1. (16 pts.) Give a complete and acceptable name for each of the following structures. Indicate stereochemistry if required.

(a) 

1-bromo-4-methylcyclohexa-1,4-diene 1,4 can be before cyclohexa

(b) 

Z,Z-4-bromo-5-chlorohept-3,5-dien-1-yne; Z,Z anywhere OK; 3,5-heptadien-1-yne also OK; cis OK

(c) 

3-cyclohexyl-6-cyclopropyl-2-methylheptane

(d) 

4R-chloropentan-2R-ol OK if use hydroxy; R, R anywhere OK
2. (12 pts) For each of the molecules shown below, indicate the number of non-equivalent protons (the number of different signals you would expect in the proton NMR)

(a) \[ \text{ } \] \quad \[ 3 \] \quad \text{(b) } \[ \text{ } \] \quad \[ 6 \]

(c) \[ \text{ } \] \quad \[ 2 \] \quad \text{(d) } \[ \text{ } \] \quad \[ 4 \]

3 pts ea
3. (44 pts) For each of the following reactions or series of reactions, draw the structure of the required reagent(s) (over the arrow) or the reactant or major organic product (in the box). Be sure to indicate stereochemistry where this is pertinent. **4 pts ea, partial credit for intermediates**

(a)

\[
\begin{array}{c}
\text{CH}_3\text{COCH}_3 \\
\text{2} \text{PhLi} \\
\text{then H}_2\text{O} \\
\hline
\end{array}
\]

\[
\begin{array}{c}
\text{CH}_3\text{OH} \\
\text{Ph} \\
\text{Ph} \\
\end{array}
\]

answer is NOT CH\text{\textsubscript{3}}OH

(b)

\[
\begin{array}{c}
\text{OH} \\
\text{1. H}_2\text{SO}_4 \\
\hline
\text{Br} \\
\text{2. Br}_2/\text{H}_2\text{O} \\
\end{array}
\]

quiz 7, exam 3

(c)

\[
\begin{array}{c}
\text{Cyclohexene or } \text{Cyclohexene} \\
\text{CR}_2 \\
\text{CR}_2 \\
\text{O}_3, \text{then } (\text{CH}_3)_2\text{S} \\
\end{array}
\]

12-memb ring w/2 db also OK

(d)

\[
\begin{array}{c}
\text{HC} = \text{C} \\
\text{1. NaNH}_2 \\
\hline
\text{CH}_3\text{CH}_2\text{COCH}_3 \\
\text{2. CH}_3\text{CH}_2\text{Br} \\
\text{3. HgSO}_4, \text{H}_2\text{SO}_4, \text{H}_2\text{O} \\
\end{array}
\]
(e)  
\[ \text{cyclohexylLi} \xrightarrow{1. \, \vphantom{\Delta} \text{O}} \xrightarrow{2. \, \text{H}_2\text{O}} \xrightarrow{3. \, \text{PBr}_3} \text{cyclohexylBr} \]

(f)  
\[ \text{cyclohexene} \xrightarrow{1. \, \text{BH}_3\text{-THF}} \xrightarrow{2. \, \text{NaOH/H}_2\text{O}_2} \text{cyclohexeneOH} \]

OK if no stereochem, -2 wrong regiochem

(g)  
\[ \text{acetone} \xrightarrow{\text{LiAlH}_4\text{ excess}} \xrightarrow{\text{ether solvent then H}_2\text{O}} \text{HO-CH}_2\text{-CH}_2\text{OH} \]

answer is NOT CH$_3$OH

(h)  
\[ \text{cyclohexylBr} \xrightarrow{\text{Kl \, \vphantom{\Delta} \text{acetone}}} \text{cyclohexylI} \]

-2 wrong stereochem
(i) \[ \text{Br}_2/\text{light} \rightarrow \text{monobrominated product} \]

