SOLUTIONS MANUAL FOR
ORGANIC CHEMISTRY: AN ACID-BASE APPROACH, SECOND EDITION

by Michael B. Smith
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27. (a) Nitric acid is a stronger acid than water, so water is the base and nitric acid is the acid in this reaction to generate the nitrate anion (conjugate base) and the hydronium ion (conjugate acid).

\[
K_a = \frac{[\text{NO}_3^-] [\text{H}_3\text{O}^+]}{[\text{HNO}_3] [\text{H}_2\text{O}]}
\]

Nitric acid is a stronger acid than water, so water is the base and nitric acid is the acid in this reaction to generate the nitrate anion (conjugate base) and the hydronium ion (conjugate acid).

(b) Water is a stronger acid than ammonia, so ammonia is the base and water is the acid in this reaction. The reaction products are hydroxide anion (conjugate base) and the ammonium ion (conjugate acid).

\[
K_a = \frac{[\text{HO}^-] [\text{NH}_4^+]}{[\text{H}_2\text{O}] [\text{NH}_3]}
\]

Water is a stronger acid than ammonia, so ammonia is the base and water is the acid in this reaction. The reaction products are hydroxide anion (conjugate base) and the ammonium ion (conjugate acid).

(c) Hydrobromic acid is a stronger acid than ammonia, so ammonia is the base and HBr is the acid in this reaction to generate the bromide anion (conjugate base) and the ammonium ion (conjugate acid).

\[
K_a = \frac{[\text{Br}^-] [\text{NH}_4^+]}{[\text{HBr}] [\text{NH}_3]}
\]

Hydrobromic acid is a stronger acid than ammonia, so ammonia is the base and HBr is the acid in this reaction to generate the bromide anion (conjugate base) and the ammonium ion (conjugate acid).

(d) Hydrochloric acid is a stronger acid than water, so water is the base and HCl is the acid in this reaction to generate the chloride anion (conjugate base) and the hydronium ion (conjugate acid).

\[
K_a = \frac{[\text{Cl}^-] [\text{H}_3\text{O}^+]}{[\text{HCl}] [\text{H}_2\text{O}]}
\]

Hydrochloric acid is a stronger acid than water, so water is the base and HCl is the acid in this reaction to generate the chloride anion (conjugate base) and the hydronium ion (conjugate acid).

(e)
Note that the acidic hydrogen atom is attached to a carbon atom. The amide anion is clearly a base, which is a very strong base. Therefore, the strong base can react with the weakly acidic “carbon acid”. In other words, \( \text{NH}_2^- \) is the base and chloroform is the acid in this reaction that generates the anion \( \text{CCl}_3^- \) (the conjugate base) and ammonia, \( \text{NH}_3 \), which is the conjugate acid.

28. The main reason is likely the relative size of the bromide ion (182 pm or 1.82 Å) versus the chloride ion (100 pm, or 1.00 Å). Greater charge dispersal for the bromide ion leads to greater stability of that conjugate base, and a larger \( K_a \).

29.

\[
K_a = \frac{[\text{H}_3\text{O}^+][\text{Cl}^-]}{[\text{HCl}]}
\]

In this reaction, water is the base that reacts with the HCl. If water is omitted, the base has been excluded from the equilibrium expression for an acid-base reaction.

30. (a) \( \text{NH}_3 \)  (b) \( \text{H}_3\text{CO}^- \)  (c) \( \text{NO}_3^- \)  (d) \( \text{Br}^- \)  (e) \( \text{NH}_2^- \)  (f) \( \text{CH}_3^- \)

31. The ‘ate complex in the “box” is the reaction product, where N of ammonia is the electron donor (the base).

32. Oxygen is more electronegative than nitrogen, so nitrogen is more electron-rich, and will be a better electron-donor. In addition, the ‘ate’ complex from ammonia is an ammonium salt whereas water will react to form an oxonium salt. The ammonium salt is more stable, which contributes to the overall increased Lewis basicity of the nitrogen atom in ammonia.

33. In these neutral molecules, phosphorus is larger than nitrogen, with covalent radii of 106 and 71 pm (1.06 Å and 0.71 Å), respectively. The charge density of nitrogen is greater. Therefore, ammonia is expected to be the stronger Lewis base.

34. An ate complex is the salt generated by reaction of a Lewis acid with a Lewis base. The atom derived from the Lewis base expands its valence and assumes a positive charge, whereas the atom derived from the Lewis base expand its valence and assumes a negative charge.

35.
36. The C—H bond is much stronger than the N—H bond, so it is more difficult to break. Nitrogen is larger and better able to accommodate charge relative to carbon, so H₃C⁺ is significantly less stable (more reactive) than H₂N⁺. In addition, nitrogen is more electronegative than carbon, so the amide anion is more stable, which means that it is less reactive (it is a stronger base). If the NH₂ conjugate base is more stable, K_a is larger, and ammonia is a stronger acid.

37. (a) CH₃OH is the strongest acid in this series. The O—H bond is more polarized and easier to break, and the methoxide anion, H₃CO⁻, is more stable than the anions from CH₄ or CH₃NH₃. NaF does not have an acidic proton, and it is not a Brønsted–Lowry acid.
(b) As explained in section 2.4, the size of the conjugate base increases from fluoride towards iodide, so the iodide in is more stable. This means that K_a is larger for HI and decreases going towards HF. Since iodide is much larger, the H—I bond is longer, and weaker, so it is easier to break relative to the others.

38. The iodide in is much larger, and the charge is dispersed over a greater area. Therefore, it is more difficult for iodide to donate electrons to an acid relative to fluoride. In other words, iodide is a weaker base.

39. As shown, nitric acid generates the resonance stabilized nitrate anion. In the nitrate anion, the charge is dispersed over several atoms, which makes it more difficult for that species to donate electrons to an acid. For hydroxide ion, HO⁻, the charge is concentrated on the oxygen atom, and it is much easier to donate electrons. The charge is not dispersed as in the nitrate anion, and hydroxide is more basic.

40. The fluoride is much more stable relative to the methide anion, H₃C⁻, because fluoride is more electronegative. Therefore, it retains electrons whereas the less electronegative carbon does not. Therefore, carbon will donate electron more easily and the methide anion is the stronger base.

41. Determine the pK_a for each of the following.
(a) K_a = 1.45x10⁵  (b) K_a = 3.6x10⁻¹²  (c) K_a = 6.7x10⁻³¹  (d) K_a = 18  (e) K_a = 3.8x10¹⁴
pK_a = -log₁₀ K_a.
(a) 5.16  (b) 11.44  (c) 30.17  (d) -1.26  (e) -14.6

42. The more acidic acid will have the smaller pK_a. Of this series, HCl is the strongest acid (pK_a -7) relative to HF (pK_a 3.17). Water has a pK_a of 15.7 and ammonia has a pK_a of about 25. Clearly, HCl has the smallest pK_a.
43. The least acidic acid will have the largest $pK_a$. Of this series, HCl is the strongest acid ($pK_a \approx 7$) relative to HF ($pK_a \approx 3.17$). Water has a $pK_a$ of 15.7 and ammonia has a $pK_a$ of about 25. Clearly, ammonia is the least acidic and has the largest $pK_a$.

44. NaF is an ionic salt, $\text{Na}^+$ and $\text{F}^-$. The electron rich fluoride ion is the only atom of these two that can donate electrons, so F is the basic atom.

45. Clearly, water is more acidic. Figure 2.5 shows that oxygen is more electronegative than sulfur, so the O—H bond is more polarized than the C—S bond, and should be weaker. This is consistent with a larger $K_a$ for water ($\text{p}K_a$). Further, the more electronegative oxygen atom in the HO$^-$ anion makes it a poorer electron donor relative to HS$^-$, so hydroxide is the stronger base. This is also consistent with a larger $K_a$ for water.

46. 

\[ \text{A} \quad \xrightarrow{\text{OH bond weaker}} \quad \text{B} \]

The reaction of A gives the conjugate base shown, and B gives the conjugate base indicated. In both cases, the charge is dispersed over three atoms (resonance). The OH bond is weaker than the NH bond, and that proton is easier to remove. Oxygen holds onto electron better than nitrogen (it is more electronegative), so the conjugate base from A is less likely to donate electrons (it is more stable, which shifts the equilibrium towards the conjugate base). Although it is not obvious from the diagram, the charge dispersal is more efficient in the conjugate base from A. All of these combine to make A much more acidic ($pK_a$ of 4.8 versus 46).

47. 

\[ \text{H}_3\text{C} = \text{C} = \text{O} - \quad \xrightarrow{\text{NaOH}} \quad \text{H}_3\text{C} = \text{C} = \text{O}^- + \text{HOH} \]

\[ \text{H}_3\text{C} - \text{O} - \quad \xrightarrow{\text{NaOH}} \quad \text{H}_3\text{C} - \text{O}^- + \text{HOH} \]
(a) The conjugate base derived from formic acid is resonance stabilized by charge dispersal over several atoms, as shown. The conjugate base from methanol has the charge concentrated on oxygen, and no charge dispersal is possible.
(b) If there is a larger concentration of the conjugate base, the equilibrium is shifted toward the right (towards the conjugate base), and $K_a$ is larger.
(c) If $K_a$ for formic acid is much larger, it will be the stronger acid, and will react better with NaOH.

48. Since F is more electronegative than B, one predicts that C—F is the more polarized covalent bond.
49. Aluminum has d orbitals and boron does not. According to the rules presented for Lewis acid strength, the d orbitals are more available for donation, which makes AlCl₃ the weaker Lewis acid.

50.

\[
\text{NH}_4\text{Cl} + \text{NaOH} \rightleftharpoons \text{NH}_3 + \text{HOH} + \text{NaCl}
\]
22. Al is 1s^22s^22p^63s^23p^1  He is 1s^2  Be is 1s^22s^2  Mg is 1s^22s^22p^63s^2  
Cl is 1s^22s^22p^63s^23p^5  Br is 1s^22s^22p^63s^23p^63d^{10}4s^24p^5  Ti is 1s^22s^22p^63s^23p^63d^{2}4s^2  
Cu is 1s^22s^22p^63s^23p^63d^{10}4s^1

23. 

24. Both are group 1 elements. Potassium is a larger atom, which means that the 4s^1 electron is held less tightly than the 3s^1 electron on sodium. Using a very simple rationale, it should be easier to lose the electron from potassium, and the resulting K^+ ion is larger than the Na^+ ion and will be more stable.

25. No single orbital may hold more than two electrons, and if there is more than one orbital of the same energy (degenerate orbitals), no one orbital may hold two electrons until all orbitals hold one. For the second row, there is one s-orbital and three degenerate p-orbitals. Therefore, adding one electron to the 2s-orbital yields lithium (Li) and adding the second to that orbital yields beryllium (Be). Adding one electron to a 2p-orbitals gives boron (B), and the second electron goes to a different 2p-orbital to give carbon (C), and the third fills the last 2p-orbitals to yield nitrogen (N). The next electron will spin pair in a 2p-orbital to give oxygen (O) and the net electron will spin pair to give fluorine (F).

26. The four hydrogen atoms about carbon in methane arrange as far as possible from each other, with carbon in the middle: a tetrahedron. Ammonia has three atoms and a lone electron pair, with nitrogen in the middle of a tetrahedron. Since the electron pair cannot be seen, the shape of the three hydrogen atoms and the nitrogen constitutes a pyramidal structure.

27. 

The sp^3 hybridized carbon atoms are indicated by the arrows.

28.
29. The numbers indicate that it requires less energy to remove an electron from K (4.341 eV, 124.3 kcal mol\(^{-1}\)), so it is expected to be the most reactive. Since Li (5.392 eV, 113.5 kcal mol\(^{-1}\)) has the highest ionization potential, it is more difficult to lose an electron and it will be less reactive than Na (5.139 eV, 100.4 kcal mol\(^{-1}\)), the least reactive of the three. Therefore, K is more reactive than Na, which is more reactive than Li.

30. \(\Delta H^\circ = H^\circ_{\text{products}} - H^\circ_{\text{reactants}}\)
(a) \(\Delta H^\circ = (H^\circ_{\text{C-Br}} + H^\circ_{\text{H-O}}) - (H^\circ_{\text{H-Br}} + H^\circ_{\text{C-O}})\)
\[\Delta H^\circ = (67 + 104.2) - (87.4 + 257.3) = 171.2 - 344.7 = -173.5 \text{ kcal mol}^{-1}.\]
(b) \(\Delta H^\circ = 2xH^\circ_{\text{C-I}} - (H^\circ_{\text{C-C}} + H^\circ_{\text{I-I}})\)
\[\Delta H^\circ = 2\times50 - (145 + 36.5) = 100 - 181.5 = -81.5 \text{ kcal mol}^{-1}.\]
(c) \(\Delta H^\circ = (H^\circ_{\text{C-O}} + H^\circ_{\text{C-H}}) - (H^\circ_{\text{O-H}} + H^\circ_{\text{C-C}})\)
\[(257.3 + 80.6) - (104.2 + 145) = 337.9 - 249.2 = 88.7 \text{ kcal mol}^{-1}.\]
(d) \(\Delta H^\circ = (H^\circ_{\text{C-N}} + H^\circ_{\text{N-H}}) - (H^\circ_{\text{C-C}} + H^\circ_{\text{H-I}})\)
\[\Delta H^\circ = (50 + 75) - (184 + 71.4) = 125.0 - 255.4 = -130.45 \text{ kcal mol}^{-1}.\]

31. \(I-\text{CH}_3\) (C—I = 56 kcal or 234 kJ mol\(^{-1}\)); \(\text{Br—CH}_3\) (C—Br = 70 kcal or 293 kJ mol\(^{-1}\)); \(\text{Cl—CH}_3\) (C—Cl = 84 kcal or 351 kJ mol\(^{-1}\)).
Iodine is larger than Br, which is larger than Cl. The C—I bond distance is the greatest, and the C—Cl is least, which correlates with the weaker C—I bond and the stronger C—Cl bond.

33.

34.

(a) C—N  (b) N—O  (c) C—H  (d) Cl—Br  (e) B—C
(f) Li—C  (g) C—F  (h) N—H  (i) H—Cl

35.

(a) C—N  (b) N—O  (c) C—H
   *Polarized covalent*  *Polarized covalent*  *Nonpolarized covalent*

(d) C—F  (e) C—C  (f) Li—C
   *Polarized covalent*  *Nonpolarized covalent*  *Polarized covalent*

36. The covalent bond formed from two sp$^3$ hybridized carbon atoms is predicted to be relatively strong when compared to a polarized covalent bond (it is much weaker than an ionic bond). Since it is not polarized, the electrons are distributed equally between the two carbon nuclei. This symmetrical bond with most of the electron density between the nuclei is predicted to be strong.

37.

(a)  
(b)  
(c)  
(d)  
(e)  
(f)  

4 Polarized bonds, but they all cancel. Dipole moment = 0

No polarized bonds. Dipole moment should be 0
38. After loss of one electron, the electronic configuration of the ion F\(^{+}\) is \(1s^22s^22p^4\).

40. Iodine is much larger than fluorine, so the C—I bond distance is greater than that of C—F. Based on this simple analysis, the C—I bond should be weaker than the C—F bond because there is less electron density per unit distance between the nuclei. Based on this simple analysis, the C—I bond should be more reactive with a nucleophile in a chemical reaction.

41. Lithium tends to form Li\(^+\) with loss of one electron in the outmost shell, to give the Nobel gas configuration, which is quite stable. Fluorine is in group 17 tends to form an anion by gaining one electron to give the Noble gas electronic configuration, which is more stable. Therefore, LiF tends to form an ionic bond.

   Carbon is in the middle of the periodic table and electron transfer is not energetically feasible, but sharing electrons in a covalent bond is energetically practical (i.e., lower in energy).

42. A 2p-orbital has a dumb-bell shape, whereas the 4s-orbital is spherical.

43. The C—C bond is the least polarized because there is no heteroatom, and no difference in electronegativity of the bonded atoms. In C—N, C—O and C—F, one atom is more polarized than the other, leading to a polarized covalent bond.

44. Sodium (Na) has the electronic configuration \(1s^22s^22p^63s^1\). Loss of one electron generates the ion, Na\(^+\), so the electronic configuration is \(1s^22s^22p^6\).

45. There is greater difference in energy between 1s- and 2p-orbitals than between 2s- and 2p-. Mixing a 1s- and a 2p-orbital is expected to generate a higher energy molecular orbital, \textit{if it can form at all}, which is unlikely.

46. The C—O bond will be a sp\(^3\) hybrid orbital in a \(\sigma\)-covalent bond, similar to that formed for a C—C bond. It will have the familiar hybrid orbital shape:
25. Butane

Decane

Tridecane

26. (a)

Longest chain = 4
butane

Longest chain = 4
propane

Longest chain = 5
pentane

(b)

27. (a) Structures (a)-(d) + (g) have the same empirical formula, and are isomers.
(b) The isomers with the formula \(C_6H_{14}\) are marked.

\[
\begin{align*}
\text{Isomers} & \\
\text{C}_6\text{H}_{12} & \quad \text{C}_6\text{H}_{14} & \quad \text{C}_6\text{H}_{14} & \quad \text{C}_8\text{H}_{18} & \quad \text{C}_6\text{H}_{14}
\end{align*}
\]

28.

(a) \[\text{Octane}\]

(b) \[\text{3,7-Diethyldecane}\]

(c) \[\text{3,3,7-Trimethylundecane}\]

(d) \[\text{6-Propylpentadecane}\]

29.

(a) \[\text{1,1,4,4-Tetramethylcyclohexane}\]

(b) \[\text{3,9-Dimethyl-8-(2,2-dimethylpropyl)nonadecane}\]

(c) \[\text{Octane}\]

(d) \[\text{6-Bromo-6-ethyl-3-methyldecane}\]
30. (a) Isomers of 1-bromo-octane will have the formula C₈H₁₇Br.
Several are shown, but there are others.

- 2-Bromo-6-methylheptane
- 3-Bromo-4-methylmethylheptane
- 2-Bromo-2,3-dimethylhexane
- 3,3-Dimethyl-4-bromo-hexane
- 2-Bromo-2,4,4-trimethylpentane
- 3-Bromo-2,3,4-trimethylpentane

(b) With a formula C₆H₁₂, assume they are cyclic alkanes. Several are shown, but there are others.

- Cyclohexane
- Methylcyclopentane
- 1-Ethylcyclobutane
- 1,2-Dimethylcyclobutane
- 1,1,3-Trimethylcyclopropane

31. (a) 3,5-Dimethylheptane has a formula C₉H₂₀.

(b) Isomers of cycloheptane will have the formula C₇H₁₄.
32. (a) 1,2,3-Triethylcycloheptane
(b) 3,4-Dichloro-5-(3-methylbutyl)hexadecane
(c) 1-Chloro-2,2,4,4-tetramethylhexane
(d) 2,2-Dibromo-3-methyloctane
(e) 1,1-Diethylcyclohexane
(f) 5-(1-Methylpropyl)decane

33. A sample weighing 0.6000 g was burned in the presence of oxygen to yield 0.7692 g of water and 1.8827 g of CO₂.
\[
g \text{C} = 0.2727 \times 1.8827 = 0.5134 \text{ g and } g \text{ H} = 0.1111 \times 0.7692 = 0.0855 \text{ g}
\]\nAssume the molecule is a hydrocarbon, so
\[
\% \text{C} = \frac{0.5134}{(0.5134 + 0.0855)} = \frac{0.5134}{0.5989} \times 100 = 85.81\%
\]\n\[
\% \text{H} = \frac{0.0855}{0.5989} \times 100 = 14.28\%
\]
Assume 100 g, so there are 85.81 g of C and 14.28 g of H
\[
\text{mol C} = 85.81/12 = 7.15 \quad \text{and} \quad \text{mol H} - 14.28/1 = 14.28
\]
so, 14.28/7.15 = 2H/C = CH₂ = any cyclic alkane formula \( C_nH_{2n} \)

34. For a 5-carbon chain, use pent-.

35. In ethylcyclohexane, the substituent chain has fewer carbon atoms than the ring, so the base name is cyclohexane. In cyclohexyldecane, the long chain has more carbon atoms than the ring, so the base name is dodecane.
36. Calculate the % C and H, as well as an empirical formula for each of the following using the combustion analysis provided.

(a) A sample weighing 0.52 g was burned in the presence of oxygen to yield 0.6688 g of water and 1.6344 g of CO₂.

\[
g \text{ C} = 0.2727 \times 1.6344 = 0.4457 \text{ g} \quad \text{and} \quad g \text{ H} = 0.1111 \times 0.6688 = 0.0743 \text{ g}
\]

Assume the molecule is a hydrocarbon, so

\[
\% \text{ C} = \frac{0.4457}{0.4457 + 0.0743} \times 100 = 85.71\%
\]

\[
\% \text{ H} = \frac{0.0743}{0.52} \times 100 = 14.29\%
\]

Assume 100 g, so there are 85.71 g of C and 14.98 g of H

mol C = 85.71/12 = 7.14 and mol H - 14.29/1 = 14.29

so, \(14.29/7.14 = 2\text{H/C} = \text{CH}_2\) = any cyclic alkane formula \(C_nH_{2n}\)

(b) A sample weighing 0.81 g was burned in the presence of oxygen to yield 0.8578 g of water and 2.6208 g of CO₂.

\[
g \text{ C} = 0.2727 \times 2.6208 = 0.7147 \text{ g} \quad \text{and} \quad g \text{ H} = 0.1111 \times 0.8578 = 0.0953 \text{ g}
\]

Assume the molecule is a hydrocarbon, so

\[
\% \text{ C} = \frac{0.7147}{0.7147 + 0.0953} \times 100 = 88.23\%
\]

\[
\% \text{ H} = \frac{0.0953}{0.81} \times 100 = 11.77\%
\]

Assume 100 g, so there are 88.23 g of C and 11.77 g of H

mol C = 88.23/12 = 7.35 and mol H - 11.77/1 = 11.77

so, \(11.77/7.35 = 1.6\text{H/C} = \text{CH}_1.6 \times 2 = C_2H_{3.2}\) or \(x3 = C_3H_{4.8}\) or \(x4 = C_4H_{6.5}\) or \(x5 = C_5H_{8}\)

The last one makes sense, and matches the alkane formula \(C_nH_{2n+2}\), so, \(C_5H_8\).

37.

(a) 1,1,3,3-Tetramethylcyclooctane

(b) 4,4-Dichloro-2,6-dimethylheptane

(c) 1,3,5-Triethylcyclohexane

(d) Dimethylcyclohexane

(e) Nonane

(f) 6-(1,1-Diethylbutyl)-3,3,7-trifluorotetradecane

(g) Fluoromethane
38. A and F and G are identical, octane. B and E are identical, 3-ethylhexane. C and I are identical, 2,5-dimethylhexane. D and H are identical, 3,3-dimethylhexane.

There are four different structures of A-I, which are isomers, all with the formula C₈H₁₈.
40.

Nonane

3-Methyloctane

4-Methyloctane

2-Methyloctane

2,4-Dimethylheptane

2,6-Dimethylheptane

2-Ethylheptane

3,3-Dimethylheptane

2,3-Dimethylheptane

4-Ethyl-2-methylhexane

41.

(a) 3,3,5-Trichlorodecane

Cl Cl Cl

(b) 2,6-Dimethyl-3-fluorohexane

F

(c) 2,2-Dichloro-4,4-dibromoheptane

Br Br Cl Cl
59.

(a) \( \text{Br}_3\text{C}^\text{sp3}\text{Br} \)  
(b) \( \text{sp}^3\text{C}^\text{sp}^2\text{CH}_2\)  
(c) \( \text{CH}_3\)  
(d) \( \text{Cl}_3\text{C}^\text{sp3}\text{CH}_2\text{CH}_3 \)  
(e) \( \text{Br}_3\text{C}^\text{sp}^3\text{CH}^=\text{CH}_2 \)  
(f) \( \text{CH}_2\text{sp}^2\text{C}^\text{sp}^3\text{CH}_2 \)

60. (a) \( \text{C}_{10}\text{H}_{20} \)  
(b) \( \text{C}_{20}\text{H}_{42} \)  
(c) \( \text{C}_8\text{H}_{14} \)  
(d) \( \text{C}_{16}\text{H}_{34} \)  
(e) \( \text{C}_9\text{H}_{16} \)  
(f) \( \text{C}_{100}\text{H}_{200} \)

(a) alkene or cyclic alkane; (b) alkane; (c) alkyne; (d) alkane; (e) alkyne; (f) alkene or cyclic alkane

61.

(a) \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \)  
(b) \( \text{(CH}_3)_2\text{CHCH}_2\text{CH}_2\text{CH}_3 \)

(c) \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}^=\text{CH}_2 \)  
(d) \( \text{CH}_3\text{CH}_2\text{C}^=\text{C(CH}_2)_8\text{CH}_3 \)

62. Structures (a), (c) and (d) have resonance forms that involve a C=N, C=O or C=Cl structure, respectively.

Structure (b) is an oxocarbenium ion, and the adjacent carbon is sp\(^3\) hybridized. All valences are satisfied, and there is not possibility of a C=O structure. The same is true for (f), where the nitrogen is present as ammonium. Cation (e) cannot form a C=C unit to the adjacent sp\(^3\) hybridized carbon, which has all valences satisfied.
63. (a) \( \text{C} \rightarrow \text{N} \)  (b) \( \text{N} \rightarrow \text{O} \)  (c) \( \text{C} \rightarrow \text{H} \)  (d) \( \text{Cl} \rightarrow \text{Br} \)  (e) \( \text{B} \rightarrow \text{C} \)  
   (f) \( \text{Li} \rightarrow \text{C} \)  (g) \( \text{C} \rightarrow \text{F} \)  (h) \( \text{N} \rightarrow \text{H} \)  (i) \( \text{H} \rightarrow \text{Cl} \)

64. (a) \( \text{C} \rightarrow \text{N} \)  \text{Polarized covalent}  
   (b) \( \text{N} \rightarrow \text{O} \)  \text{Polarized covalent}  
   (c) \( \text{C} \rightarrow \text{H} \)  \text{Nonpolarized covalent}  
   (d) \( \text{C} \rightarrow \text{F} \)  \text{Polarized covalent}  
   (e) \( \text{C} \rightarrow \text{C} \)  \text{Nonpolarized covalent}  
   (f) \( \text{Li} \rightarrow \text{C} \)  \text{Polarized covalent}  

65. (a)  
   (b)  
   (c)  
   (d)  
   (e) 

66. Counting the electron pair, there are four different groups on N. If you make a model of both structures, you cannot superimpose them: they are different. However, they rapidly interconvert by fluxional inversion, so there is essentially a 50:50 mixture of both (see Sections 5.8.4 and 9.9.2).
67. In (b), (c), and (d), the π-bond is directly connected to the negatively charged atom. Therefore, the electrons on the negatively charged oxygen atom can be delocalized into the adjacent π-bonds, leading to the resonance structures shown. Note that (b) and (c) are the same!

68.

69.

70. In (b), (c), and (d), the π-bond is directly connected to the negatively charged atom. Therefore, the electrons on the negatively charged oxygen atom can be delocalized into the adjacent π-bonds, leading to the resonance structures shown. Note that (b) and (c) are the same!
71. **B:** \[\text{H}^+ - \text{CH}_2\text{CN} \rightarrow [\text{B:} - \text{H} - \text{CH}_2\text{CN}] \rightarrow \text{B:H} + \text{CH}_2\text{CN}\]

This carbanion is resonance stabilized, so the proton of acetonitrile is relatively acidic, and relatively easy to remove if a strong base is used (see Chapter 22).

72. Reactions (a) and (c) are two electron transfer reactions, whereas reaction (b) is a radical process, which means that it proceeds by one electron transfer as shown.

(a) \[\text{I}^- \rightarrow \text{CH}_3\text{Cl} \rightarrow \text{CH}_3\text{I} \rightarrow \text{Cl}^-\]

(b) \[\text{I}^- \rightarrow \text{CH}_3 \rightarrow \text{I}^-\]

(c) \[(\text{CH}_3)_2\text{C}^- \rightarrow \text{Cl}^- \rightarrow (\text{CH}_3)_2\text{C}^-\]

73. Reaction with a base generates alkoxide anion A. Resonance delocalization leads to the resonance contributors shown, and the charge can be delocalized to the second oxygen, as in B. It is possible to view B and A as an “extended carboxylate anion” because of the delocalization that is made possible by the intervening π-bonds. This extension of reactivity by intervening π-bonds is known as vinylogy, and tropolone is considered to be a “vinylogous” carboxylic acid. In other words, the OH proton of tropolone is acidic in large part because the resulting conjugate base is resonance stabilized in a way that allows the carbonyl group to be involved, much like the carboxylate anion seen in carboxylic acids.

74. A and B are isomers. C and D and F are isomers. G and I are isomers. E and H have no isomers

75. Note: The term \(E^-\) should be used with (a) and also for (c), but this nomenclature will not be discussed until Chapter 9. Therefore, for this problem, leaving out the \(E\) term is OK.
(a) 5-(2,2-dimethylbutyl)hexadec-2-ene  
(b) 4,5,6,7-tetraethyldec-2-yn

(c) 7,8-di(1,1-dimethylethyl)pentadeca-1,3-diene  
(d) 1,3,3,5,5,6-hexamethylcyclohexene

(e) 1-cyclopropyl-2-ethylcycloheptene  
(f) 5,5-diethylnon-3-yn

76.

(a)  
(b)  
(c)  
(d)  
(e)  
(f)  
(g)  
(h)  

4-Ethyl-4-methyloctane  
6-Ethyl-7-methylnona-5-en-1-yn  
6-Methyl-7-(3-methylbutan-2-yl)tridec-6-ene  
4,5,5,6-Tetramethyloct-3-ene

3-Ethyl-5-methylhex-1-yn  
5-Ethyl-4,8-dimethylnona-1,6-diyne  
7-Methyl-6-(tert-pentyl)dec-1-yn  
2,4,4,5,5-Pentamethylhex-2-ene
Note: The (E/Z) nomenclature for certain alkenes is omitted, because those terms will not be discussed until Section 9.6.3.

There are many answers for this question. Only 12 representative structures are provided.
79. Note: E/Z nomenclature is not introduced until Chapter 9, so it is omitted here.

80. The E/Z nomenclature is not discussed until Chapter 9, so it is omitted here.

2,4-Dimethyl-3-phenylpentan-3-ol

3-Phenylhex-3-ene  2-Chlorocyclopentanol
4-Ethyl-3-methyltetradec-3-ene

4-Methylhept-3-ene

7,10-Dimethyldodecan-6-ol

4-Cyclopropyl-2-methylpentan-2-ol

Hex-2,3-diol

4,5-Dibromooc-4-ene

3-Methyl-3-hept-3-ene

4-Phenyl-hex-3-en-2-ol

4-Chloro-3-fluorohept-3-ene

Hept-6-yn-2-ol

2-Methylcycloheptan-1-ol

5,6-Diphenylheptan-2-ol

8-Chloro-5-(3-ethylheptyl)pentadecan-1-ol

Heptane-3,4,5-triol

1,2,3,4,5,6-Hexamethycyclohexan-1-ol

4-Phenylctane-1,8-diol

3-Chloronon-8-en-1-ol
82.

(a) \(N,N\)-(1-Methylethyl)butan-1-amine

(b) 1-Butylpiperidine

(c) \(N\)-Methylcyclohexanamine

(d) 2-Phenylpentan-1-amine

(e) 7,7-Dimethyl-N-phenyloctan-2-amine

(f) 1-Chloro-\(N\)-chloromethylmethanamine (bis(chloromethyl)amine)

83.

(a) 2-Methylcyclobutanone

(b) 2-Ethylhexanal

(c) 3-Methyl-4-phenylpentan-2-one

(d) 2-Methylhexan-3-one

(e) 6-Bromo-5,5-dimethylhexan-3-one

(f) 1-Ethylcyclohexanecarbaldehyde

(g) Dicyclohexymethanone (Dicyclohexyl ketone)

(h) 4,4-Dichloro-2,3,6-trimethyloctanal

(i) Formal (Formaldehyde)

(j) 4-Phenylbutanal
84. Draw the structure of the following molecules.

(a) 8-Phenyl octanoic acid

(b) 3,3,6-Tetrabromohexadecanoic acid

(c) 2,5-Dimethylhexanedioic acid

(d) 3-Chlorocyclohexane-1-carboxylic acid

(e) 2,5-Dimethylcyclopentanecarbaldehyde

85. A $\pi$-bond is formed by sideways overlap of two adjacent and parallel p-orbitals. A $\sigma$-bond is formed by the direct overlap of two hybrid orbitals, and all of the electron density of the bond is concentrated on a line between the two carbon nuclei. In a $\pi$-bond, only some of the electron density is shared. If the shared electron density is less in a $\pi$-bond, it is a weaker bond.

86.

Methanesulfonic acid

Acetic acid

(a) Both products are shown. Methanesulfonic acid gives the methanesulfonate anion and acetic acid gives the acetate anion.

(b) A sight difference in O—H bond strength for sulfuric acid is based on the greater electron withdrawing effect of the sulfonyl unit relative to the carbonyl unit. Both conjugate bases are resonance stabilized, but there are more resonance contributors for the methanesulfonate anion, so it is more stable. This increased stability for the conjugate base should shift $K_a$ toward products, making the sulfonic acid more acidic. In addition, sulfur is a large atom relative to carbon, and this will contribute to increase charge dispersal, also making the sulfonic acid more acidic.
87. Fluoromethane (CH$_3$F) has a single polarized bond and is the more polar molecule. Methane and ethylene are hydrocarbons with no polarized bonds, and nonpolar. The four C—F bonds in tetrafluoromethane cancel, so the molecule is nonpolar.

88. Propanoic acid (third choice from the left) is the only molecule capable of hydrogen bonding, since it has the polarized O—H unit. The ether and the ketone are capable of dipole-dipole interactions, but do not have a polarized X—H bond, and butane only has nonpolarized C—H bonds.

89. The methanesulfonate anion is resonance stabilized, as shown, so the charge is dispersed over several atoms, and there is less electron density available for donation: it is a weaker base. The methoxide anions derived from methanol is not resonance stabilized, so the charge is localized on the oxygen atom, and readily available for donation: it is more basic. In other words, the charge density on oxygen in methoxide is much greater than the charge density on oxygen in the methanesulfonate anion.

90.

91. Hexane will have the **highest** boiling point. All are straight-chain alkanes, and hexane has the greatest mass.
92.

(a) $\text{FC} = 6-0.5(6)-2 = +1$

(b) $\text{FC} = 5-0.5(6)-2 = 0$

(c) $\text{FC} = 7-0.5(2)-6 = 0$

(d) $\text{FC} = 6-0.5(8)-0 = 0$

(e) $\text{FC} = 6-0.5(4)-4 = 0$

(f) $\text{FC} = 7-0.5(2)-6 = 0$

93.

(4-Methylcyclohexyl)methanol
(4-Methylcyclohexanemethanol)
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46. (a) \( K_a = 6.35 \times 10^{-6} \) : \( pK_a = 5.2 \)
(b) \( K_a = 12.1 \times 10^7 \) : \( pK_a = -8.1 \)
(c) \( K_a = 18.5 \times 10^{-12} \) : \( pK_a = 10.7 \)
(d) \( K_a = 9.2 \times 10^{-3} \) : \( pK_a = 2.04 \)
(e) \( K_a = 10.33 \times 10^{-8} \) : \( pK_a = -9.0 \)
(f) \( 0.08 \times 10^{-3} \) : \( pK_a = 4.1 \)

47. (a) \( pK_a = 6.78 \) : \( K_a = 1.66 \times 10^{-7} \)
(b) \( pK_a = -3.2 \) : \( K_a = 1584 \)
(c) \( pK_a = 23.5 \) : \( K_a = 3.12 \times 10^{-24} \)
(d) \( pK_a = -3.2 \) : \( K_a = 1584 \)
(e) \( pK_a = 35.8 \) : \( K_a = 1.583 \times 10^{-36} \)
(f) \( pK_a = -11.1 \) : \( K_a = 1.26 \times 10^{11} \)

48.

(a) \( \text{H}_3\text{C}^-\text{CH}_2\text{C}=\text{O}+\text{OH}^- \rightarrow \text{H}_3\text{C}^-\text{CH}_2\text{C}=\text{O}^-+\text{H}_2\text{O} \)

(b) \( \text{H}_3\text{C}^-\text{CH}_2\text{C}=\text{O}^-+\text{NH}_2^- \rightarrow \text{H}_3\text{C}^-\text{CH}_2\text{C}=\text{O}^-+\text{H-NH}_2 \)

(c) \( \text{H}_3\text{C}^-\text{CH}_2\text{C}=\text{O}^-+\text{OH}^- \rightarrow \text{H}_3\text{C}^-\text{CH}_2\text{C}=\text{O}^-+\text{H}_2\text{O} \)

(d) \( \text{H}_3\text{C}^-\text{CH}_2\text{C}=\text{O}^-+\text{NH}_2^- \rightarrow \text{H}_3\text{C}^-\text{CH}_2\text{C}=\text{O}^-+\text{H-NH}_2 \)

(e) \( \text{N}=\text{C}^-+\text{OH}^- \rightarrow \text{N}=\text{C}^-+\text{H}_2\text{O} \)

(f) \( \text{N}=\text{C}^-+\text{NH}_2^- \rightarrow \text{N}=\text{C}^-+\text{H-NH}_2 \)

(g) \( \text{H}_3\text{C}^-\text{SOH}^-+\text{OH}^- \rightarrow \text{H}_3\text{C}^-\text{SO}^-+\text{H}_2\text{O} \)

(h) \( \text{H}_3\text{C}^-\text{SOH}^-+\text{NH}_2^- \rightarrow \text{H}_3\text{C}^-\text{SO}^-+\text{H-NH}_2 \)
49. As noted in A, the COOH group is close to the Cl, which is held in space due to the rigid nature of the molecule. Therefore, internal hydrogen bonding is possible in A, through-space effect, but not in B. Internal hydrogen bonding will lead to enhanced acidity for A relative to B. In other words, carboxylic acid A has a smaller $pK_a$ than carboxylic acid B.

51. Acid (A) is slightly more acidic because the proton of the COOH unit is closer to the Cl, which allows better internal hydrogen bonding (a through-space effect) when compared to acid (B).
53. (a) Sodium hydroxide (NaOH). The conjugate acid is water, which is slightly more acidity than propanol, so propanol will likely react as a weak acid.

(b) Hydrochloric acid (HCl). The conjugate acid is chloride ion, and HCl is a much stronger acid than propanol, so proposal will react as a base.

(c) Water (H₂O). The conjugate acid is the hydronium ion, which is a much stronger acid than propanol, so propanol will likely react as a very weak base or a very weak acid. For all practical purposes, it is neutral.

(d) Ethanol (CH₃CH₂OH). The conjugate acid is an oxonium ion, which is a much stronger acid than propanol, so propanol will likely react as a very weak base or a very weak acid. For all practical purposes, it is neutral.

(e) Sodium amide (NaNH₂). The conjugate acid is ammonia, which is a significantly weaker acid than propanol, so proposal will likely react as an acid.

(f) Butan-2-one. The conjugate acid is an oxonium ion, which is a much stronger acid than propanol, so propanol will likely react as a very weak base or a very weak acid. For all practical purposes, it is neutral.

(g) Methane (CH₄). Methane is not acidic or basic, so there is no reaction at all with propanol, so it is neutral.
(h) Sulfuric acid (H$_2$SO$_4$). The conjugate acid is hydrogen sulfate ion, and sulfuric acid is a much stronger acid than propanol, so propanol will react as a base.

54.

\[
\begin{align*}
&\text{(a)} \quad \begin{array}{c}
\text{CH}_2=CH-CH=CH_2 \quad \text{or} \\
\text{CH}_2=CH-CH=CH_2
\end{array} \\
&\quad \begin{array}{c}
\text{CH}_2=CH-CH=CH_2 \\
\text{CH}_2=CH-CH=CH_2
\end{array} + H-NH_2
\end{align*}
\]

These are enolate anions. See Section 22.5.1

\[
\begin{align*}
&\text{(b)} \quad \begin{array}{c}
\text{CH}_2=CH-CH=CH_2 \\
\text{CH}_2=CH-CH=CH_2
\end{array} \\
&\quad \begin{array}{c}
\text{CH}_2=CH-CH=CH_2 \\
\text{CH}_2=CH-CH=CH_2
\end{array} + H-NH_2
\end{align*}
\]

55. Maleic acid (A) with a pK$_a$ of ~1.8 is more acidic because one carboxyl group is relatively close to the OH unit of a second carboxyl group (they are on the same side of the molecule), so internal hydrogen bonding is possible. In fumaric acid (B), the pK$_a$ is ~3 is higher (less acidic), in large part because the two COOH units are on opposite sides of the rigid alkene unit. There is no rotation about the C=C unit.

\[
\begin{align*}
&\text{(c)} \quad \begin{array}{c}
\text{CH}_2=CH-CH=CH_2 \\
\text{CH}_2=CH-CH=CH_2
\end{array} \\
&\quad \begin{array}{c}
\text{CH}_2=CH-CH=CH_2 \\
\text{CH}_2=CH-CH=CH_2
\end{array} + H-NH_2
\end{align*}
\]

This H is more acidic due to proximity of two C=O units

\[
\begin{align*}
&\text{(d)} \quad \begin{array}{c}
\text{CH}_2=CH-CH=CH_2 \\
\text{CH}_2=CH-CH=CH_2
\end{array} \\
&\quad \begin{array}{c}
\text{CH}_2=CH-CH=CH_2 \\
\text{CH}_2=CH-CH=CH_2
\end{array} + H-NH_2
\end{align*}
\]

\[
\begin{align*}
&\text{(e)} \quad \begin{array}{c}
\text{CH}_2=CH-CH=CH_2 \\
\text{CH}_2=CH-CH=CH_2
\end{array} \\
&\quad \begin{array}{c}
\text{CH}_2=CH-CH=CH_2 \\
\text{CH}_2=CH-CH=CH_2
\end{array} + H-NH_2
\end{align*}
\]

56. In 5-bromopentanoic acid, the bromine atom is very far away from the polarized O—H unit, so there is no through-bond or through-space inductive effect. In 2-bromopentanoic acid, the Br is relatively close so there is a through-bond inductive effect, and internal hydrogen bonding is possible (leading to a through-space inductive effect) that leads to enhanced acidity.
57. Propanoic acid reacts faster with diethylamine, which is a much stronger base than diethyl ether, so propanoic acid is more acidic in diethylamine than it is in ethyl ether. This means that $K_a$ for the reaction with diethylamine is larger and $K_a$ for the reaction with diethyl ether is smaller.

