CHAPTER 13 Summary

BIG IDEA The electromagnetic spectrum includes all light waves, not just those visible to humans. Ray diagrams can be used to describe light waves and to predict the results of interactions with surfaces.

SECTION 1 Characteristics of Light

- Light is electromagnetic radiation that consists of oscillating electric and magnetic fields with different wavelengths.
- The frequency times the wavelength of electromagnetic radiation is equal to *c*, the speed of light.
- The brightness of light is inversely proportional to the square of the distance from the light source.

KEY TERM

electromagnetic wave

SECTION 2 Flat Mirrors

- Light obeys the law of reflection, which states that the incident and reflected angles of light are equal.
- Flat mirrors form virtual images that are the same distance from the mirror's surface as the object is.

KEY TERMS

reflection
angle of incidence
angle of reflection
virtual image

SECTION 3 Curved Mirrors

- The mirror equation relates object distance, image distance, and focal length of a spherical mirror.
- The magnification equation relates image height or distance to object height or distance, respectively.

KEY TERMS

concave spherical mirror
real image
convex spherical mirror

SECTION 4 Color and Polarization

- Light of different colors can be produced by adding light consisting of the primary additive colors (red, green, and blue).
- Pigments can be treated as subtractive colors (magenta, yellow, and cyan).
- Light can be linearly polarized by transmission, reflection, or scattering.

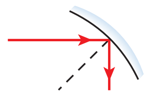
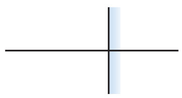
KEY TERM

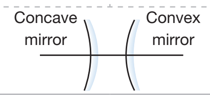
linear polarization

VARIABLE SYMBOLS

Quantities		Units	
p	object distance	m	meters
q	image distance	m	meters
R	radius of curvature	m	meters
f	focal length	m	meters
M	magnification	(unitless)	

DIAGRAM SYMBOLS

Light rays (real)	
Light rays (apparent)	
Normal lines	
Flat mirror	



Problem Solving

See **Appendix D: Equations** for a summary of the equations introduced in this chapter. If you need more problem-solving practice, see **Appendix I: Additional Problems.**

Characteristics of Light

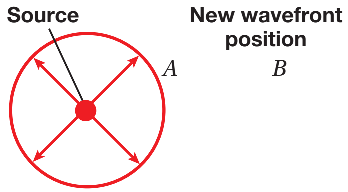
REVIEWING MAIN IDEAS

1. Which band of the electromagnetic spectrum has
   a. the lowest frequency?
   b. the shortest wavelength?

2. Which of the following electromagnetic waves has the highest frequency?
   a. radio
   b. ultraviolet radiation
   c. blue light
   d. infrared radiation

3. Why can light be used to measure distances accurately? What must be known in order to make distance measurements?

4. For the diagram below, use Huygens's principle to show what the wave front at point *A* will look like at point *B*. How would you represent this wave front in the ray approximation?



5. What is the relationship between the actual brightness of a light source and its apparent brightness from where you see it?

CONCEPTUAL QUESTIONS

6. Suppose an intelligent society capable of receiving and transmitting radio signals lives on a planet orbiting Procyon, a star 11.5 light-years away from Earth. If a signal were sent toward Procyon in 1999, what is the earliest year that Earth could expect to receive a return message? (Hint: A light-year is the distance light travels in one year.)

7. How fast do x-rays travel in a vacuum?

8. Why do astronomers observing distant galaxies talk about looking backward in time?

9. Do the brightest stars that you see in the night sky necessarily give off more light than dimmer stars? Explain your answer.

PRACTICE PROBLEMS

For problems 10–13, see Sample Problem A.

10. The compound eyes of bees and other insects are highly sensitive to light in the ultraviolet portion of the spectrum, particularly light with frequencies between 7.5×10^{14} Hz and 1.0×10^{15} Hz. To what wavelengths do these frequencies correspond?

11. The brightest light detected from the star Antares has a frequency of about 3×10^{14} Hz. What is the wavelength of this light?

