Spectroscopy

IR

Typical Infrared Absorption Values For Various Types of Bonds

- 3200-3400 cm\(^{-1}\) O-H stretch
- 2850-3100 cm\(^{-1}\) C-H stretch
- 2100-2260 cm\(^{-1}\) C=N
- 1650-1800 cm\(^{-1}\) C=O stretch

For aldehydes: Fermi doublet at ~2800 and 2700 cm\(^{-1}\)
1. (Klein 2.22, 5e) Match each spectrum with the appropriate compound and identify the signals that justify your choice.

**Spectrum A**

**Peak Assignment:**
3010: Csp2-H
2900: Csp3-H
Answer: A

Spectrum B

Peak Assignment:
3600-2400: -COOH
1700: C=O
1600: C=C

Answer: C

Spectrum C
Peak Assignment:
2900: Csp3-H
1700: C=O

Answer: E

Spectrum D
Peak Assignment:
3500-3200: NH2
2900: Csp3-H

Answer: F

Spectrum E
Peak Assignment:
3300: Csp-H
2900: Csp3-H
2100: alkyne

Answer: D

Spectrum F
Peak Assignment:
3600-3200: -OH
2900: Csp3-H

Answer: B

2. Describe if the following pairs of molecules can be distinguished by IR spectroscopy. Explain your reasoning by listing out the difference in expected peaks.

(a) ![Molecule Image]

Left: Csp3-H, C=O
Right: Aldehyde Csp2-H, Csp3-H, C=O
Can be distinguished

(b)
3. Match the following structure to the corresponding IR spectrum shown below. All compounds have the molecular formula C₅H₉NO. Not all structures will be used.
Important Peaks:
3400-3000 -NH (one peak = one H)
2900 Csp3-H
1700 C=O
Answer: B

Important Peaks:
3400-3200 -NH
3010 Csp2-H
2990 Csp3-H

Spectrum C

Answer: C

Important peaks:
2990 Csp3-H
4. Identify the following indicated atoms or groups of atoms as (a) homotopic, enantiotopic, diastereotopic, or unrelated; (b) same or different chemical shifts.

a. Enantiotopic; same chemical shift

b.
Diastereotopic; different shift  

Homotopic (symmetric); same shift  

Enantiotopic; same shift
5. Give the formula, degrees of unsaturation, number of unique C13 NMR peaks, and number of unique 1H NMR peaks for the compounds below.

(a) Formula: C8H14O2
UN: 2
Number of 13C NMR peaks: 6
Number of 1H NMR peaks: 4

(b)

![Structure diagram](attachment:structure_diagram_b.png)

Formula: C5H10O2
UN: 1
Number of C13 NMR peaks: 3
Number of 1H NMR peaks: 2

(c)

![Structure diagram](attachment:structure_diagram_c.png)

Formula: C6H8O2
UN: 3
Number of C13 NMR peaks: 6
Number of 1H NMR peaks: 6

(d)
Formula: C4H6O2
UN: 2
Number of C13 NMR peaks: 4
Number of 1H NMR peaks: 4

6. Match the following 1H NMR spectra to the corresponding compound.

A
B
C
D
E
F

Spectrum A
Chemical Shift | Integration | Splitting | Assignment
--- | --- | --- | ---
8.4 | 1 | s, broad | Amide H
6.5 | 1 | dd | Alkene H
6.1 | 1 | dd | Alkene H
5.7 | 1 | dd | Alkene H
3.2 | 2 | quar | X-CH2-CH3
1.1 | 3 | t | -CH2-CH3

The doublets of doublets are hard to see but it looks like this when zoomed in.
<table>
<thead>
<tr>
<th>Chemical Shift</th>
<th>Integration</th>
<th>Splitting</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.2</td>
<td>1</td>
<td>s</td>
<td>Aldehyde H</td>
</tr>
<tr>
<td>3.4</td>
<td>4</td>
<td>t</td>
<td>X-CH2-CH2- Overlapping top and bottom halves</td>
</tr>
<tr>
<td>6.1</td>
<td>4</td>
<td>t</td>
<td>X-CH2-CH2-</td>
</tr>
</tbody>
</table>

The two connected CH2’s furthest away from N don’t split each other because they are all equivalent, so it only shows as a triplet split by the CH2 connected to the N.

