5 Periodicity and the Electronic Structure of Atoms

5.1 $\nu = 102.5 \text{ MHz} = 102.5 \times 10^6 \text{ Hz} = 102.5 \times 10^6 \text{ s}^{-1}$

$$\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^8 \text{ m/s}}{102.5 \times 10^6 \text{ s}^{-1}} = 2.93 \text{ m}$$

5.2 The wave with the shorter wavelength (b) has the higher frequency. The wave with the larger amplitude (b) represents the more intense beam of light. The wave with the shorter wavelength (b) represents blue light. The wave with the longer wavelength (a) represents red light.

5.3 IR, $\lambda = 1.55 \times 10^{-6}$ m

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34} \text{ J}\cdot\text{s})\left(\frac{3.00 \times 10^8 \text{ m/s}}{1.55 \times 10^{-6} \text{ m}}\right)(6.022 \times 10^{23}\text{/mol})$$

$E = 7.72 \times 10^4$ J/mol = 77.2 kJ/mol

UV, $\lambda = 250 \text{ nm} = 250 \times 10^{-9}$ m

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34} \text{ J}\cdot\text{s})\left(\frac{3.00 \times 10^8 \text{ m/s}}{250 \times 10^{-9} \text{ m}}\right)(6.022 \times 10^{23}\text{/mol})$$

$E = 4.79 \times 10^5$ J/mol = 479 kJ/mol

X ray, $\lambda = 5.49 \text{ nm} = 5.49 \times 10^{-9}$ m

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34} \text{ J}\cdot\text{s})\left(\frac{3.00 \times 10^8 \text{ m/s}}{5.49 \times 10^{-9} \text{ m}}\right)(6.022 \times 10^{23}\text{/mol})$$

$E = 2.18 \times 10^7$ J/mol = 2.18×10^4 kJ/mol

5.4 $$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34} \text{ J}\cdot\text{s})\left(\frac{3.00 \times 10^8 \text{ m/s}}{2.3 \times 10^{-3} \text{ m}}\right)(6.022 \times 10^{23}\text{/mol})$$

E = 52 J/mol = 0.052 kJ/mol

$$74 \text{ kJ} \times \frac{1 \text{ mol photons}}{0.052 \text{ kJ}} = 1.4 \times 10^3 \text{ mol photons}$$

5.5 $$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34} \text{ J}\cdot\text{s})\left(\frac{3.00 \times 10^8 \text{ m/s}}{390 \times 10^{-9} \text{ m}}\right)(6.022 \times 10^{23}\text{/mol})$$

$E = 3.07 \times 10^5$ J/mol = 307 kJ/mol

The energy is less than the work function. Electrons will not be ejected.

5.6 (a) Ag is predicted to have the higher work function because Rb is further left on the periodic table and holds its electrons less tightly.
(b) Rb because lower energies correspond to longer wavelength.

5.7 $m = 2$; $R_\infty = 1.097 \times 10^{-2}\ nm^{-1}$

$$\frac{1}{\lambda} = R_\infty\left[\frac{1}{m^2} - \frac{1}{n^2}\right];\ \frac{1}{\lambda} = R_\infty\left[\frac{1}{2^2} - \frac{1}{7^2}\right];\ \frac{1}{\lambda} = 2.519 \times 10^{-3}\ nm^{-1};\ \ \lambda = 397.0\ nm$$

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ J\cdot s)\left(\frac{3.00 \times 10^8\ m/s}{397.0 \times 10^{-9}\ m}\right)(6.022 \times 10^{23}\ /mol)$$

$E = 3.015 \times 10^5$ J/mol = 301.5 kJ/mol

5.8 $m = 3$; $R_\infty = 1.097 \times 10^{-2}\ nm^{-1}$

(a) $$\frac{1}{\lambda} = R_\infty\left[\frac{1}{m^2} - \frac{1}{n^2}\right];\ \frac{1}{\lambda} = R_\infty\left[\frac{1}{3^2} - \frac{1}{4^2}\right];\ \frac{1}{\lambda} = 5.333 \times 10^{-4}\ nm^{-1};\ \ \lambda = 1875\ nm$$

(b) $$\frac{1}{\lambda} = R_\infty\left[\frac{1}{m^2} - \frac{1}{n^2}\right];\ \frac{1}{\lambda} = R_\infty\left[\frac{1}{3^2} - \frac{1}{\infty^2}\right];\ \frac{1}{\lambda} = 1.219 \times 10^{-3}\ nm^{-1};\ \ \lambda = 820.4\ nm$$

5.9 $$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}\ kg\ m^2\ s^{-1}}{(1150\ kg)(24.6\ m/s)} = 2.34 \times 10^{-38}\ m$$

5.10 $\lambda = 1 nm/10 = 1 \times 10^{-10}$ m

$$\lambda = \frac{h}{mv};\quad v = \frac{h}{m\lambda} = \frac{6.626 \times 10^{-34}\ kg\ m^2\ s^{-1}}{(9.1 \times 10^{-31}\ kg)(1 \times 10^{-10}\ m)} = 7 \times 10^6\ m/s$$

5.11 4f

5.12

n	l	m_l	Orbital	No. of Orbitals
5	0	0	5s	1
	1	−1, 0, +1	5p	3
	2	−2, −1, 0, +1, +2	5d	5
	3	−3, −2, −1, 0, +1, +2, +3	5f	7
	4	−4, −3, −2, −1, 0, +1, +2, +3, +4	5g	9

There are 25 possible orbitals in the fifth shell.

5.13 $n = 4$, $l = 0$, 4s

5.14 The g orbitals have four nodal planes.

5.15 Ti, $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^2$ or [Ar] $4s^2 3d^2$

[Ar] $\underline{\uparrow\downarrow}$ (4s) $\underline{\uparrow}$ $\underline{\uparrow}$ $\underline{\ \ }$ $\underline{\ \ }$ $\underline{\ \ }$ (3d)

5.16 (a) 43 electrons = Tc (b) 28 electrons = Ni

5.17 Si (valence shell of n = 3) and Sn (valence shell of n = 5) are in the same group (4A). Atoms get larger as you go down a group, therefore, Sn is larger than Si. Cs (valence shell of n = 6) is in group 1A. atoms get smaller as you go across a period. Cs is below and to the left of Si and Sn, therefore Cs is larger than both Si and Sn.
smallest Si < Sn < Cs largest

5.18 Iodine has the largest atomic radius of the three halogens. C–I would be the longest bond length.

5.19 (a) 5% (b) 20%

5.20 (b) kinetic energy of high speed electrons

5.21 (a) The fluorescent bulb does not emit all the wavelengths of light that would be emitted from a white light source. Notice that there are dark regions between the colored peaks.
(b) Fluorescent light does appear as "white light" because its line spectrum has contributions from all the colors (blue, green, yellow, orange, and red).

5.22 (a) [Xe] $6s^2 4f^{14} 5d^{10}$
(b) [Xe] $\underline{\uparrow\downarrow}$ (6s) $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ (4f) $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ (5d)
(c) There are no unpaired electrons.

5.23 (a) [Xe] $6s^1 4f^{14} 5d^{10} 6p^1$
(b) [Xe] $\underline{\uparrow}$ (6s) $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ (4f) $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ $\underline{\uparrow\downarrow}$ (5d) $\underline{\uparrow}$ $\underline{\ \ }$ $\underline{\ \ }$ (6p)
(c) There are 2 unpaired electrons.

