CHAPTER 22
ALCOHOLS, ETHERS, PHENOLS, AND THIOLS

SOLUTIONS TO REVIEW QUESTIONS

1. The question allows great freedom of choice. These shown here are very simple examples of each type.

(a) an alkyl halide

(b) a phenol

(c) an ether

(d) an aldehyde

(e) a ketone

(f) a carboxylic acid

(g) an ester

(h) a thiol

2. Alkenes are almost never made from alcohols because the alcohols are almost always the higher value material. This is because recovering alkenes from hydrocarbon sources in an oil refinery (primarily catalytic cracking) is a relatively cheap process.


Examples:

\[
\text{CH}_3\text{CH}_2\text{OH} \xrightarrow{[O]} \text{CH}_3\text{C}═\text{H} + \text{H}_2\text{O}
\]

\[
\text{CH}_3\text{C}═\text{H} \xrightarrow{[O]} \text{CH}_3\text{C}―\text{OH}
\]

4. 1,2-Ethanediol is superior to methanol as an antifreeze because of its low volatility. Methanol is much more volatile than water. If the radiator leaks gas under pressure (normally steam), it would primarily leak methanol vapor so you would soon have no antifreeze. Ethylene glycol has a lower volatility than water, so it does not present this problem.
5. Oxidation of alcohols affects the hydroxyl carbon in two ways: (1) the carbon adds a new bond to oxygen; (2) the carbon loses a bond to hydrogen. When the hydroxyl carbon is not directly bonded to hydrogen (as in tertiary alcohols), oxidation is difficult.

6. Menthol affects neurons that sense temperature. Binding of this alcohol to a neuron adjusts the neuron’s temperature sensitivity. The neuron then signals “pleasantly cool” even though the temperature is actually warm.

7. The liver oxidizes ingested methanol, first to methanal (formaldehyde) and then to methanoic acid (formic acid). Methanoic acid is much more toxic than methanol. This acid causes metabolic acidosis and inhibition of central energy metabolism that can lead to death.

8. The following classes of organic compounds can be easily formed from alcohols: aldehydes, ketones, and carboxylic acids by oxidation; alkenes and ethers by dehydration; esters by esterification.

9. ![Chemical Reaction Image]

- Benzene + propene
- Cumene hydroperoxide + phenol + acetone
- Oxidation of alcohols affects the hydroxyl carbon in two ways: (1) the carbon adds a new bond to oxygen; (2) the carbon loses a bond to hydrogen. When the hydroxyl carbon is not directly bonded to hydrogen (as in tertiary alcohols), oxidation is difficult.

10. Some common phenols include (a) hydroquinone, a photographic reducer and developer, (b) vanillin, a flavoring, (c) eugenol, used to make artificial vanillin, (d) thymol, used as an antiseptic in mouthwashes, (e) butylated hydroxytoluene (BHT) an antioxidant and, (f) the cresols, used as disinfectants.

11. Low molar mass ethers present two hazards. They are very volatile and their highly flammable vapors form explosive mixtures with air. They also slowly react with oxygen in the air to form unstable explosive peroxides.

12. Ethanol (molar mass = 46.07) is a liquid at room temperature because it has a significant amount of hydrogen bonding between molecules in the liquid state, and thus has a much higher boiling point than would be predicted from molar mass alone. Dimethyl ether (molar mass = 46.07) is not capable of hydrogen bonding to itself, so has low attraction between molecules, making it a gas at room temperature.
SOLUTIONS TO EXERCISES

1. (a) $\text{CH}_3\text{CHCH}_3$

   (b) $\text{CH}2\text{-OH}$

   (c) $\text{CH}_3\text{CH}_2\text{CHCH}_2\text{CHCH}_2\text{OH}$

2. (a) $\text{CH}_3\text{C}-\text{OH}$

   (b) $\text{CH}_3\text{CCH}_2\text{CH}_3$

   (c) $\text{CH}_3\text{C}-\text{CHCH}_2\text{CHCH}_2\text{CH}_3$

   (d) $\text{CH}_3\text{CHCH}_2\text{CCH}_3$

   (e) $\text{CH}2\text{-OH}$

   (f) $\text{CH}_3\text{CH}_2\text{OH}$

   (g) $\text{CH}_3\text{C}-\text{CHCH}_2\text{CH}_3$

   (h) $\text{CH}_3\text{C}-\text{CHCH}_2\text{CH}_3$

   (i) $\text{CH}_3\text{C}-\text{CHCH}_2\text{CH}_3$

   (j) $\text{CH}_3\text{C}-\text{CHCH}_2\text{CH}_3$

   (k) $\text{CH}_3\text{C}-\text{CHCH}_2\text{CH}_3$

   (l) $\text{CH}_3\text{C}-\text{CHCH}_2\text{CH}_3$
3. There are only five isomers:

