1. Which set of quantum numbers is not possible?
   (A) \( n = 2, l = 1, m_l = +1, m_s = -\frac{1}{2} \)
   (B) \( n = 3, l = 2, m_l = +1, m_s = +\frac{1}{2} \)
   (C) \( n = 4, l = 4, m_l = -1, m_s = +\frac{1}{2} \)
   (D) \( n = 5, l = 2, m_l = 2, m_s = -\frac{1}{2} \)

2. Which of the following sets of quantum numbers \( n, l, m_l, m_s \) correspond to a valence electron in a neutral atom of arsenic (As)?
   (A) 3, 0, 0, +1/2
   (B) 3, 2, 1, −1/2
   (C) 4, 0, 0, +1/2
   (D) 4, 2, 1, −1/2

3. What property of the oxygen atom is represented by the equation \( \text{O}(g) + e^- \rightarrow \text{O}^-(g) \)?
   (A) electronegativity
   (B) first electron affinity
   (C) first ionization energy
   (D) lattice energy

4. Which of the following isoelectronic species has the largest radius?
   (A) K\(^+\)
   (B) Ca\(^{2+}\)
   (C) P\(^3-\)
   (D) S\(^2-\)

5. Rank the elements Si, Ge, As in increasing order of their first ionization energies.
   (A) \( \text{Si} < \text{Ge} < \text{As} \)
   (B) \( \text{As} < \text{Ge} < \text{Si} \)
   (C) \( \text{Ge} < \text{As} < \text{Si} \)
   (D) \( \text{Ge} < \text{Si} < \text{As} \)

6. Which gas-phase atom or ion has the following ground state?
   \[ [\text{Ar}] \overset{3d}{\begin{array}{c} \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \end{array}} \]
   (A) Mn
   (B) Co
   (C) Fe\(^+\)
   (D) Ca\(^{2+}\)

7. Which halogen has the greatest first ionization energy?
   (A) F
   (B) Cl
   (C) Br
   (D) I

8. Which gas-phase atom has the largest radius?
   (A) Na
   (B) K
   (C) Mg
   (D) Ca

9. Atomic nitrogen has a higher ionization energy than atomic oxygen. This is best explained by
   (A) the lower electron-electron repulsion in nitrogen.
   (B) the greater effective nuclear charge of nitrogen.
   (C) the fact that the electron ionized in N is from the 2s subshell, while that ionized from O is from the 2p subshell.
   (D) the fact that N has an odd number of electrons while O has an even number.

10. The first four ionization energies of an element are approximately 738, 1450, 7.7 x 10\(^3\), and 7.2 x 10\(^4\) kJ/mol. To which periodic group does this element belong?
    |   |   |
    | A | 1 |
    | B | 2 |
    | C | 3 |
    | D | 16 |
    | E | 17 |

11. Place the following in order of increasing radius.
    \[ \text{Ca}^{2+} < \text{S}^{2-} < \text{Cl}^- \]
    (a) \( \text{Ca}^{2+} < \text{Cl}^- < \text{S}^{2-} \)
    (b) \( \text{Cl}^- < \text{Ca}^{2+} < \text{S}^{2-} \)
    (c) \( \text{S}^{2-} < \text{Cl}^- < \text{Ca}^{2+} \)
    (d) \( \text{Ca}^{2+} < \text{S}^{2-} < \text{Cl}^- \)
    (e) \( \text{Cl}^- < \text{S}^{2-} < \text{Ca}^{2+} \)
12. How many of the following species are diamagnetic?
   \[ \text{Cs, Zr}^{2+}, \text{Al}^{3+}, \text{Ar} \]
   - A. 1
   - B. 3
   - C. 0
   - D. 2
   - E. 4

13. Which ionization process requires the most energy?
   - A. \( W(g) \rightarrow W^+(g) + e^- \)
   - B. \( W^+(g) \rightarrow W^{2+}(g) + e^- \)
   - C. \( W^{2+}(g) \rightarrow W^{3+}(g) + e^- \)
   - D. \( W^{3+}(g) \rightarrow W^{4+}(g) + e^- \)
   - E. \( W^{4+}(g) \rightarrow W^{5+}(g) + e^- \)