7. Compound A is a precursor molecule of dopamine in the human body. You ran a sample of compound A through mass spectroscopy by electron impact ionization and obtained a [M]+ of 165.0788. The molecular formula and expected masses of some possible molecules are given below.

- $\text{C}_9\text{H}_9\text{N}_4\text{O}$ 165.0777
- $\text{C}_8\text{H}_5\text{O}_4$ 165.0187
- $\text{C}_8\text{H}_7\text{NO}_3$ 165.0426
- $\text{C}_8\text{H}_9\text{N}_2\text{O}_2$ 165.0664
- $\text{C}_8\text{H}_{11}\text{N}_3\text{O}$ 165.0903
- $\text{C}_8\text{H}_{13}\text{N}_4$ 165.1142
- $\text{C}_9\text{H}_9\text{O}_3$ 165.0552
- $\text{C}_9\text{H}_{11}\text{NO}_2$ 165.0790
- $\text{C}_9\text{H}_{13}\text{N}_2\text{O}$ 165.1029
- $\text{C}_9\text{H}_{15}\text{N}_3$ 165.1267
- $\text{C}_{10}\text{H}_{13}\text{O}_2$ 165.0916

(a) What’s the molecular formula of compound A?

$\text{C}_9\text{H}_{11}\text{NO}_2$
(b) What is the degree of unsaturation of compound A?

\[ UN = \frac{2 \times (\text{# of C}) + 2 + (\text{# of N}) - (\text{# of H}) - (\text{# of X})}{2} \]

\[ = \frac{(2 \times 9 + 2 + 1 - 11)}{2} \]

\[ = 5 \]

(c) The IR, \(^1\)H NMR, and \(^{13}\)C NMR spectra of compound A are given below. Propose the structure of the amino acid based on the data provided.

IR spectra:

\(^1\)H NMR spectra:

\(^{13}\)C NMR spectra:
IR peaks:

<table>
<thead>
<tr>
<th>Wavenumber</th>
<th>Intensity</th>
<th>Functional Group</th>
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</thead>
<tbody>
<tr>
<td>3600-2800</td>
<td>broad, strong</td>
<td>-COOH</td>
</tr>
<tr>
<td>1650</td>
<td>strong</td>
<td>C=O</td>
</tr>
<tr>
<td>1600</td>
<td>strong</td>
<td>C=C</td>
</tr>
</tbody>
</table>

-NH₂, Csp₂-H and Csp₃-H peaks “buried” by -COOH peak

1H NMR:

<table>
<thead>
<tr>
<th>Chemical Shift</th>
<th>Integration</th>
<th>Splitting</th>
<th>Assignment</th>
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<tbody>
<tr>
<td>12.9</td>
<td>1</td>
<td>s</td>
<td>-COOH</td>
</tr>
<tr>
<td>8.71</td>
<td>2</td>
<td>s</td>
<td>-NH₂</td>
</tr>
<tr>
<td>7.1</td>
<td>5</td>
<td>m</td>
<td>Phenyl H</td>
</tr>
<tr>
<td>4.18</td>
<td>1</td>
<td>t</td>
<td>H on α C</td>
</tr>
<tr>
<td>3.4</td>
<td>1</td>
<td>m</td>
<td>CH₂ next to α C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(diastereotopic)</td>
</tr>
</tbody>
</table>
13C NMR

<table>
<thead>
<tr>
<th>Chemical Shift</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>175</td>
<td>-COOH</td>
</tr>
<tr>
<td>140-120</td>
<td>Phenyl C</td>
</tr>
<tr>
<td>57</td>
<td>α C</td>
</tr>
<tr>
<td>37</td>
<td>CH2 next to α C</td>
</tr>
<tr>
<td></td>
<td>(diastereotopic)</td>
</tr>
</tbody>
</table>

Phenylalanine
(Note the existence of stereogenic center at the alpha carbon although not expected to be distinguished by spectroscopy in 51A)

Cumulative

1. Use the molecule below to answer parts A-C.
a) Label the functional groups of the molecule. Label groups as $1^\circ$, $2^\circ$, or $3^\circ$ when appropriate.
b) Count the number of stereogenic centers of the molecule, then label each as R or S.