\[
\begin{align*}
\text{CH}_3 & \quad \text{CH}_3 & \quad \text{H}_2\text{C} \quad \text{OH} \\
\text{CH}_3\text{CCH}_2\text{CH}_2\text{OH} & \quad \text{CH}_3\text{CHCHCH}_2\text{OH} & \quad \text{CH}_3\text{CHCCH}_3 \\
\text{CH}_3 & \quad \text{CH}_3 & \quad \text{CH}_3 \\
\text{HO} & \quad \text{CH}_3 & \quad \text{CH}_3 \\
\text{CH}_3\text{CHCCH}_3 & \quad \text{CH}_3\text{CH}_2\text{CCH}_2\text{OH} & \\
\text{CH} & \quad \text{CH}_3 & \\
\end{align*}
\]

4. There are only eight isomers:

\[
\begin{align*}
\text{CH}_3 & \quad \text{CH}_3 & \quad \text{CH}_3 \\
\text{HOCH}_2\text{CHCH}_2\text{CH}_2\text{CH}_3 & \quad \text{CH}_3\text{CCH}_2\text{CH}_2\text{CH}_3 & \quad \text{CH}_3\text{CHCHCH}_2\text{CH}_3 \\
& \quad \text{OH} & \quad \text{OH} \\
\text{CH}_3 & \quad \text{CH}_3 & \quad \text{CH}_3 \\
\text{CH}_3\text{CHCH}_2\text{CHCH}_3 & \quad \text{CH}_3\text{CHCH}_2\text{CH}_2\text{CH}_2\text{OH} & \quad \text{HOCH}_2\text{CH}_2\text{CHCH}_2\text{CH}_3 \\
\text{CH}_3 & \quad \text{CH}_3 & \quad \text{CH}_3 \\
\text{CH}_3\text{CHCHCH}_2\text{CH}_3 & \quad \text{CH}_3\text{CH}_2\text{CCH}_2\text{CH}_3 & \quad \text{OH} & \quad \text{OH} \\
\end{align*}
\]

5. (a) primary alcohols (where the hydroxyl carbon is bonded to one other carbon): c, f;
   (b) secondary alcohols (where the hydroxyl carbon is bonded to two other carbons): a, e;
   (c) tertiary alcohols (where the hydroxyl carbon is bonded to three other carbons): d; diol
   (where the compound contains two hydroxyl groups): none; triols (where the compound
   contains three hydroxyl groups): b.
6. (a) primary alcohols (where the hydroxyl carbon is bonded to one other carbon): none; (b) secondary alcohols (where the hydroxyl carbon is bonded to two other carbons): a, c, d; (c) tertiary alcohols (where the hydroxyl carbon is bonded to three other carbons): b, f; diol (where the compound contains two hydroxyl groups): none; triols (where the compound contains three hydroxyl groups): e.

7. The names of the compounds are:
(a) 1-butanol (butyl alcohol) 
(b) 2-propanol (isopropyl alcohol) 
(c) 2-methyl-3-phenyl-1-propanol 
(d) oxirane (ethylene oxide) 
(e) 2-methyl-2-butanol 
(f) 2-methylcyclohexanol 
(g) 2,3-dimethyl-1,4-butanediol

8. The names of the compounds are:
(a) ethanol (ethyl alcohol) 
(b) 2-phenylethanol 
(c) 3-methyl-3-pentanol 
(d) 1-methylcyclopentanol 
(e) 3-pentanol 
(f) 1,2-propanediol 
(g) 4-ethyl-2-hexanol

