

••8 A satellite in Earth orbit maintains a panel of solar cells of area 2.60 m^2 perpendicular to the direction of the Sun's light rays. The intensity of the light at the panel is 1.39 kW/m^2 . (a) At what rate does solar energy arrive at the panel? (b) At what rate are solar photons absorbed by the panel? Assume that the solar radiation is monochromatic, with a wavelength of 550 nm , and that all the solar radiation striking the panel is absorbed. (c) How long would it take for a “mole of photons” to be absorbed by the panel?

$$8. (a) \quad P = (1.39 \text{ kW} / \text{m}^2)(2.60 \text{ m}^2) = 3.61 \text{ kW}.$$

$$(b) \quad R = \frac{P}{E_{\text{ph}}} = \frac{3.61 \times 10^3 \text{ W}}{(6.63 \times 10^{-34} \text{ J} \cdot \text{s})(2.998 \times 10^8 \text{ m/s}) / (550 \times 10^{-9} \text{ m})} \\ = 1.00 \times 10^{22} \text{ photons/s}.$$

$$(c) \quad t = \frac{N_A}{R} = \frac{6.02 \times 10^{23}}{1.00 \times 10^{22} / \text{s}} = 60.2 \text{ s}.$$

•**16** You wish to pick an element for a photocell that will operate via the photoelectric effect with visible light. Which of the following are suitable (work functions are in parentheses): tantalum (4.2 eV), tungsten (4.5 eV), aluminum (4.2 eV), barium (2.5 eV), lithium (2.3 eV)?

16. The energy of the most energetic photon in the visible light range (with wavelength of about 400 nm) is about $E = (1240 \text{ eV}\cdot\text{nm}/400 \text{ nm}) = 3.1 \text{ eV}$ (using the value $hc = 1240 \text{ eV}\cdot\text{nm}$). Consequently, barium and lithium can be used, since their work functions are both lower than 3.1 eV.

••20 The wavelength associated with the cutoff frequency for silver is 325 nm. Find the maximum kinetic energy of electrons ejected from a silver surface by ultraviolet light of wavelength 254 nm.

$$K_{\max} = E_{\text{photon}} - \Phi = \frac{hc}{\lambda} - \frac{hc}{\lambda_{\max}} = \frac{1240 \text{ eV} \cdot \text{nm}}{254 \text{ nm}} - \frac{1240 \text{ eV} \cdot \text{nm}}{325 \text{ nm}} = 1.07 \text{ eV}.$$

••22 An orbiting satellite can become charged by the photoelectric effect when sunlight ejects electrons from its outer surface. Satellites must be designed to minimize such charging. Suppose a satellite is coated with platinum, a metal with a very large work function ($\Phi = 5.32 \text{ eV}$). Find the longest wavelength of incident sunlight that can eject an electron from the platinum.

22. To find the longest possible wavelength λ_{max} (corresponding to the lowest possible energy) of a photon which can produce a photoelectric effect in platinum, we set $K_{\text{max}} = 0$ in Eq. 38-5 and use $hf = hc/\lambda$. Thus $hc/\lambda_{\text{max}} = \Phi$. We solve for λ_{max} :

$$\lambda_{\text{max}} = \frac{hc}{\Phi} = \frac{1240 \text{ eV} \cdot \text{nm}}{5.32 \text{ eV}} = 233 \text{ nm}.$$

••25 X rays with a wavelength of 71 pm are directed onto a gold foil and eject tightly bound electrons from the gold atoms. The ejected electrons then move in circular paths of radius r in a region of uniform magnetic field $\vec{B}$. For the fastest of the ejected electrons, the product Br is equal to $1.88 \times 10^{-4} \text{ T} \cdot \text{m}$. Find (a) the maximum kinetic energy of those electrons and (b) the work done in removing them from the gold atoms. 