12. What is the wavelength for an FM radio signal if the number on the dial reads 99.5 MHz?

13. What is the wavelength of a radar signal that has a frequency of 33 GHz?

Flat Mirrors

REVIEWING MAIN IDEAS

14. For each of the objects listed below, identify whether light is reflected diffusely or specularly.
    a. a concrete driveway
    b. an undisturbed pond
    c. a polished silver tray
    d. a sheet of paper
    e. a mercury column in a thermometer

15. If you were stranded on an island, where would you align a mirror to use sunlight to signal a searching aircraft?

16. If you are standing 2 m in front of a flat mirror, how far behind the mirror is your image? What is the magnification of the image?

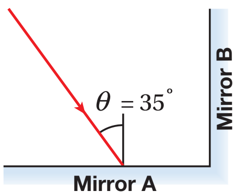
CONCEPTUAL QUESTIONS

17. When you shine a flashlight across a room, you see the beam of light on the wall. Why do you not see the light in the air?

18. How can an object be a specular reflector for some electromagnetic waves yet be diffuse for others?

19. A flat mirror that is 0.85 m tall is attached to a wall so that its upper edge is 1.7 m above the floor. Use the law of reflection and a ray diagram to predict whether this mirror will show a person who is 1.7 m tall his or her complete reflection.

20. Two flat mirrors make an angle of 90.0° with each other, as diagrammed at right. An incoming ray makes an angle of 35° with the normal of mirror A. Use the law of reflection to determine the angle of reflection from mirror B. What is unusual about the incoming and reflected rays of light for this arrangement of mirrors?



21. If you walk 1.2 m/s toward a flat mirror, how fast does your image move with respect to the mirror? In what direction does your image move with respect to you?

22. Why do the images produced by two opposing flat mirrors appear to be progressively smaller?

Curved Mirrors

REVIEWING MAIN IDEAS

23. Which type of mirror should be used to project movie images on a large screen?

24. If an object is placed outside the focal length of a concave mirror, which type of image will be formed? Will it appear in front of or behind the mirror?

25. Can you use a convex mirror to burn a hole in paper by focusing light rays from the sun at the mirror's focal point?

26. A convex mirror forms an image from a real object. Can the image ever be larger than the object?

27. Why are parabolic mirrors preferred over spherical concave mirrors for use in reflecting telescopes?

CONCEPTUAL QUESTIONS

28. Where does a ray of light that is parallel to the principal axis of a concave mirror go after it is reflected at the mirror's surface?

29. What happens to the real image produced by a concave mirror if you move the original object to the location of the image?

30. Consider a concave spherical mirror and a real object. Is the image always inverted? Is the image always real? Give conditions for your answers.

31. Explain why enlarged images seem dimmer than the original objects.

32. What test could you perform to determine if an image is real or virtual?

33. You've been given a concave mirror that may or may not be parabolic. What test could you perform to determine whether it is parabolic?

PRACTICE PROBLEMS

For problems 34–35, see Sample Problem B.

34. A concave shaving mirror has a radius of curvature of 25.0 cm. For each of the following cases, find the magnification and determine whether the image formed is real or virtual and upright or inverted.

a. an upright pencil placed 45.0 cm from the mirror
b. an upright pencil placed 25.0 cm from the mirror
c. an upright pencil placed 5.00 cm from the mirror

35. A concave spherical mirror can be used to project an image onto a sheet of paper, allowing the magnified image of an illuminated real object to be accurately traced. If you have a concave mirror with a focal length of 8.5 cm, where would you place a sheet of paper so that the image projected onto it is twice as far from the mirror as the object is? Is the image upright or inverted, real or virtual? What would the magnification of the image be?

For problem 36, see Sample Problem C.

36. A convex mirror with a radius of curvature of 45.0 cm forms a 1.70 cm tall image of a pencil at a distance of 15.8 cm behind the mirror. Calculate the object distance for the pencil and its height. Is the image real or virtual? What is the magnification? Is the image inverted or upright?

Color and Polarization

REVIEWING MAIN IDEAS

37. What are the three primary additive colors? What happens when you mix them?

38. What are the three primary subtractive colors (or primary pigments)? What happens when you mix them?

39. Explain why a polarizing disk used to analyze light can block light from a beam that has been passed through another polarizer. What is the relative orientation of the two polarizing disks?

