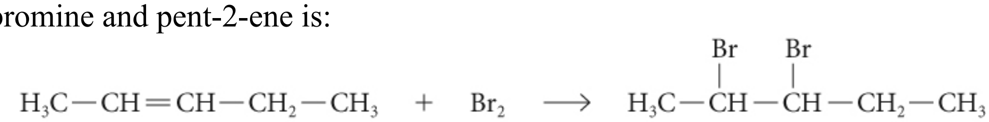
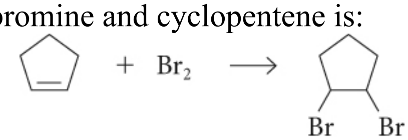
Chapter 1 Review, pages 72–77

Knowledge

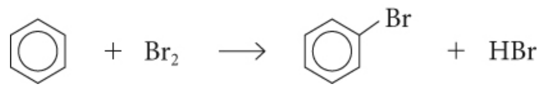
1. (b)
2. (d)
3. (b)
4. (d)
5. (c)
6. (d)
7. (c)
8. (d)
9. (c)
10. (d)
11. (a)
12. True
13. True
14. False. Markovnikov's rule states that, in an addition reaction involving a hydrogen atom, the hydrogen atom will usually bond to the carbon atom with the *most* hydrogen atoms attached.
15. False. Aromatic compounds usually undergo *substitution* reactions.
16. False. A compound that is a benzene ring with a hydroxyl group on one of the carbon atoms is called *phenol*.
17. False. An *ether* is formed from the reaction of two alcohols.
18. True
19. False. A ketone can be *hydrogenated* to produce a *secondary* alcohol.
20. False. Carboxylic acid molecules are much *more* polar than the corresponding alkane molecules.
21. (a) (vii)
(b) (ii)
(c) (iv)
(d) (viii)
(e) (iii)
(f) (vi)
(g) (i)
(h) (v)
22. (a) The reaction is an addition reaction. The equation representing the reaction of bromine and pent-2-ene is:



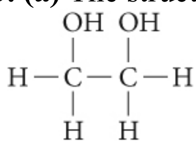
(b) The reaction is an addition reaction. The equation representing the reaction of bromine and cyclopentene is:



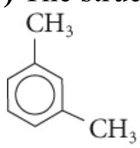
(c) The reaction is a substitution reaction. The equation representing the reaction of bromine and benzene is:



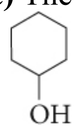
23. (a) The structure of ethan-1,2-diol is:



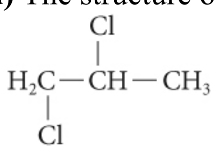
(b) The structure of 1,3-dimethylbenzene is:



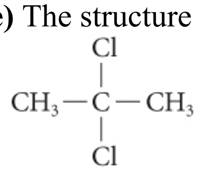
(c) The structure of cyclohexanol is:



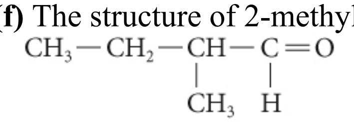
(d) The structure of 1,2-dichloropropane is:



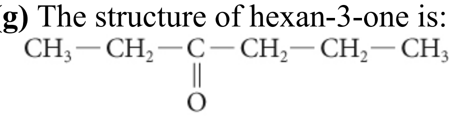
(e) The structure of 2,2-dichloropropane is:



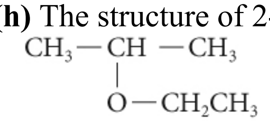
(f) The structure of 2-methylbutanal is:



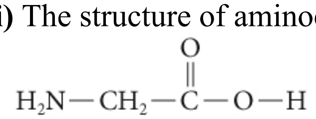
(g) The structure of hexan-3-one is:



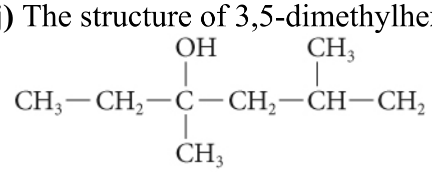
(h) The structure of 2-ethoxypropane is:



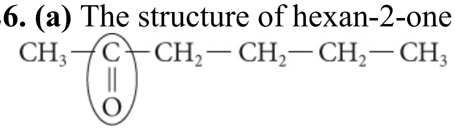
(i) The structure of aminoethanoic acid is:



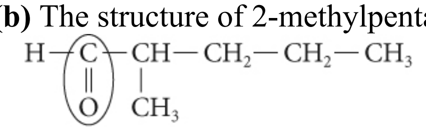
(j) The structure of 3,5-dimethylhexan-3-ol is:



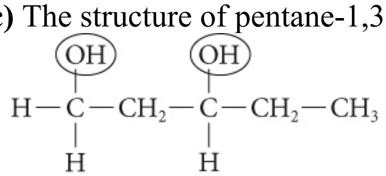
24. (a) The non-alkyl functional groups in testosterone are the carbonyl group (–C═O), the carbon–carbon double bond (C═C), and the hydroxyl group (–OH).
(b) The non-alkyl functional groups in ibuprofen are the phenyl (–C_6H_5) group and the carboxyl group (–COOH).
(c) The non-alkyl functional groups in amphetamine are the phenyl (–C_6H_5) group and the amino group (–NH_2).
25. (a) The functional group is the hydroxyl group (–OH). The compound is primary alcohol. The name of the compound is propan-1-ol.
(b) The functional group is the carboxyl group (–COOH). The compound is a carboxylic acid. The name of the compound is propanoic acid.
(c) The functional group is the carbonyl group (–C═O) at the terminal carbon. The compound is an aldehyde. The name of the compound is hexanal.
(d) The functional group is the ether group (–C–O–C–). The compound is an ether. The name of the compound is 1-ethoxypropane.
(e) The functional group is the amino group (–NH_2). The compound is a primary amine. The name of the compound is methanamine.
(f) The functional group is the carbonyl group (–C═O). The compound is a ketone. The name of the compound is pentan-2-one.
(g) The functional group is the ester group (–COOC–). The compound is an ester. The name of the compound is propylethanoate.
(h) The functional group is the amide group (–CON–). The compound is an amide. The name of the compound is *N*-methylpropanamide.
(i) The functional group is the carbonyl group (–C═O). The compound is a ketone. The name of the compound is pentan-3-one.
(j) The functional group is the carboxyl group (–COOH). The compound is a carboxylic acid. The name of the compound is methanoic acid.
26. (a) The structure of hexan-2-one is:



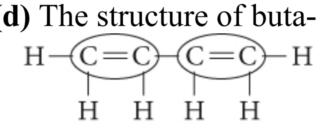
(b) The structure of 2-methylpentanal is:



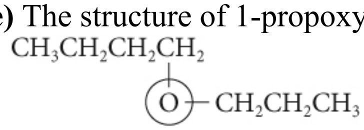
(c) The structure of pentane-1,3-diol is:



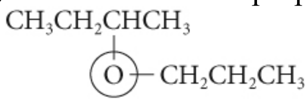
(d) The structure of buta-1,3-diene is:



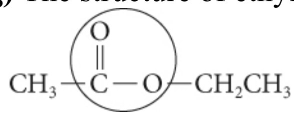
(e) The structure of 1-propoxybutane is:



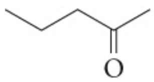
(f) The structure of 2-propoxybutane is:

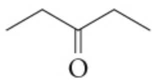


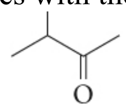
(g) The structure of ethyl ethanoate is:



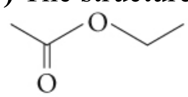
27. (a) The structures of three ketones with the molecular formula $C_5H_{10}O$ are:

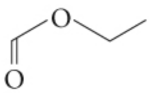

pentan-2-one


pentan-3-one

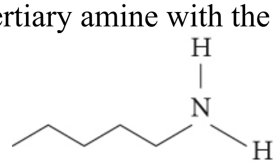

3-methylbutan-2-one

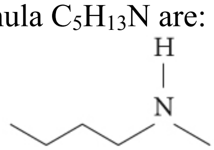
(b) The structures of two esters with the molecular formula $C_3H_6O_2$ are:

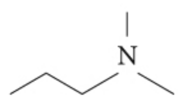

methyl ethanoate


ethyl methanoate

(c) Answers may vary. Sample answer: The structures of a primary, a secondary, and a tertiary amine with the formula $C_5H_{13}N$ are:


pentan-1-amine


N-methylbutan-1-amine


N,*N*-dimethylpropan-1-amine

Understanding

28. Answers may vary. Sample answer: Hydrogen bonding is a type of intermolecular interaction in which the hydrogen atom attached to a highly electronegative atom (N, O, or F) on one molecule is strongly attracted to an electronegative atom on another molecule. In the CH_2CF_2 molecule, the electronegativities of the carbon and hydrogen atoms are so similar that the C–H bond is almost non-polar. Therefore, it is not possible for this hydrogen atom to form a hydrogen bond with the fluorine atom on another CH_2CF_2 molecule, even though the fluorine atom carries a partial negative charge.

29. Answers may vary. Sample answer: I would look at the saturation of the hydrocarbons and the size of the molecules. Saturated hydrocarbon chains can rotate freely around the single carbon–carbon bonds. Each long hydrocarbon chain is a flexible structure that allows the chains to find an optimal packing position. This maximizes the London forces between molecules. More thermal energy is required to overcome the attractive forces and separate the molecules. Unsaturated hydrocarbon chains contain double bonds. These double bonds limit the amount of rotation around the carbon–carbon bonds. The van der Waals interactions are weaker, so it takes less thermal energy to separate the carbon chains with unsaturation. Therefore, the boiling point of a given unsaturated compound is lower than that of its saturated counterpart. The boiling points of hydrocarbons are also related to the length of the carbon chain. As the chain gets longer, the boiling point gets higher because more London forces can form between longer molecules.

30. Answers may vary. Sample answers:

(a) Propane is an alkane. Propane can be prepared by the addition reaction (hydrogenation) of propene with hydrogen in the presence of heat and a catalyst. The chemical equation representing the reaction is:

$$H_3C-HC{=}CH_2 \quad + \quad H_2 \quad \xrightarrow{\text{catalyst}} \quad H_3C-CH_2-CH_3$$

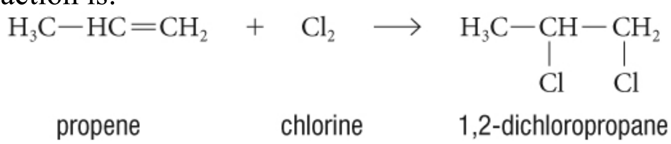
propene hydrogen propane

(b) Chloromethane is a monohalogenated alkane. Chloromethane can be produced by the substitution reaction of methane with chlorine. The chemical equation representing the reaction is:

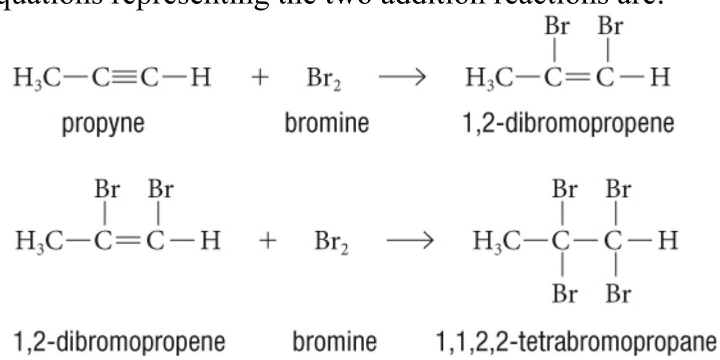
$$CH_4 \quad + \quad Cl_2 \quad \rightarrow \quad CH_3Cl \quad + \quad HCl$$

methane chlorine chloromethane hydrogen chloride

(c) 1,2-dichloropropane is a dihalogenated alkane. 1,2-dichloropropane can be produced by the addition reaction of propene with chlorine. The chemical equation representing the reaction is:



(d) 1,1,2,2-tetrachloropropane is a tetrahalogenated alkane. 1,1,2,2-tetrachloropropane can be produced by the addition reaction of propyne with bromine. The chemical equations representing the two addition reactions are:



(e) Chlorobenzene is a halogenated benzene. Chlorobenzene can be produced by the substitution reaction of benzene with chlorine in the presence of a catalyst. The chemical equation representing the reaction is:

$$C_6H_6 \quad + \quad Cl_2 \quad \xrightarrow{\text{catalyst}} \quad C_6H_5Cl \quad + \quad HCl$$

benzene chlorine chlorobenzene hydrogen chloride

(f) Propene is an alkene. Propene can be produced by the dehydration reaction of propan-1-ol in the presence of sulfuric acid. The chemical equation representing the reaction is:

$$H_3C-CH_2-CH_2OH \quad \xrightarrow{H_2SO_4} \quad H_3C-HC{=}CH_2 \quad + \quad H_2O$$

propan-1-ol propene water

31. Answers may vary. Sample answer: The sequence of reactions needed to produce propanone, starting with propane, is as follows:
First react propane with chlorine to form
1-chloropropane. Next react 1-chloropropane with concentrated hydroxide solution to form propan-1-ol. Then use a dehydration reaction to convert propan-1-ol to propene. Using a hydration reaction, turn propene into propan-2-ol. Finally, use controlled oxidation to oxidize propan-2-ol to propanone.

32. Ethanoic acid molecules have two polar groups, a carbonyl and a hydroxyl group, so they are very polar. Ethanol molecules have only one polar group, the hydroxyl group, which can form hydrogen bonds. Ethanal molecules have only one carbonyl group, which can participate in dipole–dipole interactions but not hydrogen bonds, so they are less polar. Ethane is a saturated hydrocarbon so its molecules are non-polar. The boiling points of compounds with similar masses increase with the strengths of the dipole interactions based on the strengths of the polar groups in the molecules. Therefore, the compounds in order of increasing boiling points are ethane, ethanal, ethanol, and ethanoic acid.

33. Answers may vary. Sample answers:

(a) From the name 2-chloro-2-butyne, carbon number 2 in the 4-carbon chain forms a carbon single bond with carbon number 1 and a triple bond with carbon number 3, and with a chlorine atom bonded to it. Altogether, this carbon number 2 forms five bonds. Since a carbon can form at most four bonds, the compound 2-chloro-2-butyne does not exist.

(b) From the name 2-methyl-2-propanone, carbon number 2 in the 3-carbon chain forms two carbon single bonds with carbon number 1 and carbon number 3, forms a double bond with an oxygen atom, and has a methyl group attached to it. Altogether, this carbon number 2 forms five bonds. Since a carbon can form at most four bonds, the compound 2-methyl-2-propanone does not exist.

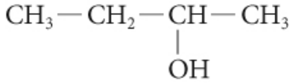
(c) From the name 1,1-dimethylbenzene, carbon number 1 in the benzene ring has two methyl groups attached to it. However, as any carbon in the benzene ring, it is single bonded to one neighbouring carbon and double bonded to another. With the two methyl groups, the carbon forms five bonds. Since a carbon can form at most four bonds, the compound
1,1-dimethylbenzene does not exist.

