Chapter 2

Reactions of Organic Compounds

Solutions for Practice Problems
Student Textbook page 63

1. Problem
Identify each reaction as an addition, substitution, or elimination reaction.

(a) $\text{CH}_3\text{CH}2\text{CH}2\text{OH} + \text{HBr} \rightarrow \text{CH}_3\text{CH}2\text{CH}3 + \text{HOH}$
   - **Solution**: No double bond is broken or formed. Two reactants form two products. The $\text{OH}$ group in the organic reactant is replaced with a $\text{Br}$ atom. This is a substitution reaction.

(b) $\text{CH}_3\text{CH}2\text{CH}2\text{Cl} + \text{Cl}_2 \rightarrow \text{CH}_3\text{CH}2\text{CH}3 + \text{Cl}_2$
   - **Solution**: A double bond becomes a single bond. Two reactants become one product. The organic product has more non-carbon atoms bonded to carbon (14 in total) than the organic reactant (12 in total). This is an addition reaction.

(c) $\text{Cl} \rightarrow \text{ }$
   - **Solution**: A double bond is formed. One reactant forms two products (HCl is eliminated from the reactant). This is an elimination reaction.

2. Problem
Identify each reaction as an oxidation or a reduction. The oxidizing and reducing agents are not shown.

(a) $\text{CH}_3\text{CHCHCH}2\text{CH} \rightarrow \text{CH}_3\text{CHCHCH}2\text{CH}_3$
   - **Solution**: A double bond is broken. Two reactants become one product. The organic product has fewer non-carbon atoms bonded to carbon (11 in total) than the organic reactant (12 in total). This is a reduction reaction.

(b) $\text{CH}_3\text{CH}2\text{CH}2\text{CH}2\text{CH}_3$
   - **Solution**: A double bond is formed. One reactant forms two products (HCl is eliminated from the reactant). This is an elimination reaction.
Solution
(a) The reactant has 16 C—H bonds and one double C=O bond. The product has 15 C—H bonds, one double C=O bond, and one C—O bond. This is an oxidation, since the product has gained a C—O bond and lost a C—H bond.
(b) The reactant has 12 C—H bonds, while the product has 14 C—H bonds. The product has gained C—H bonds, so this is a reduction. (Note that this is also an addition reaction. The other reactant, H₂, is not shown.)
(c) The reactant has two C=O bonds, while the product has two C—O bonds. Also, although they are not shown, two new C—H bonds have been formed at the site of each double bond. Since the product has lost C—O bonds and gained C—H bonds, this is a reduction.

3. Problem
Classify each reaction in two different ways: for example, as oxidation and as an elimination reaction.

(a) \[ \text{CH}_3\text{C}≡\text{C}−\text{H} + \text{H}_2 \rightarrow \text{CH}_3\text{C}≡\text{C}−\text{CH}_2\text{CH}_3\]

(b) \[ \text{CH}_3−\text{C}−\text{OH} + \text{HO}−\text{CH}_3 \rightleftharpoons \text{CH}_3−\text{C}−\text{O}−\text{CH}_3 + \text{HOH} \]

Solution
(a) A double bond becomes a single bond so this is an addition reaction. Also, the product has gained two C—H bonds, so this is a reduction.
(b) Two organic molecules combine to form a large organic molecule, producing water as a second product. This is a condensation reaction. Also, the —OH group on the carboxylic acid is replaced with the methoxy —OCH₃ group, so this is a substitution reaction.

4. Problem
Identify the type of reaction.

(a) \[ \text{CH}_3−\text{CH}≡\text{CH}_2 + \text{HOH} \rightarrow \text{CH}_3−\text{CH}−\text{CH}_3 \]

(b) \[ \text{CH}_3−\text{CH}_2−\text{C}−\text{CH}_2−\text{CH}_3 \rightarrow \text{CH}_3−\text{CH}_2−\text{C}−\text{CH}_2−\text{CH}_3 \]

Solution
(a) A double bond becomes a single bond. This is an addition reaction.
(b) The product loses a C—H bond, and gains a C—O bond, so this is an oxidation.
Solutions for Practice Problems
Student Textbook pages 67–68

5. Problem
Draw the reactants and products of the following reaction.
3-ethyl-2-heptene + HOH → 3-ethyl-3-heptanol + 3-ethyl-2-heptanol

Use Markovnikov’s rule to predict which of the two products will form in the greater amount.