9. Chief product of dehydration
(a) \( \text{CH}_3 \) \( \text{CH}_2 \text{CHCH}_2 \text{CH}_3 \) 2-methyl-2-buten e
(b) \( \text{CH}_2 \text{CHCH}_2 \text{CH}_3 \) 2-pentene
(c) \[ \text{cyclohexene} \]

10. Chief product of dehydration
(a) \( \text{CH}_3 \) \( \text{CH}_2 \text{CHCH}_2 \text{CH}_3 \) 1-methylcyclopentene
(b) \( \text{CH}_3 \) \( \text{CHCH}_2 \text{CH}_3 \) 2-buten e
(c) \( \text{CH}_3 \) \( \text{CHCH}_2 \text{CHCH}_2 \text{CH}_3 \) 2-methyl-2-pentene
11. (a) \( \text{cyclopentanol} \)
   \[
   \begin{array}{c}
   \text{OH} \\
   \text{cyclopentanol}
   \end{array}
   \]

   (b) \( \text{2-methyl-1-butanol} \)
   \[
   \begin{array}{c}
   \text{CH}_3-	ext{CH}_2-	ext{CH}-	ext{OH} \\
   \text{CH}_3
   \end{array}
   \]

12. (a) \( \text{1,2-dimethylcyclohexanol} \)
   \[
   \begin{array}{c}
   \text{CH}_3 \\
   \text{OH} \\
   \text{cyclopentanol}
   \end{array}
   \]

   (b) \( \text{4,4-dimethyl-1-pentanol} \)
   \[
   \begin{array}{c}
   \text{HO}-\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \\
   \text{CH}_3
   \end{array}
   \]

13. Primary alcohols oxidize to carboxylic acids; secondary alcohols oxidize to ketones; tertiary alcohols don’t easily oxidize.

   (a) \( \text{butanone} \)
   \[
   \begin{array}{c}
   \text{O} \\
   \text{butanone}
   \end{array}
   \]

   (b) \( \text{3-ethylpentanoic acid} \)
   \[
   \begin{array}{c}
   \text{HOOCCH}_2\text{CHCH}_2\text{CH}_3 \\
   \text{CH}_2\text{CH}_3
   \end{array}
   \]
14. Primary alcohols oxidize to carboxylic acids; secondary alcohols oxidize to ketones; tertiary alcohols don’t easily oxidize.
   (a) HCOOH, methanoic acid, formic acid.
   (b) NR
   (c) CH₃COOH, ethanoic acid, acetic acid
   (d) CH₃CH₂CCH₂CH₂CH₃ 3-hexanone

15. Upon ester hydrolysis, the alcohol forms from the alkyl group and oxygen bonded to the C=O.
   (a) HOCH₂CH₂CH₂CH₃ 1-butanol
   (b) HOCH₂CH₃ ethanol
   (c) CH₃CHCH₃ 2-propanol

16. Upon ester hydrolysis, the alcohol forms from the alkyl group and oxygen bonded to the C=O.
   (a) \( \text{cyclopentanol} \)
   (b) HO–CH₂–CH–CH₃ 2-methyl-1-propanol
   (c) CH₃OH methanol

17. (a) CH₃CHBrCH₃ 2-bromopropane
    (b) bromocyclohexane (cyclohexyl bromide)
18. (a) CH₃CH₂CH₂CH₃
   \[ \text{2-butanol} \]

(b) CH₃CHCHCH₂CH₃
   \[ \text{3-ethyl-2-pentanol} \]

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

19. (a) \(2 \text{CH}_3\text{CH}_2\text{OH} + \text{H}_2\text{SO}_4 \xrightarrow{140^\circ\text{C}} \text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3 + \text{H}_2\text{O}\)
   \[ \text{diethyl ether} \]

(b) \(\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} + \text{H}_2\text{SO}_4 \xrightarrow{180^\circ\text{C}} \text{CH}_3\text{CH}==\text{CH}_2 + \text{H}_2\text{O}\)
   \[ \text{propene} \]

(c) \(\text{CH}_3\text{CH(OH)CH}_2\text{CH}_3 \xrightarrow{\text{K}_2\text{Cr}_2\text{O}_7, \text{H}_2\text{SO}_4} \text{CH}_3\text{CCH}_2\text{CH}_3 + \text{H}_2\text{O}\)
   \[ \text{2-butanone} \]

