Alcohols

- contain one or more hydroxyl groups, –OH,
- –OH is the functional group for alcohol
- higher boiling temperatures than hydrocarbons of comparable molar mass
- Shorter-chain alcohols are very soluble in water because of their size, polarity, and hydrogen bonding.
Naming Alcohols

• Use the alkane of the parent chain.
• If the name starts with a vowel drop the -e from the end of the alkane name and replace it with -ol.

Examples

\(\text{CH}_3\text{OH}:\)

\(\text{C}_2\text{H}_5\text{OH}\)
Write the IUPAC name for the following alcohol:

```
\begin{align*}
\text{CH}_3 & \quad \text{H} \\
\text{CH}_3 & \quad \text{CH} \quad \text{C} \quad \text{CH}_3 \\
                   & \quad \text{OH}
\end{align*}
```

1. Identify the longest continuous carbon chain on which the alcohol functional group—the hydroxyl (-OH) group—is located; e.g., four carbon atoms.
2. Write the prefix for the name to indicate the number of carbons in the longest chain; e.g., "but" for a four-carbon chain.
3. Add an "an" to the prefix to indicate that all of the carbon-carbon bonds are single bonds; e.g., "butan-".
4. Number the carbon chain from the end nearest the hydroxyl group; e.g., 1-4 from the right (in this case).
5. If necessary, add the locant (number) for the hydroxyl group to the name; e.g., "butan-2-".
6. Complete the parent name with "-ol" to indicate that the compound is an alcohol; e.g., "butan-2-ol".
7. Indicate the presence of any substituent as a prefix; e.g., "methylbutan-2-ol".
8. If necessary, add the locant (number) to indicate the location of the substituent; e.g., "3-methylbutan-2-ol".
9. Double-check to make sure that the numbers are necessary to differentiate this compound from a similar compound; e.g., 2-methyl-1-butanol.

The name of this alcohol is 3-methylbutan-2-ol.
Due to their physical and chemical properties, alcohols have many technological applications. Provide the molecular and structural formulas for alcohols (a) and (b), and the molecular and condensed formulas for alcohols (c) and (d).

(a) methanol (race car fuel)  (c) propan-1-ol (solvent for organic compounds)
(b) ethanol (gasoline additive)  (d) butan-1-ol (used for manufacturing rayon)

Solution

(a) methanol: $\text{CH}_3\text{OH}(l)$

(b) ethanol: $\text{C}_2\text{H}_5\text{OH}(l)$

(c) propan-1-ol: $\text{C}_3\text{H}_7\text{OH}(l)$

(d) butan-1-ol: $\text{C}_4\text{H}_9\text{OH}(l)$
Primary, Secondary, and Tertiary Alcohols

- *primary* (1°) alcohols, in which the carbon atom carrying the –OH group is bonded to one other carbon atom, as in CH₃CH₂CH₂CH₂OH(l), butan-1-ol
- *secondary* (2°) alcohols, in which the carbon atom carrying the –OH group is bonded to two other carbon atoms, as in CH₃CHOHCH₂CH₃(l), butan-2-ol
- *tertiary* (3°) alcohols, in which the carbon atom carrying the –OH group is bonded to three other carbon atoms, as in (CH₃)₃COH(l), 2-methylpropan-2-ol
SAMPLE problem 10.3

Name the following alcohol from its condensed structural formula and indicate whether it is a primary, secondary, or tertiary alcohol.

\[
\begin{align*}
\text{CH}_3 \\
\text{CH}_3 &\quad \text{C} \quad \text{CH}_2 \quad \text{CH}_2 \quad \text{CH}_3 \\
\quad \text{OH}
\end{align*}
\]

1. Identify the longest C chain. Since it is five Cs long, the alcohol is a pentanol.
2. Look at where the hydroxyl groups are attached. An \(-\text{OH}\) group is located on the second C atom, so the alcohol is a pentan-2-ol.
3. Look to see where any other group(s) are attached. A methyl group is located on the second C atom, so the alcohol is 2-methylpentan-2-ol.
4. Since the second C atom, to which the OH is attached, is attached to three other carbon atoms, the alcohol is a tertiary alcohol.
The following alcohol is used as a toxic denaturant for ethanol, as an octane booster in gasoline, as a paint remover, and for manufacturing perfumes. Name this alcohol from its condensed structural formula.