Solution

\[
\begin{align*}
\text{CH}_2 &=\text{CH}_3 \\
\text{CH}_3\text{CH} &=\text{C} \quad \text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \\
\text{OH} &=
\end{align*}
\]

3-ethyl-3-heptanol

\[
\begin{align*}
\text{CH}_2 &=\text{CH}_3 \\
\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3 + \text{Br} \rightarrow \text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \\
\text{Br} &=
\end{align*}
\]

3-ethyl-2-heptanol

The −OH group goes to the third carbon atom, which is the more substituted carbon atom, that is, the carbon atom that is bonded to the largest number of other carbon atoms. Therefore, the main product is 3-ethyl-3-heptanol.

6. Problem
Name the reactants and products of each reaction. Use Markovnikov’s rule to predict which of the two products will form in the greater amount.

(a) \[\text{CH}_2\text{=CHCH}_2\text{CH}_2\text{CH}_3 + \text{HBr} \rightarrow \text{CH}_3\text{CHCH}_2\text{CH}_2\text{CH}_3 + \text{Br} \rightarrow \text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3\]

(b) \[\text{CH}_3\text{CH} &=\text{C} \quad \text{CH}_2\text{CH}_2\text{CH}_3 + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \\
\text{OH} &=
\]

Solution

(a) 1-hexene + hydrobromic acid → 2-bromohexane + 1-bromohexane
The bromine atom will go to the second carbon atom, since that atom is bonded to more carbon atoms than the first atom. The major product will be 2-bromohexane.
(b) 2-methyl-2-pentene + water → 2-methyl-2-pentanol + 2-methyl-3-pentanol
   The –OH group will go to the second, more substituted carbon atom.
   2-methyl-2-pentanol is the major product.

7. Problem
   Draw the major product of each reaction.
   (a) CH₃CH=CH₂ + Br₂ →
   (b) CH₂=CH₂ + HOH →
   (c) CH₃CH=CH₂CH₃ + HBr →
   (d) (CH₃)₂C=CHCH₂CH₂CH₃ + HCl →

Solution
   (a) Only one product is possible, since one of the reactants is symmetrical.
      The product is 1,2-dibromopropane.
      \[
      \text{CH}_3\text{-CH} = \text{CH}_2
      \begin{array}{c|c}
        \text{Br} & \text{Br}
      \end{array}
      \]
   (b) Only one product is possible, since one of the reactants is symmetrical.
      \[
      \text{CH}_3\text{-CH} = \text{OH}
      \]
   (c) Both reactants are asymmetrical, so two products are possible. The bromine atom
      will add to the second carbon atom, so the major product is 2-bromobutane.
      \[
      \begin{array}{c|c}
        \text{Br} & \\
      \end{array}
      \text{CH}_3\text{-CH} = \text{CH}_2\text{-CH}_3
      \]
   (d) Both reactants are asymmetrical, so two products are possible. The Cl atom will
      add to the second carbon atom, which has more bonds to other carbon atoms
      than the third carbon atom. The major product is 2-chloro-2-methylhexane.
      \[
      \begin{array}{c|c|c|c}
        \text{CH}_3 & \text{C} & \text{CH}_2 & \text{CH}_2\text{-CH}_2\text{-CH}_3
      \end{array}
      \begin{array}{c|c|c|c|c}
        \text{Cl} & \\
      \end{array}
      \]

8. Problem
   For each reaction, name and draw the reactants that are needed to produce the
   given product.
   (a) ? + ? → CH₃CH(Cl)CH₃
   (b) ? + ? → Br→CH₂CH₂→Br
      \[
      \begin{array}{c|c|c|c|c|c}
        & \text{OH} & & & & \\
      \end{array}
      \]
   (c) ? + HOH → CH₃CH₂CCH₂CH₃
      \[
      \begin{array}{c|c|c|c|c}
        & \text{CH}_3 & & & \\
      \end{array}
      \]
   (d) CH₂=CHCH₃ + ? → CH₃CH₂CH₃

Solution
   (a) This is probably an addition reaction, since water is not shown as a second
      product (in which case, it could be a substitution reaction of CH₃CH(OH)CH₃
      and HCl). The organic reactant in an addition reaction must have a double bond.
      The two reactants are propene and hydrochloric acid, shown below.
      \[
      \text{CH}_3 = \text{CH} = \text{CH}_2 + \text{HCl}
      \]
   (b) This is an addition reaction. The reactants are ethene and bromine, shown below.
      \[
      \text{CH}_2 = \text{CH} + \text{Br}_2
      \]
This is an addition reaction. There are two possible answers to this question. Both answers are given below.

