Answer the following four free response questions. Make sure to show all your work for full credit (100 pts. total).

1. (48 pts. total) Consider the structure of \textit{N-demethylglycopyrrolate} shown below, a drug that reduces the production of saliva in patients that suffer from excessive drooling:

\begin{center}
\includegraphics[width=0.5\textwidth]{structure.png}
\end{center}

\textit{N-demethylglycopyrrolate}

A. (3 pts.) Identify the THREE functional groups present (exclude the benzene ring).

1) \textbf{alcohol} \\
2) \textbf{ester} \\
3) \textbf{amine}

B. (4 pts.) Determine the molecular formula of \textit{N-demethylglycopyrrolate}.
\textbf{C_{18}H_{25}NO_{3}}

C. (6 pts.) Circle one answer in each row that so that your response best describes the O–C=O bond angle in \textit{N-demethylglycopyrrolate}.

<table>
<thead>
<tr>
<th>a bit less than</th>
<th>exactly equal to</th>
<th>a bit more than</th>
</tr>
</thead>
<tbody>
<tr>
<td>45°</td>
<td>60°</td>
<td>90°</td>
</tr>
<tr>
<td></td>
<td>109.5°</td>
<td>120°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>180°</td>
</tr>
</tbody>
</table>

Now circle the phrase(s) below that correctly describe(s) \textit{N-demethylglycopyrrolate}.

\textbf{optically active} \hspace{1cm} \textbf{optically inactive} \hspace{1cm} \textbf{chiral} \hspace{1cm} \textbf{achiral} \hspace{1cm} \textbf{aromatic}

Finally, can one tell if \textit{N-demethylglycopyrrolate} is either dextrorotatory or levorotatory without the use of a polarimeter?

\textbf{CIRCLE: YES OR NO}
D. (4 pts.) Clearly label all the stereocenters in N-demethylglycopyrrolate shown above, labeling each one as either $R$ or $S$. **See above**

E. (6 pts.) Consider the two structural derivatives of N-demethylglycopyrrolate shown in the boxes below. Identify the various intermolecular forces present that would have to be overcome to boil each compound, and determine whether the compound is expected to have a HIGHER OR LOWER boiling point than N-demethylglycopyrrolate.

![Intermolecular Forces](image1)

Intermolecular Forces present:

**London Dispersion Forces (only)**

HIGHER OR **LOWER** boiling point (CIRCLE ONE)?

![Intermolecular Forces](image2)

Intermolecular Forces present:

**London Dispersion Forces and Dipole-Dipole Interactions**

HIGHER OR **LOWER** boiling point (CIRCLE ONE)?
F. (2 pts.) There are several known resonance structures for $N$-demethylglycopyrrolate. Draw the most significant resonance structure in the box below.

G. (8 pts.) How many diastereomers are possible for $N$-demethylglycopyrrolate? 2

How many enantiomers are possible for $N$-demethylglycopyrrolate? 1

Draw one enantiomer and one diastereomer of $N$-demethylglycopyrrolate in the box below (if they exist; otherwise, write NOT POSSIBLE and briefly explain):

H. (3 pts.) Is $N$-demethylglycopyrrolate expected to be miscible in the fatty tissue of the body? Briefly explain why or why not. Since the fatty tissue of the body is predominantly nonpolar, and $N$-demethylglycopyrrolate is a polar molecule, the latter is NOT MISCIBLE in the fatty tissue of the body.
I. (8 pts.) In pharmaceutical chemistry, molecules with similar structures will often be synthesized in attempt to find more effective drugs or to eliminate unwanted side effects. Drawn below is a structural analog of \textit{N-demethylglycopyrrolate}, called \textit{Molecule A}.

\textit{Molecule A}

Draw the most stable and least stable chair conformations of \textit{Molecule A}. (Hint: you may wish to abbreviate a portion of \textit{Molecule A} as an "R" group for simplicity, but you must clearly identify your abbreviation.)

\begin{align*}
\text{MOST STABLE} & \quad \text{LEAST STABLE} \\
\text{RO} & \quad \text{OR} \\
\text{CH}_3 & \quad \text{CH}_3 \\
\text{NH}_2 & \quad \text{NH}_2 \\
\text{CH}_3 & \quad \text{CH}_3
\end{align*}

J. (4 pts.) Finally, consider \textit{Molecule B} below, another derivative of \textit{N-demethylglycopyrrolate}. Draw the expected Fischer Projection for this derivative molecule in the box. (You may abbreviate the benzene ring as "phenyl").