2 enantiomers of this also OK

exam 2, exam 3

(j) \[ \text{OH} \rightarrow 1. \text{TsCl/pyridine} \]

\[ 2. \text{KOrBu/tBuOH} \]

TsCl = \[
\begin{array}{c}
\text{H}_3\text{C} \\
\text{O} \\
\text{SO}_2\text{Cl}
\end{array}
\]

(k) \[ \text{Me} \rightarrow 1. \text{mCPBA} \]

\[ 2. \text{H}_2\text{O/H}^\ominus \]

mCPBA = meta-chloroperoxybenzoic acid
4. (30 pts) Give a complete and efficient syntheses which will produce three out of five compounds shown below. Show each step and each intermediate. DO NOT draw mechanisms. As starting materials, you can use cyclohexanol, any alcohols containing four or less carbon atoms, and any inorganic reagents. PROBLEM 11-56. 10 pts ea

Many other possibilities in each case
5. (18 pts) The molecule shown below is **Artemisinin**, which is a drug that possesses the most rapid action of all current drugs against malaria. It was discovered by Tu Youyou, a Chinese scientist, who was awarded half of the 2015 Nobel Prize in Medicine for her discovery. Artemisinin is isolated from sweet wormwood, a herb employed in Chinese traditional medicine.

(a) Determine the hybridization of the indicated atoms and place the answers in the square boxes provided.

(b) Assign the R, S stereochemistry of the indicated atoms and place the answers in the circles provided.

(c) Write the number of chiral carbon atoms (chirality centers) in Artemisin in the box provided to the right of the structure. **3 pts ea**

![Diagram of Artemisinin with hybridization and stereochemistry labeled](image-url)
6. (20 pts) Propose reaction mechanisms, showing all intermediates (no transition states), all charges and/or unpaired electrons, and indicate the flow of electrons with arrows, for the formation of two products shown in transformation below. *Covered in lecture*
7. (6 pts) In the two boxes below, carefully draw the two chair conformations of cis, cis-1,2,3-trichlorocyclohexane. Put a star in the box of the most stable conformation. 2 pts each structure, 2 pts star.
8. (12 pts) Ozonolysis followed by reductive workup (Me₂S) of a compound with the formula C₁₂H₂₀ gives only the diketone shown below. Draw two possible structures for this compound. **6 pts each structure**
9. (12 pts) Alkene shown below can be mono-brominated to give four different products. Draw structures of these products in the boxes provided. Draw all geometric isomers, but if product is formed as a pair of enantiomers, draw only one enantiomer. **2 pts each structure, 2 pts A or B below; if 4 or more below then 0 pts**

\[
\text{A} \xrightarrow{\text{Br}_2/\text{light}} \quad B + C + D + E
\]

Are any of the compounds A to E achiral? If yes, write which ones: __A, B_____________
10. (8 pts) A molecule with formula $C_{10}H_{14}$ has the proton NMR spectrum shown below. Draw structure in the box provided and include any reasoning for partial credit.

Partial credit: ethyl gp 2 pts, benzene ring 2 pts, 1,4-disubstituted benzene 3 pts
11. (10 pts) A molecule with formula C₆H₁₂O shows the NMR spectrum reproduced below. In IR spectrum, an intensive peak at 1715 cm⁻¹ is observed. Draw its structure in the box on next page and be sure to include any reasoning for partial credit.

Partial credit – ethyl 2 pts, iPr 2 pts, ketone 2 pts
12. (12 pts) A molecule with formula C_{11}H_{14}O_{4} shows IR and NMR spectra that are reproduced below. Draw its structure in the box and be sure to include any reasoning for partial credit.
Partial credit – OMe 2 pts, ethyl 2 pts, C=O 2 pts, benzene ring 2 pts, 1,3,5-trisubstituted benzene 4 pts
Structure with aldehyde and 2H on ring also acceptable
Extra Credit Above 200 Pts (18 pts)
In the boxes provided below, draw molecules that have the molecular formulas given and that show only one line in their $^1$H (proton) NMR spectra:

