1. (20 pts)
(a) (3 pts each) Form acceptable Lewis structures for the following uncharged compounds by adding the necessary nonbonding electrons and multiple bonds:

![Lewis structure of carbon dioxide](image)

Carbon Dioxide

![Lewis structure of formamide](image)

Formamide

(b) (3 pts each) Assign formal charges as necessary to the atoms in the following Lewis structures.

![Lewis structure of bicarbonate](image)

Bicarbonate

![Lewis structure of glycine](image)

Glycine (an amino acid)

(c) (4 pts) A full description of bicarbonate (above) requires two main resonance structures. The one you completed was one; draw the other one:

![Resonance structure of bicarbonate](image)

(d) (4 pts) Shown below is another commonly published representation of Glycine. Is this a valid resonance structure of the version in (b)? Please circle your answer and explain.

Yes

No

![Alternative representation of glycine](image)

Explanation:
2. (20 pts) Consider the five Newman projections below.

(a) (2 pts) All of these diagrams depict compounds of formula _____________.

(b) (4 pts) Structure ____ represents a compound different from the other four. This compound’s IUPAC name is _________________________________.

(c) (2 pts) The other four depict (IUPAC name):_______________________________.

Of the four in (c),...

(d) (2 pts) …which two structures represent staggered conformations? _____ and _____.

(e) (2 pts) …which two structures represent energy maxima (high points) on the torsional potential energy surface? _____ and _____.

(f) (4 pts) For two of the above structures there are additional conformations of equal energy. Which ones are they? _____ and _____. Draw their same-energy conformations by completing the Newman projections, labeled F and G below.

(g) (4 pts) In the box below, take structure A to be at 0° and sketch the rotational potential energy diagram, placing structures A-G (except for the misfit) in your picture.
3. (20 pts)
   (a) (12 pts) Draw structures to represent the following IUPAC names
      (i) 2-chloro-2-fluoroethanol
      (ii) 1,1,2-trimethylcyclopentane
      (iii) 3,3-diethylpentane

   (b) (2 pts) Which of the compounds in (a) has no dipole? Please circle your answer
       (i)  (ii)  (iii)

   (c) (3 pts) Why don’t we have to give a number to show the hydroxy group position in compound (i), a substituted alcohol?
       Explanation:

   (d) (3 pts) Why don’t we have to indicate cis or trans in describing (ii), a cycloalkane?
       Explanation:
4. (20 pts) Structural analysis by spectroscopy
(a) (3 pts each) For each pair of compounds in the grid below, propose a spectroscopic method to tell them apart, and explain what you would look for with the suggested method.

<table>
<thead>
<tr>
<th>Compounds</th>
<th>Method &amp; Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
</tbody>
</table>

(b) (8 pts) Below are $^1$H NMR and IR spectra for some MSU students’ favorite substance of abuse (ethanol). Please identify the key features that confirm this structure—i.e., assign the three NMR peaks to the sites in the molecule, explain their splitting patterns, and predict their respective integrals. Similarly, identify at least three features of the IR spectrum that support the structural assignment.

![1H NMR Spectrum](image1)

![IR Spectrum](image2)
5. Consider the following equilibrium constant values (from Bruice, Table 2.10, p. 112) for interconversions between the two chair conformations of substituted cyclohexanes.

<table>
<thead>
<tr>
<th>R</th>
<th>K(eq/ax)</th>
<th>ΔG(eq/ax) (kcal/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>CH₃</td>
<td>18</td>
<td>1.7</td>
</tr>
<tr>
<td>CH₂CH₃</td>
<td>21</td>
<td>1.8</td>
</tr>
<tr>
<td>CH(CH₃)₂</td>
<td>35</td>
<td>2.1</td>
</tr>
<tr>
<td>C(CH₃)₃</td>
<td>4800</td>
<td>5.0</td>
</tr>
</tbody>
</table>

a. (3 pts) In which structure above is R axial? (Circle your choice): A   B

b. (6 pts) Use the templates below to construct Newman projections of the three ethyl rotation energy minima as viewed down the CH₃CH₂–CH(CH₂)₅ (i.e. ethyl-cyclohexyl) bond in ethylcyclohexane (the cyclohexane ring is already shown).

c. (6 pts) Rank the three conformations in part (b) higher or lower in energy (two are the same) by circling the correct word for each.

d. (5 pts) The equilibrium constants in part (a) translate into the energy differences shown at right (from the relationship ΔG = -RTln K; ΔG = “Gibbs free energy difference”). Along the way from R = CH₃ to R = C(CH₃)₃, the methyl, ethyl, and isopropyl groups have axial-equatorial ΔG values (1.7, 1.8, 2.1) within 0.4 kcal/mol—hardly different. But the next jump, to the t-butyl group, raises the ΔG up to 5 kcal/mol! Explain, using careful drawings on the templates below and a few carefully chosen words, why this last methyl replacement makes a difference so much bigger than the others. (Hint: how would the conformations you produced in part (b) be affected by chair-chair flipping of the cyclohexane part?)
6. (20 pts) More on structural analyses based on spectroscopies:
   (a) (8 pts) For each compound below, circle and label (with a,b,c… as in the example at right) the groups of equivalent \(^1\)H sites. If it’s helpful, feel free to add H’s as appropriate to the structures.

   (i) ![Structure](image1)
   (ii) ![Structure](image2)
   (iii) ![Structure](image3)
   (iv) ![Structure](image4)

(b) (6 pts) Only one of the above compounds would show simple singlets (i.e. unsplit peaks) in its \(^1\)H NMR spectrum. Redraw the compound and point out the site(s) responsible.

(c) (6 pts) Compounds (iii) and (iv) in part (a) are isomers. Could you tell them apart by IR spectroscopy? How? Identify at least two spectroscopic differences you could easily see. (Assume the strained cyclopropane ring doesn’t do anything special.)