4

c) How many stereoisomers are possible for this structure?

\[2^4 = 16\]

2. Use the molecule below to answer parts a-c.
a) Draw 3 resonance structures for the molecule.

\[ \text{Citrate} \]

b) Label the hybridization of each carbon atom.

There's no stereogenic center.
3. Use the reaction below to follow parts a-e.

\[ \text{CBr} + \text{OH}^- \rightarrow \text{CHOH}^- + \text{Br}^- \]

a) Label the reaction as substitution, addition, or elimination.

Substitution

b) Draw a curved arrow mechanism to convert the reactant to the product. Assume that the reaction is concerted (occurs in one step).

\[ \text{CBr} + \text{OH}^- \rightarrow \text{CHOH}^- + \text{Br}^- \]

c) Estimate the $\Delta H_{\text{rxn}}$ of the reaction in kJ/mol.

$\Delta H_{\text{rxn}} = \text{bonds broken} - \text{bonds formed}$

$= 285 - 393 = -108 \text{ kJ/mol}$
d) Based on your value from part c, draw an energy diagram for the reaction. Label the axes, starting material, product, activation energy, and $\Delta H^\circ$.

![Energy Diagram](image)

\[\text{Reactant} \rightarrow \text{Ea} \rightarrow \text{Product} \downarrow \Delta H^\circ\]

e) Draw the transition state for the reaction.

![Transition State](image)

4. Consider the following acid-base reaction.

\[
\text{\[\delta-\]O\[\delta-\]} + \text{CH}_3\text{SO}_3\text{H} \rightleftharpoons \]

a) Complete the acid-base reaction by adding the conjugate acid and base in the products. Label the acids and bases.

\[
\begin{align*}
\text{O} & + \text{CH}_3\text{SO}_3\text{H} \\
\text{base} & \quad \text{acid} \\
\leftrightarrow & \quad \text{H}^+ \\
\text{O} & + \text{CH}_3\text{SO}_3^- \\
\text{conjugate acid} & \quad \text{conjugate base}
\end{align*}
\]

b) Show the appropriate pKa of the acid on each side of the equation.

\[
\begin{align*}
\text{O} & + \text{CH}_3\text{SO}_3\text{H} \\
pKa: -1.2 & \quad \text{pKa: -3.6} \\
\leftrightarrow & \\
\text{H}^+ & + \text{CH}_3\text{SO}_3^-
\end{align*}
\]

c) Which side is favored at equilibrium (left or right)? Explain why.

The left side is favored, because and acid-base equilibrium reaction will favor the product with the weaker conjugate acid (higher pKa).

d) What is the approximate equilibrium constant?

\[
\begin{align*}
\text{Ke}_q &= 10^{(\text{products-reactants})} \\
\text{Ke}_q &= 10^{(-3.6-(-1.2))} \\
\text{Ke}_q &= 10^{-2.4} \\
\text{Ke}_q &= 4.0 \times 10^{-3}
\end{align*}
\]

5. For each of the following pairs of molecules, circle which is the more stable conformation.
a)

\[ \text{more stable (trans)} \]

b)

\[ \text{more stable (only 2 gauche interactions)} \]

c)

\[ \text{more stable (bulky substituent in equatorial position)} \]
6. Label all compounds below as chiral, achiral, or meso. Then, identify the stereochemical relationship between the 2 compounds. The possibilities are enantiomers, diastereomers, constitutional isomers, and identical.
a) chiral, chiral, enantiomers

b) achiral, achiral, diastereomers

c) meso, meso, identical

d) chiral, chiral, identical

7. Consider the following reaction.

a) In the alkene halogenation reaction mechanism, an intermediate called a bridged halonium is formed. Draw the last step of the mechanism to show the formation of product A.
b) Assume the optical specific rotation of 1,2-dibromocyclohexane is +19.5°. If a sample of product B has an optical rotation of +11.2°, what is the percentage of each enantiomer in the product? Assume the sample only contains the enantiomers of 1,2-dibromocyclohexane.

\[
\text{ee} = \left( \frac{11.2}{19.5} \right) \times 100\% = 57.4\%
\]

Product B is in excess.

