936 | CHAPTER 29 | PARTICLES AND WAVES

11. A stone is dropped from the top of a building. As the stone falls, does its de Broglie wavelength increase, decrease, or remain the same? Provide a reason for your answer.

12. An electron and a neutron have different masses. Is it possible, according to Equation 29.8, that they can have the same de Broglie wavelength? Account for your answer.

PROBLEMS

Note to Instructors: Most of the homework problems in this chapter are available for assignment via an online homework management program such as WileyPLUS or WebAssign, and those marked with the icon are presented in a guided tutorial format that provides enhanced interactivity. See Preface for additional details.

In working these problems, ignore relativistic effects.

ssm Solution is in the Student Solutions Manual.

www Solution is available on the World Wide Web at www.wiley.com/college/cutnell

Section 29.3 Photons and the Photoelectric Effect

1. ssm Ultraviolet light with a frequency of $3.00 \times 10^{15}$ Hz strikes a metal surface and ejects electrons that have a maximum kinetic energy of 6.1 eV. What is the work function (in eV) of the metal?

2. Two sources produce electromagnetic waves. Source B produces a wavelength that is three times the wavelength produced by source A. Each photon from source A has an energy of $2.1 \times 10^{-18}$ J. What is the energy of a photon from source B?

3. An FM radio station broadcasts at a frequency of 98.1 MHz. The power radiated from the antenna is $5.0 \times 10^4$ W. How many photons per second does the antenna emit?

4. The maximum wavelength that an electromagnetic wave can have and still eject electrons from a metal surface is 485 nm. What is the work function $W_o$ of this metal? Express your answer in electron volts.

5. ssm Ultraviolet light is responsible for sun tanning. Find the wavelength (in nm) of an ultraviolet photon whose energy is $6.4 \times 10^{-19}$ J.

6. Light is shining perpendicularly on the surface of the earth with an intensity of 680 W/m$^2$. Assuming all the photons in the light have the same wavelength (in vacuum) of 730 nm, determine the number of photons per second per square meter that reach the earth.

7. Radiation of a certain wavelength causes electrons to have a maximum kinetic energy of 0.68 eV to be ejected from a metal whose work function is 2.75 eV. What will be the maximum kinetic energy (in eV) with which this same radiation ejects electrons from another metal whose work function is 2.17 eV?

8. Multiple-Concept Example 3 provides pertinent information for problems such as this. The maximum wavelength for which an electromagnetic wave can eject electrons from a platinum surface is 196 nm. When radiation with a wavelength of 141 nm shines on the surface, what is the maximum speed of the ejected electrons?

9. ssm Consult Interactive LearningWare 29.1 at www.wiley.com/college/cutnell for background material relating to this problem. An owl has good night vision because its eyes can detect a light intensity as small as $5.0 \times 10^{-13}$ W/m$^2$. What is the minimum number of photons per second that an owl eye can detect if its pupil has a diameter of 8.5 mm and the light has a wavelength of 510 nm?

10. A proton is located at a distance of 0.420 m from a point charge of +8.30 $\mu$C. The repulsive electric force moves the proton until it is at a distance of 1.58 m from the charge. Suppose that the electric potential energy lost by the system is carried off by a photon that is emitted during the process. What is its wavelength?

11. ssm www A laser emits $1.30 \times 10^{18}$ photons per second in a beam of light that has a diameter of 2.00 mm and a wavelength of 514.5 nm. Determine (a) the average electric field strength and (b) the average magnetic field strength for the electromagnetic wave that constitutes the beam.

12. (a) How many photons (wavelength = 620 nm) must be absorbed to melt a 2.0-kg block of ice at 0 °C into water at 0 °C? (b) On the average, how many H$_2$O molecules does one photon convert from the ice phase to the water phase?

Section 29.4 The Momentum of a Photon and the Compton Effect

13. A light source emits a beam of photons, each of which has a momentum of $2.3 \times 10^{-20}$ kg·m/s. (a) What is the frequency of the photons? (b) To what region of the electromagnetic spectrum do the photons belong? Consult Figure 24.10 if necessary.

