CHAPTER 7 QUANTUM THEORY AND ATOMIC STRUCTURE

The value for the speed of light will be 3.00×10^8 m/s except when more significant figures are necessary, in which cases, 2.9979×10^8 m/s will be used.

7.1 All types of electromagnetic radiation travel as waves at the same speed. They differ in both their frequency and wavelength.

7.2 a) Figure 7.3 describes the electromagnetic spectrum by wavelength and frequency. Wavelength increases from left (10^{-2} nm) to right (10^{12} nm). The trend in increasing wavelength is: **x-ray < ultraviolet < visible < infrared < microwave < radio waves**.
b) Frequency is inversely proportional to wavelength according to the equation $c = \lambda\upsilon$, so frequency has the opposite trend: **radio < microwave < infrared < visible < ultraviolet < x-ray**.
c) Energy is directly proportional to frequency according to the equation $E = h\upsilon$. Therefore, the trend in increasing energy matches the trend in increasing frequency: **radio < microwave < infrared < visible < ultraviolet < x-ray**. High-energy electromagnetic radiation disrupts cell function. It makes sense that you want to limit exposure to ultraviolet and x-ray radiation.

7.3 a) Refraction is the bending of light waves at the boundary of two media, as when light travels from air into water.
b) Diffraction is the bending of light waves around an object, as when a wave passes through a slit about as wide as its wavelength.
c) Dispersion is the separation of light into its component colors (wavelengths), as when light passes through a prism.
d) Interference is the bending of light through a series of parallel slits to produce a diffraction pattern of brighter and darker spots.
Note: Refraction leads to a dispersion effect and diffraction leads to an interference effect.

7.4 Evidence for the wave model is seen in the phenomena of diffraction and refraction. Evidence for the particle model includes the photoelectric effect and blackbody radiation.

7.5 a) Frequency: **A** > **B** > **C**
b) Energy: **A** > **B** > **C**
c) Amplitude: **A** > **C** > **B**
d) Since wave A has a higher energy and frequency than B, wave **A** is more likely to cause a current.
e) Wave **B** is more likely to be infrared radiation since Wave C has a longer wavelength than B.

7.6 Radiation (light energy) occurs as quanta of electromagnetic radiation, where each packet of energy is called a photon. The energy associated with this photon is fixed by its frequency, $E = h\nu$. Since energy depends on frequency, a threshold (minimum) frequency is to be expected. A current will flow as soon as a photon of sufficient energy reaches the metal plate, so there is no time lag.

7.7 Plan: Wavelength is related to frequency through the equation $c = \lambda\nu$. Recall that a Hz is a reciprocal second, or $1/\text{s} = \text{s}^{-1}$. Assume that the number "950" has three significant figures.
Solution:
$c = \lambda\nu$

$$\lambda(\text{m}) = \frac{c}{\nu} = \frac{3.00 \times 10^8\ \text{m/s}}{(950.\text{kHz})\left(\frac{10^3\ \text{Hz}}{1\ \text{kHz}}\right)\left(\frac{\text{s}^{-1}}{\text{Hz}}\right)} = 315.8 = \mathbf{316\ m}$$

$$\lambda\ (\text{nm}) = \frac{c}{\nu} = \frac{3.00 \text{ x } 10^{8}\ \text{m/s}}{(950.\ \text{kHz})\left(\frac{10^{3}\ \text{Hz}}{1\,\text{k Hz}}\right)\left(\frac{\text{s}^{-1}}{\text{Hz}}\right)}\left(\frac{1\ \text{nm}}{10^{-9}\ \text{m}}\right) = 3.158 \text{ x } 10^{11} = \mathbf{3.16 \text{ x } 10^{11}\ nm}$$

$$\lambda\ (\text{Å}) = \frac{c}{\nu} = \frac{3.00 \text{ x } 10^{8}\ \text{m/s}}{(950.\ \text{kHz})\left(\frac{10^{3}\ \text{Hz}}{1\ \text{kHz}}\right)\left(\frac{\text{s}^{-1}}{\text{Hz}}\right)}\left(\frac{1\ \text{Å}}{10^{-10}\ \text{m}}\right) = 3.158 \text{ x } 10^{12} = \mathbf{3.16 \text{ x } 10^{12}\ Å}$$

7.8 Wavelength and frequency relate through the equation c = λν. Recall that a Hz is a reciprocal second, or 1/s = s^{-1}.