(d) \(\text{CH}_3\text{CH}_2\text{C}==\text{OCH}_2\text{CH}_3 \xrightarrow{\text{H}^+ / \text{H}_2\text{O}} \text{CH}_3\text{CH}_2\text{COOH} + \text{CH}_3\text{CH}_2\text{OH}\)
   \[ \text{propanoic acid} \quad \text{ethanol} \]

20. (a) \(2 \text{CH}_3\text{CH}_2\text{OH} + 2 \text{Na} \rightarrow 2 \text{CH}_3\text{CH}_2\text{O}^-\text{Na}^+ + \text{H}_2\)

(b) \(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{\text{K}_2\text{Cr}_2\text{O}_7, \text{H}_2\text{SO}_4} \text{CH}_3\text{CH}_2\text{CH}_2\text{COH}\)

(c) \[ \text{cyclopentene} \xrightarrow{\text{H}_2\text{O}, \text{H}_2\text{SO}_4} \text{cyclopentane} \]

(d) \(\text{CH}_3\text{CH}_2\text{C}==\text{OCH}_3 + \text{NaOH} \rightarrow \text{CH}_3\text{CH}_2\text{C}==\text{O}^-\text{Na}^+ + \text{CH}_3\text{OH}\)
21. (a) 2-methyl-1-propanol

\[
\text{CH}_2-\text{CH}-\text{CH}_3
\]

(b) 3-methyl-2-butanol

\[
\text{CH}_3-\text{CH}-\text{CH}_3
\]

(c) cyclopentanol

22. (a) Methanol, \(\text{CH}_3-\text{OH}\)

(b) 2,2-dimethyl-1-propanol \(\text{CH}_3-\text{C}-\text{CH}_2-\text{OH}\)

(c) 3,3-dimethyl-1-pentanol \(\text{CH}_3-\text{CH}_2-\text{C}-\text{CH}_2\text{CH}_2-\text{OH}\)

23. (a) methanol
   (b) 2-methyl-1-propanol
   (c) cyclohexanol

24. (a) cyclopentanol
   (b) 2-propanol
   (c) 2-methyl-2-propanol

25. (a) \(o\)-methylphenol

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

(b) \(m\)-dihydroxybenzene

\[
\begin{array}{c}
\text{OH} \\
\text{OH} \\
\end{array}
\]
(c) 4-hydroxy-3-methoxybenzaldehyde

\[ \text{H} \rightarrow \text{C} = \text{O} \]
\[ \text{OCH}_3 \]

26. (a) \( p \)-nitrophenol          (b) 2,6-dimethylphenol

\[ \text{H} \rightarrow \text{OH} \]
\[ \text{NO}_2 \]
\[ \text{H}_3\text{C} \]
\[ \text{OCH}_3 \]
\[ \text{CH}_3 \]

(c) \( o \)-dihydroxybenzene

\[ \text{H} \rightarrow \text{OH} \]
\[ \text{OH} \]

27. (a) phenol          (c) 2-ethyl-5-nitrophenol
(b) \( m \)-methylphenol (d) 4-bromo-2-chlorophenol

28. (a) \( p \)-dihydroxybenzene (hydroquinone)          (c) 2,4-dinitrophenol
(b) 2,4,6-trimethylphenol          (d) \( m \)-hexylphenol

29. Order of increasing solubility in water [c (lowest), a, b, d (highest)]
   (c) \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \) (1)
   (b) \( \text{CH}_3\text{CH(OH)}\text{CH}_2\text{CH}_2\text{CH}_3 \) (3)
   (a) \( \text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_2\text{CH}_3 \) (2)
   (d) \( \text{CH}_3\text{CH(OH)}\text{CH(OH)}\text{CH}_2\text{CH}_3 \) (4)

30. Order of decreasing solubility in water: [a (highest), d, c, b (lowest)]
   (a) \( \text{CH}_3\text{CH(OH)}\text{CH(OH)}\text{CH}_2\text{OH} \) (1)
   (c) \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \) (3)
   (d) \( \text{CH}_3\text{CH(OH)}\text{CH}_2\text{CH}_2\text{OH} \) (2)
   (b) \( \text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3 \) (4)

