracted light rays, they arrive at the tip of the cone in phase. When all of the light rays arrive in phase, constructive interference is observed as a “bright spot”.

Applications

23. Alternating current means that the charges are constantly accelerating, creating a changing electric field that produces an electromagnetic wave with a frequency equal to that of the alternating direction of the current in the high voltage wires. When these EMR waves encounter radio waves, they may interfere constructively and destructively, thus altering the form of the radio waves. This is observed as interference in the radio signal.

24. (a) Water

Given

$$n_{\text{water}} = 1.33 \quad \text{from Table 13.4}$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

Required

speed of light in water (v)

Analysis and Solution

The refractive index of water for 589 nm light is 1.33. This index is a ratio of the speed of light in a vacuum to that of the light in water. This ratio can be used to determine the speed of the light in water.

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

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

$$v = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{1.33}$$

$$v = 2.26 \times 10^8 \frac{\text{m}}{\text{s}}$$

Paraphrase

The speed of 589 nm yellow light in water is 2.26×10^8 m/s.

- (b) ethanol

Given

$$n_{\text{ethanol}} = 1.37 \quad \text{from Table 13.4}$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

Required

speed of light in ethanol (v)

Analysis and Solution

The refractive index of ethanol for 589 nm light is 1.37. This index is a ratio of the speed of light in a vacuum to that of the light in ethanol. This ratio can be used to determine the speed of the light in ethanol.

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

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

$$v = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{1.37}$$

$$v = 2.19 \times 10^8 \text{ m/s}$$

Paraphrase

The speed of 589 nm yellow light in ethanol is 2.19×10^8 m/s.

(c) Lucite®

Given

$$n_{\text{Lucite}} = 1.52 \text{ from Table 13.4}$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

Required

speed of light in Lucite® (v)

Analysis and Solution

The refractive index of Lucite® for 589 nm light is 1.52. This index is a ratio of the speed of light in a vacuum to that of the light in Lucite®. This ratio can be used to determine the speed of the light in Lucite®.

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

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

$$v = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{1.52}$$

$$v = 1.97 \times 10^8 \text{ m/s}$$

Paraphrase

The speed of 589 nm yellow light in Lucite® is 1.97×10^8 m/s.

(d) quartz glass

Given

$$n_{\text{quartz glass}} = 1.47 \text{ from Table 13.4}$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

Required

speed of light in quartz glass (v)

Analysis and Solution

The refractive index of quartz glass for 589 nm light is 1.47. This index is a ratio of the speed of light in a vacuum to that of the light in quartz glass. This ratio can be used to determine the speed of the light in quartz glass.

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

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

$$v = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{1.47}$$

$$v = 2.04 \times 10^8 \frac{\text{m}}{\text{s}}$$

Paraphrase

The speed of 589 nm yellow light in quartz glass is 2.04×10^8 m/s.

(e) diamond

Given

$$n_{\text{diamond}} = 2.42 \text{ from Table 13.4}$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

Required

speed of light in diamond (v)

Analysis and Solution

The refractive index of diamond for 589 nm light is 2.42. This index is a ratio of the speed of light in a vacuum to that of the light in diamond. This ratio can be used to determine the speed of the light in diamond.

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

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

$$v = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{2.42}$$

$$v = 1.24 \times 10^8 \frac{\text{m}}{\text{s}}$$

Paraphrase

The speed of 589 nm yellow light in diamond is 1.24×10^8 m/s.

25. Given

$$\frac{1 \text{ rotation}}{8 \text{ sides}}$$

$$c = 3.00 \times 10^8 \text{ m}$$

$$f = 5.50 \times 10^2 \text{ Hz}$$

Required

distance (d)

Analysis and Solution

Unit analysis can be used to determine the distance that the light can travel during 1/8th of a rotation. The given information must be arranged as follows

$$d = \frac{\cancel{\text{rot}}}{\text{side}} \times \frac{\text{m}}{\cancel{\text{s}}} \times \frac{\cancel{\text{s}}}{\cancel{\text{rot}}}$$

$$d_{\text{total}} = \frac{1 \text{ rot}}{8 \text{ side}} \times \frac{3.00 \times 10^8 \text{ m}}{1 \text{ s}} \times \frac{1 \text{ s}}{5.50 \times 10^2 \text{ rot}}$$

$$d_{\text{total}} = 68181.81818 \text{ m}$$

$$d = \frac{68181.81818 \text{ m}}{2} = 3.41 \times 10^4 \text{ m}$$

Paraphrase

The fixed mirror should be placed 3.41×10^4 m from the rotating mirror.