Let Product B = x, % Product A = (1-x)

\[x - (1-x) = 57.4\% \]
\[2x - 1 = 57.4\% \]
\[2x = 157.4\% \]
\[x = 78.7\% \]

% R : 100% - 78.7% = 21.3%

So, Product B=78.7%, Product A=21.3%

c) Explain how an IR spectra of the products could be used to determine whether or not the reaction occurred to completion.

If the reaction reached completion, there would no longer be an IR peak from 1600-1670 from the alkene.

d) How many H NMR signals are present in product B?

5

8. Follow the task for each pair of molecules.

a) Give the IUPAC name.
b) Identify the compound with the higher boiling point.
c) Identify the compound that is more acidic.
### Appendix

#### pKa Table:

<table>
<thead>
<tr>
<th>Compound</th>
<th>pKa</th>
</tr>
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<tbody>
<tr>
<td>HI</td>
<td>-10</td>
</tr>
<tr>
<td>HBr</td>
<td>-9</td>
</tr>
<tr>
<td>HCl</td>
<td>-7</td>
</tr>
<tr>
<td>H$_2$SO$_3$H</td>
<td>-3.6</td>
</tr>
<tr>
<td>CH$_3$CO$_2$H</td>
<td>4.2</td>
</tr>
<tr>
<td>CH$_3$NH$_2$</td>
<td>4.6</td>
</tr>
<tr>
<td>CH$_3$NO$_2$</td>
<td>10.2</td>
</tr>
<tr>
<td>CH$_3$OH</td>
<td>10.2</td>
</tr>
<tr>
<td>CH$_3$CN</td>
<td>25</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>50</td>
</tr>
</tbody>
</table>

#### Periodic Table of the Elements
Table 6.2 Bond Dissociation Energies for Some Common Bonds \([A^{-}B \rightarrow A^{+} + B]\)