CONCEPTUAL QUESTIONS

40. Explain what could happen when you mix the following:
- **a.** cyan and yellow pigment
- **b.** blue and yellow light
- **c.** pure blue and pure yellow pigment
- **d.** green and red light
- **e.** green and blue light

41. What color would an opaque magenta shirt appear to be under the following colors of light?
- **a.** white
- **b.** red
- **c.** cyan
- **d.** green
- **e.** yellow

42. A substance is known to reflect green and blue light. What color would it appear to be when it is illuminated by white light? By blue light?

43. How can you tell if a pair of sunglasses has polarizing lenses?

44. Why would sunglasses with polarizing lenses remove the glare from your view of the hood of your car or a distant body of water but not from a tall metal tank used for storing liquids?

45. Is light from the sky polarized? Why do clouds seen through polarizing glasses stand out in bold contrast to the sky?

Mixed Review

REVIEWING MAIN IDEAS

46. The real image of a tree is magnified −0.085 times by a telescope's primary mirror. If the tree's image forms 35 cm in front of the mirror, what is the distance between the mirror and the tree? What is the focal length of the mirror? What is the value for the mirror's radius of curvature? Is the image virtual or real? Is the image inverted or upright?

47. A candlestick holder has a concave reflector behind the candle, as shown below. The reflector magnifies a candle −0.75 times and forms an image 4.6 cm away from the reflector's surface. Is the image inverted or upright? What are the object distance and the reflector's focal length? Is the image virtual or real?

48. A child holds a candy bar 15.5 cm in front of the convex side-view mirror of an automobile. The image height is reduced by one-half. What is the radius of curvature of the mirror?

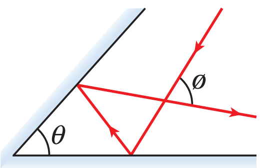
49. A glowing electric light bulb placed 15 cm from a concave spherical mirror produces a real image 8.5 cm from the mirror. If the light bulb is moved to a position 25 cm from the mirror, what is the position of the image? Is the final image real or virtual? What are the magnifications of the first and final images? Are the two images inverted or upright?

50. A convex mirror is placed on the ceiling at the intersection of two hallways. If a person stands directly underneath the mirror, the person's shoe is a distance of 195 cm from the mirror. The mirror forms an image of the shoe that appears 12.8 cm behind the mirror's surface. What is the mirror's focal length? What is the magnification of the image? Is the image real or virtual? Is the image upright or inverted?

51. The side-view mirror of an automobile has a radius of curvature of 11.3 cm. The mirror produces a virtual image one-third the size of the object. How far is the object from the mirror?

52. An object is placed 10.0 cm in front of a mirror. What type must the mirror be to form an image of the object on a wall 2.00 m away from the mirror? What is the magnification of the image? Is the image real or virtual? Is the image inverted or upright?

53. The reflecting surfaces of two intersecting flat mirrors are at an angle of θ ($0° < \theta < 90°$), as shown in the figure below. A light ray strikes the horizontal mirror. Use the law of reflection to show that the emerging ray will intersect the incident ray at an angle of $\phi = 180° - 2\theta$.



54. Show that if a flat mirror is assumed to have an "infinite" radius of curvature, the mirror equation reduces to $q = -p$.

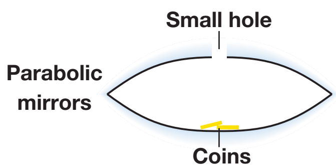
55. A real object is placed at the zero end of a meterstick. A large concave mirror at the 100.0 cm end of the meterstick forms an image of the object at the 70.0 cm position. A small convex mirror placed at the 20.0 cm position forms a final image at the 10.0 cm point. What is the radius of curvature of the convex mirror? (Hint: The first image created by the concave mirror acts as an object for the convex mirror.)

56. A dedicated sports-car enthusiast polishes the inside and outside surfaces of a hubcap that is a section of a sphere. When he looks into one side of the hubcap, he sees an image of his face 30.0 cm behind the hubcap. He then turns the hubcap over and sees another image of his face 10.0 cm behind the hubcap.

a. How far is his face from the hubcap?
b. What is the radius of curvature of the hubcap?
c. What is the magnification for each image?
d. Are the images real or virtual?
e. Are the images upright or inverted?

57. An object 2.70 cm tall is placed 12.0 cm in front of a mirror. What type of mirror and what radius of curvature are needed to create an upright image that is 5.40 cm in height? What is the magnification of the image? Is the image real or virtual?

