### PROBLEMS

#### 25-2 Photon Theory and the Photoelectric Effect

1. At what rate does the Sun emit photons? For simplicity, assume that the Sun’s entire emission at the rate of $3.9 \times 10^{26}$ W at the single wavelength of 550 nm.

2. A spectral emission line is electromagnetic radiation that is emitted in a wavelength range narrow enough to be taken as a single wavelength. One such emission line that is important in astronomy has a wavelength of 21 cm. What is the photon energy in the electromagnetic wave at that wavelength?

3. The meter was once defined as 1650763.73 wavelengths of the orange light emitted by a source containing krypton-86 atoms. What is the photon energy of that light?

4. A special kind of light bulb emits monochromatic light of wavelength 630 nm. Electric energy is supplied to it at the rate of 60 W, and the bulb is 93% efficient at converting that energy to light energy. How many photons are emitted by the bulb during its lifetime of 730 h?

5. What are the energy and momentum of a photon in Ne-He laser light of wavelength 632 nm?

6. Light of frequency $0.85 \times 10^{15}$ Hz falls on a metal surface. If the maximum kinetic energy of the photoelectrons is 1.7 eV, what is the work function of the metal?

7. The threshold wavelength for the photoelectric effect in tungsten is 270 nm. Calculate the work function of tungsten, and calculate the maximum kinetic energy that a photon can have when radiation of 120 nm falls on tungsten.

8. Light strikes a sodium surface, causing photoelectric emission. The stopping potential for the ejected electrons is 5.0 V, and the work function of sodium is 2.2 eV. What is the wavelength of the incident light?

9. The work function of tungsten is 4.50 eV. Calculate the speed of the fastest electrons ejected from a tungsten surface when light whose photon energy is 5.8 eV shines on the surface.

10. The stopping potential for electrons emitted from a surface illuminated by light of wavelength 491 nm is 0.710 V. When the incident wavelength is changed to a new value, the stopping potential is 1.43 V. (a) What is the new wavelength? (b) What is the work function of the surface?

#### 25-3 Photons and the Compton Effect

11. The wavelength of the coming x-rays in a Compton scattering experiment is $7.078 \times 10^{-2}$ nm, and the wavelength of the outgoing x-rays is $7.314 \times 10^{-2}$ nm. At what angle was the scattered radiation measured?

12. Light of wavelength 2.4 pm is directed onto a target containing free electrons. (a) Find the wavelength of light scattered at 30° from the incident direction. (b) Do the same for a scattering angle of 120°?

13. A certain x-ray beam has a wavelength of 35.0 pm. (a) What is the corresponding frequency? Calculate the corresponding (b) photon energy and (c) photon momentum.

14. What is the maximum wavelength shift for a Compton collision between a photon and a free proton?

15. What percentage increase in wavelength leads to a 75% loss of photon energy in a
16. Through what angle must a 200 keV photon must be scattered by a free electron so that the photon loses 10% of its energy?

25-5 Wave Nature of Matter

17. What is the de Broglie wavelength of an electron whose energy is (a) 1.0 eV? (b) 10 eV? (c) 100 eV? (d) 1.0×10^9 eV? (e) What size targets would you need to observe diffraction of electrons of each of these wavelengths?

18. What is the de Broglie wavelength of a proton, of mass 1.67×10^{-27} kg, with kinetic energy (a) 1.0 MeV; (b) 10 MeV; (c) 300 MeV? Neglect relativistic effects.

19. The spacing between scattering planes in a crystal is 0.2 nm. What is the scattering angle from such a crystal with electrons of energy 40 eV for which a first maximum is observed?

20. Suppose that you want to carry out diffraction experiments with the proton of Problem 19. What spacing of scatters would you need in each of the three cases of energy 1.0 MeV, 10 MeV, and 300 MeV?

25-7 Schrödinger’s Equation

21. Show that the wave function \( \psi = A e^{i(kx - \omega t)} \) is a solution to the one-dimensional stationary Schrödinger’s equation (Eq. 25-25) when \( U = 0 \).

22. The wavefunction for a moving particle confined to a one-dimensional box is

\[
\psi(x) = A \sin\left( \frac{n \pi x}{L} \right)
\]

Use the normalization condition on \( \psi \) to show that

\[
A = \sqrt{\frac{2}{L}}
\]

25-8 Heisenberg’s Uncertainty Principle

23. A proton has a kinetic energy of 1.0 MeV. If its momentum is measured with an uncertainty of 5%, what is the minimum uncertainty in its position?

24. Imagine playing baseball in a universe (not ours) where the Plank constant is 0.60 J·s. What would be the uncertainty in the position of a 0.5 kg baseball that is moving at 20 m/s along an axis if the uncertainty in the speed is 1.0 m/s?

25. The uncertainty in momentum on an electron with a kinetic energy of approximately 25 eV is 10 percent. What is the minimum uncertainty in its position?

25-9 Barrier Tunneling

26. A beam of electrons with energy 1.0 eV approaches a potential barrier with \( U_0 = 2.0 \) eV, whose width is 0.10 nm. Estimate the fraction of electrons that tunnel through the barrier.

27. A truck of mass 2000 kg travels at 1.0 m/s and approaches a smooth bump whose average height is 20 cm and whose average width is 0.5 m. Estimate the tunneling factor for the truck from Eq. 25-31.

Problems

1. \( 1.1 \times 10^45 \) photons/s.

2. 5.9 μeV.
3. 2.05 eV.
4. \(4.6 \times 10^{26}\) photons/s.
5. \(3.15 \times 10^{-19}\) J (1.97 eV), \(1.05 \times 10^{-27}\) kg·m/s.
6. 1.8 eV.
7. \(7.37 \times 10^{-19}\) J (4.60 eV), \(9.21 \times 10^{-19}\) J (5.75 eV).
8. 173 nm.
9. 676 km/s.
10. (a) 382 nm; (b) 1.82 eV.
11. 88.3°.
12. (a) 2.7 pm; (b) 6.05 pm.
13. (a) \(8.57 \times 10^{18}\) Hz; (b) 35.4 keV; (c) \(1.89 \times 10^{-23}\) kg·m/s.
14. \(2.65 \times 10^{-15}\) m.
15. 300%.
16. 44°.
17. (a) 1.23 nm; (b) 0.39 nm; (c) 0.12 nm; (d) \(1.24 \times 10^{-15}\) m; (e) approximate size as the wavelengths.
18. (a) \(2.9 \times 10^{-14}\) m; (b) \(9.2 \times 10^{-15}\) m; (c) \(1.7 \times 10^{-15}\) m.
19. 76°.
20. (a) \(2.96 \times 10^{-14}\) m; (b) \(9.3 \times 10^{-15}\) m; \(1.7 \times 10^{-15}\) m.
21. proof problem.
22. proof problem.
23. \(4.6 \times 10^{-14}\) m.
24. 0.096 m.
25. 0.196 nm.
26. 0.36.
27. \(T \approx e^{-3.2 \times 10^7} \approx 0.\)