5.24 (a) 7d, n = 7, l = 2, m_l = –2, –1, 0, 1, 2
(b) 6p, n = 6, l = 1, m_l = –1, 0, 1
(c) $$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ J\cdot s)\left(\frac{3.00 \times 10^8\ m/s}{434.7 \times 10^{-9}\ m}\right)(6.022 \times 10^{23}\ /mol)$$
$E = 2.75 \times 10^5$ J/mol = 275 kJ/mol

5.25 The shortest wavelength corresponds to the highest energy, therefore, 126.8 nm corresponds to 8p → 6s; 140.2 nm corresponds to 7p → 6s; and 185.0 nm corresponds to 6p → 6s.

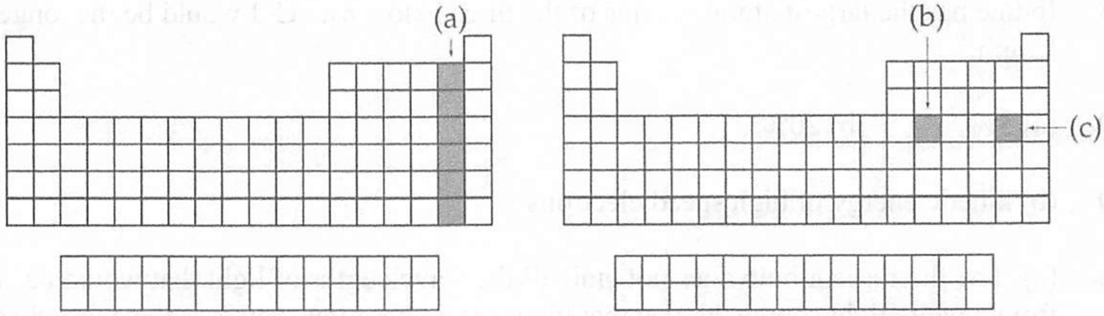
Conceptual Problems

5.26 The wave with the larger amplitude (a) has the greater intensity. The wave with the shorter wavelength (a) has the higher energy radiation. The wave with the shorter wavelength (a) represents yellow light. The wave with the longer wavelength (b) represents infrared radiation.

5.27 (a) Transitions (a) and (b) are absorptions. (a) is of lower energy and longer wavelength.
(b) Transitions (c) and (d) are emissions. (d) is of higher energy and shorter wavelength.

5.28 (a) $3p_y$ $n = 3, l = 1$ (b) $4d_{z^2}$ $n = 4, l = 2$

5.29



5.30 The green element, molybdenum, has an anomalous electron configuration. Its predicted electron configuration is [Ar] $5s^2\ 4d^4$. Its anomalous electron configuration is [Ar] $5s^1\ 4d^5$ because of the resulting half-filled d-orbitals.

5.31 [Ar] $4s^2\ 3d^{10}\ 4p^1$ is Ga.

5.32 There are 34 total electrons in the atom, so there are also 34 protons in the nucleus. The atom is selenium (Se)
Se, [Ar] ↿⇂ (4s) ↿⇂ ↿⇂ ↿⇂ ↿⇂ ↿⇂ (3d) ↿⇂ ↑ ↑ (4p)

5.33 Ca and Br are in the same period, with Br to the far right of Ca. Ca is larger than Br. Sr is directly below Ca in the same group, and is larger than Ca. The result is
Sr (215 pm) > Ca (197 pm) > Br (114 pm)

Section Problems
Wave Properties of Radiant Energy (Section 5.1)

5.34 Violet has the higher frequency and energy. Red has the higher wavelength.

5.35 Ultraviolet light has the higher frequency and the greater energy. Infrared light has the longer wavelength.

5.36 1.15×10^{-7} m = 115×10^{-9} m = 115 nm = UV
2.0×10^{-6} m = 2000×10^{-9} m = 2000 nm = IR
The visible region is (380 to 780 nm) is completely within this range. The ultraviolet and infrared regions are partially in this range.

5.37 290 MHz = 290×10^{6} Hz = 2.9×10^{8} Hz = radio waves
90 GHz = 90×10^{9} Hz = 9.0×10^{10} Hz = microwaves
Radio waves and microwaves are in this region.

5.38 $\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^{8}\text{ m/s}}{5.5 \times 10^{15}\text{ s}^{-1}} = 5.5 \times 10^{-8}\text{ m}$

5.39 $\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^{8}\text{ m/s}}{4.33 \times 10^{-3}\text{ m}} = 6.93 \times 10^{10}\text{ s}^{-1} = 6.93 \times 10^{10}\text{ Hz}$

5.40 (a) $\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^{8}\text{ m/s}}{825 \times 10^{6}\text{ s}^{-1}} \times \frac{1\text{ cm}}{1 \times 10^{-2}\text{ m}} = 36.4\text{ cm}$

(b) $\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^{8}\text{ m/s}}{875 \times 10^{6}\text{ s}^{-1}} \times \frac{1\text{ cm}}{1 \times 10^{-2}\text{ m}} = 34.3\text{ cm}$

5.41 (a) $\nu = \frac{c}{\lambda} = \frac{3.00 \times 10^{8}\text{ m/s}}{1300 \times 10^{-9}\text{ m}} = 2.3 \times 10^{14}\text{ s}^{-1}$

(b) $\text{time} = \frac{\text{distance}}{\text{speed}} = \frac{12 \times 10^{3}\text{ m}}{3.00 \times 10^{8}\text{ m/s}} = 4.0 \times 10^{-5}\text{ s}$

Particlelike Properties of Radiant Energy (Section 5.2)

5.42 (a) $\nu = 99.5\text{ MHz} = 99.5 \times 10^{6}\text{ s}^{-1}$
$E = h\nu = (6.626 \times 10^{-34}\text{ J·s})(99.5 \times 10^{6}\text{ s}^{-1})(6.022 \times 10^{23}\text{ /mol})$
$E = 3.97 \times 10^{-2}\text{ J/mol} = 3.97 \times 10^{-5}\text{ kJ/mol}$
$\nu = 1150\text{ kHz} = 1150 \times 10^{3}\text{ s}^{-1}$
$E = h\nu = (6.626 \times 10^{-34}\text{ J·s})(1150 \times 10^{3}\text{ s}^{-1})(6.022 \times 10^{23}\text{ /mol})$
$E = 4.589 \times 10^{-4}\text{ J/mol} = 4.589 \times 10^{-7}\text{ kJ/mol}$
The FM radio wave (99.5 MHz) has the higher energy.
(b) $\lambda = 3.44 \times 10^{-9}$ m

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\text{ J·s})\left(\frac{3.00 \times 10^{8}\text{ m/s}}{3.44 \times 10^{-9}\text{ m}}\right)(6.022 \times 10^{23}/\text{mol})$$

$E = 3.48 \times 10^{7}\text{ J/mol} = 3.48 \times 10^{4}\text{ kJ/mol}$
$\lambda = 6.71 \times 10^{-2}$ m

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\text{ J·s})\left(\frac{3.00 \times 10^{8}\text{ m/s}}{6.71 \times 10^{-2}\text{ m}}\right)(6.022 \times 10^{23}/\text{mol})$$

$E = 1.78\ \text{J/mol} = 1.78 \times 10^{-3}\ \text{kJ/mol}$
The X ray ($\lambda = 3.44 \times 10^{-9}$ m) has the higher energy.

