7. QUANTUM THEORY OF THE ATOM

Solutions to Exercises

Note on significant figures: If the final answer to a solution needs to be rounded off, it is given first with one nonsignificant figure, and the last significant figure is underlined. The final answer is then rounded to the correct number of significant figures. In multiple-step problems, intermediate answers are given with at least one nonsignificant figure; however, only the final answer has been rounded off.

7.1 Rearrange the equation $c = \nu\lambda$, which relates wavelength to frequency and the speed of light (3.00×10^8 m/s):

$$\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^8 \text{ m/s}}{3.91 \times 10^{14} \text{ /s}} = 7.6\underline{7}2 \times 10^{-7} = 7.67 \times 10^{-7} \text{ m, or } 767 \text{ nm}$$

7.2 Rearrange the equation $c = \nu\lambda$, which relates frequency to wavelength and the speed of light (3.00×10^8 m/s). Recognize that 456 nm = 4.56×10^{-7} m.

$$\nu = \frac{c}{\lambda} = \frac{3.00 \times 10^8 \text{ m/s}}{4.56 \times 10^{-7} \text{ m}} = 6.5\underline{7}8 \times 10^{14} = 6.58 \times 10^{14} \text{ /s}$$

7.3 First, use the wavelengths to calculate the frequencies from c = $\nu\lambda$. Then calculate the energies using E = hν.

$$\nu = \frac{c}{\lambda} = \frac{3.00 \times 10^{8}\ \text{m/s}}{1.0 \times 10^{-6}\ \text{m}} = 3.\underline{0}0 \times 10^{14}\ \text{/s}$$

$$\nu = \frac{c}{\lambda} = \frac{3.00 \times 10^{8}\ \text{m/s}}{1.0 \times 10^{-8}\ \text{m}} = 3.\underline{0}0 \times 10^{16}\ \text{/s}$$

$$\nu = \frac{c}{\lambda} = \frac{3.00 \times 10^{8}\ \text{m/s}}{1.0 \times 10^{-10}\ \text{m}} = 3.\underline{0}0 \times 10^{18}\ \text{/s}$$

$$E = h\nu = 6.63 \times 10^{-34}\ \text{J}\bullet\text{s} \times 3.00 \times 10^{14}\ \text{/s} = 1.\underline{9}89 \times 10^{-19} = 2.0 \times 10^{-19}\ \text{J (IR)}$$

$$E = h\nu = 6.63 \times 10^{-34}\ \text{J}\bullet\text{s} \times 3.00 \times 10^{16}\ \text{/s} = 1.\underline{9}89 \times 10^{-17} = 2.0 \times 10^{-17}\ \text{J (UV)}$$

$$E = h\nu = 6.63 \times 10^{-34}\ \text{J}\bullet\text{s} \times 3.00 \times 10^{18}\ \text{/s} = 1.\underline{9}89 \times 10^{-15} = 2.0 \times 10^{-15}\ \text{J (x-ray)}$$

The x-ray photon (shortest wavelength) has the greatest amount of energy; the infrared photon (longest wavelength) has the least amount of energy.

7.4 From the formula for the energy levels, $E = -R_H/n^2$,obtain the expressions for both E_i and E_f. Then calculate the energy change for the transition from n = 3 to n = 1 by subtracting the lower value from the upper value. Set this equal to hν. The result is

$$\left[\frac{-R_H}{9}\right] - \left[\frac{-R_H}{1}\right] = \frac{8R_H}{9} = h\nu$$

The frequency of the emitted radiation is

$$\nu = \frac{8R_H}{9h} = \frac{8}{9} \times \frac{2.179 \times 10^{-18}\ \text{J}}{6.63 \times 10^{-34}\ \text{J}\bullet\text{s}} = 2.9\underline{2}1 \times 10^{15} = 2.92 \times 10^{15}\ \text{/s}$$

Since $\lambda = c/\nu$,

$$\lambda = \frac{3.00 \times 10^{8}\ \text{m/s}}{2.92 \times 10^{15}\ \text{/s}} = 1.0\underline{2}7 \times 10^{-7} = 1.03 \times 10^{-7}\ \text{m, or 103 nm}$$

7.5 Calculate the frequency from $c = \nu\lambda$, recognizing that 589 nm is 5.89×10^{-7} m.

$$\nu = \frac{c}{\lambda} = \frac{3.00 \times 10^{8}\ \text{m/s}}{5.89 \times 10^{-7}\ \text{m}} = 5.0\underline{9}3 \times 10^{14} = 5.09 \times 10^{14}\ /\text{s}$$

Finally, calculate the energy difference.

$$E = h\nu = 6.63 \times 10^{-34}\ \text{J}\bullet\text{s} \times 5.093 \times 10^{14}\ /\text{s} = 3.3\underline{7}66 \times 10^{-19} = 3.38 \times 10^{-19}\ \text{J}$$

7.6 To calculate wavelength, use the mass of an electron, $m = 9.11 \times 10^{-31}$ kg, and Planck's constant ($h = 6.63 \times 10^{-34}$ J•s, or 6.63×10^{-34} kg•m^2/s^2).

$$\lambda = \frac{h}{mv} = \frac{6.63 \times 10^{-34}\ \text{kg} \bullet \text{m}^2/\text{s}}{9.11 \times 10^{-31}\ \text{kg} \times 2.19 \times 10^{6}\ \text{m/s}} = 3.3\underline{2}3 \times 10^{-10}\ \text{m (332 pm)}$$

7.7 a. The value of n must be a positive whole number greater than zero. Here, it is zero. Also, if n is zero, there would be no allowed values for l and m_l.

b. The values for l can range only from zero to (n - 1). Here, l has a value greater than n.

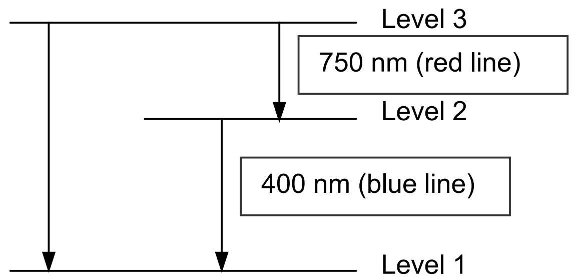
c. The values for m_l range from -l to +l. Here, m_l has a value greater than l.

d. The values for m_s are either + 1/2 or -1/2. Here, it is zero.

■ Answers to Concept Checks

7.1 The frequency and wavelength are inversely related. Therefore, if the frequency is doubled, the wavelength is halved. Red light has a wavelength around 700 nm, so doubling its frequency halves its wavelength to about 350 nm, which is in the ultraviolet range just beyond the visible spectrum.

7.2 Since the transitions are between adjacent levels, the energy-level diagram must look something like the following diagram with the red transition between two close levels and the blue transition between two more widely spaced levels. (The three levels could be spaced so the red and blue transitions are interchanged, with the blue transition above the red one.)



The transition from the top level to the lowest level would correspond to a transition that is greater in energy change than either of the other two transitions. Thus, the three transitions, from lowest to highest energy change, are in order: red, blue, and the transition from the highest to lowest level. The last transition would have the highest frequency and therefore the shortest wavelength. It would lie just beyond the blue portion of the visible spectrum in the ultraviolet region.

7.3 The de Broglie relation says the wavelength of a particle is inversely proportional to both mass and speed. So, to maintain the wavelength constant while the mass increases would mean the speed would have to decrease. In going from a particle with the mass of an electron to one with that of a proton, the speed would have to decrease by a factor of about 2000 in order to maintain the same wavelength. The proton would have to have a speed approximately 2000 times slower than an electron of the same wavelength.