25. (a) From $r = m_e v / eB$, the speed of the electron is $v = rBe / m_e$. Thus,

$$\begin{aligned} K_{\max} &= \frac{1}{2} m_e v^2 = \frac{1}{2} m_e \left(\frac{rBe}{m_e} \right)^2 = \frac{(rB)^2 e^2}{2m_e} = \frac{(1.88 \times 10^{-4} \text{ T} \cdot \text{m})^2 (1.60 \times 10^{-19} \text{ C})^2}{2(9.11 \times 10^{-31} \text{ kg})(1.60 \times 10^{-19} \text{ J/eV})} \\ &= 3.1 \text{ keV}. \end{aligned}$$

(b) Using the value $hc = 1240 \text{ eV} \cdot \text{nm}$, the work done is

$$W = E_{\text{photon}} - K_{\max} = \frac{1240 \text{ eV} \cdot \text{nm}}{71 \times 10^{-3} \text{ nm}} - 3.10 \text{ keV} = 14 \text{ keV}.$$

••26 In a photoelectric experiment using a sodium surface, you find a stopping potential of 1.85 V for a wavelength of 300 nm and a stopping potential of 0.820 V for a wavelength of 400 nm. From these data find (a) a value for the Planck constant, (b) the work function Φ for sodium, and (c) the cutoff wavelength λ_0 for sodium.

$$eV_{01} = hc/\lambda_1 - \Phi, \quad eV_{02} = hc/\lambda_2 - \Phi,$$

$$h = \frac{e(V_1 - V_2)}{c(\lambda_1^{-1} - \lambda_2^{-1})} = \frac{1.85 \text{ eV} - 0.820 \text{ eV}}{(3.00 \times 10^{17} \text{ nm/s}) \left[(300 \text{ nm})^{-1} - (400 \text{ nm})^{-1} \right]} = 4.12 \times 10^{-15} \text{ eV} \cdot \text{s}.$$

$$\Phi = \frac{3(V_2\lambda_2 - V_1\lambda_1)}{\lambda_1 - \lambda_2} = \frac{(0.820 \text{ eV})(400 \text{ nm}) - (1.85 \text{ eV})(300 \text{ nm})}{300 \text{ nm} - 400 \text{ nm}} = 2.27 \text{ eV}.$$

$$\lambda_{\text{max}} = \frac{hc}{\Phi} = \frac{1240 \text{ eV} \cdot \text{nm}}{2.27 \text{ eV}} = 545 \text{ nm}.$$

••30 X rays of wavelength 0.0100 nm are directed in the positive direction of an x axis onto a target containing loosely bound electrons. For Compton scattering from one of those electrons, at an angle of 180° , what are (a) the Compton shift, (b) the corresponding change in photon energy, (c) the kinetic energy of the recoiling electron, and (d) the angle between the positive direction of the x axis and the electron's direction of motion?

30. (a) Eq. 38-11 yields

$$\Delta\lambda = \frac{h}{m_e c} (1 - \cos\phi) = (2.43 \text{ pm})(1 - \cos 180^\circ) = +4.86 \text{ pm}.$$

(b) Using the value $hc = 1240 \text{ eV}\cdot\text{nm}$, the change in photon energy is

$$\Delta E = \frac{hc}{\lambda'} - \frac{hc}{\lambda} = (1240 \text{ eV}\cdot\text{nm}) \left(\frac{1}{0.01 \text{ nm} + 4.86 \text{ pm}} - \frac{1}{0.01 \text{ nm}} \right) = -40.6 \text{ keV}.$$

(c) From conservation of energy, $\Delta K = -\Delta E = 40.6 \text{ keV}$.

(d) The electron will move straight ahead after the collision, since it has acquired some of the forward linear momentum from the photon. Thus, the angle between $+x$ and the direction of the electron's motion is zero.