5.43 $\nu = 400\ \text{MHz} = 400 \times 10^{6}\ \text{s}^{-1}$
$E = (6.626 \times 10^{-34}\ \text{J·s})(400 \times 10^{6}\ \text{s}^{-1})(6.02 \times 10^{23}/\text{mol}) = 0.160\ \text{J/mol} = 1.60 \times 10^{-4}\ \text{kJ/mol}$

5.44 (a) $E = 90.5\ \text{kJ/mol} \times \dfrac{1000\ \text{J}}{1\ \text{kJ}} \times \dfrac{1\ \text{mol}}{6.02 \times 10^{23}} = 1.50 \times 10^{-19}\ \text{J}$

$\nu = \dfrac{E}{h} = \dfrac{1.50 \times 10^{-19}\ \text{J}}{6.626 \times 10^{-34}\ \text{J·s}} = 2.27 \times 10^{14}\ \text{s}^{-1}$

$\lambda = \dfrac{c}{\nu} = \dfrac{3.00 \times 10^{8}\ \text{m/s}}{2.27 \times 10^{14}\ \text{s}^{-1}} = 1.32 \times 10^{-6}\ \text{m} = 1320 \times 10^{-9}\ \text{m} = 1320\ \text{nm}$, near IR

(b) $E = 8.05 \times 10^{-4}\ \text{kJ/mol} \times \dfrac{1000\ \text{J}}{1\ \text{kJ}} \times \dfrac{1\ \text{mol}}{6.02 \times 10^{23}} = 1.34 \times 10^{-24}\ \text{J}$

$\nu = \dfrac{E}{h} = \dfrac{1.34 \times 10^{-24}\ \text{J}}{6.626 \times 10^{-34}\ \text{J·s}} = 2.02 \times 10^{9}\ \text{s}^{-1}$

$\lambda = \dfrac{c}{\nu} = \dfrac{3.00 \times 10^{8}\ \text{m/s}}{2.02 \times 10^{9}\ \text{s}^{-1}} = 0.149\ \text{m}$, radio wave

(c) $E = 1.83 \times 10^{3}\ \text{kJ/mol} \times \dfrac{1000\ \text{J}}{1\ \text{kJ}} \times \dfrac{1\ \text{mol}}{6.02 \times 10^{23}} = 3.04 \times 10^{-18}\ \text{J}$

$\nu = \dfrac{E}{h} = \dfrac{3.04 \times 10^{-18}\ \text{J}}{6.626 \times 10^{-34}\ \text{J·s}} = 4.59 \times 10^{15}\ \text{s}^{-1}$

$\lambda = \dfrac{c}{\nu} = \dfrac{3.00 \times 10^{8}\ \text{m/s}}{4.59 \times 10^{15}\ \text{s}^{-1}} = 6.54 \times 10^{-8}\ \text{m} = 65.4 \times 10^{-9}\ \text{m} = 65.4\ \text{nm}$, UV

5.45 (a) $E = h\nu = (6.626 \times 10^{-34}\ \text{J·s})(5.97 \times 10^{19}\ \text{s}^{-1})\left(\dfrac{1\ \text{kJ}}{1000\ \text{J}}\right)(6.022 \times 10^{23}/\text{mol})$

$E = 2.38 \times 10^{7}\ \text{kJ/mol}$

(b) $E = h\nu = (6.626 \times 10^{-34}\ \text{J·s})(1.26 \times 10^{6}\ \text{s}^{-1})\left(\dfrac{1\ \text{kJ}}{1000\ \text{J}}\right)(6.022 \times 10^{23}/\text{mol})$

$E = 5.03 \times 10^{-7}\ \text{kJ/mol}$

(c) $E = h\nu = (6.626 \times 10^{-34}\ \text{J·s})\left(\dfrac{3.00 \times 10^{8}\ \text{m/s}}{2.57 \times 10^{2}\ \text{m}}\right)\left(\dfrac{1\ \text{kJ}}{1000\ \text{J}}\right)(6.022 \times 10^{23}/\text{mol})$

$E = 4.66 \times 10^{-7}\ \text{kJ/mol}$

5.46 (a) $\lambda = \dfrac{c}{\nu} = \dfrac{3.00 \times 10^{8}\ \text{m/s}}{2.9 \times 10^{18}\ \text{s}^{-1}} = 1.0 \times 10^{-10}\ \text{m}$

(b) $E = h\nu = (6.626 \times 10^{-34}\ J \cdot s)(2.9 \times 10^{18}\ s^{-1})\left(\dfrac{1\ kJ}{1000\ J}\right)(6.022 \times 10^{23}/mol)$

$E = 1.2 \times 10^{6}$ kJ/mol

(c) X rays

5.47 (a) $\nu = \dfrac{c}{\lambda} = \dfrac{3.00 \times 10^{8}\ m/s}{450 \times 10^{-9}\ m} = 6.67 \times 10^{14}\ s^{-1}$

(b) $E = h\nu = (6.626 \times 10^{-34}\ J \cdot s)(6.67 \times 10^{14}\ s^{-1})\left(\dfrac{1\ kJ}{1000\ J}\right)(6.022 \times 10^{23}/mol)$

$E = 266$ kJ/mol

(c) Blue

5.48 $\nu = 9{,}192{,}631{,}770\ s^{-1} = 9.19263 \times 10^{9}\ s^{-1}$

$E = h\nu = (6.626 \times 10^{-34}\ J{\cdot}s)(9.19263 \times 10^{9}\ s^{-1})\left(\dfrac{1\ kJ}{1000\ J}\right)(6.022 \times 10^{23}/mol) = 3.668 \times 10^{-3}\ kJ/mol$

5.49 $E = \left(310\ \dfrac{kJ}{mol}\right)\left(\dfrac{1000\ J}{1\ kJ}\right)\left(\dfrac{1\ mol}{6.022 \times 10^{23}}\right) = 5.15 \times 10^{-19}\ J$

$E = \dfrac{hc}{\lambda},\quad \lambda = \dfrac{hc}{E} = \dfrac{(6.626 \times 10^{-34}\ J \cdot s)(3.00 \times 10^{8}\ m/s)}{5.15 \times 10^{-19}\ J} = 3.86 \times 10^{-7}\ m = 386\ nm$

5.50 (a) $\lambda = \dfrac{c}{\nu} = \dfrac{3.00 \times 10^{8}\ m/s}{3.85 \times 10^{14}\ s^{-1}} = 7.79 \times 10^{-7}\ m = 779 \times 10^{-9}\ m = 779\ nm$

$E = h\nu = (6.626 \times 10^{-34}\ J \cdot s)(3.85 \times 10^{14}\ s^{-1}) = 2.55 \times 10^{-19}\ J$

(b) $\lambda = \dfrac{c}{\nu} = \dfrac{3.00 \times 10^{8}\ m/s}{4.62 \times 10^{14}\ s^{-1}} = 6.49 \times 10^{-7}\ m = 649 \times 10^{-9}\ m = 649\ nm$

$E = h\nu = (6.626 \times 10^{-34}\ J \cdot s)(4.62 \times 10^{14}\ s^{-1}) = 3.06 \times 10^{-19}\ J$

(c) $\lambda = \dfrac{c}{\nu} = \dfrac{3.00 \times 10^{8}\ m/s}{7.41 \times 10^{14}\ s^{-1}} = 4.05 \times 10^{-7}\ m = 405 \times 10^{-9}\ m = 405\ nm$

$E = h\nu = (6.626 \times 10^{-34}\ J \cdot s)(7.41 \times 10^{14}\ s^{-1}) = 4.91 \times 10^{-19}\ J$

5.51 (a) $\lambda = \dfrac{c}{\nu} = \dfrac{3.00 \times 10^{8}\ m/s}{4.35 \times 10^{14}\ s^{-1}} = 6.90 \times 10^{-7}\ m = 690 \times 10^{-9}\ m = 690\ nm$, yes.

(b) $E = 43\ kJ/mol \times \dfrac{1000\ J}{1\ kJ} \times \dfrac{1\ mol}{6.02 \times 10^{23}} = 7.1 \times 10^{-20}\ J$

$\nu = \dfrac{E}{h} = \dfrac{7.1 \times 10^{-20}\ J}{6.626 \times 10^{-34}\ J{\cdot}s} = 1.1 \times 10^{14}\ s^{-1}$

$\lambda = \dfrac{c}{\nu} = \dfrac{3.00 \times 10^{8}\ m/s}{1.1 \times 10^{14}\ s^{-1}} = 2.8 \times 10^{-6}\ m = 2800 \times 10^{-9}\ m = 2800\ nm$, no.