■ Answers to Review Questions

7.1 Light is a wave, which is a form of electromagnetic radiation. In terms of waves, light can be described as a continuously repeating change, or oscillation, in electric and magnetic fields that can travel through space. Two characteristics of light are wavelength (often given in nanometers, nm), and frequency. The eye can see the light of wavelengths from about 400 nm (violet) to less than 800 nm (red).

7.2 The relationship among the different characteristics of light waves is $c = \nu\lambda$, where ν is the frequency, λ is the wavelength, and c is the speed of light.

7.3 Starting with the shortest wavelengths, the electromagnetic spectrum consists of gamma rays, x rays, far ultraviolet (UV), near UV, visible light, near infrared (IR), far IR, microwaves, radar, and TV/FM radio waves (longest wavelengths).

7.4 The term "quantized" means the possible values of the energies of an atom are limited to only certain values. Planck was trying to explain the intensity of light of various frequencies emitted by a hot solid at different temperatures. The formula he arrived at was $E = nh\nu$, where E is energy, n is a whole number ($n = 1, 2, 3, \ldots$), h is Planck's constant, and ν is frequency.

7.5 Photoelectric effect is the term applied to the ejection of electrons from the surface of a metal or from other materials when light shines on it. Electrons are only ejected when the frequency (or energy) of light is larger than a certain minimum, or threshold, value that is constant for each metal. If a photon has a frequency equal to or greater than this minimum value, then it will eject one electron from the metal surface.

7.6 The wave-particle picture of light regards the wave and particle depictions of light as complementary views of the same physical entity. Neither view alone is a complete description of all the properties of light. The wave picture characterizes light only by wavelength and frequency. The particle picture characterizes light only as having an energy equal to $h\nu$.

7.7 The equation that relates the particle properties of light is $E = h\nu$. The symbol E is energy, h is Planck's constant, and ν is the frequency of the light.

7.8 According to physical theory at Rutherford's time, an electrically charged particle revolving around a center would continuously lose energy as electromagnetic radiation. As an electron in an atom lost energy, it would spiral into the nucleus (in about 10^{-10} s). Thus, the stability of the atom could not be explained.

7.9 According to Bohr, an electron in an atom can have only specific energy values. An electron in an atom can change energy only by going from one energy level (of allowed energy) to another energy level (of allowed energy). An electron in a higher energy level can go to a lower energy level by emitting a photon of an energy equal to the difference in energy. However, when an electron is in its lowest energy level, no further changes in energy can occur. Thus, the electron does not continuously radiate energy as thought at Rutherford's time. These features solve the difficulty alluded to in Question 7.8.

7.10 Emission of a photon occurs when an electron in a higher energy level undergoes a transition to a lower energy level. The energy lost is emitted as a photon.

7.11 Absorption of a photon occurs when a photon of a certain required energy is absorbed by a certain electron in an atom. The energy of the photon must be equal to the energy necessary to excite the electron of the atom from a lower energy level, usually the lowest, to a higher energy level. The photon's energy is converted into electronic energy.

7.12 The diffraction of an electron beam is evidence of electron waves. A practical example of diffraction is the operation of the electron microscope.

7.13 The square of a wave function equals the probability of finding an electron within a region of space. More complex mathematical manipulations of the wave function yield values for other parameters.

7.14 The uncertainty principle says we can no longer think of the electron as having a precise orbit in an atom similar to the orbit of the planets around the sun. This principle says it is impossible to know with absolute precision both the position and the speed of a particle such as an electron. Application of Heisenberg's uncertainty principle shows that the uncertainties of position and speed are significant when the principle is applied to electrons.

7.15 Quantum mechanics vastly changes Bohr's original picture of the hydrogen atom in that we can no longer think of the electron as having a precise orbit around the nucleus in this atom. Recall that Bohr's theory depended on the hydrogen electron having specific energy values and thus specific positions and speeds around the nucleus. But quantum mechanics and the uncertainty principle say it is impossible to know with absolute precision both the speed and the position of an electron. So Bohr's energy levels are only the most probable paths of the electrons.

7.16 a. The principal quantum number can have an integer value between one and infinity.

b. The angular momentum quantum number can have any integer value between zero and (n - 1).

c. The magnetic quantum number can have any integer value between -l and +l.

d. The spin quantum number can be either +1/2 or -1/2.

7.17 The notation is *4f*. This subshell contains seven orbitals.

7.18 An *s* orbital has a spherical shape. A *p* orbital has two lobes positioned along a straight line through the nucleus at the center of the line (a dumbbell shape).

■ Answers to Conceptual Problems

7.19 Wavelength and frequency are inversely related. Moreover, ultraviolet light is at higher frequency than yellow light. Doubling the frequency of a beam of light would give that beam a higher frequency than yellow light, whereas doubling the wavelength would give that beam a lower frequency than yellow light. Consequently, the beam with frequency doubled must be the one in the ultraviolet region.

(continued)

Here is another way to look at the problem. Energy is directly related to the frequency and inversely related to the wavelength. Thus, the beam whose frequency is doubled will increase in energy whereas the beam whose wavelength is doubled will decrease in energy. Since yellow light is in the visible region of the spectrum, which is lower in energy than the ultraviolet region (Figure 7.5), the beam whose frequency is doubled will be higher in energy and thus in the UV region of the spectrum.

7.20 Frequency is inversely related to wavelength. Thus, the infrared radiation with a wavelength that is one thousand times larger than the visible light would have a frequency one thousand times smaller than the visible light. But, the visible light has a frequency that is one thousand times smaller than that of the X radiation. This makes the frequency of the X radiation one million times larger that the frequency of the infrared radiation. Therefore, since energy is directly related to the frequency, the energy of the X radiation would be one million times as large as the energy of the infrared radiation.

7.21 That one color of light does not result in an ejection of electrons implies that that color has too little energy per photon. Of the two colors, red and green, red light has less energy per photon. So, you expect the experiment with red light results in no ejection of photons whereas the experiment with green light must be the one that ejects electrons. (Two red photons have more than enough energy to eject an electron, but this energy needs to be concentrated in only one photon to be effective.) In the photoelectric effect, one photon of light ejects at most one electron. Therefore, in the experiment with green light, one electron is ejected.

7.22 Ultraviolet radiation is higher in energy than red light (Figure 7.5). Since an atom that started in the ground state cannot emit more energy than it absorbed, the absorbed photon must be higher in energy than the emitted photon. This makes the emitted photon (photon 2) the red light.

7.23 Energy is inversely proportional to the wavelength of the radiation. The transition from the highest to the lowest energy levels would involve the greatest energy change and thus the shortest wavelength, x nm.

7.24 In a transition from the n = 1 to the n = 5 energy level, an atom will absorb a photon with the same energy as the photon that was emitted in the transition from the n = 5 to the n = 1 energy level. Since yellow light was emitted, the experiment using yellow light will promote the electron to the n = 5 level.

7.25 A proton is approximately 2000 times the weight of an electron. Also, from the de Broglie relation, l = h/mv, you see that the wavelength is inversely proportional to both the mass and the speed of the particle. Considering the protons in parts b and c, since the mass is the same in both parts, the proton with the smaller speed, part b, will have a longer wavelength. Now, comparing the electron in part a with the proton in part b, since both have the same speed, the electron in part a with the smaller mass will have the longer wavelength. Therefore, the electron in part a will have the longest wavelength.