14. An atom of element number 33 (As) is in its ground electronic state. Which one of the following sets of quantum numbers could not apply to any of its electrons?
   - A. \( n = 2 \), \( l = 1 \), \( m_l = -1 \), \( m_s = +1/2 \)
   - B. \( n = 3 \), \( l = 2 \), \( m_l = 0 \), \( m_s = +1/2 \)
   - C. \( n = 4 \), \( l = 0 \), \( m_l = 0 \), \( m_s = +1/2 \)
   - D. \( n = 4 \), \( l = 1 \), \( m_l = 1 \), \( m_s = +1/2 \)
   - E. \( n = 4 \), \( l = 1 \), \( m_l = 1 \), \( m_s = -1/2 \)

15. Consider the set of isoelectronic atoms and ions \( A^2-, B^+, C^+, D^+, \) and \( E^{2+} \). Which arrangement of relative radii is correct?
   - A. \( A^2- > B^+ > C > D^+ > E^{2+} \)
   - B. \( E^{2+} > D^+ > C > B > A^2- \)
   - C. \( A^2- > B^+ > C > D^+ > E^{2+} \)
   - D. \( A^2- < B^+ < C > D^+ > E^{2+} \)
   - E. None of these is correct.

16. Choose the statement that is TRUE.
   - A. Outer electrons efficiently shield one another from nuclear charge. F
   - B. Core electrons effectively shield outer electrons from nuclear charge. T
   - C. Valence electrons are most difficult of all electrons to remove. F
   - D. Core electrons are the easiest of all electrons to remove. F
   - E. All of the above are true.

II. Short Answer

1. Imagine an alternate universe in which space unicorns and neon pegasi (the plural form of pegasus) exist. In this world, the value of the angular momentum quantum number, \( l \), can have the values \( l = 1 \) to \( n \) (instead of \( l = 0 \) to \( n-1 \)). Assuming that all other quantum numbers can take only the possible values in our world and that all of the other rules of quantum mechanics apply (including the Pauli Exclusion Principle):
   - A. What is the electron configuration of cerium, \( \text{Ce} \) (element 58)?
     \[ \text{Ce}^{58+} : 1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 4f^{14} \]
     - 26e-

   - B. How many unpaired electrons are there in an atom of scandium, \( \text{Sc} \) (element 21)?
     \[ \text{Sc}^{21+} : 1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 \]
     - 5 unpaired e-
3. A. Write out the electron configurations of a potassium atom, a potassium ion, a titanium atom, and a doubly charged titanium ion.

\[
\text{K atom: } [\text{Ar}]4s^1 \quad \text{Ti atom: } [\text{Ar}]4s^23d^2 \text{ or } [\text{Ar}]3d^24s^2 \quad \text{K}^+ \text{ ion: } [\text{Ar}] \quad \text{Ti}^{2+} \text{ ion: } [\text{Ar}]3d^2
\]

B. Write a paragraph about the relationship between the 3d and 4s orbitals in terms of energy. When is 3d lower in energy? When is 4s lower in energy? Use the electron configurations in part A to justify your answer.

For K and Ca, there are electrons in the 4s sublevel but not in the 3d sublevel. So 4s must be lower in energy than 3d.

For Sc, Ti, etc., the 4s electron is "lost" or "removed" or "ionized" first - before the electron in 3d because 4s is higher in energy than 3d.

4. Predict the ground state electron configuration of an atom of:

A. Cesium

\[ [\text{Xe}]6s^1 \]

B. Selenium

\[ [\text{Ar}]4s^23d^{10}4p^4 \]

C. Nickel

\[ [\text{Ar}]4s^23d^8 \]

5. Using a noble gas core, predict the ground state electron configuration of an ion of

A. V³⁺

\[ [\text{Ar}]3d^2 \]

B. I⁻

\[ [\text{Xe}] \]

C. Cu⁺

\[ [\text{Ar}]3d^{10} \]

6. Write out the first and second ionization reactions for a chlorine atom.

\[
\text{Cl}(g) \rightarrow \text{Cl}^+(g) + 1e^- \\
\text{Cl}^+(g) \rightarrow \text{Cl}^{2+}(g) + 1e^-
\]

7. Write out the first and second electron affinity reactions for an argon atom.

\[
\text{Ar}(g) + 1e^- \rightarrow \text{Ar}^-(g) \\
\text{Ar}^-(g) + 1e^- \rightarrow \text{Ar}^{2-}(g)
\]
8. Sketch the periodic table and show the trends in atomic size, ionization energy, and electronegativity on it.