(c) CH₃—CH₂—C═CH—CH₃
     \H
3-methyl-2-pentene

CH₃—CH₂—C—CH₂—CH₃
     \H
2-ethyl-1-butene

(d) This is an addition reaction. The missing reactant is hydrogen, H₂. (Note: This particular reaction requires a catalyst, so the actual reactant would be a reducing agent such as H₂/Pt, where the platinum is a catalyst.)

Solutions for Practice Problems
Student Textbook page 73

9. Problem
Name each type of reaction.
(a) 1-propanol + HCl → 1-chloropropane + H₂O
(b) 1-butanol + [O] → butanal
(c) CH₃CH₂CH₂Cl + NaOH → CH₃CH₂CH₂OH + NaCl
(d) CH₃—CH—CH₂—CH₂—CH₃ H₂SO₄ Δ
     \CH₃—CH═CH—CH₂—CH₃ + H₂O

Solution
(a) The −OH group of the alcohol is replaced with a Cl atom. This is a substitution reaction.
(b) An oxidizing agent is present, so it is an oxidation. Even if the oxidizing agent were not given, you know that butanal has one more C—O bond and one less C—H bond than 1-butanol.
(c) The Cl atom in 1-chloropropane is replaced with an −OH group, so this is a substitution reaction.
(d) A double bond is formed by heating an alcohol in acid, so this is an elimination reaction. Water is produced as a second product.

10. Problem
Draw the structures of the reactants and products in parts (a) and (b) of question 9.

Solution
(a) CH₃—CH₂—CH₂—OH + HCl → CH₃—CH₂—CH₂—Cl + H₂O
     \O
(b) CH₃—CH₂—CH₂—CH₂—OH + [O] → CH₃—CH₂—CH₂—CH₂—O

11. Problem
Name each type of reaction.
(a) CH₃—CH₂—CH₂—CH₂—OH H₂SO₄ Δ
(b) CH₃—CH₂—CH₂—CH₂—CH₂—OH + [O] → (i) + [O] → (ii)
Solution

(a) An alcohol is heated in the presence of sulfuric acid. These are the conditions required for an elimination reaction.

(b) An oxidizing agent is present, and the reactant is not a tertiary alcohol. An oxidation will occur.

(c) A substitution reaction will occur.

(d) A substitution reaction will occur.

(e) An oxidation will occur.

(f) A substitution reaction will occur.

12. Problem

Draw and name the products of each reaction in question 11.

Solution

(a) 1-butene + water

\[
\text{CH}_3\text{-CH} = \text{CH} = \text{CH}_2 + \text{H}_2\text{O}
\]

(b) (i) pentanal

\[
\text{CH}_3\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_2 + \text{H}_2\text{O}
\]

(ii) pentanoic acid

\[
\text{CH}_3\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-C} + \text{OH}
\]

(c) 2-bromo-3-methylbutane + water

\[
\text{Br} \quad \text{CH}_3\text{-CH} = \text{CH} = \text{CH}_3 + \text{H}_2\text{O}
\]

(d) 2-methyl-1-propanol + sodium bromide

\[
\text{CH}_3\text{-CH}_2\text{-OH} + \text{NaBr}
\]

(e) butanone

\[
\text{CH}_3\text{-CH}_2\text{-C} + \text{CH}_3
\]
13. Problem
Is the following reaction possible? Why or why not?

\[
\text{CH}_3\text{CH}_2\text{CH}_2\text{C} \text{OH} + [\text{O}] \rightarrow
\]

Solution
No, this reaction cannot occur. Tertiary alcohols have no hydrogen atom available to be removed, so they do not react with ordinary oxidizing agents.