$$\lambda(\text{m}) = \frac{c}{\nu} = \frac{3.00 \text{ x } 10^{8}\ \text{m/s}}{(93.5\ \text{MHz})\left(\frac{10^{6}\ \text{Hz}}{1\ \text{MHz}}\right)\left(\frac{\text{s}^{-1}}{\text{Hz}}\right)} = 3.208556 = \mathbf{3.21\ m}$$

$$\lambda\ (\text{nm}) = \frac{c}{\nu} = \frac{3.00 \text{ x } 10^{8}\ \text{m/s}}{(93.5\ \text{MHz})\left(\frac{10^{6}\ \text{Hz}}{1\ \text{MHz}}\right)\left(\frac{\text{s}^{-1}}{\text{Hz}}\right)}\left(\frac{1\ \text{nm}}{10^{-9}\,\text{m}}\right) = 3.208556 \text{ x } 10^{9} = \mathbf{3.21 \text{ x } 10^{9}\ nm}$$

$$\lambda\ (\text{Å}) = \frac{c}{\nu} = \frac{3.00 \text{ x} 10^{8}\,\text{m/s}}{(93.5\ \text{MHz})\left(\frac{10^{6}\ \text{Hz}}{1\ \text{MHz}}\right)\left(\frac{\text{s}^{-1}}{\text{Hz}}\right)}\left(\frac{1\ \text{Å}}{10^{-10}\ \text{m}}\right) = 3.208556 \text{ x } 10^{10} = \mathbf{3.21 \text{ x } 10^{10}\ Å}$$

7.9 Plan: Frequency is related to energy through the equation E = hν. Note that 1 Hz = 1 s^{-1}.
Solution:
E = hν
$E = (6.626 \text{ x } 10^{-34}\ \text{J•s})\ (3.8 \text{ x } 10^{10}\ \text{s}^{-1}) = 2.51788 \text{ x } 10^{-23} = \mathbf{2.5 \text{ x } 10^{-23}\ J}$

7.10 $$E = \frac{hc}{\lambda} = \frac{(6.626 \text{ x } 10^{-34}\ \text{J} \bullet \text{s})(3.00 \text{ x } 10^{8}\ \text{m/s})}{1.3\ \text{Å}}\left(\frac{1\ \text{Å}}{10^{-10}\ \text{m}}\right) = 1.529 \text{ x } 10^{-15} = \mathbf{1.5 \text{ x } 10^{-15}\ J}$$

7.11 Since energy is directly proportional to frequency (E = hν) and frequency and wavelength are inversely related (ν = c/λ), it follows that energy is inversely related to wavelength ($E = \frac{hc}{\lambda}$). As wavelength decreases, energy increases. In terms of increasing energy the order is **red < yellow < blue**.

7.12 Since energy is directly proportional to frequency (E = hν): UV (ν = 8.0 x 10^{15} s^{-1}) > IR (ν = 6.5 x 10^{13} s^{-1}) > microwave (ν = 9.8 x 10^{11} s^{-1}) or **UV > IR > microwave**.

7.13 Plan: Frequency and wavelength can be calculated using the speed of light: c = λν.
Solution:

$$\lambda\ (\text{nm}) = c/\nu = \frac{2.9979 \text{ x } 10^{8}\ \text{m/s}}{(22.235\ \text{GHz})\left(\frac{10^{9}\ \text{Hz}}{1\ \text{GHz}}\right)\left(\frac{\text{s}^{-1}}{\text{Hz}}\right)}\left(\frac{1\ \text{nm}}{10^{-9}\ \text{m}}\right) = 1.3482797 \text{ x } 10^{7} = \mathbf{1.3483 \text{ x } 10^{7}\ nm}$$

$$\lambda\ (\text{Å}) = c/\nu = \frac{2.9979 \text{ x } 10^{8}\ \text{m/s}}{(22.235\ \text{GHz})\left(\frac{10^{9}\ \text{Hz}}{1\ \text{GHz}}\right)\left(\frac{\text{s}^{-1}}{\text{Hz}}\right)}\left(\frac{1\ \text{Å}}{10^{-10}\ \text{m}}\right) = 1.34827973 \text{ x } 10^{8} = \mathbf{1.3483 \text{ x } 10^{8}\ Å}$$

7.14 Frequency and wavelength can be calculated using the speed of light: $c = \lambda\nu$.

a) $$\nu = c/\lambda = \frac{3.00 \text{ x } 10^8 \text{ m/s}}{9.6\ \mu\text{m}}\left(\frac{1\ \mu\text{m}}{10^{-6}\text{ m}}\right) = 3.125 \text{ x } 10^{13} = \mathbf{3.1 \textbf{ x } 10^{13}\ s^{-1}}$$

b) $$\lambda(\mu\text{m}) = c/\nu = \frac{2.9979 \text{ x } 10^8 \text{ m/s}}{\left(8.652 \text{ x } 10^{13}\text{ Hz}\right)\left(\frac{\text{s}^{-1}}{\text{Hz}}\right)}\left(\frac{1\ \mu\text{m}}{10^{-6}\text{ m}}\right) = 3.464979 = \mathbf{3.465\ \mu m}$$