Following the arrows:
- Atomic size increases
- IE decreases
- EN decreases

9. Draw the orbital diagrams (hint: with a box for each orbital and an arrow for each electron) for the following two species that is consistent with your understanding of the relationship between the 3d/4s, 4d/5s, etc., energy levels:
   A. Cl atom: show all orbitals
   B. Ca ion: use noble gas core [Kr], show all other orbitals

10. Please answer both of these questions about trends in atomic size:
   A. What is the trend in atomic sizes for atoms as you go from top to bottom down the periodic table? Why? Please be specific—just like we were in class.

As you go down the same group in the periodic table, the sizes of atoms increases because the largest principal energy level, \( n \), increases.

B. What is the trend in atomic sizes for atoms as you go from left to right across the periodic table? Why? Please be specific—just like we were in class.

As you go from left to right across a period, the sizes of atoms decreases because the effective nuclear charge increases while the largest principal energy level remains constant.
11. The energy required to move an electron from one level to another in any one-electron system can be approximated as:

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

For He, \( Z = 2 \)

where \( Z \) is the atomic number. The first ionization energy for helium is shown in the table below.

<table>
<thead>
<tr>
<th>Ionization</th>
<th>Enthalpy kJ/mol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>2372.3</td>
</tr>
</tbody>
</table>

A. Write the first ionization energy reaction for helium. Underneath each atom or ion in the reaction, write out its electron configuration.

\[ \text{He} (g) \rightarrow \text{He}^+ (g) + \text{e}^- \]

\[ 1s^2 \rightarrow 1s^1 \]

B. Fill in the following "ladder" energy diagram with energy values for each line. The "zero point" energy for this ladder diagram is defined as the energy of the He\(^{2+}\) ion. All other chemical species will have lower (more negative) energies.

<table>
<thead>
<tr>
<th>Energy (kJ/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>-328.2</td>
</tr>
<tr>
<td>-583.5</td>
</tr>
<tr>
<td>-1313.0</td>
</tr>
<tr>
<td>-1313.0</td>
</tr>
<tr>
<td>-5251</td>
</tr>
<tr>
<td>-7623</td>
</tr>
<tr>
<td>-2372.3</td>
</tr>
</tbody>
</table>

This transition is the 1\( \text{E}_1 \)

\[ \text{He}^+ \rightarrow \text{He} \]
12. Would a helium atom get bigger, smaller, or remain the same size if one of its electrons was excited from the ground state to an excited state? Explain your reasoning.

He atom: 1s² Any excited state will take an e⁻ into a higher principal energy level, so it will be bigger.

13. Explain in terms of their electron configurations and what you know about atom/ion stability to explain why Fe²⁺ is more easily oxidized to Fe³⁺ than Mn²⁺ is to Mn³⁺. Write the noble gas core electron configuration of each ion in the table below.

<table>
<thead>
<tr>
<th></th>
<th>Fe²⁺</th>
<th>Fe³⁺</th>
<th>Mn²⁺</th>
<th>Mn³⁺</th>
</tr>
</thead>
</table>

When Fe²⁺ is oxidized to Fe³⁺, it becomes the Fe³⁺ has a half-filled, particularly stable e⁻ configuration which is also pretty low energy. Going to a stable, low energy state makes it easy to do relatively.

Mn²⁺ → Mn³⁺ is just the opposite: starting at a relatively low energy state & moving away from it.
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.

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

When one e⁻ goes through the double slits, it is the probability of the e⁻ going through 1 slit that interferes with the probability of the same e⁻ going through the other slit.

C. How would the pattern change if electrons were shot 1,000 at a time at the screen instead of one at a time?

No change in the pattern other than the pattern would form faster.