58. If there is no base, HCl cannot react as an acid. Therefore, HCl is technically not a base under such conditions. The real point of this question is to emphasize that an acid only reacts as an acid in the presence of a base, and that the strength of the acid depends on the strength of the base it reacts with.

59. Butanoic acid is a weaker acid than acetic acid. Compare RCH$_2$COOH with CH$_3$COOH, where R is an ethyl group. The alkyl group is electron releasing relative to the carbon attached to the carbonyl, which diminishes the acidity by strengthening the O—H bond by inductive effects. Formic acid is a stronger acid than acetic acid for the same reason. Compare HCOOH with CH$_3$COOH, where the methyl group is electron releasing relative to H.

60.

(a) \[ \text{Cl—H} \quad \text{NEt}_3 \quad \rightarrow \quad \text{Cl}^- \quad \text{H—NEt}_3 \]

(b) \[ \text{F}_3\text{B} \quad \text{NEt}_3 \quad \rightarrow \quad \text{F}_3\text{B—NEt}_3 \]

(c) \[ \text{CH}_3\text{CH}_2\text{COO—H} \quad \text{NEt}_3 \quad \rightarrow \quad \text{CH}_3\text{CH}_2\text{COO}^- \quad \text{H—NEt}_3 \]

(d) \[ \text{Cl}_3\text{Al} \quad \text{NEt}_3 \quad \rightarrow \quad \text{Cl}_3\text{Al—NEt}_3 \]

(e) \[ \text{CH}_3\text{SO}_3—\text{H} \quad \text{NEt}_3 \quad \rightarrow \quad \text{CH}_3\text{SO}_3^- \quad \text{H—NEt}_3 \]

(f) \[ \text{Cl}_3\text{Fe} \quad \text{NEt}_3 \quad \rightarrow \quad \text{Cl}_3\text{FeAl—NEt}_3 \]

61. It is possible to look at the reverse reaction of the conjugate acid derived from reaction of an amine with an acid (an ammonium salt). For the reverse reaction where the ammonium salt—base pair is on the left, and the amine and H:base are on the right, $K_a$ can be determined. It is also possible to look at the reaction of an amine with water to yield the conjugate acid–conjugate base, and use the term $K_B$. The
term \( K_B \) is used to evaluate the basicity of a base (e.g., an amine), and a larger value of \( K_B \) (small \( pK_B \)) indicates a strong base whereas a smaller value of \( K_B \) (large \( pK_B \)) indicates a weaker base.

62. Look at the amine precursors to the amide anions. Diisopropylamine is a weaker acid than diethylamine, which makes diisopropylamide a stronger base. The reason is probably some steric hindrance of the isopropyl group relative to ethyl for removal of the proton from nitrogen, as it is slightly more difficult for the base to approach the proton in diisopropylamine.

63.

(a) Triphenylphosphine

(b) Butylphosphine

(c) Ethylphenylphosphine

(d) 1,2-(Diphenylphosphino)ethane

64.

(a) \( \text{O}^+\text{H} \)  
(b) \( \text{H}_3\text{C}^-\text{O}^+\text{CH}_3 \)  
(c) \( \text{H}^+\text{N}^-\text{H} \)  
(d) \( \text{H}^+\text{O}^-\text{H} \)  
(e) \( \text{H}^+\text{C}^-\text{O}^-\text{H} \)  
(f) \( \text{H}_3\text{C}^+\text{S}^-\text{CH}_3 \)  
(g) \( \text{H}^+\text{O}^-\text{H} \)  
(h) \( \text{O}^+\text{H} \)  
(i) \( \text{H}^+\text{N}^-\text{H} \)  
(j) \( \text{H}_3\text{C}^+\text{O}^-\text{H} \)  
(k) \( \text{H}^+\text{O}^-\text{H} \)
65. The reaction of diethylamine with HCl yields Et₂NH₂⁺ as the conjugate acid, an ammonium salt. Ammonium salts are acidic, and the NH unit of the ammonium salt is capable of hydrogen bonding with the protic solvent ethanol, leading to increased stabilization of the conjugate acid. The hydrogen bonding in diethyl ether is much less because there is no O—H bond, and the ethyl group provides some steric hindrance when the oxygen atom approaches another molecule. The increased stability of the conjugate acid in ethanol shifts $K_a$ toward the conjugate acid, which is consistent with diethylamine as a stronger base in ethanol than in diethyl ether.

66. The F is more electronegative than O, which is more electronegative than N. Based on this trend, the electrons on nitrogen in $\text{NH}_2$ should be more available for donation, making it the strongest nucleophile in this series.

67. The amide anion ($\text{NH}_2$) has a much higher charge density (two unshared electron pairs) relative to the neutral molecule ammonia (NH₃), which has one unshared electron pair. Therefore, ammonia is less able to donate electrons to a positive carbon, and it is a much weaker nucleophile in its reaction with acetone than is the amide anion.

68. The conjugate base of propyne is CH₃C≡C⁻Na⁺, and the alkyne has a $pK_a$ of ~ 25. This $pK_a$
indicates that the alkyne anion is a reasonably strong base. Therefore, the alkyne anion may react as a base with water (pK_a, 15.7), whereas no such reaction is possible if the neutral solvent THF is used.

71. Sodium methoxide (NaOMe) can react with the slightly acidic proton of methanol in an acid–base reaction, but in order to attack the carbon atom as a nucleophile, OH must “leave” (be displaced). In simple terms, hydroxide is a very poor leaving group in this reaction, and the acid-base reaction is more facile and much faster.

72. \[ \Delta H^o = H^o_{\text{products}} - H^o_{\text{reactants}} \]

(a) \[ \text{CH}_3\text{OH} + \text{NH}_3 \rightarrow \text{CH}_3\text{O}^- + \text{^NH}_4^+ \]
(b) \[ \text{Cl}_2\text{CH} + \text{H}_2\text{O} \rightarrow \text{Cl}_2\text{C}^- + \text{OH}_3^- \]
(c) \[ \text{CH}_3\text{ONa} + \text{ICH}_3 \rightarrow \text{CH}_3\text{OCH}_3 \] (ignore NaI)

(a) \( \Delta H^o = (H^o_{\text{N-H}}) - (H^o_{\text{H-O}}) \)
\( \Delta H^o = (75) - (104.2) = -29.2 \text{ kcal mol}^{-1}. \)
(b) \( \Delta H^o = (H^o_{\text{H-O}}) - (H^o_{\text{C-H}}) \)
\( \Delta H^o = (104.2) - (104) = 0.2 \text{ kcal mol}^{-1}. \)
(c) \( \Delta H^o = (H^o_{\text{C-O}}) - (H^o_{\text{C-I}}) \)
\( \Delta H^o = (91) - (56) = 35 \text{ kcal mol}^{-1}. \)

73. Assume that \( \Delta S \) is zero, so \( \Delta G^o = \Delta H^o \). \( \Delta H^o = H^o_{\text{products}} - H^o_{\text{reactants}} \)
\( \Delta H^o = H^o_{\text{C-O}} - H^o_{\text{C-I}} = 91 - 56 = +35 \text{ kcal mol}^{-1}. \)
This number indicates an endothermic reaction, which is consistent with a reversible process. It is important to state that this is not the only criterion for reversibility in a reaction.

74. (a) HCOOH (formic acid)  (b) CH_3OH (methanol)  (c) CH_3SO_3H (methanesulfonic acid)

This question is very misleading. It was given to make a point. If the same base is used, all of the bond dissociation energies will be the same in that an O—H bond is broken in the reactants. Therefore, \( \Delta G^o \) and \( \Delta H^o \) calculations cannot be used to determine differences in reactivity. Stability of the conjugate base is the usual criterion for determining differences in acidity for these three compounds.

75. By analogy with carboxylic acids, the closer an electron-withdrawing substituent (e.g., chlorine) to the sulfonic acid proton, the more acidic: due to internal hydrogen bonding (through space inductive effects). Therefore, 2-chlorobutanesulfonic acid should be the most acidic. There is probably very little difference in pK_a for the other two sulfonic acids. 3-Methylbutanesulfonic acid has an electron-releasing methyl group, but it is somewhat removed from the sulfonic acid unit. The methyl group probably exerts a small effect, but this molecule is probably slightly less acidic than hexanesulfonic acid.
76. In the amide, the electron pair is partly delocalized on the adjacent carbonyl, and the electron-withdrawing effects of the carbonyl diminish the availability of the electron pair for donation. Therefore, it is a weaker base than the amine, where the electron pair is reasonably available for donation.

77. In N-chloromethanamine (ClNHCH₃), the electron-withdrawing chlorine group should diminish the availability of the electron pair on nitrogen, relative to methanamine. Therefore, methanamine is the more basic.

78. The more hindered amine is (Me₃C)₃N, with the three bulky tert-butyl groups, relative to the three relatively unhindered ethyl groups in (CH₃CH₂)₃N (e.g., Et₃N). It is more difficult for the proton of formic acid to approach the nitrogen atom in (Me₃C)₃N, making it less reactive and a weaker base. Remember that fluxional inversion about nitrogen occurs in both amines, which exacerbates the steric hindrance in (Me₃C)₃N.

79. Trimethylarsine (Me₃As) has the larger arsenic atom relative to nitrogen of trimethylamine, but it is slightly less electronegative (see section 2.5.1). In general, electronegativity and basicity decreases going down the periodic table, so the electron density on nitrogen is more available, and it is the stronger base. This means that trimethylamine will react faster with the Lewis acid, BF₃.
80. There is no doubt that the oxygen of the ether is a much stronger base than the fluorine atom of fluoromethane: O is less electronegative than F, and the oxonium ion product is more stable than the C—F—Al unit resulting from fluoromethane. Therefore, AlCl₃ reacts faster with diethyl ether.

81. The reason why certain products are marked as major will be explained in Chapter 10. The “squiggle” line indicates that the halogen can be on either side of the molecule, as explained in Chapter 9.

82. The reason why certain products are marked as major will be explained in Chapter 10. The “squiggle” line indicates that the halogen can be on either side of the molecule, as explained in Chapter 9.

(a) 

(b) 

(c) 

(d) 

(e) 

(f)
Spectroscopic Problems (to be done only after chapter 14 is read and understood)

In all of the following, IR data is from Table 14.3 (Section 14.3.3). The \(^1\)H NMR data is from Table 14.5 (Section 14.4.7).
85. Triethylamine has no hydrogen atoms attached to nitrogen, so there will be no signal in the 3300-3500 cm\(^{-1}\) region. The ammonium salt does have a N-H group, and will therefore show a bond in that region.

86. The OH unit in propan-2-ol is capable of hydrogen-bonding, which effectively changes the O—H bond distance, which in turn influences the amount of shielding. As the amount of internal hydrogen bonding changes, the chemical shift of the proton changes.

87. The answer is similar to the phenomenon in question 86. The OH unit in a carboxylic acid is capable of hydrogen bonding, which effectively changes the O—H bond distance, which in turn influences the amount of shielding. The extent of internal hydrogen-bonding is much greater for the acidic proton of a carboxylic acid, which greatly diminishes the amount of shielding. In other words, that proton is very deshielded, and far downfield.

88. In the IR, the tertiary amine trimethylamine will have no signals in the 3300-3500 cm\(^{-1}\) region, the secondary amine N-methylaminoethane will have a singlet in that region, and the primary amine, propan-1-amine will have a doublet (2 peaks) in that region.
Chapter 07
Solutions Manual
Organic Chemistry. An Acid-Base Approach 2nd Edition

17.

(a) \[ \text{NaCN} \rightarrow \text{HO-CN} \]
    \[ \text{NaNH}_2 \rightarrow \text{HO-NH}_2 \text{ poor yield} \]
    \[ \text{NaI} \rightarrow \text{essentially no reaction} \]

(b) \[ \text{Ph-CN} \]
    \[ \text{Ph-NH}_2 \text{ poor yield} \]
    \[ \text{Ph-I} \text{ essentially no reaction} \]

(c) \[ \text{H-CN} \]
    \[ \text{H-NH}_2 \text{ poor yield} \]
    \[ \text{H} \text{ essentially no reaction} \]

18.

(a) \[ \text{HI} \rightarrow \text{I-Major} \text{ I-Minor} \]
    \[ \text{Also see Chapter 10} \]

(b) \[ \text{HBr} \rightarrow \text{Br} \]

(c) \[ \text{HCl} \rightarrow \text{Cl} \]
19. $\Delta H^o = H^o_{\text{products}} - H^o_{\text{reactants}}$

All of these hypothetic reactions are endothermic as written. The point of this exercise is to begin the process of learning those reactions are reasonable and those that are unlikely.

(a) $\Delta H^o = H^o_{\text{products}} - H^o_{\text{reactants}}$

$$\begin{align*}
\text{(a)} & \quad \text{CH}_3\text{I} + \text{CH}_3\text{OH} & \rightarrow & \quad \text{H}_3\text{C} - \text{O}^+ + \text{I}^- \\
\text{(b)} & \quad \text{CH}_3\text{CH}_3 + \text{CH}_3\text{NH}_2 & \rightarrow & \quad \text{H}_3\text{C} + \text{H}_3\text{C}^+ + \text{CH}_3^- \\
\text{(c)} & \quad \text{CH}_3\text{CH}_3 + (\text{CH}_3)_3\text{C}-\text{Cl} & \rightarrow & \quad \text{CH}_3\text{Cl} + (\text{CH}_3)_3\text{C}-\text{CH}_3 \\
\text{(d)} & \quad (\text{CH}_3)_3\text{CCH}_3 + \text{I}^- & \rightarrow & \quad (\text{CH}_3)_3\text{C}^- + \text{CH}_3^- 
\end{align*}$$

$\Delta H^o = (H^o_{\text{products}} - H^o_{\text{reactants}})$

(a) $\Delta H^o = (H^o_{\text{C-O}} - (H^o_{\text{C-I}})$

$$\Delta H^o = (91) - (56) = +35 \text{ kcal (146.5 kJ) mol}^{-1}.$$

(b) $\Delta H^o = (H^o_{\text{N-C}} - (H^o_{\text{C-C}})$

$$\Delta H^o = (87) - (88) = -1 \text{ kcal (-4.18 kJ) mol}^{-1}.$$

(c) $\Delta H^o = (H^o_{\text{C-C1}} + H^o_{\text{C-C}}) - (H^o_{\text{C-C1}} + H^o_{\text{C-C}})$

$$\Delta H^o = (84 + 88) - (84 + 88) = 172 - 172 = 0 \text{ kcal (0 kJ) mol}^{-1}.$$

(d) $\Delta H^o = (H^o_{\text{C-1}} - (H^o_{\text{C-C}})$

$$\Delta H^o = (56) - (88) = -32 \text{ kcal (-134.0 kJ) mol}^{-1}.$$

20. $\Delta G^o = \Delta H^o + T \Delta S^o$, and $\Delta H^o = 56 \text{ kcal (234.5 kJ) mol}^{-1}, T = 100 \text{ °C},$ and $\Delta S^o = 3.2 \text{ cal}^{-1}$. Remember that temperature must be converted to kelvin. The calculation suggests that the temperature must be lowered for -20,625 K, which is obviously impossible. The temperature cannot be lowered below absolute zero, which is 0 K.

$\Delta G^o = \Delta H^o + T \Delta S^o$, so

$\Delta G^o = 56 \text{ kcal (234.5 kJ) mol}^{-1} + 373.15 \times 0.0032 \text{ kcal mol}^{-1} = 56 - 1.19 = 54.8 \text{ kcal (229.4 kJ) mol}^{-1}$

The $\Delta S^o$ term is (0.0032/56) x 100 = 0.0057%.

To calculate the temperature for $\Delta G^o = -10$: $\Delta G^o = -10 = 56 + x (0.0032)$

$$-10 - 56 /0.0032 = x, \text{ so } x = -66/0.0032 = -20,625$$

21. The transition state is that portion of the energy curve that represents the point at which bonds begin to break in the reaction and begin to form in the product. The difference in energy between the energy of the reactants and the energy of the transition state is the activation energy.

22. A transition state is not a detectable or isolable entity, but rather a point on an energy surface. It is not possible to “see” it.

23. No! Energy equal to the activation energy ($E_{\text{act}}$) must be added to initiate the reaction, and this has nothing to do with whether or not the overall reaction is endothermic or exothermic.
24. Plot ln [A] vs time in seconds. The slope of the line is the first-order rate constant, \( k \). The half-life is \( 0.693/k \). Based on the plot, using the best straight line possible, the slope is 0.006, so the rate constant \( k = 0.006 \). Half-life \( = \ln 2/k = 0.693/0.006 = 115.5 \) s.

<table>
<thead>
<tr>
<th>[A]</th>
<th>ln[A]</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>0.693</td>
<td>0</td>
</tr>
<tr>
<td>1.5</td>
<td>0.405</td>
<td>25</td>
</tr>
<tr>
<td>0.95</td>
<td>-0.05</td>
<td>50</td>
</tr>
<tr>
<td>0.7</td>
<td>-0.36</td>
<td>100</td>
</tr>
<tr>
<td>0.52</td>
<td>-0.65</td>
<td>150</td>
</tr>
<tr>
<td>0.40</td>
<td>-0.92</td>
<td>200</td>
</tr>
<tr>
<td>0.29</td>
<td>-1.24</td>
<td>250</td>
</tr>
<tr>
<td>0.23</td>
<td>-1.47</td>
<td>300</td>
</tr>
<tr>
<td>0.19</td>
<td>-1.66</td>
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</tr>
<tr>
<td>0.12</td>
<td>-2.12</td>
<td>400</td>
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</table>

25. Based on the plot of the data, the second order rate constant is 0.0051.

<table>
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<th>( AB_0 )</th>
<th>( A_0B )</th>
<th>( AB_0/A_0B )</th>
<th>( \ln(AB_0/A_0B) )</th>
<th>time(s)</th>
</tr>
</thead>
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<tr>
<td>.00048</td>
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<td>0</td>
</tr>
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<td>.00043</td>
<td>.00039</td>
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<td>.095</td>
<td>17.8</td>
</tr>
<tr>
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<td>.113</td>
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<td>.00031</td>
<td>.00015</td>
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<tr>
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<td>.00011</td>
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<td>.971</td>
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<td>.00028</td>
<td>.00008</td>
<td>3.5</td>
<td>1.253</td>
<td>240.1</td>
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</tbody>
</table>

26. Calculate the half-life, given the following data. First-order half-life \( = 0.693/k \). Second-order half life \( = 1/k[A_o] \), where for second-order reactions, assume \( [A]_o = 0.5 \).

(a) A first-order reaction where \( k = 1.2 \times 10^{-6} \): half-life \( = 5.78 \times 10^5 \)
(b) A second-order reaction where \( k = 4.5 \): half-life \( = 0.44 \)
(c) A first-order reaction where \( k = 5.8 \times 10^3 \): half-life \( = 11.95 \times 10^{-5} \)
(d) A second-order reaction where \( k = 9.25 \times 10^{-4} \): half-life \( = 2162 \)
(e) A first-order reaction where \( k = 0.6 \times 10^{-9} \): half-life \( = 1.16 \times 10^9 \)
(f) A second-order reaction where \( k = 3.44 \times 10^{12} \): half-life \( = 5.83 \times 10^{-13} \)

27. \( \Delta G^\circ = -RT (\ln K) = -2.303 \, RT \, (\log K) \) and the reaction temperature is 25 °C (298.15 K). \( R = 1.986 \) cal deg\(^{-1} \) mol\(^{-1} \), \( T = \) temperature in kelvin, and \( e = 2.718 \) (base of natural logarithms).
28. \( \Delta G^\circ = -RT \ln(K) = -2.303 \frac{RT}{\Delta G^\circ} \) and the reaction temperature is 25 °C (298.15 K).

\( R = 1.986 \text{cal deg}^{-1} \text{mol}^{-1}, T = \text{temperature in kelvin}, \) and \( e = 2.718 \) (base of natural logarithms).

\( RT \) for all reactions = 1.986x298.15 = 592.13 x -2.303 = -1363.7.

Assume that \( \Delta S^\circ \) is zero, so \( \Delta G^\circ = \Delta H^\circ \) in all cases, so \( \frac{\Delta G^\circ}{-2.303RT} = \frac{\Delta G^\circ}{-1363.7} \)

\[ K = 10^{\left( \frac{\Delta G^\circ}{-1363.7} \right)} \]

(a) \(-1.5 \text{kcal} (-6.3 \text{kJ}) \text{mol}^{-1} \) \( \frac{\Delta G^\circ}{-1363.7} = 1.1 \times 10^{-3} \) \( K = 0.997 \)

(b) \(100.3 \text{kcal} (419.9 \text{kJ}) \text{mol}^{-1} \) \( \frac{\Delta G^\circ}{-1363.7} = -0.074 \) \( K = 1.18 \)

(c) \(-4.5 \times 10^4 \text{cal} (-18.8 \times 10^4 \text{J}) \text{mol}^{-1} \) \( \frac{\Delta G^\circ}{-1363.7} = 138.16 \) \( K = 6.92 \times 10^{-139} \)

(d) \(18.5 \text{kcal} (77.5 \text{kJ}) \text{mol}^{-1} \) \( \frac{\Delta G^\circ}{-1363.7} = -0.014 \) \( K = 1.03 \)

(e) \(-33 \text{kcal} (-138.2 \text{kJ}) \text{mol}^{-1} \) \( \frac{\Delta G^\circ}{-1363.7} = 0.024 \) \( K = 0.946 \)

(f) \(-12.5 \times 10^6 \text{kcal} (-12.5 \times 10^7 \text{kJ}) \text{mol}^{-1} \) \( \frac{\Delta G^\circ}{-1363.7} = 9166.2 \) \( K = 0 \)

29. At least five half-lives are required for 98% completion. If the half-life is 8 h, then 8x5 = 40 h will be required.

30. If \( K = 10^{\left( \frac{\Delta G^\circ}{-1363.7} \right)} \), then for reaction A, \( K = 1.40 \), and for reaction B, \( K = 1.03 \). For reaction A, the equilibrium constant suggests there is more product than reactant, so we anticipate the ability to isolate the product. In the case of reaction B, the equilibrium constant is close to 1, so there will be close to a 1:1 mixture of reactants and products. The answer to this question depends on how easy it will be to separate reactions and products. If it is relatively easy to separate these compounds, then product can be isolated from both A and B, but the yield of product will be higher from reaction A.

31. 

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

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\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]

\[ \text{H} \quad \text{I} \quad \text{H} \]
32. If there are carbocation intermediates, then the final product must arise by the reaction of bromide ion with carbocation B. However, the reaction of HBr and the alkene reactant must give carbocation A. The only way to obtain the final product is for a skeletal rearrangement to occur, from A to B. This rearrangement occurs by transfer of a hydrogen atom from A to B, generating the more stable tertiary carbocation B from the less stable carbocation A. This rearrangement is referred to as a 1,2-hydride shift.

33 There is no indication that a transient product appears and is then consumed. Based only on this curve, one must conclude there is no intermediate.

34. For the two competing reactions, both reactions are second order, and the starting concentration is assumed to be 1. Therefore, the half-life = 1/k. For reaction A, 1/360 = 0.003 s, and for reaction B, 1/3.5 = 0.29 s. Based on this calculation, formation of D is faster than formation of C, so D is likely to be the major product of this reaction.

35. Which of the following is likely to be the best two-electron donor in a reaction with CH₃Cl? Explain. Based on electronegativity, and larger size of the ion, which means more charge dispersal, chloride ion should be the poorest electron donor (weakest nucleophile). The methyl group in CH₃O⁻ electron releasing relative to the H in HO⁻. Therefore, the electron density on O in methoxide anion is greater, and it should be the best electron donor (strongest nucleophile).
40. 
(a) *cis*-2,3-Dimethyloxirane  (b) *N*,3-Diethylpyrrolidine  (c) 4-Hydroxypiperidine

(d) 3-Chlorooxetane  (e) *N*-phenyl-2-methylaziridine  (f) 3,4-Dimethyltetrahydrofuran

41. A *gauche* conformation is a staggered conformation in which the two substituents (Cl) do not eclipse any other atom, and the substituents are not as far away as possible (the anti conformation).

42. Assuming that each chair conformation is locked, then the molecule with the fewest axial substituents will have the least transannular interactions. The molecule circled has no axial substituents, only equatorial, whereas all of the others have several axial substituents. The last structure on the left is a boat conformation, which does not have axial or equatorial substituents, but the “flagpole” chlorine atoms are close in space, and this constitutes significant transannular strain.
43. The circled structure has the most axial bromine atoms.

44. Cyclopropane is a flat molecule with significant Baeyer strain. It is reasonable to assume that the molecule with the most cyclopropane rings will have the greatest Baeyer strain. The circled molecule fits that description, but what may be less obvious, is that attaching four cyclopropane units to the four-membered ring will flatten the four-membered ring, introducing even more Baeyer strain.

45. The *anti* conformation is marked. It is a staggered conformation with the two Cl atoms as far apart as possible (180°).
47. In the gauche conformation, internal hydrogen bonding is possible in an aprotic solvent, but methanol is a protic solvent. Therefore, intermolecular hydrogen-bonding with the solvent should stabilize the anti conformation more than the gauche.

48. The flat structures are the highest in energy, and the boat-conformations are the lowest. The boat-conformation with the two chlorine atoms in flagpole positions has the highest transannular strain, and the boat-conformation that has hydrogen atoms in the flagpole positions (circled) has the least amount of transannular strain, and is the lowest energy conformation.

49. The large chlorine atoms are in close proximity, and the steric repulsion will elongate or at least distort the three-membered ring to accommodate the six chlorine atoms. For this reason, the C—C bonds in hexachlorocyclopropane are expected to be weaker when compared to cyclopropane. Indeed, molecular modeling indicates the C—C bond distance in cyclopropane is 1.502 Å (150.2 pm), whereas the C—C bond distance in hexachlorocyclopropane is 1.524 Å (152.2 pm).
53. There are two boat conformations in equilibrium. The molecule that is circled has two bromine atoms on each carbon, so both boat conformations will have the Br—Br transannular strain. In the third molecule, there is a Br—Br interaction in one boat, but a H—H interaction in the other, which is less than the transannular strain in the molecule circled. In the other two molecules, the H—Br transannular interaction is much less.
54. Conformation A has three axial groups (Cl, Br, Me) and B has two axial groups (Br, Cl). Since the relative steric demands of the substituents are unknown, simply count the number of axial groups, and B has only two. Therefore, the equilibrium should favor more B and less A.

55.

(a) butane

(b) 1,2-difluoroethane

(c) 2,2,3,3-tetramethylbutane

(d) 1,2-dimethoxyethane

(e) pentane

(f) 1-chloropropane
(a) butane

(b), 1,2-difluoroethane

(c) 2,2,3,3-tetramethylbutane

(d) 1,2-dimethoxyethane

(e) pentane

(f) 1-chloropropane
59. The hand-held models do not show the actual size of the atoms, and certainly not the amount of space that a methyl group actually occupies. The space-filling molecular model shown is much better, and clearly indicates that the two terminal methyl groups effectively compete for the same space, which is the source of the steric hindrance.

60. The covalent radius of Cl is 99 pm and a methyl group has a covalent radius is 200 pm. The methyl group is larger. However, each chlorine atom has three unshared electron pairs that contribute to the Cl—Cl repulsion, which effectively raises the energy of the steric repulsion.

61.
62. When the bonds are all syn, one gets a twisted structure as shown that is much higher in energy than the extended structure obtained when all the bonds are anti.

63. Octane has an extended type structure, assuming all bonds possible have an anti conformation. cis-Oct-4-ene shows a twist in the middle whereas trans-hex-3-ene has an extended structure. The all trans tetraene also has an extended structure.

64. In the gas phase, the molecule should exist primarily in the gauche conformation shown due to stabilization via internal hydrogen-bonding. In the hydrogen bonding solvent methanol, intermolecular hydrogen-bonding effectively makes the OH groups larger and the minimal conformation will have the OH groups anti in order to minimize steric hindrance.

65. The syn and anti rotamers are shown. In the presence of water, intermolecular hydrogen-bonding effectively increases the ‘size’ of the OH group, so there is a greater energy preference for the anti-rotamer.
66. The trans C—C=C—C unit has the constraint that bond angles about each sp\(^2\) carbon atom is 120°, which imposes severe constraints on the remainder of the molecule. In other words, the trans double bond requires the other two carbons to have their bond angles distorted, and the bond lengths must also be distorted. It is simply too high in energy to exist. Cyclohexyne is worse. The C—C≡C—C unit is linear, which requires even greater distortion of bond angles and bond distances.

67. The geometry of the C=C unit is planar, but in A it is not possible to flatten the molecule due to the bicyclic nature of the molecule. To flatten the molecule would essentially squash the atoms together, which is simply too high in energy. The C=C unit in B can flatten out without distortion of the rest of the molecule.

68. Attempting to confine three adjacent linear C≡C units to a ring would require severe distortion to the point that it is simply impossible.

69. The lowest energy rotamer will have the planar C=C units anti. The planar nature of these units makes them effectively larger than the methyl groups.

70. Octa-1,3,5,7-tetrayne will be linear because each C≡C unit is linear:

71. In 3,4-dichlorooctane, the two Cl atoms will be *anti*, as will the two propyl groups. Each propyl group is only slightly larger than a methyl because there is rotation about each bond, and each bond will effectively exist as an *anti* rotamer, as shown in the extended conformation to the left.
72. Two possibilities are shown. There does not appear to be a large difference, but A may have a bit more steric hindrance because Br is larger than Cl, and there is no great difference in steric hindrance between methyl and ethyl. The choice is not obvious, however.

73. All geminal compounds are in red. All vicinal compounds are in blue.
74. Examination of 2,2,5,5-tetramethylhexane-3,4-diol shows that if the two very large tert-butyl groups align in an anti conformation to minimize steric hindrance, then the two hydroxyl groups are also anti. The conformation is therefore driven by alignment of the sterically bulky groups.

75. The angular nature of the ether linkage allows an extended conformation in which all C—C bonds are anti.

76. Intramolecular hydrogen bonding of the hydroxyl group and the acidic carboxyl proton is possible, as shown. In hexane solvent, a nonpolar solvent that cannot form a hydrogen bond with the acid, intramolecular hydrogen bonding is maximized, so it is assumed that 3-hydroxybutanoic acid assumes a conformation similar to that shown. In other words, the intramolecular hydrogen-bonding overrides the normal syn-anti conformations.

77. The conformation is not obvious. The planar nature of the C=O units may lead to the two CHO groups in an anti relationship. However, aldehydes are capable of internal dipole–dipole interactions, and a gauche rotamer is shown with the assumption that this conformation may have more stability. Note that this is an educated guess, and the rather simple analysis done here cannot give the answer. This problem is presented to emphasize that conformation is often the result of complex interactions, and sometimes the correct answer is, I don’t know for sure.
78. In terms of Bayer strain, (f) has the most, followed by (b). Planar structure (a) has some Baeyer strain, as does (e). The order is likely (f) > (b) > (a) > (e) > (c) > (d).

In terms of torsion strain, planar cyclohexane has more than cyclopropane or cyclobutane, and chair cyclohexane has none. The order is (a) > (b) > (f) > (e) > (c) > (d).

79. The hydrogen atoms indicated in all three molecules are sufficiently close that there are transannular interactions. The representative transannular interactions are marked in each structure.

80.
81. In trans-1,4-dimethylcyclohexane, the transannular interaction involves methyl-hydrogen in both conformations. The energy of each conformation is about the same, so there should be a roughly equal amount of each conformer. In cis-1,4-dimethylcyclohexane, however, one conformation has a methyl-methyl transannular interaction and the other has a hydrogen-hydrogen interaction that is much lower in energy than the conformation with methyl interactions. Therefore, the cis-isomer will have a large preference for the lower energy conformation.

82. Either chair conformation of 1,2-di-tert-butylcyclohexane requires that one of the very bulky tert-butyl groups assume an axial position, which imposes a high energy barrier due to A-strain. In the boat conformation, both tert-butyl groups are “pseudo-equatorial”, which removes the A-strain and is much lower in energy.

83. It appears that the diisopropyl derivative, with the larger isopropyl groups, will have a greater amount of A-strain. The methyl groups will spend more time “outside” the ring cavity, however, as shown. This phenomenon is due to rotation about the C—C bonds (ring carbon—CHMe₂) to minimize steric interactions. This finding means that the difference in A-strain for isopropyl vs methyl is not necessarily as great as might be expected.
84. The two chair conformations of cis-1,2-diisopropylcyclohexane show that one group is axial and one is equatorial in each conformation. Therefore, the A-strain is the same in both conformations, and there should be a roughly equal amount of each. In trans-1,2-diisopropylcyclohexane, one chair conformation has both groups axial, which imposes a great deal of A-strain, whereas the other chair confirmation has both groups equatorial. The latter is much lower in energy because it has no A-strain. Therefore, trans-1,2-diisopropylcyclohexane will exist primarily as the diequatorial conformation.

85. From the diagrams, it is clear that the boat conformation of 1,1,4,4,5,5-hexamethylcycloheptane has some transannular strain because the methyl groups are closer together than in the chair conformation.

86. Cyclooctane has a relatively high amount of transannular strain, and cyclooctanol also has this transannular strain. Oxidation to the ketone (Section 17.2) flattens out the three carbons associated with the carbonyl unit, which diminishes some of the transannular strain, which is more apparent in the space-filling models. Diminished transannular strain makes the oxidation more facile, whereas reduction of the ketone to yield the alcohol will introduce more transannular strain. This increased strain imposes a slight energy barrier to the reduction, which makes it a bit more difficult.
87. The two chair conformations of cis-3,6-dimethylocyclohexene show that there is one *pseudo-axial* methyl and one *pseudo-equatorial* methyl in both conformations. Therefore, they are expected to have roughly the same energy and one will not be present in greater amount than the other.

![Cis-3,6-dimethylocyclohexene conformations](image)

88. Conversion of the flat C=C unit to the methyl group introduces A-strain in methylcyclohexane, which means that it is higher in energy than methylenecyclohexane. The A-strain is the source of the energy barrier mentioned in the question.

![Conversion of C=C to methyl group](image)

89. One boat conformation of cis-1,4-cyclohexanedicarboxylic acid (shown) has internal hydrogen-bonding between the two carboxyl groups, which stabilizes that conformation. Therefore, there is a relatively high percentage of this particular *boat* conformation.

![cis-1,4-cyclohexanedicarboxylic acid](image)

90. Methoxycyclohexane (A) exists primarily in the chair conformation due to diminished A-strain when compared to the conformation with the OMe group axial. In 2-methoxypyran (B) you can imagine an interaction of the lone electron pairs on the two oxygen atoms when the OMe group is equatorial (B'), which is minimized when the OMe group is axial. This simplistic explanation indicates that the electron pair interaction is higher in energy than the A-strain imposed by the axial methoxy group. As noted in the question, this is an overly simplistic explanation for a more complicated issue, but based on what is known from this chapter, it is a reasonable explanation.

![Methoxycyclohexane and methoxypyran](image)
36. The molecule shown has a carbon atom with four different groups attached. In the molecule marked CHBrF, carbon has only three substituents, and it is not a real molecule - it is a trick. The circled molecule has four different atoms or groups (H, Cl, Br, OH), so the carbon is a stereogenic center, and the molecule is chiral.

\[
\begin{array}{cccc}
\text{FCH}_2\text{CH}_2\text{Br} & \text{CCl}_4 & \text{CHBrF} & \text{BrCHClOH}
\end{array}
\]

37. 
(a) \begin{array}{cc}
\text{c} & \text{b} \\
\text{CH}_2\text{CH}_2\text{Br} & \text{CH}_2\text{CHBrCH}_3
\end{array}
\quad \begin{array}{cc}
\text{d} & \text{a} \\
\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} & \text{CH}_2\text{F}
\end{array}

(b) \begin{array}{cc}
\text{b} & \text{a} \\
\text{CH}_2\text{CH}_2\text{OH} & \text{CH}_2\text{CHBrCH}_3
\end{array}
\quad \begin{array}{cc}
\text{c} & \text{d} \\
\text{CH}_2\text{CH}_2\text{CH}_2\text{I} & \text{CH}_2\text{CH}_3
\end{array}

38. \[ A(+70°) + A'(-70°) = -35°. \] Assume that \( A + A' = 1 \), so \( A = 1 - A' \)
(1 - A')(+70°) + A'(-70°), so 70° - 70°A' = 70°A' = -35°
-140°A' = -35° - 140° = -105°, so \( A' = -105°/140° = 0.75 \).
If \( A' = 0.75 \), then \( A = 0.25 \), or 25% of \( A \) and 75% of \( A' \).

39. All contribute to specific rotation except group priority.

<table>
<thead>
<tr>
<th>path length</th>
<th>group priority</th>
<th>concentration</th>
<th>( \alpha )</th>
</tr>
</thead>
</table>

40. If \( [\alpha] \) for the \((R)\)-enantiomer of a molecule is \(-50°\), then \( [\alpha] \) for the \((S)\)-enantiomer has the same magnitude but with the opposite sign, which is \(+50°\).

\[\begin{array}{cccc}
+50° & -50° & +5° & -5° & 0°
\end{array}\]

41. If \( [\alpha] \) for \( R \) is \(-20°\), then \( 0.6(-20°) + 0.4(+20°) = [\alpha] \) for a mixture of enantiomers = \(-12° + 8° = -4°\).

\[\begin{array}{cccc}
+10° & -10° & +20° & -20° & 0° & +4° & -4°
\end{array}\]

42. The \( [\alpha] \) for a racemic mixture is always \( 0° \) because a racemic mixture is a 50:50 mixture of both enantiomers. Therefore, \( 0.5(+° R) + 0.5(-° S) = 0° \).

\[\begin{array}{cccc}
+100° & -100° & +50° & -50° & 0°
\end{array}\]
43. If the specific rotation of a pure enantiomer is $+100^\circ$, then specific rotation for the other enantiomer is $-100^\circ$. If the specific rotation of a mixture of both enantiomers is $-20^\circ$, then 

$$-20^\circ = x(+100^\circ) + y(-100^\circ),$$

and

$$x + y = 1,$$ so

$$x = 1 - y.$$ Therefore,

$$-20^\circ = 1 - y(+100^\circ) - 100^\circ y$$ and 

$$-20^\circ = 100^\circ - 100^\circ y - 100^\circ y,$$ or

$$-20^\circ = 100^\circ - 200^\circ y,$$ and 

$$-120^\circ = -200^\circ y,$$ so

$$y = -120^\circ/-200^\circ,$$ and

$$y = 0.6,$$ so

$$x = 0.4.$$ The ratio is therefore 60:40.

44. Which of the following is the enantiomer of $(2R)$-bromohexane?

[Diagrams of 2-bromohexane and other stereoisomers]

45. The circled solvents each have a stereogenic center, and therefore they cannot be used for determining $[\alpha]$ of a compound in a polarimeter.

[Diagrams of solvents with chiral centers]

46. 

(a) (b) (c) (d) (e) (f)
47.

(a) \( (S) \)

Chiral. It has an enantiomer

(b) \( (S) \)

A meso compound. It has a superimposable mirror image, so it does not have an enantiomer

(c) \( (S) \)

There is no stereogenic center so it has a superimposable mirror image, and no enantiomer

(d) \( \)

Chiral. It has an enantiomer

This diol is symmetrical, and it has a superimposable mirror image, so there is no enantiomer

(f) \( \)

The mirror images are not superimposable. These compounds are enantiomers, and represent a chiral molecule

48.

(a) \( \)

(b) \( \)

49.

(a) \( (3R)-Bromopentan-(2S)-ol \)

(3R)-Bromopentan-(2S)-ol

(b) \( (R)-4-Methyldodecane \)

(\( R \))-4-Methyldodecane

(c) \( (2R,3S,4R)-2,3,4-Trichloroheptane \)

(\( 2R,3S,4R \))-2,3,4-Trichloroheptane

(d) \( \)

Heptan-(3S)-ol

Heptan-(3S)-ol

(e) \( \)

3-Ethyl-3-methyloctane

This question is a trick!

(f) \( \)

Hept-1-en-(3R)-ol

C3 has two ethyl groups, so there is no stereogenic center
50.

(a) +18°/(1.1x2.5) = +6.55°
(b) -176°/0.3 x 5.0) = -117.3°
(c) -1.4°/(5.4 x 2.5) = -0.10°
(d) +94°/(2.3 x 3.0) = +13.6°

51. In all cases, convert centimeters (cm) to decimeters (dm), 1 cm = 0.1 dm.
(a) +18°/(1.1x2.5) = +6.55°
(b) -176°/0.3 x 5.0) = -117.3°
(c) -1.4°/(5.4 x 2.5) = -0.10°
(d) +94°/(2.3 x 3.0) = +13.6°

52. Calculate the percentage of each enantiomer and the %ee for the mixture given the following information.

(a) [α]D = +18.6° for the S-enantiomer and [α]D = -2.5° for the mixture.

\[ S(+18.6°) + R(-18.6°) = -2.5° \]
Assume that \( S + R = 1 \), so \( S = 1-R \)
\( (1-R)(+18.6°) + R(-18.6°) \), so \( 18.6° \cdot 18.6° -18.6° -18.6° = -2.5° \)
\( 18.6° -37.2° R = -2.5° \), so \( R = -2.5° \cdot -18.6°/-37.2° = -21.1/-37.2 = 0.567 \).

