This exam has eight (8) questions for a total of 90 points. Please check before beginning to make sure no questions are missing. IMPORTANT: All answers must be given in the space provided or, if necessary, on the back of that page. Scratch paper is available in the front of the room. However, please be aware that Scratch work will not be collected or graded.
Periodic Table of the Elements

<table>
<thead>
<tr>
<th>Group</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>O</th>
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</thead>
<tbody>
<tr>
<td>Period</td>
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<tr>
<td>1.</td>
<td>1S</td>
<td>Li</td>
<td>Be</td>
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<td>2.</td>
<td>15</td>
<td>B</td>
<td>C</td>
<td>N</td>
<td>O</td>
<td>F</td>
<td>Ne</td>
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<tr>
<td>3.</td>
<td>3</td>
<td>Na</td>
<td>Mg</td>
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<tr>
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<td>4</td>
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<td>Ca</td>
<td>Se</td>
<td>Ti</td>
<td>V</td>
<td>Cr</td>
<td>Mn</td>
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<tr>
<td>5.</td>
<td>5</td>
<td>Rb</td>
<td>Sr</td>
<td>Y</td>
<td>Zr</td>
<td>Nb</td>
<td>Mo</td>
<td>Tc</td>
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<tr>
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<td>6</td>
<td>Cs</td>
<td>Ba</td>
<td>La</td>
<td>HF</td>
<td>Ta</td>
<td>W</td>
<td>Re</td>
</tr>
<tr>
<td>7.</td>
<td>7</td>
<td>Fr</td>
<td>Ra</td>
<td>Ac</td>
<td></td>
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</tr>
</tbody>
</table>

8.  |  8 | La | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yb | Lu |
| 9.  |  9 | Th | Pa | U  | Np | Pu | Am | Cm | Bk | Cf | Es | Fm | Md | No | Lw |

ADVICE: A picture is worth a thousand words!
1. Sodium hydride (NaH) and Borane (BH₃) undergo an acid-base reaction to produce a new compound "X" that contains both ionic and covalent bonds.

(a) Describe as completely as possible the structures of NaH and BH₃, including the nature of any nonbonding valence orbitals, hybridization states for all covalent bonds (for example, sp-s, etc.), and provide accurate bond angles where appropriate. Also, clearly identify which species is the acid or base and whether it fits the Lewis or Bronsted definition. (10 pts).

\[ \text{Na}^+ \text{H}^- \quad \text{vacant p-orbital} \]

or

\[ \text{N}_3^- \text{H} \quad \text{Lewis acid} \]

(b) Describe as completely as possible the structure of "X". Same criteria as above. (5 pts).

\[ \text{sp}^2 \text{- hybrid} \rightarrow \]

\[ \text{exactly Lewis pair} \]

2. For each compound shown below calculate the formal charge for all non-hydrogen atoms, and draw as many resonance structures as possible, showing formal charges for each. (15 pts).

(a) \[ \text{H}_2\text{C}=\text{N}=\text{N} \quad \longrightarrow \quad \text{H}_2\text{C}^-\text{N}=\text{N}^+ \quad \left[ \quad \longrightarrow \quad \text{H}_2\text{C}^-\text{N}=\text{N}^+ \quad \right] \]

and others

(b) \[ \text{H}_2\text{C}=\text{C}=\text{N}=\text{O} : \quad \longrightarrow \quad \text{H}_2\text{C}^-\text{C}=\text{N}=\text{O} : \quad \left[ \quad \longrightarrow \quad \text{H}_2\text{C}^-\text{C}=\text{N}=\text{O} : \quad \right] \]

and others

(c) \[ \text{H}_2\text{C}=\text{N}=\text{C} : \quad \longrightarrow \quad \text{H}_2\text{C}^-\text{N}=\text{C} : \]
3. Arrange the members of each group below in order of decreasing basicity (i.e. strongest base on the left, weakest on the right) Briefly explain your reasoning (3 - 4 words should suffice). (15 pts).

(a) $\text{F}^-$, $\text{OH}^-$, $\text{NH}_2^-$, $\text{CH}_3^-$

\[
\begin{align*}
\text{CH}_3^- & \quad \text{N}\text{H}_2^- & \quad \text{CH}_2^- & \quad \text{F}^-
\end{align*}
\]
increasing electronegativity, increasing stability, weaker base.

(b) $\text{F}^-$, $\text{Cl}^-$, $\text{Br}^-$, $\text{I}^-$

\[
\begin{align*}
\text{F}^- & \quad \text{Cl}^- & \quad \text{Br}^- & \quad \text{I}^-
\end{align*}
\]
similar electronegativity, increasing size, increasing stability, weaker base

(c) $\text{OH}^-$, $\text{SH}^-$, $\text{SeH}^-$

\[
\begin{align*}
\text{OH}^- & \quad \text{SH}^- & \quad \text{SeH}^-
\end{align*}
\]
similar electronegativity, increasing size, increasing stability, weaker base.

4. For each of the four butane derivatives listed below sight along the C2-C3 bond and draw Newman projections of the most stable and least stable conformations (ONLY!). Assign strain energy values to each conformation. Which of the eight conformations you have drawn is most strained and which is least strained? These can be circled and labeled (20 pts).

(a) 2-Methylbutane

(b) 2,2-Dimethylbutane
5. Fluoromethane (CH₃F) has a smaller dipole moment than chloromethane (CH₃Cl), even though fluorine is more electronegative than chlorine. Why is this so? Please illustrate with an accurate three-dimensional drawing. (5 pts).

6. Divalent carbon species called "carbene" are highly reactive species which generally cannot be isolated. The simplest member of this class is called "methylene" and has the formula :CH₂. The two non-bonding electrons in :CH₂ can either be paired in a single orbital or unpaired in different orbitals. Provide an accurate, three-dimensional drawing of each species, including the hybridization at carbon, the nature of the covalent C-H bonds, the approximate bond angles, and the type of carbon orbitals involved for non-bonding electrons. Do either of these species have a charge? (5 pts).
7. For each pair of compounds given below, circle the one which will be the more stable. Please show the pertinent interactions as accurately as possible with three-dimensional drawings. **You need not provide absolute energy differences.** (10 pts).

(a) 1,1,2,2-Tetramethylcyclohexane or 1,1,4,4-Tetramethylcyclohexane

(b) cis-1,2-Dimethylcyclopropane or 1,1-Dimethylcyclopropane

3x (2x 1,3 diaxial interactions) 2x gauche interactions

2x (2x 1,3 diaxial interactions) (only)

1x eclipsed CH₃ - CH₃
3x eclipsed H - H
2x eclipsed CH₃ - H

8. Why does an axial tert-butyl group on cyclohexane have a much larger 1,3-diaxial interaction with hydrogen than an isopropyl group, but an isopropyl group has roughly the same 1,3-diaxial interaction with hydrogen as an ethyl or methyl group? This question can be answered with accurate, three-dimensional drawings showing the relevant steric interactions. (5 pts).

Axial tert-butylcyclohexane must have one methyl group positioned above the ring and competing for space with two axial ring protons. In other axial alkylcyclohexanes, such as isopropylcyclohexane, the methyl group is replaced by a hydrogen, which has a smaller space requirement. The steric strain in tert-butylcyclohexane is therefore larger.