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

**Solution**

This tertiary alcohol is 2,3-dimethylbutan-2-ol.
Polyalcohols

• contain more than one hydroxyl group

ethane-1,2-diol (ethylene glycol)

propane-1,2,3-triol (glycerol)
SAMPLE problem 10.4

Draw a structural formula for butane-1,3-diol.

First, write the C skeleton for the parent molecule, butane.

\[ \text{C} - \text{C} - \text{C} - \text{C} \]

Next, attach an OH group to the first and third C atoms.

\[ \text{C} - \text{C} - \text{C} - \text{C} \]
\[ \text{H} - \text{O} \quad \text{H} - \text{O} \]

Finally, complete the remaining C bonds with H atoms.

\[ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \]
\[ \text{H} - \text{C} - \text{C} - \text{C} - \text{C} - \text{H} \]
\[ \text{O} \quad \text{H} \quad \text{O} \quad \text{H} \]
\[ \text{H} \quad \text{H} \]
Cyclic and Aromatic Alcohols

\[ \text{C}_6\text{H}_{11}\text{OH} \quad \text{cyclohexanol} \]

\[ \text{C}_6\text{H}_5\text{OH} \quad \text{phenol} \]

**COMMUNICATION example 3**

Draw a line structural formula for cyclopentane-1,2-diol.

**Solution**

![Structural formula of cyclopentane-1,2-diol]
Practice

5. Write IUPAC names for the following compounds:
   (a) CH₃—CH—CH₂—CH₃
       OH
   (b) CH₃—CH—CH₂—CH₂—CH₂
       OH
   (c) OH
   (d) OH

6. Draw a structural formula for
   (a) 3-methylbutan-1-ol
   (b) methylpropan-2-ol
   (c) cyclohexanol
   (d) phenol

7. Draw line structural formulas and name:
   (a) an isomer of butanol that is a secondary alcohol
   (b) the isomers of C₆H₅OH that are pentanols

8. Explain briefly why methanol has a higher boiling point than methane.

9. Predict the order of increasing boiling points for the following compounds, and give reasons for your answer.
   (a) ethane, methanol, and fluoromethane
   (b) butan-1-ol, pentane, and 1-chlorobutane

10. Glycerol is more viscous than water, and can lower the freezing point of water. When added to biological samples, it helps to keep the tissues from freezing, thereby reducing damage. From your knowledge of the molecular structure of glycerol, suggest reasons to account for these properties of glycerol.

11. Use your knowledge of intermolecular forces to predict, with reasoning,
    (a) the relative boiling points of ethane, chloroethane, and ethanol.
    (b) the relative solubility in water of ethane, chloroethane, and ethanol.
Practice
(Pages 430–431)
5. (a) butan-2-ol
   (b) pentan-2-ol
   (c) cyclohexane-1,3-diol
6. (a) \[
\begin{align*}
&\text{CH}_3 \\
&\text{CH}_3-\text{CH}-\text{CH}_2-\text{CH}_2-\text{OH}
\end{align*}
\]
   (b) \[
\begin{align*}
&\text{CH}_3 \\
&\text{CH}_3-\text{CH}-\text{CH}_3
\end{align*}
\]
   (c) \[
\text{OH}
\]
   (d) \[
\text{phenol}
\]
7. (a) \[
\text{pentan-1-ol}
\]
   (b) \[
\text{pentan-2-ol}
\]
   (c) \[
\text{pentan-3-ol}
\]
8. The presence of a hydroxyl group in methanol makes the molecule more polar than methane, and allows hydrogen bonding between molecules. This increase in intermolecular forces results in a higher boiling point.