7.15 Frequency and energy are related by $E = h\nu$, and wavelength and energy are related by $E = hc/\lambda$.

$$\nu(\text{Hz}) = \frac{E}{h} = \frac{\left(1.33\text{ MeV}\right)\left(\frac{10^6\text{ eV}}{1\text{ MeV}}\right)\left(\frac{1.602 \text{ x } 10^{-19}\text{ J}}{1\text{ eV}}\right)}{6.626 \text{ x } 10^{-34}\text{ J} \bullet \text{s}}\left(\frac{\text{Hz}}{\text{s}^{-1}}\right) = 3.2156 \text{ x } 10^{20} = \mathbf{3.22 \textbf{ x } 10^{20}\ Hz}$$

$$\lambda\text{ (m)} = \frac{hc}{E} = \frac{\left(6.626 \text{ x } 10^{-34}\text{ J} \bullet \text{s}\right)\left(3.00 \text{ x } 10^8\text{ m/s}\right)}{\left(1.33\text{ MeV}\right)\left(\frac{10^6\text{ eV}}{1\text{ MeV}}\right)\left(\frac{1.602 \text{ x } 10^{-19}\text{ J}}{1\text{ eV}}\right)} = 9.32950 \text{ x } 10^{-13} = \mathbf{9.33 \textbf{ x } 10^{-13}\ m}$$

The wavelength can also be found using the frequency calculated in the equation $c = \lambda\nu$.

7.16 Plan: a) The least energetic photon has the longest wavelength (242 nm). b) The most energetic photon has the shortest wavelength (2200 Å).

Solution:

a) $$\nu = \frac{c}{\lambda} = \frac{3.00 \text{ x } 10^8\text{ m/s}}{242\text{ nm}}\left(\frac{1\text{ nm}}{10^{-9}\text{ m}}\right) = 1.239669 \text{ x } 10^{15} = \mathbf{1.24 \textbf{ x } 10^{15}\ s^{-1}}$$

$$E = \frac{hc}{\lambda} = \frac{\left(6.626 \text{ x } 10^{-34}\text{ J} \bullet \text{s}\right)\left(3.00 \text{ x } 10^8\text{ m/s}\right)}{242\text{ nm}}\left(\frac{1\text{ nm}}{10^{-9}\text{ m}}\right) = 8.2140 \text{ x } 10^{-19} = \mathbf{8.21 \textbf{ x } 10^{-19}\ J}$$

b) $$\nu = \frac{c}{\lambda} = \frac{3.00 \text{ x } 10^8\text{ m/s}}{2200\text{ Å}}\left(\frac{1\text{ Å}}{10^{-10}\text{ m}}\right) = 1.3636 \text{ x } 10^{15} = \mathbf{1.4 \textbf{ x } 10^{15}\ s^{-1}}$$

$$E = \frac{hc}{\lambda} = \frac{\left(6.626 \text{ x } 10^{-34}\text{ J} \bullet \text{s}\right)\left(3.00 \text{ x } 10^8\text{ m/s}\right)}{2200\text{ Å}}\left(\frac{1\text{ Å}}{10^{-10}\text{ m}}\right) = 9.03545 \text{ x } 10^{-19} = \mathbf{9.0 \textbf{ x } 10^{-19}\ J}$$

7.17 "*n*" in the Rydberg equation is equal to a Bohr orbit of quantum number "*n*" where $n = 1, 2, 3, ...\infty$.

7.18 Bohr's key assumption was that the electron in an atom does not radiate energy while in a stationary state, and the electron can move to a different orbit by absorbing or emitting a photon whose energy is equal to the difference in energy between two states. These differences in energy correspond to the wavelengths in the known spectra for the hydrogen atoms. A solar system model does not allow for the movement of electrons between levels.

7.19 An absorption spectrum is produced when atoms absorb certain wavelengths of incoming light as electrons move from lower to higher energy levels and results in dark lines against a bright background. An emission spectrum is produced when atoms that have been excited to higher energy emit photons as their electrons return to lower energy levels and results in colored lines against a dark background. Bohr worked with emission spectra.

7.20 Plan: The quantum number *n* is related to the energy level of the electron. An electron *absorbs* energy to change from lower energy (lower *n*) to higher energy (higher *n*), giving an absorption spectrum. An electron *emits* energy as it drops from a higher energy level (higher *n*) to a lower one (lower *n*), giving an emission spectrum.

Solution:

a) **absorption** b) **emission** c) **emission** d) **absorption**