26. Given

8 sides / 1 rotation

$f = 600$ rot /s (Hz)

$d = 6.00 \times 10^4$ m

Required

speed of light (c)

Analysis and Solution

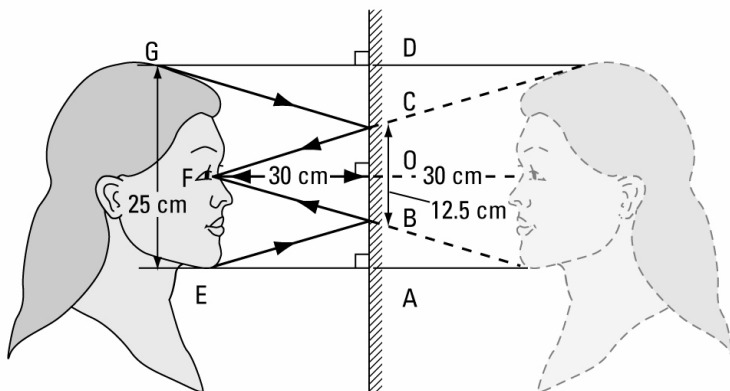
The round trip distance is 6.00×10^4 m. The light must travel this distance in time Δt , which is equal to one-eighth of the period of rotation. Using this time and the total distance, the speed of light can be calculated using

$$c = \frac{\Delta d}{\Delta t} \quad T = \frac{1}{f} \quad \Delta t = \frac{1}{8}T \quad c = \frac{\Delta d}{\Delta t}$$
$$c = \frac{6.00 \times 10^4 \text{ m}}{2.083333333 \times 10^{-4} \text{ s}} \quad T = \frac{1}{600 \text{ Hz}} \quad \Delta t = \frac{1}{8}(1.66666667 \times 10^{-3} \text{ s}) \quad c = 2.88 \times 10^8 \text{ m/s}$$
$$T = 1.66666667 \times 10^{-3} \text{ s} \quad \Delta t = 2.083333333 \times 10^{-4} \text{ s} \quad c = 2.88 \times 10^8 \text{ m/s}$$

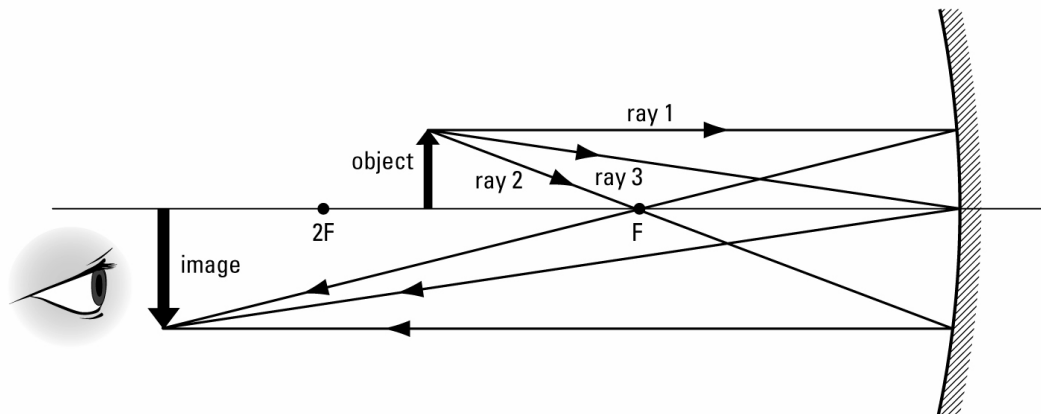
Paraphrase

The speed of light in air was found to be 2.88×10^8 m/s.

27. An image that forms in a plane mirror is erect, virtual, and the same size as the object.
28. Using a ray diagram and measuring the distance (shown in green below) between the upper ray and lower ray point of incidence reveals that the portion of the mirror needed to see the entire face is equal to 12.5 cm or half the height of the object.