9. (a) In order of their increasing boiling point: ethane, fluoromethane, methanol.
   The order of the boiling points depends on the order of the strengths of the intermolecular forces that exist among molecules in a substance. All substances will have London forces with strengths depending on the number of electrons per molecule. Since the number of electrons in these substances is the same, the observed trend depends on the presence of other intermolecular attractions. Ethane has only London forces among its molecules. Both fluoromethane and methanol consist of polar molecules with dipole–dipole forces. Methanol has the highest boiling point because it also has hydrogen bonding.
   (b) In order of increasing boiling point: pentane, 1-chlorobutane, butan-1-ol.
   All molecules have a similar number of electrons. Pentane has the lowest boiling point because its molecules are nonpolar, and, as a result, have only London forces between them. The higher boiling point of 1-chlorobutane is a result of dipole–dipole forces between its molecules, in addition to its London forces. Butan-1-ol has the highest boiling point because its molecules attract each other with all three types of intermolecular forces, in particular hydrogen bonding.

10. Each molecule of glycerol contains three hydroxyl groups which can hydrogen-bond with water, interfering with the attractions between water molecules and thus interfering with the freezing of water. When water in tissues does not freeze, there is less damage to the tissues.

11. (a) 

- [Ethane molecule diagram]
- [Chloroethane molecule diagram]
- [Ethanol molecule diagram]

   ethane    chloroethane    ethanol

   As the strength of intermolecular forces increases, the boiling point also increases, due to the increase in attraction between the molecules. To vaporize, the molecules with higher forces need more energy. Since ethane only has London forces and also has the fewest number of electrons (18), it has the weakest intermolecular forces. Chloroethane has more electrons (34) than ethane, and is polar due to the chlorine, so will rank next in strength of intermolecular forces. Ethanol, due to its hydrogen bonding, will have the strongest intermolecular force even though it has slightly fewer electrons (26) than chloroethane.

   [Boiling points are: ethane (-88.6 °C), chloroethane (12.3 °C), ethanol (78.5 °C)]

   (b) The solubility of molecules in water is dependent on the strength of attraction between the molecule and the water. Ethanol is not only polar but is capable of hydrogen bonding with water molecules. Ethanol should have the highest solubility in water. Chloroethane is the next most soluble because it is polar due to the chlorine atom. Polar molecules tend to be at least partially soluble in polar water. Ethane would be the least soluble in water because it is nonpolar.

12. (a) \( CH_4(g) + H_2O(l) \rightarrow CO(g) + 3 H_2(g) \)
   (b) \( CO(g) + H_2(g) \rightarrow CH_3OH(l) \)

13. (a) \( CH_3 - CH_2 \rightarrow CH_2 = CH_2 + H - H \)
   (b) \( CH_3 = CH_2 + H - O - H \rightarrow CH_3 - CH_2 - OH \)

14. (a) \( CH_3 - CH_2 - OH(l) + 3 O_2(g) \rightarrow 2 CO_2(g) + 3 H_2O(g) \)
   (b) \( 2 CH_3 - OH(l) + 3 O_2(g) \rightarrow CO_2(g) + 2 H_2O(g) \)

15. (a) \( 5.0 \% \times 355 \text{ mL} = 18 \text{ mL} \)
   (b) \( 12 \% \times 150 \text{ mL} = 18 \text{ mL} \)
Elimination Reactions

Producing Ethene by Cracking Ethane

\[
\text{ethane} \rightarrow \text{ethene} + \text{hydrogen}
\]

Producing Ethene by Elimination Reactions

\[
\text{ethanol} \rightarrow \text{ethene} + \text{water}
\]

\[
\text{chloroethane} + \text{hydroxide ion} \rightarrow \text{ethene} + \text{chloride ion} + \text{water}
\]

dehydrohalogenation
**COMMUNICATION example 4**

The elimination of a halide ion from an organic halide is the most common method for preparing a specific alkene in the laboratory. Write a structural formula equation for the preparation of but-2-ene from 2-chlorobutane, in the presence of a strong base.