(c) $\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^{8}\ \text{m/s}}{706 \times 10^{12}\ \text{s}^{-1}} = 4.25 \times 10^{-7}\ \text{m} = 425 \times 10^{-9}\ \text{m} = 425\ \text{nm}$, yes.

5.52 Both (c) & (d) are below the threshold energy and no electrons would be ejected. (b) would eject the least number of electrons.

5.53 (a) is above the threshold energy and has a high amplitude. It will cause the largest number of electrons to be ejected.

5.54 $E = (436\ \text{kJ/mol})\left(\frac{1000\ \text{J}}{1\ \text{kJ}}\right)\left(\frac{1\ \text{mol}}{6.022 \times 10^{23}\ \text{photon}}\right) = 7.24 \times 10^{-19}\ \text{J/photon}$

$\nu = \frac{E}{h} = \frac{7.24 \times 10^{-19}\ \text{J}}{6.626 \times 10^{-34}\ \text{J·s}} = 1.09 \times 10^{15}\ \text{s}^{-1} = 1.09 \times 10^{15}\ \text{Hz}$

5.55 $206.5\ \text{kJ} = 206.5 \times 10^{3}\ \text{J}$; $E = \frac{206.5 \times 10^{3}\ \text{J}}{1\ \text{mol}} \times \frac{1\ \text{mol}}{6.022 \times 10^{23}} = 3.429 \times 10^{-19}\ \text{J}$

$E = \frac{hc}{\lambda}$, $\lambda = \frac{hc}{E} = \frac{(6.626 \times 10^{-34}\ \text{J·s})(3.00 \times 10^{8}\ \text{m/s})}{3.429 \times 10^{-19}\ \text{J}} = 5.797 \times 10^{-7}\ \text{m} = 580.\ \text{nm}$

Atomic Line Spectra and Quantized Energy (Section 5.3)

5.56 The deuterium lamp produces a continuous emission spectrum.

5.57 The sodium-vapor lamp produces a line emission spectrum.

5.58 For n = 3; $\lambda = 656.3\ \text{nm} = 656.3 \times 10^{-9}\ \text{m}$

$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ \text{J·s})\left(\frac{2.998 \times 10^{8}\ \text{m/s}}{656.3 \times 10^{-9}\ \text{m}}\right)\left(\frac{1\ \text{kJ}}{1000\ \text{J}}\right)(6.022 \times 10^{23}/\text{mol})$

$E = 182.3\ \text{kJ/mol}$

For n = 4; $\lambda = 486.1\ \text{nm} = 486.1 \times 10^{-9}\ \text{m}$

$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ \text{J·s})\left(\frac{2.998 \times 10^{8}\ \text{m/s}}{486.1 \times 10^{-9}\ \text{m}}\right)\left(\frac{1\ \text{kJ}}{1000\ \text{J}}\right)(6.022 \times 10^{23}/\text{mol})$

$E = 246.1\ \text{kJ/mol}$

For n = 5; $\lambda = 434.0\ \text{nm} = 434.0 \times 10^{-9}\ \text{m}$

$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ \text{J·s})\left(\frac{2.998 \times 10^{8}\ \text{m/s}}{434.0 \times 10^{-9}\ \text{m}}\right)\left(\frac{1\ \text{kJ}}{1000\ \text{J}}\right)(6.022 \times 10^{23}/\text{mol})$

$E = 275.6\ \text{kJ/mol}$

5.59 486.1 nm = 486.1 x 10^{-9} m

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ J\cdot s)\left(\frac{2.998 \times 10^{8}\ m/s}{486.1 \times 10^{-9}\ m}\right)\left(\frac{1\ kJ}{1000\ J}\right)(6.022 \times 10^{23}/mol)$$

E = 246.1 kJ/mol

5.60 m = 1, n = ∞; R_∞ = 1.097 x 10^{-2} nm^{-1}

$$\frac{1}{\lambda} = R_\infty\left[\frac{1}{m^2} - \frac{1}{n^2}\right];\ \frac{1}{\lambda} = R_\infty\left[\frac{1}{1^2} - \frac{1}{\infty^2}\right] = R_\infty = 1.097 \times 10^{-2}\ nm^{-1};\ \lambda = 91.16\ nm$$

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ J\cdot s)\left(\frac{2.998 \times 10^{8}\ m/s}{91.16 \times 10^{-9}\ m}\right)\left(\frac{1\ kJ}{1000\ J}\right)(6.022 \times 10^{23}/mol)$$

E = 1312 kJ/mol

5.61 m = 2, n = ∞; R_∞ = 1.097 x 10^{-2} nm^{-1}

$$\frac{1}{\lambda} = R_\infty\left[\frac{1}{m^2} - \frac{1}{n^2}\right];\ \frac{1}{\lambda} = R_\infty\left[\frac{1}{2^2} - \frac{1}{\infty^2}\right] = \frac{R_\infty}{4} = 2.743 \times 10^{-3}\ nm^{-1};\ \lambda = 364.6\ nm$$

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ J\cdot s)\left(\frac{2.998 \times 10^{8}\ m/s}{364.6 \times 10^{-9}\ m}\right)\left(\frac{1\ kJ}{1000\ J}\right)(6.022 \times 10^{23}/mol)$$

E = 328.1 kJ/mol

5.62 m = 4, n = 5; R_∞ = 1.097 x 10^{-2} nm^{-1}

$$\frac{1}{\lambda} = R_\infty\left[\frac{1}{m^2} - \frac{1}{n^2}\right];\ \frac{1}{\lambda} = R_\infty\left[\frac{1}{4^2} - \frac{1}{5^2}\right] = 2.468 \times 10^{-4}\ nm^{-1};\ \lambda = 4051\ nm$$

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ J\cdot s)\left(\frac{2.998 \times 10^{8}\ m/s}{4051 \times 10^{-9}\ m}\right)\left(\frac{1\ kJ}{1000\ J}\right)(6.022 \times 10^{23}/mol)$$

E = 29.55 kJ/mol, IR

m = 4, n = 6; R_∞ = 1.097 x 10^{-2} nm^{-1}

$$\frac{1}{\lambda} = R_\infty\left[\frac{1}{m^2} - \frac{1}{n^2}\right];\ \frac{1}{\lambda} = R_\infty\left[\frac{1}{4^2} - \frac{1}{6^2}\right] = 3.809 \times 10^{-4}\ nm^{-1};\ \lambda = 2625\ nm$$

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ J\cdot s)\left(\frac{2.998 \times 10^{8}\ m/s}{2625 \times 10^{-9}\ m}\right)\left(\frac{1\ kJ}{1000\ J}\right)(6.022 \times 10^{23}/mol)$$

E = 45.60 kJ/mol, IR

5.63 m = 3, n = 4; R_∞ = 1.097 x 10^{-2} nm^{-1}

$$\frac{1}{\lambda} = R_\infty\left[\frac{1}{m^2} - \frac{1}{n^2}\right];\ \frac{1}{\lambda} = R_\infty\left[\frac{1}{3^2} - \frac{1}{4^2}\right] = 5.333 \times 10^{-4}\ nm^{-1};\ \lambda = 1875\ nm$$

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ J\cdot s)\left(\frac{2.998 \times 10^8\ m/s}{1875 \times 10^{-9}\ m}\right)\left(\frac{1\ kJ}{1000\ J}\right)(6.022 \times 10^{23}/mol)$$