14. A photon of red light (wavelength = 720 nm) and a Ping-Pong ball (mass = $2.2 \times 10^{-3}$ kg) have the same momentum. At what speed is the ball moving?

15. ssm In a Compton scattering experiment, the incident X-rays have a wavelength of 0.2685 nm, and the scattered X-rays have a wavelength of 0.2703 nm. Through what angle $\theta$ in Figure 29.10 are the X-rays scattered?

16. Incident X-rays have a wavelength of 0.3120 nm and are scattered by the "free" electrons in graphite. The scattering angle in Figure 29.10 is $\theta = 135.0^\circ$. What is the magnitude of the momentum of (a) the incident photon and (b) the scattered photon? (For accuracy, use $h = 6.626 \times 10^{-34}$ J·s and $c = 2.998 \times 10^8$ m/s.)

17. Refer to Interactive Solution 29.17 at www.wiley.com/college/cutnell for help in solving this problem. An incident X-ray photon of wavelength 0.2750 nm is scattered from an electron that is initially at rest. The photon is scattered at an angle of $\theta = 180.0^\circ$ in Figure 29.10 and has a wavelength of 0.2825 nm. Use the conservation of linear momentum to find the momentum gained by the electron.

18. The X-rays detected at a scattering angle of $\theta = 163^\circ$ in Figure 29.10 have a wavelength of 0.1867 nm. Find (a) the wavelength of an incident photon, (b) the energy of an incident photon, (c) the energy of a scattered photon, and (d) the kinetic energy of the recoil electron. (For accuracy, use $h = 6.626 \times 10^{-34}$ J·s and $c = 2.998 \times 10^8$ m/s.)

19. ssm www What is the maximum amount by which the wavelength of an incident photon could change when it undergoes Compton scattering from a nitrogen molecule (N$_2$)?

20. An X-ray photon is scattered at an angle of $\theta = 180.0^\circ$ from an electron that is initially at rest. After scattering, the electron has a speed of $4.67 \times 10^5$ m/s. Find the wavelength of the incident X-ray photon.
Section 29.5 The De Broglie Wavelength and the Wave Nature of Matter

21. The interatomic spacing in a crystal of table salt is 0.282 nm. This crystal is being studied in a neutron diffraction experiment, similar to the one that produced the photograph in Figure 29.13a. How fast must a neutron (mass = 1.67 × 10^{-27} kg) be moving to have a de Broglie wavelength of 0.282 nm?

22. A bacterium (mass = 2 × 10^{-12} kg) in the blood is moving at 0.33 m/s. What is the de Broglie wavelength of this bacterium?

23. **ssm** As Section 27.5 discusses, sound waves diffract, or bend, around the edges of a doorway. Larger wavelengths diffract more than smaller wavelengths. (a) The speed of sound is 343 m/s. With what speed would a 55.0-kg person have to move through a doorway to diffract to the same extent as a 128-Hz bass tone? (b) At the speed calculated in part (a), how long (in years) would it take the person to move a distance of one meter?

24. **ssm** A photon has the same momentum as an electron that is moving with a speed of 4.50 × 10^6 m/s.

25. A photon has the same wavelength as an electron moving with a speed of 2.0 × 10^5 m/s. What is the wavelength of the photon?

26. A particle has a de Broglie wavelength of 2.7 × 10^{-10} m. Then its kinetic energy doubles. What is the particle's new de Broglie wavelength, assuming that relativistic effects can be ignored?

27. **ssm** From a cliff that is 9.5 m above a lake, a young woman (mass = 41 kg) jumps from rest, straight down into the water. At the instant she strikes the water, what is her de Broglie wavelength?

28. The width of the central bright fringe in a diffraction pattern on a screen is identical when either electrons or red light (vacuum wavelength = 661 nm) pass through a single slit. The distance between the screen and the slit is the same in each case and is large compared to the slit width. How fast are the electrons moving?

29. Consult Interactive Solution 29.29 at www.wiley.com/college/cutnell to explore a model for solving this problem. In a television picture tube the electrons are accelerated from rest through a potential difference V. Just before an electron strikes the screen, its de Broglie wavelength is 0.900 × 10^{-11} m. What is the potential difference?