7.26 For the first shell, the quantum numbers would have the following allowable values:

$n = 1 \quad l = 1 \quad m_l = 0, +1, -1$

For the second shell, the quantum numbers would have the following allowable values:

$n = 2 \quad l = 1 \quad m_l = 0, +1, -1$

$l = 2 \quad m_l = 0, +1, -1, +2, -2$

7.27 a. The frequency is directly proportional to the energy difference between the two transition levels ($\Delta E = h\nu$). The lowest frequency corresponds with the smallest energy difference. Thus the n = 3 to n = 2 transition will emit the lowest frequency light.

b. The highest frequency corresponds with the largest energy difference. Thus the n = 3 to n = 5 transition will require (absorb) the highest frequency light.

c. Since the frequency is proportional to the energy difference between two transition levels, the energy difference is the same for absorption and transmission, and the color light is the same for both. Thus, green light is absorbed.

7.28 a. The higher energy would correspond with the larger orbital, which is on the right.

b. Since the orbital on the right is higher in energy than the orbital on the left, the transition of an electron from the orbital on the right to the one on the left would be accompanied by the release of energy.

c. An orbital of the same type that is higher in energy would have the same width, but would be taller.

■ Solutions to Practice Problems

Note on significant figures: If the final answer to a solution needs to be rounded off, it is given first with one nonsignificant figure, and the last significant figure is underlined. The final answer is then rounded to the correct number of significant figures. In multiple-step problems, intermediate answers are given with at least one nonsignificant figure; however, only the final answer has been rounded off. Starting with Problem 7.29, the value 2.998 x 10^8 m/s will be used for the speed of light.

7.29 Solve $c = \lambda\nu$ for λ:

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^8 \text{ m/s}}{1.365 \times 10^6 \text{ /s}} = 219.\underline{6}3 = 219.6 \text{ m}$$

7.30 Solve $c = \lambda\nu$ for λ:

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^8 \text{ m/s}}{1.258 \times 10^{10} \text{ /s}} = 0.0238\underline{3}1 = 0.02383 \text{ m} \quad (2.383 \text{ cm})$$

7.31 Solve $c = \lambda\nu$ for ν. Recognize that 478 nm = 478 x 10^{-9} m, or 4.78 x 10^{-7} m.

$$\nu = \frac{c}{\lambda} = \frac{2.998 \times 10^8 \text{ m/s}}{4.78 \times 10^{-7} \text{ m}} = 6.2\underline{7}1 \times 10^{14} = 6.27 \times 10^{14} \text{ /s}$$

7.32 Solve $c = \lambda\nu$ for ν. Recognize that 656 nm = 656 x 10^{-9} m = 6.56 x 10^{-7} m.

$$\nu = \frac{c}{\lambda} = \frac{2.998 \times 10^8 \text{ m/s}}{6.56 \times 10^{-7} \text{ m}} = 4.5\underline{7}0 \times 10^{14} = 4.57 \times 10^{14} \text{ /s}$$

7.33 Radio waves travel at the speed of light, so divide the distance by c:

$$56 \times 10^9 \text{ m} \times \frac{1 \text{ s}}{2.998 \times 10^8 \text{ m}} = 1\underline{8}6.7 = 1.9 \times 10^2 \text{ s}$$

7.34 Electromagnetic signals travel at the speed of light, so divide the distance by c:

$$998 \times 10^9 \text{ m} \times \frac{1 \text{ s}}{2.998 \times 10^8 \text{ m}} = 33\underline{2}8.8 = 3.33 \times 10^3 \text{ s} \quad (0.925 \text{ hr})$$

7.35 To do the calculation, divide one meter by the number of wavelengths in one meter to find the wavelength of this transition. Then, use the speed of light (with nine digits for significant figures) to calculate the frequency:

$$\lambda = \frac{1 \text{ m}}{1{,}650{,}763.73} = 6.507802\underline{1}06 \times 10^{-7} \text{ m}$$

$$\nu = \frac{c}{\lambda} = \frac{2.99792458 \times 10^{8} \text{ m/s}}{6.507802106 \times 10^{-7} \text{ m}} = 4.94886516\underline{2} \times 10^{14} = 4.94886516 \times 10^{14} \text{ /s}$$

7.36 To find the wavelength, divide the speed of light (with nine digits for significant figures) by the frequency:

$$\lambda = \frac{c}{\nu} = \frac{2.99792458 \times 10^{8} \text{ m/s}}{9{,}192{,}631{,}770 \text{ /s}} = 0.032612255\underline{7}2 = 0.0326122557 \text{ m}$$

7.37 Solve for E, using E = hν, and use four significant figures for h:

$$E = h\nu = (6.626 \times 10^{-34} \text{ J}\bullet\text{s}) \times (1.365 \times 10^{6} \text{ /s}) = 9.04\underline{4}4 \times 10^{-28}$$

$$= 9.044 \times 10^{-28} \text{ J}$$

7.38 Solve for E, using E = hν, and use four significant figures for h:

$$E = h\nu = (6.626 \times 10^{-34} \text{ J}\bullet\text{s}) \times (1.258 \times 10^{10} \text{ /s}) = 8.33\underline{5}50 \times 10^{-24}$$

$$= 8.336 \times 10^{-24} \text{ J}$$

7.39 Recognize that 535 nm = 535 x 10^{-9} m = 5.35 x 10^{-7} m. Then, calculate ν and E.

$$\nu = \frac{c}{\lambda} = \frac{2.998 \times 10^{8} \text{ m/s}}{5.35 \times 10^{-7} \text{ m}} = 5.6\underline{0}37 \times 10^{14} \text{ /s}$$

$$E = h\nu = (6.626 \times 10^{-34} \text{ J}\bullet\text{s}) \times (5.6037 \times 10^{14}\text{/s}) = 3.7\underline{1}3 \times 10^{-19} = 3.71 \times 10^{-19} \text{ J}$$

7.40 Recognize that 451 nm = 451 x 10^{-9} m = 4.51 x 10^{-7} m. Then, calculate ν and E.

$$\nu = \frac{c}{\lambda} = \frac{2.998 \times 10^{8} \text{ m/s}}{4.51 \times 10^{-7} \text{ m}} = 6.6\underline{4}74 \times 10^{14} \text{ /s}$$

$$E = h\nu = (6.626 \times 10^{-34} \text{ J}\bullet\text{s}) \times (6.6474 \times 10^{14}\text{/s}) = 4.4\underline{0}4 \times 10^{-19} = 4.40 \times 10^{-19} \text{ J}$$

7.41 First, calculate the wavelength of this transition from the frequency using the speed of light:

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^8 \text{ m/s}}{3.84 \times 10^{14} \text{ /s}} = 7.8\underline{0}72 \times 10^{-7} = 7.81 \times 10^{-7} \text{ m (781 pm)}$$

Using Figure 7.5, note that 781 nm is just on the edge of the red end of the spectrum and is barely visible to the eye.

7.42 First, calculate the wavelength of this transition from the frequency using the speed of light:

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^8 \text{ m/s}}{5.41 \times 10^{14} \text{ /s}} = 5.5\underline{4}1 \times 10^{-7} = 5.54 \times 10^{-7} \text{ m (554 pm)}$$

Using Figure 7.5, note that 554 nm is in the yellow-green region of the spectrum and is visible to the eye.