<table>
<thead>
<tr>
<th>Bond</th>
<th>(\Delta H^\circ) kJ/mol</th>
<th>(kcal/mol)</th>
<th>Bond</th>
<th>(\Delta H^\circ) kJ/mol</th>
<th>(kcal/mol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H--Z bonds</td>
<td></td>
<td></td>
<td>R--X bonds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H--F</td>
<td>569</td>
<td>(136)</td>
<td>CH(_3)--F</td>
<td>456</td>
<td>(109)</td>
</tr>
<tr>
<td>H--Cl</td>
<td>431</td>
<td>(103)</td>
<td>CH(_3)--Cl</td>
<td>351</td>
<td>(84)</td>
</tr>
<tr>
<td>H--Br</td>
<td>368</td>
<td>(88)</td>
<td>CH(_3)--Br</td>
<td>293</td>
<td>(70)</td>
</tr>
<tr>
<td>H--I</td>
<td>297</td>
<td>(71)</td>
<td>CH(_3)--I</td>
<td>234</td>
<td>(56)</td>
</tr>
<tr>
<td>H--OH</td>
<td>498</td>
<td>(119)</td>
<td>CH(_3)CH--F</td>
<td>448</td>
<td>(107)</td>
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<tr>
<td>Z--Z bonds</td>
<td></td>
<td></td>
<td>CH(_3)CH--Cl</td>
<td>339</td>
<td>(81)</td>
</tr>
<tr>
<td>H--H</td>
<td>435</td>
<td>(104)</td>
<td>CH(_3)CH--Br</td>
<td>285</td>
<td>(68)</td>
</tr>
<tr>
<td>F--F</td>
<td>159</td>
<td>(38)</td>
<td>CH(_3)CH--I</td>
<td>222</td>
<td>(53)</td>
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<tr>
<td>Cl--Cl</td>
<td>242</td>
<td>(60)</td>
<td>(CH(_3))(_2)CH--F</td>
<td>444</td>
<td>(106)</td>
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<tr>
<td>Br--Br</td>
<td>192</td>
<td>(46)</td>
<td>(CH(_3))(_2)CH--Cl</td>
<td>335</td>
<td>(80)</td>
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<tr>
<td>I--I</td>
<td>151</td>
<td>(36)</td>
<td>(CH(_3))(_2)CH--Br</td>
<td>285</td>
<td>(68)</td>
</tr>
<tr>
<td>HO--OH</td>
<td>213</td>
<td>(51)</td>
<td>(CH(_3))(_2)CH--I</td>
<td>222</td>
<td>(53)</td>
</tr>
<tr>
<td>R--H bonds</td>
<td></td>
<td></td>
<td>(CH(_3))(_2)C--F</td>
<td>444</td>
<td>(106)</td>
</tr>
<tr>
<td>CH(_3)--H</td>
<td>435</td>
<td>(104)</td>
<td>(CH(_3))(_2)C--Cl</td>
<td>331</td>
<td>(80)</td>
</tr>
<tr>
<td>CH(_3)CH--H</td>
<td>410</td>
<td>(98)</td>
<td>(CH(_3))(_2)C--Br</td>
<td>272</td>
<td>(65)</td>
</tr>
<tr>
<td>CH(_3)CH(_2)CH--H</td>
<td>410</td>
<td>(98)</td>
<td>(CH(_3))(_2)C--I</td>
<td>209</td>
<td>(50)</td>
</tr>
<tr>
<td>CH(_2)CH--H</td>
<td>397</td>
<td>(95)</td>
<td>R--OH bonds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH(_3)C--H</td>
<td>381</td>
<td>(91)</td>
<td>CH(_3)--OH</td>
<td>389</td>
<td>(93)</td>
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<tr>
<td>CH(_2)=CH--H</td>
<td>435</td>
<td>(104)</td>
<td>CH(_3)CH--OH</td>
<td>393</td>
<td>(94)</td>
</tr>
<tr>
<td>HO--C--H</td>
<td>523</td>
<td>(125)</td>
<td>CH(_3)CH(_2)CH--OH</td>
<td>385</td>
<td>(92)</td>
</tr>
<tr>
<td>CH(_2)=CHCH--H</td>
<td>364</td>
<td>(87)</td>
<td>(CH(_3))(_2)CH--OH</td>
<td>401</td>
<td>(96)</td>
</tr>
<tr>
<td>C(_2)H(_5)--H</td>
<td>490</td>
<td>(119)</td>
<td>(CH(_3))(_2)C--OH</td>
<td>401</td>
<td>(96)</td>
</tr>
<tr>
<td>C(_3)H(_5)CH--H</td>
<td>356</td>
<td>(83)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R--R bonds</td>
<td></td>
<td></td>
<td>A-value (equatorial preference for a cyclohexane substituent) in kJ/mol</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH(_3)--CH(_3)</td>
<td>368</td>
<td>(88)</td>
<td>-CH(_3)</td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td>CH(_3)--CH(_2)CH(_3)</td>
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<td>(85)</td>
<td>-CH(_2)CH(_3)</td>
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<td></td>
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<tr>
<td>CH(_3)--CH=CH(_2)</td>
<td>385</td>
<td>(92)</td>
<td>Phenyl</td>
<td>11.7</td>
<td></td>
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<td>CH(_3)--C\equiv CH</td>
<td>489</td>
<td>(117)</td>
<td>-CHO</td>
<td>3.0</td>
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<tr>
<td>A-value (equatorial preference for a cyclohexane substituent) in kJ/mol</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>-CH(_3)</td>
<td>7.3</td>
<td>-CH(_2)CH(_3)</td>
<td>7.5</td>
<td></td>
<td></td>
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<tr>
<td>-C(CH(_3))(_3)</td>
<td>20</td>
<td>Phenyl</td>
<td>11.7</td>
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<tr>
<td>-C\equiv CH (ethyne)</td>
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<td>-CHO</td>
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<td>-CO(_2)CH(_3)</td>
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<td>-Br</td>
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<td></td>
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<tr>
<td>-NH(_2)</td>
<td>7.1</td>
<td>-NO(_2)</td>
<td>4.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conversions:
1.0 kcal/mol = 4.184 kJ/mol
R = 1.985 cal/K*mol or 8.314 J/K*mol
0 °C = 273.15 K
Planck's constant: \( h = 6.626 \times 10^{-34} \text{ J*s} \)
1.0 acre = 4.047 × 10\(^3\) m\(^2\)
1.0 cubit = 524 mm
Bluish-green light (\(\delta\text{w}i\)) = 524 nm = 1.0 microcubit
**Interpretation of Infrared Spectra**