30. **ssm** The de Broglie wavelength of a proton in a particle accelerator is 1.50 × 10^{-14} m. Determine the kinetic energy (in joules) of the proton.

31. The kinetic energy of a particle is equal to the energy of a photon.

32. A magnesium surface has a work function of 3.68 eV. Electromagnetic waves with a wavelength of 215 nm strike the surface and eject electrons. Find the maximum kinetic energy of the ejected electrons. Express your answer in electron volts.

33. **ssm** In the lungs there are tiny sacs of air, which are called alveoli. The average diameter of one of these sacs is 0.25 mm. Consider an oxygen molecule (mass = 5.3 × 10^{-26} kg) trapped within a sac. What is the minimum uncertainty in the velocity of this oxygen molecule?

34. Review Conceptual Example 7 as background for this problem. When electrons pass through a single slit, as in Figure 29.15, they form a diffraction pattern. As Section 29.6 discusses, the central bright fringe extends to either side of the midpoint, according to an angle θ given by sin θ = λ/2, where λ is the de Broglie wavelength of the electron and W is the width of the slit. When θ is the same size as W, λ = 90°, and the central fringe fills the entire observation screen. In this case, an electron passing through the slit has roughly the same probability of hitting the screen either straight ahead or anywhere off to one side or the other. Now, imagine yourself in a world where Planck's constant is large enough so you exhibit similar effects when you walk through a 0.90-m-wide doorway. Your mass is 82 kg and you walk at a speed of 0.50 m/s. How large would Planck's constant have to be in this hypothetical world?

35. **ssm** Particles pass through a single slit of width 0.200 mm (see Figure 29.15). The de Broglie wavelength of each particle is 633 nm. After the particles pass through the slit, they spread out over a range of angles. Use the Heisenberg uncertainty principle to determine the minimum range of angles.

36. The minimum uncertainty Δv in the position y of a particle is equal to its de Broglie wavelength. Determine the minimum uncertainty in the speed of the particle, where this minimum uncertainty Δv is expressed as a percentage of the particle's speed v (Percentage = Δv/v × 100%). Assume that relativistic effects can be ignored.

Section 29.6 The Heisenberg Uncertainty Principle

37. A particle has a speed of 1.2 × 10^6 m/s. Its de Broglie wavelength is 8.4 × 10^{-14} m. What is the mass of the particle?

38. The dissociation energy of a molecule is the energy required to break apart the molecule into its separate atoms. The dissociation energy for the cyanoan molecule is 1.22 × 10^{-18} J. Suppose that this energy is provided by a single photon. Determine the (a) wavelength and (b) frequency of the photon. (c) In what region of the electromagnetic spectrum (see Figure 24.10) does this photon lie?

39. **ssm** The de Broglie wavelength of a proton in a particle accelerator is 1.50 × 10^{-14} m. Determine the kinetic energy (in joules) of the proton.

40. What is (a) the wavelength of a 5.0-eV photon and (b) the de Broglie wavelength of a 5.0-eV electron?
\[ \lambda = \frac{c}{f} = \frac{c}{(E/h)} = \frac{hc}{E} = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})(3.0 \times 10^8 \text{ m/s})}{6.4 \times 10^{-19} \text{ J}} = 3.1 \times 10^{-7} \text{ m} = \boxed{310 \text{ nm}} \]

6. **REASONING** Light intensity \( I \) is the power that passes perpendicularly through a surface divided by the area of that surface (Equation 16.8). The number \( N \) of photons per second per square meter that reaches the earth is the light intensity divided by the energy \( E \) of a single photon; \( N = I/E \). The energy of a single photon is \( E = hf \) (Equation 29.2), where \( h \) is Planck’s constant and \( f \) is the frequency of the photon. The frequency of the photon is related to its wavelength \( \lambda \) by Equation 16.1 as \( f = c/\lambda \), where \( c \) is the speed of light in a vacuum. Therefore, we have

\[
N = \frac{I}{E} = \frac{I}{hf} = \frac{I}{h \left(\frac{c}{\lambda}\right)} = \frac{I \lambda}{hc}
\]