Therefore, 56.7% R and 43.4% S. Using Figure 9.15, 15% ee (R).

(b) [α]D = -166° for the R-enantiomer and [α]D = -154° for the mixture.

\[ S(+166°) + R(-166°) = -154° \]
Assume that \( S + R = 1 \), so \( S = 1-R \)
\( 1-R(166°)-166° R = -154° \), so 166° -166° 166° -154° = -154°
\( -332° R = -154°-166° \), so -332° R = 320°, so \( R = 320°/-332° = 0.964 \).

Therefore, 96.4% R and 3.6% S. Using Figure 9.15, 98% ee (R).

(c) [α]D = -45° for the S-enantiomer and [α]D = +27° for the mixture.

\[ S(-45°) + R(+45°) = +27° \]
Assume that \( S + R = 1 \), so \( S = 1-R \)
\( (1-R)(-45°) + 45° = +27° \), so -45° +45° R +45° R = +27°
\( 90° R = 27°+45° \), so 90° R = 72°, so \( R = 72°/90° = 0.8 \).

Therefore, 80% R and 20% S. Using Figure 9.15, 60% ee (R).

(d) [α]D = +208° for the R-enantiomer and [α]D = -118° for the mixture.

\[ S(-208°) + R(+208°) = -118° \]
Assume that \( S + R = 1 \), so \( S = 1-R \)
\( (1-R)(-208°) + R(208°) = -118° \), so -208° +208° R +208° R = -118°
\( -208° +416° R = -118° \), so 416° R = -118° +208°, so 416° R = 90°, so \( R = 90°/416° = 0.22 \).

Therefore, 22% R and 78% S. Using Figure 9.15, 56% ee (S).

53. If the product is a racemate, then there is a 50:50 mixture of the (R) and (S) enantiomers, which means that the specific rotation is 0°.
If the $[\alpha]^{20}_D = -77^\circ$ for the (S)-iodide and it reacts to give a new iodide with complete inversion, the product will be the (R) iodide, and the specific rotation will have the same magnitude as that for the S-iodide, but it will have the opposite sign: $+77^\circ$.

55. Determine the absolute configuration of each stereogenic carbon in the following molecules.

(a)  
(b)  
(c)  
(d)  
(e)  
(f)  

Due to fluxional inversion, N is racemic and should not be marked

56. Determine if each of the following alkenes has an (E) or (Z) double bond, or no stereoisomers.

(a)  
(b)  
(c)  
(d)  
(e)  
(f)  

57.  
(a) 3,3-Diphenyl-(4E)-nonen-1-ol  
(b) 2,3,4,5-Tetrachlorohex-(2Z)-ene  
(c) 3-Bromo-6-fluorodeca-(3Z,6E)-dien-2-one  
(d) 3-Ethylhept-(2E)-ene
(e) 5-(1-Methylethyl)-4-(2,2-dimethylpropyl)dodec-(4Z)-ene

(f) 3,4-Dichlorohex-(3Z)-ene

58.

(a) 2,3-Dibromo-(2Z)-pentene  
(cis-2,3-Dibromo-2-pentene  
overlap

(b) 3-Ethyl-(3Z)-octene  
(cis-3-ethyl-3-octene  
overlap

(d) 4-Ethyl-(3E)-heptene  
(cis-4-ethyl-3-heptene

(e) 3-Ethyl-4,5-dimethyl-(2Z)-hexene


(a) 3,4-Dichlorohexane

(b) 2-Bromo-3-methylhexane
(c) 4-Phenyl-3-heptanol

(d) 3,4-Dibromohexane

(e) 2,5-Hexanediol

(f) 3,4,5-Heptanetriol
60. One of the diastereomers is a meso compound, which should not be used in reactions because it is not a chiral molecule. Only the chiral diastereomer should be used.

61. Both enantiomers are shown. If ibuprofen racemizes, then it will exist as a 50:50 mixture of \((R):(S)\) enantiomers, and the specific rotation will equal 0°.
63. In (a), (b) and (c) there are superimposable structures, either the mirror image, or the mirror image of the ring flip conformation. Therefore, all of these are meso compounds and the structures shown represent one single structure. Compound (d) has two enantiomers and the two different chairs are diastereomers of each other, as are their mirror images.

(a) *cis*-2-Chlorocyclohexanol

(b) *trans*-1,4-Dimethylcyclohexane
65. Give an unambiguous IUPAC name to each of the following.

(a) 2-Methylpentan-(3R)-ol

(b) (3R,5R,E)-5-(1-Methylethyl)-3-methyl-5-enolic acid

(c) (2S,3S,4S)-2-Ethyl-3,4-dimethylhex-5-ynal

(d) (1S,3S,4R)-1-Cyclopropyl-3-methyl-4-phenylhexan-1-ol

(e) (3R,5R,7R)-5-Bromo-3-methyl-7-phenyloctan-2-one

(f) (4R,5R,E)-4-Bromo-1-chloro-5-methylhepta-1,6-diene
66. Name each of the following

(a) \((4S\)\)-5,5-Dimethylbicyclo-\([2.1.1]\)hexan-1-ol

(b) \((1R,5S)\)-3,3-Diethylbicyclo-\([3.1.0]\)hexane

(c) \((1,4s)\)-Bicyclo[2.2.2]-octa-2,5-diene

(d) \((1R,5S)\)-9,9-Dichlorobicyclo-\([3.3.1]\)non-2-ene

(e) \((1R,2S,6R)\)-2,7-Dichlorobicyclo[4.2.0]octane

(f) \((1R,5S)\)-1,3-Dimethylbicyclo-\([3.3.0]\)octane

67.

68. Mirror image (2\(S\),3\(S\))
Two structures but one compound
Since (2Z)-3-methylpent-2-ene has no stereogenic center, the specific rotation is 0°.

79.
80. Using Figure 9.15:  (a) 82:18 \( R:S = 62\% \text{ ee} \)  
(b) 55:45 \( R:S = 10\% \text{ ee} \)  
(c) 99:1 \( R:S > 99.5\% \text{ ee} \)  
(d) 75:25 \( R:S = 50\% \text{ ee} \) 

81. \( S(+100^\circ) + R(-100^\circ) = +91^\circ \text{C} \). Assume that \( S + R = 1 \), so \( S = 1-R \). 
\((1-R)(100^\circ) + R(-100^\circ) = 91^\circ \), so \( 100^\circ-100^\circ R-100^\circ R = 91^\circ \) 
\( 100^\circ-200^\circ R = 91^\circ \), so \( -200^\circ R = 91^\circ-100^\circ \), and \( -200^\circ R = 91^\circ-100^\circ = -9^\circ \), and \( R = -9^\circ/-200^\circ = 0.045 \) Therefore, 4.5\% \( R \) and 95.5\% \( S \). Using Figure 9.10, 92\% ee (\( S \)). 

82. The term 0\% indicates there is no excess of one enantiomer over the other, which means that it is a 50:50 mixture (racemic). 

83. It simply means that fluxional inversion is much more difficult with phosphines when compared with amines. The P has a (S) configuration as drawn. 

84. Determine the absolute configuration for each nitrogen atom in the following molecules:
63. Carbon substituents are electron releasing with respect to a π-bond, so the more carbon substituents, the more electron rich the π-bond, and the more stable it will be. The circled alkene is the most highly substituted (the most carbon substituents).

64. \( \text{Br}_2 \quad \text{HCl} \quad \text{BH}_3 \quad \text{CH}_3\text{CO}_2\text{H} \quad \text{H}_2\text{O} \)

65. Only an alkyne will react with HBr to give a vinyl bromide. The two alkynes are circled.

66. A peroxycacid is required to convert an alkene to an epoxide.

\( \text{CH}_3\text{OH} \quad \text{CH}_3\text{CO}_2\text{H} \quad \text{CH}_3\text{CO}_2\text{H} \quad \text{NaOH} \)

67. Secondary carbocations are more stable than 1° > 2° vinyl carbocation > 1° vinyl carbocation.

68. The resonance stabilized carbocation is more stable than the 1° or 2° aliphatic carbocations.
69. Of these reagents, only borane adds to alkenes or alkynes in an anti-Markovnikov manner.

70. Of these reagents, only borane adds to alkenes or alkynes in an anti-Markovnikov manner.

71. The reaction proceeds by initial formation of a vinyl chloronium ion. Subsequent anti-attack by the chloride counterion leads to the vinyl dichloride shown, with the (E)-stereochemistry.

72. Both HBr and sulfuric acid are strong enough acids to react with the alkene to yield an intermediate carbocation. When HBr reacts, the counterion is the bromide ion and the hydrogen sulfate ion results from the reaction with sulfuric acid. The hydrogen sulfate ion is resonance stabilized, making it a relatively weak nucleophile, whereas the bromide ion is a very good nucleophile. Therefore, the more nucleophilic bromide ion dominates the reaction with the carbocation, leading to bromocyclohexane.

73. 2,3-Dimethylbut-2-ene reacts faster with HCl than does but-2-ene because it is an acid-base reaction, and the more highly substituted C=C unit in 2,3-dimethylbut-2-ene leads to a more electron rich \( \pi \)-bond, which makes it a stronger base. In other words, it will react faster with HCl. In addition, the tertiary carbocation intermediate derived from 2,3-dimethylbut-2-ene is more stable than the secondary carbocation derived from but-2-ene, and the increased stability should lead to a lower activation energy and a faster reaction.
74. Addition of 1 equivalent of HCl will add to 1,1-diphenylhexa-1,5-diene to give the chloride shown, via carbocation A. Reaction with the other C=C unit generates a secondary carbocation B, whereas A is a benzylic carbocation where the charge is delocalized into two benzene rings. Carbocation A is much more stable as an intermediate, and will form preferentially over B, yielding the major product shown.

75. The reaction of 2-methylprop-2-ene with acid will generate a tertiary carbocation, which is relatively stable. Reaction of acetone with an acid generates the resonance stabilized oxocarbenium ion shown. Two resonance contributors are drawn, one with the charge on oxygen after reaction with the acid, and the second contributor with the charge on carbon, which is generated by transfer of the two electrons in the \( \pi \)-bond to oxygen, leaving behind C\(^+\) and placing the electron pair on oxygen. In the absence of any other information, the resonance stabilized oxocarbenium ion should be more stable than the tertiary carbocation where there is no resonance.

76. In both reactions, the tertiary carbocation is formed. In the case of HCl, chloride ion is a good nucleophile, reacting with the carbocation to generate the chloride product. In the case of sulfuric acid, the hydrogen sulfate anion is resonance stabilized, and a weak nucleophile. In addition, if the hydrogen sulfate anion reacts with the carbocation, the hydrogen sulfate product is rather unstable, and fragments to regenerate the carbocation. Under these conditions, the hydrogen sulfate anion reacts as a base to remove a proton from the carbon adjacent to C\(^+\), generating the alkene. This latter reaction is known as an E1 reaction, and will be discussed in Section 12.4.
Although the reaction is presumably done in water, chloride ion is the best nucleophile. Therefore, the chloride ion reacts with the initially formed oxocarbenium ion to give the chloride.

In A, the allylic alcohol leads to a resonance stabilized allylic carbocation, and the tertiary cation site is more reactive when reaction occurs with the next C= unit, to generate a secondary carbocation. The alkyne unit in A will ultimately react with a carbocation to form a vinyl carbocation. Vinyl carbocations are much more reactive, and will quickly react with water to give an enol, which tautomerizes to a ketone. This latter reactions will effectively stop the cation cyclization process.

An oxocarbenium ion

Although the reaction is presumably done in water, chloride ion is the best nucleophile. Therefore, the chloride ion reacts with the initially formed oxocarbenium ion to give the chloride.
80. Nitrogen is not a polarizable atom, so there is essentially no driving force to react with an alkene \( \pi \)-bond. Diatomic bromine has the polarizable bromine atom, and proximity to a \( \pi \)-bond leads to a polarized \( \text{Br—Br} \) bond, which leads to the ionic bromonium ion intermediate. Diatomic nitrogen is not similarly polarized, so such a similar reaction does not occur.

81. The molecule shown has relatively large isopropyl groups that block the approach of the bulky Br—Br molecule to the \( \text{C=} \text{C} \) unit. Therefore, formation of the bromonium ion is sluggish. If it does form, the isopropyl groups will sterically hinder approach of the nucleophilic bromide ion to one of the carbon atoms of the three-membered ring bromonium ion, again limiting the amount of product formed. The steric hindrance in the alkene is perhaps better seen in the molecular models that are provided, especially the space-filling model on the right.

82. The major product or products are shown in each case. No mechanisms are provided.

(a) \[ \text{HCl} \rightarrow \text{Cl} + \text{CH}_3\text{CH}_2\text{CH}_2\text{Cl} \]

(b) \[ \text{HBr} \rightarrow \text{Br} + \text{CH}_3\text{CH}_2\text{CH}_2\text{Br} \]

(c) \[ \text{Br}_2, \text{CCl}_4 \rightarrow \text{Br} \]
83. Initial reaction with HCl generates the 2° vinyl carbocation. This reaction produces the nucleophilic chloride ion, which is more nucleophilic than the oxygen atom of ethanol, which is the solvent. Subsequent reaction with the nucleophilic oxygen atom of ethanol leads to an oxonium, and loss of a proton, in an acid-base reaction (probably with ethanol as the base, or another molecule of the alkyne) leads to the vinyl ether product.
84. In principle, formation of the bromonium ion, and the anticipated trans-dibromide product will generate a trans C=C unit in the cyclooctene product. This product should be rather high in energy, due to the constraints of the ring and the geometric demands to the trans- double bond. The predicted higher energy of the product suggests that the reaction will have a high activation energy and/or may be endothermic. It is difficult to predict endo- vs exothermic energy without looking at the enthalpy, and the entropy of the reaction.

85. The major product or products for each reaction are shown. No mechanisms are provided.

(a) \[ \text{1. BH}_3, \text{ether} \hspace{1cm} \text{2. H}_2\text{O}_2, \text{NaOH} \]

(b) \[ \text{1. 9-BBN, ether} \hspace{1cm} \text{2. NaOH, H}_2\text{O}_2 \]

(c) \[ \text{1. O}_3, -78^\circ\text{C} \hspace{1cm} \text{2. Me}_2\text{S} \]

(d) \[ \text{HBr} \hspace{1cm} t\text{-BuOOt-Bu} \]

(e) \[ \text{1. 9-BBN, ether} \hspace{1cm} \text{2. NaOH, H}_2\text{O}_2 \]

(f) \[ \text{HgSO}_4, \text{Hg(OAc)}_2 \hspace{1cm} \text{H}_2\text{O}, \text{H}_3\text{PO}_4 \]

(g) \[ \text{HCO}_3\text{H} \hspace{1cm} \text{aq THF} \]

(h) \[ \text{1. O}_3, -78^\circ\text{C} \hspace{1cm} \text{2. H}_2\text{O}_2 \]
86. Molecule \( A \) is symmetrical, so hydroboration occurs at either carbon of the C=C unit to yield the same product, with 9-BBN leading to two possible transition states. In one, from the “top” face, there is severe steric hindrance between a methyl group and the bulky 9-BBN unit, whereas the other transition state, formed from the “bottom” is essentially free of steric hindrance. Therefore, the lower transition state predominates to give the alkylborane shown, and oxidation yields the alcohol as the major product.
87. 

\[ 	ext{MeCH}_2{}^+ \overset{\text{cat. H}^+}{\rightarrow} \text{MeCH}_3{}^+ \overset{\text{H}_2\text{O}}{\rightarrow} \text{MeCH}_3\overset{\text{OH}}{\rightarrow} \text{MeCH}_3\text{OH} \]

88. 

(a) 1-Ethylcycloheptene

(b) 2-Phenylbut-1-ene

(c) 3,4-Diethylhex-3-ene

(d) 3,3-Dimethylhex-1-yne

\[ \text{C}_3\text{H}_7\text{I} \rightarrow \text{C}_3\text{H}_7\text{OH} \rightarrow \text{C}_3\text{H}_7\text{CHO} \]

89. The major product or products are shown. No mechanisms are provided.

(a) 

\[ \text{I}_2, \text{CCl}_4 \rightarrow \text{I} \]
(b) 1. $\text{O}_3$, $-78^\circ\text{C}$
2. $\text{H}_2\text{O}_2$

(c) Os$_4$, Me$_3$COOH

(d) Br$_2$, CCl$_4$

(e) ether

(f) HOCl

(g) H$_2$O$_2$

(h) Via a carbocation, so a cis/trans mixture

(i) HBr

(j) + HCO$_2$H

(k) I$_2$, CCl$_4$

(l) catalytic $\text{H}_2\text{SO}_4$
90. Give the major product for each reaction.

(a) \[
\begin{align*}
\text{HBr} & \rightarrow \text{Br} \\
\end{align*}
\]

(b) \[
\begin{align*}
\text{Br}_2, \text{CCl}_4 & \rightarrow \text{Br} \\
\end{align*}
\]

(c) \[
\begin{align*}
\text{I}_2, \text{CCl}_4 & \rightarrow \text{I} \\
\end{align*}
\]

(d) \[
\begin{align*}
\text{HOCl} & \rightarrow \text{OH} \\
\end{align*}
\]
91. 

(r) \[ \text{Me} \quad \text{H} \quad \text{ether} \quad \text{HI} \quad \rightarrow \quad \text{Me} \quad \text{H} \quad \text{I} \quad \text{Me} \quad \text{I} \]

(s) \[ \text{Me} \quad \text{H} \quad \text{Me} \quad \text{HBr} \quad \rightarrow \quad \text{Me} \quad \text{Br} \quad \text{Me} \quad \text{Br} \quad \text{racemic, via carbocation, with rearrangement from initially formed 2° cation} \]

(t) \[ \text{Me} \quad \text{H} \quad \text{Br} \quad \text{Br} \quad \text{racemic} \quad \text{Br}_2 \quad \text{CCl}_3 \quad \rightarrow \quad \text{Me} \quad \text{H} \quad \text{Br} \quad \text{Br} \]

(u) \[ \text{Ph} \quad \text{OH} \quad \text{OH} \quad \text{racemic} \quad \text{OsO}_4 \quad \text{NaHSO}_3 \quad \text{H}_2\text{O} \quad \rightarrow \quad \text{Ph} \quad \text{OH} \quad \text{OH} \]

(v) \[ \text{Me} \quad \text{OH} \quad \text{OH} \quad \text{H} \quad \text{H} \quad \text{OH} \quad \text{1. BH}_3 \quad \text{ether} \quad \text{2. NaOH, H}_2\text{O}_2 \quad \rightarrow \quad \text{Me} \quad \text{OH} \quad \text{OH} \quad \text{H} \quad \text{H} \quad \text{OH} \]

92. 

(a) \[ \text{Ph} \quad \text{OH} \quad \text{OH} \quad \text{1. Hg(OAc)}_2 \quad \text{H}_2\text{O} \quad \rightarrow \quad \text{Ph} \quad \text{OH} \quad \text{OH} \quad \text{2. NaBH}_4 \]

(b) \[ \text{Ph} \quad \text{OMe} \quad \text{OMe} \quad \text{1. Hg(OAc)}_2 \quad \text{MeOH} \quad \rightarrow \quad \text{Ph} \quad \text{OMe} \quad \text{OMe} \quad \text{2. NaBH}_4 \]

(c) \[ \text{Ph} \quad \text{OH} \quad \text{OH} \quad \text{1. Hg(OAc)}_2 \quad \text{H}_2\text{O} \quad \rightarrow \quad \text{Ph} \quad \text{OH} \quad \text{OH} \quad \text{2. NaBH}_4 \]

(d) \[ \text{Ph} \quad \text{OMe} \quad \text{OMe} \quad \text{1. Hg(OAc)}_2 \quad \text{EtOH} \quad \rightarrow \quad \text{Ph} \quad \text{OMe} \quad \text{OMe} \quad \text{2. NaBH}_4 \]

(a) \[ \text{Ph} \quad \text{OH} \quad \text{OH} \quad \text{1. BH}_3 \quad \text{ether} \quad \rightarrow \quad \text{Ph} \quad \text{OH} \quad \text{OH} \quad \text{2. NaOH, H}_2\text{O}_2 \]

(b) \[ \text{Ph} \quad \text{OH} \quad \text{OH} \quad \text{1. Hg(OAc)}_2 \quad \text{H}_2\text{O} \quad \rightarrow \quad \text{Ph} \quad \text{OH} \quad \text{OH} \quad \text{2. NaBH}_4 \]
93. Under acidic conditions, methoxyethene will react to form a rather stable oxocarbenium ion. The increased stability, relative to the carbocation formed from ethene, will make subsequent reactions with additional molecules of alkene slower.

94. The C=C unit reacts with the radical formed from AIBN to form a carbon radical, but the radical may form on either of the two carbon atoms. Both A and B are secondary radicals, and should have approximately equal stability. Since there is no difference in relative stability, it is anticipated that both will form, in roughly equal amounts.

95. Read and understand Chapter 25 before attempting 96–99 and 114–117.
97. 

(a) \[
\text{Hg(OAc)}_2 \cdot \text{H}_2\text{O} \\
\text{NaBH}_4 \\
\text{H}_3\text{O}^+ \\
\text{PBr}_3
\]

(b) 

98. 

\[
\text{O}_3, -78 \degree \text{C} \\
\text{Me}_2\text{S}
\]

99. 

\[
\text{CH}_3\text{CO}_3\text{H} \\
\text{Me}_2\text{S}
\]

100. 

\[
-78 \degree \text{C} \\
\text{NaOH}, \text{H}_2\text{O}_2
\]

101. 

\[
\text{O}_3, -78 \degree \text{C} \\
\text{H}_2\text{O}_2
\]

102. 

\[
\text{O}_3, -78 \degree \text{C} \\
\text{Me}_2\text{S}
\]
103.

\[
\begin{align*}
\text{Hexane-2,3-diol} & \\
\text{Et} & \\
\text{Et} & \\
\end{align*}
\]

104.

\[
\begin{align*}
\text{OH} & \\
\text{OH} & \\
\text{aq KMnO}_4, \text{NaOH} & \\
\text{aq OsO}_4, \text{t-BuOOH} & \\
\end{align*}
\]

105. The \((E)\)-alkene has fixed stereochemistry because there is no rotation about the \(\text{C}=\text{C}\) bond. The reaction proceeds via formation of a bromonium ion, which is a three-membered ring that does not allow rotation, so the stereochemistry of all groups is fixed. The second bromine adds anti to the first one, which means that it adds from only one face. Given that the stereochemistry of the groups is fixed in the alkene, and fixed in the bromonium ion, anti attack leads to only one stereoisomer, the meso compound.

\[
\begin{align*}
\text{Et} & \\
\text{Et} & \\
\text{H} & \\
\text{H} & \\
\text{Et} & \\
\text{Et} & \\
\end{align*}
\]

Both \((3S,4R)\) and \((3R,4S)\)
It is a meso compound

106.

\[
\begin{align*}
\text{2,9-Dibromo-3-methyl-4-(2,2-dimethylpropyl)non-(3E)-ene} & \\
\text{1,2-Difluorocyclohexene} & \\
\end{align*}
\]
The reaction of 3,3-dimethylpent-1-ene and BH$_3$ leads to two transition states, A and B. In B, there is more steric hindrance of boron and the carbon toms than in A, so A leads to the final product, which is the borane shown, which has the BH$_2$ group on the less substituted carbon atom.

109.

\[
\begin{align*}
H_3C-C &\equiv C-CCH_3 \\
&\xrightarrow{H^+} H_3C-C &\equiv C-CCH_3 \\
&\xrightarrow{OH_2} H_3C-C &\equiv C-CCH_3 \\
&\xrightarrow{H_3O^+} H_3C-C &\equiv C-CCH_3 \\
&\xrightarrow{-H^+} H_3C-C &\equiv C-CCH_3
\end{align*}
\]
The reaction proceeds via an initially formed bromonium ion, and only diatomic bromine will generate this intermediate. Since HBr reacts to form a carboxation, cis/trans has no meaning, and borane gives a cis product whereas catalytic hydrogenation gives a mixture of cis and trans.

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Spectroscopy Problems. Chapter 14 must be read and understood before attempting these problems.
119. The $^1$H NMR for A shows one ethyl group (two signals) since it is symmetrical. The $^1$H NMR for B shows four signals including a unique singlet worth three H atoms: a methyl group with no neighbors.

120. Chemical shift differences in the NMR: >2 ppm for CH$_2$ in the ketone, but about 1.5 ppm for CH$_2$ in the diol, and the diol will have a signal at about 3.8 ppm for HO-CH.
121. Hex-2-yne

no distinguishing signals for either bromide in the IR

This is characterized by a downfield CH$_2$ group of the bromomethyl, which is missing in the other bromide

122. Hex-2-yne
123. 3-(Bromomethyl)pentane
124. C$_4$H$_8$O, Butan-2-ol
125. 1,5-Dichloropentane.

126. starting material, based on spectral data

or

127. 4-Methylpentan-2-ol
1. $\text{O}_3, -78 \degree C$

2. $\text{Me}_2\text{S}$

Precursor to A

Ozonide

$\text{A}$

$\text{HCHO}$
47.

48. Note that diethyl ether and THF are aprotic and will best facilitate second order reactions, but first order reactions are most facile in water and slow in virtually all other solvents. The way the question is worded, ethanol and formic acid allow second-order reactions to proceed faster than water, and so they may also be circled.

49. The circled carbocation is a primary carbocation, which is much less stable than the secondary or tertiary carbocations that constitute the other choices. There are fewer stabilizing alkyl groups on the primary carbocation.

50. The circled primary bromide is the most reactive because it offers the least amount of steric hindrance in the pentacoordinate $S_N2$ transition state, relative to the transition states for the other choices.
51. Methane has no electrons to donate, and water and methanol are neutral molecules. Although both of these neutral molecules are nucleophilic, the higher concentration of electron density on the methoxide anion makes it the strongest nucleophile. The hydrogen sulfate anion is a weak nucleophile due to resonance delocalization of the excess electron density.

\[
\begin{align*}
\text{CH}_3\text{O}^- & \quad \text{H}_2\text{O} & \quad \text{CH}_4 & \quad \text{CH}_3\text{OH} & \quad \text{HSO}_4^- \\
\end{align*}
\]

52. In water, ionization would give a primary carbocation, which is very unstable. It is also true that the energy required to achieve such an ionization is too high. Therefore, an S\textsubscript{N}1 reaction is very unlikely. Water is a weak nucleophile, and S\textsubscript{N}2 displacement of the bromide would give an oxonium ion. Loss of a proton would then give the alcohol. This is unlikely due to the weak nucleophilicity of water in this reaction, and the very slow rate of this particular reaction. It is more likely that there is simply no reaction at all.

53. This is an S\textsubscript{N}2 reaction, and it proceeds with 100\% inversion of configuration at the stereogenic carbon.
58.

59. The three-membered ring oxirane is much more strained than the four-membered ring oxetane. Reactions with HI will open both rings, but the greater relief of strain in the oxirane makes that reaction faster than the identical reaction with oxetane.

60. In the presence of triethylamine and thionyl chloride, butan-(2S)-ol is converted to (2R)-chlorobutane because it proceeds with inversion of configuration due to the presence of the nucleophilic chloride ion in the reaction medium, by an S_N2 reaction.

61.
62. There is a high concentration of charge density on oxygen in methoxide, which makes it rather reactive (relatively unstable) when compared to the methanesulfonate anion, which is resonance stabilized by delocalization of the charge density. This stabilization of the ion after it leaves contributes to its being a good leaving group. In addition, the C—O bond of the methanesulfonate is longer and weaker than the C—O bond of methoxide because the sulfur atom is larger, and the sulfonate group is larger and more electron withdrawing. The longer and weaker bond is easier to break, contributing to a better leaving group.

63. 1-Bromo-2-cyclohexylethane is a “normal” primary alkyl halide, as is 1-bromo-2-cyclohexyl-2-methylpropane. However, the pentacoordinate $S_N2$ transition state for 1-bromo-2-cyclohexyl-2-methylpropane is somewhat more sterically crowded that that for 1-bromo-2-cyclohexylethane, so the reaction is expected to be slower, which means that the reaction will have a longer half-life.
65. In 1,3-dibromo-4,4-dimethylpentane, one bromide is a relatively normal primary bromide, but the other is a neopentyl bromide. Neopentyl bromide is extremely unreactive in $S_N2$ reactions due to excessive steric hindrance in the pentacoordinate $S_N2$ transition state. Therefore, the reaction with the simple primary bromide is much faster and leads to the major product.

66. Of the solvents used in this book, for all practical purposes water is the only one that can ionize the halide so an $S_N1$ reaction can occur. Ionization is very slow in ethanol, so the $S_N2$ process dominates the reaction that leads to the major product because it is faster.

67. Since this is an $S_N2$ reaction, the rate depends on the concentration of both RX and the nucleophile, NaX. Increasing the concentration of one of them will allow the rate to increase and the reaction to be completed faster. Since NaX is the cheap component, increasing the concentration of NaX to 10 equiv for 1 equiv of RX will diminish the reaction time from 100 to 10 h. Adding more NaX can adjust the rate further is necessary.

68. The boiling point of 1-iodopentane is 155–157 °C, DMF is 153 °C, THF is 66 °C, acetone is 56 °C and diethyl ether is 35 °C. The dielectric constant of DMF is 36.7, THF is 7.6, acetone is 20.7 and diethyl ether is 4.3.

The best solvent for this reaction is DMF, but the boiling point is too close to the product for facile separation. The solvent will play an influential role, even if the product is isolated by liquid-liquid (column) chromatography. Diethyl ether has a low boiling point and is easily removed, facilitating isolation of the product, but the low dielectric indicates that the reaction will be slower. Acetone often contains water and is difficult to dry. The best choice is probably THF. Note that DMF is a perfectly good solvent and there are methods for separating product from solvent, it just may take more work.
69. The product of the reaction with diethylamine is an ammonium salt. Therefore, the transition state has a different charge distribution that the normal $S_N2$ transition state, as shown. In water, which separates charges, charge separation will accelerate the reaction, whereas THF as a solvent does not provide stabilization at all.

70. The nitrate anion ($\text{NO}_3^-$) is resonance stabilized, so the charge is dispersed. If the charge is dispersed over several atoms, then it is more difficult to donate electrons to an electrophilic atom, which means it is less nucleophilic.

71. The iodide ion is a nucleophile and replaces the bromine atom in an $S_N2$ reaction. Iodine is also a better leaving group relative to bromine, so it is more reactive with the azide anion, which accelerates the reaction. When iodide ion is displaced by azide ion, it once again becomes available for reaction with another molecule of the alkyl bromide.

72. Reaction via carbon gives the usual nitrile, whereas reaction at nitrogen generates what is known as an isonitrile. The formal charge on nitrogen in an isonitrile is +1 and the charge on the carbon is -1. The isonitrile is charged, and presumably will form more readily if water is the solvent, whereas the nitrile should form more readily in an aprotic solvent. If there is a mixture of nitrile and isonitrile, the isonitrile can be removed, in principle, by simply washing the mixture with water since the more polar isonitrile should be more soluble in water.
74. The secondary halide is less reactive than the primary halide due to more steric hindrance in the pentacoordinate S_N2 transition state.

75. Bromine is much larger than fluorine, so the C—Br bond distance is greater than the C—F bond distance, so it is weaker. In addition, the bromide ion is much larger than the fluoride ion, so after it leaves there is greater charge dispersal for bromide ion, which makes it more stable.

76. Many, if not most, organic molecules are insoluble in water, and alkyl halides are notorious for being insoluble in water. On the other hand, water is required for ionization reactions. The solution is to mix the water, or the ionization, with an organic cosolvent, to solubilize the reactants.

77. Ionization would generate the cycloheptatrienyl cation, which has four resonance contributors. This carbocation is very stable due to charge dispersal, and the great stability indicates a low activation energy and facile formation. The product is a nitrile generated by reaction of the nucleophilic cyanide with the carbocation.
78. Ionization of 4-phenyl-3-buten-2-ol generates a resonance-stabilized carbocation, with five resonance contributors. The charge is delocalized into the benzene ring. The increased stability of the intermediate means that formation of this intermediate is facile, which accounts for the rapid reaction in aqueous solution. In aqueous solution, the primary alkyl bromide does not undergo ionization to a primary cation, and the aqueous solution slows the Sn2 reaction.

79. Ionization of butan-(2S)-ol leads to a planar carbocation, which in turn leads to the racemic 2-iodobutane. If the observation is that 4,4-diethyl-2,2-dimethyl-3-(1-methylethyl)hexan-(3S)-ol undergoes ionization to a cation but gives more of the (S)-enantiomer than the (R), then the carbocation cannot be planar. In fact, the steric hindrance of the groups attached to C\(^+\) prevents planarity, so the incoming nucleophile approaches from the most open face. The molecular model shows the steric hindrance, and there is a slight distortion from planarity for the C\(^+\).
80. Ionization to the planar carbocation destroys the stereogenic center, and after rearrangement via a 1,2-hydride shift, the tertiary carbocation is symmetrical and achiral. In other words, when iodide ion reacts to form the product, the carbon bearing the iodine atom is not chiral because it also bears two propyl groups, making it a symmetrical molecule.

81. This result implies that the reaction is not ‘pure’ S_N_1, but rather proceeds by two different mechanisms. Some of the reaction occurs by S_N_1, via ionization to a carbocation, and product arises by that mechanism should not be influenced by the concentration of the nucleophile. Some of the product must arise by an S_N_2 mechanism, in which case an increase in nucleophile concentration will have an influence on the rate. In this book, there is a tendency to categorize reactions as 100% one thing or another, proceeding by one distinct mechanism. In real life, there are reaction conditions and molecules that react by more than one mechanism, which is the case in this example. It is one of those things you should keep in the back of your mind if you actually run an experiment in the lab, although for the purposes of doing the homework problems in this book, assume a single mechanism is operative.
Counterintuitive. To get this product, elimination must give the alkene and reaction with H⁺ must give the less stable 2° carbocation, which can react with water. The reaction of the alkene with H⁺ should be reversible, so it is not entirely unreasonable.
84. The products are the carbocation and nitrogen gas, which is a remarkably stable molecule. Therefore, $N_2^+$ is a remarkably good leaving group, which facilitates ionization to the carbocation.

$$R-N_2^+ = R-N\equiv N^+ \rightarrow R^+ + N\equiv N \text{ (nitrogen gas)}$$

(a) 2-Aminopentane

(b) 1-Amino-2-methylcyclohexane

(c) 1-Amino-2,2-dimethylpropane
85.

86. As with question 82, there is a mixture of two mechanisms: mostly $S_N2$, with some $S_N1$. Remember that the ammonium salt is an ion, and in aqueous media some ionization to the carbocation is possible. This ionization is responsible for the observed stereochemical mixture of products.

87. The major product or products are given. No mechanisms are provided.

(a) $\text{OH} \xrightarrow{\text{HBr}} \text{Br}$

(b) $\text{OH} \xrightarrow{\text{SOCl}_2} \text{Cl}$

(c) $\text{OH} \xrightarrow{1. B_2H_6, THF} \xrightarrow{2. H_2O_2, NaOH} \xrightarrow{3. NaNH_2} \xrightarrow{4. CH_3I, THF} \text{OCH}_3$

(d) $\text{Br} \xrightarrow{\text{NaN}_3, THF} \text{N}_3$

(e) $\text{OH} \xrightarrow{\text{Cl}_2, \text{light}} \text{Cl}$

(f) $\text{OH} \xrightarrow{\text{POCl}_3} \text{Cl}$

NaNH$_2$ reacts with the alcohol to give an alkoxide, which reacts with CH$_3$I by an $S_N2$ reaction.
(g) $\text{Br} \xrightarrow{\text{KI, H}_2\text{O-THF}} \text{I}$

(h) $\text{Cl} \xrightarrow{\text{NaBr, aq THF, reflux}} \text{Br}$

(i) $\text{O} \xrightarrow{\text{cat TsOH, NaCN, THF}} \text{CN}$

(j) $\text{OH} \xrightarrow{\text{cat H}^+, \text{H}_2\text{O, THF, NaCN}} \text{NC}$

(k) $\text{Br} \xrightarrow{\text{CH}_3\text{O}^+\text{Na}^+, \text{THF}} \text{OCH}_3$

(l) $\text{OH} \xrightarrow{1. \text{I}_2 \text{P}_{\text{red}}, 2. \text{NaN}_3, \text{THF-H}_2\text{O}} \text{N}_3$

(m) $\text{OH} \xrightarrow{\text{HBr}} \text{Br}$

(n) $\text{I} \xrightarrow{\text{NaCN, THF}} \text{CN}$

(o) $\text{I, CH}_3 \xrightarrow{\text{NaN}_3, \text{THF, 0 °C}} \text{No reaction (N.R.)}$

(p) $\text{Cl} \xrightarrow{\text{NaI, EtOH, reflux, 200 d}} \text{OEt}$

(q) $\text{Br} \xrightarrow{\text{NaN}_3, \text{THF, heat}} \text{N}_3$

(r) $\text{O} \xrightarrow{\text{NaN}_3, \text{THF}} \text{OH}$
88. The major product or products are given. No mechanisms are provided.

(a) \[
\text{Cl} \quad \xrightarrow{\text{KI, THF} \atop \text{H}_2\text{O}} \quad \text{Cl} + \text{I} \quad \text{Via S}_1\text{N} \text{ with allylic carbocation}
\]

(b) \[
\text{Br} \quad \xrightarrow{1, \text{HBr} \atop \text{2. NaCN, DMF}} \quad \text{CN} \quad \text{Via 1° bromide, then S}_2\text{N with CN}
\]

(c) \[
\text{OH} \quad \xrightarrow{\text{NaH, THF}} \quad \text{O} \quad \text{An internal S}_2\text{N via alkoxide}
\]

(d) \[
\text{Br} \quad \xrightarrow{1. 9-BBN, ether \atop 2. H}_2\text{O}_2, \text{NaOH} \atop 3. \text{SOCl}_2 \atop 4. \text{K-phthalimide}} \quad \text{CN} \quad \text{Via 1° alcohol, then conversion to chloride, then S}_2\text{N}
\]

(e) \[
\text{OH} \quad \xrightarrow{\text{conc. HBr}} \quad \text{OH} + \text{CH}_3\text{Br}
\]

(f) \[
\text{OH} \quad \xrightarrow{1. \text{NaH, THF} \atop 2. 2S-bromobutane \atop 3. \text{HI}} \quad \text{OH} \quad \text{Via S}_1\text{N with allylic carbocation, then S}_2\text{N with CN}
\]

(g) \[
\text{I} \quad \xrightarrow{1 \text{ equivalent NaCN}} \quad \text{CN} + \text{Cl} \quad \text{S}_1\text{N product, with rearrangement}
\]

(h) \[
\text{Br} \quad \xrightarrow{\text{KI, aq. THF} \atop \text{heat}} \quad \text{S}_1\text{N product, with rearrangement}
\]

(i) \[
\text{2. HC} = \text{C}^- \text{Na}^+, \text{THF} \atop 3. \text{NaH, THF} \atop 4. \text{CH}_3\text{I}} \quad \text{Via CN opening of initial epoxide}
\]

(j) \[
\text{2. NaCN, DMF} \atop 3. \text{dilute } \text{H}_3\text{O}^+ \quad \text{Via CN opening of initial epoxide}
\]
89. Radical chlorination of cyclohexane gives only one product because there is only one type of hydrogen. There are 12 hydrogen atoms, but they are all chemically identical, hence, one product. Hexane has three different types of hydrogen atoms: six methyl hydrogen atoms and two sets of different methylene atoms. Therefore, there are six identical methyl protons, four identical CH\(_2\) protons, and another set of four identical CH\(_2\) protons, and radical chlorination gives three different products.

90. The lack of selectivity is due to formation of allylic radicals. There are two different kinds of hydrogen atoms that lead to two different allylic radical. Each radical will lead to bromination at two carbon atoms, but in one case the same bromide is formed. Therefore there are three different products, although in two of the products, they will exist as (E) and (Z) isomers, so in reality there are five different products.
91. For 3-methylpentane, there is no great difference in the rate of hydrogen abstraction for the different types of hydrogen atoms. There are four different types of hydrogen atoms, so there are four different products. In the case of 3-phenylpentane, however, one of the hydrogen atoms is benzylic, so formation of the corresponding radical is very fast because of the resonance stability of the radical. Therefore, there must be a large rate preference to form the benzylic chloride shown, which is the major product.

Synthesis. Do not attempt the following until you have read and understood Chapter 25.

92.

(a) \[
\text{O} \quad \text{O} \quad \text{OH} \quad 1. \text{PBr}_3 \quad 2. \text{Na phthalimide, THF} \quad 3. \text{N}_2\text{H}_4
\]

(b) \[
\text{OH} \quad 1. \text{SOCl}_2 \quad 2. \text{Me}_2\text{NH}
\]

(c) \[
\text{HO} \quad 1. \text{SOCl}_2 \quad 2. \text{Na phthalimide, THF} \quad 3. \text{N}_2\text{H}_4
\]

(d) \[
\text{Br} \quad 1. \text{Na phthalimide, THF} \quad 2. \text{N}_3\text{H}_4 \quad 3. \text{PhCH}_2\text{Br}
\]
Spectroscopic problems. Do not attempt these problems until you have read and understood Chapter 14.
Both C=C units will absorb at about 1650 cm\(^{-1}\) in the IR.