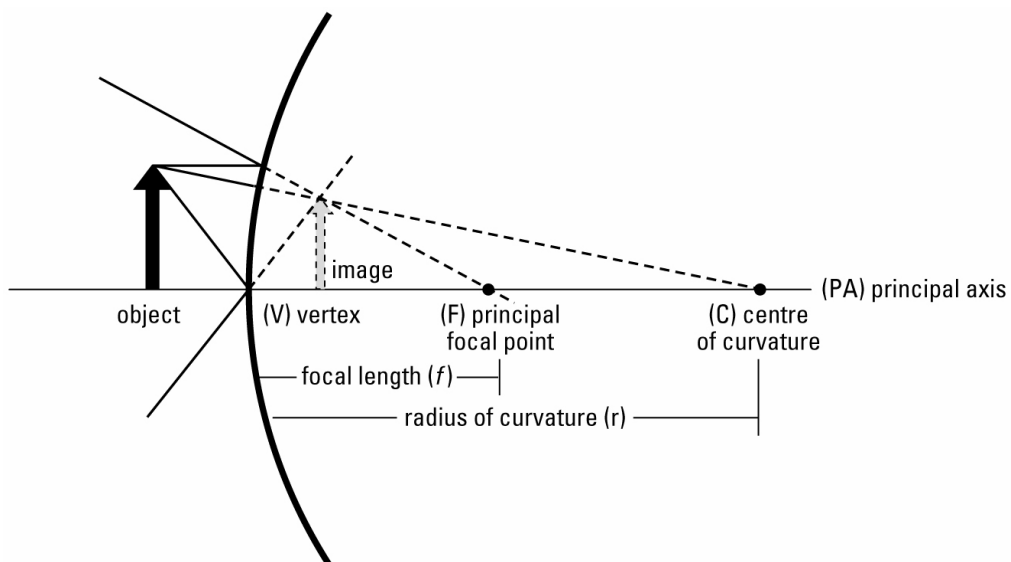


29. Incident Ray 1 is parallel to the principal axis. Any ray that is parallel to the principal axis will reflect through the focal point on a converging mirror.
- Incident Ray 2 travels through the focal point. Any ray that passes through the focal point on a converging mirror will be reflected back parallel to the principal axis.
- Incident Ray 3 travels towards the vertex. The vertex acts as a plane reflector, where the angle of incidence is equal to the angle of reflection.



- (a) the image is located at 37.4 cm from the vertex and it is real
- (b) the image is inverted
- (c) the image is magnified 1.5X

30.



31. A virtual image is produced by a converging mirror whenever an object is placed between the focal point and the vertex of the mirror. If the object is beyond the focal point, the image is real and if the object is located at the focal point, no image will form.

32. **Given**

$$h_o = +15.0 \text{ cm}$$

$$d_o = 20.0 \text{ cm}$$

$$f = -10.0 \text{ cm}$$

Required

image height (h_i)

image distance (d_i)

Analysis and Solution

The location of the image can be found using the mirror equation as follows:

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

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

$$\frac{1}{d_i} = \frac{1}{-10.0 \text{ cm}} - \frac{1}{+20.0 \text{ cm}}$$

$$d_i = -6.67 \text{ cm}$$

The height of the image can be found by comparing the ratio of the image and object height to the image and object distances as follows:

$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$h_i = \frac{-(-6.67 \text{ cm})(15.0 \text{ cm})}{20.0 \text{ cm}}$$

$$h_i = 5.00 \text{ cm}$$

Paraphrase

The virtual image forms 6.67 cm from the mirror and it is 5.00 cm high.

33. Given

$$h_i = -20.0 \text{ cm}$$

$$d_o = 12.0 \text{ cm}$$

$$f = 11.0 \text{ cm}$$

Required

image height (h_i)

Analysis and Solution

The image distance is required to solve for the object height, but it is not given. It can be determined using the thin lens equation as follows:

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

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

$$\frac{1}{d_i} = \frac{1}{11.0 \text{ cm}} - \frac{1}{12.0 \text{ cm}}$$

$$d_i = 132 \text{ cm}$$

The height of the object can be found by comparing the ratio of the image and object height to the image and object distances as follows:

$$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_o = \frac{h_i d_o}{-d_i}$$

$$h_o = \frac{(-20.0 \text{ cm})(12.0 \text{ cm})}{-132 \text{ cm}}$$

$$h_o = 1.82 \text{ cm}$$

Paraphrase

The object is 1.82 cm high.

34. Given

$$\theta_1 = 35.0^\circ$$

$$n_1 = 1.00$$

$$n_2 = 1.47$$

$$\lambda_1 = 610 \text{ nm}$$

Required

The angle of refraction (θ_2)

The wavelength in the quartz glass (λ_2)

Analysis and Solution

The angle of refraction and the wavelength in the quartz glass are calculated using the general form of Snell's Law.

