Part I. Short Answer. Answer 7 of the next 8 questions. You MUST cross out the one you wish not to be graded. 5 points each.

1. Place the following elements in order of increasing first ionization energy: Mg, Na, Rb, Cl.

   lowest IE $\text{Rb} < \text{Na} < \text{Mg} < \text{Cl}$ highest IE

2. Which transition would involve the emission of a photon with the longest wavelength?

   Circle ONE
   A) $E_1 \rightarrow E_3$
   B) $E_2 \rightarrow E_3$
   C) $E_3 \rightarrow E_1$
   D) $E_3 \rightarrow E_2$

   longest wavelength is the lowest $\Delta E$. $E = \frac{hc}{\lambda}$

3. Place the following isoelectronic ions in order of increasing ionic radius.

   $\text{Na}^+$, $\text{O}^{2-}$, $\text{F}^-$

   smallest radius $\text{Na}^+ < \text{F}^- < \text{O}^{2-}$ largest radius

4. Identify the elements or ions represented by the following electronic configurations.

   $X^+$ [He] $2s^2\ 2p^4$  \hspace{1cm} $X^- = \text{N}^-$
   $X^{2+}$ [Ar] $3d^2$  \hspace{1cm} $X^{2+} = \text{Ti}^{2+}$
   $X$ [Kr] $5s^2\ 4d^{10}\ 5p^4$  \hspace{1cm} $X = \text{Te}$

5. Give the ground state electronic configuration for the following atoms and ions.

   A) $\text{Cl}$ $[\text{Ne}]\ 3s^2\ 3p^5$
   B) $\text{Sc}^+$ $[\text{Ar}]\ 3d^1$
   C) $\text{Cu}$ $[\text{Ar}]\ 4s^1\ 3d^{10}$
6. Identify four quantum numbers that can be used to describe an electron in the depicted atomic orbital.

\[
\begin{align*}
\ell &= 1 \\
|m| &= -1, 0, 1 \text{ (any are correct)} \\
\frac{m}{2} &= \pm \frac{1}{2} \text{ or } \pm \frac{1}{2} \text{ (either)}
\end{align*}
\]

7. Place the following molecules in order of increasing polarity:
HF, Cl₂, NO, HCl.

less polar Cl₂ < NO < HCl < HF more polar

8. Which third period element has the successive ionization energies (IE) given in kJ/mol in the table?

<table>
<thead>
<tr>
<th></th>
<th>IE (1)</th>
<th>IE (2)</th>
<th>IE (3)</th>
<th>IE (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>737</td>
<td>1451</td>
<td>7733</td>
<td>10540</td>
</tr>
</tbody>
</table>

A) Cl  
B) P  
\[\text{Mg}\]  
D) Na

\[\text{Mg} \text{ has a really high 3rd ionization energy because } \text{ it is removed from the noble gas core.}\]

Part II. Problems. Answer 3 of the next 4 questions. You MUST cross out the one you wish not to be graded. 11 points each.

9. A. Calculate the uncertainty in position of an electron moving at a speed of \((1.50 \times 10^5 \pm 1. \times 10^3)\) m/s.

\[
\Delta r \approx \frac{\hbar}{4\pi m \Delta v} = \frac{6.626 \times 10^{-34} \text{ J s}}{4.77 \times 9.10939 \times 10^{-31} \text{ kg} \cdot 1.5 \times 10^5 \text{ m/s}} = 7 \times 10^{-8} \text{ m}
\]

B. Is the uncertainty in position larger or smaller than the de Broglie wavelength of the electron? Show your work.

\[
\lambda = \frac{\hbar}{m v} = \frac{6.626 \times 10^{-34} \text{ J s}}{9.10939 \times 10^{-31} \text{ kg} \cdot 1.5 \times 10^5 \text{ m/s}} = 0.4849 \times 10^{-8} \text{ m}
\]

\[
\lambda = 4.8 \times 10^{-9} \text{ m or 4.8 nm}
\]

The uncertainty is larger than the wavelength.
10. How many electrons in an atom can have the following quantum numbers?

A) n=2, l=3, m_l=-3  \hspace{1cm} 0 \hspace{1cm} \text{electrons}

B) n=2 l=0 \hspace{1cm} 2 \hspace{1cm} \text{electrons}

C) n=3, l=2, m_s=+1/2 \hspace{1cm} 5 \hspace{1cm} \text{electrons}

11. Label each as having either a paramagnetic or diamagnetic ground state electron configuration. In ONE sentence, explain how you know.

A) Ca^{2+} \hspace{1cm} \underline{\text{diamagnetic}}

Why? All electrons are paired. Electron configuration is the same as Ar

B) K \hspace{1cm} \underline{\text{paramagnetic}}

Why? There is an unpaired electron in the 4s orbital.

C) O_2 \hspace{1cm} \underline{\text{paramagnetic}}

Why? This was an in class demo. We saw it stick to the magnet. The MO diagram also shows us there are unpaired e^- in the 2\pi^* orbital.

