1. Multiple Choice

1. Which graph best describes the radial wavefunction of a 2s orbital?

   (A) \( \psi \)  \( \psi \)  
   (B)  
   (C)  
   (D)  

2. The energy required to break one mole of hydrogen-hydrogen bonds in \( \text{H}_2 \) is 436 kJ. What is the longest wavelength of light with sufficient energy to break a single hydrogen-hydrogen bond?

   (A) 122 nm  (B) 132 nm  
   (C) 274 nm  (D) 656 nm

\[
\frac{436 \text{ kJ}}{\text{mol}} \times 1000 \text{ J} = \frac{436 \times 10^3 \text{ J}}{\text{mol}} \times \frac{1 \text{ mol}}{1 \text{ kJ}} = \frac{436 \times 10^3 \text{ J}}{1 \text{ kJ}} \times \frac{1 \text{ mol}}{1} \times \frac{1 \text{ kJ}}{1000 \text{ J}} \times \frac{1 \text{ mol}}{1 \text{ kJ}} 
\]

\[
E = \frac{hc}{\lambda} \quad \lambda = \frac{hc}{E} = \frac{(6.626 \times 10^{-34} \text{ J} \cdot \text{s})(3.00 \times 10^8 \text{ m/s})}{7.24 \times 10^{-19} \text{ J/bond}} 
\]

\[
\lambda = 2.75 \times 10^{-7} \text{ m} = 275 \text{ nm} 
\]

3. The shape of an atomic orbital is associated with
   A. the principal quantum number \( (n) \).
   B. the angular momentum quantum number \( (l) \).
   C. the magnetic quantum number \( (m) \).
   D. the spin quantum number \( (m_s) \).
   E. the magnetic and spin quantum numbers, together.

4. The Schrödinger wave equation
   A. calculates the position and momentum of an electron at any given time.
   B. is used to determine the wavelength of small particles.
   C. proves that electrons have both positive and negative spins.
   D. inaccurately predicts circular orbits of electrons around nuclei.
   E. can be solved to find the probability of finding an electron in a region of space.
5. Which of the following statements is false?  
   A. The emission spectrum of an element is evidence of the quantized nature of the energy states in atoms. T
   B. Part of the Bohr model proposed that electrons in the hydrogen atom are located regions of probability around the nucleus. F
   C. The wave and particle nature of electrons are complementary properties. T
   D. For multi-electron atoms, the sublevels in each major energy level are not degenerate due to electron shielding. T
   E. More than one of the above is false.

6. Give the set of three quantum numbers that could represent the electron lost to form the Rb⁺ ION from the Rb atom.
   A. n = 5, l = 0, m_l = 1  
   B. n = 4, l = 1, m_l = 1  
   C. n = 5, l = 1, m_l = 0  
   D. n = 4, l = 1, m_l = 0  
   E. n = 5, l = 0, m_l = 0

II. Short Answer

1. Sunscreens generally advertise that they absorb ultraviolet radiation of two types: UVA and UVB. UVA has a wavelength range of 315–400 nm. UVB has a wavelength range of 280–315 nm. Calculate the following properties for the middle wavelength of UVA and of UVB light. Show your work for all parts for at least UVA to receive credit.
   A. The frequency
   B. The energy of one photon
   C. The energy of the light in kJ/mol (kJ per mol of photons)
   D. The number of photons required to supply 100.0 J of energy

<table>
<thead>
<tr>
<th>Type</th>
<th>A. Frequency</th>
<th>B. Energy/photon</th>
<th>C. Energy/mol</th>
<th>D. # photons</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVA 358 nm</td>
<td>$8.38 \times 10^{14}$ s⁻¹</td>
<td>$5.55 \times 10^{-19}$ J</td>
<td>$334 \text{ kJ/mol}$</td>
<td>$1.80 \times 10^{20}$ photons</td>
</tr>
<tr>
<td>UVB 298 nm</td>
<td>$1.01 \times 10^{15}$ s⁻¹</td>
<td>$6.69 \times 10^{-19}$ J</td>
<td>$403 \text{ kJ/mol}$</td>
<td>$1.49 \times 10^{20}$ photons</td>
</tr>
</tbody>
</table>

$\lambda = 358 \text{ nm}$  
$\nu = \frac{c}{\lambda} = \frac{3.00 \times 10^8 \text{ m/s}}{358 \times 10^{-9} \text{ m}} = 8.38 \times 10^{14} \text{ s}^{-1}$