**Solution**

\[
\begin{align*}
\text{H} & \text{H} \quad \text{H} \quad \text{H} \\
\text{H} & \text{C} \text{C} \quad \text{C} \text{C} \quad \text{H} + \text{OH}^{-} \rightarrow \text{H} & \text{H} \quad \text{C} \text{C} \quad \text{C} \quad \text{H} + \text{Cl}^{-} + \text{H}_2\text{O} \\
\text{H} & \text{H} \quad \text{Cl} \quad \text{H} & \text{H} \quad \text{H}
\end{align*}
\]

**COMMUNICATION example 5**

The elimination of the elements of a water molecule from an alcohol is the second most common method for preparing a specific alkene in the laboratory. Write a structural formula equation for the preparation of but-2-ene from butan-2-ol, in the presence of a catalyst.

**Solution**

\[
\begin{align*}
\text{H} & \text{H} \quad \text{H} \quad \text{H} \\
\text{H} & \text{C} \text{C} \quad \text{C} \text{C} \quad \text{H} \rightarrow \text{H} & \text{C} \text{C} \quad \text{C} \quad \text{C} \quad \text{H} + \text{H}_2\text{O} \\
\text{H} & \text{H} \quad \text{OH} \quad \text{H} & \text{H} \quad \text{H}
\end{align*}
\]
18. Write a structural formula equation to represent the synthesis of ethene by reacting bromoethane with a strong base.

19. Alkenes can be manufactured by three different chemical processes. Write structural formula equations for each of the following hypothetical chemical processes:
   (a) Butane is cracked into but-2-ene.
   (b) 1-chlorobutane undergoes an elimination reaction in a strongly basic solution to produce but-1-ene, chloride ions, and water.
   (c) butan-1-ol undergoes an elimination reaction to produce but-1-ene and water.

20. Write structural formula equations for the synthesis of propene by three different processes.

21. Chemical engineers face many difficulties during the technological design of ethane cracking plants (Figure 6). Suggest a different solution to each of the following problems encountered when ethane is thermally cracked:
   (a) 40% of the ethane remains uncracked after coming from the ethane cracker
   (b) ethyne (acetylene) is produced in addition to ethene
   (c) hydrogen and methane are produced
Practice

(Page 433)

18. \[
\begin{align*}
\text{Br} & \quad \text{H} \\
H - C - C - H + OH^- & \rightarrow H - C - C - H + H^- + Br^- \\
\text{H} & \quad \text{H} \\
\end{align*}
\]

19. (a) \[
\begin{align*}
\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{CH}_3 & \rightarrow \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_3 + \text{H}_2 \\
\end{align*}
\]
(b) \[
\begin{align*}
\text{Cl} - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_3 + \text{OH}^- & \rightarrow \text{CH}_2 = \text{CH} - \text{CH}_2 - \text{CH}_3 + \text{Cl}^- + \text{H}_2\text{O} \\
\end{align*}
\]
(c) \[
\begin{align*}
\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{OH} & \rightarrow \text{CH}_3 - \text{CH} - \text{CH}_2 - \text{CH}_3 + \text{H}_2\text{O} \\
\end{align*}
\]

20. elimination:

\[
\begin{align*}
\text{H} - \text{C} - \text{C} - \text{C} - \text{OH} & \rightarrow \text{H} - \text{C} - \text{C} = \text{C} + \text{H}_2\text{O} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\end{align*}
\]

elimination with a strong base:

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

\[
\begin{align*}
\text{H} - \text{C} - \text{C} - \text{C} - \text{H} + \text{OH}^- & \rightarrow \text{C} = \text{C} - \text{C} - \text{H} + \text{Cl}^- + \text{H}_2\text{O} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\end{align*}
\]

cracking:

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

21. (a) One solution to the problem of having too much ethane remaining as the chemicals are removed from the cracker is to separate the ethane and ethene, and then reintroduce the ethane into the cracker.

(b) One solution to the problem of producing ethyne along with ethene would be to remove the chemicals more quickly, before ethene has a chance to convert to ethyne. By removing the chemicals early, there is a good chance that there will be a significant amount of ethene that has not been converted to ethyne.