**SOLUTION** The number of photons per second per square meter that reach the earth is

\[
N = \frac{I \lambda}{hc} = \frac{(680 \text{ W/m}^2)(730 \times 10^{-9} \text{ m})}{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})(3.0 \times 10^8 \text{ m/s})} = \boxed{2.5 \times 10^{21} \text{ photons/}(\text{s} \cdot \text{m}^2)}
\]

7. **REASONING AND SOLUTION** In the first case, the energy of the incident photon is given by Equation 29.3 as

\[
hf = KE_{\text{max}} + W_0 = 0.68 \text{ eV} + 2.75 \text{ eV} = 3.43 \text{ eV}
\]

In the second case, a rearrangement of Equation 29.3 yields

\[
KE_{\text{max}} = hf - W_0 = 3.43 \text{ eV} - 2.17 \text{ eV} = \boxed{1.26 \text{ eV}}
\]

8. **REASONING AND SOLUTION** The work function of the material (using \( \lambda = 196 \text{ nm} \)) is found from

\[
W_0 = hf = hc/\lambda = 1.01 \times 10^{-18} \text{ J}
\]

The maximum kinetic energy of the ejected electron is (using \( \lambda = 141 \text{ nm} \))

\[
KE_{\text{max}} = hf - W_0 = hc/\lambda - W_0 = 3.96 \times 10^{-19} \text{ J}
\]

The speed of the electron is then

\[
v = \sqrt{\frac{2(KE_{\text{max}})}{m}} = \sqrt{\frac{2(3.96 \times 10^{-19} \text{ J})}{9.11 \times 10^{-31} \text{ kg}}} = \boxed{9.32 \times 10^5 \text{ m/s}}
\]
15. **REASONING** The angle \( \theta \) through which the X-rays are scattered is related to the difference between the wavelength \( \lambda' \) of the scattered X-rays and the wavelength \( \lambda \) of the incident X-rays by Equation 29.7 as

\[
\lambda' - \lambda = \frac{h}{mc} (1 - \cos \theta)
\]

where \( h \) is Planck's constant, \( m \) is the mass of the electron, and \( c \) is the speed of light in a vacuum. We can use this relation directly to find the angle, since all the other variables are known.

**SOLUTION** Solving Equation 29.7 for the angle \( \theta \), we obtain

\[
\cos \theta = 1 - \frac{mc}{h} (\lambda' - \lambda)
\]

\[
= 1 - \left( \frac{9.11 \times 10^{-31} \text{ kg}}{6.63 \times 10^{-34} \text{ J} \cdot \text{s}} \right) \left( \frac{3.00 \times 10^8 \text{ m/s}}{0.2703 \times 10^{-9} \text{ m} - 0.2685 \times 10^{-9} \text{ m}} \right) = 0.26
\]

\[
\theta = \cos^{-1}(0.26) = 75^\circ
\]

16. **REASONING AND SOLUTION**

a. According to Equation 29.6, the magnitude of the momentum of the incident photon is

\[
p = \frac{h}{\lambda} = \frac{6.626 \times 10^{-34} \text{ J} \cdot \text{s}}{0.3120 \times 10^{-9} \text{ m}} = 2.124 \times 10^{-24} \text{ kg} \cdot \text{m/s}
\]

b. The wavelength of the scattered photon is, from Equation 29.7,

\[
\lambda' = \lambda + \frac{h}{mc} (1 - \cos \theta)
\]

where \( \theta \) is the scattering angle. Combining this expression with Equation 29.6, we find that the magnitude of the momentum of the scattered photon is

\[
p' = \frac{h}{\lambda'} = \frac{h}{\lambda + \left( \frac{h}{mc} \right)(1 - \cos \theta)}
\]

\[
= \frac{6.626 \times 10^{-34} \text{ J} \cdot \text{s}}{0.3120 \times 10^{-9} \text{ m} + \left( \frac{6.626 \times 10^{-34} \text{ J} \cdot \text{s}}{(9.109 \times 10^{-31} \text{ kg})(2.998 \times 10^8 \text{ m/s})} \right)(1 - \cos 135.0^\circ)}
\]

\[
= 2.096 \times 10^{-24} \text{ kg} \cdot \text{m/s}
\]
SOLUTION  a. Since the wavelengths are equal, we have that

\[ \lambda_{\text{sound}} = \lambda_{\text{person}} \]

\[ \lambda_{\text{sound}} = \frac{h}{m_{\text{person}} v_{\text{person}}} \]