$E = h \nu = (6.626 \times 10^{-34} \text{ J} \cdot \text{s})(8.38 \times 10^{14} \text{ s}^{-1}) = 5.55 \times 10^{-19} \text{ J}$

$\frac{5.55 \times 10^{-19} \text{ J}}{1 \text{ photon}} \div \frac{6.022 \times 10^{23} \text{ photons}}{1 \text{ mol photons}} = \frac{334 \text{ kJ/mol}}{1000 \text{ J}}$

$\frac{100.0 \text{ J}}{5.55 \times 10^{-19} \text{ J}} = 1.80 \times 10^{20} \text{ Photons}$

$\lambda = 298 \text{ nm}$
2. Calculate the wavelength of the light that is emitted or absorbed (and state which one it is) in the following electron transitions in the helium ion, He⁺. What type of electromagnetic radiation (UV, visible, etc.) is being emitted/absorbed for each?

A. from \( n = 11 \) to \( n = 12 \)

\[
E = -2.18 \times 10^{-18} \text{ J} \left(z^2\right) \left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) = -2.18 \times 10^{-18} \text{ J} \left(z^2\right) \left(\frac{1}{12^2} - \frac{1}{11^2}\right)
\]

\[
E = 1.15 \times 10^{-20} \text{ J} \quad \lambda = \frac{h \cdot c}{E} = \frac{(6.626 \times 10^{-34} \text{ J} \cdot \text{s})(2.998 \times 10^8 \text{ m/s})}{1.15 \times 10^{-20} \text{ J}} = 1.72 \times 10^5 \text{ m}
\]

infrared, absorbed

B. from \( n = \infty \) to \( n = 1 \)

\[
E = -2.18 \times 10^{-18} \text{ J} \left(z^2\right) \left(\frac{1}{n_i^2} - \frac{1}{\infty^2}\right) = -8.72 \times 10^{-18} \text{ J}
\]

\[
\lambda = \frac{(6.626 \times 10^{-34} \text{ J} \cdot \text{s})(2.998 \times 10^8 \text{ m/s})}{-8.72 \times 10^{-18} \text{ J}} = 2.28 \times 10^{-8} \text{ m} = 22 \text{ nm}
\]

ultraviolet or X-ray, emitted

3. What are all possible values of the quantum numbers \( n, l \) and \( m_l \) for an electron in each of the following sublevels?

A. 5s

\( n = 5 \) \( l = 0 \) \( m_l \) could be only 0

B. 3d

\( n = 3 \) \( l = 2 \) \( m_l \) could be -2, -1, 0, 1 or 2

C. 2p

\( n = 2 \) \( l = 1 \) \( m_l \) could be -1, 0, or 1

4. Draw a picture of the following orbitals:

A. 1s, 2s, and 3s on the same set of axes

B. 2s and 2p\( x \) on the same set of axes

C. 2p\( x \), 2p\( y \), and 2p\( z \) on the same set of axes
5. A. deBroglie equation (on conversion and equation sheet): What is the wavelength of an electron traveling at $5.31 \times 10^6$ m/s?

$$\lambda_{\text{matter}} = \frac{h}{mv} = \frac{6.626 \times 10^{-34} \text{J} \cdot \text{s}}{9.1 \times 10^{-31} \text{kg} \times (5.31 \times 10^6 \text{m/s})}$$

$$\lambda = 1.37 \times 10^{-10} \text{ m}$$

B. Heisenberg Uncertainty Principle problem (on conversion and equation sheet): For the electron in A, the uncertainty in its velocity is 10% of its velocity. Calculate the uncertainty in its position.

$$\Delta x \cdot \Delta v = \frac{\hbar}{4\pi}$$

$$\Delta v = 10\% \text{ of } 5.31 \times 10^6 \text{m/s} = 5.31 \times 10^5 \text{m/s}$$

$$\Delta x = \frac{\hbar}{4\pi \Delta v} = \frac{6.626 \times 10^{-34} \text{J} \cdot \text{s}}{4\pi (9.1 \times 10^{-31} \text{kg})(5.31 \times 10^5 \text{m/s})} = 1.09 \times 10^{-9} \text{ m}$$

6. Many microwaves ovens use “microwave” radiation with a frequency of 2450 Ghz to heat food. The microwave radiation is absorbed by water molecules in the food or beverage. Assuming the specific heat capacity of coffee is the same as that of water and assuming that a microwave oven is rated at 1000 J/second (1000 Watts),