Solutions for Practice Problems
Student Textbook page 78

14. Problem
Identify each type of reaction. (Oxidizing and reducing agents are not shown.)

(a) \[ \text{O} \rightarrow \text{OH} \]
(b) \[ \text{(CH}_3\text{)}_3\text{C} \text{C} \text{C(CH}_3\text{)}_3 \rightarrow \text{(CH}_3\text{)}_3\text{C} \text{C} \text{C(CH}_3\text{)}_3 \]
(c) 2-pentanone \rightarrow 2-pentanol
(d) hexanoic acid + ethanol ⇌ ethyl hexanoate + water
(e) butyl methanoate + water ⇌ methanoic acid + 1-butanol

Solution
(a) The product has lost a C—O bond and gained a C—H bond (at the carbon bonded to the oxygen atom). This is a reduction.
(b) A ketone is reduced to an alcohol. This is a reduction.
(c) This is a reduction.
(d) This is an esterification (condensation) reaction.
(e) This is a hydrolysis reaction.

15. Problem
(a) Name the reactants and products of the first two reactions in question 14.
(b) Draw the reactants and products of the last three reactions in question 14.

Solution
(a) cyclobutanone, cyclobutanol; 2,2,4,4-tetramethyl-3-pentanone, 2, 2, 4, 4-tetramethyl-3-pentanol
(b) \[ \text{CH}_3\text{—CH}_2\text{—CH}_2\text{—C—CH}_3 \quad \text{CH}_3\text{—CH}_2\text{—CH}_2\text{—CH—CH}_3 \]
\[ \text{2-pentanone} \quad \text{2-pentanol} \]
16. Problem
Name and draw the product(s) of each reaction.
(a) hexanal + [O] → hexanoic acid
(b) octanal + [H] → 1-octanol
(c) propanoic acid + methanol ⇌ methyl propanoate + water
(d) propyl ethanoate + water ⇌ ethyl hexanoate
(e) 3-hexanone + [H] → 3-hexanol
(f) 2-propanol + 3-methylpentanoic acid ⇌ 2-propyl 3-methylpentanoate (isopropyl 3-methylpentanoate)

Solution
(a) hexanoic acid

(b) 1-octanol

(c) methyl propanoate + water

(d) 1-propanol + ethanoic acid

(e) 3-hexanol

(f) 2-propyl 3-methylpentanoate (isopropyl 3-methylpentanoate)
17. Problem
Name and draw the reactant(s) in each reaction.
(a) \( \text{?} + [\text{H}] \rightarrow \text{CH}_3\text{CH}_2\text{CH(}\text{CH}_3\text{)}\text{CH}_2\text{OH} \)
(b) \( \text{?} + [\text{O}] \rightarrow \text{?} + [\text{O}] \rightarrow \text{CH}_3\text{CH}_2\text{OH} \text{CH}_2\text{COOH} \)
(c) \( \text{?} + \text{?} \rightarrow \text{CH}_3\text{CH}_2\text{CH(}\text{O})\text{C} \)

Solution
(a) 2-methylbutanal
(b) 1-pentanol; pentanal
(c) 1-propanol + 3-methylhexanoic acid

Solutions for Practice Problems
Student Textbook page 84

18. Problem
A monomer called methylmethacrylate polymerizes to form an addition polymer that is used to make bowling balls. What is the name of this polymer?

Solution
The name of the polymer is based on the name of the monomer, so the polymer is polymethylmethacrylate (commonly known as PMMA).

19. Problem
Classify each polymerization reaction as an addition or condensation polymerization reaction.
(a) \( n\text{HO}--\text{C}--\text{O}--\text{OH} + n\text{HO}--\text{CH}_2--\text{C}--\text{OH} \rightarrow \)

(b) \( n\text{CH}_2=\text{CH} \rightarrow \text{CH}_2--\text{CH}--\text{CH}_2--\text{CH}--\cdots \)

(c) \( n\text{HO}--\text{CH}_2--\text{C}--\text{OH} \rightarrow \text{O}--\text{CH}_2--\text{C}--\text{O}--\text{CH}_2--\text{C}--\cdots \)
Solution
(a) Ester bonds are formed between monomers, so this is a condensation polymerization.
(b) The reactant has a double bond, while the product does not. Therefore, this is an addition polymerization.
(c) Ester bonds are formed between monomers, so this is a condensation polymerization.