7.43 Solve the equation $E = -R_H/n^2$ for both E_5 and E_3; equate to $h\nu$, and solve for ν.

$$E_5 = \frac{-R_H}{5^2} = \frac{-R_H}{25}; \qquad E_3 = \frac{-R_H}{3^2} = \frac{-R_H}{9}$$

$$\left[\frac{-R_H}{25}\right] - \left[\frac{-R_H}{9}\right] = \frac{16 R_H}{225} = h\nu$$

The frequency of the emitted radiation is:

$$\nu = \frac{16 R_H}{225 h} = \frac{16}{225} \times \frac{2.179 \times 10^{-18} \text{ J}}{6.626 \times 10^{-34} \text{ J} \bullet \text{s}} = 2.3\underline{3}8 \times 10^{14} = 2.34 \times 10^{14} \text{ /s}$$

7.44 Solve the equation $E = -R_H/n^2$ for both E_4 and E_3; equate to $h\nu$, and solve for ν.

$$E_4 = \frac{-R_H}{4^2} = \frac{-R_H}{16}; \qquad E_3 = \frac{-R_H}{3^2} = \frac{-R_H}{9}$$

$$\left[\frac{-R_H}{16}\right] - \left[\frac{-R_H}{9}\right] = \frac{7 R_H}{144} = h\nu$$

The frequency of the emitted radiation is:

$$\nu = \frac{7 R_H}{144 h} = \frac{7}{144} \times \frac{2.179 \times 10^{-18} \text{ J}}{6.626 \times 10^{-34} \text{ J} \bullet \text{s}} = 1.5\underline{9}86 \times 10^{14} = 1.60 \times 10^{14} \text{ /s}$$

7.45 Solve the equation $E = -R_H/n^2$ for both E_2 and E_1.

$$E_2 = \frac{-R_H}{2^2} = \frac{-R_H}{4}; \qquad E_1 = \frac{-R_H}{1^2} = \frac{-R_H}{1}$$

$$\left[\frac{-R_H}{4}\right] - \left[\frac{-R_H}{1}\right] = \frac{3R_H}{4} = h\nu$$

The frequency of the emitted radiation is:

$$\nu = \frac{3R_H}{4h} = \frac{3}{4} \times \frac{2.179 \times 10^{-18}\ \text{J}}{6.626 \times 10^{-34}\ \text{J} \bullet \text{s}} = 2.4\underline{6}6 \times 10^{15}\ /\text{s}$$

The wavelength can now be calculated.

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^{8}\ \text{m/s}}{2.466 \times 10^{15}\ /\text{s}} = 1.2\underline{1}55 \times 10^{-7} = 1.22 \times 10^{-7}\ \text{m (near UV)}$$

7.46 Solve the equation $E = -R_H/n^2$ for both E_5 and E_4; solve for ν, and convert to λ.

$$E_5 = \frac{-R_H}{5^2} = \frac{-R_H}{25}; \qquad E_4 = \frac{-R_H}{4^2} = \frac{-R_H}{16}$$

$$\left[\frac{-R_H}{25}\right] - \left[\frac{-R_H}{16}\right] = \frac{9R_H}{400} = h\nu$$

The frequency of the emitted radiation is:

$$\nu = \frac{9R_H}{400h} = \frac{9}{400} \times \frac{2.179 \times 10^{-18}\ \text{J}}{6.626 \times 10^{-34}\ \text{J} \bullet \text{s}} = 7.3\underline{9}9 \times 10^{13}\ /\text{s}$$

The wavelength can now be calculated.

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^{8}\ \text{m/s}}{7.399 \times 10^{13}\ /\text{s}} = 4.0\underline{5}17 \times 10^{-6} = 4.05 \times 10^{-6}\ \text{m (near IR)}$$

7.47 This is the highest energy transition from the n = 6 level, so the electron must undergo a transition to the n = 1 level. Solve the Balmer equation using Bohr's approach:

$$E_6 = \frac{-R_H}{6^2} = \frac{-R_H}{36}; \qquad E_1 = \frac{-R_H}{1^2} = \frac{-R_H}{1}$$

$$h\nu = \left[\frac{-R_H}{36}\right] - \left[\frac{-R_H}{1}\right] = \frac{35R_H}{36}$$

The frequency of the emitted radiation is:

$$\nu = \frac{35R_H}{36\,h} = \frac{35}{36} \times \frac{2.179 \times 10^{-18}\ \mathrm{J}}{6.626 \times 10^{-34}\ \mathrm{J \bullet s}} = 3.1\underline{9}7 \times 10^{15}\ /\mathrm{s}$$

The wavelength can now be calculated.

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^{8}\ \mathrm{m/s}}{3.197 \times 10^{15}\ /\mathrm{s}} = 9.3\underline{7}69 \times 10^{-8} = 9.38 \times 10^{-8}\ \mathrm{m}\ \ (93.8\ \mathrm{nm})$$

7.48 This is the lowest energy transition from the n = 6 level, so the electron must undergo a transition to the n = 5 level. Solve the Balmer equation using Bohr's approach:

$$E_6 = \frac{-R_H}{6^2} = \frac{-R_H}{36}; \qquad E_5 = \frac{-R_H}{5^2} = \frac{-R_H}{25}$$

$$h\nu = \left[\frac{-R_H}{36}\right] - \left[\frac{-R_H}{25}\right] = \frac{11R_H}{900}$$

$$\nu = \frac{11R_H}{900\,h} = \frac{11}{900} \times \frac{2.179 \times 10^{-18}\ \mathrm{J}}{6.626 \times 10^{-34}\ \mathrm{J \bullet s}} = 4.0\underline{1}9 \times 10^{13}\ /\mathrm{s}$$

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^{8}\ \mathrm{m/s}}{4.019 \times 10^{13}\ /\mathrm{s}} = 7.4\underline{5}8 \times 10^{-6} = 7.46 \times 10^{-6}\ \mathrm{m}\ \ (7460\ \mathrm{nm})$$

7.49 Noting that 422.7 nm = 4.227×10^{-7} m, convert the 422.7 nm to frequency. Then convert the frequency to energy using $E = h\nu$.

$$\nu = \frac{c}{\lambda} = \frac{2.998 \times 10^{8}\ \text{m/s}}{4.227 \times 10^{-7}\ \text{m}} = 7.09\underline{2}5 \times 10^{14}\ \text{/s}$$

$$E = h\nu = (6.626 \times 10^{-34}\ \text{J}\bullet\text{s}) \times 7.09\underline{2}5 \times 10^{14}\ \text{/s}) = 4.69\underline{9}4 \times 10^{-19}$$

$$= 4.699 \times 10^{-19}\ \text{J}$$

7.50 Noting that 285.2 nm = 2.852×10^{-7} m, convert the 285.2-nm wavelength to frequency. Then convert the frequency to energy using $E = h\nu$.

$$\nu = \frac{c}{\lambda} = \frac{2.998 \times 10^{8}\ \text{m/s}}{2.852 \times 10^{-7}\ \text{m}} = 1.05\underline{1}1 \times 10^{15}\ \text{/s}$$

$$E = h\nu = (6.626 \times 10^{-34}\ \text{J}\bullet\text{s}) \times 1.05\underline{1}1 \times 10^{15}\ \text{/s}) = 6.96\underline{4}58 \times 10^{-19}$$

$$= 6.965 \times 10^{-19}\ \text{J}$$

7.51 The mass of a neutron = 1.67493×10^{-27} kg. Its speed or velocity, v, of 4.15 km/s equals 4.15×10^{3} m/s. Substitute these parameters into the de Broglie relation, and solve for λ:

$$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}\ \text{kg}\bullet\text{m}^2/\text{s}}{1.67493 \times 10^{-27}\ \text{kg} \times 4.15 \times 10^{3}\ \text{m/s}}$$

$$= 9.5\underline{3}2 \times 10^{-11} = 9.53 \times 10^{-11}\ \text{m} \quad \text{or} \quad 95.3\ \text{pm}$$