31. The three compounds have about the same molar mass but differ with respect to hydrogen bonding and polarity. Compound (b) (1-propanethiol) does not hydrogen bond, is nonpolar, and so, has the lowest boiling point. Compound (c) (diethyl ether) is polar but does not hydrogen bond to itself. It has a higher boiling point than compound (b). Compound a (1,2-propanediol) hydrogen bonds to itself and has the highest boiling point.
32. The three compounds have about the same molar mass but differ with respect to hydrogen bonding and polarity. Compound (c) (pentane) does not hydrogen bond, is nonpolar, and so, has the lowest boiling point. Compound (b) (diethyl ether) is polar but does not hydrogen bond to itself. It has a higher boiling point than Compound (c). Compound (a) (2-butanol) hydrogen bonds to itself and has the highest boiling point.

33. (a) common, isopropyl methyl ether; IUPAC, 2-methoxypropane  
(b) common, ethyl phenyl ether; IUPAC, ethoxybenzene  
(c) common, butyl ethyl ether; IUPAC, 1-ethoxybutane

34. (a) common, ethyl methyl ether; IUPAC, methoxyethane  
(b) common, ethyl isobutyl ether; IUPAC, 1-ethoxy-2-methylpropane  
(c) common, ethyl phenyl ether; IUPAC, ethoxybenzene

35. Fourteen isomeric ethers; \( \text{C}_6\text{H}_{14}\text{O} \)

\[
\begin{align*}
\text{CH}_3\text{OCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 & & \text{CH}_3 \quad \text{CH}_3\text{OCHCH}_2\text{CH}_2\text{CH}_3 \\
\text{methyl-}n\text{-pentyl ether (1-methyxpentane)} & & 2\text{-methoxypentane} \\
\text{CH}_2\text{CH}_3 & & \text{CH}_3 \\
\text{CH}_3\text{OCHCH}_2\text{CH}_3 & & \text{CH}_3\text{OCH}_2\text{CHCH}_2\text{CH}_3 \\
3\text{-methoxypentane} & & 1\text{-methoxy-2-methylbutane} \\
\text{CH}_3 & & \text{CH}_3 \quad \text{CH}_3 \\
\text{CH}_3\text{OCH}_2\text{CH}_2\text{CHCH}_3 & & \text{CH}_3\text{OCH} — \text{CHCH}_3 \\
1\text{-methoxy-3-methylbutane} & & 2\text{-methoxy-3-methylbutane} \\
\text{CH}_3 & & \text{CH}_3 \\
\text{CH}_3\text{OCH}_2\text{C} — \text{CH}_3 & & \text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \\
1\text{-methoxy-2,2-dimethylpropane} & & n\text{-butyl ethyl ether (1-ethoxybutane)} \\
\text{CH}_3 & & \text{CH}_3 \\
\text{CH}_3\text{CH}_2\text{OCHCH}_2\text{CH}_3 & & \text{CH}_3\text{CH}_2\text{OCH}_2\text{CHCH}_3 \\
\text{secc-butyl ethyl ether (2-ethoxybutane)} & & \text{ethyl isobutyl ether (1-ethoxy-2-methylpropane)}
\end{align*}
\]
35. (cont).

\[
\begin{align*}
\text{CH}_3 & \quad \text{CH}_3CH_2CH_2OCH_2CH_2CH_3 \\
\text{CH}_3CH_2OC & \quad \text{CH}_3 \\
\text{CH}_3 & \quad \text{di-}n\text{-propyl ether} \\
t\text{-butyl ethyl ether} & \quad (1\text{-propanol}) \\
(2\text{-ethoxy-2-methylpropane}) & \quad (1\text{-propoxypropane}) \\
\text{CH}_3 & \quad \text{CH}_3CH_3 \\
\text{CH}_3CH_2CH_2OCHCH_3 & \quad \text{CH}_3CHOCHCH_3 \\
isopropyl-n\text{-propyl ether} & \quad \text{diisopropyl ether}
\end{align*}
\]