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}$$

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

$$\theta_2 = \sin^{-1} \left(\frac{(1.00) \sin(35^\circ)}{1.47} \right)$$

$$\theta_2 = 23^\circ$$

$$\frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$$

$$\lambda_2 = \frac{\lambda_1 n_1}{n_2}$$

$$\lambda_2 = \frac{(610 \text{ nm})(1.00)}{1.47}$$

$$\lambda_2 = 415 \text{ nm}$$

Paraphrase

The angle of refraction is 23° and the wavelength in the quartz glass is 415 nm.

- 35.** Total internal reflection can only occur when the light ray is bent away from the normal line as it enters a new medium. This will only occur when light travels from a high index medium into a low index medium.
- no – total internal reflection cannot occur since light is travelling from a low index medium ($n_{\text{air}} = 1.00$) into a high index medium ($n_{\text{water}} = 1.33$)
 - yes – total internal reflection can occur since light is travelling from a high index medium ($n_{\text{water}} = 1.33$) into a low index medium ($n_{\text{air}} = 1.00$)
 - yes - total internal reflection can occur since light is travelling from a high index medium ($n_{\text{Lucite}} = 1.52$) into a low index medium ($n_{\text{water}} = 1.33$)
 - no – total internal reflection cannot occur since light is travelling from a low index medium ($n_{\text{water}} = 1.33$) into a high index medium ($n_{\text{diamond}} = 2.42$)

36. Given

$$v_{\text{unknown}} = 2.67 \times 10^8 \text{ m/s}$$

$$n_{\text{water}} = 1.33 \quad \text{from Table 13.4}$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

Required

The refractive index of the unknown material (n_{unknown})

Analysis and Solution

The index of refraction is a ratio of the speed of light in the medium to the speed of light in a vacuum.

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

$$n_{\text{unknown}} = \frac{c}{v_{\text{unknown}}}$$

$$n_{\text{unknown}} = \frac{3.00 \times 10^8 \text{ m/s}}{2.67 \times 10^8 \text{ m/s}}$$

$$n_{\text{unknown}} = 1.12$$

Paraphrase and Verify

The unknown material has a refractive index of 1.12, which is less than that of water at 1.33.

37. Given

From Table 13.4:

$$n_{\text{water}} = 1.33$$

$$n_{\text{diamond}} = 2.42$$

$$n_{\text{air}} = 1.00$$

$$n_{\text{Lucite}} = 1.52$$

Required

The critical angle for each boundary (θ_{critical})

Analysis and Solution

The critical angle can be found using Snell's Law and assuming that the angle of refraction is equal to 90° when total internal reflection occurs.

$$n_2 \sin \theta_{\text{critical}} = n_1 \sin 90^\circ$$

$$\theta_{\text{critical}} = \sin^{-1} \left(\frac{n_1 \sin 90^\circ}{n_2} \right)$$

$$\theta_{\text{critical water/air}} = \sin^{-1} \left(\frac{1.00 \sin 90^\circ}{1.33} \right)$$

$$\theta_{\text{critical water/air}} = 48.8^\circ$$

$$\theta_{\text{critical diamond/air}} = \sin^{-1} \left(\frac{1.00 \sin 90^\circ}{2.42} \right)$$

$$\theta_{\text{critical diamond/air}} = 24.4^\circ$$

$$\theta_{\text{critical diamond/water}} = \sin^{-1} \left(\frac{1.33 \sin 90^\circ}{2.42} \right)$$

$$\theta_{\text{critical diamond/water}} = 33.3^\circ$$

$$\theta_{\text{critical Lucite/air}} = \sin^{-1} \left(\frac{1.00 \sin 90^\circ}{1.52} \right)$$

$$\theta_{\text{critical Lucite/air}} = 41.1^\circ$$

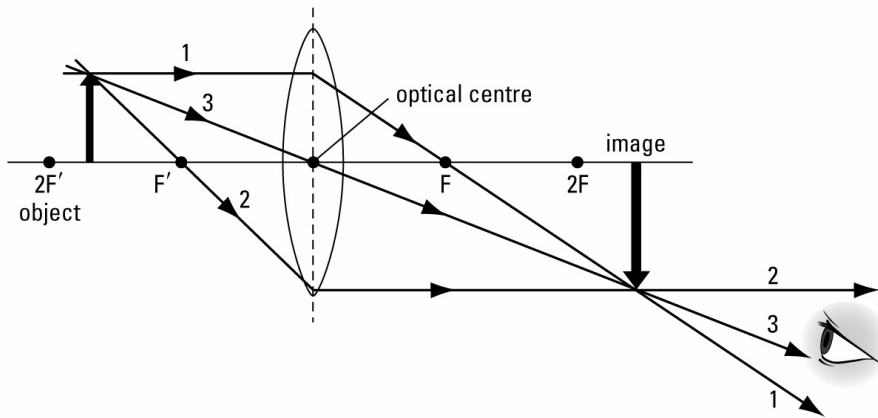
Paraphrase

The critical angle for a water–air boundary is 48.8° ; for a diamond–air boundary it is 24.4° ; for a diamond–water boundary it is 33.3° ; and for a Lucite®–air boundary it is 41.1° .