Solving for \( v_{\text{person}} \), and using the relation \( \lambda_{\text{sound}} = v_{\text{sound}} / f_{\text{sound}} \) (Equation 16.1), we have

\[ v_{\text{person}} = \frac{h}{m_{\text{person}} \left( \frac{v_{\text{sound}}}{f_{\text{sound}}} \right)} = \frac{hf_{\text{sound}}}{m_{\text{person}} v_{\text{sound}}} \]

\[ = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s}) (128 \text{ Hz})}{(55.0 \text{ kg}) (343 \text{ m/s})} = 4.50 \times 10^{-36} \text{ m/s} \]

b. At the speed calculated in part (a), the time required for the person to move a distance of one meter is

\[ t = \frac{x}{v} = \frac{1.0 \text{ m}}{4.50 \times 10^{-36} \text{ m/s}} \left( \frac{1.0 \text{ h}}{3600 \text{ s}} \right) \left( \frac{1 \text{ day}}{24 \text{ h}} \right) \left( \frac{1 \text{ year}}{365.25 \text{ days}} \right) = 7.05 \times 10^{27} \text{ years} \]

24. REASONING  The speed \( v \) of a particle is related to the magnitude \( p \) of its momentum by \( v = p/m \) (Equation 7.2). The magnitude of the momentum is related to the particle’s de Broglie wavelength \( \lambda \) by \( p = h/\lambda \) (Equation 29.8), where \( h \) is Planck’s constant. Thus, the speed of a particle can be expressed as \( v = h/(m\lambda) \). We will use this relation to find the speed of the proton.

SOLUTION  The speeds of the proton and electron are

\[ v_{\text{proton}} = \frac{h}{m_{\text{proton}} \lambda_{\text{proton}}} \quad \text{and} \quad v_{\text{electron}} = \frac{h}{m_{\text{electron}} \lambda_{\text{electron}}} \]

Dividing the first equation by the second equation, and noting that \( \lambda_{\text{electron}} = \lambda_{\text{proton}} \), we obtain

\[ \frac{v_{\text{proton}}}{v_{\text{electron}}} = \frac{m_{\text{electron}} \lambda_{\text{electron}}}{m_{\text{proton}} \lambda_{\text{proton}}} = \frac{m_{\text{electron}}}{m_{\text{proton}}} \]
Using values for $m_{\text{electron}}$ and $m_{\text{proton}}$ taken from the inside of the front cover, we find that the speed of the proton is

$$v_{\text{proton}} = v_{\text{electron}} \left( \frac{m_{\text{electron}}}{m_{\text{proton}}} \right) = (4.50 \times 10^6 \text{ m/s}) \left( \frac{9.11 \times 10^{-31} \text{ kg}}{1.67 \times 10^{-27} \text{ kg}} \right) = 2.45 \times 10^3 \text{ m/s}$$

25. **REASONING AND SOLUTION** The momentum of the photon is $p = h/\lambda$ and that of the electron is $p = mv$. Equating and solving for the wavelength of the photon,

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34} \text{ J} \cdot \text{s}}{(9.11 \times 10^{-31} \text{ kg})(2.0 \times 10^5 \text{ m/s})} = 3.6 \times 10^{-9} \text{ m}$$

26. **REASONING** The de Broglie wavelength $\lambda$ is related to Planck's constant $h$ and the magnitude $p$ of the particle's momentum. The magnitude of the momentum can be related to the particle's kinetic energy. Thus, using the given wavelength and the fact that the kinetic energy doubles, we will be able to obtain the new wavelength.