$E = 63.80\ kJ/mol$, IR

$m = 3, n = 5;\ R_\infty = 1.097 \times 10^{-2}\ nm^{-1}$

$$\frac{1}{\lambda} = R_\infty\left[\frac{1}{m^2} - \frac{1}{n^2}\right];\ \frac{1}{\lambda} = R_\infty\left[\frac{1}{3^2} - \frac{1}{5^2}\right] = 7.801 \times 10^{-4}\ nm^{-1};\ \lambda = 1282\ nm$$

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ J\cdot s)\left(\frac{2.998 \times 10^8\ m/s}{1282 \times 10^{-9}\ m}\right)\left(\frac{1\ kJ}{1000\ J}\right)(6.022 \times 10^{23}/mol)$$

$E = 93.00\ kJ/mol$, IR

5.64 $m = 2;\ R_\infty = 1.097 \times 10^{-2}\ nm^{-1}$

$$\frac{1}{\lambda} = R_\infty\left[\frac{1}{m^2} - \frac{1}{n^2}\right];\ \frac{1}{\lambda} = R_\infty\left[\frac{1}{2^2} - \frac{1}{6^2}\right] = 2.438 \times 10^{-3}\ nm^{-1}$$

$\lambda = 410.2\ nm = 410.2 \times 10^{-9}\ m$

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ J\cdot s)\left(\frac{2.998 \times 10^8\ m/s}{410.2 \times 10^{-9}\ m}\right)\left(\frac{1\ kJ}{1000\ J}\right)(6.022 \times 10^{23}/mol)$$

$E = 291.6\ kJ/mol$

5.65 $m = 5;\ R_\infty = 1.097 \times 10^{-2}\ nm^{-1}$

$$\frac{1}{\lambda} = R_\infty\left[\frac{1}{m^2} - \frac{1}{n^2}\right]$$

$$n = 6,\ \frac{1}{\lambda} = R_\infty\left[\frac{1}{5^2} - \frac{1}{6^2}\right] = 1.341 \times 10^{-4}\ nm^{-1};\ \lambda = 7458\ nm = 7458 \times 10^{-9}\ m$$

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ J\cdot s)\left(\frac{2.998 \times 10^8\ m/s}{7458 \times 10^{-9}\ m}\right)\left(\frac{1\ kJ}{1000\ J}\right)(6.022 \times 10^{23}/mol)$$

$E = 16.04\ kJ/mol$

$$n = 7,\ \frac{1}{\lambda} = R_\infty\left[\frac{1}{5^2} - \frac{1}{7^2}\right] = 2.149 \times 10^{-4}\ nm^{-1};\ \lambda = 4653\ nm = 4653 \times 10^{-9}\ m$$

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ J\cdot s)\left(\frac{2.998 \times 10^8\ m/s}{4653 \times 10^{-9}\ m}\right)\left(\frac{1\ kJ}{1000\ J}\right)(6.022 \times 10^{23}/mol)$$

$E = 25.71\ kJ/mol$

The lines in this series are in the infrared region of the electromagnetic spectrum.

Wavelike Properties of Particles (Section 5.4)

5.66 $$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}\ kg\ m^2\ s^{-1}}{(9.11 \times 10^{-31}\ kg)(0.99 \times 3.00 \times 10^8\ m/s)} = 2.45 \times 10^{-12}\ m,\ \gamma\ ray$$

5.67 $\lambda = \dfrac{h}{mv} = \dfrac{6.626 \times 10^{-34}\ \text{kg m}^2\ \text{s}^{-1}}{(1.673 \times 10^{-27}\ \text{kg})(0.25 \times 3.00 \times 10^{8}\ \text{m/s})} = 5.28 \times 10^{-15}\ \text{m}, \gamma\ \text{ray}$

5.68 156 km/h = 156×10^3 m/3600 s = 43.3 m/s; 145 g = 0.145 kg

$$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}\ \text{kg m}^2\ \text{s}^{-1}}{(0.145\ \text{kg})(43.3\ \text{m/s})} = 1.06 \times 10^{-34}\ \text{m}$$

The wavelength is too small, compared to the object, to observe.

5.69 1.55 mg = 1.55×10^{-3} g = 1.55×10^{-6} kg

$$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34}\ \text{kg m}^2\ \text{s}^{-1}}{(1.55 \times 10^{-6}\ \text{kg})(1.38\ \text{m/s})} = 3.10 \times 10^{-28}\ \text{m}$$

The wavelength is too small, compared to the object, to observe.

5.70 145 g = 0.145 kg; 0.500 nm = 0.500×10^{-9} m

$$v = \frac{h}{m\lambda} = \frac{6.626 \times 10^{-34}\ \text{kg m}^2\ \text{s}^{-1}}{(0.145\ \text{kg})(0.500 \times 10^{-9}\ \text{m})} = 9.14 \times 10^{-24}\ \text{m/s}$$

5.71 750 nm = 750×10^{-9} m

$$v = \frac{h}{m\lambda} = \frac{6.626 \times 10^{-34}\ \text{kg m}^2\ \text{s}^{-1}}{(9.11 \times 10^{-31}\ \text{kg})(750 \times 10^{-9}\ \text{m})} = 970\ \text{m/s}$$

Orbitals and Quantum Mechanics (Sections 5.5–5.8)

5.72 0.68 g = 0.68×10^{-3} kg

$$(\Delta x)(\Delta mv) \ge \frac{h}{4\pi};\quad \Delta x \ge \frac{h}{4\pi(\Delta mv)} = \frac{6.626 \times 10^{-34}\ \text{kg m}^2\ \text{s}^{-1}}{4\pi(0.68 \times 10^{-3}\ \text{kg})(0.1\ \text{m/s})} = 8 \times 10^{-31}\ \text{m}$$

5.73 $4.0026\ \text{amu} \times \dfrac{1.660\,540 \times 10^{-27}\ \text{kg}}{1\ \text{amu}} = 6.6465 \times 10^{-27}\ \text{kg};\quad (\Delta x)(\Delta mv) \ge \dfrac{h}{4\pi}$

$$\Delta x \ge \frac{h}{4\pi(\Delta mv)} = \frac{6.626 \times 10^{-34}\ \text{kg m}^2\ \text{s}^{-1}}{4\pi(6.6465 \times 10^{-27}\ \text{kg})(0.01 \times 1.36 \times 10^{3}\ \text{m/s})} = 5.833 \times 10^{-10}\ \text{m}$$

5.74 The Heisenberg uncertainty principle states that one can never know both the position and the velocity of an electron beyond a certain level of precision. This means we cannot think of electrons circling the nucleus in specific orbital paths, but we can think of electrons as being found in certain three-dimensional regions of space around the nucleus, called orbitals.

5.75 The probability of finding the electron drops off rapidly as distance from the nucleus increases, although it never drops to zero, even at large distances. As a result, there is no definite boundary or size for an orbital. However, we usually imagine the boundary surface of an orbital enclosing the volume where an electron spends 90% of its time.

5.76 n is the principal quantum number. The size and energy level of an orbital depends on n. l is the angular-momentum quantum number. l defines the three-dimensional shape of an orbital. m_l is the magnetic quantum number. m_l defines the spatial orientation of an orbital. m_s is the spin quantum number. m_s indicates the spin of the electron and can have either of two values, $+\frac{1}{2}$ or $-\frac{1}{2}$.

5.77 (a) is not allowed because for $l = 0$, $m_l = 0$ only.
(b) is allowed.
(c) is not allowed because for n = 4, $l = 0, 1, 2$, or 3 only.

5.78 (a) 4s $n = 4; l = 0; m_l = 0; m_s = \pm\frac{1}{2}$
(b) 3p $n = 3; l = 1; m_l = -1, 0, +1; m_s = \pm\frac{1}{2}$
(c) 5f $n = 5; l = 3; m_l = -3, -2, -1, 0, +1, +2, +3; m_s = \pm\frac{1}{2}$
(d) 5d $n = 5; l = 2; m_l = -2, -1, 0, +1, +2; m_s = \pm\frac{1}{2}$

5.79 (a) 3s (b) 2p (c) 4f (d) 4d

5.80 Co $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,4s^2\,3d^7$
(a) is not allowed because for $l = 0$, $m_l = 0$ only.
(b) is not allowed because n = 4 and $l = 2$ is for a 4d orbital.
(c) is allowed because n = 3 and $l = 1$ is for a 3p orbital.