7.52 The mass of a proton = 1.67262×10^{-27}. Its speed or velocity, v, of 6.21 km/s equals 6.21×10^{3} m/s. Substitute these parameters into the de Broglie relation, and solve for λ:

$$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}\ \text{kg}\bullet\text{m}^2/\text{s}}{1.67262 \times 10^{-27}\ \text{kg} \times 6.21 \times 10^{3}\ \text{m/s}}$$

$$= 6.3\underline{7}9 \times 10^{-11} = 6.38 \times 10^{-11}\ \text{m} \quad \text{or} \quad 63.8\ \text{pm}$$

A wavelength of 63.8 pm would be in the x-ray region of the spectrum.

7.53 The mass of an electron equals 9.10953 x 10^{-31} kg. The wavelength, λ, given as 10.0 pm, is equivalent to 1.00 x 10^{-11} m. Substitute these parameters into the de Broglie relation, and solve for the frequency, ν:

$$v = \frac{h}{m\lambda} = \frac{6.626 \times 10^{-34}\ \text{kg} \bullet \text{m}^2/\text{s}}{9.10953 \times 10^{-31}\ \text{kg} \times 1.00 \times 10^{-11}\ \text{m}} = 7.2\underline{7}3 \times 10^7$$

$$= 7.27 \times 10^7\ \text{m/s}$$

7.54 The mass of a neutron equals 1.67493 x 10^{-27} kg. The wavelength, λ, given as 10.0 pm, is equivalent to 1.00 x 10^{-11} m. Substitute these parameters into the de Broglie relation, and solve for the frequency, ν:

$$v = \frac{h}{m\lambda} = \frac{6.626 \times 10^{-34}\ \text{kg} \bullet \text{m}^2/\text{s}}{1.67493 \times 10^{-27}\ \text{kg} \times 1.00 \times 10^{-11}\ \text{m}} = 3.9\underline{5}5 \times 10^4$$

$$= 3.96 \times 10^4\ \text{m/s}$$

7.55 Substitute the 1.45 x 10^{-1} kg mass of the baseball and the 30.0 m/s velocity, v, into the de Broglie relation, and solve for wavelength (recall that 1 pm = 10^{-12} m).

$$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}\ \text{kg} \bullet \text{m}^2/\text{s}}{1.45 \times 10^{-1}\ \text{kg} \times 30.0\ \text{m/s}} = 1.5\underline{2}3 \times 10^{-34} = 1.52 \times 10^{-34}\ \text{m}$$

$$= 1.52 \times 10^{-22}\ \text{pm}$$

Because this is much smaller than 100 pm, the wavelength is much smaller than the diameter of one atom.

7.56 The mass of O_2 to three significant figures is 32.00 ÷ 6.022 x 10^{23} = 5.313 x 10^{-23} g = 5.313 x 10^{-26} kg. Substitute this mass and the 521 m/s velocity, v, into the de Broglie relation, and solve for wavelength (recall that 1 pm = 10^{-12} m).

$$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}\ \text{kg} \bullet \text{m}^2/\text{s}}{5.313 \times 10^{-26}\ \text{kg} \times 521\ \text{m/s}} = 2.3\underline{9}37 \times 10^{-11} = 2.39 \times 10^{-11}\ \text{m}$$

$$= 23.9\ \text{pm}$$

Because this is on the order of 100 pm, the wavelength is on the order of an atomic diameter.

7.57 The possible values of l range from zero to (n - 1), so l may be 0, 1, 2, or 3. The possible values of m_l range from - l to + l, so m_l may be -3, -2, -1, 0, +1, +2, or +3.

7.58 The possible l values are 0, 1, 2, 3, and 4. The possible m_l values are -4, -3, -2, -1, 0, 1, 2, 3, or 4.

7.59 For the M shell, n = 3; there are three subshells in this shell (l = 0, 1, and 2). An *f* subshell has l = 3; the number of orbitals in this subshell is 2(3) + 1 = 7 (m_l = -3, -2, -1, 0, 1, 2, and 3).

7.60 For the N shell, n = 4; there are four subshells in this shell (l = 0, 1, 2, and 3). For a *g* subshell, the value of l = 4; the number of orbitals in this subshell is 2(4) + 1 = 9 (m_l = -4, -3, -2, -1, 0, 1, 2, 3, and 4).

7.61 a. 6*d* b. 5*g* c. 4*f* d. 6*p*

7.62 a. 3*p* b. 4*d* c. 4*s* d. 5*f*

7.63 a. Not permissible; m_s may be only + 1/2 or -1/2.
b. Not permissible; l can only be as large as (n - 1).
c. Not permissible; m_l may not exceed +2 in magnitude.
d. Not permissible; n may not be zero.
e. Not permissible; m_s may only be + 1/2 or -1/2.

7.64 a. Not permissible; n starts at 1, not at zero.
b. Not permissible; l may only be as large as (n - 1).
c. Permissible.
d. Not permissible; m_l may not exceed l in magnitude.
e. Permissible.

■ Solutions to General Problems

7.65 Use $c = \nu\lambda$ to calculate frequency; then use $E = h\nu$ to calculate energy.

$$\nu = \frac{c}{\lambda} = \frac{2.998 \times 10^{8} \text{ m/s}}{4.61 \times 10^{-7} \text{ m}} = 6.5\underline{0}3 \times 10^{14} = 6.50 \times 10^{14} \text{ /s}$$

$$E = h\nu = (6.626 \times 10^{-34} \text{ J}\bullet\text{s}) \times (6.503 \times 10^{14}\text{/s}) = 4.3\underline{0}9 \times 10^{-19}$$

$$= 4.31 \times 10^{-19} \text{ J}$$

7.66 Use $c = \nu\lambda$ to calculate frequency; then use $E = h\nu$ to calculate energy.

$$\nu = \frac{c}{\lambda} = \frac{2.998 \times 10^{8} \text{ m/s}}{5.54 \times 10^{-7} \text{ m}} = 5.4\underline{1}15 \times 10^{14} = 5.41 \times 10^{14} \text{ /s}$$

$$E = h\nu = (6.626 \times 10^{-34} \text{ J}\bullet\text{s}) \times (5.4115 \times 10^{14}\text{/s}) = 3.5\underline{8}56 \times 10^{-19}$$

$$= 3.59 \times 10^{-19} \text{ J}$$

7.67 Calculate the frequency corresponding to 4.10×10^{-19} J. Then convert that to wavelength.

$$\nu = \frac{E}{h} = \frac{4.10 \times 10^{-19} \text{ J}}{6.626 \times 10^{-34} \text{ J} \bullet \text{s}} = 6.1\underline{8}7 \times 10^{14} \text{ /s}$$

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^{8} \text{ m/s}}{6.187 \times 10^{14} \text{ /s}} = 4.8\underline{4}5 \times 10^{-7} = 4.85 \times 10^{-7} \text{ m} = 485 \text{ nm (blue)}$$