2 Methyl groups and 2 alkene H

1 Methyl group and 3 alkene H

\[ \text{Br} \]
\[ \text{(S)} \]
\[ \text{2S-bromohexane} \]

\[ \text{CN} \]
\[ \text{(R)} \]
IR: 2230 cm\(^{-1}\)

\[ \text{OH} \]
IR: 3300 cm\(^{-1}\) for both

Unsymmetrical, so a more complicated \(^1\text{H}\) NMR spectrum. No singlet methyls and there is a CH downfield, adjacent to the OH

The symmetry leads to a simple \(^1\text{H}\) NMR spectrum that includes a singlet methyl. No protons on a carbon adjacent to O suggests 3° alcohol.
98. \( N,N \)-dimethylethanamine, \( \text{C}_4\text{H}_{11}\text{N} \).

99. Hex-2-yne, \( \text{C}_6\text{H}_{10} \).

100. Dipropyl ether, \( \text{C}_6\text{H}_{14}\text{O} \).

101. 2-Ethyl-2-methyl-1,3-propanediol.

102. 2-Bromohexane.

103. \[
\begin{align*}
\text{A} & \xrightarrow{\text{aq H}^+} \text{B} \\
\text{B} & \xrightarrow{1. \text{NaH}} \text{C} \\
\;
\end{align*}
\]

104. 2-Methylbutanenitrile, \( \text{C}_5\text{H}_9\text{N} \).
25. The circled alkene has more electron releasing alkyl groups on the C=C, which makes the π-bond stronger, making the alkene is more stable.

26. 

- \( \text{KOH, EtOH} \)
- \( \text{NaCl, ether} \)
- \( \text{NaNH}_2\text{NH}_3 \)
- \( \text{EtOH, NaOEt} \)
- \( \text{aq H}_2\text{SO}_4 \)
- \( \text{H}_2\text{O, 0 °C} \)

27.

28.

29.

(a) 2-Chloro-1-methylcyclopentan-1-ol
(b) 2-Bromohex-(2Z)-ene
(c) 2,3,4,6-Tetramethylhept-(3E)-ene
(d) Non-8-yn-3-ol

30.
31. Although (2S)-bromopentane is chiral and has one stereogenic center, the β-carbon is NOT a stereogenic center, and both protons are removed in an E2 reaction. Removal of one of the protons leads to the (E) isomer, whereas removal of the other proton leads to the (Z) isomer. The rotamers for removal of each β-proton are shown, and the alkene product resulting from each. Both products are produced.

32. A C=C unit attached to a bridgehead carbon is significantly more strained than one that is away from the bridgehead. A C=C unit, made of sp² carbon atoms that are trigonal planar, will flatten that region of the molecule. Forming the C=C unit toward the bridgehead demands that those carbon are flattened, which requires severe distortion and is too high in energy to occur in this system. Therefore, an E2 reaction with 2-bromobicyclo[2.2.1]hexane will give bicyclo[2.2.1]hex-2-ene as the major product.

33. 2-Bromobicyclo[2.1.1]hexane

KOH, EtOH

Bicyclo[2.1.1]hex-2-ene

Major product

This alkene is NOT formed because it would require severe distortion at the bridgehead carbon atoms
34. The alcohol is more acidic than the β-hydrogen, so it is reasonable that reaction with ethoxide will generate an alkoxide base. An S_N2 displacement of the nearby bromine atom is possible, but this reaction would form the four-membered ring ether (A). Formation of a strained four-membered ring is rather difficult due to the higher energy of that strained ring. Remember that formation of the alkoxide is a reversible acid-base reaction, and an alternative reaction is possible. Reaction of ethoxide with the β-hydrogen atom next to the bromine-bearing carbon will initiate an E2 reaction to give alkene B. Given the high-energy requirements for generation of A and the reversible nature of alkoxide formation, it is likely that under these conditions the alkene (B) is the major product via the E2 reaction.

![Diagram of the reaction](image)

35. The six-centered transition state of 2-ethylmalonic acid required for decarboxylation effectively has the oxygen of one carbonyl attack the acidic proton of the other. In 2-ethylbut-3-enoic acid, the requisite six-center transition state requires that an alkene unit attack the acidic proton of the carboxyl group. A simplistic idea is that the carbonyl oxygen is more basic than the alkene unit, so the reaction should be faster, and occur under milder conditions. The product of the dicarboxylic acid reaction is an enol, whereas the product of the alkene-acid is an alkene. The enol is more stable due to the electron releasing oxygen atoms, and remember that this enol tautomerizes to the stable carboxylic acid unit. Therefore, the product is more stable, which also drives the reaction and makes decarboxylation of the dicarboxylic acid more facile (it occurs at a lower temperature).

![Diagram of reactions](image)
36. The two possible reactions are E2 and S_N2. There are no β-hydrogen atoms, so no acid–base reaction is possible and an E2 reaction cannot occur. For an S_N2, a pentacoordinate transition state is required, and the bulky groups raise the activation energy of that reaction so high that it does not occur.

37. The two possible reactions are E2 and S_N2. There are no β-hydrogen atoms, so no acid–base reaction is possible and an E2 reaction cannot occur. For an S_N2, a pentacoordinate transition state is required, and the bulky groups raise the activation energy of that reaction so high that it does not occur.

38. Hydrogen bromide reacts with the alcohol to form an oxonium ion, which is either displaced by the nucleophilic bromide ion to yield the bromide by an S_N2 pathway, or ionization to a carbocation is followed by reaction with the nucleophilic bromide ion by a S_N1 pathway. When sulfuric acid reacts with the alcohol, an oxonium ion is also formed, but the counterion is the hydrogen sulfate anion. This anion is resonance stabilized and is not very nucleophilic. Therefore, either the S_N2 or S_N1 pathways are problematic. In addition, the sulfate ester formed via the S_N2 pathway is very unstable and will ionize to form a carbocation. The hydrogen sulfate anion is basic enough to initiate an E1 reaction via the carbocation, which leads to cyclohexene.
39. In this reaction, 3-methylhept-2-ene is the product that is expected from an E2 reaction. However, the leaving group (NMe₃) is tethered to the base (hydroxide), so hydroxide can only remove the β-hydrogen atom via an eclipsed rotamer. This restriction means that the lowest energy transition state will lead to product, which is the one with the least steric crowding, which leads to the less substituted alkene, 3-methylhept-1-ene, as the major product.

40. Draw the major product expected from each of the following reactions.

(a) 
\[
\begin{align*}
&\text{Br} \\
\rightarrow \\
&\text{I}
\end{align*}
\]

(b) 
\[
\begin{align*}
&\text{Br} \\
\rightarrow \\
&\text{NaOEt, EtOH}
\end{align*}
\]

(c) 
\[
\begin{align*}
&\text{OH} \\
\rightarrow \\
&1. \text{SOCl₂} \\
&2. \text{t-BuOK, t-BuOH}
\end{align*}
\]

(d) 
\[
\begin{align*}
&\text{OH} \\
\rightarrow \\
&\text{conc. H₂SO₄}
\end{align*}
\]

(e) 
\[
\begin{align*}
&\text{I} \\
&\rightarrow \\
&\text{KOH, EtOH}
\end{align*}
\]

(f) 
\[
\begin{align*}
&\text{Br} \\
\rightarrow \\
&\text{Ph, MeBr}
\end{align*}
\]

(g) 
\[
\begin{align*}
&\text{Br} \\
\rightarrow \\
&\text{NaOEt, EtOH}
\end{align*}
\]
41. An E2 reaction with 2,3-dibromopentane will yield the more highly substituted alkene because the reaction is under thermodynamic control. Therefore, elimination will occur by removal of the $\beta$-hydrogen on the carbon bearing the bromine. If heated for a long time with an excess of base, the vinyl bromide can also undergo elimination, to form an alkyne. Elimination to form the alkyne requires removal of the $\beta$-hydrogen atom, and removing the $\beta$-hydrogen atom from a sp$^2$ carbon on a C=C unit is more difficult than removing a $\beta$-hydrogen atom from an sp$^3$ carbon. In other words, the hydrogen atom on an sp$^3$ carbon is more acidic than the hydrogen on an sp$^2$ carbon.
42.

43. There is only one $\beta$-hydrogen, and removal by the base will generate a new C=C bond, but this will also generate an allene. Note that this question is more hypothetical, and that formation of allenes this way is not as easy as this reaction suggests because loss of Br from a sp$^2$ carbon is requires higher energy, which usually requires significantly more heating for an extended time.

![Chemical structure](attachment:image.png)

44. Loss of water from the initial oxonium ion leads to the carbocation. This benzylic C$^+$ unit will delocalize the charge into all three benzene rings (resonance), and the extensive charge delocalization makes it very stable.

![Chemical structure](attachment:image.png)

45. The reaction conditions stated in the problem favor an E1 reaction, which requires ionization to give a carbocation. Formation of a carbocation, which has a sp$^2$-hybridized carbon atom requires flattening of the molecule at the atoms attached to C$. In this case, C$^+$ is a bridgehead carbon atom, so flattening would lead to significant distortion of the bicyclic system. This requirement raises the activation energy for ionization and formation of the carbocation. If the carbocation does form, an E1 reaction would lead to one of the two alkene products shown. A $\pi$-bond in this molecule requires flattening at the bridgehead carbon, which is not possible because it would require extreme distortion of the bicyclic system. In other words, the energy required to form the alkene product is prohibitively high. The energy barrier imposed by the required distortion to form the carbocation intermediate and/or the alkene products makes the reaction very difficult, if not impossible.

![Chemical structure](attachment:image.png)
46. Examining the structure shown for 2-methylbutanedioic acid indicates that if one carbonyl attacked the acidic proton, loss of \( CO_2 \) would required "dumping" the electrons from the \( C—C=O \) bond on an sp3-hybridized carbon (\( C* \)). This electron-transfer sequence would form a carbanion, which is a high-energy intermediate, but not an enol because \( C* \) is not adjacent to the C+O unit marked in green. Because a high-energy carbanion would be formed, the energy demands are too high. For 1,3-dicarboxylic acids, the product is an enol, which can tautomerize to the carboxylic acid. Therefore, there is an atom that can accept the electrons with 1,3-dicarboxylic acids, but not with 1,4-dicarboxylic acids, and decarboxylation of 1,4-dicarboxylic acid is very difficult if not impossible.

47. The oxygen atom in \( B \) is a stronger base in the reaction with the acidic proton of the COOH unit when compared to the C=C unit. In addition, decarboxylation of \( B \) leads to an enol, which tautomerizes to the carboxylic acid, whereas decarboxylation of \( A \) leads to an alkene. The enol derived from decarboxylation of \( B \) is more stable than the product derived from decarboxylation of \( A \), which makes the overall process more facile (occurs at a lower temperature).

48. The base in this reaction is the oxygen atom that is attached to N, and an intramolecular acid-base reaction with a \( \beta \)-hydrogen atom must occur via an eclipsed rotamer, as shown. The lowest energy eclipsed rotamer will be the one in which the base removes the proton from the less substituted \( \beta \)-carbon, leading to the less substituted alkene.
49. The reaction proceeds by a syn-elimination mechanism, which is an internal acid-base reaction via the lowest energy eclipsed rotamer, but the oxygen of an ester is a significantly weaker base than the hydroxide in used in the Hofmann elimination, or than the negative oxygen in the Cope elimination from question 48. Therefore, the reaction is much slower and requires much higher reaction temperatures to overcome the high activation energy for reaction.

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

\[\text{H}_3\text{CO} \quad \text{H} \quad \text{A} \quad \text{H} \quad \text{2-Methylhex-1-ene}\]

50.

\[
\begin{align*}
\text{A} & \quad \text{1. HBr} \\
& \quad \text{2. KOH, EtOH} \\
\text{B} &
\end{align*}
\]

51. The ring is so large that formation of a triple bond proceed without significant problems.

\[
\begin{align*}
\text{A} & \quad \text{1. Br}_2, \text{CCl}_4 \\
& \quad \text{2. excess t-BuOK} \\
& \quad \text{t-BuOH, heat} \\
\text{B} &
\end{align*}
\]

52. The actual conformation of the molecule is shown, and it is clear that the bromine is in an equatorial position, so it cannot undergo an E2 reaction (no trans axial \(\beta\)-hydrogen). It is also true that the bicyclic nature of the molecule effectively locks it into the conformation shown, so there is no chance that the bromine can assume an axial position. Therefore, there is no E2 reaction.
53. Once the alkoxide is formed, the orbitals of the bonds are aligned so that transfer of electrons to form the carbonyl will break the adjacent bond, and those electrons approach the bromine-bearing carbon from the back (180° attack) to displace the bromide leaving group and form the new C=C unit.

Synthesis Problems. Do not attempt until you have read and understood Chapter 25.

54. 

55. Reagents are provided for each synthesis.

Spectroscopic problems. Do not attempt until you have read and understood Chapter 14.

56. 1-Methylcyclohexene
57. 

\[ \text{Br} \quad \xrightarrow{\text{E2}} \quad \text{Minor} \quad \text{Major} \]

58. 

IR: about 1650 cm\(^{-1}\)  
NMR: alkene proton and \(\text{C} = \text{C-CH}_3\)

IR: no distinguishing peaks  
NMR: nothing past 3.6 ppm and a \text{OCH}_3 singlet.

59. 5,5-Dimethylhex-1-ene.

60. Methylcyclopentene.

61. 

\[ \text{NaOMe} \quad \xrightarrow{\text{THF}} \quad \text{OCH}_3 \]

Chapter 13
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14.

\[ \text{Cl} \quad \text{O} \quad \text{NH}_3 \quad \text{Me}_3\text{COH} \quad \text{OH} \quad \text{H}_2\text{O} \]

\[ \text{CCl}_4 \quad \text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3 \quad \text{CH}_3\text{CH}_2\text{OH} \quad \text{Cl} \]

This is an S_N2 reaction, so the reaction proceeds with complete inversion of configuration, and (2R)-bromobutane is converted to (2S)-iodobutane.

15.

\[ \text{O} \quad \text{NH}_3 \quad \text{DMF} \quad \text{OH} \quad \text{H}_2\text{O} \]

\[ \text{CCl}_4 \quad \text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3 \quad \text{CH}_3\text{CH}_2\text{OH} \quad \text{Cl} \]

16.

\[ \text{Inversion product} \]

\[ \text{I} \quad \text{Br} \quad \text{I} \quad \text{Br} \]

17. Best nucleophile

\[ \text{CH}_3\text{O} \quad \text{H}_2\text{O} \quad \text{CH}_4 \quad \text{CH}_3\text{OH} \quad \text{HSO}_4^- \]

18. An S_N2 reaction of the secondary halide 2-bromobutane has a relatively low activation barrier to the pentacoordinate transition state. However, 2-bromo-2-methylbutane is a tertiary halide with a large activation barrier to the sterically hindered pentacoordinate transition state, so the S_N2 reaction does not proceed.

19. Water assists in the ionization of compounds via dipole interaction of both the H of water and the oxygen of water. Therefore, there is a + and a - polarized atom, and the positive H forms a dipole interaction with the negative ion or atom, and the negative oxygen forms a dipole with the positive ion or atom. These dipole interactions facilitate the ionization, and once the ions are formed, these interactions cause each ion to be effectively "surrounded" with water (solvation), which helps to stabilize each ion. Therefore, water facilitates ionization and solvates the ions. No other solvent is as
efficient at solvating both cations and anions. Since S_N1 and E1 proceed by ionization to a carbocation, water facilitates these reactions, whereas ionization is very slow in most any other solvent. The other solvents are simply not as good as solvation and stabilization.

20.

\[ + \quad + \quad (\text{Least stable}) \quad + \quad (\text{Most stable}) \quad + \]

21.

\[ \text{NaOEt} \quad H_2O \quad CH_4 \quad \text{NaNH}_2 \quad HNO_3 \]

22. increased by 2  decreased by 2  no effect  \(\text{increased by 10}\)  decreased by 10

23.

24.
25. 

One enantiomer

KOH, EtOH

HBr

Racemic

26. The major product or products are shown. No mechanisms are provided.

(a) 

KI, aq THF

(b) 

NaCN, THF, 0°C

No reaction (N.R.)

(c) 

cat. H⁺, aq THF

(d) 

KOH, EtOH

(e) 

Br

NaH

THF

(f) 

1. PBr₃

2. MeC=CNa⁺
(g) 1-Heptyne

1. BuLi, THF
2. benzyl bromide

(h)

1. P_{red}/I_2
2. NaOEt, EtOH

(i)

KCN, DMF

(j)

NaNH_2, NH_3
(k) \[
\begin{align*}
\text{Br} & \quad \xrightarrow{\text{KOH, EtOH}} \quad \text{(Z)} \\
\end{align*}
\]

(l) \[
\begin{align*}
\text{Br} & \quad \xrightarrow{\text{KI, aq THF}} \\
\end{align*}
\]

(m) \[
\begin{align*}
\text{OH} & \quad \xrightarrow{1. \text{MeSO}_2\text{Cl}} \quad \text{CN} \\
\text{2. NaCN, DMF} & \\
\end{align*}
\]

(n) \[
\begin{align*}
\text{Br} & \quad \xrightarrow{\text{NaOMe, THF}} \quad \text{OMe} \\
\end{align*}
\]

(o) \[
\begin{align*}
\text{OH} & \quad \xrightarrow{1. \text{NaH, THF}} \quad \text{(R)} \\
\text{2. (2S)-bromopentane} & \\
\end{align*}
\]

(p) \[
\begin{align*}
\text{(Z)} & \quad \xrightarrow{1. \text{HBr}} \quad \text{Br} \\
\text{2. NaI, THF} & \quad \text{N.R. with NaI} \\
\end{align*}
\]

(q) \[
\begin{align*}
\text{(S)} & \quad \xrightarrow{\text{NaCN, DMF}} \quad \text{(R)} \\
\end{align*}
\]

(r) \[
\begin{align*}
\text{Br} & \quad \xrightarrow{\text{KI, THF, reflux, 1 month}} \quad \text{No reaction (N.R.)} \\
\end{align*}
\]

(s) \[
\begin{align*}
\text{CH}_3 & \quad \xrightarrow{\text{H}_2\text{O, KI, heat}} \quad \text{(R)} \\
\text{H}_3\text{C} & \\
\text{Br} & \\
\end{align*}
\]
38.  
(a) M (100) 100%  M+1 (101) 6.66%  M+2 (102) 0.42%  C₆H₁₂O, 1 ring or π-bond.  
(b) M (149) 100%  M+1 (150) 11.46%  M+2 (151) 0.62%  C₁₀H₁₅N, 4 rings or π-bonds.  
(c) M (96) 100%  M+1 (97) 7.77%  M+2 (98) 0.30%  C₇H₁₂, 2 rings or π-bonds.  
(d) M (96) 100%  M+1 (97) 6.66%  M+2 (98) 0.42%  C₆H₈O, 3 rings or π-bonds.  
(e) M (110) 100%  M+1 (111) 8.88%  M+2 (112) 0.39%  C₈H₁₄, 2 rings or π-bonds.  
(f) M (83) 100%  M+1 (84) 5.91%  M+2 (85) 0.15%  C₃H₉N, 2 rings or π-bonds.  

39.  
**CH₃Br**  
Chemical formula: CH₃Br  
Exact mass: 93.94  
Molecular weight: 94.94  
m/z: 93.94 (100.0%), 95.94 (97.3%), 94.95 (1.1%), 96.94 (1.1%)  
Elemental analysis: C, 12.65; H, 3.19; Br, 84.16  

40.  
**Chemical formula:** C₅H₅BrCl  
**Exact mass:** 247.86  
**Molecular weight:** 250.36  
m/z: 249.86 (100.0%), 251.86 (69.3%), 247.86 (44.1%), 253.85 (13.4%), 250.86 (4.4%), 252.86 (3.1%), 248.86 (1.9%)  
**Elemental analysis:** C, 19.19; H, 2.82; Br, 63.83; Cl, 14.16  

Based on 75% 35Cl + 25% 37Cl + 2 each of 100% ⁷⁹Br + 98% ⁸¹Br  
C₄H₈ = 55  
248 + mass based on lowest mass isotopes.  
Higher mass peaks are 55+35+79+79 = 248  
and 55+35+79+81 = 250; 55+35+81+81 = 252; 37+79+79 = 250  
37+81+79 = 252; 37+81+81 = 254.  

41.  
Butane, C₄H₁₀, M:M+1 = 100:4.44  
Hexan-2-ol, C₆H₁₄O, M:M+1 = 100:6.66  
Toluene (methylbenzene), C₇H₈, M:M+1 = 100:7.77  
Triethylamine, C₆H₁₅N, M:M+1 = 100:7.03  
Butanenitrile, C₄H₇N, M:M+1 = 10:4.81
42. The ratio of $M:M+1$ for $C^{100}_{100}H_{202} = 100:111$

43. An $M:M+1$ ratio in a mass spectrum was 100:24. If $M+1 = 24$, then $24/1.11 = 21.6$. If there is experimental error, then this must be rounded to C22. This question is very ambiguous, but it is given here for a reason. It shows that sometimes there is experimental error that casts doubt on the real answer. In a laboratory, if possible, always obtain more data to confirm and/or verify a result.

44.

Chemical formula: CHCl$_3$

Exact mass: 117.91

Molecular weight: 119.38

$m/z$: 117.91 (100.0%), 119.91 (95.9%), 121.91 (30.6%), 123.91 (3.3%), 118.92 (1.1%), 120.91 (1.0%)

Elemental analysis: C, 10.06; H, 0.84; Cl, 89.09

45. Based of the exact mass of the daughter ion, identify the fragment lost from the original molecule. Suggest a cleavage that would lead to that daughter ion.

(a) $M$ = 86.0732 and the daughter ion has a mass of 57.0341. Loss of 29.0391. Loss of ethyl

(b) $M$ = 86.0732 and the daughter ion has a mass of 68.0626. Loss of 18.0106. Loss of water

(c) $M$ = 114.1045 and the daughter ion has a mass of 58.0419. Loss of 56.0626. Loss of butyl

(d) $M$ = 122.0368 and the daughter ion has a mass of 77.0392. Loss of 44.9976. Loss of CO$_2$
46. If a radical cation formed from naphthalene has the structure shown, it is possible to delocalize the charge over the $\pi$-bonds, and dispersal of charge density makes the radical cation lower in energy, and more stable. Therefore, resonance delocalization explains the stability of this radical cation.

47. 

48. If a radical cation formed from naphthalene has the structure shown, it is possible to delocalize the charge over the $\pi$-bonds, and dispersal of charge density makes the radical cation lower in energy, and more stable. Therefore, resonance delocalization explains the stability of this radical cation.

49. (a) For $\text{C}_6\text{H}_{12}\text{O}_2$, there is 1 ring or $\pi$-bond. Since the C=O unit of the ester has a $\pi$-bond, this ester is saturated.
(b) $m/z$ 29 is $\text{C}_2\text{H}_5$, 43 is $\text{C}_3\text{H}_7$, and 71 could be $\text{C}_4\text{H}_2\text{O}_2$ or $\text{C}_4\text{H}_6\text{O}$.

50. Yes! The energy is transferred to the masses (atoms) at each end of the spring (bond), and the more energy that is applied to the spring, the more the spring (bond) must vibrate to dissipate that energy.
51. $\nu = (1/2\pi) (f/\mu) = 0.159(f/\mu)$, where $\mu = \text{(mass}_1\text{)(mass}_2\text{)} / (\text{mass}_1 + \text{mass}_2$

(a) $k = 5.1 \times 10^5$ dynes cm$^{-1}$ for C-H. $\mu = 12x1/13 = 0.923$, so $\nu = 0.159(5.1\times10^5/0.923) = 87.9$ cm$^{-1}$.
(b) $k = 5.9 \times 10^5$ dynes cm$^{-1}$ for C-H. $\mu = 12x1/13 = 0.923$, so $\nu = 0.159(5.9\times10^5/0.923) = 101.6$ cm$^{-1}$.
(c) $k = 7.6 \times 10^5$ dynes cm$^{-1}$ for C-C. $\mu = 12x12/24 = 6$, so $\nu = 0.159(7.6\times10^5/6) = 20.1$ cm$^{-1}$.
(d) $k = 17.5 \times 10^5$ dynes cm$^{-1}$ for C≡N. $\mu = 12x14/26 = 6.46$, so $\nu = 0.159(17.5\times10^5/26) = 10.7$ cm$^{-1}$.
(e) $k = 12.3 \times 10^5$ dynes cm$^{-1}$ for C=O. $\mu = 12x16/28 = 6.86$, so $\nu = 0.159(12.31\times10^5/6.86) = 28.5$ cm$^{-1}$.

52. Structure B does not have an OH group, and the IR spectrum most certainly does: the broad peak between 3200–3600 cm$^{-1}$.

53. First of all, there are eight peaks, suggesting eight carbons. Note that there are two peaks at ~ 78 ppm (sorry for the scale). Structures A-C have six or five carbons? The peaks at 78 are due to solvent. This leaves six carbon atoms, which automatically excludes C. There is a carbonyl peak at ~ 168 ppm, consistent with an ester carbonyl. The telling peaks are at 130 and 138 ppm, which are clearly due to a C=C unit. Therefore, structure B fits the NMR.

54. At very dilute concentrations, there is minimal hydrogen-bonding, which leads to sharp absorption peaks rather than the broad peaks usually associated with OH unit. At very dilute concentrations, each of the two O—H bonds can be seen.

55. What IR absorptions would be expected for each of the following?
(a) 1-butyne : 2210 + 3300 cm$^{-1}$  (b) 2-butyn-1-ol : 2210 + 3300–3500 cm$^{-1}$
(c) 1,2-dichloroethyne: 2210 cm$^{-1}$  (d) 3-cyanobutanoic acid: 2240 + 2500–3000 + 1730 cm$^{-1}$

56. (a) Methylene cyclopentane and methylocyclopentene. IR, C=C at 1650 cm$^{-1}$  1. NMR: 2 alkene H for methylene cyclopentane vs one alkene H for methylocyclopentene + a singlet methyl
(b) Cyclopentanone and pent-3-enal. IR, 1725 cm$^{-1}$ for cyclopentanone vs 2817 + 1730 + 1650 cm$^{-1}$. NMR: cyclopentane has only methylene groups, but pen-3-enal has the alkene protons at ~ 4.8–5.5 ppm, a methyl group, and the aldehyde signal at ~ 9–10 ppm.
57. Possible structures are given. Other possibilities must include the given functional group, but there are many structural possibilities as long no other functional groups are incorporated.

58. \[
\frac{345}{x} = \frac{60}{270}, \quad x = \frac{(345)(270)}{60}, \quad x = 1552.5 \text{ Hz.} \quad 1552.5/270 \times 10^6 = 5.75 \text{ ppm.}
\]
\[
\frac{350}{x} = \frac{60}{270}, \quad x = \frac{(350)(270)}{60}, \quad x = 1575 \text{ Hz.} \quad 1575/270 \times 10^6 = 5.83 \text{ ppm.}
\]
\[
\frac{345}{x} = \frac{60}{600}, \quad x = \frac{(345)(600)}{60}, \quad x = 1575 \text{ Hz.} \quad 3450/600 \times 10^6 = 5.75 \text{ ppm.}
\]
\[
\frac{350}{x} = \frac{60}{600}, \quad x = \frac{(350)(600)}{60}, \quad x = 1575 \text{ Hz.} \quad 3500/600 \times 10^6 = 5.83 \text{ ppm.}
\]

59. The quartet at 4.3 ppm is linked to the triplet at 1.4 ppm (ratio of 2:3). This is an ethyl group, and the CH₂ unit is either attached to Cl or O. If attached to Cl, the structure is chloroethane, which does not use up all the atoms, so the structure must be OCH₂CH₃. The peak in the IR suggests a carbonyl, so it is likely this is an ester, or COOCH₂CH₃. The other peak in the NMR is a singlet worth 2H, and it is downfield at ~ 4 ppm. If we add up all the fragments, only the Cl remains, and if we have ClCH₂, the then structure of the molecule must be ClCH₂CO₂CH₂CH₃. The CH₂ is connected to both a Cl and a C=O, so it is further downfield. The downfield shift of the OCH₂ is due to the electron withdrawing effects of the ClCH₂ group. The molecule is **ethyl chloroacetate**.
60. The IR suggests a carbonyl, and there is only one oxygen, so this compound is probably an aldehyde or ketone. The formula suggests one ring or π-bond, which is accounted for by the C=O unit, so these are not cyclic compounds and there are no C=C units. A is very symmetrical, accounting for seeing only two carbon peaks, and the peak at ~ 14 ppm is a methyl, and the other is probably a CH₂. The carbonyl carbon is not apparent (note the peaks at 78 ppm are due to solvent).

It is not uncommon for carbonyl carbons, which normally resonates past 200 ppm, to be weak. The symmetry in the NMR spectrum suggests this is pentan-3-one. The carbonyl carbon is apparent in B at ~ 210 ppm, as are the other four carbons. This ketone is unsymmetrical. There are two different methyl groups and two different methylene carbons, and one is more downfield than the other, so one methylene is closer to the carbon than the other. Given this information, the likely structure for B is pentan-2-one.

\[ A = \text{pentan-3-one.} \quad B = \text{pentan-2-one.} \]

61. A spectrum with a singlet at 1.1 ppm (integrates to 3 H) and a singlet at 3.8 pm (integrates to 1 H) indicates that the ratio is 1:3, 2:6, or 3:9. The predicted chemical shift for the OMe group in methyl 2,2-dimethylpropanoate is about 3.5, whereas the methyl signal of the O=C-Me group is about 2.2. For the given chemical shifts, only 1,1-dimethylethyl ethanoate fits this data.

\[
\begin{align*}
\text{Methyl 2,2-dimethyl propanoate} & \quad \text{1,1-Dimethylethyl ethanoate} \\
\text{Singlet at 3.5 (3 H)} & \quad \text{Singlet at 0.9 (9 H)} \\
\text{Singlet at 0.9 (9 H)} & \quad \text{Singlet at 2.2 (3 H)}
\end{align*}
\]

62. This methyl group is attached to a cyclohexane, and the molecule exists in two equilibrating chair conformations. At low temperatures, below the activation barrier for conversion of one chair to the other, both chair conformations will exist. At low temperatures, the methyl group in each chair will have a different environment (one axial and one equatorial) so they will have different chemical shifts. This difference can be seen in the ¹H NMR, so there are two signals. At higher temperatures, the equilibration is rapid, and the two different methyl signals are effectively in equilibrium, and they coalesce into one signal (the average of the two separate signals).
63. A M+2 = 98% of M indicates the presence of bromine.

64. A peak at $m/z$ 179 relative to a parent ion at $m/z$ = 208 indicates loss of 29 mass units, which corresponds to an ethyl group. Therefore, all structures that have an ethyl group should be circled. There is only one.

65. Any molecule that has a $\pi$-bond will exhibit magnetic anisotropy in the $^1H$ NMR spectrum.

66. The IR data suggests the presence of an aldehyde. Therefore, the two aldehydes circled are possibilities.

67. A singlet at 5.9 ppm, as well as a triplet at 1.0 ppm and a quartet at 3.5 ppm. Based on chemical shift, the signal at 5.9 ppm suggests proximity to two functional groups because there are no $\pi$-bonds in the choices. Of these, only the circled compound fits. The circled compound also has the quartet:triplet characteristic of an ethyl group. The molecule is symmetrical, which is why there appears to be only one ethyl group. In the other cases, only one has an ethyl group, and that one also has a single methyl that should appear at ~ 3.5 ppm. The choice can be made solely on chemical shift, but the multiplicity of all but the circled compound does not fit the given data.
68. Peaks at 2850–2960 cm\(^{-1}\) in the IR indicate C—H, so any structure that does NOT have a CH should be circled. There are two.

69.

(a) How many different signals will appear in the \(^1\)H NMR spectrum of A? Two different signals, one for the CH\(_2\) and one for the identical tert-butyl groups.
(b) How many different signals will appear in the \(^1\)H NMR spectrum of B? Four different signals, one for the aldehyde proton, one for the CH group, and the two tert-butyl groups will likely give slightly different signals, although they will have very similar, if not overlapping signals.
(c) In A, the chemical shift of the CH\(_2\) will be \(\sim 3–3.5\) and will integrate for 2 H, whereas the CH in B will be slightly further downfield \(\sim 3.2–3.7\) ppm due to the presence of the carbon group, but it will only integrate to 1 H. The most distinguishing feature is the aldehyde proton in B, which is missing in A. The two tert-butyl groups in A will show up as one singlet, integrating for 18 H, whereas they may be two slightly different singlets in B, each integrating for 9 H.

70. Peaks in the 7–8 ppm region of a \(^1\)H NMR spectrum indicate the presence of aromatic CH, so no peaks in that region indicate there are no aromatic CH. The circled compounds have no aromatic CH. Note that pentan-3-one has no benzene rings at all, so it clearly does not have aromatic CH.
71. Both questions are answered by comparison of the anisotropy diagrams shown.
(a) Ethene absorbs at ~ 5.4 ppm in the $^1$H NMR spectrum whereas the proton for ethyne absorbs ~ 2.3
because the two $\pi$-bonds in the alkyne orient the secondary magnetic field such that the protons of
ethyne are in the shielding portion of the anisotropy field, and are upfield. In the others, the protons are
oriented in the deshielding portion of the anisotropy field and are downfield.
(b) The aldehyde H—C=O unit appears at ~ 9.4 ppm because the signal is pushed down field by two
factors: inductive effects of the carbonyl deshield the proton, and the anisotropy of the $\pi$-bond also
deshield. The combination of these two effects pushes the aldehyde proton far downfield. In an alcohol,
the H of the alcohol H—C—O appears ~ 3.5 ppm because there is no anisotropy (no $\pi$-bonds), but there
is the inductive effect caused by proximity to the electron withdrawing oxygen atom. Since only one
effect is operative, the signal is not as far downfield as noted for the aldehyde.

72. Water will damage salt plates, so water or any solvent that contains water should be avoided.

73. A solvent that has protons cannot be used in $^1$H NMR because those signals will appear and either
“swamp out” signals for the sample, or obscure signals from the sample. Only solvents with no protons
may be used, and this usually means exchanging protons for deuterium in the solvent.

74. 0 1 2 3 4 5 6

75. $^1$H $^{13}$C $^{34}$S $^{35}$Cl $^{81}$Br $^3$H
76. Based on this simplistic figure, there are CH, and the peak at ~ 4.4 microns (µ) is consistent with a triple bond. Since this molecule has a formula of C₅H₈, it is a hydrocarbon, and the only possible functional group is an alkyne with a C≡C.

<table>
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<th>3</th>
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<th>5</th>
<th>6</th>
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<td>alcohol</td>
<td>ether</td>
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<tr>
<td>1° amine</td>
<td>2° amine</td>
<td>3° amine</td>
<td>nitrile</td>
<td></td>
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<td>alkene</td>
<td>alkane</td>
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</tr>
</tbody>
</table>

77. If we refer to Figure 14.1, the shorter frequency (cm) corresponds to higher energy. The unit in IR is cm⁻¹, or 1/cm, so 3200 cm⁻¹ (corresponds to 0.0003 cm) is higher in energy than 180 cm⁻¹ (corresponds to 0.0005 cm).

78. The molecular ion of C₅H₉Cl is based on the lowest mass isotopes, for ¹²C, ¹H and ³⁵Cl. This corresponds to m/z 104 (60 for C, 9 for H and 35 for Cl). Use the isotope masses, not the mass from the periodic table, which is the mass of all isotopes based on their natural abundance. Atomic Cl is 75:26 mixture of ³⁵Cl and ³⁷Cl, which gives 35.45 for the mass. In MS, use 35, not 35.45.

79. The molecular ion for CH₃(CH₂)₅NH₂ is m/z 101, and a peak at m/z 84 corresponds to 101-84 or m/z 17, which is the m/z for ammonia (NH₃). By analogy with an alcohol, a primary amine may lose ammonia.

80. The mass of pentan-3-one is m/z 86, and that of methyl butanoate is m/z 102 due to the extra oxygen atom. Analysis of the molecular ion of each compound should allow them to be distinguished. In the IR, both will show a carbonyl at ~ 1725 cm⁻¹ so MS is the best way to distinguish these compounds.

81. The only molecule with protons upfield of the OCH₃ signal are in N-ethyl-N-methylethanamine.
82. Compounds such as this have NO protons at all.

83. 2,4-Dimethylpentan-3-one.

84. 2,3-Dimethylbutane.

85. Cyclopentenone.

86. 3-Phenylpentan-3-ol.

87. 2,3-Dibromobutane.

88. N,N-Diethylpropanamine.

89. Hex-2-yne.

90. Isobutynitrile.

91. Allyl vinyl ether.

92. 1-Ethylcyclopentene
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Organic Chemistry. An Acid-Base Approach 2nd Edition

28.
(a) \( \text{MgI} \) (b) \( \text{MgBr} \) (c) \( \text{MgBr Ph} \) (d) \( \text{MgBr} \)

29.
(a) \( \text{Li} \) (b) \( \text{Li} \) (c) \( \text{Li Ph} \) (d) \( \text{Li} \)

30.
(a) \( \text{Li} \) (b) \( \text{Li} \) (c) \( \text{Li Ph} \) (d) \( \text{CH}_3\text{Li} \)

31.
(a) \( \text{MgBr} \) \( \text{Et}_2\text{NH} \) \( \xrightarrow{\text{Et}_2\text{N}^-\text{MgBr}^+} \)
(b) \( \text{MgBr} \) \( \text{NH}_2 \) \( \xrightarrow{\text{NH}^-\text{MgBr}^+} \)
(c) \( \text{MgBr} \) \( \text{NH} \) \( \xrightarrow{\text{N}^-\text{MgBr}^+} \)
(d) \( \text{MgBr} \) \( \text{OH} \) \( \xrightarrow{\text{O}^-\text{MgBr}^+} \)
(e) \( \text{MgBr} \) \( \equiv \equiv \) \( \xrightarrow{\equiv^-\text{MgBr}^+} \)
32.

(a) \[
\begin{array}{c}
\text{Li} \\
\text{HNEt}_2
\end{array} \quad \rightarrow \quad \begin{array}{c}
\text{Li} \\
\text{Li}^{+}\text{NEt}_2
\end{array}
\]

(b) \[
\begin{array}{c}
\text{Li} \\
\text{NH}_2
\end{array} \quad \rightarrow \quad \begin{array}{c}
\text{Li} \\
\text{NH}^{-}\text{Li}^+
\end{array}
\]

(c) \[
\begin{array}{c}
\text{Li} \\
\text{NH}
\end{array} \quad \rightarrow \quad \begin{array}{c}
\text{Li} \\
\text{N}^{-}\text{Li}^+
\end{array}
\]

(d) \[
\begin{array}{c}
\text{Li} \\
\text{OH}
\end{array} \quad \rightarrow \quad \begin{array}{c}
\text{Li} \\
\text{O}^{-}\text{Li}^+
\end{array}
\]

(e) \[
\begin{array}{c}
\text{Li} \\
\text{H}
\end{array} \quad \rightarrow \quad \begin{array}{c}
\text{Li} \\
\text{H}^{-}\text{Li}^+
\end{array}
\]

(f) \[
\begin{array}{c}
\text{Li} \\
\text{NH}_2
\end{array}_2 \quad \rightarrow \quad \begin{array}{c}
\text{Li} \\
\text{N}^{-}\text{Li}^+
\end{array}_2
\]

(g) \[
\begin{array}{c}
\text{Li} \\
\text{PhCH}_2\text{Br}
\end{array} \quad \rightarrow \quad \begin{array}{c}
\text{Li} \\
\text{CH}_2\text{Ph} \\
\text{LiBr}
\end{array}
\]

(h) \[
\begin{array}{c}
\text{Li} \\
\text{Br}
\end{array} \quad .5 \text{ CuI} \quad \rightarrow \quad \begin{array}{c}
\text{Li} \\
\text{Cu}^{-}\text{Li}
\end{array}
\]

(i) \[
\begin{array}{c}
\text{Li} \\
\text{I}
\end{array} \quad \rightarrow \quad \begin{array}{c}
\text{Li} \\
\text{Li}
\end{array}
\]

No reaction (perhaps some elimination to 2-methylpropene)
33. Only allylic and benzylic halides give good yields in this reaction. The compound that is circled is the only allylic bromide among the choices given.

![Allylic Bromide](image)

34.

(a) \[ \text{Br} \quad \xrightarrow{\text{Me}_2\text{CuLi, ether \ -10 °C}} \quad \text{CH}_3 \]

(b) \[ \text{Ph} \quad \xrightarrow{\text{Me}_2\text{CuLi, ether \ -10 °C}} \quad \text{Ph} \quad \text{CH}_3 \]

(c) \[ \text{I} \quad \xrightarrow{\text{Me}_2\text{CuLi, ether \ -10 °C}} \quad \text{CH}_3 \]

35. Give the names of the final product, if any, for each of the following reactions.

(a) 2-iodopentane + 1. Mg/ether  2. acetylene  Pentane + HC≡CMgI

(b) phenylmagnesium bromide + 1. CuBr/THF/-10 °C  2. 2-bromopentane. 2-Phenylpentane

(c) 2-bromobut-2-ene + 1. Li/THF  2. CuI/THF/-10 °C  3. iodomethane. 2-Methylbut-2-ene

(d) 2-bromobut-2-ene + 1. Mg/THF  2. but-1-yne. Butene + EtC≡CMgBr

(e) 3-bromocyclopentene + 1. Mg/THF  2. benzyl bromide. 3-Benzylcyclopentene

(f) butylmagnesium chloride + water. Butane

(g) 2-methylhexylmagnesium bromide + 1,2-dimethoxyethane. No reaction

(h) 1-iodopentane + 1. Li  2. 2-iodo-2-methylpentane. Probably no reaction since a 3° RLi is less stable than a 1° RLi

(i) phenyllithium + 1. Cul/THF/-10 °C  2. 2-bromohexane. 2-Phenylhexane

(j) \( n \)-butyllithium + 1. 1-propyne  2. dilute aqueous acid. Prop-1-yne + butane

(k) \( n \)-butyllithium + \( N \)-methyl-1-aminopentane. \( N \)-Lithio \( N \)-methyl-1-aminopentane + butane

(l) methylithium + 2,2,4,4-tetramethylhexane. No reaction

36. Propan-2-ol has an acidic OH unit, and this proton will react as an acid in the presence of the Grignard reagent, which is a powerful base.