36. Six isomeric ethers: C_5H_{12}O

\[
\begin{align*}
\text{CH}_3OCH_2CH_2CH_2CH_3 & \quad \text{CH}_3OCHCH_2CH_3 \\
n\text{-butyl methyl ether} & \quad \text{sec\text{-butyl methyl ether} } \\
(1\text{-methoxybutane}) & \quad (2\text{-methoxybutane}) \\
\text{CH}_3 & \quad \text{CH}_3 \\
\text{CH}_3OCH_2CHCH_3 & \quad \text{CH}_3OCCH_3 \\
isobutyl methyl ether & \quad t\text{-butyl methyl ether} \\
(1\text{-methoxy-2-methylpropane}) & \quad (2\text{-methoxy-2-methylpropane}) \\
\text{CH}_3CH_2OCH_2CH_2CH_3 & \quad \text{CH}_2CH_2OCHCH_3 \\
et\text{yl }n\text{-propyl ether} & \quad \text{ethyl isopropyl ether} \\
(1\text{-ethoxypropane}) & \quad (2\text{-ethoxypropane})
\end{align*}
\]

37. Possible combinations of reactants to make the following ethers by the Williamson synthesis:

(a) \( \text{CH}_3CH_2OCH_3 \)

\( \text{CH}_3\text{ONa} + \text{CH}_3\text{CH}_2\text{Cl} \) or

\( \text{CH}_3\text{CH}_2\text{ONa} + \text{CH}_3\text{Cl} \)
(b) \[ \text{CH}_2\text{OCH}_2\text{CH}_3 \quad \text{CH}_2\text{ONa} + \text{CH}_3\text{CH}_2\text{Cl} \]

or \[ \text{CH}_2\text{Cl} + \text{CH}_3\text{CH}_2\text{ONa} \]

(c) \[ \text{O}--\text{CH}_2\text{CH}_3 \quad \text{CH}_3\text{ONa} + \text{CH}_3\text{CH}_2\text{Cl} \]

38. Possible combinations of reactants to make the following ethers by the Williamson synthesis:

(a) \[ \text{CH}_3\text{CH}_2\text{CH}_2\text{OCH}_2\text{CH}_2\text{CH}_3 \quad \text{CH}_3\text{CH}_2\text{CH}_2\text{ONa} + \text{CH}_3\text{CH}_2\text{CH}_2\text{Cl} \]

(b) \[ \text{HCOCH}_2\text{CH}_2\text{CH}_3 \quad \text{HCONa} + \text{CH}_3\text{CH}_2\text{CH}_2\text{Cl} \]

(c) \[ \text{O}--\text{CH}_2\text{CH}_3 \] cannot be made by the Williamson synthesis. Cannot use secondary RX.

39. IUPAC names

(a) 2-methyl-2-butanol
(b) cyclohexanol
(c) 2-methyl-2-propanol
(d) 2-methyl-3-pentanol

40. IUPAC names

(a) 2-methylcyclopentanol
(b) 2,3-dimethyl-2-pentanol
(c) 2-propanol
(d) 3-ethyl-2,2,4-trimethyl-3-pentanol

41. (a) \[ \text{CH}_3\text{CHCH}_3 \quad \text{CH}_3\text{CHCH}_3 \]

(b) \[ \text{CH}_3\text{CH}_2\text{CHCH}_2\text{CH}_2\text{SH} \quad \text{CH}_3\text{CH}_3 \]
42. (a) \[
\text{SH} \quad \text{CH}_2\text{CH}_3
\]

(b) \[
\text{CH}_3\text{CH}_2\text{CHCH}_2\text{CH}_3 \quad \text{SH}
\]

(c) \[
\text{CH}_3 \quad \text{CH}_3\text{CH}_2\text{CCH}_2\text{SH} \quad \text{CH}_3
\]

43. 4-hexylresorcinol or 4-hexyl-1,3-dihydroxybenzene

44. \[
\text{cis-1,2-cyclopentanediol} \quad \text{trans-1,2-cyclopentanediol}
\]

45. The phenol compound (3-methylphenol) is more acidic than the alcohol compound (benzyl alcohol) but is less acidic than carbonic acid.
46. The name “catecholamine” is built of two pieces, “catechol” and “amine.” A catechol is a phenol derivative that contains an additional hydroxyl group (o-hydroxyphenol).

![Catechol structure]

(An amine is a “–NH₂” functional group.)