- 38.** (a) Incident Ray 1 is parallel to the principal axis. Any ray that is parallel to the principal axis will refract through the focal point on a converging lens.
Incident Ray 2 travels through the focal point. Any ray that passes through the focal point on a converging lens will be refracted parallel to the principal axis.

Incident Ray 3 travels straight through the optical centre of the lens and is not refracted.

Ray Diagram

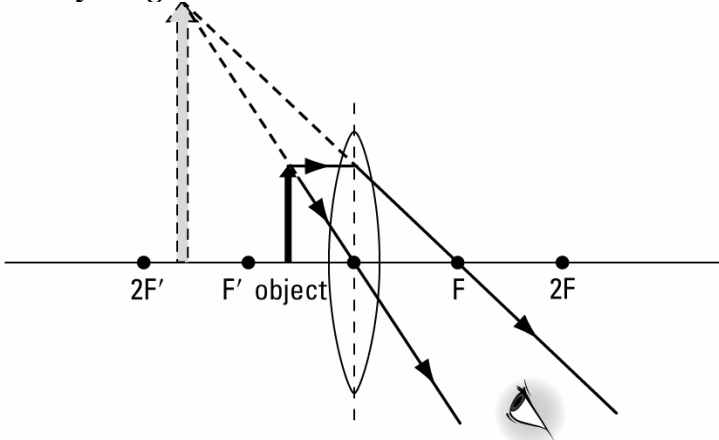


Paraphrase

According to the ray diagram, when the object is located between $2F'$ and F' for a converging lens, the image that forms is real, inverted and magnified, and located beyond $2F$.

- (b) Incident Ray 1 is parallel to the principal axis. Any ray that is parallel to the principal axis will refract through the focal point on a converging lens.
Incident Ray 2 travels straight through the optical centre of the lens and is not refracted.

Ray Diagram



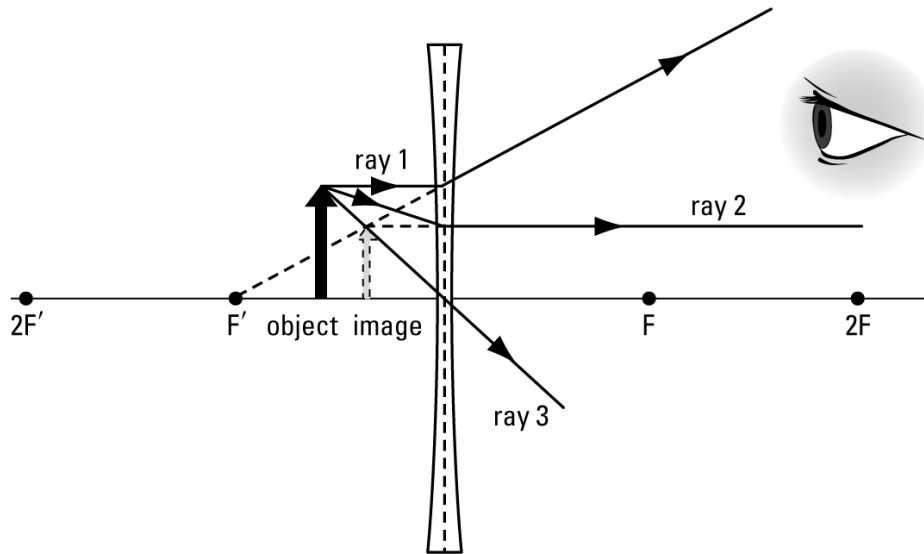
Paraphrase

According to the ray diagram, when the object is located between F' and the converging lens, the image that forms is virtual, erect and magnified.

- (c) Incident Ray 1 is parallel to the principal axis. Any ray that is parallel to the principal axis will appear as though it passed through the virtual focal point on a diverging lens.
Incident Ray 2 travels towards the virtual the focal point. Any ray that is directed at the virtual focal point on a diverging lens will be refracted parallel to the principal axis.

Incident Ray 3 travels straight through the optical centre of the lens and is not refracted.

Ray Diagram



Paraphrase

According to the ray diagram, when the object is located between F' and the diverging lens, the image that forms is virtual, erect and diminished.