**SOLUTION** The de Broglie wavelength is

$$\lambda = \frac{h}{p}$$

The kinetic energy and the magnitude of the momentum are

$$KE = \frac{1}{2}mv^2 \quad (6.2) \quad p = mv \quad (7.2)$$

where $m$ and $v$ are the mass and speed of the particle. Substituting Equation 7.2 into Equation 6.2, we can relate the kinetic energy and momentum as follows:

$$KE = \frac{1}{2}mv^2 = \frac{m^2v^2}{2m} = \frac{p^2}{2m} \quad \text{or} \quad p = \sqrt{2m(KE)}$$

Substituting this result for $p$ into Equation 29.8 gives

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2m(KE)}}$$
Applying this expression for the final and initial wavelengths \( \lambda_f \) and \( \lambda_i \), we obtain

\[
\lambda_f = \frac{h}{\sqrt{2m(KE)_f}} \quad \text{and} \quad \lambda_i = \frac{h}{\sqrt{2m(KE)_i}}
\]

Dividing the two equations and rearranging reveals that

\[
\frac{\lambda_f}{\lambda_i} = \frac{\frac{h}{\sqrt{2m(KE)_f}}}{\frac{h}{\sqrt{2m(KE)_i}}} = \sqrt{\frac{(KE)_i}{(KE)_f}} \quad \text{or} \quad \lambda_f = \lambda_i \sqrt{\frac{(KE)_i}{(KE)_f}}
\]

Using the given value for \( \lambda_i \) and the fact that \( KE_f = 2(KE_i) \), we find

\[
\lambda_f = \lambda_i \sqrt{\frac{(KE)_i}{(KE)_f}} = (2.7 \times 10^{-10} \text{ m}) \sqrt{\frac{KE_i}{2(KE_i)}} = 1.9 \times 10^{-10} \text{ m}
\]

27. SSM REASONING AND SOLUTION The de Broglie wavelength \( \lambda \) of the woman is given by Equation 29.8 as \( \lambda = h / p \), where \( p \) is the magnitude of her momentum. The magnitude of the momentum is \( p = mv \), where \( m \) is the woman's mass and \( v \) is her speed. According to Equation 3.6b of the equations of kinematics, the speed \( v \) is given by \( v = \sqrt{2a_y y} \), since the woman jumps from rest. In this expression, \( a_y = -9.80 \text{ m/s}^2 \) and \( y = -9.5 \text{ m} \). With these considerations we find that

\[
\lambda = \frac{h}{mv} = \frac{h}{m \sqrt{2a_y y}} = \frac{6.63 \times 10^{-34} \text{ J} \cdot \text{s}}{(41 \text{ kg}) \sqrt{2(-9.80 \text{ m/s}^2)(-9.5 \text{ m})}} = 1.2 \times 10^{-36} \text{ m}
\]

28. REASONING The width of the central bright fringe in the diffraction patterns will be identical when the electrons have the same de Broglie wavelength as the wavelength of the photons in the red light. The de Broglie wavelength of one electron in the beam is given by Equation 29.8, \( \lambda_{\text{electron}} = h / p \), where \( p = mv \).

SOLUTION Following the reasoning described above, we find

\[
\lambda_{\text{red light}} = \lambda_{\text{electron}}
\]
29. **REASONING** When the electron is at rest, it has electric potential energy, but no kinetic energy. The electric potential energy $E_{\text{PE}}$ is given by $E_{\text{PE}} = eV$ (Equation 19.3), where $e$ is the magnitude of the charge on the electron and $V$ is the potential difference. When the electron reaches its maximum speed, it has no potential energy, but its kinetic energy is $\frac{1}{2}mv^2$. The conservation of energy states that the final total energy of the electron equals the initial total energy:

$$\frac{1}{2}mv^2 = eV$$

Solving this equation for the potential difference gives $V = \frac{mv^2}{e}$. The speed of the electron can be expressed in terms of the magnitude $p$ of its momentum by $v = \frac{p}{m}$ (Equation 7.2). The magnitude of the electron’s momentum is related to its de Broglie wavelength $\lambda$ by $p = \hbar/\lambda$ (Equation 29.8), where $\hbar$ is Planck’s constant. Thus, the speed can be written as $v = \frac{\hbar}{m\lambda}$. Substituting this expression for $v$ into $V = \frac{mv^2}{e}$ gives $V = \frac{\hbar^2}{2me\lambda^2}$.