47. Oxidation products from ethylene glycol include

![Oxidation products from ethylene glycol]

48. In each compound, the most oxidized carbon will have the most positive oxidation number and, commonly, the most bonds to oxygen. In contrast, the most reduced carbon will have the most negative oxidation number and, commonly, the most bonds to hydrogen. The most reduced carbon has been circled while an asterisk has been placed by the most oxidized carbon.

![Oxidation numbers and bonds]

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49. (a) \[ CH_3CHCH_3 + \text{Cr}_2O_7^{2-} \rightarrow CH_3CCH_3 \]

(b) \[ CH_3CH_2CH_2CH=CH_2 + \text{H}^+ \rightarrow CH_3CH_2CH_2CHCH_3 \]

(c) \[ 2 CH_3CH_2OH + 2 \text{Na} \text{(metal)} \rightarrow 2 CH_3CH_2ONa + H_2 \]

(d) \[ CH_3CH_2CH=CH_2 + \text{H}^+ \rightarrow CH_3CH_2CHCH_3 \]

(e) \[ CH_3CH_2CH_2CH_2OH \xrightarrow{\text{H}_2\text{SO}_4} CH_3CH=CHCH_3 + CH_3CH_2CH=CH_2 \]

(f) \[ CH_3CH_2CH_2Cl \xrightarrow{\text{NaOH}} CH_3CH_2CH_2OH \xrightarrow{\text{Cr}_2O_7^{2-}} CH_3CH_2CH=CH_2 \]

50. \[ \text{CH}_3\text{C} + \text{NaOH} \rightarrow \text{CH}_3\text{C} + \text{H}_2\text{O} \]

\[ \text{CH}_3\text{CH}_3 + \text{Cl}_2 \xrightarrow{\text{light}} \text{CH}_3\text{CH}_2\text{Cl} + \text{HCl} \]

\[ \text{O}^-\text{Na}^+ + \text{CH}_3\text{CH}_2\text{Cl} \rightarrow \text{OCH}_2\text{CH}_3 + \text{NaCl} \]
51. A simple chemical test to distinguish between:
   (a) ethanol and dimethyl ether. Ethanol will react readily with potassium dichromate and sulfuric acid to make acetaldehyde. Visibly, the orange color of the dichromate changes to green. Ethanol reacts with metallic sodium to produce hydrogen gas. Dimethyl ether does not react with either of these reagents.
   (b) 1-pentanol and 1-pentene. 1-pentene will rapidly decolorize bromine as it adds to the double bond. 1-pentanol does not react.
   (c) *p*-methylphenol has acidic properties so it will react with sodium hydroxide. Methoxybenzene does not have acidic properties and will not react with sodium hydroxide.

52. Isomers of C₈H₁₀O

53. Only compound (a) will react with NaOH.

\[ \text{OH} + \text{NaOH} \rightarrow \text{O}^\text{Na}^- + \text{H}_2\text{O} \]
54. Order of increasing boiling points.
1-pentanol < 1-octanol < 1,2-pentanediol
138°C 194°C 210°C
All three compounds are alcohols. 1-pentanol has the lowest molar mass and hence the lowest boiling point. 1-octanol has a higher molar mass and therefore a higher boiling point than 1-pentanol. 1,2-pentanediol has two —OH groups and therefore forms more hydrogen bonds than the other two alcohols which causes its higher boiling point.

55. (a) The primary carbocation that is formed first is unstable.
\[ \text{CH}_3 \quad + \text{CH}_2 \text{—CH—CH}_2 \text{—CH}_3 \]
Thus, the primary carbocation shifts to a much more stable, tertiary carbocation

\[ \text{CH}_3 \quad \text{CH}_3 \text{—C—CH}_2 \text{—CH}_3 \quad + \]
It is this intermediate that goes on to form the major product, 2-methyl-2-butene.

\[ \text{CH}_3 \quad \text{CH}_3 \text{—C═CH—CH}_3 \]
(b) Hydration will not form 2-methyl-1-butanol because the double bond lies between the middle two carbons in 2-methyl-2-butene. By Markovnikov’s Rule, the —H will add to the double bonded carbon that already has a hydrogen. Thus, 2-methyl-2-butanol will be the major product.