1. Molecules that have internal mirror planes are always: *Circle the correct answer*

   chiral           achiral           meso           enantiomers

2. The most stable carbocation shown below is:

   ![Carbocation Images]

3. The major product formed when 2-bromo-3,3-dimethyl-pentane is reacted with aqueous NaOH is:

   ![Product Images]

4. Which of the following carbocations is not a resonance structure of the other three?

   ![Carbocation Images]

5. Circle the strongest acid from the list below.

   water           ammonia           methane           hydroxide

6. Which of the following can be reacted with sodium ethoxide to form diethyl ether?

   ![Reactants Images]
7. Which of the following compounds has 3 signals in its $^{13}$C NMR spectrum?

8. Circle the compound below that contains the least ring strain.

9. Circle the product of Br$_2$ addition (Br$_2$, CH$_2$Cl$_2$) to cis-3-hexene.

10. Circle the product formed when 3-hexyne is hydrogenated with H$_2$ (g) using a palladium catalyst on graphite (reaction shown below).

11. Provide clear structural drawings for the following compounds.

   a) methylene chloride:

   b) *para*-toluene sulfonyl chloride (tosyl chloride):

   c) butyllithium:
12. Briefly explain why rotation around the central bond of 1,3-butadiene requires greater energy than rotation around the central bond of butane. *Both molecules are shown below with arrows pointing to the bonds undergoing rotation.*

![Rotation Diagram]

13. Supply missing reagents (over the arrows) and compound structures (in the boxes) to complete the following transformations. *Multiple reagents/steps may be needed. Be sure to pay attention to stereochemistry.*

(a)

(b)

(c)

(d) \[\text{CH}_3\text{CH}=\text{CH}_2\text{CH}_3\] \[\rightarrow\] \[\text{H}_3\text{C}\text{OH}\text{CH}_3\text{CH}_3\]

(e) \[\text{CH}_3\text{CH}=\text{CH}_2\text{CH}_3\] \[\rightarrow\] \[\text{HO}\text{CH}_3\text{CH}_3\]

(f) \[\text{CH}_3\text{CH}=\text{CH}_2\text{CH}_3\] \[\rightarrow\] \[\text{H}_3\text{CO}\text{CH}_3\text{CH}_3\]

(g) \[\text{CH}_3\text{CH}=\text{CH}_2\text{CH}_3\] \[\rightarrow\] \[\text{H}_3\text{CO}\text{CH}_3\text{CH}_3\]
14. Starting with 1-methylcyclopentene, provide the missing reagent(s) to carry out each of the following reactions. *Multiple steps may be needed.*

a) 

b) 

c) 

d) 

e) 

f) 

15. You have a sample of a chiral compound. If the optical rotation of the (+)-enantiomer is reported at +50.0° and your sample has an optical rotation of +20.0°, what percent of your sample is the (+)-enantiomer?
16. Draw \textit{trans}\textsubscript{1,4}-diisopropylcyclohexane in its lowest-energy conformation.

17. Classify each pair of compounds as \textbf{structural isomers, enantiomers, diastereomers, or identical}.

a) 
\begin{align*}
\text{Answer:} & \\
\end{align*}

b) 
\begin{align*}
\text{Answer:} & \\
\end{align*}

c) 
\begin{align*}
\text{Answer:} & \\
\end{align*}

18. a) Provide a name for the compound (chemical formula C\textsubscript{4}H\textsubscript{8}Br\textsubscript{2}) that is shown in the box below. Remember to assign configuration to all stereocenters

\begin{align*}
\text{Name} & \\
\end{align*}
b) Four structures with the formula C₄H₈Br₂ are shown below. Circle each compound that is a diastereomer of the compound in the box above. Put a square around each achiral compound.

![Chemical structures](image)

19. The structure of nicotine, a highly addictive substance found in tobacco, is shown below.

![Nicotine structure](image)

a) Draw nicotine with its stereocenter in the naturally occurring (S)-configuration.

b) Is nicotine more likely to act as an acid or a base? Explain your answer.
20. An unknown compound gives the following spectral data:

**Mass spec:** Molecular ion region has the following series of 4 peaks (values are given as mass/charge ratios with relative intensities as percentages): 212 (100%), 213 (10%), 214 (97%), 215 (9%).

**IR:** multiple absorbances between 3080-2900 cm⁻¹, strong absorbance at 1692 cm⁻¹, weaker absorbance at 1588 cm⁻¹.

**¹H NMR in CDCl₃:** doublet at 7.83 ppm (integration = 1), doublet at 7.60 ppm (integration = 1), quartet at 2.97 ppm (integration = 1), triplet at 1.22 ppm (integration = 1.5).

a) What information can you deduce from the mass spectral data?

b) What information can you deduce from the IR data?

c) What information can you deduce from the NMR data?

d) What is the identity of the unknown compound?
21. On the drawing of the compound below, place a label on each hydrogen atom (showing that they are chemically equivalent or inequivalent), and complete the chart describing the compound’s $^1$H NMR spectrum (the methyl group hydrogens have been identified for you, please follow this format).

![Diagram of the compound](image)

<table>
<thead>
<tr>
<th>Signal</th>
<th>Integration</th>
<th>Multiplicity</th>
<th>Approximate Chemical Shift (δ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hₐ</td>
<td>6 Hydrogens</td>
<td>Singlet</td>
<td>2.1 ppm</td>
</tr>
</tbody>
</table>
22. You calculate the energies (heats of formation) of two species in conformational equilibrium:

\[ \text{A} \quad \text{B} \]

Calculated energies:
conformer A: -24.6 kcal/mol
conformer B: -23.3 kcal/mol

a) What is the approximate equilibrium constant (k) at 25 °C for the equation shown above? *Circle your answer from the choices provided below.*

- \( k = 10 \)
- \( k = 1 \)
- \( k = 0 \)
- \( k = 0.1 \)
- \( k = 0.01 \)

23. Identify the major product produced when A is treated with the following reagents. Be sure to pay close attention to stereochemistry where appropriate.
24. Consider the following E1 reaction coordinate diagram:

a) On the above diagram, label the activation energy for the overall reaction of $A \rightarrow C/D$

b) Is the reaction from $A \rightarrow C/D$ endergonic or exergonic?

c) If this reaction proceeds under thermodynamic control, at the end of the reaction what species would be in the highest amount, $A$, $B$, $C$, or $D$?

d) If this reaction proceeds under thermodynamic control, at the end of the reaction what species would be in the smallest amount, $A$, $B$, $C$, or $D$?
25. In the boxes provided, fill in the missing reagents and compound structures to complete the synthetic sequences.

```
[\text{BH}_3] \\
[\text{H}_2\text{O}, \text{NaOH}_{(aq)}] \\
[\text{H}_3\text{O}^+] \\
```

26. Provide a complete mechanism for the following transformation. \textit{Draw all relevant intermediates, including resonance structures.}

```
[\text{acidic ethanol}] \\
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[Chemical structures and reactions diagram]
27. Heating of the secondary iodide shown below in acetic acid leads to the two indicated products (these are the major products). Provide a mechanism for the formation of each product. *Be sure your mechanism describes the formation of both observed products.* *Acetic acid is both a reagent in the reaction and the solvent.*