5.81 Se $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,4s^2\,3d^{10}\,4p^4$
(a) is not allowed because for n = 3, $l = 0$, 1 or 2.
(b) is not allowed because n = 4 and $l = 2$ is for a 4d orbital.
(c) is allowed because n = 4 and $l = 1$ is for a 4p orbital.

5.82 For n = 5, the maximum number of electrons will occur when the 5g orbital is filled:
[Rn] $7s^2\,5f^{14}\,6d^{10}\,7p^6\,8s^2\,5g^{18}$ = 138 electrons

5.83 n = 4, $l = 0$ is a 4s orbital. The electron configuration is $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,4s^2$. The number of electrons is 20.

5.84 $\lambda = 330\text{ nm} = 330 \times 10^{-9}\text{ m}$

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\text{ J·s})\left(\frac{3.00 \times 10^8\text{ m/s}}{330 \times 10^{-9}\text{ m}}\right)\left(\frac{1\text{ kJ}}{1000\text{ J}}\right)(6.022 \times 10^{23}/\text{mol})$$

$E = 363\text{ kJ/mol}$

5.85 $795\text{ nm} = 795 \times 10^{-9}\text{ m}$

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\text{ J·s})\left(\frac{3.00 \times 10^8\text{ m/s}}{795 \times 10^{-9}\text{ m}}\right)\left(\frac{1\text{ kJ}}{1000\text{ J}}\right)(6.022 \times 10^{23}/\text{mol})$$

$E = 151\text{ kJ/mol}$

5.86 C $1s^2 2s^2 2p^2$

n	l	m_l	m_s
1	0	0	+½
1	0	0	–½
2	0	0	+½
2	0	0	–½
2	1	–1	+½
2	1	0	+½

5.87 O $1s^2 2s^2 2p^4$

n	l	m_l	m_s
1	0	0	+½
1	0	0	–½
2	0	0	+½
2	0	0	–½
2	1	–1	+½
2	1	0	+½
2	1	+1	+½
2	1	–1	–½

5.88 Sr [Kr] $5s^2$

n	l	m_l	m_s
5	0	0	+½
5	0	0	–½

5.89 Mo [Kr] $5s^2 4d^4$
(c) are valid quantum numbers for a 4d electron.

5.90 A 4s orbital has three nodal surfaces.

4s orbital

nodes are white

regions of maximum electron probability are black

5.91 The number of nodal planes in a subshell equals the value of the l quantum number.

5.92 The different colors in the two lobes of the p orbitals indicate different phases. The different phases play a role in bonding.

5.93 The orbital is a d orbital with l =2.

Orbital Energy Levels in Multielectron Atoms (Section 5.9)

5.94 Part of the electron-nucleus attraction is canceled by the electron-electron repulsion, an effect we describe by saying that the electrons are shielded from the nucleus by the other electrons. The net nuclear charge actually felt by an electron is called the effective nuclear charge, Z_{eff}, and is often substantially lower than the actual nuclear charge, Z_{actual}.

$$Z_{eff} = Z_{actual} - \text{electron shielding}$$

5.95 Electron shielding gives rise to energy differences among 3s, 3p, and 3d orbitals in multielectron atoms because of the differences in orbital shape. For example, the 3s orbital is spherical and has a large probability density near the nucleus, while the 3p orbital is dumbbell shaped with a node at the nucleus. An electron in a 3s orbital can penetrate closer to the nucleus than an electron in a 3p orbital can and feels less of a shielding effect from other electrons. Generally, for any given value of the principal quantum number n, a lower value of *l* corresponds to a higher value of Z_{eff} and to a lower energy for the orbital.

5.96 4s > 4d > 4f

5.97 K < Ca < Se < Kr

5.98 The number of elements in successive periods of the periodic table increases by the progression 2, 8, 18, 32 because the principal quantum number n increases by 1 from one period to the next. As the principal quantum number increases, the number of orbitals in a shell increases. The progression of elements parallels the number of electrons in a particular shell.

5.99 The n and *l* quantum numbers determine the energy level of an orbital in a multielectron atom.

5.100 (a) 5d (b) 4s (c) 6s

5.101 (a) 2p < 3p < 5s < 4d (b) 2s < 4s < 3d < 4p (c) 3d < 4p < 5p < 6s

5.102 (a) 3d after 4s (b) 4p after 3d (c) 6d after 5f (d) 6s after 5p

5.103 (a) 3s before 3p (b) 3d before 4p (c) 6s before 4f (d) 4f before 5d

Electron Configurations (Sections 5.10 –5.12)

5.104 (a) Ti, Z = 22 $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^2$
(b) Ru, Z = 44 $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^6$
(c) Sn, Z = 50 $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^2$
(d) Sr, Z = 38 $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2$
(e) Se, Z = 34 $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^4$

5.105 (a) Z = 55, Cs [Xe] $6s^1$ (b) Z = 40, Zr [Kr] $5s^2\,4d^2$
(c) Z = 80, Hg [Xe] $6s^2\,4f^{14}\,5d^{10}$ (d) Z = 62, Sm [Xe] $6s^2\,4f^6$

5.106 (a) Rb, Z = 37 [Kr] ↑ (5s)
(b) W, Z = 74 [Xe] ↑↓ (6s) ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ (4f) ↑ ↑ ↑ ↑ _ (5d)
(c) Ge, Z = 32 [Ar] ↑↓ (4s) ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ (3d) ↑ ↑ _ (4p)
(d) Zr, Z = 40 [Kr] ↑↓ (5s) ↑ ↑ _ _ _ (4d)

5.107 (a) Z = 25, Mn [Ar] ↑↓ (4s) ↑ ↑ ↑ ↑ ↑ (3d)
(b) Z = 56, Ba [Xe] ↑↓ (6s)
(c) Z = 28, Ni [Ar] ↑↓ (4s) ↑↓ ↑↓ ↑↓ ↑ ↑ (3d)
(d) Z = 47, Ag [Kr] ↑ (5s) ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ (4d)

5.108 (a) O $1s^2 2s^2 2p^4$ ↑↓ ↑ ↑ (2p) 2 unpaired e^-
(b) Si $1s^2 2s^2 2p^6 3s^2 3p^2$ ↑ ↑ _ (3p) 2 unpaired e^-
(c) K [Ar] $4s^1$ 1 unpaired e^-
(d) As [Ar] $4s^2 3d^{10} 4p^3$ ↑ ↑ ↑ (4p) 3 unpaired e^-

5.109 (a) Z = 31, Ga (b) Z = 46, Pd

5.110 (a) Ra [Rn] $7s^2$ [Rn] ↑↓ (7s)
(b) Sc [Ar] $4s^2 3d^1$ [Ar] ↑↓ (4s) ↑ _ _ _ _ (3d)
(c) Lr [Rn] $7s^2 5f^{14} 6d^1$ [Rn] ↑↓ (7s) ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ (5f) ↑ _ _ _ _ (6d)
(d) B [He] $2s^2 2p^1$ [He] ↑↓ (2s) ↑ _ _ (2p)
(e) Te [Kr] $5s^2 4d^{10} 5p^4$ [Kr] ↑↓ (5s) ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ (4d) ↑↓ ↑ ↑ (5p)

5.111 (a) 3d, n = 3, l = 2
(b) 2p, n = 2, l = 1, m_l = −1, 0, +1
3p, n = 3, l = 1, m_l = −1, 0, +1
3d, n = 3, l = 2, m_l = −2, −1, 0, +1, +2

(c) N, $1s^2 2s^2 2p^3$ so the 3s, 3p, and 3d orbitals are empty.
(d) C, $1s^2 2s^2 2p^2$ so the 1s and 2s orbitals are filled.
(e) Be, $1s^2 2s^2$ so the 2s orbital contains the outermost electrons.
(f) 2p and 3p (↑ ↑ __) and 3d (↑ ↑ __ __ __).