7.68 Calculate the frequency corresponding to 3.34×10^{-19} J. Then convert that to wavelength.

$$\nu = \frac{E}{h} = \frac{3.34 \times 10^{-19} \text{ J}}{6.626 \times 10^{-34} \text{ J} \bullet \text{s}} = 5.0\underline{4}07 \times 10^{14} \text{ /s}$$

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^{8} \text{ m/s}}{5.0407 \times 10^{14} \text{ /s}} = 5.9\underline{4}7 \times 10^{-7} = 5.95 \times 10^{-7} \text{ m} = 595 \text{ nm (yellow)}$$

7.69 Solve for frequency using $E = h\nu$.

$$\nu = \frac{E}{h} = \frac{4.34 \times 10^{-19}\ \text{J}}{6.626 \times 10^{-34}\ \text{J} \bullet \text{s}} = 6.5\underline{4}9 \times 10^{14} = 6.55 \times 10^{14}\ /\text{s}$$

7.70 Solve for frequency using $E = h\nu$.

$$\nu = \frac{E}{h} = \frac{5.90 \times 10^{-19}\ \text{J}}{6.626 \times 10^{-34}\ \text{J} \bullet \text{s}} = 8.9\underline{0}4 \times 10^{14} = 8.90 \times 10^{14}\ /\text{s}$$

7.71 First calculate E_p, the energy of the 345-nm photon, noting that it is equivalent to 3.45×10^{-7} m.

$$E_p = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34}\ \text{J} \bullet \text{s})(2.998 \times 10^{8}\ \text{m/s})}{3.45 \times 10^{-7}\ \text{m}} = 5.7\underline{5}78 \times 10^{-19}\ \text{J}$$

Now, subtract the work function of Ca = 4.34×10^{-19} J (Problem 7.69) from E_p:

$$5.7578 \times 10^{-19}\ \text{J} - 4.34 \times 10^{-19}\ \text{J} = 1.4\underline{1}78 \times 10^{-19}\ \text{J}$$

Note that, for this situation, $E = 1/2mv^2$. Recall that the mass of the electron is 9.1095×10^{-31} kg. Now calculate speed, v:

$$v = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2 \times 1.4178 \times 10^{-19}\ \text{J}}{9.1095 \times 10^{-31}\ \text{kg}}} = 5.5\underline{7}9 \times 10^{5} = 5.58 \times 10^{5}\ \text{m/s}$$

7.72 First calculate E_p, the energy of the 285-nm photon, noting that it is equivalent to 2.85×10^{-7} m.

$$E_p = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34}\ \text{J} \bullet \text{s})(2.998 \times 10^{8}\ \text{m/s})}{2.85 \times 10^{-7}\ \text{m}} = 6.9\underline{7}0 \times 10^{-19}\ \text{J}$$

Now, subtract the work function of Mg = 5.90×10^{-19} J (Problem 7.70) from E_p:

$$6.970 \times 10^{-19}\ \text{J} - 5.90 \times 10^{-19}\ \text{J} = 1.070 \times 10^{-19}\ \text{J}$$

Note that, for this situation, $E = 1/2mv^2$. Recall that the mass of the electron is 9.1095×10^{-31} kg. Now calculate speed, v:

$$v = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2 \times 1.070 \times 10^{-19}\ \text{J}}{9.1095 \times 10^{-31}\ \text{kg}}} = 4.8\underline{4}7 \times 10^{5} = 4.85 \times 10^{5}\ \text{m/s}$$

7.73 This is a transition from the n = 5 level to the n = 2 level. Solve the Balmer equation using Bohr's approach.

$$E_5 = \frac{-R_H}{5^2} = \frac{-R_H}{25}; \qquad E_2 = \frac{-R_H}{2^2} = \frac{-R_H}{4}$$

$$h\nu = \left[\frac{-R_H}{25}\right] - \left[\frac{-R_H}{4}\right] = \frac{21R_H}{100}$$

$$\nu = \frac{21R_H}{100\,h} = \frac{21}{100} \times \frac{2.179 \times 10^{-18}\ \text{J}}{6.626 \times 10^{-34}\ \text{J}\bullet\text{s}} = 6.9\underline{0}59 \times 10^{14}\ /\text{s}$$

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^{8}\ \text{m/s}}{6.9059 \times 10^{14}\ /\text{s}} = 4.3\underline{4}1 \times 10^{-7} = 4.34 \times 10^{-7}\ \text{m}\ \ (434\ \text{nm})$$

7.74 This is a transition from the n = 3 level to the n = 2 level. Solve the Balmer equation using Bohr's approach.

$$E_3 = \frac{-R_H}{3^2} = \frac{-R_H}{9}; \qquad E_2 = \frac{-R_H}{2^2} = \frac{-R_H}{4}$$

$$h\nu = \left[\frac{-R_H}{9}\right] - \left[\frac{-R_H}{4}\right] = \frac{5\,R_H}{36}$$

$$\nu = \frac{5\,R_H}{36\,h} = \frac{5}{36} \times \frac{2.179 \times 10^{-18}\ \text{J}}{6.626 \times 10^{-34}\ \text{J}\bullet\text{s}} = 4.5\underline{6}74 \times 10^{14}\ /\text{s}$$

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^{8}\ \text{m/s}}{4.5674 \times 10^{14}\ /\text{s}} = 6.5\underline{6}3 \times 10^{-7} = 6.56 \times 10^{-7}\ \text{m}\ \ (656\ \text{nm})$$

7.75 Use 397 nm = 3.97×10^{-7} m, and convert to frequency and then to energy.

$$\nu = \frac{c}{\lambda} = \frac{2.998 \times 10^{8}\ \text{m/s}}{3.97 \times 10^{-7}\ \text{m}} = 7.5\underline{5}1 \times 10^{14}\ /\text{s}$$

$$E = h\nu = (6.626 \times 10^{-34}\ \text{J}\bullet\text{s}) \times (7.551 \times 10^{14}) = 5.0\underline{0}37 \times 10^{-19}\ \text{J}$$

(continued)

Substitute this energy into the Balmer formula recalling that the Balmer series is an emission spectrum, so ΔE is negative:

$$E_2 = \frac{-R_H}{2^2} = \frac{-R_H}{4}; \qquad E_i = \frac{-R_H}{n_i^2}$$

$$\left[\frac{-R_H}{4}\right] - \left[\frac{-R_H}{n_i^2}\right] = -R_H\left[\frac{1}{4} - \frac{1}{n_i^2}\right] = E \quad \text{(of line)}$$

$$\left[\frac{1}{4} - \frac{1}{n_i^2}\right] = \frac{5.0037 \times 10^{-19}\ \text{J}}{2.179 \times 10^{-18}\ \text{J}} = 0.22\underline{9}63$$

$$\frac{1}{n_i^2} = \frac{1}{4} - 0.22\underline{9}63 = 0.02\underline{0}36$$

$$n_i = \left[\frac{1}{0.02036}\right]^{1/2} = 7.\underline{0}07 = 7.0 \quad (= n)$$

7.76 Convert 9.50×10^{-8} m into frequency and then to energy.

$$\nu = \frac{c}{\lambda} = \frac{2.998 \times 10^{8}\ \text{m/s}}{9.50 \times 10^{-8}\ \text{m}} = 3.1\underline{5}57 \times 10^{15}\ \text{/s}$$

$$E = h\nu = (6.626 \times 10^{-34}\ \text{J}\bullet\text{s}) \times (3.1557 \times 10^{15}) = 2.0\underline{9}10 \times 10^{-18}\ \text{J}$$