**X-H Region**
- Phenol & Alcohols: \( \text{RO-H} \)
  - 3700 - 3500 sharp
  - or
  - 3200 - 3600 broad (H-bonded)

- Acids: \( \text{ROH} \)
  - 2800 - 3600 very broad

- Amines & Amides: \( \text{RNH}_2 \)
  - 3300 - 3500
  - 2 bands: \( \text{N-H} \) primary
  - 1 band: \( \text{N-H} \) secondary

- C-H Bonds: \( \text{C-H} \)
  - 3200 - 3300
  - 3000 - 3200
  - 2900 - 3000
  - 2700 - 2800

**sp Region**
- Acetylenes: \( \text{C=C} \)
  - 2100 (weak or absent if highly symmetrical)

- Nitriles: \( \text{C≡N} \)
  - 2200

- Carbon dioxide: \( \text{O=C=O} \)
  - 2350

**Double Bond Region**
- Alkenes: \( \text{C=C} \)
  - 1600 - 1670 weak unless conjugated

- Imines: \( \text{C=N} \)
  - 1600 - 1700

- Nitro: \( \text{NO}_2 \)
  - 1350 and 1550

**Carbonyl Groups:**
- Anhydrides: \( \text{O=C=O} \)
  - 1800 - 1840 (2 bands)

- Acid Chlorides: \( \text{O} = \text{C} = \text{Cl} \)
  - 1800

- Esters: \( \text{O=C-O} \)
  - 1725 - 1750

- Acids: \( \text{O=H} \)
  - 1710

- Amides: \( \text{O=C-NH}_2 \)
  - 1650

- Aldehydes: \( \text{O} = \text{C} = \text{H} \)
  - 1725

- Carboxylate: \( \text{CO}_2^- \)
  - 1550-1610 and 1400

- Ketones: \( \text{O=CH} \) and \( \text{O} = \text{C} = \text{O} \)
  - 1710

  \[
  \text{Ring Contraction: add 30 for each contraction}
  \]

  \[
  \text{Conjugation: subtract 30}
  \]
<table>
<thead>
<tr>
<th>Type of proton</th>
<th>Chemical shift (ppm)</th>
<th>Type of proton</th>
<th>Chemical shift (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{C} - \text{H} )</td>
<td>0.9–2</td>
<td>( \text{R} - \text{C} = \text{H} )</td>
<td>4.5–6</td>
</tr>
<tr>
<td>( \text{RCH}_3 )</td>
<td>~0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \text{R}_2\text{CH} )</td>
<td>~1.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \text{R}_3\text{CH} )</td>
<td>~1.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \equiv \text{H} )</td>
<td>1.5–2.5</td>
<td>( \text{R} - \text{C} = \text{O} )</td>
<td>9–10</td>
</tr>
<tr>
<td>( \equiv \text{H} )</td>
<td>~2.5</td>
<td>( \text{R} - \text{C} = \text{OH} )</td>
<td>10–12</td>
</tr>
<tr>
<td>( \equiv \text{H} )</td>
<td>2.5–4</td>
<td>( \text{R} - \text{O} ) or ( \text{R} - \text{N} )</td>
<td>1–5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of carbon</th>
<th>Chemical shift (ppm)</th>
<th>Type of carbon</th>
<th>Chemical shift (ppm)</th>
</tr>
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<tbody>
<tr>
<td>( \equiv \text{C} )</td>
<td>5–45</td>
<td>( \equiv \text{C} )</td>
<td>100–140</td>
</tr>
<tr>
<td>( \equiv \text{C} )</td>
<td>30–80</td>
<td>( \equiv \text{C} )</td>
<td>120–150</td>
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<tr>
<td>( \equiv \text{C} )</td>
<td>65–100</td>
<td>( \equiv \text{C} )</td>
<td>160–210</td>
</tr>
<tr>
<td>( \equiv \text{C} )</td>
<td>5–45</td>
<td>( \equiv \text{C} )</td>
<td>100–140</td>
</tr>
</tbody>
</table>