5.112 Order of orbital filling:
$1s \rightarrow 2s \rightarrow 2p \rightarrow 3s \rightarrow 3p \rightarrow 4s \rightarrow 3d \rightarrow 4p \rightarrow 5s \rightarrow 4d \rightarrow 5p \rightarrow 6s \rightarrow 4f \rightarrow 5d \rightarrow 6p \rightarrow 7s \rightarrow 5f \rightarrow 6d \rightarrow 7p \rightarrow 8s \rightarrow 5g$
Z = 121

5.113 A g orbital would begin filling at atomic number = 121 (see 5.82). There are nine g orbitals that can each hold two electrons. The first element to have a filled g orbital would be atomic number = 138.

5.114 Na^+ $1s^2 2s^2 2p^6$

5.115 Cl^- $1s^2 2s^2 2p^6 3s^2 3p^6$

5.116 Z = 116 [Rn] $7s^2 5f^{14} 6d^{10} 7p^4$

5.117 Z = 119 [Rn] $7s^2 5f^{14} 6d^{10} 7p^6 8s^1$

Electron Configurations and Periodic Properties (Section 5.13)

5.118 Atomic radii increase down a group because the electron shells are farther away from the nucleus.

5.119 Across a period, the effective nuclear charge increases, causing a decrease in atomic radii.

5.120 F < O < S

5.121 Cl < As < K < Rb

5.122 (a) K, lower in group 1A
(b) Ta, lower in group 5B
(c) V, farther to the left in same period
(d) Ba, four periods lower and only one group to the right

5.123 (a) Ge, lower in group 4A
(b) Pt, lower in group 8B
(c) Sn, farther to the left in same period
(d) Rb, lower in group 1A

Multiconcept Problems

5.124 m = 2; n = 3; R = 1.097 x 10^{-2} nm^{-1}

$$\frac{1}{\lambda} = Z^2R\left[\frac{1}{m^2} - \frac{1}{n^2}\right]; \quad \frac{1}{\lambda} = (2^2)R\left[\frac{1}{2^2} - \frac{1}{3^2}\right] = 6.094 \times 10^{-3}\ nm^{-1}$$

λ = 164 nm

5.125 m = 1; n = 4; R = 1.097 x 10^{-2} nm^{-1}

$$\frac{1}{\lambda} = Z^2R\left[\frac{1}{m^2} - \frac{1}{n^2}\right]; \quad \frac{1}{\lambda} = (3^2)R\left[\frac{1}{1^2} - \frac{1}{4^2}\right] = 9.256 \times 10^{-2}\ nm^{-1}$$

λ = 10.8 nm

5.126 (a)

row 1	n = 1,	l = 0	1s	2 elements
		l = 1	1p	6 elements
		l = 2	1d	10 elements
row 2	n = 2,	l = 0	2s	2 elements
		l = 1	2p	6 elements
		l = 2	2d	10 elements
		l = 3	2f	14 elements

There would be 50 elements in the first two rows.

(b) There would be 18 elements in the first row [see (a) above]. The fifth element in the second row would have atomic number = 23.

(c) Z = 12   1s: ↑↓   1p: ↑↓ ↑↓ ↑↓   1d: ↑ ↑ ↑ ↑ _

5.127 (a) Sr, Z = 38   [Kr]   5s: ↑↓

(b) Cd, Z = 48   [Kr]   5s: ↑↓   4d: ↑↓ ↑↓ ↑↓ ↑↓ ↑↓

(c) Z = 22, Ti   [Ar]   4s: ↑↓   3d: ↑ ↑ _ _ _

(d) Z = 34, Se   [Ar]   4s: ↑↓   3d: ↑↓ ↑↓ ↑↓ ↑↓ ↑↓   4p: ↑↓ ↑ ↑

5.128 La ([Xe] $6s^2$ $5d^1$) is directly below Y ([Kr] $5s^2$ $4d^1$) in the periodic table. Both have similar valence electron configurations, but for La the valence electrons are one shell farther out leading to its larger radius.

Although Hf ([Xe] $6s^2$ $4f^{14}$ $5d^2$) is directly below Zr ([Kr] $5s^2$ $4d^2$) in the periodic table, Zr and Hf have almost identical atomic radii because the 4f electrons in Hf are not effective in shielding the valence electrons. The valence electrons in Hf are drawn in closer to the nucleus by the higher Z_{eff}.

5.129 For K, $Z_{eff} = \sqrt{\dfrac{(418.8 \text{ kJ/mol})(4^2)}{1312 \text{ kJ/mol}}} = 2.26$

For Kr, $Z_{eff} = \sqrt{\dfrac{(1350.7 \text{ kJ/mol})(4^2)}{1312 \text{ kJ/mol}}} = 4.06$

5.130 75 W = 75 J/s; 550 nm = 550 x 10^{-9} m; (0.05)(75 J/s) = 3.75 J/s

$$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34} \text{ J}\cdot\text{s})\left(\frac{3.00 \times 10^8 \text{ m/s}}{550 \times 10^{-9} \text{ m}}\right) = 3.61 \times 10^{-19} \text{ J/photon}$$

$$\text{number of photons} = \frac{3.75 \text{ J/s}}{3.61 \times 10^{-19} \text{ J/photon}} = 1.0 \times 10^{19} \text{ photons/s}$$

5.131 q = (350 g)(4.184 J/g·°C)(95 °C – 20 °C) = 109,830 J
λ = 15.0 cm = 15.0 x 10^{-2} m

$$E = (6.626 \times 10^{-34} \text{ J}\cdot\text{s})\left(\frac{3.00 \times 10^8 \text{ m/s}}{15.0 \times 10^{-2} \text{ m}}\right) = 1.33 \times 10^{-24} \text{ J/photon}$$

$$\text{number of photons} = \frac{109{,}830 \text{ J}}{1.33 \times 10^{-24} \text{ J/photon}} = 8.3 \times 10^{28} \text{ photons}$$

5.132 48.2 nm = 48.2 x 10^{-9} m

$$E(\text{photon}) = 6.626 \times 10^{-34} \text{ J}\cdot\text{s} \times \frac{3.00 \times 10^8 \text{ m/s}}{48.2 \times 10^{-9} \text{ m}} \times \frac{1 \text{ kJ}}{1000 \text{ J}} \times \frac{6.022 \times 10^{23}}{\text{mol}} = 2.48 \times 10^3 \text{ kJ/mol}$$

$$E_K = E(\text{electron}) = \tfrac{1}{2}(9.109 \times 10^{-31} \text{ kg})(2.371 \times 10^6 \text{ m/s})^2\left(\frac{1 \text{ kJ}}{1000 \text{ J}}\right)\left(\frac{6.022 \times 10^{23}}{\text{mol}}\right)$$

$$E_K = 1.54 \times 10^3 \text{ kJ/mol}$$

$E(\text{photon}) = E_i + E_K$; $E_i = E(\text{photon}) - E_K = (2.48 \times 10^3) - (1.54 \times 10^3) = 940$ kJ/mol