(c) One solution to the problem of producing methane and hydrogen instead of ethene during the cracking of ethane is to change the conditions of the reaction, including the reaction pressures, temperatures, and/or the catalysts.
SUMMARY

**Alcohols and Elimination Reactions**

**Alcohols**

Functional group:
- OH, hydroxyl group

Naming alcohols:
- Drop the "e" from the alkane name and add "ol"; e.g., ethane becomes ethanol.
- If necessary, add a number (or numbers) to communicate where the hydroxyl group(s) is (are) located; e.g., propan-1-ol and propan-2-ol.
- If the alcohol has two or three hydroxyl groups, it is a diol or a triol, respectively; e.g., ethane-1,2-diol and propane-1,2,3-triol. For diols and triols, do not drop the "e" from the alkane name.

**Preparation:**

Addition reactions with water
- alkenes + water $\rightarrow$ alcohols

$$R\overset{\text{catalyst}}{\underset{\text{H}}{\overset{\rightarrow}{\underset{\text{H}}{\text{R}}}}} C\overset{\text{OH}}{\underset{\text{H}}{\overset{\rightarrow}{\underset{\text{H}}{\text{R}}}}}$$

(R and R’ can be the same or different alkyl groups. Isomers often result.)

**Elimination Reactions**

- alcohols $\rightarrow$ alkenes + water

$$R\overset{\text{catalyst}}{\underset{\text{OH}}{\overset{\rightarrow}{\underset{\text{H}}{\text{R}}}}} C\overset{\text{OH}}{\underset{\text{H}}{\overset{\rightarrow}{\underset{\text{H}}{\text{R}}}}}$$

- organic halides + OH$^-\rightarrow$ alkenes + halide ion + water

$$R\overset{\text{OH}}{\underset{\text{X}}{\overset{\rightarrow}{\underset{\text{H}}{\text{R}}}}}$$

18
Section 10.3 Questions

1. Write structural formulas and IUPAC names for all saturated alcohols with four carbon atoms and one hydroxyl group.

2. Explain why the propane that is used as fuel in a barbecue is a gas at room temperature, but propane-2-ol, used as rubbing alcohol, is a liquid at room temperature.

3. Draw the structural formulas and write the IUPAC names of the two alkenes that are formed when hexan-2-ol undergoes an elimination reaction in the presence of an acid catalyst.

4. Write an equation using structural formulas to show the production of each of the following alcohols from an appropriate alkene:
   (a) butan-2-ol
   (b) methylpropan-2-ol

5. A major use of organic halides is in the preparation of unsaturated compounds. Predict the products of the following elimination reaction. Write a word equation and a structural formula equation.

6. Classify and write structural formula equations for the following catalyzed organic reactions:
   (a) ethene + water → ethanol
   (b) butan-2-ol → but-1-ene + but-2-ene + water
   (c) ethene + hypochlorous acid (HClOaq) → 2-chloroethanol
   (d) cyclohexanol + oxygen

7. Draw structural formulas to represent the elimination reaction of 2-chloropentane to form an alkene. Include reactants, reaction conditions, and all possible products and their IUPAC names.

8. The nomenclature of organic compounds is similar across classes of compounds. Name the following alkenes, alkenes, and alcohols.
   (a) CH₂=CH—CH₂—CH₂
   (b) CH₂=CH(CH₂)₃—CH₂
   (c) CH₂=CH—CH₂—CH₂
   (d) CH₂—CH₂—CH₂
   (e) CH₂—CH₂—CH₂—OH
   (f) CH₂=CH—CH(OH)—CH₂
   (g) CH₂=CH(CH₂)₃—CH₂
   (h) CH₂—CH₂—CH(OH)—CH₂

9. Draw line structural formulas for the following alcohols:
   (a) propane-2-ol
   (b) phenol (hydroxybenzene)
   (c) propane-1,2,3-triol (glycerol)
   (d) cyclohexanol

10. Complete the Hypothesis (including reasoning), Analysis, and Evaluation (2, 3) for the following investigation report:

Purpose
The purpose of this investigation is to test a hypothesis concerning the relative boiling points and solubility of alcohols. Assume that solubility means in water.

Problems
(a) What is the trend in boiling points for C₇–C₁₀ primary alcohols?
(b) What is the trend in solubility for C₇–C₁₀ primary alcohols?