39. Given

$$h_o = 4.00 \text{ cm}$$

$$d_o = 5.00 \text{ cm}$$

$$f = -10.0 \text{ cm}$$

Required

image distance (d_i)

image height (h_i)

image attributes (location, type, attitude, and magnification)

Analysis and Solution

The image distance and height can be calculated with the thin lens and magnification equation. The image attributes can be determined based on the sign and/or magnitude of the image distance and height.

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

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

$$\frac{1}{d_i} = \frac{1}{-10.0 \text{ cm}} - \frac{1}{5.00 \text{ cm}}$$

$$d_i = -3.33 \text{ cm}$$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

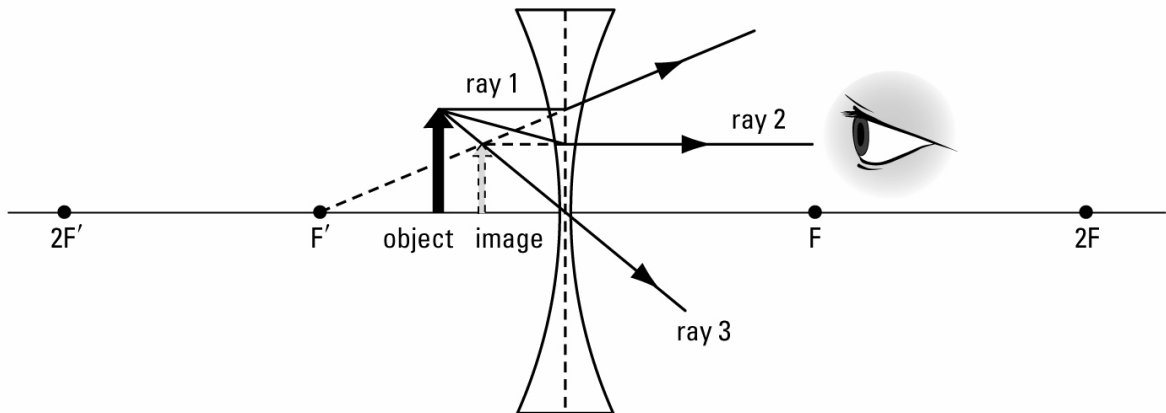
$$h_i = \frac{-(-3.333333 \text{ cm})(4.00 \text{ cm})}{5.00 \text{ cm}}$$

$$h_i = 2.67 \text{ cm}$$

Paraphrase and Verify

The image forms 3.33 cm from the lens with a height of 2.67 cm. Since the image distance is negative it is a virtual image. The image is erect and diminished.

Ray Diagram



40. Given

$$d = 5.3 \times 10^{-5} \text{ m}$$

$$n = 1, 2, 3$$

$$\lambda = 6.30 \times 10^{-7} \text{ m}$$

Required

angle of diffraction to the first, second, and third antinodes (θ)

Analysis and Solution

The first, second, and third antinode are regions of constructive interference, where the path difference must be, respectively, one, two, and three whole wavelengths. Therefore, the generalization for the difference in path lengths for an antinode can be used to calculate the angle of diffraction for each of the first three antinodes.

$$\lambda = \frac{d \sin \theta}{n}$$

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

For first, second, and third antinodes:

$$\theta = \sin^{-1} \left(\frac{(6.30 \times 10^{-7} \text{ m})(1)}{5.3 \times 10^{-5} \text{ m}} \right)$$

$$\theta = 0.68^\circ$$

$$\theta = \sin^{-1} \left(\frac{(6.30 \times 10^{-7} \text{ m})(2)}{5.3 \times 10^{-5} \text{ m}} \right)$$

$$\theta = 1.4^\circ$$

$$\theta = \sin^{-1} \left(\frac{(6.30 \times 10^{-7} \text{ m})(3)}{5.3 \times 10^{-5} \text{ m}} \right)$$

$$\theta = 2.0^\circ$$

Paraphrase

The angles to the 1st, 2nd, and 3rd antinodes, are respectively 0.68° , 1.4° , and 2.0° .

41. Given

$$d = 2.5 \times 10^{-4} \text{ m}$$

$$n = 1$$

$$\theta = 0.050^\circ$$

Required

wavelength (λ) and colour of light

Analysis and Solution

The wavelength of the light can be calculated using the generalization for the first nodal region of destructive interference, where the path difference must be one-half of a wavelength. The colour of the light can be identified by comparing the wavelength to the spectrum for visible light.

$$\lambda = \frac{d \sin \theta}{n - \frac{1}{2}}$$

$$\lambda = \frac{(2.5 \times 10^{-4} \text{ m})(\sin 0.050^\circ)}{1 - \frac{1}{2}}$$

$$\lambda = 4.4 \times 10^{-7} \text{ m}$$

Paraphrase

The wavelength of light producing this pattern is $4.4 \times 10^{-7} \text{ m}$, which corresponds to the colour violet.