58. A "floating coin" illusion consists of two parabolic mirrors, each with a focal length of 7.5 cm, facing each other so that their centers are 7.5 cm apart (see the figure below). If a few coins are placed on the lower mirror, an image of the coins forms in the small opening at the center of the top mirror. Use the mirror equation, and draw a ray diagram to show that the final image forms at that location. Show that the magnification is 1 and that the image is real and upright. (Note: A flashlight beam shined on these images has a very startling effect. Even at a glancing angle, the incoming light beam is seemingly reflected off the images of the coins. Do you understand why?)



59. Use the mirror equation and the equation for magnification to prove that the image of a real object formed by a convex mirror is always upright, virtual, and smaller than the object. Use the same equations to prove that the image of a real object placed in front of any spherical mirror is always virtual and upright when $p < |f|$.

60. Use trigonometry to derive the mirror and magnification equations. (Hint: Note that the incoming ray between the object and the mirror forms the hypotenuse of a right triangle. The reflected ray between the image point and the mirror is also the hypotenuse of a right triangle.)

ALTERNATIVE ASSESSMENT

1. Suntan lotions include compounds that absorb the ultraviolet radiation in sunlight and therefore prevent the ultraviolet radiation from damaging skin cells. Design experiments to test the properties of varying grades (SPFs) of suntan lotions. Plan to use blueprint paper, film, plants, or other light-sensitive items. Write down the questions that will guide your inquiry, the materials you will need, the procedures you plan to follow, and the measurements you will take. If your teacher approves your plan, perform the experiments and report or demonstrate your findings in class.

2. The Egyptian scholar Alhazen studied lenses, mirrors, rainbows, and other light phenomena early in the Middle Ages. Research his scholarly work, his life, and his relationship with the Caliph al-Hakim. How advanced were Alhazen's inventions and theories? Summarize your findings, and report them to the class.

3. Work in cooperative groups to explore the use of corner and ceiling mirrors as low-tech surveillance devices. Make a floor plan of an existing store, or devise a floor plan for an imaginary one. Determine how much of the store could be monitored by a clerk if flat mirrors were placed in the corners. If you could use curved mirrors in such a system, would you use concave or convex mirrors? Where would you place them? Identify which parts of the store could be observed with the curved mirrors in place. Note any disadvantages that your choice of mirrors may have.

4. Research the characteristics, effects, and applications of a specific type of electromagnetic wave in the spectrum. Find information about the range of wavelengths, frequencies, and energies; natural and artificial sources of the waves; and the methods used to detect them. Find out how they were discovered and how they affect matter. Learn about any dangers associated with them and about their uses in technology. Work together with others in the class who are researching other parts of the spectrum to build a group presentation, brochure, chart, or webpage that covers the entire spectrum.

5. The Chinese astronomer Chang Heng (78–139 CE) recognized that moonlight was a reflection of sunlight. He applied this theory to explain lunar eclipses. Make diagrams showing how Chang might have represented the moon's illumination and the path of light when Earth, the moon, and the sun were in various positions on ordinary nights and on nights when there were lunar eclipses. Find out more about Chang's other scientific work, and report your findings to the class.

6. Explore how many images are produced when you stand between two flat mirrors whose reflecting surfaces face each other. What are the locations of the images? Are they identical? Investigate these questions with diagrams and calculations. Then test your predicted results with parallel mirrors, perpendicular mirrors, and mirrors at angles in between. Which angles produce one, two, three, five, and seven images? Summarize your results with a chart, diagram, or computer presentation.

GRAPHING CALCULATOR PRACTICE

Mirrors

Mirrors produce many types of images: virtual or real, enlarged or reduced, and upright or inverted. The mirror equation and the magnification equation can help sort things out. The mirror equation relates the object distance (p), image distance (q), and focal length (f) to one another.

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

Image size can be determined from the magnification equation.

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

Magnification values that are greater than 1 or less than –1 indicate that the image of an object is larger than the object itself. Negative magnification values indicate that an image is real and inverted, while positive magnification values indicate that an image is virtual and upright.

In this graphing calculator activity, the calculator will produce a table of image distance and magnification for various object distances for a mirror with a known focal length. You will use this table to determine the characteristics of the images produced by a variety of mirrors and object distances.

Go online to HMHScience.com to find the skillsheet and program for this graphing calculator activity.