(d) From the name 2-pentanal, the compound is a 5-carbon aldehyde with the carbonyl group attached to carbon number 2. By definition, all aldehydes have the carbonyl group located at the terminal carbon, carbon number 1 or carbon number 5 in this case. Therefore, the compound
2-pentanal does not exist.

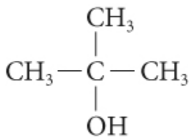
(e) From the name 3-hexanoic acid, the compound is a 6-carbon carboxylic acid with the carboxyl group attached to carbon number 3. By definition, all carboxylic acids have the carboxyl group located at the terminal carbon, carbon number 1 or carbon number 6 in this case. Therefore, the compound 3-hexanoic acid does not exist. In addition, in 3-hexanoic acid the carboxyl group would have to be bonded to two carbons, which would result in five bonds on the carboxyl carbon since that carbon already has one bond to the hydroxyl and a double bond to the carbonyl. Since a carbon can form at most four bonds, the compound 3-hexanoic acid does not exist.

(f) From the name 5,5-dibromo-1-cyclobutanol, the carbon ring of cyclobutanol has only 4 carbon atoms. It does not have carbon number 5 in the ring structure that the two bromine atoms can attach to. Therefore, the compound 5,5-dibromo-1-cyclobutanol does not exist.

34. (a) A secondary alcohol with the formula $C_4H_{10}O$ is butan-2-ol, and its structural formula is:



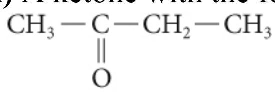
(b) A tertiary alcohol with the formula $C_4H_{10}O$ is 2-methylpropan-2-ol, and its structural formula is:



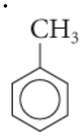
(c) Answers may vary. Sample answer: An ether with the formula $C_4H_{10}O$ is ethoxyethane, and its structural formula is:

$CH_3-CH_2-O-CH_2-CH_3$

(d) A ketone with the formula C_4H_8O is butanone, and its structural formula is:



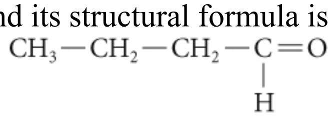
(e) An aromatic compound the formula C_7H_8 is methylbenzene, and its structural formula is:



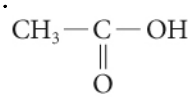
(f) Answers may vary. Sample answer: An alkene with the formula C_6H_{10} is hexa-1,3-diene, and its structural formula is:

$CH_2=CH-CH=CH-CH_2-CH_3$

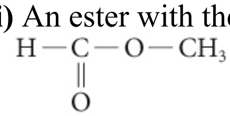
(g) Answers may vary. Sample answer: An aldehyde with the formula C_4H_8O is butanal, and its structural formula is:



(h) A carboxylic acid with the formula $C_2H_4O_2$ is ethanoic acid, and its structural formula is:



(i) An ester with the formula $C_2H_4O_2$ is methyl methanoate, and its structural formula is:



35. (a) The reaction of producing ethene from ethanol is a dehydration reaction. The equation representing the reaction is:

$$\underset{\text{ethanol}}{CH_3CH_2OH} \xrightarrow{H_2SO_4} \underset{\text{ethene}}{CH_2CH_2} + \underset{\text{water}}{H_2O}$$

(b) The reaction of producing ethoxyethane from ethanol is a dehydration reaction. The equation representing the reaction is:

$$2\ \underset{\text{ethanol}}{CH_3CH_2OH} \xrightarrow{H_2SO_4} \underset{\text{ethoxyethane}}{CH_3CH_2OCH_2CH_3} + \underset{\text{water}}{H_2O}$$

(c) The reaction of producing propanal from an alcohol, for example, propan-1-ol, is an oxidation reaction. The equation representing the reaction is:

$CH_3CH_2CH_2OH + [O] \rightarrow CH_3CH_2CHO + H_2O$
propan-1-ol propanal water

(d) Answers may vary. Sample answer: The reaction of producing a secondary pentanol, for example, pentan-2-ol, from an alkene, pent-1-ene, is an addition reaction. The equation representing the reaction is:

$CH_3CH_2CH_2CHCH_2 + H_2O \xrightarrow{\text{catalyst, acid}} CH_3CH_2CH_2CH(OH)CH_3$
pent-1-ene water pentan-2-ol

(e) The reaction of producing ethanoic acid from ethanol, an alcohol, is an oxidation reaction in two stages. The equations representing the reactions are:

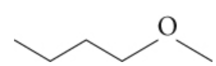
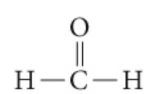
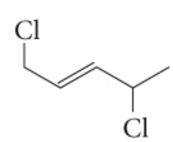
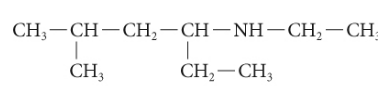
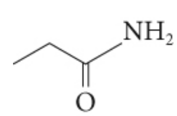
$CH_3CH_2OH + [O] \rightarrow CH_3CHO + H_2O$
ethanol ethanal water

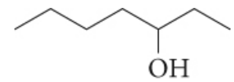
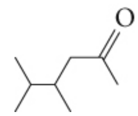
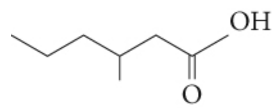
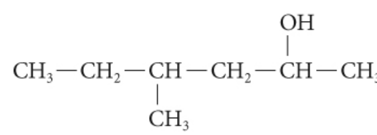
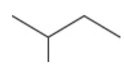
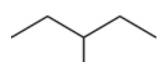
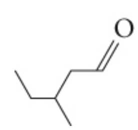
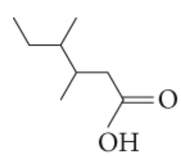
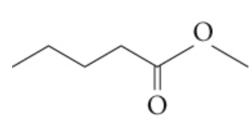
$CH_3CHO + [O] \rightarrow CH_3COOH$
ethanal ethanoic acid

(f) The reaction of producing ethyl methanoate from methanoic acid, an acid, and ethanol, an alcohol, is a condensation reaction (esterification). The equation representing the reaction is:

$HCOOH + CH_3CH_2OH \xrightarrow[\text{heat}]{\text{conc. } H_2SO_4} HCOOCH_2CH_3 + H_2O$
methanoic acid ethanol ethyl methanoate water

36. Table 1

Name	Condensed structure	Line diagram or structural formula	Type of compound
1-methoxybutane	$CH_3CH_2CH_2CH_2OCH_3$		ether
methanal	HCHO		aldehyde
1,4-dichloropent-2-ene	$CH_2ClCHCHCHClCH_3$		alkene
N-ethyl-5-methylhexan-3-amine	$CH_3CH(CH_3)CH_2CH(CH_2CH_3)NHCH_2CH_3$		amine
propanamide	$CH_3CH_2CONH_2$		amide

heptan-3-ol	$CH_3CH_2CH_2CH_2CH(OH)CH_2CH_3$		alcohol
4,5-dimethylhexan-2-one	$CH_3CH(CH_3)CH(CH_3)CH_2COCH_3$		ketone
3-methylhexanoic acid	$CH_3CH_2CH_2CH(CH_3)CH_2COOH$		carboxylic acid
4-methylhexan-2-ol	$CH_3CH_2CH(CH_3)CH_2CH(OH)CH_3$		alcohol
2-methylbutane	$CH_3CH(CH_3)CH_2CH_3$		alkane
3-methylpentane	$CH_3CH_2CH(CH_3)CH_2CH_3$		alkane
3-methylpentanal	$CH_3CH_2CH(CH_3)CH_2CHO$		aldehyde
3,4-dimethylhexanoic acid	$CH_3CH_2CH(CH_3)CH(CH_3)CH_2COO$ H		carboxylic acid
methyl pentanoate	$CH_3CH_2CH_2CH_2COOCH_3$		ester