Evidence
Table 1 Boiling Points and Solubilities of Various Alcohols

<table>
<thead>
<tr>
<th>Alcohol</th>
<th>Boiling point (°C)</th>
<th>Solubility (mL/100 mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>methanol</td>
<td>65</td>
<td>miscible</td>
</tr>
<tr>
<td>ethanol</td>
<td>78</td>
<td>miscible</td>
</tr>
<tr>
<td>propan-1-ol</td>
<td>97</td>
<td>miscible</td>
</tr>
<tr>
<td>butan-1-ol</td>
<td>117</td>
<td>9.1</td>
</tr>
<tr>
<td>pentan-1-ol</td>
<td>138</td>
<td>3.0</td>
</tr>
<tr>
<td>hexan-1-ol</td>
<td>157</td>
<td>slight</td>
</tr>
</tbody>
</table>

11. Use the information in this section and from your own research to continue gathering perspective statements concerning the statement that we should be saving more fossil fuels for petrochemical use in the future.

Extensions

12. Alcohols have gained increased popularity as an additive to gasoline, as a fuel for automobiles. "Gasohols" may contain up to 10% methanol and ethanol, and are considered more environmentally friendly than gasoline alone.

(a) Write balanced chemical reaction equations for the complete combustion of methanol and ethanol.

(b) When small amounts of water are present in the gasoline in the gas lines of a car, the water may freeze and block gasoline flow. Explain how using a gasohol would affect this problem.

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13. Radiator antifreeze and coolant is ethane-1,2-diol (ethylene glycol). Ethylene glycol is usually mixed 50:50 with water for use in the radiator. Large quantities of this chemical product are produced near Fort Saskatchewan and Scaddington, Alberta. Ethene reacts with oxygen in one reactor to produce ethylene oxide (C₂H₄O). The ethylene oxide then reacts with water in a second reactor to produce ethylene glycol.

(a) Write structural formula equations for these reactions.

(b) Explain why ethylene glycol is a better choice as a radiator antifreeze and coolant than ethanol.

(c) Explain why methanol, rather than ethylene glycol, is used as a windshield wiper antifreeze.

(d) Which is more toxic, methanol or ethylene glycol?

(e) Use a reference to find the freezing point of a 50:50 mixture of ethylene glycol and water.

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Section 10.3 Questions

1. \[ \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 \] butane

2. Propane is a nonpolar hydrocarbon with weak intermolecular forces; thus it has a low boiling point and is a gas at room temperature. Propan-2-ol is an alcohol, with a polar hydroxyl group and strong intermolecular hydrogen bonds, thus it has a higher boiling point than propane and is a liquid at room temperature.

3. \[ \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 \] hex-1-ene

4. (a) \[ \text{CH}_2 = \text{CH} - \text{CH} = \text{CH}_2 + \text{H}_2 \text{O} \rightarrow \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 \] hex-2-ene

(b) \[ \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 + \text{H}_2 \text{O} \rightarrow \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 \]

5. \[ \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 + \text{OH}^- \rightarrow \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 + \text{H}_2 \text{O} + \text{Cl}^- \]

chloroform + hydroxide → ethane + water + chloride

6. (a) addition: \[ \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 + \text{H}_2 \text{O} \rightarrow \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 \]

(b) elimination (dehydration): \[ \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 + \text{H}_2 \text{O} \rightarrow \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 + \text{H}_2 \text{O} \]

(c) addition: \[ \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 + \text{H}_2 \text{O} \rightarrow \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 + \text{H}_2 \text{O} \]

(d) combustion: \[ \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2 \text{O} \]

7. \[ 2 \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 + 2 \text{OH}^- \rightarrow \text{CH}_3 - \text{CH} = \text{CH} - \text{CH}_2 - \text{CH}_3 + 2 \text{H}_2 \text{O} \]

pent-1-ene

8. (a) butane

(b) methylpropane (or 2-methylpropane)

(c) but-2-ene
(d) methylpropene (or 2-methylprop-1-ene)
(e) butan-1-ol
(f) butan-2-ol
(g) methylpropan-1-ol (or 2-methylpropan-1-ol)
(h) methylpropan-2-ol (or 2-methylpropan-2-ol)

9. (a) 

(c) 

(b) 

(d) 

10. Purpose
The purpose of this investigation is to test a hypothesis concerning the relative boiling points and solubility of alcohols.