- CH$_3$OCH$_3$
- CH$_3$OOCH$_3$
- C$_2$H$_6$O
- C$_2$H$_6$O$_2$
- C$_8$H$_{18}$
- C$_8$H$_{16}$
- C$_6$H$_3$Cl$_3$
- C$_6$H$_4$Cl$_2$

3 pts ea
The Periodic Table of Elements
### TABLE 12-2 Summary of IR Stretching Frequencies

<table>
<thead>
<tr>
<th>Frequency (cm(^{-1}))</th>
<th>Functional Group</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>3300</td>
<td>alcohol</td>
<td>O—H</td>
</tr>
<tr>
<td></td>
<td>amine, amide</td>
<td>N—H</td>
</tr>
<tr>
<td></td>
<td>alkyne</td>
<td>≡C—H</td>
</tr>
<tr>
<td>3000</td>
<td>alkane</td>
<td>——C—H</td>
</tr>
<tr>
<td></td>
<td>alkene</td>
<td>——C—H</td>
</tr>
<tr>
<td></td>
<td>acid</td>
<td>O—H</td>
</tr>
<tr>
<td>2200</td>
<td>alkyne</td>
<td>——C≡C—</td>
</tr>
<tr>
<td></td>
<td>nitrile</td>
<td>——C≡N</td>
</tr>
<tr>
<td>1710 (very strong)</td>
<td>carbonyl</td>
<td>——C=O</td>
</tr>
<tr>
<td>1660</td>
<td>alkene</td>
<td>——C=C—</td>
</tr>
<tr>
<td></td>
<td>imine</td>
<td>——C=N</td>
</tr>
<tr>
<td></td>
<td>amide</td>
<td>——C=O</td>
</tr>
</tbody>
</table>

Ethers, esters, and alcohols also show C—O stretching between 1000 and 1200 cm\(^{-1}\).
<table>
<thead>
<tr>
<th>Type of Proton</th>
<th>Approximate $\delta$</th>
<th>Type of Proton</th>
<th>Approximate $\delta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>alkane ($\text{-CH}_3$)</td>
<td>0.9</td>
<td>$\text{C} = \text{C} &lt; \text{CH}_3$</td>
<td>1.7</td>
</tr>
<tr>
<td>alkane ($\text{-CH}_2$-)</td>
<td>1.3</td>
<td>$\text{Ph} - \text{H}$</td>
<td>7.2</td>
</tr>
<tr>
<td>alkane ($\text{-CH}$-)</td>
<td>1.4</td>
<td>$\text{Ph} - \text{CH}_3$</td>
<td>2.3</td>
</tr>
<tr>
<td>$\text{O}$</td>
<td></td>
<td>$\text{R} - \text{CHO}$</td>
<td>9–10</td>
</tr>
<tr>
<td>$\text{-C} - \text{CH}_3$</td>
<td>2.1</td>
<td>$\text{R} - \text{COOH}$</td>
<td>10–12</td>
</tr>
<tr>
<td>$\text{-C} = \text{C} - \text{H}$</td>
<td>2.5</td>
<td>$\text{R} - \text{OH}$</td>
<td>variable, about 2–5</td>
</tr>
<tr>
<td>$\text{R} - \text{CH}_2 - \text{X}$</td>
<td>3–4</td>
<td>$\text{Ar} - \text{OH}$</td>
<td>variable, about 4–7</td>
</tr>
<tr>
<td>($\text{X} = \text{halogen, O}$)</td>
<td></td>
<td>$\text{R} - \text{NH}_2$</td>
<td>variable, about 1.5–4</td>
</tr>
</tbody>
</table>

*Note:* These values are approximate, as all chemical shifts are affected by neighboring substituents. The numbers given here assume that alkyl groups are the only other substituents present. A more complete table of chemical shifts appears in Appendix 1.