5.133 Charge on electron = 1.602 x 10^{-19} C; 1 V·C = 1 J = 1 kg m^2/s^2
(a) E_K = (30,000 V)(1.602 x 10^{-19} C) = 4.806 x 10^{-15} J

$$E_K = \tfrac{1}{2}mv^2; \quad v = \sqrt{\frac{2E_K}{m}} = \sqrt{\frac{2 \times 4.806 \times 10^{-15} \text{ kg m}^2/\text{s}^2}{9.109 \times 10^{-31} \text{ kg}}} = 1.03 \times 10^8 \text{ m/s}$$

$$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34} \text{ kg m}^2/\text{s}}{(9.109 \times 10^{-31} \text{ kg})(1.03 \times 10^8 \text{ m/s})} = 7.06 \times 10^{-12} \text{ m}$$

(b) $$E = \frac{hc}{\lambda} = (6.626 \times 10^{-34} \text{ J}\cdot\text{s})\left(\frac{3.00 \times 10^8 \text{ m/s}}{1.54 \times 10^{-10} \text{ m}}\right) = 1.29 \times 10^{-15} \text{ J/photon}$$

5.134 Substitute the equation for the orbit radius, r, into the equation for the energy level, E, to get $E = \frac{-Ze^2}{2\left(\frac{n^2 a_o}{Z}\right)} = \frac{-Z^2e^2}{2a_o n^2}$

Let E_1 be the energy of an electron in a lower orbit and E_2 the energy of an electron in a higher orbit. The difference between the two energy levels is

$$\Delta E = E_2 - E_1 = \frac{-Z^2e^2}{2a_o n_2^2} - \frac{-Z^2e^2}{2a_o n_1^2} = \frac{-Z^2e^2}{2a_o n_2^2} + \frac{Z^2e^2}{2a_o n_1^2} = \frac{Z^2e^2}{2a_o n_1^2} - \frac{Z^2e^2}{2a_o n_2^2}$$

$$\Delta E = \frac{Z^2e^2}{2a_o}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

Because Z, e, and a_o are constants, this equation shows that ΔE is proportional to $\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ where n_1 and n_2 are integers with $n_2 > n_1$.

This is similar to the Balmer-Rydberg equation where $1/\lambda$ or ν for the emission spectra of atoms is proportional to $\left[\frac{1}{m^2} - \frac{1}{n^2}\right]$ where m and n are integers with $n > m$.

5.135 (a) $\frac{\uparrow 0 \downarrow}{1s}$ $\frac{\uparrow 0 \downarrow}{2s}$ $\frac{\uparrow 0 \downarrow \;\; \uparrow 0 \downarrow \;\; \uparrow 0 \downarrow}{2p}$ $\frac{\uparrow 0 \downarrow}{3s}$ $\frac{\uparrow 0 \downarrow \;\; \uparrow 0 \;\; \uparrow 0}{3p}$ $\frac{\quad}{4s}$

Two partially filled orbitals.

(b) The element in the 3rd column and 4th row under these new rules would have an atomic number of 30 and be in the s-block.

5.136 (a) $E = h\nu$; $\nu = \frac{E}{h} = \frac{7.21 \times 10^{-19}\ J}{6.626 \times 10^{-34}\ J \cdot s} = 1.09 \times 10^{15}\ s^{-1}$

(b) $E(\text{photon}) = E_i + E_K$; from (a), $E_i = 7.21 \times 10^{-19}\ J$

$$E(\text{photon}) = \frac{hc}{\lambda} = (6.626 \times 10^{-34}\ J \cdot s)\left(\frac{3.00 \times 10^8\ m/s}{2.50 \times 10^{-7}\ m}\right) = 7.95 \times 10^{-19}\ J$$

$E_K = E(\text{photon}) - E_i = (7.95 \times 10^{-19}\ J) - (7.21 \times 10^{-19}\ J) = 7.4 \times 10^{-20}\ J$

Calculate the electron velocity from the kinetic energy, E_K.

$E_K = 7.4 \times 10^{-20}\ J = 7.4 \times 10^{-20}\ kg \cdot m^2/s^2 = \frac{1}{2}mv^2 = \frac{1}{2}(9.109 \times 10^{-31}\ kg)v^2$

$$v = \sqrt{\frac{2 \times (7.4 \times 10^{-20}\ kg \cdot m^2/s^2)}{9.109 \times 10^{-31}\ kg}} = 4.0 \times 10^5\ m/s$$

$$\text{de Broglie wavelength} = \frac{h}{mv} = \frac{6.626 \times 10^{-34}\ kg \cdot m^2/s}{(9.109 \times 10^{-31}\ kg)(4.0 \times 10^5\ m/s)} = 1.8 \times 10^{-9}\ m = 1.8\ nm$$

5.137 (a) $E = h\nu$; $\nu = \frac{E}{h} = \frac{4.70 \times 10^{-16}\ J}{6.626 \times 10^{-34}\ J \cdot s} = 7.09 \times 10^{17}\ s^{-1}$

(b) $\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^{8}\ m/s}{7.09 \times 10^{17}\ s^{-1}} = 4.23 \times 10^{-10}\ m = 0.423 \times 10^{-9}\ m = 0.423\ nm$

(c) $\lambda = \frac{h}{mv}$; $v = \frac{h}{m\lambda} = \frac{6.626 \times 10^{-34}\ kg \cdot m^2/s}{(9.11 \times 10^{-31}\ kg)(4.23 \times 10^{-10}\ m)} = 1.72 \times 10^{6}\ m/s$

(d) $E_K = \frac{mv^2}{2} = \frac{(9.11 \times 10^{-31}\ kg)(1.72 \times 10^{6}\ m/s)^2}{2} = 1.35 \times 10^{-18}\ kg \cdot m^2/s^2 = 1.35 \times 10^{-18}\ J$

5.138 (a) 5f subshell: $n = 5, l = 3, m_l = -3, -2, -1, 0, +1, +2, +3$
3d subshell: $n = 3, l = 2, m_l = -2, -1, 0, +1, +2$

(b) In the H atom the subshells in a particular energy level are all degenerate, i.e., all have the same energy. Therefore, you only need to consider the principal quantum number, n, to calculate the wavelength emitted for an electron that drops from the 5f to the 3d subshell.

$m = 3, n = 5$; $R_\infty = 1.097 \times 10^{-2}\ nm^{-1}$

$\frac{1}{\lambda} = R_\infty \left[\frac{1}{m^2} - \frac{1}{n^2}\right]$; $\frac{1}{\lambda} = R_\infty \left[\frac{1}{3^2} - \frac{1}{5^2}\right]$; $\frac{1}{\lambda} = 7.801 \times 10^{-4}\ nm^{-1}$; $\lambda = 1282\ nm$

(c) $m = 3, n = \infty$; $R_\infty = 1.097 \times 10^{-2}\ nm^{-1}$

$\frac{1}{\lambda} = R_\infty \left[\frac{1}{m^2} - \frac{1}{n^2}\right]$; $\frac{1}{\lambda} = R_\infty \left[\frac{1}{3^2} - \frac{1}{\infty^2}\right]$; $\frac{1}{\lambda} = R_\infty \left[\frac{1}{3^2}\right] = 1.219 \times 10^{-3}\ nm^{-1}$; $\lambda = 820.4\ nm$

$E = (6.626 \times 10^{-34}\ J \cdot s)\left(\frac{3.00 \times 10^{8}\ m/s}{820.4 \times 10^{-9}\ m}\right)(6.022 \times 10^{23}/mol) = 1.46 \times 10^{5}\ J/mol = 146\ kJ/mol$

5.139 (a) [Kr] $5s^2\ 4d^{10}\ 5p^6$ (b) [Kr] $5s^2\ 4d^{10}\ 5p^5\ 6s^1$

(c) Both Xe^* and Cs have a single electron in the 6s orbital with similar effective nuclear charges. Therefore the 6s electrons in both cases are held with similar strengths and require almost the same energy to remove.