Problem
(a) What is the trend in boiling points for C₁ – C₆ primary alcohols?
(b) What is the trend in solubility for C₁ – C₆ primary alcohols?

Hypothesis
As the number of electrons per molecule increases for each alcohol, the boiling point will increase due to the increasing strength of London forces. Also, as the number of carbon atoms per molecule increases, the nonpolar portion of the molecules becomes larger, decreasing the solubility of the alcohol in the polar water.

Analysis
According to the evidence, the boiling point increases from methanol to hexan-1-ol and the solubility decreases from methanol to hexan-1-ol.

Evaluation
The hypothesis is judged to be acceptable because the evidence provided clearly agrees with the trends expected. The purpose was accomplished.

11. Pro Perspectives
• Scientific: Alcohols are frequently used as solvents in organic reactions because they are effective for both polar and nonpolar compounds.
• Technological: Increasingly, one of the most important technological applications of alcohols is as a gasoline additive.
• Economic: Grain-based ethanol plants are adding another significant market for grain farmers.
• Political: Provincial legislation to include 10% ethanol in gasoline, and tax incentives, will accelerate the expansion of the ethanol industry.

Con Perspectives
• Ecological: It is better for the environment to produce alcohols from renewable plant materials than to produce them from nonrenewable fossil fuels.

Extension
12. (a) \[ 2 \text{CH}_3\text{OH}(l) + 3 \text{O}_2(g) \rightarrow 2 \text{CO}_2(g) + 4 \text{H}_2\text{O}(g) \]

\[ \text{CH}_3\text{CH}_2\text{OH}(l) + 3 \text{O}_2(g) \rightarrow 2 \text{CO}_2(g) + 3 \text{H}_2\text{O}(g) \]
(b) Methanol and ethanol, having both polar hydroxyl groups and nonpolar carbon chains, are soluble in both water and in gasoline; thus water droplets are dissolved in the alcohol and do not form ice, which blocks gasoline flow.

13. (a) 

\[
\text{H} \quad \text{C} = \text{C} \quad + \quad \frac{1}{2} \text{O}_2 \rightarrow \quad \text{H} \quad \text{C} - \text{C} \\
\text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H}
\]

\[
\text{H} \quad \text{O} - \text{OH} \quad + \quad \text{H}_2\text{O} \rightarrow \quad \text{H} \quad \text{C} \quad \text{C} \quad \text{H} \\
\text{H} \quad \text{H} \quad \text{H}
\]

(b) Ethylene glycol is a better choice as a radiator antifreeze and coolant than ethanol because it has a much higher boiling point (197 °C vs 79 °C) due to its stronger London forces and hydrogen bonding. A mixture of ethylene glycol and water can be heated to a higher temperature before it boils, compared to a mixture of ethanol and water. Ethylene glycol also has a larger specific heat capacity than ethanol, which allows for the absorption of larger amounts of heat from an engine for the same increase in temperature.

(c) Methanol, rather than ethanol glycol, is used as a windshield wiper antifreeze for three reasons. First, ethylene glycol has a higher melting point (−13 °C vs −97 °C), which means it is likely to get too viscous or even freeze at temperatures that can occur during winter. Second, ethylene glycol is more viscous than methanol, which could make clearing the liquid from the windshield a problem. Spilled or sprayed ethylene glycol, with its higher boiling point and lower volatility, evaporates very slowly compared to methanol, which evaporates much more quickly.

(d) According to the Material Safety Data Sheet (MSDS) references, methanol is more toxic than ethylene glycol. The lowest reported lethal dose for a human is 428 mg/kg for methanol and 786 mg/kg for ethylene glycol.

(e) A 50:50 dilution of ethylene glycol in water has a freezing point of −37 °C.