37. Although (2S)-bromohexane is chiral, upon reaction with Mg, the Grignard reagent is configurationally unstable, so it will revert to a racemic mixture. Reaction with CuBr forms a magnesium cuprate that reacts with iodoethane to yield the product, 3-methylheptane. This alkane product is racemic because the Grignard reagent it is derived from is racemic, despite the fact that the starting bromide was chiral. The point of this problem is to emphasize that a Grignard reagent formed from a chiral halides will almost always be racemic.
38. Vinyl Grignard reagents are less stable and they are more difficult to form because a C=C—X bond is stronger than a C—C—X bond (sp² vs sp³ for carbon). THF is a stronger Lewis base when compared to diethyl ether, and it provides more coordination with the halide which assists in the Mg insertion, and after formation of the Grignard reagent, the THF is better Lewis base, and has better coordination with the Mg of the Grignard reagent, which helps to stabilize that product.

39. 

40. Both are pyrophoric, which means that they react with oxygen in the air and with moisture in the air. Based on the results, tert-butyllithium is much more reactive than n-butyllithium.

41. The positive head pressure of nitrogen excludes air and moisture from the reaction. Remember that organolithium reagents react with both water and air. The reaction temperature should be maintained between -78 → 0 °C, but at lower temperatures the reaction with an amine may be very slow. The reaction is faster at the higher temperature. Amines are very weak acids, and increasing the temperature raises the rate of the reaction. Addition of pent-1-yne to the LDA solution should generate the lithium alkyne anion of pent-1-yne along with diisopropylamine. Subsequent addition of allyl bromide, leads to an S_N2 reaction of the alkyne anion nucleophile with the allyl bromide to yield oct-1-en-4-yne.
42. Octane is formed by reaction of \( n \)-butyllithium with unreacted 1-bromobutane (or 1-iodobutane). The \( n \)-butyllithium is prepared by reaction of the halobutane and lithium metal, and as the butyllithium is formed there is a competition between reaction of halobutane with lithium metal and reaction with the newly formed \( n \)-butyllithium to give octane. This coupling reaction is known as the Wurtz reaction, and the octane is a hydrocarbon so it is not removed from the reaction mixture.

**Spectroscopy Problems. Do not attempt these until after you have studied Chapter 14.**

43. Infrared cannot be used to see if bromododecane was converted to dodecane because the C—Br unit does not have a distinguishing peak that is easily detected. Therefore, there is nothing to check. Proton NMR may be used because the chemical shift of the CH\( _2 \)Br signal of the bromide will be downfield at ~3.7 ppm, whereas in the alkane no signal will be downfield of 1.5–1.7 ppm. Therefore, \(^1\)H NMR can be used exclusively as a diagnostic tool to distinguish the bromoalkane from the alkane.

44. Infrared cannot be used alone because the C—Br unit does not have a distinguishing peak that is easily detected, and the internal alkyne unit of both molecules will show a peak at 2220 cm\(^{-1}\). Proton NMR may be used because the chemical shift of the CH\( _2 \)Br signal of the bromide will be downfield relative to the signal in the alkyne with an alkyl substituent. The bromide starting material and the hydrocarbon product have different masses, so the molecular ion can be used to distinguish the two molecules. In addition, the bromide will have a M+2 peak in the mass spectrum that is near 100% of the molecular ion, and the hydrocarbon product will not.

45.
28. 

(a) \[ \text{1-Cyclopropylpentan-1-one} \]  
(b) \[ \text{3-Ethenylcyclopentan-1-one} \]  
(c) \[ \text{(Z)-9-Chloro-5,5-dimethylnon-3-enal} \]  
(d) \[ \text{4,5-Dicyclopentynon-6-yn-2-one} \]  
(e) \[ \text{3,4,5-Trimethylcyclohexane-1-carbaldehyde} \]  
(f) \[ \text{6-(3,3-Dimethylbutyl)octadecan-3-one} \]  
(g) \[ \text{2-Cyclohexylcyclohexanone} \]  
(h) \[ \text{6-Phenylhex-5-ynal} \]

29. There is less steric hindrance about the carbonyl carbon of an aldehyde than with a ketone, so butanal should be more reactive in acyl addition reactions when compared with butan-2-one.

30. 

(a) \[ \text{3,3,5,5-Tetramethylocyclohexanone} \]  
(b) \[ \text{3-Ethyl-2-propylpent-2-enal} \]  
(c) \[ \text{1,1,1,3-Tetraphenylpentan-2-one} \]
31. The substituent does not have more carbon atoms than the ring, so it is named as a cyclopropane derivative, and the name is 1-propylcyclopropanecarbaldehyde.

32.

(a) 5-Oxohexanoic acid
(b) 6-Oxohexanoic acid
(c) 6-Oxohexanoic acid

33.

(a) (dibutyl ketone)
(b) (Methyl ethyl ketone)
(c) (Ethyl vinyl ketone)
(d) (Dibenzyl ketone)
(e) (Phenyl propyl ketone)

34. Intramolecular hydrogen bonding in 2-hydroxybutanoic acid weakens the O—H bond of the acid, making it more acidic. The hydroxyl group in 4-hydroxybutanoic acid is too far away for effective hydrogen bonding. Imagine a five-membered ring being formed for hydrogen bonding in the 2-hydroxy versus a seven-membered ring for 4-hydroxy.
35.

36. There is a great deal of steric hindrance around the carbonyl carbon in 3,3,5,5-tetraethylheptan-4-one that hinders approach of a nucleophile, and makes it less reactive in acyl addition reactions when compared to the unhindered heptan-4-one.

37. The tetrahedral intermediate is the same for both reactions. Once formed, ethoxide is a better leaving group relative to the amide anion. For this reason, the ester is converted to the amide, but the amide is NOT converted to the ester.

38.

(a) 3,3-Dimethylheptanoic acid  
(b) 1-Phenylcyclohexanecarboxylic acid  
(c) Hexanedioic acid  
(Adipic acid)

(d) 3-Methyl-2-(1,1-dimethylpropyl)heptanoic acid  
(e) 7,11,12-Triethyl-2,3-dimethylhexadecanoic acid
39. 

(a) \[\text{Butanoic 2-methylpropanoic anhydride (Butyric isobutyric anhydride)}\]

(b) \[\text{Butyl 2,3-dimethylbutanoate}\]

(c) \[\text{1-Methylethyl 2-methylpropanoate (Isopropyl isobutyrate)}\]

(d) \[\text{N-Ethyl-N,3,3-trimethylbutanamide}\]

(e) \[\text{2-Butylheptanoyl chloride}\]

(f) \[\text{N,N,3-Trimethylbutanamide}\]

(g) \[\text{Cyclohexyl ethanoate (Cyclohexyl acetate)}\]

(h) \[\text{2-Cyclooctylpropanamide}\]

(i) \[\text{Methyl decanoate}\]

(j) \[\text{Propanoic anhydride (Propionic anhydride)}\]

(k) \[\text{3,3-Diphenylpentanoyl chloride}\]

(l) \[\text{4-Chlorobutanoyl chloride}\]

40. Iodide is a better leaving group than chloride, because it is a larger atom (weakens the C—X bond) and the larger iodide ion has greater charge dispersal. If iodide is a better leaving group, then butanoyl iodide should be much more reactive than butanoyl chloride. It is!

41. The alkyne anion is a better nucleophile. Reaction with the ketone will generate a C—C bond, which is quite strong, whereas reaction with iodide will generate the weaker C—I bond. The alkoxide intermediate from reaction with iodide should easily expel iodide because it is a good leaving group, making the reaction reversible. These combine to make the alkyne anion a much better nucleophile.

42. 

(a) \[\text{N,N-Diphenylhexanamide}\]

(b) \[\text{Cyclobutyl 3,3-dimethylhexanoate}\]

(c) \[\text{Dipentanoic anhydride}\]

(d) \[\text{Hexadec-(5Z)-enoyl chloride}\]

(e) \[\text{Ethyl oct-4-ynoate}\]
43. Since $n$-butyllithium is a good nucleophile, acyl substitution will lead to the ketone. What is not obvious from this chapter, is that the ketone is more reactive than the ester, and it will compete for reaction with the butyllithium.

\[
\text{BuLi} \quad \text{OMe} \rightarrow \text{O} \quad \text{Bu}
\]

44. The product or products are shown. No mechanisms are provided.

(a) \[
\text{CHO} \quad \text{1. HC≡C:Na}^+ \quad \text{2. H}_2\text{O}^+ \rightarrow \text{OH}
\]

(b) \[
\text{O} \quad \text{1. KCN} \quad \text{2. dilute H}_2\text{O}^+ \rightarrow \text{CN}
\]
(c) \[\text{CHO} \xrightarrow{\text{NaCl}} \text{No reaction (N.R.)}\]

(d) \[\text{O} \xrightarrow{1. \text{MeLi}} \xrightarrow{2. \text{dilute H}_3\text{O}^+} \text{OH}\]

(e) \[\text{O} \xrightarrow{1. \text{PhMgBr}} \xrightarrow{2. \text{H}_3\text{O}^+} \text{HO Ph}\]

(f) \[\text{H}^+ \xrightarrow{} \text{OH} \quad \text{No other products}\]

(g) \[\text{O} \xrightarrow{1. \text{MeMgBr}} \xrightarrow{2. \text{H}_3\text{O}^+} \text{OH CH}_3\]

(h) \[\text{O} \xrightarrow{\text{HNEt} \_2} \xrightarrow{\text{heat}} \text{O NEt}_2\]

(i) \[\text{Cl} \xrightarrow{\text{NaOMe}} \text{OMe}\]

(j) \[\text{CHO} \xrightarrow{1. \text{BuLi}} \xrightarrow{2. \text{H}_3\text{O}^+} \text{HO Bu}\]

(k) \[\text{CO}_2\text{H} \xrightarrow{\text{CH}_3\text{MgBr}} \text{CO}_2^-\text{MgBr}^+ + \text{CH}_4\]

(l) \[\text{CHO} \xrightarrow{\text{H}_2\text{O}} \xrightarrow{\text{MeLi}} \text{CHO} + \text{CH}_4\]
46. In A, intramolecular hydrogen bonding is possible that enhances the acidity, whereas the carboxyl groups are too far apart in B for such hydrogen-bonding.

47. The oxocarbenium ion from pentan-3-one has two resonance contributors, whereas the oxocarbenium ion from methyl pentanoate has three, and is more stable. The more stable (less reactive = less acidic) oxocarbenium ion is formed from the stronger carbonyl base. Based on the stability of these conjugate acids, the ester is less basic.

48. Protonation of the carbonyl oxygen is reversible. The oxocarbenium in is a very strong acid, which means it is very reactive and the equilibrium for this reaction lies to the left, so $K_a$ for this reaction expected to be $<< 1$.

49.

SYNTHESIS

There are no synthesis problems associated with this chapter
SPECTROSCOPY. You should read and understand Chapter 14 before attempting these problems.

50. \[ \text{Pentan-2-one} \]

51. \[ \text{2-Methylpentanal} \]

52. \[ \text{Hex-2-enal} \]

53. \[ \text{Hex-3-enoic acid} \]

54. \[ \text{N},2,2\text{-trimethylpropanamide} \]

55. \[ \text{2,2-Dimethylpropanoic acid} \]

56. \[ \text{Hexanoyl chloride} \]

57. \[ \text{Isobutyric anhydride} \]
58. \[ \text{Pent-4-eneoic acid} \]

\[
\begin{align*}
\text{O} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{H} \\
\end{align*}
\]

O
31. 

(a) \text{Oxidation} \quad \begin{align*} \text{O} & \quad \text{OH} \\
\text{OH} & \quad \text{NMe}
\end{align*}

(b) \text{Reduction} \quad \begin{align*} \text{OH} & \quad \text{OMe} \\
\text{NMe} & \quad \text{Br}
\end{align*}

(c) \text{Reduction} \quad \begin{align*} \text{Br} & \quad \text{H}
\end{align*}

(d) \text{Oxidation} \quad \begin{align*} \text{OH} & \quad \text{CHO}
\end{align*}

(e) \text{Oxidation} \quad \begin{align*} \text{CHO} & \quad \text{CHO}
\end{align*}

32. The chromate ester derived from 3,3-dimethylpentan-2-ol is more sterically hindered, and it is more difficult to remove the proton from the adjacent carbon. Therefore, the reaction is slower.

4-Methylpentan-2-ol

3,3-Dimethylpentan-2-ol

33. 

(a) \begin{align*} \text{HO} & \quad \text{EtOEt} \\
\text{H} & \quad \text{H}
\end{align*}

(b) \begin{align*} \text{H} & \quad \text{H}
\end{align*}

(c) \begin{align*} \text{HO} & \quad \text{HO}
\end{align*}
34. The answer to this question is not completely obvious from the discussion in the book. Collins reagent is formed by mixing chromium trioxide in pyridine, and then adding this mixture to dichloromethane. Pyridinium chlorochromate is isolated as an orange solid by mixing chromium trioxide in aq HCl, and isolating the precipitate. It is likely that the Collins regent is more complex since the equilibrium is different in pyridine than in water, and the HCl reacts to form a chlorochromate. They are different, but certainly related.

35. The major products are
(a) 4,4-Diphenylhexanoic acid  (b) Cyclohexanecarbaldehyde  (c) Cycloheptanone.

36.  

37. Excess ozone will react with both C=C units, although at least some of the cleavage from only one C=C is likely. Workup with hydrogen peroxide will generate the carboxylic acids.

38.  

a net oxidation
39. Alkyl groups are electron releasing with respect to the π-bond of an alkene. The more substituted the alkene, the higher the electron density available for donation in the π-bond. The reaction with the peroxycacid is driven by electron donation from the π-bond to the electrophilic oxygen of the peroxycacid. Therefore, the more highly substituted alkene is the more reactive, and 3,4-dimethylhex-3-ene undergoes epoxidation faster than does hex-3-ene.

40.

(a) \[
\begin{array}{c}
\text{OH} \\
\text{CH}_2\text{Cl}_2
\end{array}
\]  
\[
\text{N}^+ \text{H} \text{CrO}_3\text{Cl}^- 
\]
\[
\text{O} 
\]

(b) \[
\begin{array}{c}
\text{OH} \\
\text{CH}_2\text{Cl}_2
\end{array}
\]  
\[
\text{N}^+ \text{H} \text{CrO}_3\text{Cl}^- 
\]  
\[
\text{No reaction (N.R.)}
\]

(c) \[
\begin{array}{c}
\text{1. OsO}_4 \cdot t\text{-BuOH} \\
\text{2. HIO}_4
\end{array}
\]  
\[
\text{CHO} 
\]
Via diol

(d) \[
\begin{array}{c}
\text{1. HBr} \\
\text{2. KOH, EtOH} \\
\text{3. O}_3, -78 ^\circ\text{C} \\
\text{4. Me}_2\text{S}
\end{array}
\]  
\[
\text{CHO} + \text{O} \longrightarrow \text{O} 
\]
Steps 1 and 2 yield the same alkene shown

(e) \[
\begin{array}{c}
\text{1. BH}_3 \cdot \text{ether} \\
\text{2. NaOH, H}_2\text{O}_2 \\
\text{3. PCC, CH}_2\text{Cl}_2
\end{array}
\]  
\[
\text{CHO} 
\]
Via 1° alcohol

(f) \[
\begin{array}{c}
\text{1. Hg(OAc)}_2 \cdot \text{H}_2\text{O} \\
\text{2. NaBH}_4 \text{ then hydrolysis} \\
\text{3. Na}_2\text{Cr}_2\text{O}_7, \text{aq acetone} \\
\text{H}_2\text{SO}_4
\end{array}
\]  
\[
\text{K} 
\]

41. The trifluoroacetyl group is electron withdrawing, which makes the electrophilic oxygen of the peroxycacid more positive via inductive effects. The more positive the oxygen, the more reactive will be the peroxycacid.

42. The reaction occurs by electron donation from the π-bond to ozone in a 1,3-dipolar reaction. The more electron rich the π-bond, the faster the reaction is expected to be. Since a tetrasubstituted alkene has more electron releasing alkyl group, the π-bond is more electron rich, and it reacts faster.

43.

\[
\begin{array}{c}
\text{O} \\
\text{H}
\end{array}
\]  
\[
\text{OH} 
\]
\[
\text{OH} 
\]
\[
\text{OH} 
\]
\[
\text{OH} 
\]
\[
\text{OH} 
\]
Synthesis. Do not attempt these problems until you have read and understood Chapter 25.
Spectroscopic problems. Do not attempt these problems until you have read and understood Chapter 14.
50. In the presence of the mercuric salts, the more stable secondary vinyl carbocation is formed, which reacts with water to form an oxonium ion. Loss of a proton gives the enol, which tautomerizes to the product, pentan-2-one. The singlet at 2.1 ppm is due to the methyl group adjacent to the carbonyl.

51. IR: Cyclohexanone has a C=O at about 1725 cm⁻¹ but the conjugated C=O appears at about 1695 cm⁻¹

52. The second product of the epoxidation is trifluoroacetic acid, which is a very strong acid. As the epoxide is formed, it reacts with the trifluoroacetic acid to generate a carbocation, which can rearrange to a more stable oxocarbenium ion. Loss of a proton lead to the observed ketone. By adding a buffer to the reaction, (e.g., sodium acetate), the trifluoroacetic acid product is buffered, which means that acid-catalyzed processes are minimized.
53. In the IR, the alcohol will have the broad peak at $\sim 3300$ cm$^{-1}$, and this peak will disappear as it is oxidized to the conjugated ketone, which will have a carbonyl peak at $\sim 1695$ cm$^{-1}$. The alcohol will have a C=C peak at $\sim 1650$ cm$^{-1}$. In the $^1$H NMR, the ketone will have a single methyl signal at $\sim 2.3$ ppm. The methyl group adjacent to the alcohol-bearing carbon will be a doublet. Both of the molecules will have alkene protons and an ethyl group.

\[ \text{Hex-3-en-2-ol} \xrightarrow{\text{PDC}} \text{conjugated ketone} \]

[IR and NMR spectra of Hex-3-en-2-ol and conjugated ketone]

54. In the IR, both will have a carbonyl peak at $\sim 1725$ cm$^{-1}$, but the aldehyde will also have the aldehyde proton signal at 2817 cm$^{-1}$. In the $^1$H NMR, the aldehyde will have the signal at 9-10 ppm, which is missing from the ketone. The ketone will have a singlet methyl signal at $\sim 2.2$ ppm that is missing from the aldehyde.

\[ \text{3-Phenyl-1-pentanal} \xrightarrow{} \text{3-Phenylpentan-2-one} \]

[IR and NMR spectra of 3-Phenyl-1-pentanal and 3-Phenylpentan-2-one]

55. In the IR, the aldehyde will have the aldehyde proton peak at $\sim 2817$ cm$^{-1}$ and the carbonyl peak at 1725 cm$^{-1}$. The carboxylic acid will have the carbonyl at $\sim 1725$ cm$^{-1}$, but it will also have a broad absorption at 2500–3000 cm$^{-1}$. In the $^1$H NMR, the most obvious difference is the singlet at 9-10 ppm for the aldehyde, but at $\sim 12$ ppm for the acid.

A simple alternative is to wash the mixture with an aqueous solution of NaHCO$_3$. The carboxylic acid will react in an acid–base reaction to give the carboxylate anion, which is water soluble. The aldehyde can be separated and the acid regenerated by treating the aqueous solution with dilute HCl.
56. The signal for oxirane is shifted upfield because of the strain of the three-membered ring. The strain causes the bonds to "bow" from linearity between the nuclei, which diminishes the effects due to the proximity of the electron pairs on oxygen relative to the hydrogen atoms. The result is greater shielding, and the signal moves upfield relative to methyl ether.

57. The aldehyde unit has the polarized C=O bond, and the electron withdrawing effect of the oxygen leads to greater deshielding relative to the nonpolarized alkene, C=C. In effect, the bond polarization and anisotropy effects are additive.

58. There will be few differences in the IR, but in the $^1$H NMR, butane-2,3-diol will show a doublet for the methyl groups, whereas butane-1,4-diol has no methyl groups, only methylene.

59. 3,5,5-Trimethylhexanal
60. 2-Methylpentane-2,4-diol

61. 1,2-Epoxyhexane

62. 2-Propylpentanoic acid

63. Pent-2-enal (E or Z is OK)

64. 2,3-Dimethylsuccinic acid
56. Both are pentane-2-one, which will react to yield the product.

57. Grignard reagents are strong bases that will react with the acidic hydrogen of the OH unit in ethanol, which is a strong acid in the presence of this powerful base.

58. Although (2S)-bromohexane is a chiral molecule, upon reaction with Mg, the Grignard reagent is configurationally unstable at the carbon bearing the Mg, so the product will be a racemic mixture. Reaction with pentan-2-one will give the alcohol, but since the Grignard reagent is racemic, the alcohol is racemic and a mixture of diastereomers.

59. Vinyl Grignard reagents are less stable and they are more difficult to form because a C=C—X bond is stronger than a C—C—X bond (sp² vs sp³ for carbon). The solvent THF is a stronger Lewis base when compared to diethyl ether as the solvent, because it provides more coordination with the halide. This increased basicity assists in the Mg insertion, and after formation of the Grignard reagent, the THF is a better Lewis base, with better coordination of the Mg of the Grignard reagent, which helps to stabilize that product.

60. The ketal from this reaction would be a nine-membered ring. The transannular strain in nine-membered rings is so great that a cyclization reaction to generate such a ring will have such a high activation barrier that it simply does not form.
61. Note that the C=C—N unit is essentially planar in an enamine. In B, the methyl group on the C=C unit will have steric interaction with the isopropyl groups on nitrogen, which will hinder its formation. In A, that particular methyl group can rotate away so there is less steric hindrance and this enamine will form faster than B.

62. React each with 2,4-dinitrophenylhydrazine. The two derivatives will have different melting points, and by looking up the melting points for these two derivatives in the literature, the two are easily distinguished. A bit more research would show that the conjugated ketone will give an orange-red 2,4-dinitrophenylhydrazone whereas the nonconjugated ketone will yield a yellowish 2,4-dinitrophenylhydrazone. The two compounds are easily distinguished using this method.

63.
65. The enol form is stabilized by internal hydrogen bonding, as shown. Such stabilization is not possible with simple mono-ketones.

66. The carbonyl is too sterically hindered and the nucleophilic carbon of the Grignard reagent cannot come close enough for bonding. A slower reaction involves coordination of the carbonyl oxygen with the magnesium, formation of ethene and transfer of hydride to the acyl carbon, leading to reduction of the ketone.

If acyl addition cannot occur, coordination with the Mg—O leads to transfer of a hydride to the acyl carbon, loss of ethene, and reduction of the ketone.

Steric hindrance prevents close approach of the Grignard reagent to the acyl carbon
68. Both have a π-bond and both will react as a Lewis base or a Brønsted–Lowry base. However, The C=O unit is polarized and the C=C unit is not, which allows the carbonyl to undergo acyl addition in which a nucleophile donates electrons to the electron-deficient carbonyl carbon, breaking the weak π-bond and forming an alkoxide product.
69. In aqueous solutions 1,1,1-trichloroethanal forms the hydrate (chloral hydrate), which is quite stable and there is a sizable concentration in aqueous media. If the carbonyl carbon is “tied up” as a hydrate, acyl addition reactions do not occur.

70. Sulfuric acid is rather insoluble in organic solvents, whereas methanesulfonic acid is mostly soluble in organic solvents. In addition, sulfuric acid is an oxidizing acid that may initiate unwanted side-reactions or even decomposition of the starting material.

71.

![Hemiketals and Ketals](image)

72.

(a) \(\text{O} \quad \text{NaCN} \quad \text{CN} \quad \text{O}^-\text{Na}^+\)

(b) \(\text{O} \quad \text{NaOEt} \quad \text{OEt} \quad \text{O}^-\text{Na}^+\)

(c) \(\text{O} \quad \text{NaC=CEt} \quad \text{C=CEt} \quad \text{O}^-\text{Na}^+\)

(d) \(\text{O} \quad \text{MeMgBr} \quad \text{Me} \quad \text{O}^-\text{MgBr}^+\)

(e) \(\text{O} \quad \text{MeLi} \quad \text{Me} \quad \text{O}^-\text{Li}^+\)

(f) \(\text{O} \quad \text{EtNH}_2 \quad \text{O}^- \quad \text{N} \quad \text{H} \quad \text{+} \quad \text{H} \quad \text{N} \quad \text{H} \)
73. Give the complete mechanism for each of the following transformations.

(a) 

\[
\begin{align*}
\text{CH}_3\text{C}_3\text{H}_7\text{O} & \xrightleftharpoons{H^+} \text{CH}_3\text{C}_3\text{H}_7\text{O}^+ \\
\text{CH}_3\text{C}_3\text{H}_7\text{C}_3\text{H}_7\text{OH} & \xrightleftharpoons{H^+} \text{CH}_3\text{C}_3\text{H}_7\text{C}_3\text{H}_7\text{O}^+ \xrightleftharpoons{\text{H}_2\text{O}} \text{CH}_3\text{C}_3\text{H}_7\text{C}_3\text{H}_7\text{O}^+ \\
\text{CH}_3\text{C}_3\text{H}_7\text{C}_3\text{H}_7\text{O} & \xrightleftharpoons{H^+} \text{CH}_3\text{C}_3\text{H}_7\text{C}_3\text{H}_7\text{O}^+ & \xrightleftharpoons{\text{H}_2\text{O}} \text{CH}_3\text{C}_3\text{H}_7\text{C}_3\text{H}_7\text{O}^+ \\
\end{align*}
\]

(b) 

\[
\begin{align*}
\text{CH}_3\text{C}_3\text{H}_7\text{Me} & \xrightleftharpoons{H^+} \text{CH}_3\text{C}_3\text{H}_7\text{Me}^+ \\
\text{CH}_3\text{C}_3\text{H}_7\text{Me} & \xrightleftharpoons{H^+} \text{CH}_3\text{C}_3\text{H}_7\text{Me}^+ & \xrightleftharpoons{\text{H}_2\text{O}} \text{CH}_3\text{C}_3\text{H}_7\text{Me}^+ \\
\text{CH}_3\text{C}_3\text{H}_7\text{Me}^+ & \xrightleftharpoons{H^+} \text{CH}_3\text{C}_3\text{H}_7\text{Me}^+ & \xrightleftharpoons{\text{H}_2\text{O}} \text{CH}_3\text{C}_3\text{H}_7\text{Me}^+ \\
\end{align*}
\]

(c) 

\[
\begin{align*}
\text{C}_3\text{H}_7\text{O} & \xrightleftharpoons{H^+} \text{C}_3\text{H}_7\text{OH} \\
\text{C}_3\text{H}_7\text{OH} & \xrightleftharpoons{H^+} \text{C}_3\text{H}_7\text{OH} & \xrightleftharpoons{\text{H}_2\text{O}} \text{C}_3\text{H}_7\text{OH} \\
\text{C}_3\text{H}_7\text{OH} & \xrightleftharpoons{H^+} \text{C}_3\text{H}_7\text{OH} & \xrightleftharpoons{\text{H}_2\text{O}} \text{C}_3\text{H}_7\text{OH} \\
\end{align*}
\]
74. Phenylglyoxal (A) forms a relatively stable hydrate because of the stabilization provided by the adjacent electron withdrawing carbonyl group. No hydrogen atom is on the carbon adjacent to the carbonyl carbon, so there is no mechanism that will allow loss of water. Therefore, A cannot easily form an enol. In addition, formation of the carbocation shown is destabilized (a $\text{C}^+$ next to a $\text{C}^\delta+$ would constitute a high energy intermediate. Formation of the hydrate from B is straightforward, and loss of water to the enol and tautomerization back to the aldehyde is facile, so this hydrate is not very stable.
75. From a synthetic viewpoint, the ketal is formed from the ketone shown. Note that any synthesis must account for the absolute stereochemistry of the groups in the acyclic ketone in order to generate the ketal with the correct stereochemistry. Note also how the \((R)/(S)\) configuration changes when the ring system is opened to the cyclic ketone since there are now two OH units. The molecule is drawn in the same perspective as B to show the stereochemical relationships, and then again in the extended conformation.

![Chemical structures](image)

76. Formation of the ketal from propane-1,3-diol requires formation of a stable six-membered ring, whereas formation of the ketal from octane-1,8-diol requires formation of a high energy nine-membered ring. The transannular strain inherent to a nine-membered ring poses an energy barrier that is too high for formation of this ketal.

![Chemical structures](image)

77. 

(a) \[
\begin{array}{c}
\text{OCH}_2\text{CH}_3 \\
\text{OCH}_2\text{CH}_3 \\
\end{array} \quad \xrightarrow{\text{cat. TsOH}} \quad \begin{array}{c}
\text{O} \\
+ 2 \text{EtOH} \\
\end{array}
\]

(b) \[
\begin{array}{c}
\text{H}_3\text{CO} \\
\text{OCH}_3 \\
\text{H}_2\text{O/THF} \\
\end{array} \quad \xrightarrow{\text{cat. TsOH}} \quad \begin{array}{c}
\text{O} \\
+ 2 \text{MeOH} \\
\end{array}
\]

(c) \[
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{H}_2\text{O/THF} \\
\end{array} \quad \xrightarrow{\text{cat. TsOH}} \quad \begin{array}{c}
\text{O} \\
+ \text{HOCH}_2\text{CH}_2\text{OH} \\
\end{array}
\]

(d) \[
\begin{array}{c}
\text{OCH}_2\text{CH}_2\text{CH}_3 \\
\text{OCH}_2\text{CH}_2\text{CH}_3 \\
\text{H}_2\text{O/THF} \\
\end{array} \quad \xrightarrow{\text{cat. TsOH}} \quad \begin{array}{c}
\text{CHO} \\
+ 2 \text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \\
\end{array}
\]

(e) \[
\begin{array}{c}
\text{S} \\
\text{S} \\
\text{Ph} \\
\text{BF}_3, \text{H}_2\text{O} \\
\text{THF} \\
\end{array} \quad \xrightarrow{\text{BF}_3, \text{H}_2\text{O}} \quad \begin{array}{c}
\text{PhCHO} \\
\text{SH} \\
\text{SH} \\
\end{array}
\]

(f) \[
\begin{array}{c}
\text{O} \\
\text{Ph} \\
\text{H}_2\text{O/THF} \\
\end{array} \quad \xrightarrow{\text{cat. TsOH}} \quad \begin{array}{c}
\text{O} \\
\text{Ph} \\
\text{OH} \\
\end{array}
\]
(g) \[
\begin{align*}
\text{SCH}_3 & \xrightarrow{\text{BF}_3, \text{H}_2\text{O}, \text{THF}} \text{CH}_3\text{CO} + 2 \text{CH}_3\text{SH}
\end{align*}
\]

78.

(a)

\[
\begin{align*}
\text{H}^+ & \xrightarrow{\text{MeOH}} \text{H}^+ \xrightarrow{\text{Me}^- \xrightarrow{\text{OMe}}} \text{H}^+ \xrightarrow{\text{Me}^- \xrightarrow{\text{OMe}}} \text{H}^+ \xrightarrow{\text{Me}^- \xrightarrow{\text{OMe}}} \text{H}^+ \xrightarrow{\text{Me}^- \xrightarrow{\text{OMe}}} \text{H}^+
\end{align*}
\]

(b)

\[
\begin{align*}
\text{H}^+ & \xrightarrow{\text{H}_2\text{O}} \text{H}^+ \xrightarrow{\text{H}_2\text{O}} \text{H}^+ \xrightarrow{\text{H}_2\text{O}} \text{H}^+ \xrightarrow{\text{H}_2\text{O}} \text{H}^+ \xrightarrow{\text{H}_2\text{O}} \text{H}^+ \xrightarrow{\text{H}_2\text{O}} \text{H}^+
\end{align*}
\]

(c)

\[
\begin{align*}
\text{C}_5\text{H}_{11}\text{O} & \xrightarrow{\text{EtOH}} \text{C}_5\text{H}_{11}\text{O} \xrightarrow{\text{EtOH}} \text{C}_5\text{H}_{11}\text{O} \xrightarrow{\text{EtOH}} \text{C}_5\text{H}_{11}\text{O} \xrightarrow{\text{EtOH}} \text{C}_5\text{H}_{11}\text{O} \xrightarrow{\text{EtOH}} \text{C}_5\text{H}_{11}\text{O} \xrightarrow{\text{EtOH}} \text{C}_5\text{H}_{11}\text{O}
\end{align*}
\]

(d)

\[
\begin{align*}
\text{Bu} & \xrightarrow{\text{H}_2\text{O}} \text{Bu} \xrightarrow{\text{H}_2\text{O}} \text{Bu} \xrightarrow{\text{H}_2\text{O}} \text{Bu} \xrightarrow{\text{H}_2\text{O}} \text{Bu} \xrightarrow{\text{H}_2\text{O}} \text{Bu} \xrightarrow{\text{H}_2\text{O}} \text{Bu}
\end{align*}
\]
79.

4-Phenyl-1,1-dimethoxy-cyclohexane

2,2-Dimethyl-4,4-diphenyl-1,3-dioxane

1,1-Diethylthiopentane

2,2-(Diisopropoxy)-3,4-dimethylhexane

2-Butyl-1,3-dioxolane

80.
81. Although it may not obvious, the mixed OH-SH thiohydrate is known to be very unstable, and it will undergo elimination and revert back to the ketone, just like a hydrate. Given this instability, it is very unlikely that any of the thiohydrate product (HS-C-SH) will ever be formed under these conditions.

82. Yes. Dilute acid hydrolysis will convert the dioxolane to a ketone, and it should be possible to treat A with BF\textsubscript{3} under conditions that will convert the dithiolane to a ketone. In each case, the other protected carbonyl will not be hydrolyzed.

83. If the ether reacts with an electrophilic atom, the product is an oxonium salt. If an ether reacts with a carbonyl, a trialkyl oxonium salt would be formed, that does not have a proton. The oxonium ion is highly reactive, but formation of this ion is reversible and cannot proceed to product. In other words, the oxygen of an ether is a remarkably poor nucleophile for acyl addition reactions.

84. The major product or products are shown. No mechanisms are provided.
(c) 
\[ \text{OCH} \rightarrow \text{N-NHPh} \]

(d) 
\[ \text{PhNHNH}_2, \text{cat H}^+ \rightarrow \text{HN-NHPh} \]

(e) 
\[ \text{CHO} \rightarrow \text{Ph-NHPh} \]

(f) 
\[ \text{cat. H}^+ \rightarrow \text{BuO-OBu} \]

(g) 
\[ \text{O} \rightarrow \text{N-NHPh} \]

(h) 
\[ \text{H}_2\text{O} \rightarrow \text{AC} + \text{HOCH}_2\text{CH}_2\text{OH} \]

(i) 
\[ \text{2,4-dinitrophenylhydrazine} \rightarrow \text{Ph-N-H-NO}_2 \]

(j) 
\[ \text{1. MeCO}_3\text{H, 2. PhMgBr, 3. H}_2\text{O}^+ \rightarrow \text{Via epoxide} \]
85. Acid hydrolysis will lead to the sugar shown, and benzaldehyde. Along the way, cyanide is released as a leaving group. Presumably, laetrile kills cells by exposing them to deadly cyanide, but it is unlikely there is any selectivity for cancerous cells versus normal cells.

86.

87. Compound B is not as susceptible to hydrolysis. For all practical purposes it is just an ether, and acid hydrolysis of an ether is very difficult unless HBr is used. Compound A is an acetal, and subject to the hydrolysis mechanism discussed in this chapter.

88. The logical product is the enamine, formed by the usual mechanism. An alternative product arises by interaction of the pendant hydroxyl group with the iminium salt (or another intermediate) to form the cyclic N,O-ketal shown.
89. Hydrolysis of trioxolane eventually leads to the hydrate of formaldehyde, which is converted to formaldehyde. All three C—O units of trioxolanes are converted to 3 equivalents of formaldehyde upon acid hydrolysis.

\[
\begin{align*}
\text{O} & \quad \text{H}^+ \\ \\
\text{O} & \quad \text{O} \quad \text{+} \\ \\
\text{O} & \quad \text{H} \\ \\
\text{H} & \quad \text{O} \quad \text{C} \quad \text{OH} \\ \\
\text{O} & \quad \text{H} \\ \\
\text{H} & \quad \text{O} \quad \text{C} \quad \text{OH} \\ \\
\text{H} & \quad \text{C} \quad \text{O} \\
\text{H} & \quad \text{OH} \\
\text{H} & \quad \text{H} \\
\text{formaldehyde}
\end{align*}
\]

90. (a) 3,4-Dimethylheptan-3-ol. (b) Phenylcyclohexanol (c) \(\text{CH}_3\text{CH}_2\text{C}≡\text{C}^+\text{Mgl}\) + \(\text{CH}_3\)H.
(d) Dicyclopentylmethanol. (e) Butane. (f) 5,7-Dimethylundecan-5-ol.
(g) 2-Methylheptan-2-ol. (h) 4-Ethyl-1,1-diphenylheptan-1-ol. (i) Prop-1-yne.
(j) 1-Phenylhexan-1-ol. (k) 4-Phenylbutan-2-ol.

91. This multi-step a reaction is one in which each step is reversible. In an equilibrium, removing one product from the reaction shifts the equilibrium towards product. If two products are formed and one is removed, the equilibrium shifts to produce more of both products. Using Le Chatlier’s principle, removal of water, which is a product along with the acetal or ketal, will shift the equilibrium and drive the reaction towards the acetal or ketal.

92. The product or products are shown. No mechanisms are provided.
Synthesis. Do not attempt these problems until you have read and understood Chapter 25.

93.
1. PhMgBr, THF
2. H$_3$O$^+$

1. Mg, THF
2. cyclohexanone
3. H$_3$O$^+$

1. NaNH$_2$, NH$_3$
2. 2-hexanone
3. H$_3$O$^+$

1. Mg, THF
2. cyclopentanone
3. H$_3$O$^+$
Spectroscopy Problems. Do not attempt these problems until you have read and understood Chapter 14.

96. Differences between an imine and the alkene unit of an enamine are minimal. In the $^1$H NMR, an enamine will have an alkene H between 4.5-5.5 ppm, whereas an imine will not. Two groups will be on nitrogen in an enamine, and only one on the nitrogen in an imine. Depending of the nature of the groups on nitrogen, there may be other differences in the $^1$H NMR.
97. There is a distinct ethyl group in the $^1$H NMR, and integration will reveal that there are two ethyl groups. The collection of methylene groups at about 1.8-2.1 ppm suggests a ring, but there is no way to absolutely correlate these peaks with a four-membered ring. The mass spectrum will show a weak molecular ion, and a prominent M-18 peak, in accord with a tertiary alcohol. There will be a prominent M-29 peak for loss of an ethyl group. There are characteristics of fragmentation for four-membered rings, but they have not been discussed in this book, so the only reasonable thing to be gained from the mass spectrum is the presence of ethyl groups and the suggestion of an alcohol.

98. \[ C_8H_{14}O. \]

99. There are two rings or \( \pi \)-bonds, and one of them is a carbonyl. The position of the carbonyl suggests a conjugated carbonyl. The absence of a peak at \( \sim 2800 \text{ cm}^{-1} \) indicates the compound is not an aldehyde, so it is a conjugated ketone. The absence of a peak at \( 2270 \text{ cm}^{-1} \) indicates that it is not an alkyne, which is consistent with the number of \( \pi \)-bonds, so it is indeed an acyclic conjugated ketone. There is nothing to indicate the specific structure of the seven-carbon conjugated ketone. Two examples are shown, but there are other possible isomers.
The conjugated ketone (cyclopent-2-enone) will show a carbonyl at $\sim 1695 \text{ cm}^{-1}$ whereas the non-conjugated ketone (cyclopent-3-enone) will show a normal carbonyl at $\sim 1725 \text{ cm}^{-1}$. The $^1\text{H}$ NMR of cyclopent-3-enone is rather simple, showing only one type of alkene proton and the methylene protons adjacent to the carbonyl. Cyclopent-2-enone shows several peaks, including two different alkenyl protons and two different methylene groups, one further downfield than the other as it is next to the carbonyl. Reaction of each of the ketones with 2,4-dinitriophenylhydrazine will give the 2,4-dinitrophenylhydrazone product. The product derived from cyclopent3-one will be yellow-orange or just yellow, whereas the product derived from cyclopent-2-enone will be red-orange due to the conjugation.

101. 1-Phenylbutan-2-one

102. Benzaldehyde diethyl acetal

103. 4-Phenylbut-3-en-2-one

104. Diisopropylamine

105. 1-Hexyn-3-ol
106. 4-Methylpent-1-ene to 4-methylpentan-1-ol to 3,7-dimethyloctan-3-ol

\[
\text{A} \xrightarrow{1. \text{9-BBN}} \text{B} \xrightarrow{2. \text{NaOH} \; \text{H}_2\text{O}_2} \text{C} \\
\text{Mg} \xrightarrow{\text{MgBr}} \text{D} \xrightarrow{\text{O}} \text{E} \\
\text{I-Phenylbutan-1-ol}
\]
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31.