Substitute this energy into the Balmer formula recalling that the Lyman series is an emission spectrum, so ΔE is negative, and $n_f = 1$:

$$E_1 = \frac{-R_H}{1^2} = \frac{-R_H}{1}; \qquad E_i = \frac{-R_H}{n_i^2}$$

$$\left[\frac{-R_H}{1}\right] - \left[\frac{-R_H}{n_i^2}\right] = -R_H\left[\frac{1}{1} - \frac{1}{n_i^2}\right] = E \quad \text{(of line)}$$

$$\left[1 - \frac{1}{n_i^2}\right] = \frac{2.0910 \times 10^{-18}\ \text{J}}{2.179 \times 10^{-18}\ \text{J}} = 0.95\underline{9}62$$

(continued)

$$\frac{1}{n_i^2} = 1 - 0.95962 = 0.04037$$

$$n_i = \left[\frac{1}{0.04037}\right]^{1/2} = 4.\underline{9}76 = 5 \ (= n)$$

7.77 Employ the Balmer formula using Z = 2 for the He^+ ion.

$$E_3 = (2)^2 \frac{-R_H}{3^2} = (4)\frac{-R_H}{9}; \qquad E_2 = (2)^2 \frac{-R_H}{2^2} = (4)\frac{-R_H}{4}$$

$$4\left[\frac{-R_H}{9}\right] - 4\left[\frac{-R_H}{4}\right] = 4 \times \frac{5R_H}{36} = h\nu$$

The frequency of the radiation is

$$\nu = \frac{4 \times 5\,R_H}{36\,h} = \frac{20}{36} \times \frac{2.179 \times 10^{-18}\ J}{6.626 \times 10^{-34}\ J \bullet s} = 1.8\underline{2}69 \times 10^{15}\ /s$$

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^{8}\ m/s}{1.8269 \times 10^{15}\ /s} = 1.6\underline{4}09 \times 10^{-7} = 1.64 \times 10^{-7}\ m \ \ (164\ nm;\ near\ UV)$$

7.78 Employ the Balmer formula using Z = 3 for the Li^{2+} ion.

$$E_4 = (3)^2 \frac{-R_H}{4^2} = (9)\frac{-R_H}{16}; \qquad E_3 = (3)^2 \frac{-R_H}{3^2} = (9)\frac{-R_H}{9}$$

$$9\left[\frac{-R_H}{16}\right] - 9\left[\frac{-R_H}{9}\right] = 9 \times \frac{7R_H}{144} = h\nu$$

$$\nu = \frac{9 \times 7\,R_H}{144\,h} = \frac{63}{144} \times \frac{2.179 \times 10^{-18}\ J}{6.626 \times 10^{-34}\ J \bullet s} = 1.4\underline{3}87 \times 10^{15}\ /s$$

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^{8}\ m/s}{1.4387 \times 10^{15}\ /s} = 2.0\underline{8}37 \times 10^{-7} = 2.08 \times 10^{-7}\ m \ \ (208\ nm;\ UV)$$

7.79 First, use the wavelength of 10.0 pm (1.00×10^{-11} m) and the mass of 9.1095×10^{-31} kg to calculate the velocity, v. Then, use the kinetic energy equation to calculate kinetic energy from velocity.

$$v = \frac{h}{m\lambda} = \frac{6.626 \times 10^{-34}\ kg \bullet m^2/s}{9.1095 \times 10^{-31}\ kg \ \times \ 1.00 \times 10^{-11}\ m} = 7.2\underline{7}37 \times 10^7 \text{ m/s}$$

$$E = 1/2mv^2 = 1/2 \times (9.1095 \times 10^{-31} \text{ kg}) \times (7.273 \times 10^7 \text{ m/s})^2 = 2.4\underline{0}9 \times 10^{-15} \text{ J}$$

$$E_{eV} = 2.409 \times 10^{-15} \text{ J} \times \frac{1\,eV}{1.602 \times 10^{-19}\ J} = 1.5\underline{0}3 \times 10^4 = 1.50 \times 10^4 \text{ eV}$$

7.80 First, use the wavelength of 10.0 pm (1.00×10^{-11} m) and the mass of 1.675×10^{-27} kg to calculate the velocity, v. Then, use the kinetic energy equation to calculate kinetic energy from velocity.

$$v = \frac{h}{m\lambda} = \frac{6.626 \times 10^{-34}\ kg \bullet m^2/s}{1.675 \times 10^{-27}\ kg \ \times \ 1.00 \times 10^{-11}\ m} = 3.9\underline{5}58 \times 10^4 \text{ m/s}$$

$$E = 1/2mv^2 = 1/2 \times (1.675 \times 10^{-27} \text{ kg}) \times (3.9558 \times 10^4 \text{ m/s})^2 = 1.3\underline{1}05 \times 10^{-18} \text{ J}$$

$$E_{eV} = 1.3105 \times 10^{-18} \text{ J} \times \frac{1\,eV}{1.602 \times 10^{-19}\ J} = 8.1803 = 8.18 \text{ eV}$$

7.81 a. Five b. Seven c. Three d. One

7.82 a. Seven b. Nine c. One d. Three

7.83 The possible subshells for the n = 6 shell are 6*s*, 6*p*, 6*d*, 6*f*, 6*g*, and 6*h*.

7.84 The possible subshells for the n = 7 shell are 7*s*, 7*p*, 7*d*, 7*f*, 7*g*, 7*h*, and 7*i*.

■ Solutions to Cumulative-Skills Problems

7.85 First, use Avogadro's number to calculate the energy for one Cl_2 molecule.

$$\frac{239 \text{ kJ}}{1 \text{ mol}} \times \frac{1000 \text{ J}}{1 \text{ kJ}} \times \frac{1 \text{ mol}}{6.022 \times 10^{23} \text{ molecules}} = 3.9\underline{6}87 \times 10^{-19} \text{ J/molecule}$$

Then, convert energy to frequency and finally to wavelength.

$$\nu = \frac{E}{h} = \frac{3.9687 \times 10^{-19} \text{ J}}{6.626 \times 10^{-34} \text{ J} \bullet \text{s}} = 5.9\underline{8}97 \times 10^{14} \text{ /s}$$

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^{8} \text{ m/s}}{5.9897 \times 10^{14} \text{ /s}} = 5.0\underline{0}52 \times 10^{-7} \text{ m} \quad \text{(501 nm; visible region)}$$

7.86 First, use Avogadro's number to calculate the energy per H_2 molecule.

$$\frac{432 \text{ kJ}}{1 \text{ mol}} \times \frac{1000 \text{ J}}{1 \text{ kJ}} \times \frac{1 \text{ mol}}{6.022 \times 10^{23} \text{ molecules}} = 7.1\underline{7}36 \times 10^{-19} \text{ J/molecule}$$

Then, convert energy to frequency and finally to wavelength.

$$\nu = \frac{E}{h} = \frac{7.1736 \times 10^{-19} \text{ J}}{6.626 \times 10^{-34} \text{ J} \bullet \text{s}} = 1.0\underline{8}26 \times 10^{15} \text{ /s}$$

$$\lambda = \frac{c}{\nu} = \frac{2.998 \times 10^{8} \text{ m/s}}{1.0826 \times 10^{15} \text{ /s}} = 2.7\underline{6}91 \times 10^{-7} \text{ m} \quad \text{(277 nm; UV)}$$