12. Fill the empty MO diagrams below and rank H_2, H_2^-, and H_2^+ in terms of increasing bond order.

\[ \text{Bond order} = \frac{\text{\# e\textsuperscript{-} in bonding orbitals}}{2} - \frac{\text{\# e\textsuperscript{-} in antibonding orbitals}}{2} \]

B.O.: \hspace{1cm} H_2 = 1 \hspace{1cm} H_2^- = \frac{1}{2} \hspace{1cm} H_2^+ = \frac{1}{2}

Ranking: \hspace{1cm} H_2^+ = H_2^- < H_2
Part III. Problems. Answer 2 of the next 3 questions. You MUST cross out the one you wish not to be graded. **16 points each.**

13. Isoprene is a molecule produced and naturally released into the atmosphere by plants. It is partially responsible for making the Blue Ridge Mountains in Virginia appear blue.

A) **Complete the Lewis structure** of isoprene (C₃H₈) so that all formal charges are zero. Fill in the blanks about the molecular geometry and bond angles of the three indicated carbons.

The molecular geometry of Cₐ is **tetrahedral**. The bond angles of Cₐ are **109.5°**

The molecular geometry of Cₚ is **trigonal planar**. The bond angles of Cₚ are **120°**

The molecular geometry of Cₙ is **trigonal planar**. The bond angles of Cₙ are **120°**

B) Fill in the blank: There are **12** sigma (σ) bonds and **2** pi (π) bonds in isoprene.

C) Using the bond enthalpies, what is the **enthalpy of combustion** for isoprene (C₃H₈) expressed in kJ/mol?

<table>
<thead>
<tr>
<th>Bond Type</th>
<th>C-H</th>
<th>C-C</th>
<th>C-O</th>
<th>O-H</th>
<th>C=O</th>
<th>C=C</th>
<th>O=O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond Enthalpy (kJ/mol)</td>
<td>413</td>
<td>348</td>
<td>358</td>
<td>463</td>
<td>799</td>
<td>614</td>
<td>495</td>
</tr>
</tbody>
</table>

\[
C₃H₈ + 7O₂ \rightarrow 5CO₂ + 4H₂O
\]

\[
\Delta H = H(\text{bonds broken}) - H(\text{bonds formed})
\]

\[
\Delta H = 8(C-H) + 2(C-C) + 2(C=O) + 7(O=O)
- \left(10(C=O) + 8(H-O)\right)
\]

\[
= 8 \cdot 413 + 2 \cdot 348 + 2 \cdot 614 + 7 \cdot 495 - (10 \cdot 799 + 8 \cdot 463) \text{ kJ/mol}
\]

\[
= 8693 - 11094 \text{ kJ/mol} = -3001 \text{ kJ/mol}
\]
14. For each of the following molecules:

a) draw a reasonable Lewis structure and resonance structures if indicated,

b) describe the molecular geometry and polarity, and

c) give the hybridization on the central atom.

A. AsH$_3$

\[ \begin{array}{c}
\text{H} - \overset{\cdot}{\text{As}} - \overset{\cdot}{\text{H}} \\
\text{H}
\end{array} \]

- Trigonal pyramidal
- Polar
- Hybridization $sp^3$

B. SO$_2$ (S is central atom)

\[ \begin{array}{c}
\overset{\cdot}{\text{O}} = \overset{\cdot}{\text{S}} = \overset{\cdot}{\text{O}}
\end{array} \]

- Bent
- Polar
- Hybridization $sp^2$

C. SNO$^-$ (2 resonance structures total)

\[ \begin{array}{c}
\overset{\cdot}{\text{S}} = \overset{\cdot}{\text{N}} - \overset{\cdot}{\text{O}}
\end{array} \to \begin{array}{c}
\overset{\cdot}{\text{S}} - \overset{\cdot}{\text{N}} = \overset{\cdot}{\text{O}}
\end{array} \]

- Bent
- Polar
- Hybridization $sp^2$

D. Circle the most stable resonance structure for SNO$^-$ in part (C) and in one sentence explain why it is the most stable.

The negative formal charge is placed on the most electronegative atom.
15. Below is template for the molecular orbital diagram of BN⁻.

A) Fill in the labels for the three unnamed molecular orbitals.

1. \( \sigma_{2p}^* \)
2. \( \Pi_{2p}^* \)
3. \( \Pi_{2p} \)

4. \( \sigma_{2s}^* \)
5. \( \sigma_{2s} \)

B) Using the above molecular orbital diagram, determine the bond order of BN⁻.

\[ B.O. = \frac{7}{2} - \frac{7}{2} = \frac{5}{2} = 2.5 \]

C) Is BN⁻ paramagnetic or diamagnetic?

Paramagnetic

D) Sketch a picture of the \( \sigma_{2p} \) orbital.

Electron density is between the two nuclei:

A node is located on each atom.