32. The OMe groups attached to Al in LiAlH(OMe)₃ are electron withdrawing, so the Al—H bond is less polarized (less δ-), and LiAlH(OMe)₃ is weaker than LiAlH₄. The electron releasing NaBHEt₃ makes the B—H bond more polarized (more δ-), so it is a stronger reducing agent than NaBH₄.

33. The Al—H bond in LiAlH₄ is more polarized than the B—H bond in sodium borohydride, so Al—H is more reactive with the acidic proton of water. Lithium aluminum hydride will react with water in an acid-base reaction, which emphasizes the δ- polarization of the H (a hydride).

34. The product is the sodium salt of butanoic acid, CH₃CH₂CH₂CO₂⁻Na⁺. Sodium borohydride is not a strong enough reducing agent to reduce the carboxylic acid.

35.
36. An amalgam is most commonly an alloy of mercury with another metals, but it has sometimes been more broadly defined as a mixture of different elements.

37. Reduction of 5-oxooctanal with NaBH₄ reduces the aldehyde first because it is less hindered and more reactive. Excess reagent will reduce both the aldehyde and the ketone units, but if the stoichiometry and reaction time are carefully controlled, it is possible to selectively reduce the aldehyde in the presence of the ketone. Note that it is often difficult to do this with NaBH₄.

38. Lithium triethylborohydride is LiBHEt₃ and lithium trimethoxyaluminum hydride is LiAlH(OMe)₃. As noted in question 30, the OMe groups attached to Al in LiAlH(OMe)₃ are electron withdrawing, which makes the Al—H bond less polarized (less δ-), so it is weaker than LiAlH₄. The electron releasing NaBHEt₃ makes the B-H bond more polarized (more δ-), so it is stronger than NaBH₄.

39. The major product or products are shown. No mechanisms are provided.

(a) 
\[
\text{CHO} \quad \xrightarrow{1. \text{NaBH}_4, \text{EtOH}} \quad \text{CH}_2\text{OH}
\]

(b) 
\[
\text{Br} \quad \xrightarrow{1. \text{KI}, \text{refluxing acetone}} \quad \text{H}_2\text{O}
\]

(c) 
\[
\text{OH} \quad \xrightarrow{1. \text{PCC}, \text{CH}_2\text{Cl}_2} \quad \text{OH}
\]

(d) 
\[
\text{Br} \quad \xrightarrow{1. \text{PBr}_3, \text{THF}} \quad \text{CH}_2\text{NH}_2
\]

(e) 
\[
\text{OH} \quad \xrightarrow{1. \text{NaCN}, \text{THF}} \quad \text{CH}_2\text{NH}_2
\]

(f) 
\[
\text{O} \quad \xrightarrow{1. \text{LiAlH}_4, \text{ether}} \quad \text{OH}
\]
40. Hydrogenation requires that the C=C unit of the alkene coordinate to the surface of the transition metal catalyst. While cyclopentene readily coordinates to palladium and is easily hydrogenated 1,2-diter-tert-butylcyclopentene has a sterically hindered C=C unit that inhibits approach to and coordination with the Pd, so the hydrogenation is much slower.

41. Hexan-2-ol

42.

43. The electron is transferred to the benzene ring at a carbon that generates a radical anion. The most stable radical anion will NOT have the negative charge on the carbon bearing the OMe group in any of the resonance contributors. The resonance contributors formed are those formed in this reaction, and the product is the diene shown, with the OMe group of a C=C unit.
44. Triphenylmethane (Ph$_3$C—H).

45. Hydrogenation is a surface reaction in that the hydrogen must coordinate with the surface of the metal in order to break the H—H bond to form hydrogen radicals coordinated to the metal. Likewise, the C=C unit must coordinate to the surface of the metal. The larger the surface of the metal, the more coordination, and the faster will be the rate of the reaction.

46. Hydride reducing agents do not reduce nonconjugated alkenes. Therefore, if hex-5-enal is reduced with NaBH$_4$, the product will be hex-5-en-1-ol. Hydrogenation using a Pd catalyst has a greater affinity for reduction of alkenes relative to carbonyl compounds. Therefore, treatment of hex-5-enal with one equivalent of H$_2$ and Pd-C catalyst, usually in ethanol or methanol, should give hexanal as the major product, although some reduction of the aldehyde will undoubtedly occur to give hexan-1-ol. Reduction of hex-5-enal to hexan-1-ol is easily accomplished using a large excess of hydrogen gas with a Pd or Pt catalyst.

47.

48. The major product or products are shown. No mechanisms are provided.
49. Give the product of each individual step where appropriate, and the final product for each of the following:

(a) Hex-(2E)-ene.
(b) Lithium salt of pentan-2-ol (lithium 2-pentoxide).
(c) Hept-(3Z)-ene.
(d) Butan-1-ol and then butanal.
(e) 2-Phenylpentane.
(f) Ethylcyclopentanol and then 1-bromo-1-ethylcyclopentane and then the Grignard reagent and then ethylcyclopentane.
50. In this reaction the ammonia functions as an acid in the presence of the carbanion intermediate \((R_3C^- + H—NH_2 \rightarrow R_3C—H + \text{NH}_2^-)\). Ethanol is a much stronger acid when compared to ammonia, so ethanol is added to accelerate the protonation of the carbocation intermediate.

51. Transfer of an electron generates a ketyl, and it is possible for two of the ketyls to undergo a coupling reaction via a radical coupling reaction to give the dimer shown. Hydrolysis leads to a vicinal diol. This coupling reaction is known as the pinacol reaction or just pinacol coupling.

52. (a) Methanol + 4-phenylbutan-1-ol. (b) 3-Methylhexan-2-ol. (c) 2-Methylpentanal. (d) Cyclopentylmethanol. (e) 2-Methylpentane. (f) 3-Phenylpentane.

Synthesis. Do not attempt these problems until Chapter 25 is read and understood.

53. 1. Ozonolysis followed by treatment with dimethyl sulfide. 2. Dihydroxylation followed by treatment with periodic acid. 3. Formation of an alcohol using oxymercuration or hydroboration, followed by oxidation with PCC or PDC. 4. Epoxidation with peroxycetic acid followed by reduction with LiAlH_4 and then oxidation with PCC or PDC.

54. Provide a synthesis for each of the following:

(a) 1. \(\text{Br}_2, \text{CCl}_4\)  
2. excess \(\text{KOH}, \text{EtOH}\)  
3. \(\text{NaNH}_2\)  
4. \(\text{EtI}\)  
5. \(\text{Na, NH}_3, \text{EtOH}\)

(b) 1. \(\text{HBr}\)  
2. \(\text{Mg, ether}\)  
3. \(\text{CH}_3\text{CH}_2\text{CHO}\)  
4. \(\text{H}_3\text{O}^+\)
Spectroscopic problems. Do not attempt these problems until Chapter 14 is read and understood.
IR: the alcohol has a broad peak at 3300 cm\(^{-1}\) and the aldehyde will have a peak at 1725 cm\(^{-1}\) and the aldehyde H at 2817 cm\(^{-1}\)

aldehyde H at 9-10 ppm is absent in the alcohol
57. The aldehyde proton is pushed downfield by a combination of electron withdrawing inductive effects of the C—O bond plus the anisotropy of the carbonyl π-bond. The alkene has only the downfield shift due to anisotropy of the π-bond, but there are no inductive effects.

58. The ester has a carbonyl at ~1725 cm⁻¹ and the alcohol has a broad peak at ~3300 cm⁻¹.

59. The ester has an ethyl group, with the CH₂ group connected to O. The alcohol has a CH₃ group attached to O, but it is not part of an ethyl group. The broad OH proton will also show up in the alcohol: here at ~3.8 ppm.

60. A doublet methyl.

61. No difference in the IR.
95.  
(a) 2,2-Diethylcyclobutane-1-carboxylic acid  
(b) 16-Phenylhexadecanoic acid  
(c) 1-Butyl-1,4-butanedioic acid  
(d) 4-Bromo-3-cyclopropyl-2-hydroxyhexanoic acid  
(e) 3,3-Diethyloctanenitrile

96.  
(a) Methyl 3,5-dibromohexanoate  
(b) 3-Methylbutan-2-yl cyclopentanecarboxylate  
(c) 3,3,5-Trimethylheptanoyl bromide  
(d) 3-Methyl-2-phenylbutanoic 3-phenylpropanoic anhydride  
(e) 3-Chloro-N-ethyl-N-isopropylpentanamide  
(f) (1R,2R)-N,N2-Trimethylcyclohexane-1-carboxamide  
(g) Cyclopentanecarboxylic 1,1-dimethylethanoic anhydride  
(h) Ethyl 3-isobutyl-2,2,5-trimethylhexanoate  
(i) 2,2-Dimethylhex-(3E)-enenitrile
97. The byproduct of the reaction is the strong acid trifluoroacetic acid. The buffer is added to prevent this acid from reacting with the product and causing unwanted secondary reactions.

98. An alcohol reacts with HCl to form an oxonium ion, and chloride ion can displace water to form the chloride in a substitution reaction. Reaction of the acid with HCl forms an oxocarbenium ion, which is more stable than the oxonium in derived from an alcohol. In addition, chloride ion would have to react via an acyl substitution reaction in which chloride ion displaces hydroxide, and chloride is not a strong enough nucleophile to do that, given that hydroxide is a very poor leaving group.

99. The byproduct of the reaction is the strong acid trifluoroacetic acid. The buffer is added to prevent this acid from reacting with the product and causing unwanted secondary reactions.

100. An alcohol reacts with HCl to form an oxonium ion, and chloride ion can displace water to form the chloride in a substitution reaction. Reaction of the acid with HCl forms an oxocarbenium ion, which is more stable than the oxonium in derived from an alcohol. In addition, chloride ion would have to react via an acyl substitution reaction in which chloride ion displaces hydroxide, and chloride is not a strong enough nucleophile to do that, given that hydroxide is a very poor leaving group.

101. NH₃, 25 °C  Me₂NH, 25 °C  1. SOCl₂  2. NH₃  1. MeOH, H⁺  2. NH₃, heat  Me₂NH, 250 °C

102.

103.

104.
105. The major product or products are shown. No mechanisms are provided.

(a) \[
\text{CH}_3\text{COOH} \xrightarrow{\text{SOCl}_2} \text{CH}_3\text{COCl}
\]

(b) \[
\text{C}_6\text{H}_5\text{CH}_2\text{CO}_2\text{Et} \xrightarrow{\text{Me}_2\text{NH}, \text{heat}} \text{C}_6\text{H}_5\text{CO}_2\text{NMe}_2
\]

(c) \[
\text{C}_5\text{H}_9\text{OH} \xrightarrow{\text{cat } H^+, \text{ butanoic acid}} \text{C}_5\text{H}_9\text{O} \xrightarrow{\text{heat, drying agent}} \text{C}_5\text{H}_9\text{O} \text{C}_3\text{H}_7
\]

(d) \[
\text{CH}_3\text{CO}_2\text{O} \xrightarrow{\text{cat } H^+, \text{H}_2\text{O}} \text{HO} \xrightarrow{\text{heat}} \text{HO} \text{O}
\]

(e) \[
\text{C}_6\text{H}_5\text{CH} = \text{CH} \xrightarrow{1. \text{HBr}} \text{C}_6\text{H}_4\text{CHCH}_3 \xrightarrow{2. \text{NaCN}, \text{DMF}} \text{C}_6\text{H}_4\text{CHCH}_3\text{CN}
\]

(f) \[
\text{CH}_3\text{CO}_2\text{H} \xrightarrow{1. \text{SOCl}_2} \text{CH}_3\text{COOCO}_2\text{H}
\]

(g) \[
\text{C}_6\text{H}_5\text{CO}_2\text{Et} \xrightarrow{1. \text{aq NaOH}} \text{C}_6\text{H}_5\text{CO}_2\text{H} + \text{EtOH}
\]

(h) \[
\text{CH}_3\text{CH}_2\text{CONE}_2 \xrightarrow{\text{EtOH, reflux}} \text{CH}_3\text{CH}_2\text{CONE}_2
\]

(i) \[
\text{C}_6\text{H}_5\text{COOH} \xrightarrow{\text{CH}_3\text{CH}_2\text{NH}_2, 20^\circ\text{C}} \text{C}_6\text{H}_5\text{COO}^{+}\text{NH}_3\text{Et}
\]

(j) \[
\text{CH}_2\text{CH} = \text{CH} \xrightarrow{1. \text{BH}_3, \text{ether}} \xrightarrow{2. \text{NaOH}, \text{H}_2\text{O}_2} \xrightarrow{3. \text{SOCl}_2} \xrightarrow{4. \text{NaCN}, \text{DMF}} \text{CN}
\]
106. The adjacent methyl groups sterically hinder approach to the carbonyl carbon in 1,1-dimethylethyl butanoate relative to methyl butanoate. Since reaction with hydroxide or with water under acid conditions requires a nucleophilic attack at the acyl carbon, if that carbonyl is sterically hindered the reaction will be much slower.

107. The product was methyl butanoate, from reaction with methanol. Methanol is more reactive than isopropyl alcohol, and only a five fold excess of isopropyl alcohol is probably insufficient to compensate for the difference in rate. The solution is to use isopropyl alcohol as the solvent, with no methanol.

108. The bicarbonate is a base, and it reacts with any unreacted hexanoic acid. This reaction generates the carboxylate anion of ethanoic acid, which is water soluble and easily washed away from the ester product.

109. Because the acid catalyzed reaction is reversible, removal of the water product is necessary by the use of a dehydrating agent or removal via azeotropic distillation. Either way, the reaction may be incomplete and with higher molecular weight esters both of these procedures are problematic. Drying agents are often inefficient, and some esters are sensitive to heat. Making the acid chloride is usually a high yield procedure and the subsequent reaction with an alcohol is rapid and proceeds in high yield. Using this procedure there are usually no other products, and any unreacted acid chloride is treated with water and the resulting carboxylic acid is washed with sodium bicarbonate to remove it.

110. In one sense this is a silly question, but the point is to say that an ester is more reactive and easily hydrolyzed, whereas an amide is less reactive and much more difficult to hydrolyze. This finding means that the amide is more robust and many chemical processes may occur without disrupting the amide bond.

111. In both reactions the tetrahedral intermediate shown is the intermediate. Ethoxide is a far better leaving group when compared to a dialkylamide. Once this intermediate is formed, loss of OR will always produce the amide, regardless of conditions for how the intermediate was formed.

112. The acetyl chloride is so reactive that it reacts with the water in the air to form acetic and hydrochloric acid. The fuming occurs when gaseous HCl is produced in the presence of moist air, which leads to an aerosol of hydrochloric acid.

113. Washing with aqueous bicarbonate will convert all of the unreacted carboxylic acid to the salt, which is removed by washing with water, leaving behind the neutral amide. An acid chloride is very reactive, so washing an acid chloride with aqueous bicarbonate or acid will hydrolyze the acid chloride to the corresponding acid, which defeats the purpose of making the acid chloride in the first place.

114. Thionyl chloride, oxalyl chloride, phosgene, phosphorus trichloride, phosphorus oxychloride, phosphorus pentachloride.
115. The second product in this reaction is HCl. Triethylamine is added as a base. Reaction of triethylamine with HCl gives triethylammonium chloride ($\text{HEt}_3\text{N}^+\text{Cl}^-$). Removing one product in this way drives the reaction towards the desired ester product. The water soluble ammonium salt is easily removed from the ester by simply washing with water.

116. The major product or products are shown. No mechanisms are provided.
117. When phosgene is exposed to water (moist air) it reacts as a highly reactive acid chloride, producing HCl gas and eventually carboxylic acid (HO\textsubscript{2}CO\textsubscript{2}H), which is unstable and decomposes to carbon dioxide and water. The whitish gas is generated by exposure to moist air, which will produce an aerosol of HCl, and is highly corrosive, and dangerous if inhaled. Note also phosgene may be inhaled without hydrolysis. Inside the body, phosgene can react with the amine units of proteins, forming cross-linked urea structures. Such reaction products produce many problems in humans once inhaled.

118. When thionyl chloride is exposed to water, the hydrolysis produces sulfur dioxide (SO\textsubscript{2}) and HCl. It is likely that the gaseous HCl, which when exposed to moist air forms an aerosol of concentrated HCl. Since HCl is corrosive, it is likely to be responsible for the damage.

119. A five-membered ring is lower in energy than a seven-membered ring, due to diminished transannular interactions and less torsional strain in the five-membered ring. As the lactone ring is formed by cyclization, the transition state assumes the conformation of the ring being formed. If formation of the five-membered ring is lower in energy in the transition state, then formation of the five-membered ring lactone is faster than formation of the seven-membered ring lactone.
122. Give the major product for each of the following reactions.

(a) \[
\begin{array}{c}
\text{EtOH, cat. H}^+ \\
\end{array}
\]

(b) \[
\begin{array}{c}
1\text{-aminobutane, reflux} \\
\end{array}
\]

(c) \[
\begin{array}{c}
\text{H}_3\text{O}^+ \\
\end{array}
\]

(d) \[
\begin{array}{c}
\text{MeNH}_2, \text{heat} \\
\end{array}
\]

123. It is difficult to form a 17-membered ring because it is difficult for the distal OH group to attack the acyl carbon, so the more common product is the ester shown. In other words, the intermolecular ester-forming reaction is more favorable than the intramolecular lactone-forming reaction.

124. The amide has resonance contributors that delocalize the electron pair on the oxygen, which effectively shortens the C—N bond length.
125. 4-Aminobutanoic acid has a basic amine unit and an acidic COOH unit. An internal acid–base reaction occurs to form the zwitterion shown.

\[
\begin{align*}
\text{H}_2\text{N} & \quad \text{O} \\
\text{O} & \quad \text{H}_2\text{N} \\
\text{H}_2\text{N} & \quad \text{O} \\
\text{O} & \quad \text{H}_2\text{N} \\
\end{align*}
\]

126.

(a) \[
\begin{align*}
\text{NH} & \quad \text{O} \\
\text{O} & \quad \text{H}_2\text{N} \\
\end{align*}
\]

(b) \[
\begin{align*}
\text{NH} & \quad \text{Cl} \\
\text{Cl} & \quad \text{O} \\
\end{align*}
\]

(c) \[
\begin{align*}
\text{NH} & \quad \text{Et} \\
\text{Et} & \quad \text{O} \\
\end{align*}
\]

(d) \[
\begin{align*}
\text{NH} & \quad \text{H} \quad \text{Cl} \\
\text{Cl} & \quad \text{O} \\
\end{align*}
\]

(e) \[
\begin{align*}
\text{NH} & \quad \text{O} \\
\text{O} & \quad \text{NH}_2 \quad \text{Cl}^{-} \\
\end{align*}
\]

(f) \[
\begin{align*}
\text{NH} & \quad \text{Cl} \\
\text{Cl} & \quad \text{O} \\
\end{align*}
\]

127.

\[
\begin{align*}
\text{Cl} & \quad \text{O} \\
\text{Cl} & \quad \text{O} \\
\text{H}_2\text{N} & \quad \text{NH}_2 \\
\end{align*}
\]

\[
\begin{align*}
\text{O} & \quad \text{NH} \\
\text{NH} & \quad \text{O} \\
\text{O} & \quad \text{NH} \\
\end{align*}
\]

\[
\begin{align*}
\left(\text{N.R.}\right) & \quad \text{No reaction} \\
\end{align*}
\]

\[
\begin{align*}
\left(\text{N.R.}\right) & \quad \text{No reaction} \\
\end{align*}
\]
The leaving group for acetic anhydride is acetic acid whereas the leaving group from the imide is the amide, acetamide. In acyl substitution reaction, the amide is a poor leaving group, and reactions with the amide simply do not give the acetylation reactions observed with the anhydride.

131.

Maleic acid

Furan-2,5-dione (Maleic anhydride)

Fumaric acid
132.  
(a) \[
\begin{array}{c}
\text{O} \\
\text{CO}_2\text{H}
\end{array}
\]  
(b) \[
\begin{array}{c}
\text{O} \\
\text{CO} - \text{Ph}
\end{array}
\]  
(c) \[
\begin{array}{c}
\text{Ph} \\
\text{Me}
\end{array}
\]  
(d) \[
\begin{array}{c}
\text{Ph} \\
\text{Me}
\end{array}
\]  

133. The Cl is a good leaving group and acyl substitution with an acid chloride is much faster than acyl addition to the ketone. In other words, the acid chloride is much more reactive.

134.  
(a) \[
\begin{array}{c}
\text{O} \\
\text{CO}_2\text{H}
\end{array}
\]  
(b) \[
\begin{array}{c}
\text{O} \\
\text{CO} - \text{Ph}
\end{array}
\]  
(c) \[
\begin{array}{c}
\text{BrMg}^+\cdot\text{C}≡\text{CCH}_2\text{CH}_3
\end{array}
\]  
(d) \[
\begin{array}{c}
\text{Ph}
\end{array}
\]  

135.  
\[
\begin{array}{c}
\text{C}_3\text{H}_7 \\
\text{OH}
\end{array}
\]  
\[
\begin{array}{c}
\text{C}_3\text{H}_7 \\
\text{OMe}
\end{array}
\]  
\[
\begin{array}{c}
\text{C}_3\text{H}_7 \\
\text{OH}
\end{array}
\]  
\[
\begin{array}{c}
\text{C}_3\text{H}_7 \\
\text{OMe}
\end{array}
\]  
\[
\begin{array}{c}
\text{C}_3\text{H}_7 \\
\text{OH}
\end{array}
\]  

136.  
\[
\begin{array}{c}
\text{O} \\
\text{RCO}_2\text{H}
\end{array}
\]  
\[
\begin{array}{c}
\text{O} \\
\text{RCO}_2\text{H}
\end{array}
\]  
\[
\begin{array}{c}
\text{O} \\
\text{RCO}_2\text{H}
\end{array}
\]
The major products are shown. No mechanisms are provided.

(a) $\text{MeMgBr, ether} \rightarrow \text{ether} \rightarrow \text{H}_2\text{O}^+$

(b) $\text{excess H}_2\text{O in THF} \rightarrow \text{cat H}^+$

(c) $\text{SOCl}_2 \rightarrow \text{Mg, ether} \rightarrow \text{0.5 ethyl butanoate} \rightarrow \text{H}_2\text{O}^+$

(d) $\text{SOCl}_2 \rightarrow \text{propan-2-ol}$

(e) $\text{CrO}_3, \text{H}_2\text{SO}_4, \text{aq acetone} \rightarrow \text{H}_2\text{O}^+$

(f) $\text{SOCl}_2 \rightarrow \text{MeNH}_2$

(g) $\text{SOCl}_2 \rightarrow \text{Me}_2\text{CHCH}_2\text{OH}$

(h) $\text{KCN, DMF} \rightarrow \text{H}_2\text{O}^+ \rightarrow \text{Me}_2\text{NH, DCC}$

(i) $\text{Me}_2\text{CO}_2\text{H}$

(j) $\text{Me}_2\text{CO}_2\text{H}$
138. Conversion of octanedioic acid to the corresponding anhydride requires formation of a nine-membered ring, whereas succinic acid generates a five-membered ring anhydride. The transannular interactions of the nine-membered ring raise the activation barrier for cyclization to that ring so high that it does not easily form. Formation of the lower energy five-membered ring is energetically easy.

139. 

140. 

141. 

\[
\text{H}_3\text{C}\overbrace{\text{S}}\overbrace{\text{O}}\text{Et} \quad \text{H}_3\text{C}\overbrace{\text{S}}\overbrace{\text{O}}\text{NEt}_2 \quad \text{H}_3\text{C}\overbrace{\text{S}}\overbrace{\text{O}} \quad \text{H}_3\text{C}\overbrace{\text{S}}\overbrace{\text{O}}\text{OH}
\]
Synthesis Problems. Do not attempt these problems until you have read and understood Chapter 25.
150. 

(a) \[ \text{SO}_2\text{OH} \xrightarrow{\text{SOCl}_2} \text{SO}_2\text{Cl} \]

(b) (a) then \[ \text{SO}_2\text{Cl} \xrightarrow{\text{EtOH}} \text{SO}_2\text{OEt} \]

(c) (a) then \[ \text{SO}_2\text{Cl} \xrightarrow{\text{NH}_3} \text{SO}_2\text{NH}_2 \]

(d) \[ \text{SO}_2\text{OH} \xrightarrow{\text{NaOH}} \text{SO}_2\text{O-Na}^+ \]

151. Show a complete synthesis for each of the following from the indicated starting material.

(a) \[ \xrightarrow{1. \text{HBr}} \xrightarrow{2. \text{Mg, ether}} \xrightarrow{3. \text{propanal}} \text{1. \text{PCC}} \]

(b) \[ \xrightarrow{1. 9-\text{BBN, ether}} \xrightarrow{2. \text{NaOH, H}_2\text{O}_2} \xrightarrow{3. \text{PCC}} \xrightarrow{4. \text{EtMgBr}} \xrightarrow{5. \text{H}_3\text{O}^+} \xrightarrow{6. \text{PCC}} \xrightarrow{7. \text{EtMgBr}} \xrightarrow{8. \text{H}_3\text{O}^+} \]

(c) \[ \xrightarrow{1. \text{H}_3\text{O}^+, \text{heat}} \xrightarrow{2. \text{SOCl}_2} \xrightarrow{3. \text{EtOH}} \]

(d) \[ \xrightarrow{1. \text{NaBH}_4 \quad \text{aq NH}_4\text{Cl}} \xrightarrow{2. \text{PBr}_3} \xrightarrow{3. \text{Mg, ether}} \xrightarrow{4. \text{benzophenone, H}_2\text{O}} \xrightarrow{5. \text{PBr}_3} \xrightarrow{6. \text{KOH, EtOH}} \]

(e) \[ \xrightarrow{1. \text{H}_3\text{O}^+, \text{heat}} \xrightarrow{2. \text{SOCl}_2} \xrightarrow{3. \text{EtOH}} \]

(f) \[ \xrightarrow{1. \text{BH}, \text{ether}} \xrightarrow{2. \text{H}_2\text{O}_2, \text{NaOH}} \xrightarrow{3. \text{Jones oxidation}} \xrightarrow{4. \text{SOCl}_2} \]

(g) \[ \xrightarrow{1. \text{NaBH}_4} \xrightarrow{2. \text{H}_3\text{O}^+} \xrightarrow{3. \text{PBr}_3} \xrightarrow{4. \text{Mg, ether}} \xrightarrow{5. \text{Me}_2\text{CHCHO}} \xrightarrow{6. \text{H}_3\text{O}^+} \xrightarrow{7. \text{PBr}_3} \]
Spectroscopy Problems. Do not attempt these problems until you have read and understood Chapter 14.

152. [Image of IR spectra: CO₂Et IR: carbonyl at 1725 cm⁻¹. NMR shows OEt, with triplet at 4.2 ppm.]

153. Extensive hydrogen-bonding of the carboxylic OH effectively makes it more positive (large δ⁺), and the more positive the proton, the less electron density, and the more deshielded. The range of chemical shifts are used because carboxylic acids undergo different amounts of hydrogen-bonding based on structure of the acid, concentration and the solvent used.

154. The amide I band is at 1630-1695 cm⁻¹ and the amide II is at 1500-1560 cm⁻¹. The amide I band is associated with the iminium unit (C=N) and the amide I with the carbonyl (C=O). Since both forms of the amide are usually present, we see both bands in the IR.

155. Using IR, there must be a focus on the carbonyl region. These are the peaks one should examine.
- C=O aldehydes, ketones, acids, esters: 1690–1760 cm⁻¹ (5.68–5.92 µ)
- RCO₂H: 2500–3000 cm⁻¹ (3.33–4.00 µ) and the OH at 2500–3000 cm⁻¹ (3.33–4.00 µ)
- Acid chlorides: 1802 cm⁻¹ (5.55 µ)
- Anhydrides: two bands at 1818 cm⁻¹ (5.50 µ) and 1750 cm⁻¹ (5.71 µ)

The ¹H NMR can be used. The ¹H NMR of a carboxylic acid will show the acid proton, which will be removed if the sample with treated with D₂O. An acid chloride will look much like the acid, but no acidic proton will be seen. An anhydride should show signals for both acid portions of a mixed anhydride, or it will show a symmetric pattern for a symmetrical anhydride.
156. To distinguish a primary, secondary, or tertiary amide, examine the N—H region of the IR. Examine the 3300-3500 cm\(^{-1}\) region. The primary amide should have two peaks, the secondary amide one peak and there will be no peaks in that region for the tertiary amide.

157. Add the unknown to a solution of aqueous sodium bicarbonate. Hexanoic acid will react to form the sodium salt, which is soluble in water (it will dissolve). The ester (ethyl butanoate) is insoluble in the aqueous medium and will not react with the bicarbonate, so it will show up as an oil in the water. There are also differences in the odor. Relatively low molecular weight carboxylic acids tend to have a sharp odor, whereas esters tend to have a relatively sweet or pleasant odor.

158. The IR should show a broad band between 2500–3000 cm\(^{-1}\), and a carbonyl at ~ 1725 cm\(^{-1}\). The \(^1\)H NMR should show a signal between 12-15 ppm for the COOH proton.

159. The IR should show a broad band between 2500–3000 cm\(^{-1}\), and a carbonyl at ~ 1725 cm\(^{-1}\). The \(^1\)H NMR should show a signal between 1215 ppm for the COOH proton.

160. In the IR, the CN of the nitrile will show a moderate and sharp peak at 2210-2260 cm\(^{-1}\), whereas the ketone will show a strong C=O band at 1725 cm\(^{-1}\). As the reaction proceeds, the nitrile peak should diminish and eventually disappear, whereas the carbonyl peak from the product will appear and then increase in strength as the reaction goes to completion.

161. 3-Methylpentanoic acid

162. N-Benzylacetooacetamide
163. Isobutyl formate

164. Diethyl allylmalonate

165. cis-dimethyl maleate

166. Diisobutyryl anhydride

167. 2,3-dibromopropionic acid

168. Isovaleryl chloride
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83.

(a) 1,3,5-Trimethylbenzene  
(b) m-Chlorophenol  
(c) 3,5-Dinitroanisole  
(d) Hexachlorobenzene

(e) 4-Bromophthalic acid  
(f) 4-Iodobenzenesulfonic acid  
(g) 2-Cyanobenzoic acid  
(h) Ethoxybenzene (Phenetole)

(i) 4-Bromo-3'-chlorobenzophenone  
(j) 2,6-Dinitrohydroquinone  
(k) o-Bromobenzonitrile  
(l) 1,3-Dimethylbenzenzene (m-xylene)

(m) 1,2-Di(2-methylphenyl)ethene  
(n) N-Acetyl-3-methylaniline  
(p) 2,2-Dimethyl-4-phenylhexane

84.

(a) N,2,4-Trimethylaniline  
(b) 2-Bromoisophthalic acid  
(c) 1,3-Dichloro-5-methylbenzene  
(d) 2,5-Dipropylphenol
3-Fluorobenzaldehyde

3,5-Dinitrobenzoic acid

1-(2-Bromophenyl)ethan-1-one

3-Cyano-4-ethylbenzene-sulfonic acid

5-Ethyl-2-methylbenzonitrile

5-Iodobenzene-1,3-diol

1,2-Dibromo-3-methylbenzene

1-Methoxy-3-nitrobenzene

85.

(a) \( \text{Br} \)

(b) \( \text{Br} \)

(c) \( \text{Cl} \)

(d) \( \text{Br} \)

86.

(a) \( \text{NO}_2 \)

(b) \( \text{Ph} \)

(c) \( \text{OCH}_3 \)

(d) \( \text{NO}_2 \)

(e) \( \text{NO}_2 \)

(f) \( \text{NO}_2 \)

(No reaction)

Deactivated aromatic rings do not undergo Friedel-Crafts reactions.
87. Both OH and the carbon group of the ethyl unit are electron releasing. Electron-releasing substituents stabilize positive charge at the ipso carbon, which makes that intermediate more stable and accelerates the rate of the reaction. Therefore, these groups are activating substituents in electrophilic aromatic substitution.

88.

89.

90. The major product or products are shown. No mechanisms are provided.
(c) \[ \text{phenyl} \quad \text{CH}_3 \quad \text{OCH}_3 \quad \text{AlCl}_3 \quad \text{oxalyl chloride} \quad \text{phenylacetone} \]

(d) \[ \text{benzene} \quad \text{Cl}_2, \text{FeCl}_3 \quad \text{chlorobenzophenone} \]

(e) \[ \text{propionic acid} \quad \text{1. oxalyl chloride} \quad \text{2. benzene, AlCl}_3 \quad \text{phenylpropanoic acid} \]

(f) \[ \text{acrylonitrile} \quad \text{1. H}_2\text{O}^+, \text{heat} \quad \text{2. SOCl}_2 \quad \text{3. 1-phenylhexane, AlCl}_3 \quad \text{phenylacrylonitrile} \]

(g) \[ \text{phenol} \quad \text{Cl}_2, \text{AlCl}_3 \quad \text{chlorobenzophenone} \]

(h) \[ \text{toluene} \quad \text{Me}_3\text{CCl} \quad \text{AlCl}_3 \quad \text{mesitylene} \]

(i) \[ \text{benzene} \quad \text{1. Br}_2, \text{AlCl}_3 \quad \text{2. Mg, THF} \quad \text{3. 3-methylcyclopentanone} \quad \text{4. aq H}^+ \quad \text{5-methylisoxazolidine} \]

(j) \[ \text{benzene} \quad \text{SO}_3, \text{H}_2\text{SO}_4 \quad \text{benzenesulfonic acid} \]
91. The electron-releasing groups stabilizes the positive charge on the ipso carbon in electrophilic aromatic substitution, which makes those intermediates lower in energy, and the rate of their formation is faster.

\[
\begin{align*}
\text{Br} & \quad \text{OH} & \quad \text{CH}_3 & \quad \text{O} & \quad \text{NO}_2 \\
\text{苯} & \quad \text{苯} & \quad \text{苯} & \quad \text{苯} & \quad \text{苯}
\end{align*}
\]

92. 

\[
\begin{align*}
\text{OMe} & \quad \text{OMe} & \quad \text{OMe} & \quad \text{OMe} & \quad \text{OMe} \\
\text{Cl} & \quad \text{Cl} & \quad \text{Cl} & \quad \text{Cl} & \quad \text{Cl}
\end{align*}
\]

93. 

\[
\begin{align*}
\text{苯} & \quad \xrightarrow{\text{Cl}^+} & \quad \text{苯} & \quad \xrightarrow{\text{Cl}^+} & \quad \text{苯} & \quad \xrightarrow{\text{Cl}^+} & \quad \text{苯} & \quad \xrightarrow{\text{Cl}^+} & \quad \text{苯}
\end{align*}
\]

94. The methoxy group is strongly electron releasing. The methyl group releases electron density to the oxygen, which leads to a large $\delta^-$ dipole, so it will stabilize a positive charge on the ipso carbon to a greater extent. The electron-releasing capability of OMe is so great that the benzene ring will react without the need for a Lewis acid to generate $X^+$.

95. 

\[
\begin{align*}
\text{NO}_2 \quad \text{Cl} & \quad \text{NO}_2 \quad \text{Cl} & \quad \text{NO}_2 \quad \text{Cl} & \quad \text{NO}_2 \quad \text{Cl} \\
\text{苯} & \quad \text{苯} & \quad \text{苯} & \quad \text{苯}
\end{align*}
\]
96.

97. The sulfur atom in sulfonic acid is more electrophilic and more positive than the carbon atom in acetic acid. Therefore, benzene reacts more readily. In addition, the sulfur atom is larger and can accommodate another ligand more readily than carbon.

98.

99.
100. Reaction of the diene with the Lewis acid generates an allylic cation. The C=C unit of another molecule of the diene is simply more reactive than the C=C unit of a benzene ring. Therefore, the diene reacts preferentially to form a polymer.

101. An alkyl substituent on benzene is activating, because the carbon group is electron-releasing relative the C\(^+\) of an arenium ion. Boron is less electronegative than carbon, so a PhB group should be less electron-releasing than an alkyl group. Triphenylborane may undergo electrophilic aromatic substitution, but it should be slightly slower than a methyl group, and it will be an ortho/para director. Trisubstituted boron derivative are Lewis acids in their own right. It is not clear if the reaction will be autocatalytic.

102. The carbonyl unit of the ester in phenyl acetate will withdraw electron density from the oxygen atom, making it lower in electron density, and a weaker activating substituent. Anisole has an electron releasing methyl group on oxygen, increasing the electron density and making it a stronger activating substituent. Therefore, phenyl acetate will react slower than anisole in a reaction with bromine and ferric bromide.

103. The \(\pi\)-bond of the ethylene unit is more electron rich, but a major reason is that another resonance contributor can be drawn for the arenium ion, as shown. This extra resonance contributor is not possible by reaction with ethylbenzene.
104.

105. The oxygen atom of the OMe unit may coordinate to the Br$^+$X$^-$ complex, which “holds” the electrophilic Br$^+$ closer to the ortho carbon.

106.
107. Electron transfer generates a radical anion, but electron transfer will occur so that the negative charge will not be on the carbon bearing the oxygen. Hydrogen transfer from the solvent leads to the radical, and a second electron transfer leads to another carbocation. A second hydrogen transfer leads to the alkoxide. Protonation in aqueous acid yields the alcohol, but the C=C unit isomerizes to form an enol, where the C=C units are connected (this is a conjugated system; see Chapter 23), which is more stable. The enol tautomerizes to the carbonyl, so the final product is cyclohexenone.
108.

(a) 22 π-Electrons aromatic

(b) 6π-Electrons aromatic

(c) 6π-Electrons not aromatic

(d) 4π-Electrons not aromatic

(e) 4π-Electrons not aromatic

(f) 2 π-Electrons aromatic

(g) 8π-Electrons not aromatic

(h) 4π-Electrons not aromatic

(i) 10 π-Electrons aromatic

(j) 6π-Electrons not aromatic

(k) 18 π-Electrons aromatic

(l) 20 π-Electrons not aromatic

(m) 30 π-Electrons aromatic

(n) 18 π-Electrons aromatic

(o) 14 π-Electrons aromatic
109. If reaction with Br\(^+\) places a positive charge on the ipso carbon in one of the resonance contributors, then reaction at that carbon will be faster, and all such substitution products will be formed. The Br is shown at each possible different position, and a \(*\) is shown to indicate the position of the positive charge for each resonance contributor.

Therefore

110. The OMe unit is electron releasing and activating (reacts faster). Therefore, the ring bearing the OMe will react faster than the other ring, which is another way of saying that the charge can be delocalized on the oxygen of OMe, which of course occurs only in the ring bearing the OMe.
The arenium ion for attack at each carbon is shown. A * is used to show the position of the positive charge in each ion. It is clear that attack via $\text{C}_a$ leads to an arenium ion in which the positive charge is on the ipso carbon, which allows the charge to be delocalized on the oxygen. This intermediate is more stable than the arenium ion via $\text{C}_b$, where the positive charge never appears on the ipso carbon. Therefore, the product resulting from reaction via $\text{C}_a$ is preferred.
113. The major product or products are shown. No mechanisms are provided.
114. The nitro group is electron withdrawing, which stabilizes the carbanion intermediate more than the bromine. Remember two things. First, the nucleophilic aromatic substitution places a negative charge in the ring after reaction with the benzene ring and not a positive charge, such as is formed during electrophilic aromatic substitution. Second, the bromine is polarizable so if the negative charge is on the ipso carbon adjacent to a bromine atom, Br will take on a positive dipole, which is stabilizing. However, the nitro group is more stabilizing than the bromine.

116. At elevated temperatures, the hydroxide ion will attack the carbon bearing the sulfonate anion, because SO₃ is a leaving group under these conditions. This means that the reaction occurs via nucleophilic aromatic substitution, with a negative charge in the intermediate. The nitro group at C4 will stabilize this charge whereas there is no resonance contributor where the negative charge appears at C3. Therefore, the 4-nitrobenzenesulfonyl acid will react faster to yield the product, 4-nitrophenol.

117. Give the major product of each of the following and show the intermediate product for each step:

(a) \[
\begin{align*}
&\text{Ph} \quad \xrightarrow{\text{HNO}_3, \text{H}_2\text{SO}_4} \quad \text{PhNO}_2 \\
&\quad \xrightarrow{\text{H}_2, \text{Pd-C}} \quad \text{PhNH}_2 \\
&\quad \xrightarrow{\text{NaNO}_2, \text{HBF}_4} \quad \text{PhN}_2^+\text{BF}_4^- \\
&\quad \xrightarrow{150 \degree C} \quad \text{PhF}
\end{align*}
\]

(b) \[
\begin{align*}
&\text{Ph} \quad \xrightarrow{\text{Br}_2, \text{FeBr}_3} \quad \text{Ph} \\
&\quad \xrightarrow{\text{NaNO}_2, \text{HBr}_4} \quad \text{PhNO}_2 \\
&\quad \xrightarrow{\text{H}_2, \text{Pd-C}} \quad \text{PhNH}_2 \\
&\quad \xrightarrow{\text{CuBr}} \quad \text{PhBr}
\end{align*}
\]

(c) \[
\begin{align*}
&\text{Ph} \quad \xrightarrow{\text{aq NaOH} ; \text{aq HCl}} \quad \text{Ph} \\
&\quad \xrightarrow{\text{NaNO}_2, \text{HCl}} \quad \text{PhNH}_2 \\
&\quad \xrightarrow{160 \degree C , \text{aq H}_2\text{SO}_4} \quad \text{PhOH}
\end{align*}
\]
NH₂ (d) NaNO₂, HCl
160°C, aq H₂SO₄

HNO₃, H₂SO₄ (e)

H₂, Pd-C

NaNO₂, HCl
1-aminonaphthalene

Br₂, FeBr₃ (f)

H₂SO₄

HNO₃ (g)

MgI

Mg, THF

butanal

PCC

HNO₃, H₂SO₄

CuBr

118.