42. Given

$$d = 1.4 \times 10^{-4} \text{ m}$$

$$L = 1.1 \text{ m}$$

$$x = 2.5 \times 10^{-2} \text{ m}$$

$$n = 7$$

Required

wavelength (λ) and colour of light

Analysis and Solution

The seventh node is a region of destructive interference, where the path difference must be six and one-half wavelengths. Therefore, the generalization for the difference in path lengths for a node can be used to calculate the wavelength of the

light. The colour of the light can be identified by comparing the wavelength to the spectrum for visible light.

$$\lambda = \frac{xd}{\left(n - \frac{1}{2}\right)L}$$

$$\lambda = \frac{(2.5 \times 10^{-2} \text{ m})(1.4 \times 10^{-4} \text{ m})}{\left(7 - \frac{1}{2}\right)(1.1 \text{ m})}$$

$$\lambda = 4.9 \times 10^{-7} \text{ m}$$

Paraphrase

The wavelength of light is 4.9×10^{-7} m, which corresponds to the colour blue in the visible spectrum.

43. Given

$$x = 3.7 \times 10^{-2} \text{ m}$$

$$L = 4.5 \text{ m}$$

$$\lambda = 4.90 \times 10^{-7} \text{ m}$$

$$n = 1$$

Required

slit separation (d)

Analysis and Solution

The first order antinode is a region of constructive interference, where the path difference is equal to one whole wavelength. Therefore, the generalization for the difference in path lengths for an antinode can be used to calculate the slit separation.

$$\lambda = \frac{xd}{nL}$$

$$d = \frac{\lambda n L}{x}$$

$$d = \frac{(4.90 \times 10^{-7} \text{ m})(1)(4.5 \text{ m})}{(3.7 \times 10^{-2} \text{ m})}$$

$$d = 6.0 \times 10^{-5} \text{ m}$$

Paraphrase

The two slits are separated by 6.0×10^{-5} m.

Extensions

44. The kinetic energy of the electron is related to its speed by $E_k = \frac{1}{2}mv^2$. If the electron

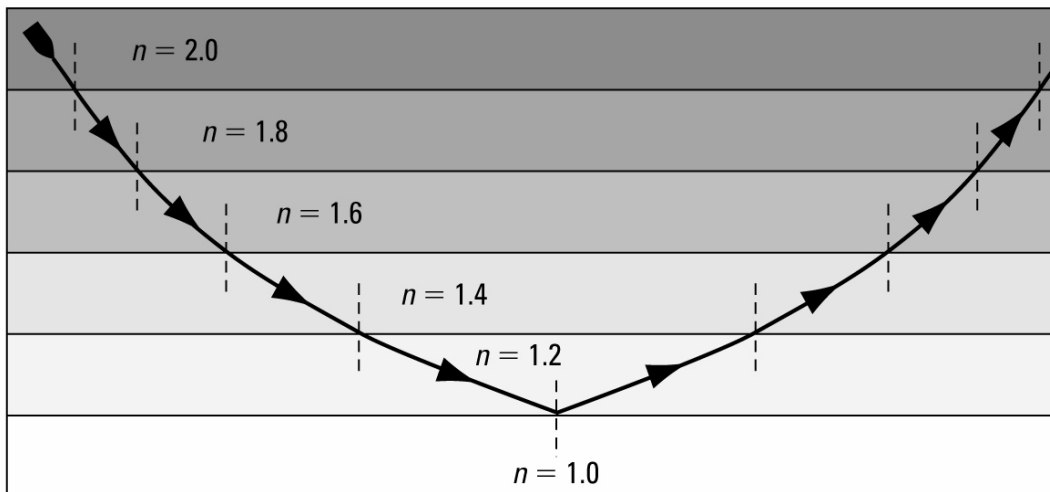
has a very high speed (a large amount of kinetic energy) when it impacts the metal barrier, it will experience a very large acceleration (acceleration = change in velocity/time). The magnitude of the acceleration is directly proportional to the rate of change in the electric field. In turn, the rate of change in the electric field corresponds to the frequency of the EMR that is produced. Therefore, the faster the electron travels the greater the acceleration needed to stop it at a barrier, and the greater the acceleration the greater the rate of change in the electric field and the higher the frequency of EMR produced.