20. Problem
Draw the product of each polymerization reaction. Include at least two linkages for each product.

(a) $n\text{HO} \rightarrow \text{CH}_2\text{CH}_2\text{CH}_2\text{OH} + n\text{HO} \rightarrow \text{C} \rightarrow \text{CH}_2\text{C} \rightarrow \text{OH} \rightarrow$

(b) $n\text{H}_2\text{C} \rightarrow \text{CH} \rightarrow$

(c) $n\text{H}_2\text{NCH}_2 \rightarrow \text{CH}_2\text{NH}_2 + n\text{HO} \rightarrow \text{C}(\text{CH}_2\text{c}) \rightarrow \text{OH} \rightarrow$

Solution
(a) \[ \cdots \rightarrow \text{O} \rightarrow \text{CH}_2\text{CH}_2 \rightarrow \text{O} \rightarrow \text{C} \rightarrow \text{CH}_2 \rightarrow \text{O} \rightarrow \text{C} \rightarrow \text{CH}_2 \rightarrow \text{O} \rightarrow \cdots \]

(b) \[ \cdots \rightarrow \text{CH}_2 \rightarrow \text{CH} \rightarrow \text{CH}_2 \rightarrow \text{CH} \rightarrow \text{CH}_2 \rightarrow \cdots \]

(c) \[ \cdots \rightarrow \text{NHCH}_2 \rightarrow \text{CH}_2\text{NH} \rightarrow \text{C}(\text{CH}_2\text{c}) \rightarrow \text{NHCH}_2 \rightarrow \text{CH}_2\text{NH} \rightarrow \text{C}(\text{CH}_2\text{c}) \rightarrow \cdots \]

21. Problem
Classify each polymer as an addition polymer (formed by addition polymerization) or a condensation polymer (formed by condensation polymerization). Then classify each condensation polymer as either a polyester or a nylon (polyamide).

(a) \[ \cdots \rightarrow \text{CH}_2 \rightarrow \text{CH} \rightarrow \text{CH}_2 \rightarrow \text{CH} \rightarrow \cdots \]

(b) \[ \cdots \rightarrow \text{NH} \rightarrow \text{CH}_2 \rightarrow \text{NH} \rightarrow \text{C} \rightarrow \text{CH}_2 \rightarrow \text{C} \rightarrow \text{NH} \rightarrow \text{CH}_2 \rightarrow \text{NH} \rightarrow \cdots \]

(c) \[ \cdots \rightarrow \text{O} \rightarrow \text{CH}_2\text{CH}_2 \rightarrow \text{O} \rightarrow \text{C} \rightarrow \text{CH}_2\text{CH}_2 \rightarrow \text{C} \rightarrow \text{O} \rightarrow \text{C} \rightarrow \text{CH}_2\text{CH}_2 \rightarrow \text{C} \rightarrow \cdots \]

(d) \[ \cdots \rightarrow \text{O} \rightarrow \text{CCH}_2\text{C} \rightarrow \text{O} \rightarrow \text{C} \rightarrow \text{O} \rightarrow \text{C} \rightarrow \text{CCH}_2\text{C} \rightarrow \cdots \]
Solution
(a) The polymer has a backbone of carbon atoms, with no ester or amide bonds, so it is an addition polymer.
(b) The polymer has amide bonds in the main chain, so it was formed by condensation polymerization. It is a condensation polymer, and it is a polyamide, or nylon.
(c) The polymer has ester bonds in the main chain, so it is a condensation polymer and a polyester.
(d) The polymer has ester bonds in the main chain, so it is a condensation polymer and a polyester.

22. Problem
Draw the structure of the repeating unit for each polymer in question 21. Then draw the structure of the monomer(s) used to prepare each polymer.

Solution
(a) repeating unit: \( \cdots \text{CH}_2-\text{CH} \cdots \)
monomer: \( \text{CH}_2=\text{CH} \)
(b) repeating unit: \( \cdots \text{NH}-\text{CH}_2-\text{NH}-\text{C}-\text{CH}_2\text{CH}_2-\text{C} \cdots \)
monomers: \( \text{H}_2\text{N}-\text{CH}_2-\text{NH}_2 \quad \text{HO}-\text{C}-\text{CH}_2\text{CH}_2-\text{C}-\text{OH} \)
(c) repeating unit: \( \cdots \text{O}-\text{CH}_2\text{CH}_2-\text{C} \cdots \)
monomer: \( \text{HO}-\text{CH}_2\text{CH}_2-\text{C}-\text{OH} \)
(d) repeating unit: \( \cdots \text{O}-\text{CCH}_2\text{C} \cdots \)
monomers: \( \text{HO}-\text{CCH}_2\text{C} \quad \text{HO}-\text{CCH}_2\text{C}-\text{OH} \)