(a) OH

(b) SO₂OCH₂CH=CH₂

(c) CO₂H

(d) Via benzyne
119. 

(a) \[
\text{NH}_2
\]
(b) \[
\text{NH}_2
\]
(c) \[
\text{NH}_2
\]
(d) \[
\text{NH}_2
\]
(e) 

120. There is only one; methyl cyclohexyl ether. \[
\text{CH}_3
\]

121. 

+ \[
\text{CO}
\]

\[
\text{OH}
\]

\[
\text{OH}
\]

\[
\text{OH}
\]

\[
\text{OH}
\]

122. 

\[
\text{OMe}
\]

\[
\text{Na, NH}_3\ 	ext{EtOH}
\]

\[
\text{OMe}
\]

\[
\text{NO}_2
\]

\[
\text{Na, NH}_3\ 	ext{EtOH}
\]

\[
\text{NO}_2
\]
123. (i) Nitrobenzene + H₂/Ni(R)  This combination gives aniline  
(ii) HCl/NaNO₂. This mixture converts aniline to benzenediazonium chloride  
(iii) KF, THF. This reagent converts the diazonium salt to the final product, fluorobenzene.

124.

125. In these reactions, the leaving group is dinitrogen (N₂), from the Ar-N₂. It is essentially a nucleophilic aromatic substitution, so an electron-withdrawing group (e.g., nitro) will stabilize the carbanion intermediate and an electron-releasing group such as OMe will destabilize the intermediate. Based on this analysis, 4-nitrobenzenediazonium chloride should react faster.

126. Benzylamine, PhCH₂NH₂.

127.

128.
129. The product formed by this reaction is phenol (PhOH), which is rather acidic ($pK_a \sim 10$). As phenol is formed, it will react with the NaOH to generate the phenoxide anion, PhO$^-$Na$^+$. Therefore at least 2 equivalents of NaOH are required: one to react with the chlorobenzene to form the phenol, and the second will react with the phenol product. If only 1 equivalent of NaOH is used, only about one-half of the chlorobenzene will react.

130. The mechanism is nucleophilic aromatic substitution ($S_{NAr}$), in which water attacks the carbon bearing the diazonium salt. Following proton transfer, loss of nitrogen leads to phenol.

If the diazonium salt is heated with CuBr, the product is bromobenzene, PhBr.

131. Since iodide is a better leaving group than chloride, and this is a substitution reaction, where it is assumed that iodobenzene will react faster than chlorobenzene.

132. Under these conditions, alkynes maybe reduced to the alkene (A) and the benzene ring may be reduced via Birch reduction to B. However, it is much more likely that the alkyne anion will form faster via the acid–base reaction.

134. 

$(E)$-1,2-diphenylethene

*(trans-stilbene)*
SYNTHESIS. Do not attempt these problems until Chapter 25 has been read and understood.

135.

136. The major product or products are given. No mechanisms are provided.

(a) \[ \text{aryl} \xrightarrow{\text{1. } Br_2, \text{FeBr}_3} \text{aryl} \xrightarrow{\text{2. } Cl_2, \text{AlCl}_3 \text{ (separate ortho)}} \text{aryl} \]

(b) \[ \text{aryl} \xrightarrow{\text{1. } HNO_3/H_2SO_4} \text{aryl} \xrightarrow{\text{2. } Br_2, \text{AlCl}_3 \text{ 3. } H_2, \text{Pd}} \text{aryl} \xrightarrow{\text{4. HONO \text{ 5. } H_3O^+ \text{, heat}} \text{ 6. NaH then EtI}} \text{aryl} \]

(c) \[ \text{aryl} \xrightarrow{\text{1. } HNO_3/H_2SO_4} \text{aryl} \xrightarrow{\text{2. } Br_2, \text{AlCl}_3 \text{ 3. } H_2, \text{Pd}} \text{aryl} \xrightarrow{\text{4. HBF}_4, \text{NaNO}_2 \text{ 5. } 150^\circ C} \text{aryl} \]

(d) \[ \text{aryl} \xrightarrow{\text{1. } Br_2, \text{FeBr}_3 \text{ 2. } SO_3, H_2SO_4 \text{ separte ortho}} \text{aryl} \xrightarrow{\text{3. } MeMgBr \text{; } H_3O^+ \text{ 4. } H_2, \text{Pd \text{ 5. } HBF}_4, \text{NaNO}_2 \text{ 6. } 150^\circ C}} \text{aryl} \]

(e) \[ \text{aryl} \xrightarrow{\text{1. propanoyl chloride, AlCl}_3 \text{ 2. } HNO_3, H_2SO_4 \text{ 3. } MeMgBr \text{; } H_3O^+ \text{ 4. } H_2, \text{Pd \text{ 5. } HBF}_4, \text{NaNO}_2 \text{ 6. } 150^\circ C}} \text{aryl} \]
137. Syntheses are shown for each compound from a selected starting material.

(f) \[ \text{butanoyl chloride, AlCl}_3 \]
\[ \text{HNO}_3, \text{H}_2\text{SO}_4 \]
\[ \text{N}_2\text{H}_4, \text{KOH} \]
\[ \text{H}_2, \text{Pd} \]
\[ \text{HONO} \]
\[ \text{H}_3\text{O}^+, \text{heat} \]

(g) \[ \text{HNO}_3, \text{H}_2\text{SO}_4 \]
\[ \text{H}_2, \text{Pd} \]
\[ \text{Ac}_2\text{O} \]
\[ \text{HNO}_3, \text{H}_2\text{SO}_4 \text{ (separate ortho)} \]
\[ \text{HONO} \]
\[ \text{CuCN} \]
\[ \text{H}_3\text{O}^+, \text{heat} \]

(h) \[ \text{propanoyl chloride, AlCl}_3 \]
\[ \text{Me}_2\text{CHMgBr} \]
\[ \text{H}_3\text{O}^+, \text{Br}_3 \]
\[ \text{KOH, EtOH} \]

(i) \[ \text{HNO}_3, \text{H}_2\text{SO}_4 \]
\[ \text{Br}_2, \text{AlCl}_3 \]
\[ \text{H}_2, \text{Pd} \]
\[ \text{HONO} \]
\[ \text{CuBr} \]

Assume hydrogenation of \text{NO}_2 is faster than hydrogenation of \text{C}=\text{O}
Spectroscopic problems. Do not attempt these problems until Chapter 14 has been read and understood.

138.

Little difference in $^1$H NMR, except the phenol will have only 1 H that exchanges with D$_2$O, whereas the amine will have 2 H

IR: phenol OH at 3300 cm$^{-1}$ is broader and more intense

Phenol is soluble in aqueous NaOH because phenol is acidic ($pK_a$, 10), whereas aniline is insoluble in aqueous NaOH.
139. The only real difference is in the aromatic region of the $^1$H NMR, ~ 7 ppm. 4-Methylanisole is more symmetrical and will have only two identical signals, as shown, whereas 2-methylanisole has more signals and the aromatic region is a bit more complex.

140. Aniline will have amine NH at $\sim$ 3300 cm$^{-1}$, and since it is a primary amine, there will be two peaks (a doublet). $N$-Acetylaniline will have one peak in the NH region, but will have the amide I and amide II peaks at 1630–1695 and 1500–1560 cm$^{-1}$, respectively.

141. Benzonitrile is the expected product. The only discernable difference is in the IR. Benzonitrile will have the nitrile peak at $\sim$ 2260 cm$^{-1}$, whereas benzamide will have the amide I and amide II peaks at 1630–1695 and 1500–1560 cm$^{-1}$.

142. The aromatic region for methylnaphthalene will integrate to nine protons, whereas the aromatic region of toluene will integrate to five, relative to the three-proton singlet for the methyl group.

143. There are no protons, so there will be NO signals in the $^1$H NMR.
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83.

84. The pK$_a$ of acetone is ~ 19. The carbon of the cyano group is δ$^+$, which makes acetonitrile less acidic (pK$_a$, 24). The nitro group is more electron-withdrawing and the charge can be delocalized on the nitro group, which makes it even more acidic, pK$_a$ = 11.

85. Ammonia is a protic solvent, so the enolate anion will react to regenerate the ketone. These are thermodynamic conditions.

86. The enolate stabilized by two adjacent carbonyl groups is more stable than the enolate anion stabilized by only one carbonyl. The presence of the methyl group, which is electron releasing, will provide further stabilization to each enolate anion.

87. Aprotic solvents are compatible with kinetic control conditions and protic solvents are compatible with thermodynamic control conditions.
89. The reaction with LDA generates the kinetic enolate, and hydrolysis will simply protonate the enolate anion to regenerate the original ketone. Because these are kinetic control conditions, the stereochemistry at the adjacent methyl group is not affected.

90.

91.

(a) 
(b) 
(c) 
(d)
These are kinetic control conditions. The Me$_2$NLi is a strong base that generates Me$_2$NH as the conjugate acid, which is a much weaker acid than the ketone. This combination favors the forward reaction but not the reverse ($K_a$ is larger). The aprotic solvent THF does not have an acidic proton to react with the enolate anion, which also favors a larger $K_a$. The low reaction temperature allows the forward reaction to occur, but provides less energy to overcome the activation barrier for the reverse reaction. The short reaction time does not give the reaction time to equilibrate: reaction of the strong base and the ketone is rapid but reaction of the enolate anion with the weak acid (the amine) is slow.

Kinetic conditions are preferred. The same enolate anion is generated by either set of conditions, but under equilibration conditions (thermodynamic), there is unreacted aldehyde in the equilibrium, which may react in an aldol condensation of the aldehyde and the enolate anion (self-condensation). Under kinetic control conditions, the aldehyde is effectively converted entirely to the enolate anion, so there is little chance of self condensation (self-condensation is minimized).

Removal of the $\alpha$-proton generates a resonance-stabilized enolate anion. Removal of the aldehyde proton places a negative charge on the carbonyl carbon, which is normally polarized $\delta^+\text{C}=\delta^-\text{O}$, and such a carbocation is not resonance stabilized and is indeed very high in energy. It does not form, which means that a base will NOT remove the aldehyde proton.
97. The aldol condensation products for each reaction is shown.

(a) 
\[
\text{O} \quad \text{O}
\]
1. LDA, THF, -78 °C
2. cyclopentanone
3. hydrolysis

(b) 
\[
\text{CHO}
\]
1. LDA, THF, -78 °C
2. 3-phenylpentanal
3. hydrolysis

(c) 
\[
\text{O}
\]
1. NaOEt, EtOH, reflux
2. hydrolysis

(d) 
\[
\text{Ph}
\]
1. LDA, ether, -78 °C
2. 4-ethyl-2-methylheptan-3-one
3. hydrolysis

(e) 
\[
\text{O}
\]
1. KOt-Bu, t-BuOH, 80 °C
2. hydrolysis

(f) 
\[
\text{O}
\]
1. NaOEt, EtOH, reflux
2. cyclopentanone
3. hydrolysis

(g) 
\[
\text{O}
\]
1. NaOEt, EtOH, reflux
2. hexan-2-one
3. hydrolysis

(h) 
\[
\text{O}
\]
1. LiN(iPr)_2, THF, -78 °C
2. hexan-2-one
3. hydrolysis

Thermodynamic, so there will be the self-condensation product of butan-2-one, and perhaps of cyclopentanone

98. Benzaldehyde does not have an α-proton, so formation of an enolate anion is impossible. The only enolate anion that can be formed is from benzophenone, and it will react with benzaldehyde because the aldehyde is more reactive to acyl addition than a ketone.

99. 3,5-Diethylheptan-4-one has a great deal of steric hindrance at the α-carbon atoms, so reaction with LDA will be rather slow, particularly at the low temperature.
100. Under these thermodynamic conditions, the enolate anion from pentanal with react with itself in a self condensation to yield the aldol product shown. To obtain the mixed aldol, kinetic control conditions must be used, treating the aldehyde with LDA in THF at -78 °C, and then adding the hexanal.

101.

1. NaOEt, EtOH, reflux
2. hexanal

102. Reaction with LDA generates the enolate anion from the 1,3-diketone unit, as shown, because that is the more acidic proton. Intramolecular aldol condensation generates a six-membered ring as shown.
103. Under thermodynamic control the more substituted enolate anion will be formed, and subsequent internal aldol condensation will form the six-membered ring with the distal carbon rather than the four-membered ring from reaction with the closest carbonyl.

104. Sodium methoxide can react with the ethyl ester to form the methyl ester. The expected Claisen product is the keto ethyl ester, but the keto methyl ester can also form if the methyl ester is generated as suggested.

105.

106.

Ketone is more acidic than the ester
107. The product or products are shown. No mechanisms are provided.

(a) \[
\text{CO}_2\text{Et} \\
\text{CO}_2\text{Et} \\
\text{NaOEt}, \text{EtOH}, \text{reflux} \\
\text{hydrolysis}
\]

(b) \[
\text{CO}_2\text{Me} \\
\text{LDA}, \text{THF}, -78^\circ \text{C} \\
\text{methyl pentanoate} \\
\text{hydrolysis}
\]

(c) \[
\text{CO}_2\text{Et} \\
\text{LDA}, \text{THF}, -78^\circ \text{C} \\
\text{2-methyloctan-4-one} \\
\text{hydrolysis}
\]

(d) \[
\text{CO}_2\text{Et} \\
\text{NaOEt}, \text{EtOH}, \text{reflux} \\
\text{Me}_3\text{C-}2\text{ethylpentanoate} \\
\text{hydrolysis}
\]

(e) \[
\text{CO}_2\text{Et} \\
\text{2 eq. SOCl}_2 \\
\text{excess MeOH}, \text{NEt}_3 \\
\text{NaOMe}, \text{MeOH}, \text{reflux} \\
\text{hydrolysis}
\]

(f) \[
\text{CO}_2\text{Et} \\
\text{DCC}, \text{EtOH} \\
\text{LDA}, \text{THF}, -78^\circ \text{C} \\
\text{ethyl cyclopentanecarboxylate} \\
\text{hydrolysis}
\]

Ketone is more acidic than the ester.

Aldehyde \(\alpha\)-H is most acidic, and formation of 6-membered ring is energetically more facile than forming a 9-membered ring.
108. The major product or products are shown. No mechanisms are provided.

1. LDA, THF, -78 °C  
2. ethyl 2-methylbutanoate  
3. hydrolysis

1. NaOEt, EtOH, reflux, PhCHO  
2. vigorous hydrolysis

1. LDA, THF, -78 °C  
2. pentan-2-one  
3. vigorous hydrolysis

No β-H for elimination, so no conjugated aldehyde

1. LDA, THF, -78 °C  
2. vigorous hydrolysis

1. LDA, THF, -78 °C  
2. ethyl butanoate  
3. 6 N HCl

109.

(a) \[ \text{PPh}_3^+ \text{Br}^- \]  
(b) \[ \text{PPh}_3^+ \text{Br}^- \]  
(c) \( \text{Ph}_3\text{P} \)
110. Diphenylphosphine will react with 2 equivalents of an alkyl halide, so there will be two sites for generation of an ylid. Triphenylphosphine can react with only 1 equivalent of an alkyl halide, so there will be only one site for generation of an ylid.

111.

112.

113. Diphenylphosphine will react with 2 equivalents of an alkyl halide, so there will be two sites for generation of an ylid. Triphenylphosphine can react with only 1 equivalent of an alkyl halide, so there will be only one site for generation of an ylid.
114.

\[ \text{LDA, THF, } -78^\circ C \]

115. If the carbonyl oxygen attacks the acidic proton, electron transfer must dump electrons on carbon to form a carbanion, which is very high in energy and does not form under most thermolysis conditions. The lack of a stable product means there is no place to “dump” the electrons if CO\(_2\) departs, and the energy requirements for this reaction are such that it does not occur.

116.

117. The \( \pi \)-bonds of the benzene ring may react a weak base, and loss of carbon dioxide generates a carbanion. Although carbanions are difficult to form, this one is resonance stabilized, so the energy requirements are feasible, but high temperatures are required. Loss of a hydrogen atom from the intermediate leads to benzene.
118. \[
\text{CH}_2(\text{CN})_2 \xrightarrow{\text{NaOEt EtOH}} \text{CH(CN)}_2 \xrightarrow{\text{O}} \text{CH(CN)}_2 \xrightarrow{\text{H, Ph}} \text{H, Ph} \xrightarrow{\text{H}_2\text{O}^+} \text{OH}
\]

119.

120. The thermodynamic enolate anion leads to a product in which there is no \(\beta\)-hydrogen atom, so elimination is not possible. The product from the kinetic enolate anion, however, does have a \(\beta\)-hydrogen and elimination proceeds as shown.

121. The carbanion derived from dinitromethane is extensively delocalized due to the nitro groups, with three resonance contributors. The stability of this carbanion makes deprotonation very facile. This means that the proton is rather acidic and will be removed with a relatively weak base (e.g., carbonate). It is likely that dehydration is very facile because the C=C unit will be conjugated to the two electron-withdrawing nitro groups, which will facilitate dehydration.
122. The enolate anion is a base as well as a nucleophile. Reaction as a nucleophile yields the calculated product, but reaction as a base with the alkyl halide leads to the alkene via an E2 reaction. A mixture of (E) (Z)-isomers are formed because the β-carbon of the alkyl halide is not chiral.

SYNTHESIS. Do not attempt these problems until Chapter 25 has been read and understood.

123.
124.

(a) \[ \text{O} \]

(b) \[ \text{CHO} \]

(c) \[ \text{O} \]

(d) \[ \text{O} \]

125. A synthesis is shown for each disconnection.

(a) \[ \text{O} \]

(b) \[ \text{O} \]

(c) \[ \text{CH}_2(\text{CO}_2\text{H})_2 \]

(d) \[ \text{CO}_3\text{H} \]

(e) \[ \text{CN} \]

(f) \[ \text{CO}_2\text{Et} \]

Spectroscopy Problems. Do not attempt these problems until Chapter 14 has been read and understood.

126. The IR will show no difference, but the \(^1\text{H} \) NMR for a methyl ester will show a single that integrates the 3H at \( \sim 3.5 \) ppm, whereas an ethyl ester will show a quartet at \( \sim 3.6 \) ppm that integrates to 2H and a triplet at \( \sim 1.2 \) ppm that integrates to 3H.
127. It really depends on the position of the keto units and the ester group, as that will determine the chemical shift and multiplicity in the $^1$H NMR. The carbon of a ketone and an ester are very similar, so it is unlikely this can be used to distinguish them. The most reasonable difference is the OCH signal of the methyl ester, at ~ 3.5 ppm, which will be lacking for the diketone.

128. There is little difference in the $^1$H NMR. A nitrile will show a medium band at 2220 cm$^{-1}$ in the IR, whereas the ketone will show a strong band at 1725 cm$^{-1}$. The imine is likely difficult to isolate, but imines show a band at ~ 1660 cm$^{-1}$ for the C=N unit.

129. The band at ~ 3340 cm$^{-1}$ is likely due to the O—H absorption of the tertiary alcohol product.

130. The lack of a signal at 2600 cm$^{-1}$ indicates it is not an acid, and the signal at ~ 1670 cm$^{-1}$ indicates the presence of a C=C—C=O unit. Therefore, it is likely that the initially formed alcohol lost a molecule of water via dehydration to yield the alkene shown.

131. The prominent COOH signal in the IR and the presence of an methyl group in the $^1$H NMR are the most salient feature. The acid will not have the methyl group at 3.5 ppm, but will have a COOH signal ~ 12 ppm. There is an extra carbon atom in the $^{13}$C NMR.
132.

IR: Broad peak at 3300 cm\(^{-1}\) for O—H

mass spectrum: Weak or absent M, but a significant M-18 peak.

133.

**Very little difference in the infrared**

Ethyl group

Two methyl groups + CH at about 2.8 ppm
134. 

Little difference in the IR

The presence of the propyl group is obvious in the $^1$H NMR

135. 

Not much difference in the IR

$^1$H NMR: Singlet methyl 
CH + CH$_2$ adjacent to C=O

$^1$H NMR: 2 different 
CH$_2$ adjacent to C=O

More complex $^1$H NMR
2 propyl groups
2 different singlet methyl groups, 
one next to C=O, the other $\beta$ to OH

More complex $^1$H NMR
2 propyl groups + 2 singlet methyls next to C=O

136. 

Hexane-2,5-dione
137. Methylene cyclopentane

138. Ethyl 3-oxopentanoate

139. 4-Hydroxy-4-methylpentan-2-one

140.

\[ \text{A} \xrightarrow{} \text{B} \xrightarrow{} \text{C} \xrightarrow{} \text{D} \xrightarrow{} \text{E} \]

141.

\[ \text{A} \xrightarrow{} \text{B} \xrightarrow{} \text{C} \xrightarrow{} \text{D} \xrightarrow{} \text{E} \]
45.

(a) 

\[ \text{2E,5Z-Nonadiene} \]

(b) 

\[ \text{1,2-Diethylcyclohexadiene} \]

(c) 

\[ \text{Hex-1-en-3-yne} \]

(d) 

\[ \text{2,3-Dimethyl-1,3-butadiene} \]

(e) 

\[ \text{2,4-Pentadienoic acid} \]

(f) 

\[ \text{3E,5E-Dodecadienal} \]

(g) 

\[ \text{1,5-Cyclooctadiene} \]

(h) 

\[ \text{1,4-Diphenyl-(1E,3E)-butadiene} \]

(i) 

\[ \text{2,3,4,5-Tetramethyl-2,4-hexadiene} \]

46. It is clear from the structures that the s-cis conformation of the (2Z,4Z)-diene has severe steric interactions for the methyl groups that raises the energy of the conformation. The methyl groups are far apart in the (2E,4E)-isomer, which makes this conformation lower in energy relative to the s-cis conformation of the (2Z,4Z)-isomer.

![Hexa-(2E,4E)-diene](image)

![Hexa-(2Z,4Z)-diene](image)

47. \( \text{HC≡C-C≡C-CH}_3 \). No! The alkyne units are linear, so s-cis and s-trans isomers are not possible.

48.

(a) 

\[ \text{Ethyl benzoate} \]

(b) 

\[ \text{Hex-3E-en-2-one} \]

(c) 

\[ \text{Pent-2-yenitrile} \]

(d) 

\[ \text{2,7-Diethylcyclohept-2-en-1-one} \]
49. Lithium aluminum hydride coordinates to the carbonyl oxygen, and can deliver hydride to the C=C unit by an intramolecular reaction, but it can also deliver hydride to the carbonyl carbon. The reason for reactivity at both sites is bond polarization of the C=O, which extends through the C=C unit by vinylogy, leading to a $\delta^+$ on the carbonyl carbon and also the terminal carbon of the C=C unit.

![Structural diagram showing bond polarization and reactivity](image)

50. Briefly explain why an acid catalyst reacts with the carbonyl oxygen of methyl vinyl ketone. Draw the resultant intermediate. The oxygen atom is more basic than the p-bond of an alkene. This is clear when examining the oxocarbenium ion via protonation of the carbonyl, which is resonance stabilized as shown. Protonation of the C=C unit will generate the unstable carbocations shown, which are not resonance stabilized.

![Structural diagram showing protonation and carbocation formation](image)
51. The allylic cation intermediate is more stable, and the conjugated ketone is more stable than the nonconjugated ketone.

52. 
(a) \(345\text{ nm }= 82.87\text{ kcal; } = 2.9\times10^4\text{ cm}^{-1}\) 
(b) \(16\times10^2\text{ cm}^{-1} = 19.14\text{ kJ; } = 6.25\times10^3\text{ nm}\) 
(c) \(1765\text{ cm}^{-1} = 5.67\times10^3\text{ nm; } = 5.05\text{ kcal; } = 5.67\times10^4\text{ Å}\) 
(d) \(325\text{ kJ }= 5.05\text{ kcal; } = 5.67\times10^3\text{ Å}\) 
(e) \(8000\text{ Å }= 35.7\text{ kcal; } = 1.25\times10^4\text{ cm}^{-1}\) 
(f) \(185\text{ kcal }= 154.5\text{ nm; } = 1545\text{ Å; } = 6.47\times10^4\text{ cm}^{-1}\)

53. If \(\varepsilon = 38,000\) for \(c = 0.5\text{ g mL}^{-1}\) (10 dm path length), calculate \(\log \frac{I_o}{I} = \varepsilon \times c \times d\)

\[= (38,000)(0.5\times10) = 190000\]

54. If \(\frac{I_o}{I} = c = 1.2\text{ g mL}^{-1}\) and the path length is 5 dm, calculate \(\varepsilon\).

\[\varepsilon = \log \left(\frac{I_o}{I}\right)/cd = (4.77\times10^{-9})/(1.2)(5) = 7.95\times10^{-10}\]

55. 
(a) Methyl vinyl ketone  
(b) Hexan-3-one  
(c) Benzaldehyde  
(d) Cyclohex-2-en-1-one

Weak-nonconjugated  Strong-conjugated  Strong-conjugated
The predicted maximum UV absorption peak for each is shown using the data in Section 23.3.D.

56. The predicted maximum UV absorption peak for each is shown using the data in Section 23.3.D.

(a) But-3-en-2-one (Methyl vinyl ketone)  
(b) Hexan-3-one  
(c) Benzaldehyde  
(d) Cyclohex-2-en-1-one

Strong-conjugated  Weak-non-conjugated  Strong-conjugated  Strong-conjugated

(e) Hepta-1,5-diene  
(f) Cyclohexa-1,3-diene  
(g) Ethyl hex-2-enoate

Weak-non-conjugated  Strong-conjugated  Strong-conjugated

(h) Styrene  
(i) Hex-3-en-2-ol

Strong-conjugated  Weak-non-conjugated

215+12+12 = 239 nm  
210 + 30+12 = 252 nm  
214+5+5+5 = 229 nm  
210+10+12 = 232 nm

253+5+5 = 263 nm  
214+5+30 = 249 nm  
(no value is given for C=C, so estimate with C=C value).
57. The major product or products are shown. No mechanisms are provided.

(a) \[ \text{HCl, -80 °C} \]
(b) \[ \text{I}_2, 60 °C \]
(c) \[ \text{HBr, 40 °C} \]
(d) \[ \text{cat. HCl, aqueous acetone} \]
(e) \[ \text{HCl, 50 °C} \]
(f) \[ \text{HCl, 50 °C} \]
(g) \[ \text{HBr, -90 °C} \]

58.
59. Reaction with HCl at the acyl carbon is reversible, and formation of the carbocation next to the $\delta^+$ carbonyl carbon is energetically unfavorable. The product will be the chloride shown. Reaction with diatomic bromine give a bromonium ion, which may be difficult to form due to the proximity of the + and $\delta^+$, but if it forms, the bromide ion will attack the bromonium ion to give the dibromide.

Further from $\delta^+$, so this is lower in energy

Two proximal positive charges are very destabilizing

60. The major product or products are shown. No mechanisms are provided.
61.

(a) 

(b) 

(c) 

62. The major product or products for each reaction sequence are shown.

(a) 

(b) 

(c) 

(d) 

(e) 

(f) 

(g)
63. 

64. In a sense, this is a trick question. The only UV active compound is the starting material. Neither the 1,2- nor the 1,4-byproduct have a conjugated chromophore that will yield a significant absorption in the UV. The \(^1\)H NMR is a far better probe to distinguish these products.

65. In both cases, the major rotamer is the s-trans because it will have the lowest energy when compared to the s-cis rotamer.
Synthesis Problems. Do not attempt these problems until Chapter 25 has been read and understood.

66. Retrosyntheses are shown. In consultation with your instructor, suggest a synthesis based on the retrosynthesis.

(a) \[
\begin{align*}
\text{Br} & \Rightarrow \text{OH} \\
\text{O} & \Rightarrow \\
\text{O} & \Rightarrow \\
\text{O} & \Rightarrow \\
\text{O}
\end{align*}
\]

(b) \[
\begin{align*}
\text{NH}_2 & \Rightarrow \\
\text{CN} & \Rightarrow \\
\text{Cl} & \Rightarrow \\
\text{Cl} & \Rightarrow \\
\text{Cl}
\end{align*}
\]

67. Show a synthesis for each of the following molecules from the designated starting material:

(a) \[
\begin{align*}
1. \text{Mg} & , \text{THF} \\
2. \text{cyclohexanone} \\
3. \text{PBr}_3 \\
4. \text{KOH} & , \text{EtOH}
\end{align*}
\]

(b) \[
\begin{align*}
1. \text{PCC} \\
2. \text{Ph}_3\text{P}=\text{CMe}_2
\end{align*}
\]

(c) \[
\begin{align*}
1. \text{succinic acid} & , \text{H}_2\text{SO}_4 \\
2. \text{SOCl}_2 \\
3. \text{AlCl}_3
\end{align*}
\]

(d) \[
\begin{align*}
1. \text{LDA} & , \text{THF} , -78 \degree \text{C} \\
2. \text{PhCH}_2\text{Br} \\
3. \text{H}_3\text{O}^+ \\
4. \text{SOCl}_2 \\
5. \text{benzene} & , \text{AlCl}_3
\end{align*}
\]
Spectroscopic problems. Do not attempt these problems until Chapter 14 has been read and understood.

68. Hexa-1,3-diene is conjugated and will be UV active, whereas hexa-1,5-diene is nonconjugated and will show no significant UV activity. The conjugated diene will react with bromine to give 1,2 and 1,4 products, whereas the nonconjugated diene will show that each alkene reacts independently.

69. Pentan-2-one is not conjugated and will not show bands in the UV, whereas pent-3-en-2-one is conjugated and will show a strong band in the UV. The carbonyl for the nonconjugated ketone will be at ~ 1725 cm\(^{-1}\) in the IR, whereas the conjugated carbonyl will be at ~ 1695 cm\(^{-1}\). The \(^1\)H and \(^13\)C NMR for the conjugated ketone will show protons and carbon in the C=C region, and the nonconjugated ketone will not.
Both are not conjugated so there is no UV. IR is the same, with a C=C peak at about 1650 cm$^{-1}$. More symmetrical.

71.

72. trans-Penta-1,3-diene

73. 2,5-Dimethylhexa-2,4-diene

74. trans-3-Hepten-2-one

75. Ethyl methacrylate

76. trans-Pent-2-enal
24. A diene must be conjugated and able to achieve a s-cis (cisoid) conformation.

25. The circled alkene has two electron withdrawing groups, which lowers the LUMO of the C=C more than any other choice, so the activation energy for the Diels-Alder reaction will be lower and it will proceed faster and under milder conditions.

26. The circled alkene has an electron releasing group, which raises the LUMO energy of the C=C more than any other choice, so the activation energy for the Diels-Alder reaction will be higher and it will be slower, requiring harsher reaction conditions.

27. This rearrangement occurs via attack of the π-bond of one alkene unit at the terminal carbon of the other C=C unit. It is clear in B that both the attacking and recipient carbon are much more sterically hindered than in A. In addition, steric repulsion of the methyl groups inhibits close approach the two carbons. Both of these phenomena work to make the rearrangement of B much slower than A.
28. When heated, the initial Diels–Alder product, which now has another C=C unit, can form a substituted furan derivative by loss of ethene, as shown. This reaction is known as a “retro-Diels-Alder” reaction and occurs at a higher temperature than what is usually required for the initial Diels–Alder reaction.

29. Cyclopentadiene is locked into a s-cis conformation since it is part of a five-membered ring. Confining the \( \pi \)-bonds to the ring also makes the \( \pi \)-electrons more available for donation, and this combination makes cyclopentadiene much more reactive.

30. Molecule A reacts faster because the Cope rearrangement relieves the strain of the three-membered ring, which is lacking in the product. Relief of strain accelerates the rate of the reaction relative to the reaction of B, where there is no strain.

31. Give the major product for each of the following reactions.

(a) [Diagram]

(b) [Diagram]

(c) [Diagram]
32. Addition of BF₃ to the Diels–Alder reaction of acrolein and buta-1,3-diene leads to coordination of the Lewis acid with the aldehyde, which withdraws more electron density from the C=C unit, and lowers the LUMO energy even more. This lowering of the LUMO energy leads to a smaller energy difference between the LUMO_{alkene} and HOMO_{diene}, which is a lower activation energy and leads to a faster reaction.

33. There are two electron-releasing alkoxy groups that raise the LUMO of the alkene to a level that the activation energy is simply too high to occur at low temperatures.
36. The major product for each is shown.

(a) \( \text{heat} \) 

(b) \( \text{heat} \) 

(c) \( \text{heat} \) 

37. The major product for each reaction is shown.

(a) Ethyl acrylate

(b) Acrylonitrile

(c) Maleic anhydride

(d) Diethyl fumarate

(e) Methyl vinyl ketone
38. **disrotatory**

(a) 

(b) 

(c) 

(d) 

**conrotatory**

(d)
39. The Diels–Alder reaction proceeds via an endo transition state, with a disrotatory motion of the methyl groups, so the circled diastereomer will be the major product. Note that all of the diastereomers are racemic, which accounts for only eight of the total $2^4 = 16$ stereoisomers. The remainder of the possible stereoisomers have a trans-relationship for the diester, which is impossible since the cis-stereochemistry of diethyl maleate is retained.

40. There are two carbonyl units, so there is greater secondary orbital interactions for the diester relative to the mono-ester.

41. The major product is shown for each reaction.

(a) 

(b) 

(c) 

(d)
42. The diene on the right has a phenyl substituent on each C=C unit. This means that the Cope rearrangement generates a new diene with more substituted alkene units, which are more stable than the monosubstituted alkene units of the diene on the left. Since this is an equilibrium process, the equilibrium will favor formation of the more stable diene, which is on the right.

43. Cyclopentadiene reacts with another molecule of cyclopentadiene at low temperature, so the Diels-Alder product shown is what is in a bottle of commercial cyclopentadiene. If this dimeric compound is heated, a retro Diels-Alder reaction occurs to regenerate 2 equivalents of cyclopentadiene. If kept cold, one can use the cyclopentadiene in other reactions.

44. Synthesis Problems. Do not attempt these problems until Chapter 25 is read and understood.

46. A synthetic scheme is provided for each problem.

(a) \[ \text{methyl vinyl ketone} \]
1. \[ \text{H}_2, \text{Pd-C} \]
2. \[ \text{Ph}_3\text{P} \rightleftharpoons \text{CMe}_2 \]

(b) \[ \text{diethyl fumerate} \]
1. \[ \text{O}_3, -78 \degree \text{C} \]
2. \[ \text{H}_2\text{O}_2 \]
3. \[ \text{excess SOCl}_2 \]
4. \[ \text{excess EtOH, heat} \]
Spectroscopic problems. Do not attempt these problems until Chapter 14 is read and understood.

47.

IR: Alkene signal at 1645 cm⁻¹

IR: Alkene signal at 1645 cm⁻¹ and the aldehyde signals at 1725 cm⁻¹ and 2815 cm⁻¹

48. The diene on the right is more stable, and it will be the major product of this equilibrium reaction.
The main difference is the two methyl groups on C=C versus two methyl groups on sp\(^3\) carbon. One has six C=C protons whereas the other has only four.

49. Bicyclo[2.2.1]hepta-2,5-diene (2,5-Norbornadiene)

50. 7-Oxabicyclo[2.2.1]hept-2-ene

51. 5-Norbornene-2,3-dicarboxylic anhydride

52. 3-(Vinyloxy)prop-1-ene (Allyl vinyl ether)

53. Cyclohex-3-ene carbonitrile
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13.

(a) 

(b) 

(c) 

(d) 

14.

(a) 

(b) 

(c) 

(d) 

(e) 

(f)
15. In all cases, the hydrolysis step for hydride reduction, Grignard reactions, or enolate anion reactions is omitted, but it is part of the synthesis and understood to be there.

(a)  
\[\text{OCH} \xrightarrow{1. \text{ BuMgBr}, 2. \text{PCC}} \text{OH} \]

(b)  
\[\text{NH}_2 \xrightarrow{1. \text{ Mg}, 2. \text{ CH}_2\text{CHO}, 3. \text{ PBr}_3, 4. \text{ NaN}_3, 5. \text{LiAlH}_4} \text{Br} \xrightarrow{1. \text{BH}_3, \text{ ether}, 2. \text{NaOH, H}_2\text{O}_2, 3. \text{PBr}_3} \text{CH} = \text{CH} \]

(c)  
\[\text{C}_5\text{H}_{10}\text{OH} \xrightarrow{1. \text{LDA, THF, } -78 \degree \text{C}, 2. \text{MeI}, 3. \text{NaBH}_4} \text{C}_5\text{H}_{8}\text{O} \xrightarrow{1. \text{Hg(OAc)}_2, \text{H}_2\text{O}, 2. \text{NaBH}_4, 3. \text{PCC}} \]

(d)  
\[\text{C}_5\text{H}_{10}\text{OH} \xrightarrow{1. \text{LDA, THF, } -78 \degree \text{C}, 2. \text{MeI}, 3. \text{NaBH}_4} \text{C}_5\text{H}_{8}\text{O} \xrightarrow{1. \text{O}_3, -78 \degree \text{C}, 2. \text{H}_2\text{O}_2, 3. \text{EtOH, H}^+, 4. \text{NaOEt, EtOH, reflux}, 5. \text{H}_3\text{O}^+, 6. 200 \degree \text{C}} \]

(e)  
\[\text{OH} \xrightarrow{\text{aq. OsO}_4, \text{r-BuOOH}} \text{OH} \xrightarrow{1. \text{Hg(OAc)}_2, \text{H}_2\text{O}, 2. \text{NaBH}_4} \]

(f)  
\[\text{H}_2, \text{Pd-BaSO}_4, \text{quinoline} \xrightarrow{1. \text{Br}_2, \text{CCl}_4, 2. \text{excess KOH, EtOH, heat}} \text{Br} \xrightarrow{1. \text{PPh}_3, 2. \text{BuLi}, 3. \text{CH}_3\text{CH}_2\text{CHO}} \]

16. In all cases, the hydrolysis step for hydride reduction, Grignard reactions, or enolate anion reactions is omitted, but it is part of the synthesis and understood to be there.

(a)  
\[\text{Me}_2\text{CHMgBr} \xrightarrow{1. \text{PCC}, 2. \text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}, 3. \text{PCC}} \]
(b) \[ \text{CH}_2=\text{CHCH}_2\text{MgBr} \]

1. PhMgBr 2. PBr\(_3\)
3. KOH, EtOH
4. MeCO\(_3\)H

1. Hg(OAc)\(_2\), H\(_2\)O
2. NaBH\(_4\)
3. PCC

(c) \[ 1. \text{aq. OsO}_4, t-\text{BuOOH} \\
2. \text{acetone, H}^+ \]

1. LiAlH\(_4\)
2. PCC
3. Ph\(_3\)P=CEt\(_2\)

(d) \[ 1. \text{LDA, THF, } -78^\circ\text{C} \\
2. \text{MeI} \\
3. \text{LiAlH}_4 \\
4. \text{PhCH}_2\text{Br} \]

(e) \[ 1. \text{Ph}_3\text{P=CHCH}_3 \\
2. \text{BH}_3, \text{ether} \\
3. \text{H}_2\text{O}_2, \text{NaOH} \\
4. \text{PBr}_3 \]

(f) \[ 1. \text{O}_3, -78^\circ\text{C} \\
2. \text{Me}_2\text{S} \\
3. (\text{CH}_2\text{CH}_2\text{CO}_2\text{Et/LDA}) \text{ (enolate addition)} \\
4. \text{H}_3\text{O}^+ \text{ (elimination and hydrolysis of ester)} \\
5. \text{H}_2, \text{Pd} \]

(f) \[ 1. \text{O}_3, -78^\circ\text{C} \\
2. \text{Me}_2\text{S} \\
3. (\text{CH}_2\text{CH}_2\text{CO}_2\text{Et/LDA}) \text{ (enolate addition)} \\
4. \text{H}_3\text{O}^+ \text{ (elimination and hydrolysis of ester)} \\
5. \text{H}_2, \text{Pd} \]
17. 

(a) \[ \text{OH} \xrightarrow{1. \text{PCC}} \xrightarrow{2. \text{Gringard of 2-bromobutane}} \xrightarrow{3. \text{PCC}} \]

(b) \[ \text{CN} \xrightarrow{1. \text{Gringard of 2-bromobutane}} \xrightarrow{2. \text{H}_2\text{O}^+} \xrightarrow{1. \text{BH}_3, \text{ether}} \xrightarrow{2. \text{NaOH}, \text{H}_2\text{O}_2} \xrightarrow{3. \text{PCC}} \]

(c) \[ \xrightarrow{4. \text{Gringard of 2-bromobutane}} \xrightarrow{5. \text{PCC}} \]

(d) \[ \xrightarrow{1. \text{Me}_3\text{CO}_3\text{H}} \xrightarrow{2. \text{MeMgBr}} \xrightarrow{3. \text{PBr}_3} \xrightarrow{4. \text{KOH}, \text{EtOH}} \xrightarrow{5. \text{BH}_3, \text{ether}} \xrightarrow{6. \text{H}_2\text{O}_2, \text{NaOH}} \xrightarrow{7. \text{PCC}} \]

(e) \[ \text{OH} \xrightarrow{1. \text{PCC}} \xrightarrow{2. \text{LDA}, \text{THF}, -78^\circ \text{C}} \xrightarrow{3. \text{EtI}} \xrightarrow{4. \text{separate isomeric products from alkylation of the other side of the carbonyl}} \]

(f) \[ \text{OHC} \xrightarrow{1. \text{CH}_3\text{CH}_2\text{CHO}} \xrightarrow{2. \text{PCC}} \]

18. 