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$$\lambda_c = \frac{h}{mc} = \frac{6.626 \times 10^{-34} \text{ J} \cdot \text{s}}{(9.109 \times 10^{-31} \text{ kg})(2.998 \times 10^8 \text{ m/s})} = 2.426 \times 10^{-12} \text{ m} = 2.43 \text{ pm}.$$

$$\lambda_c = \frac{6.626 \times 10^{-34} \text{ J} \cdot \text{s}}{(1.673 \times 10^{-27} \text{ kg})(2.998 \times 10^8 \text{ m/s})} = 1.321 \times 10^{-15} \text{ m} = 1.32 \text{ fm}.$$

$$E = (1240 \text{ eV} \cdot \text{nm}) / (2.426 \times 10^{-3} \text{ nm}) = 5.11 \times 10^5 \text{ eV} = 0.511 \text{ MeV}.$$

$$E = (1240 \text{ eV} \cdot \text{nm}) / (1.321 \times 10^{-6} \text{ nm}) = 9.39 \times 10^8 \text{ eV} = 939 \text{ MeV}.$$

••36 What is the maximum kinetic energy of electrons knocked out of a thin copper foil by Compton scattering of an incident beam of 17.5 keV x rays? Assume the work function is negligible. 

36. The initial wavelength of the photon is (using $hc = 1240 \text{ eV} \cdot \text{nm}$)

$$\lambda = \frac{hc}{E} = \frac{1240 \text{ eV} \cdot \text{nm}}{17500 \text{ eV}} = 0.07086 \text{ nm}$$

or 70.86 pm. The maximum Compton shift occurs for $\phi = 180^\circ$, in which case Eq. 38-11 (applied to an electron) yields

$$\Delta\lambda = \left(\frac{hc}{m_e c^2} \right) (1 - \cos 180^\circ) = \left(\frac{1240 \text{ eV} \cdot \text{nm}}{511 \times 10^3 \text{ eV}} \right) (1 - (-1)) = 0.00485 \text{ nm}$$

where Table 37-3 is used. Therefore, the new photon wavelength is

$$\lambda' = 0.07086 \text{ nm} + 0.00485 \text{ nm} = 0.0757 \text{ nm}.$$

Consequently, the new photon energy is

$$E' = \frac{hc}{\lambda'} = \frac{1240 \text{ eV} \cdot \text{nm}}{0.0757 \text{ nm}} = 1.64 \times 10^4 \text{ eV} = 16.4 \text{ keV}.$$

By energy conservation, then, the kinetic energy of the electron must equal

$$E' - E = 17.5 \text{ keV} - 16.4 \text{ keV} = 1.1 \text{ keV}.$$

••39 Consider a collision between an x-ray photon of initial energy 50.0 keV and an electron at rest, in which the photon is scattered backward and the electron is knocked forward. (a) What is the energy of the back-scattered photon? (b) What is the kinetic energy of the electron?

39. (a) From Eq. 38-11,

$$\Delta\lambda = \frac{h}{m_e c} (1 - \cos\theta).$$

In this case $\phi = 180^\circ$ (so $\cos \phi = -1$), and the change in wavelength for the photon is given by $\Delta\lambda = 2h/m_e c$. The energy E' of the scattered photon (with initial energy $E = hc/\lambda$) is then

$$\begin{aligned} E' &= \frac{hc}{\lambda + \Delta\lambda} = \frac{E}{1 + \Delta\lambda / \lambda} = \frac{E}{1 + (2h / m_e c)(E / hc)} = \frac{E}{1 + 2E / m_e c^2} \\ &= \frac{50.0 \text{ keV}}{1 + 2(50.0 \text{ keV}) / 0.511 \text{ MeV}} = 41.8 \text{ keV} . \end{aligned}$$

(b) From conservation of energy the kinetic energy K of the electron is given by

$$K = E - E' = 50.0 \text{ keV} - 41.8 \text{ keV} = 8.2 \text{ keV}.$$

••40 What is the maximum wavelength shift for a Compton collision between a photon and a free *proton*?

40. The $(1 - \cos \phi)$ factor in Eq. 38-11 is largest when $\phi = 180^\circ$. Thus, using Table 37-3, we obtain

$$\Delta\lambda_{\max} = \frac{hc}{m_p c^2} (1 - \cos 180^\circ) = \frac{1240 \text{ MeV} \cdot \text{fm}}{938 \text{ MeV}} (1 - (-1)) = 2.64 \text{ fm}$$

where we have used the value $hc = 1240 \text{ eV} \cdot \text{nm} = 1240 \text{ MeV} \cdot \text{fm}$.