45. The shielding on cable television wires is a conductor which absorbs EMR from outside sources. When EMR from outside sources is incident on the shielding, the

electric field induces a current in the shielding that is safely conducted to the ground. The shielding prevents the EMR from reaching the copper wire and altering the signal current.

46. The range of a two-way radio can be increased by increasing the rate of change in the electric field of the transmitter (increasing the operating voltage). This increases the frequency (energy) of the EMR signal, which produces a higher frequency signal that will travel a greater distance. A second modification would be to increase the sensitivity of the antenna by utilizing a larger amount of very low resistance wire in the antenna. These modifications will allow the radio to generate a longer-range signal, and also to receive a weak signal from a great distance.
47. When you place the concave side of a spoon on your nose and slowly pull the spoon away from your face, the spoon acts as a concave, converging, mirror. Your image disappears when the spoon reaches the focal length of the concave mirror. This occurs because an incident ray that originates at, or passes through, the focal point of a converging mirror will be reflected parallel to the principal axis. The parallel reflected rays will not cross or converge, and therefore an image does not form.
48. After light enters Earth's atmosphere it encounters a temperature gradient as it approaches the surface of Earth. The colder, upper air has a high index of refraction compared to the warmer, lower air at or near the surface. As the light passes from air with a higher index of refraction to air with a lower index of refraction, it is continually refracted away from the normal line, causing the angle of incidence to eventually exceed the critical angle at the lower levels. This results in total internal reflection, producing what we observe as a mirage.

Ray Diagram



49. A fibre-optic communications network is much more efficient than a copper network because:
- the fibres are less expensive than copper wire of equivalent length
 - there is less signal degradation and interference between multiple signals on the same fibre when compared to copper networks
 - the glass fibres are highly transparent so that repeaters (amplifiers) can be many kilometres apart, as opposed to coaxial cable repeaters that must be less than 1 km apart

Fibre optic networks are more powerful than traditional copper networks because they are:

- thinner, more flexible, and made of non-flammable materials
- able to handle a higher data-carrying capacity, based on the fibre bundle diameter

Consolidate Your Understanding

[Answers will vary, but may include concepts set out below.]

1. Electromagnetic radiation consists of perpendicular electric and magnetic fields varying with time, and propagating outward from a source at the speed of light. The fields do not require a conductor to exist. For example, the electric field produced by a capacitor has the same effect as a moving charge in a conductor, but does not require the conductor to exist. If the electric field changes, it induces a perpendicular, changing magnetic field, which in turn produces a changing electric field, and so on. The two perpendicular fields vary with time (reversing directions) as they propagate at the speed of light. The repetitively changing nature of the fields is described well by the transverse wave model.
2. A changing electric field exists in the region near any accelerating charge. Therefore, if a charge accelerates, a changing electric field is present, which induces a changing magnetic field. If the changing electric field is set in motion, the perpendicular changing magnetic field will tag along. The word “changing” is significant since a constant electric field will not induce a magnetic field, nor will a constant magnetic field induce an electric field.
3. According to the wave model of EMR, an electromagnetic wave consists of perpendicular electric and magnetic fields, varying with time and propagating at right angles to both fields. Therefore, EMR is three-dimensional, having one dimension for the varying electric field, one for the varying magnetic field, and one for the direction of propagation.
4. Experimental evidence supports Maxwell’s last prediction that EMR waves show all the phenomena associated with transverse waves. EMR obeys the law of reflection, where the angle of incidence is always equal to the angle of reflection. EMR is refracted, to varying degrees based on the size of the wavelength and speed at which the wave travels in different media. EMR diffracts, according to Huygen’s principle, and produces interference patterns that can be explained by destructive and constructive interference based on differences in path lengths that are defined by the wavelength of the EMR. EMR is also plane- polarized, since it can be completely blocked by two perpendicular polarizing filters.
5. Hertz could have investigated the phenomenon of diffraction by placing a single- or multiple-slit, grounded metal cover over his radiator. If the slits were sufficiently small, and close together, the EMR radiating from all slits would be in phase and would constructively and destructively interfere based on the path length difference to various regions. These regions could be identified and mapped by slowly moving the antenna to various locations near the radiator. A strong signal at the antenna would indicate an area of constructive interference and a weak or non-existent signal would indicate an area of destructive interference. The antenna would need to be sensitive in order to create a detailed map of the nodal and antinodal regions near the radiator.