(a) \[ \text{CHO} \xrightarrow{1. \text{LDA}, \text{THF}, -78^\circ \text{C}} \xrightarrow{2. 1\text{-bromobutane}} \xrightarrow{\text{Ph}_3\text{P=CHCH}_3} \xrightarrow{\text{MeCO}_3\text{H}} \]

(b) \[ \text{CHO} \xrightarrow{\text{MeMgBr}} \xrightarrow{\text{OH}} \xrightarrow{1. \text{PBr}_3} \xrightarrow{2. \text{MeC≡C–Na}^+} \xrightarrow{\text{H}_2, \text{Pd-C}} \xrightarrow{\text{MeCO}_3\text{H}} \]

(c) \[ \xrightarrow{1. \text{LDA}, \text{THF}, -78^\circ \text{C}} \xrightarrow{2. \text{CH}_3\text{CH}_2\text{Br}} \xrightarrow{3. \text{NaBH}_4} \xrightarrow{4. \text{PBr}_3} \xrightarrow{(\text{MeCH=CH})_2\text{CuLi}} \xrightarrow{\text{MeCO}_3\text{H}} \]
19. Cyclohexanol is converted to bromocyclohexane with PBr$_3$ and then to cyclohexene with KOH in ethanol. Ozonolysis of the alkene, with hydrogen peroxide as the second step gives the dicarboxylic acid. Esterification with ethanol and acid yields the diester, and treatment with sodium ethoxide yields the ethyl ester of cyclopentanone 2-carboxylic acid via Dieckmann condensation. Hydrolysis to the acid and heating to 250 °C leads to decarboxylation and formation of cyclopentanone.

20. Cyclohexanol is converted to bromocyclohexane with PBr$_3$ and then to cyclohexene with KOH in ethanol. Ozonolysis of the alkene, with hydrogen peroxide as the second step gives the dicarboxylic acid. Esterification with ethanol and acid yields the diester, and treatment with sodium ethoxide yields the ethyl ester of cyclopentanone 2-carboxylic acid via Dieckmann condensation. Hydrolysis to the acid and heating to 250 °C leads to decarboxylation and formation of cyclopentanone.

21. 

**Chemical Reactions**

- **(a)**
  - Conversion of cyclohexanol to cyclohexene
  - Formula: $\text{OH} \xrightarrow{1. \text{CrO}_3 \text{aq}, \text{H}_2\text{SO}_4, \text{heat}} \text{CO}_2\text{H}$
  - Formula: $\text{H}_2\text{O}^+ \xrightarrow{2. \text{EtOH}, \text{H}^+} \text{CO}_2\text{H}$

- **(b)**
  - Conversion of cyclohexene to cyclohexanone
  - Formula: $\text{Br} \xrightarrow{1. \text{NaCN}, \text{DMF}} \text{CO}_2\text{H}$
  - Formula: $\text{H}_2\text{O}^+ \xrightarrow{2. \text{H}_2\text{O}_2} \text{CO}_2\text{H}$

- **(c)**
  - Conversion of cyclohexanone to cyclopentanone
  - Formula: $\text{OH} \xrightarrow{1. \text{O}_3, \text{-78 °C}} \text{CO}_2\text{H}$
  - Formula: $\text{H}_2\text{O}^+ \xrightarrow{2. \text{H}_2\text{O}_2} \text{CO}_2\text{H}$

- **(d)**
  - Conversion of cyclopentanone to cyclopentanone
  - Formula: $\text{CO}_2\text{Et} \xrightarrow{1. \text{LDA}, \text{THF}, \text{-78 °C}} \text{CO}_2\text{H}$
  - Formula: $\text{H}_2\text{O}^+ \xrightarrow{2. \text{H}_2\text{O}_2} \text{CO}_2\text{H}$

**Diagram**

- Conversion of cyclohexanol to cyclohexene
- Conversion of cyclohexene to cyclohexanone
- Conversion of cyclohexanone to cyclopentanone
22. 
\[ \text{Sn, HCl} \] 
\[ \text{CHO \to CN} \]
\[ \text{CN \to CO}_2\text{H} \]
1. MeMgBr
2. H\text{O}^+, \text{heat}

23. 
\[ \text{CN} \to \text{CN} \]
1. MeMgBr
2. H\text{O}^+, \text{heat}

24. 
\[ \text{H}_2, \text{Pd} \]
\[ \text{Ph}_3\text{P}=\text{CHCH}_3 \]
\[ \text{CH}_3\text{CHO} \]
1. PBr\text{3}
2. KOH, EtOH

25. 
\[ \text{CHO} \]
\[ \text{CHO} \]
1. BH\text{3}, ether
2. H\text{O}_2, NaOH

Also reduction of ketones

Also reduction of acids or acid chlorides
31. The major product is shown for each reaction.

\[ \text{N},3\text{-Dimethylpyrrole} \]
\[ \text{3,4-Diacetylpyrrole} \]
\[ \text{2,4-Dichloropyrazole} \]
\[ \text{1-Methyl-4-chloroimidazole} \]

\[ \text{2,4,6-Trimethylpyridine} \]
\[ \text{5-Aminopyrimidine} \]
\[ \text{3-Nitropyrazine} \]
\[ \text{3,5-Dibromopyridazine} \]
\[ \text{2-Amino-5-methylpyrimidine} \]

32. The major product is shown for each reaction.

\[ \text{1-(Furan-2-yl)propan-1-one} \]
\[ \text{3-Bromo-2-methylthiophene} \]
\[ \text{5-Chloro-4-isopropylfuran-3-amine} \]
\[ \text{Pyridine-2,6-diamine} \]
\[ \text{1-Ethyl-4,5-dimethyl-1H-imidazole} \]

\[ \text{2-Propylpyrimidin-5-ol} \]
\[ \text{3,4-Dinitro-1H-pyrrole} \]
\[ \text{3,5-Diethyl-2-isopropyl-2H-pyran} \]
\[ \text{6-Nitropyrazin-2-amine} \]

33. The major product is shown for each reaction.

(a) \[ \text{NCH}_3 \rightarrow \text{NCH}_3 \]
(b) \[ \text{NCH}_3 \rightarrow \text{ClNCH}_3 \]
35. Molecule B should react faster. Reaction with A generates an arenium type ion in which the positive charge will be delocalized on all three nitrogen atoms, which is very destabilizing. Reaction with B generate one resonance contributor with the positive charge on nitrogen, but two where it is delocalized on carbon, so the intermediate for B is more stable. While not great, it is better than A.

36. In both cases, nucleophilic substitution at C3 will generate a negative charge in the ring that will be delocalized on either oxygen (bromofuran) or nitrogen (bromopyrrole). The charge density is larger on oxygen than on nitrogen, so an intermediate with negative charge should lead to greater instability for the oxygen-containing furan ring when compared to the nitrogen-containing pyrrole ring. Based on this analysis, 3-bromopyrrole should be more reactive.
37.

- 1,3,4-Trimethylimidazolidine
- 2,2-Diethyl-1,3-dioxolane
- 1-Butyl-3-nitropiperazine
- 2,2,6,6-Tetramethyl-1,4-dithiane
- 1,1’-(3,4-dibromopyrazolidine-1,2-diyl)-bis(ethan-1-one)
- 2,5-Dichloro-1,4-dioxane
- 4,5-Dibromo-1,3-dioxolane
- 2,2-Diethyl-1,3-dioxane
- 2-Ethyl-4-isopropyl-5-methyl-1,3-dithiolane
- 2-Isopropylhexahydopyrimidin-5-amine
- 2-(tert-Butyl)-1-propylimidazolidine
- 3,3-Dimethyl-4-nitrohexahydropyridazine

38.

- N-Acetyl-3-ethylimidazoline
- 1,2,4,5-Tetramethylpiperazine
- 3,5-Dibromotetrahydrofuran
- trans-2,3-Dimethyl-1,4-dioxane
- 1-Ethyl-4-nitropyrazolidine
- cis-3,5-Dinitropiperidine
- N-Propylaziridine
- 2,3-Diethyl oxirane
- N,2-Diethylazetidine
- 3-Chlorothiane
- 2-Phenylthiirane
- cis-2,3-Diphenyloxetane
40.  

(a) \[ \text{4,6-Dibromoquinoline} \]

(b) \[ \text{6-Methyl-7-nitroisoquinoline} \]

(c) \[ \text{6-Ethylindole} \]

(d) \[ \text{3-Butyl-5-nitroisoquinoline} \]

41. The major product or products are shown.

(a) \[ \text{O} \]

\[ \text{N} \]

\[ \text{Br} \]

\[ \text{Br} \]

\[ \text{+} \]

\[ \text{acetyl chloride} \]

\[ \text{AlCl}_3 \]

(b) \[ \text{O} \]

\[ \text{N} \]

\[ \text{OMe} \]

\[ \text{OMe} \]

\[ \text{Br} \]

\[ \text{Br} \]

\[ \text{+} \]

\[ \text{AlCl}_3 \]

(c) \[ \text{O} \]

\[ \text{N} \]

\[ \text{+} \]

\[ \text{AlCl}_3 \]
42. Pyrrole is the more reactive ring in this system, and will react with Br⁺.

43. Electrophilic substitution at C3 generates an intermediate such as the one shown. The charge is placed on C2, which means that an oxocarbenium ion resonance contributor will be formed. No other resonance contributors are possible, whereas attack at C2 generates more resonance contributors, has greater stability, and will be the lower energy intermediate that leads to the major product.

44. It is a four-π-electron system, confined to a four-membered ring, which does not follow Hückel’s rule. It is anti-aromatic, and very unstable, analogous to cyclobutadiene.
46. A Friedel-Crafts reaction would require reaction at a pyridine ring, which does not undergo electrophilic aromatic substitution reactions such as this very well. The pyridine ring is deactivated and simply reacts too slowly with an oxocarbenium ion to give the Friedel-Crafts reaction.

47. 3-Bromopyridine reacts with sodium amide, the products are 3-amino pyridine, along with 2-amino pyridine and 4-amino pyridine. This reaction proceeds via a benzyne intermediate.

48. The product is 2-hydroxypyridine, which also exists in the lactam form shown, which is known as 2-pyridone. Remember that amides can exist in the imine form (amide I and amide II bands in the IR), and this equilibrium is a form of tautomerism known as hydroxypyridine–pyridone tautomerism.

**Spectroscopic problems. Do not attempt these problems until Chapter 14 is read and understood.**

All of the following problems involve heterocycles.

49. There is a difference in the aromatic proton region. The presence of the nitrogen pushes the ortho proton further downfield relative to toluene, and there are fewer identical signals.
50. There are few differences in the $^1$H NMR for 2-methylquinoline from 4-methylquinoline, although there will be some differences in coupling constants (not observable in the spectra shown). In the $^{13}$C spectra, note that the methyl group of 2-methylquinoline is a bit further downfield due to its proximity to the nitrogen.

51. Oxygen is more effective at deshielding relative to nitrogen, because it is more electronegative, and more electron withdrawing. Therefore, the aromatic protons in the $^1$H NMR are further downfield in furan. Likewise, the aromatic carbon atoms are further downfield in the $^{13}$C of furan when compared to those carbon atoms in pyrrole.
52. Pyrazine is symmetrical, and all protons are identical, and there is only one peak in the $^1$H NMR. Pyrimidine has three different protons and they clearly show in the $^1$H NMR.

53. 2,5-Dimethylpyridine

54. 2-Ethylfuran

55. 3-Nitropyrrrole

56. 4-Pyridinemethanol
Chapter 27
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40. Triethylamine is a base, and in the presence of a secondary amine and a protic solvent an E2 reaction can occur to yield the alkene.

\[
\text{Br} \quad \text{NET}_3 \quad \text{CH} = \text{CH}_2
\]

41.

(a) \( \text{H} \quad \text{N} \quad \text{Me} \)  
(b) \( \text{Ph} \quad \text{N} \quad \text{Ph} \)  
(c) \( \text{Ph} \quad \text{Ph} \quad \text{NET}_2 \)  
(d) \( \text{N} \quad \text{Ph} \quad \text{Ph} \)

\( \text{N-Ethylpropan-1-amine} \quad 3\text{-Phenylazetidine} \quad N,N\text{-Diethyl-1,3-diphenylpentan-1-amine} \quad 3\text{-Methyl-1-propylpyrrolidine} \)

(e) \( \text{Et} \quad \text{N} \quad \text{Me} \)
(f) \( \text{Ph} \quad \text{NH}_2 \)
(g) \( \text{N} \quad \text{Me} \quad \text{Me} \)
(h) \( \text{N} \quad \text{Et} \quad \text{Et} \)

\( (2R,3R)-2,3\text{-Dimethylpiperidine} \quad 2\text{-Methylhexan-3-amine} \quad N,3,6\text{-Trimethyldecan-4-amine} \quad N,N\text{-Diethylhexan-3-amine} \)

(i) \( \text{Et} \quad \text{N} \quad \text{Et} \)
(j) \( \text{Ph} \quad \text{N} \quad \text{Ph} \)
(k) \( \text{N} \quad \text{Et} \quad \text{Et} \)

\( 1,2\text{-Diethylaziridine} \quad 1\text{-Benzy]-1,2,3,4,7,8-hexahydroazocine} \quad \text{Triethylamine} \)

42. The major product or products are shown. No mechanisms are provided.

(a) \( \text{OH} \quad \text{CH}_2\text{NH}_2 \)

1. \( \text{PBr}_3 \)
2. \( \text{KCN, THF} \)
3. \( \text{LiAlH}_4, \text{THF} \)
4. hydrolysis

(b) \( \text{OH} \quad \text{NHCH}_2\text{Ph} \)

1. \( \text{PCC, CH}_2\text{Cl}_2 \)
2. \( \text{PhCH}_2\text{NH}_2, \text{cat H}^+ \)
3. \( \text{H}_2, \text{Pd-C} \)
43. Phenyl groups are electron withdrawing relative to the propyl groups, which are electron releasing. If the phenyl groups withdraw electron density from the N—H bond, diphenylamine will have a more polarized N—H unit and will be more acidic.

44. The conjugate acid of triethylamine is Et$_3$NH$^+$ and the conjugate acid of ethylamine is EtNH$_3^+$. In general, a primary amine is a stronger base in solution relative to a tertiary amine. If ethylamine is the stronger base, then the conjugate acid will be a weaker acid when compared to the conjugate acid of the weaker base, triethylamine.

45. Give the major product for each of the following reactions:

(a) \[
\begin{align*}
\text{pentan-2-one, cat H}^+ \\
\end{align*}
\]
46. A triethylammonium salt has β-hydrogen atoms on the ethyl groups, and the least substituted alkene possible from such a salt is ethylene.
47. 

(a) Compound A should have the lowest pKₐ due to the electron-withdrawing effects of the OMe group.

(b) The second pK₂ value is for loss of a proton from the ammonium salt of the amino acid. The N-phenyl group is electron withdrawing, which will make the N-phenylammonium salt more acidic. The more acidic compounds will have the larger pK₂, so the answer is C.

48. (a) Compound A should have the lowest pKₐ due to the electron-withdrawing effects of the OMe group.

(b) The second pK₂ value is for loss of a proton from the ammonium salt of the amino acid. The N-phenyl group is electron withdrawing, which will make the N-phenylammonium salt more acidic. The more acidic compounds will have the larger pK₂, so the answer is C.
50. The phenyl group is electron withdrawing whereas the alkyl group in isoleucine is electron releasing. The electron withdrawing inductive effects of the phenyl group lead to a more acidic compound, so both pK values are smaller.

51. Acidification in an aqueous medium to pH 4 leads to hydrolysis of the ester to the acid, but it also converts the alkaline group to an ammonium salt, which is water-soluble. Therefore, the ammonium salt will not likely be soluble in hexane.

52.

53.

(a) excess BuOH
(b) \[
\text{NH}_2\]
\[
\begin{array} \text{(S)}
\end{array}
\]
\[
\begin{array} \text{O}
\end{array}
\]
\[
\text{HN}
\]
\[
\begin{array} \text{(S)}
\end{array}
\]
\[
\begin{array} \text{O}
\end{array}
\]
\[
\text{1. neutral pH}
\]
\[
\text{2. propanoyl chloride}
\]

(c) \[
\text{NH}_2\]
\[
\begin{array} \text{(S)}
\end{array}
\]
\[
\begin{array} \text{O}
\end{array}
\]
\[
\text{HN}
\]
\[
\begin{array} \text{(S)}
\end{array}
\]
\[
\begin{array} \text{O}
\end{array}
\]
\[
\text{1. EtOH, H}^+
\]
\[
\text{2. Ac}_2\text{O}
\]
\[
\text{3. succinic anhydride NaOAc}
\]

(d) \[
\text{NHAc}
\]
\[
\begin{array} \text{(S)}
\end{array}
\]
\[
\begin{array} \text{O}
\end{array}
\]
\[
\text{HN}
\]
\[
\begin{array} \text{(S)}
\end{array}
\]
\[
\begin{array} \text{O}
\end{array}
\]
\[
\text{1. H}_3\text{O}^+
\]
\[
\text{2. EtOH, cat H}^+
\]
\[
\text{3. succinic anhydride NaOAc}
\]

(e) \[
\text{Ph}
\]
\[
\begin{array} \text{O}
\end{array}
\]
\[
\text{HN}
\]
\[
\begin{array} \text{(S)}
\end{array}
\]
\[
\begin{array} \text{O}
\end{array}
\]
\[
\text{1. Br}_2, \text{PBr}_3
\]
\[
\text{2. H}_2\text{O}
\]
\[
\text{3. EtOH, cat H}^+
\]

(f) \[
\text{NH}_2\]
\[
\begin{array} \text{(S)}
\end{array}
\]
\[
\begin{array} \text{O}
\end{array}
\]
\[
\text{HN}
\]
\[
\begin{array} \text{(S)}
\end{array}
\]
\[
\begin{array} \text{O}
\end{array}
\]
\[
\text{1. LiAlH}_4
\]
\[
\text{2. aq H}^+; \text{neutralize}
\]

(g) \[
\text{NH}_2\]
\[
\begin{array} \text{(S)}
\end{array}
\]
\[
\begin{array} \text{O}
\end{array}
\]
\[
\text{HN}
\]
\[
\begin{array} \text{(S)}
\end{array}
\]
\[
\begin{array} \text{O}
\end{array}
\]
\[
\text{1. PhCOCl}
\]
\[
\text{2. dilute H}_2\text{O/H}^+
\]
54.

(a) \[
\begin{align*}
\text{Ph} & \quad \text{OH} \\
\text{H}_2\text{N} & \text{CH} \text{C} - \text{OH} \\
\text{Ph} & \quad \text{CH}_2
\end{align*}
\]
\[
\begin{align*}
1. \text{PBr}_3 \quad & 2. \text{NaCN} \\
3. \text{LDA}, \text{THF} \quad & 4. \text{Br}_2 \quad 5. \text{NaN}_3 \\
6. \text{H}_2, \text{Pd}
\end{align*}
\]

(b) \[
\begin{align*}
\text{H}_2\text{N} & \text{CH} \text{C} - \text{OH} \\
\text{H}_3\text{C} & \quad \text{CH} \text{CH}_3
\end{align*}
\]
\[
\begin{align*}
1. \text{PBr}_3, \text{Br}_3 \quad & 2. \text{NH}_3
\end{align*}
\]

(c) \[
\begin{align*}
\text{H}_2\text{N} & \text{CH} \text{C} - \text{OH} \\
\text{CH}_3
\end{align*}
\]
\[
\begin{align*}
1. \text{LiAlH}_4 \quad & 2. \text{PBr}_3 \\
3. \text{NaCN} \quad & 4. \text{H}_3\text{O}^+ \\
5. \text{PBr}_3, \text{Br}_2 \quad & 6. \text{NH}_3
\end{align*}
\]

(d) \[
\begin{align*}
\text{H}_2\text{N} & \text{CH} \text{C} - \text{OH} \\
\text{CH}_3
\end{align*}
\]
\[
\begin{align*}
1. \text{EtOH}, \text{H}^+ \quad & 2. \text{NaH} \\
3. \text{2-bromobutane} \quad & 4. \text{H}_3\text{O}^+ \quad 5. 200 ^\circ \text{C} \\
6. \text{PBr}_3, \text{Br}_2 \quad & 7. \text{NH}_3
\end{align*}
\]

55.

(a) \[
\begin{align*}
\text{CO}_2 \quad & 1. \text{Ph} \quad \text{Cl} \\
\text{NH}_3 \quad & 2. \text{aq} \text{H}^+
\end{align*}
\]
\[
\begin{align*}
\text{CO}_2 \quad & \text{NH} \\
\text{Ph} \quad & \text{NH}_3 \\
\text{Ac}_2\text{O} \quad & \text{NaOAc}
\end{align*}
\]

(b) \[
\begin{align*}
\text{CO}_2 \quad & \text{NH} \\
\text{Ph} \quad & \text{NH}_3 \\
\text{H}_3\text{O}^+
\end{align*}
\]

(c) \[
\begin{align*}
\text{CO}_2 \quad & \text{NH} \\
\text{Ph} \quad & \text{NH}_3 \\
\text{H}_3\text{O}^+
\end{align*}
\]
56. The electron pair on nitrogen is partly delocalized onto the adjacent carbonyl, which makes the electrons less available for donation. In other words, it is less basic.

57. At neutral pH, an amino acid exists as a zwitterion, so the amine unit is not NH₂, but rather NH₃⁺.
60. In phe-ala, the PhCH₂ group and the methyl group are probably anti in the best conformation.

61. 

\[
\begin{align*}
RCO_2H & \xrightarrow{\text{ninyhydrin}} RCHO + CO_2 + 4H_2O \\
\text{(a)} & \quad \text{+ glycine} \\
\text{(b)} & \quad \text{+ methionine}
\end{align*}
\]
(c) \[
\text{+ serine} \quad \text{R CH}_2\text{OH} \quad \text{OH} \quad \text{O}
\]

(d) \[
\text{+ valine} \quad \text{R = Me}_2\text{CH} \quad \text{CH}_3 \quad \text{H}
\]

(e) \[
\text{+ histidine} \quad \text{R = CH}_2\text{-imidazole} \quad \text{N} \quad \text{H}
\]

(f) \[
\text{+ arginine} \quad \text{R = CH}_2\text{(=NH)NH}_2 \quad \text{NH} \quad \text{H}
\]

62.

(a) \[
\text{H}_2\text{N-CH-C-N-CH-C-N-CH-C-N-CH-C-CH}_3 \quad \text{CH}_2 \quad \text{CH}_2 \quad \text{C=O} \quad \text{NH}_2 \quad \text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_2 \quad \text{S} \quad \text{CH}_3 \quad \text{O}
\]

(b) \[
\text{1. O}_2\text{N} \quad \text{NO}_2 \quad \text{F} \quad \text{H}_2\text{N-CH-C-N-CH-C-N-CH-C-CH}_3 \quad \text{CH}_2 \quad \text{CH}_2 \quad \text{C=O} \quad \text{NH}_2 \quad \text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_2 \quad \text{S} \quad \text{CH}_3 \quad \text{O}
\]

(c) \[
\text{2. 6N HCl} \quad \text{H}_2\text{N-CH-C-N-CH-C-N-CH-C-CH}_3 \quad \text{CH}_2 \quad \text{CH}_2 \quad \text{C=O} \quad \text{NH}_2 \quad \text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_2 \quad \text{S} \quad \text{CH}_3 \quad \text{O}
\]

(d) \[
\text{H}_2\text{N-CH-C-OH} \quad \text{H}
\]

(e) \[
\text{H}_2\text{N-CH-C-OH} \quad \text{H}
\]
66. 

(a) 

\[
\begin{align*}
H_2N - CH & \quad N - CH - OH \\
\text{CH}_2 & \quad \text{CH} \quad \text{CH}_3 \\
\text{OH} & \quad \text{CH} \quad \text{CH}_3 \\
\end{align*}
\]

1. LiAlH_4 

2. H_3O^+ 

\[
\begin{align*}
H_2N - CH & \quad N - CH - NH_2 \\
\text{CH}_2 & \quad \text{CH} \quad \text{CH}_3 \\
\text{OH} & \quad \text{CH} \quad \text{CH}_3 \\
\end{align*}
\]

(b) 

\[
\begin{align*}
H_2N - CH & \quad N - CH - OH \\
\text{CH}_3 & \quad \text{CH} \quad \text{CH}_3 \\
\text{CH}_3 & \quad \text{CH} \quad \text{CH}_3 \\
\end{align*}
\]

1. LiAlH_4 

2. H_3O^+ 

\[
\begin{align*}
H_2N - CH & \quad N - CH - OH \\
\text{CH}_3 & \quad \text{CH} \quad \text{CH}_3 \\
\text{CH}_3 & \quad \text{CH} \quad \text{CH}_3 \\
\end{align*}
\]

(c) 

\[
\begin{align*}
H_2N - CH & \quad N - CH - OH \\
\text{CH}_2 & \quad \text{CH} \quad \text{CH}_3 \\
\text{SH} & \quad \text{CH} \quad \text{CH}_3 \\
\end{align*}
\]

1. LiAlH_4 

2. H_3O^+ 

\[
\begin{align*}
H_2N - CH & \quad N - CH - OH \\
\text{CH}_2 & \quad \text{CH} \quad \text{CH}_3 \\
\text{SH} & \quad \text{CH} \quad \text{CH}_3 \\
\end{align*}
\]

67. 

(a) 

al-a-la-thr-cys-asn-val-phe-leu-thr-his-\textbf{arg}-pro-phe \hspace{1cm} \text{trypsin} 

al-a-la-thr-cys-asn-val-leu-leu-thr-his-\textbf{arg} \hspace{1cm} \text{pro-phe} 

al-a-la-thr-cys-asn-val-\textbf{phe}-leu-thr-his-arg-pro-\textbf{phe} \hspace{1cm} \text{chymotrypsin} 

al-a-la-thr-cys-asn-val-\textbf{phe} \hspace{1cm} \text{leu-thr-his-arg-pro-\textbf{phe}} 

(b) 

ty-r-ile-ile-\textbf{arg}-gln-asp-val-his-his-phe-ile-tyr \hspace{1cm} \text{trypsin} 


ty-r-ile-ile-\textbf{arg} \hspace{1cm} \text{gln-asp-val-his-his-phe-ile-tyr} 


ty-r-ile-ile-gly-gln-asp-val-his-his-\textbf{phe}-ile-tyr \hspace{1cm} \text{chymotrypsin} 

\textbf{tyr} \hspace{1cm} \textbf{tyr}-ile-ile-gly-gln-asp-val-his-his-\textbf{phe} \hspace{1cm} \text{ile-tyr}
For gly-lys-ser-phe-phe-ala-ile-ile-trp-leu-asp-met-pro-arg-glu-tyr-ile-lys-arg, assume the N-terminus is on the left (gly) and C-terminus is on the right (arg).

(a)  
\[
gly-lys \hspace{1em} \text{ser-phe-phe-ala-ile-ile-trp-leu-asp-met-pro-arg} \hspace{1em} \text{glu-tyr-ile-lys-arg} \]
\[\xrightarrow{\text{trypsin}}\]
\[
gly-ljs \hspace{1em} \text{ser-phe-phe-ala-ile-ile-trp-leu-asp-met-pro-arg} \hspace{1em} \text{glu-tyr-ile-lys-arg} \]

(b)  
\[
gly-lys-\text{ser-phe-phe-ala-ile-ile-trp-leu-asp-met-pro-arg-glu-tyr-ile-lys-arg} \]
\[\xrightarrow{\text{chymotrypsin}}\]
\[
gly-lys-\text{ser-phe-phe-ala-ile-ile-trp-leu-asp-met-pro-arg-glu-tyr-ile-lys-arg} \]

(c)  
\[
gly-lys-\text{ser-phe-phe-ala-ile-ile-trp-leu-asp-met-pro-arg-glu-tyr-ile-lys-arg} \]
\[\xrightarrow{\text{carboxypeptidase B}}\]
\[
gly-lys \hspace{1em} \text{ser-phe-phe-ala-ile-ile-trp-leu-asp-met-pro-arg} \hspace{1em} \text{glu-tyr-ile-lys-arg} \]

(d)  
\[
gly-lys-\text{ser-phe-phe-ala-ile-ile-trp-leu-asp-met-pro-arg-glu-tyr-ile-lys-arg} \]
\[\xrightarrow{\text{Staphylococcal protease}}\]
\[
gly-lys-\text{ser-phe-phe-ala-ile-ile-trp-leu-asp-met-pro-arg-glu} \hspace{1em} \text{tyr-ile-lys-arg} \]
73. The ethyl ester of 2-bromo-2-methylbutanoic acid is a tertiary halide, and the reaction with phthalimide anion is a $S_N2$ reaction. The activation energy to attain the pentacoordinate $S_N2$ transition state is too high for this reaction to occur.

74. 

75.
Spectroscopic problems. Do not attempt these problems until Chapter 14 is read and understood. These problems involve amines, amino acids, and derivatives of amino acids.

IR: The secondary amine will have one peak at about 3300 cm⁻¹, whereas the primary amine will have two.

Note: C—N downfield carbon missing in the other
In the IR, 4-aminobutanoic acid will have the broad peak associated with the COOH unit at 2500-3000 cm⁻¹, and the amino protons will be buried in this signal. In addition, there will be the carbonyl at 1725 cm⁻¹. This sharply contrasts with 4-cyanobutan-1-ol, with a broad signal at 3300 cm⁻¹ for the OH plus a sharp signal at ~2240 cm⁻¹ for the nitrile. The ¹H NMR data for the two compounds are very different. The amino acid has the acid peak at ~12 ppm in the ¹H NMR, and a carbonyl carbon at ~180 ppm in the ¹³C NMR (assuming the amino acid and not the zwitterion). The cyano–alcohol has the nitrile carbon at ~130 ppm, a doublet methyl in the ¹H NMR and a triplet methylene downfield at ~3.8 ppm, due to the CH₂—O unit.
79. Decarboxylation must occur at the malonic acid stage, before the reaction with phthalimide. Bromination of the malonate will give a tertiary bromide, which cannot react with phthalimide via substitution. Therefore, the question asks for differences between A and B. The most obvious difference is the number of carbon atoms in A, one more than B. There are also differences in the sp³ carbon atoms in A and B, where A has the methine carbon further downfield. Likewise, there are differences in the methine-methylene pattern in A and the methylene–methine pattern in B.
80.

1. HBr
2. NaN₃
3. H₂, Pd/C

No methyl groups

Doublet methyl

methyl + 3 methylene C
81. It is a bit difficult to see in the $^{13}$C NMR spectrum on the bottom left, but there are three carbonyl peaks, and only two in the spectrum on the bottom right. This clear difference would allow one to distinguish these two compounds. There are other subtle differences as well.

IR is not much help as these spectra are similar

$N$-Acetyl ethyl ester of ala-gly

$N$-Ethyl-dimethyl amide of ala-gly

82. $N$-Formyl-2-phenylalanine methyl ester.

83. $DL$-Alanyl-$DL$-serine
84. Ethyl L-leucinate

85. Dimethyl 2-bromomalonate

86. Ethyl gly-val (N-acetyl)
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30. Glycose \( \text{CHOH}_n \text{CH}_2\text{OH} \)
Glycitol \( \text{CHOH}_n \text{CH}_2\text{OH} \)
Glyconic acid \( \text{CHOH}_n \text{CO}_2\text{H} \)
Glycaric acid \( \text{CHOH}_n \text{CO}_2\text{H} \)
Uronic acid \( \text{CHOH}_n \text{CO}_2\text{H} \)

31. (a) HO\(\_\_\_\_)\(\_\_\_\_, \text{CHO} \)
(b) HO\(\_\_\_\_, \_\_\_\_, \_\_\_\_, \_\_\_\_, \text{OH} \)
(c) HO\(\_\_\_\_, \_\_\_\_, \_\_\_\_, \_\_\_\_, \text{OH} \)
(d) HO\(\_\_\_\_, \_\_\_\_, \_\_\_\_, \_\_\_\_, \text{OH} \)

32. (a) O\(\_\_\_\_, \_\_\_\_, \_\_\_\_, \_\_\_\_, \text{OH} \)
(b) O\(\_\_\_\_, \_\_\_\_, \_\_\_\_, \_\_\_\_, \text{OH} \)
(c) O\(\_\_\_\_, \_\_\_\_, \_\_\_\_, \_\_\_\_, \text{OH} \)
(d) O\(\_\_\_\_, \_\_\_\_, \_\_\_\_, \_\_\_\_, \text{OH} \)
(e) O\(\_\_\_\_, \_\_\_\_, \_\_\_\_, \_\_\_\_, \text{OH} \)
(f) O\(\_\_\_\_, \_\_\_\_, \_\_\_\_, \_\_\_\_, \text{OH} \)
(g) O\(\_\_\_\_, \_\_\_\_, \_\_\_\_, \_\_\_\_, \text{OH} \)
33. $\% \alpha (+90) + \% \beta (-38) = +18$, and since $\% \alpha + \% \beta = 1$, $\% \alpha = 1 - \% \beta$. Therefore, $(1 - \% \beta)(+90) + \% \beta (-38) = +18 = 90 - 90\% \beta - 38\% \beta = +18$, and $\% \beta (-128) = 18 - 90$, $\% \beta (-128) = -72$, so $\% \beta = -72 / -128 = 0.56$. Therefore, $\% \beta = 56\%$ and $\% \alpha = 44\%$.

34. The anomeric is not effective on C3, only on C2, so the equatorial conformation on the right should be favored.
37. α-L-Ribulofuranose  α-D-Psicopyranose  β-L-Fructofuranose  β-D-Tagatopyranose

38. O-α-D-Glucopyanosyl-(1→1)-β-D-allopyranose  O-β-D-Altopyranosyl-(1→4)-β-D-galactopyranose

O-α-D-Talopyranosyl-(1→1)-α-D-glucopyranose  O-β-D-Idopyranosyl-(1→4)-α-D-mannopyranose

39. O-α-D-Fuc(1→4)-α-D-Lyx(1→1)-α-D-Alt

O-α-D-Rib(1→4)-α-D-Xyl(1→1)-α-D-Fru

O-α-D-Al(1→4)-α-D-All(1→1)-α-D-Ido
Compounds (a) - (f) are all reducing sugars.

1. NaBH₄
2. aq NH₄Cl

Na/Hg

Br₂, pH 5

H₂, Ni(R)

HNO₃
42. Draw the major product for each of the following reactions.

(a) α-D-Glucopyranose

(b) α-D-Altropyranose

(c) α-D-Talopyranose

(d) α-D-Idofuranose

(e) α-D-Arabinopyranose
43.

(a) \[
\begin{array}{c}
\text{CHO} \\
\text{OH} \\
\text{OH} \\
\end{array}
\rightarrow
\begin{array}{c}
\text{CHO} \\
\text{OH} \\
\end{array}
\]

1. \(\text{NH}_2\text{OH}\)  
2. \(\text{Ac}_2\text{O}, \text{ZnCl}_2\)  
3. \(\text{NH}_3\)  
4. aq H⁺

(b) \[
\begin{array}{c}
\text{OH} \\
\text{OH} \\
\text{OH} \\
\end{array}
\rightarrow
\begin{array}{c}
\text{OH} \\
\text{OH} \\
\end{array}
\]

1. \(\text{NH}_2\text{OH}\)  
2. \(\text{Ac}_2\text{O}, \text{ZnCl}_2\)  
3. \(\text{NH}_3\)  
4. aq H⁺

(c) \[
\begin{array}{c}
\text{OH} \\
\text{OH} \\
\text{OH} \\
\end{array}
\rightarrow
\begin{array}{c}
\text{OH} \\
\text{OH} \\
\end{array}
\]

1. \(\text{NH}_2\text{OH}\)  
2. \(\text{Ac}_2\text{O}, \text{ZnCl}_2\)  
3. \(\text{NH}_3\)  
4. aq H⁺

(d) \[
\begin{array}{c}
\text{OH} \\
\text{OH} \\
\text{OH} \\
\end{array}
\rightarrow
\begin{array}{c}
\text{CHO} \\
\text{OH} \\
\end{array}
\]

1. \(\text{NH}_2\text{OH}\)  
2. \(\text{Ac}_2\text{O}, \text{ZnCl}_2\)  
3. \(\text{NH}_3\)  
4. aq H⁺

(e) \[
\begin{array}{c}
\text{OH} \\
\text{OH} \\
\text{OH} \\
\end{array}
\rightarrow
\begin{array}{c}
\text{OH} \\
\text{OH} \\
\end{array}
\]

1. \(\text{NH}_2\text{OH}\)  
2. \(\text{Ac}_2\text{O}, \text{ZnCl}_2\)  
3. \(\text{NH}_3\)  
4. aq H⁺

(f) \[
\begin{array}{c}
\text{OH} \\
\text{OH} \\
\text{OH} \\
\end{array}
\rightarrow
\begin{array}{c}
\text{OH} \\
\text{OH} \\
\end{array}
\]

1. \(\text{NH}_2\text{OH}\)  
2. \(\text{Ac}_2\text{O}, \text{ZnCl}_2\)  
3. \(\text{NH}_3\)  
4. aq H⁺

44.

\[
\begin{array}{c}
\text{OH} \\
\text{OH} \\
\text{OH} \\
\end{array}
\rightarrow
\begin{array}{c}
\text{AcO} \\
\text{OAc} \\
\end{array}
\]

1. \(\text{Ac}_2\text{O}, \text{H}^+\)  
2. \(\text{HBr}, \text{AcOH}\)

\[
\begin{array}{c}
\text{Br} \\
\text{AcO} \\
\text{OAc} \\
\end{array}
\]

1. \(\text{ClCN}\)

\[
\begin{array}{c}
\text{AcO} \\
\text{OAc} \\
\text{OAc} \\
\end{array}
\]

1. \(\text{Cl}_2\text{CN}\)

\[
\begin{array}{c}
\text{HO} \\
\text{AcO} \\
\end{array}
\]

2. \(\text{AcO}\)

\[
\begin{array}{c}
\text{HO} \\
\text{AcO} \\
\end{array}
\]

1. \(\text{H}_2\text{O}^+\)

\[
\begin{array}{c}
\text{OH} \\
\text{OH} \\
\text{OH} \\
\end{array}
\]

\[
\begin{array}{c}
\text{OH} \\
\text{OH} \\
\end{array}
\]

\[\text{O-}\alpha-\text{d-Ara} f(1\rightarrow4)-\alpha-\text{d-Ido} p\]
45. 

(a) \( \text{9-}(\beta\text{-d-Ribofuranoyl})\text{guanine} \)  
(b) \( \text{1-}(\beta\text{-d-Ribofuranoyl})\text{thymine} \)  
(c) \( \text{9-}(\beta\text{-d-Ribofuranoyl})\text{adenine} \)  
(d) \( \text{1-}(\beta\text{-d-Ribofuranoyl})\text{uracil} \)

46. 

(a) 

(b) 

(c) 

47. 

(a) 

(b) 

(c)
48. It depends on whether it is the α or the β sugar precursor. At best the α OH will be converted to the α-methoxy compound and the β OH will be converted to the β-methoxy compound. At worst, mutarotation of the sugar will lead to a mixture of α and β methoxy compounds.

49. Presumably, there will an anomeric effect with the nitrogen, probably not as prominent as with the oxygen substituent, but it is anticipated that the amine will prefer the axial position.
54. \( \%\alpha (+112) + \%\beta (+19) = 0.8(+112) + 0.2(+19) = 89.6 + 3.8 = 93.4^\circ \)
\( \%\alpha (+112) + \%\beta (+19) = +53, \) and since \( \%\alpha + \%\beta = 1, \) \( \%\alpha = 1-%\beta. \)
Therefore, \((1-%\beta)(+112) + \%\beta (+19) = +53 = 112 - 112%\beta +19%\beta = +53, \) and \( \%\beta (-93) = 53 - 112, \)
\( \%\beta (-93) = -59, \) so \( \%\beta = -59 / -93 = 0.63. \) Therefore, \( \%\beta = 63\% \text{ and } \%\alpha = 37\%. \)

55. \( \%\alpha (+90) + \%\beta (-38) = +18, \) and since \( \%\alpha + \%\beta = 1, \) \( \%\alpha = 1-%\beta. \)
Therefore, \((1-%\beta)(+90) + \%\beta (-38) = +18 = 90 - 90%\beta - 38%\beta = +18, \) and \( \%\beta (-128) = 18 -90, \)
\( \%\beta (-128) = -72, \) so \( \%\beta = -72 / -128 = 0.56. \) Therefore, \( \%\beta = 56\% \text{ and } \%\alpha = 44\%. \)

56.

\( \beta\)-D-Rhamnose

\( \alpha\)-Xylopyranose

\( \alpha\)-Arabinopyranose

\( \text{Major at equilibrium} \)

\( \text{Major at equilibrium} \)
57. The base-paired anti-parallel strands for A-G-G-T-A are:

58. Adenosine triphosphate

Adenosine monophosphate

Uracil diphosphate

Uracil monophosphate
Spectroscopy Problems. Do not attempt these problems until the concepts in Chapter 14 have been mastered.

These problems involve carbohydrates or nucleotide derivatives.

61.

**glucose**

IR: Aldehyde H at 2815 cm\(^{-1}\)

**glucopyranose**
The signals at about 2.3 in the deoxy compound constitute what is known as a doublet of doublets, but this special case is known as an AB quartet. The adjacent carbon atoms have stereogenic centers, which makes the two hydrogen atoms of the methylene unit diastereotopic (they are different, and give different signals). This type of signal was not discussed in Chapter 14.

63.  d-Glucitol

64.  β-d-Xylose
65. Thymidine

66. Methyl α-D-glucopyranoside