\textit{Molecule B}
2. (15 pts. total; 3 pts. each) **NOMENCLATURE!** Use the appropriate IUPAC notation to name or draw each of the organic structures below:

A. *trans*-1,4-dibutylcyclohexane

\[
\begin{align*}
&\text{H}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{C} \quad \text{CH}_2\text{CH}_2\text{CH}_3
\end{align*}
\]

B. 6-ethyl-2-methyl-4,4-dipropylcyclooctane

C. *cis*-1,2-diethylcyclopropene

D. \( m \)-fluoriodobenzene

E. *trans*-3-methyl-6-propyl-6-octen-2-ol

3. (4 pts.) Assume that you have two unlabeled bottles, one with cyclohexene and one with toluene (i.e., methylbenzene). How would you tell them apart by carrying out the learned laboratory techniques in this section? What qualitative experimental results would you expect? **To distinguish an alkene from an aromatic, one could perform the bromine test and/or the potassium permanganate test.** For the bromine test, the alkene solution will change from red to colorless as the alkene reacts with bromine. With respect to the permanganate test, the alkene solution will change from purple to brown (as the alkene is converted to a glycol). No effect is observed via either test on the aromatic.
4. (12 pts. total) **REACTIONS!** Draw the expected reactant or product for each reaction below, and write the accompanying mechanism where requested. If no reaction is expected to occur, write "NR".

A.  

\[ \text{Show mechanism:} \]

B.  

\[ \text{Show mechanism:} \]

C.  

D.  

\[ \text{NR; aromatic} \]
5. (9 pts. total; 3 pts. each) Consider the structure of Penicillin G below, a β-lactam antibiotic used in the treatment of bacterial infections caused by susceptible, usually Gram-positive, organisms:

Determine whether the following compounds are expected to have a HIGHER or LOWER boiling point than Penicillin G, and briefly explain your choice.

A. 

LOWER due to more continuous carbon chain length (i.e., Penicillin G possesses restricted bond rotation and hence is more rigid).

B. 

GREATER due to increased cyclization within the given structure, resulting in restricted bond rotation and greater rigidity.

C. 

LOWER due to more continuous carbon chain length (i.e., Penicillin G possesses restricted bond rotation and hence is more rigid).
6. (12 pts. total; 2 pts. each) Fill-in the following chart below with respect to the three listed drugs:

<table>
<thead>
<tr>
<th>Drug</th>
<th>Medicinal/Pharmaceutical Use?</th>
<th>Manufactured? (i.e., R-enantiomer/S-enantiomer/Racemic Mixture)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Captopril</td>
<td>Effective for the treatment of high blood pressure and congestive heart failure</td>
<td>S-enantiomer</td>
</tr>
<tr>
<td>Ibuprofen</td>
<td>Active as a pain and fever reliever</td>
<td>Racemic Mixture</td>
</tr>
<tr>
<td>Thalidomide</td>
<td>Used to treat morning sickness and found to be useful in the treatment of leprosy and may also be useful in the treatment of AIDS</td>
<td>R-enantiomer (as S is found to be teratogenic)</td>
</tr>
</tbody>
</table>

**BONUS!** (7 pts. total; 1 pt. each) We have learned that hydrocarbons can react in the presence of oxygen gas via combustion. Interestingly enough, hydrocarbons can also react with chlorine or bromine under high temperature conditions or in the presence of light to produce substituted halogen products.

For example, methane (CH₄) can react with chlorine gas in the presence of heat or light to produce chloromethane (CH₃Cl). If chloromethane is allowed to react with more chlorine, further chlorination produces a mixture of dichloromethane, trichloromethane, and tetrachloromethane.

Using bond-line notation, write the formulas of the seven doubly brominated isomers formed when 2,2-dimethylbutane reacts with Br₂ in the presence of heat or light.