7.87 First, calculate the energy needed to heat the 0.250 L of water from 20.0°C to 100.0°C.

$$0.250 \text{ L} \times \frac{1000 \text{ g}}{1 \text{ L}} \times \frac{4.184 \text{ J}}{(\text{g} \bullet {}^\circ\text{C})} \times (100.0\ {}^\circ\text{C} - 20.0^\circ\text{C}) = 8.3\underline{6}8 \times 10^{4} \text{ J}$$

Then, calculate the frequency, the energy of one photon, and the number of photons.

$$\nu = \frac{c}{\lambda} = \frac{2.998 \times 10^{8} \text{ m/s}}{0.125 \text{ m}} = 2.3\underline{9}8 \times 10^{9} \text{ /s}$$

(continued)

$$\text{E of one photon} = h\nu = (6.626 \times 10^{-34}\ \text{J}\bullet\text{s}) \times (2.398 \times 10^{9}/\text{s}) = 1.5\underline{8}9 \times 10^{-24}\ \text{J}$$

$$\text{No. photons} = h\nu = 8.368 \times 10^{4}\ \text{J} \times \frac{1\ \text{photon}}{1.589 \times 10^{-24}\ \text{J}} = 5.2\underline{6}56 \times 10^{28}$$

$$= 5.27 \times 10^{28}\ \text{photons}$$

7.88 First, calculate the energy needed to heat the 1.00 L of water from 20.0°C to 30.0°C.

$$1.00\ \text{L} \times \frac{1000\ \text{g}}{1\ \text{L}} \times \frac{4.184\ \text{J}}{(\text{g}\bullet{}^{\circ}\text{C})} \times (30.0\ {}^{\circ}\text{C} - 20.0{}^{\circ}\text{C}) = 4.1\underline{8}4 \times 10^{4}\ \text{J}$$

Then, calculate the frequency, the energy of one photon, and the number of photons.

$$\nu = \frac{c}{\lambda} = \frac{2.998 \times 10^{8}\ \text{m/s}}{2.80 \times 10^{-6}\ \text{m}} = 1.0\underline{7}07 \times 10^{14}\ /\text{s}$$

$$\text{E of one photon} = h\nu = (6.626 \times 10^{-34}\ \text{J}\bullet\text{s}) \times (1.0707 \times 10^{14}/\text{s}) = 7.0\underline{9}45 \times 10^{-20}\ \text{J}$$

$$\text{No. photons} = h\nu = 4.184 \times 10^{4}\ \text{J} \times \frac{1\ \text{photon}}{7.0945 \times 10^{-20}\ \text{J}} = 5.8\underline{9}74 \times 10^{23}$$

$$= 5.90 \times 10^{23}\ \text{photons}$$

7.89 First, write the following equality for the energy to remove one electron, $E_{removal}$:

$$E_{removal} = E_{425\ nm} - E_{k}\ \text{of ejected photon}$$

Use E = hν to calculate the energy of the photon. Then, recall that E_k, the kinetic energy, is $1/2mv^2$. Use this to calculate E_k.

$$E_{425\ nm} = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34}\ \text{J}\bullet\text{s})(2.998 \times 10^{8}\ \text{m/s})}{4.25 \times 10^{-7}\ \text{m}} = 4.6\underline{7}40 \times 10^{-19}\ \text{J}$$

$$E_k = 1/2mv^2 = 1/2 \times (9.1095 \times 10^{-31}\ \text{kg}) \times (4.88 \times 10^{5}\ \text{m/s})^2 = 1.0\underline{8}46 \times 10^{-19}\ \text{J}$$

Subtract to find $E_{removal}$, and convert it to kJ/mol:

$$E_{removal} = 4.6740 \times 10^{-19}\ \text{J} - (1.0847 \times 10^{-19}\ \text{J}) = 3.5\underline{8}93 \times 10^{-19}$$

$$= 3.59 \times 10^{-19}\ \text{J/electron}$$

(continued)

$$E_{removal} = \frac{3.5893 \times 10^{-19}\ J}{1\ e^-} \times \frac{6.022 \times 10^{23}\ e^-}{1\ mol} \times \frac{1\ kJ}{1000\ J} = 2.1\underline{6}1 \times 10^2$$

$$= 2.16 \times 10^2\ kJ/mol$$

7.90 First, write the following equality for the energy to remove one electron, $E_{removal}$:

$$E_{removal} = E_{405\ nm} - E_k \text{ of ejected electron}$$

Use E = hν to calculate the energy of the photon. Then, recall that E_k, the kinetic energy, is $1/2mv^2$. Use this to calculate E_k.

$$E_{405\ nm} = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34}\ J \bullet s)(2.998 \times 10^8\ m/s)}{4.05 \times 10^{-7}\ m} = 4.9\underline{0}48 \times 10^{-19}\ J$$

$$E_k = 1/2mv^2 = 1/2 \times (9.1095 \times 10^{-31}\ kg) \times (3.36 \times 10^5\ m/s)^2 = 5.1\underline{4}2 \times 10^{-20}\ J$$

Subtract to find $E_{removal}$, and convert it to kJ/mol:

$$E_{removal} = 4.9048 \times 10^{-19} - 5.142 \times 10^{-20} = 4.3\underline{9}06 \times 10^{-19}$$

$$= 4.39 \times 10^{-19}\ J/electron$$

$$E_{removal} = \frac{4.3906 \times 10^{-19}\ J}{1\ e^-} \times \frac{6.022 \times 10^{23}\ e^-}{1\ mol} \times \frac{1\ kJ}{1000\ J} = 26\underline{4}.4$$

$$= 264\ kJ/mol$$

7.91 First, calculate the energy, E, in joules using the product of voltage and charge:

$$E = (4.00 \times 10^3\ V) \times (1.602 \times 10^{-19}\ C) = 6.4\underline{0}8 \times 10^{-16}\ J$$

Now, use the kinetic energy equation, $E_k = 1/2mv^2$, and solve for velocity:

$$v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 6.408 \times 10^{-16}\ J}{9.1095 \times 10^{-31}\ kg}} = 3.7\underline{5}08 \times 10^7\ m/s$$

$$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}\ J \bullet s}{(9.1095 \times 10^{-31}\ kg) \times (3.7508 \times 10^7\ m/s)} = 1.9\underline{3}9 \times 10^{-11}$$

$$= 1.94 \times 10^{-11}\ m\ \ (19.4\ pm)$$

7.92 First, calculate the energy, E, in joules using the product of voltage and charge:

$$E = (1.00 \times 10^{4}\ \text{V}) \times (1.602 \times 10^{-19}\ \text{C}) = 1.6\underline{0}2 \times 10^{-15}\ \text{J}$$

Now, use the kinetic energy equation $E_k = 1/2mv^2$, and solve for velocity:

$$v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2 \times 1.602 \times 10^{-15}\ \text{J}}{9.1095 \times 10^{-31}\ \text{kg}}} = 5.9\underline{3}06 \times 10^{7}\ \text{m/s}$$

$$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}\ \text{J} \bullet \text{s}}{(9.1095 \times 10^{-31}\ \text{kg}) \times (5.9306 \times 10^{7}\ \text{m/s})} = 1.2\underline{2}6 \times 10^{-11}$$

$$1.23 \times 10^{-11}\ \text{m}\ \ (12.3\ \text{pm})$$

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