**SOLUTION** The potential difference that accelerates the electron is

$$V = \frac{\hbar^2}{2me\lambda^2} = \frac{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})^2}{2(9.11 \times 10^{-31} \text{ kg})(1.60 \times 10^{-19} \text{ C})(0.900 \times 10^{-11} \text{ m})^2} = 1.86 \times 10^4 \text{ V}$$

30. **REASONING AND SOLUTION** The energy of the photon is $E = hf = h\nu/\lambda_{\text{photon}}$, while the kinetic energy of the particle is $KE = (1/2)mv^2 = h^2/(2m\lambda^2)$. Equating the two energies and rearranging the result gives $\lambda_{\text{photon}} = \lambda = (2mc/h)\lambda$. Now the speed of the particle is $v = 0.050c$, so $\lambda = h/(0.050 \text{ mc})$, and

$$\frac{\lambda_{\text{photon}}}{\lambda} = \frac{2/0.050}{4.0 \times 10^4} = 4.0 \times 10^4$$
31. **REASONING** We know that the object is somewhere on the line. Therefore, the uncertainty in the object's position is \( \Delta y = 2.5 \text{ m} \). The minimum uncertainty in the object's momentum is \( \Delta p_y \) and is specified by the Heisenberg uncertainty principle (Equation 29.10) in the form \((\Delta p_y)(\Delta y) = h/(4\pi)\). Since momentum is mass \( m \) times velocity \( v \), the uncertainty in the velocity \( \Delta v \) is related to the uncertainty in the momentum by \( \Delta v = (\Delta p_y)/m \).

**SOLUTION**

a. Using the uncertainty principle, we find the minimum uncertainty in the momentum as follows:

\[
(\Delta p_y)(\Delta y) = \frac{h}{4\pi} \\
\Delta p_y = \frac{h}{4\pi \Delta y} = \frac{6.63 \times 10^{-34} \text{ J} \cdot \text{s}}{4\pi (2.5 \text{ m})} = \frac{2.1 \times 10^{-35} \text{ kg} \cdot \text{m/s}}{
\}

b. For a golf ball this uncertainty in momentum corresponds to an uncertainty in velocity that is given by

\[
\Delta v_y = \frac{\Delta p_y}{m} = \frac{2.1 \times 10^{-35} \text{ kg} \cdot \text{m/s}}{0.045 \text{ kg}} = 4.7 \times 10^{-34} \text{ m/s}
\]

c. For an electron this uncertainty in momentum corresponds to an uncertainty in velocity that is given by

\[
\Delta v_y = \frac{\Delta p_y}{m} = \frac{2.1 \times 10^{-35} \text{ kg} \cdot \text{m/s}}{9.11 \times 10^{-31} \text{ kg}} = 2.3 \times 10^{-5} \text{ m/s}
\]

32. **REASONING** We assume that the electron is moving along the \( y \) direction, and that it can be anywhere within the sphere. Therefore, the uncertainty in the electron's position is equal to the diameter \( d \) of the sphere, so \( \Delta y = d \). The minimum uncertainty \( \Delta p_y \) in the \( y \) component of the electron's momentum is given by the Heisenberg uncertainty principle as \( \Delta p_y = h/(4\pi\Delta y) \) (Equation 29.10).

**SOLUTION** Setting \( \Delta y = d \) in the relation \( \Delta p_y = h/(4\pi\Delta y) \) gives

\[
\Delta p_y = \frac{h}{4\pi \Delta y} = \frac{h}{4\pi d} = \frac{6.63 \times 10^{-34} \text{ J} \cdot \text{s}}{4\pi (6.0 \times 10^{-15} \text{ m})} = \frac{8.8 \times 10^{-21} \text{ kg} \cdot \text{m/s}}{
\}

33. **WWW REASONING AND SOLUTION** According to the uncertainty principle, the minimum uncertainty in the momentum can be determined from \( \Delta p_y \Delta y = h/(4\pi) \).