A. What are the wavelength and the energy of the microwave radiation (per photon)?

$$C = \lambda \nu \quad \lambda = \frac{C}{\nu} = \frac{3.00 \times 10^8 \text{m/s}}{2450 \times 10^9 \text{s}^{-1}} = 1.22 \times 10^{-4} \text{ m}$$

$$E = h \nu = (6.626 \times 10^{-34} \text{J} \cdot \text{s})(2450 \times 10^9 \text{s}^{-1}) = 1.62 \times 10^{-21} \text{J/photons}$$

B. How long does it take to heat up 8 oz cup of coffee from 25°C to 75°C?

$$Q_{\text{water}} = m_w C_{s,w} \Delta T_w = (226.8 \text{g})(4.184 \text{J/g°C})(50°C)$$

$$\frac{8 \text{oz}}{1 \text{ pound}} \times \frac{453.6 \text{g}}{1 \text{ pound}} = 226.8 \text{g}$$

$$4.74 \times 10^4 \text{ J} \quad \frac{1 \text{ sec}}{1000 \text{ J}} = 47.4 \text{ s}$$

7. The radius of a 1s electron orbital is determined by the distance within which 90% of the electron density is found. Why is this?

This radius is roughly how large the 1s orbital acts.
For example, 1s is the only orbital for H. It acts filled about as big as the 90% probability sphere of
8. This question is about relationships between the 1s, 2s and 2p<sub>x</sub> orbitals.
   A. Draw the 1s, 2s and 2p<sub>x</sub> orbitals on the same set of axes. Clearly show their relative sizes.
   
   \[ 2p \text{ is } \approx 3\times \text{as long as } 2s \]

   B. The radial probability functions below are for the 1s, 2s and 2p<sub>x</sub> orbitals along the x-axis. Clearly label each line with the correct type of sublevel on the graph below.

   C. Use what you know about electron shielding, orbital shape, and effective nuclear charge to explain why, for a multi-electron atom, electrons in the 2s sublevel are lower energy than electrons in the 2p<sub>x</sub> sublevel.

   The inner lobe of the 2s orbital is closer to the nucleus than the majority of the 1s orbital. This inner lobe experiences a higher nuclear charge and less electron shielding than the rest of the 2p orbital, so

   The 2s and 2p<sub>x</sub> orbitals have the same average distance from the nucleus. With no other e\(^-\) present, the fact that an e\(^-\) in 2s and in 2p would be the same distance from the nucleus means the same energy.

   D. The 2s and 2p<sub>x</sub> sublevels have the same energy in one-electron atoms. Why?
9. The table below shows the wavelengths of lines from the emission spectrum of magnesium, along with the initial and final valence electron configuration for each transition. The ionization energy of a magnesium atom is 737.8 kJ/mol. Use this information to construct an energy level diagram which shows the energy levels of the 3s, 3p, 3d, and 4s orbitals, along with the level for the ionized state. Clearly show the energy value for each level in kJ/mol. Assume that the ionized state has energy = 0.

To do this, you will need to convert each of the given wavelengths into an energy in kJ/mol and then assign that energy to one of the transitions of interest.

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Initial Configuration</th>
<th>Final Configuration</th>
<th>E (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>285.2</td>
<td>3s(^1) 3p(^1)</td>
<td>3s(^2)</td>
<td>8.7x10(^{-19})</td>
</tr>
<tr>
<td>215.4</td>
<td>3s(^1) 3d(^1)</td>
<td>3s(^2)</td>
<td>9.2x10(^{-19})</td>
</tr>
<tr>
<td>462.1</td>
<td>3s(^1) 4s(^1)</td>
<td>3s(^1) 3p(^1)</td>
<td>4.3x10(^{-19})</td>
</tr>
</tbody>
</table>

10. In the experiment below, the electron shooter shoots **one electron at a time** through the double slits at the screen. Draw the pattern that the electrons make on the screen after a long period of time in which many electrons have been shot at the screen but the electrons have been shot at the screen **one at a time**.

![Diagram of electron experiment]

- electron shooter: shoots one electron at a time
- double slit
- screen

B. Explain how the pattern you drew in A is related to the nature of the electron.

The pattern is an interference pattern, w/ the probability of the e\(^-\) going through 1st slit interfering w/ the probability of the e\(^-\) going through the other slit. This means the e\(^-\) has wave-like properties.

C. How would the pattern change if helium atoms were shot one at a time at the screen instead of electrons?

He atoms are too big. They exhibit no discernible wave-like nature.