37. (a) The compound on the right, benzoic acid, has two polar groups—a carbonyl group and a hydroxyl group—located close together, adding polarity to the molecule, which contributes to its solubility in water. However, the non-polar ring makes benzoic acid less soluble. Consequently, benzoic acid is only slightly soluble in water. Like alkanes and alkenes, benzene molecules are nonpolar which makes them insoluble in water. Therefore, benzoic acid is more soluble in water than benzene.
(b) The compound on the left, ethanoic acid, has two polar groups—a carbonyl group and a hydroxyl group—located close together, so its molecules are very polar. The carboxyl groups form hydrogen bonds with one another and with water, so ethanoic acid is very soluble in water. The methoxy group in methyl ethanoate is not as polar as a hydroxyl group and does not possess a hydrogen that it can use to form hydrogen bonds as the hydroxyl group does. Therefore, ethanoic acid is more soluble in water than methyl ethanoate is.
(c) Ethanol and decanol each contain a polar hydroxyl group and can form hydrogen bonds. The hydroxyl group will be attracted by water molecules, because water is also polar and can form hydrogen bonds. In longer chain alcohols, such as decanol, a larger part of the molecule is a hydrocarbon chain that is not attracted by water molecules. Therefore, ethanol is more soluble in water than decanol.
(d) 2-butanol has a polar hydroxyl group. The hydroxyl groups are able to form hydrogen bonds with one another and with water. Butanone has only a carbonyl group that will not form hydrogen bonds. Therefore, 2-butanol is more soluble in water than butanone.
38. (a) The carbonyl group in pentan-3-one is more polar than the ethoxy group in ethoxyethane. Therefore, pentan-3-one has a higher boiling point.
(b) Ethanal has only one polar group: a carbonyl group. Ethanoic acid has two polar groups located close together: a carbonyl group and a hydroxyl group. The molecules of ethanoic acid are thus more polar than the molecules of ethanal. Therefore, ethanoic acid has a higher boiling point than ethanal.
(c) Ethanol has a 2-carbon chain, whereas pentan-1-ol has a 5-carbon chain. So, a greater part of the pentan-1-ol molecule is non-polar. Therefore, ethanol has a higher boiling point than
pentan-1-ol.
39. Answers may vary. Sample answers:
(a) The hydration of ethene will yield ethanol, a primary alcohol. The equation representing the reaction is:

$CH_2CH_2 + H_2O \rightarrow CH_3CH_2OH$
ethene water ethanol

(b) The hydration of propene will yield propan-2-ol, a secondary alcohol. The equation representing the reaction is:

$CH_3CHCH_2 + H_2O \rightarrow CH_3CH(OH)CH_3$
propene water propan-2-ol

(c) The hydration of 2-methylprop-1-ene will yield 2-methylpropan-2-ol, a tertiary alcohol. The equation representing the reaction is:

$CH_3C(CH_3)CH_2 + H_2O \rightarrow CH_3C(CH_3)(OH)CH_3$
2-methylprop-1-ene water 2-methylpropan-2-ol

(d) The controlled oxidation of ethanol will yield ethanal, an aldehyde. The equation representing the reaction is:

$CH_3CH_2OH + [O] \rightarrow CH_3CHO + H_2O$
ethanol ethanal water

(e) The controlled oxidation of propan-2-ol will yield propanone, a ketone. The equation representing the reaction is:

$CH_3CH(OH)CH_3 + [O] \rightarrow CH_3COCH_3 + H_2O$
propan-2-ol propanone water

(f) The oxidation of ethanal will yield ethanoic acid, a carboxylic acid. The equation representing the reaction is:

$CH_3CHO + [O] \rightarrow CH_3COOH$
ethanal ethanoic acid

(g) The condensation reaction of ethanoic acid and methanol will yield methyl ethanoate, an ester. The equation representing the reaction is:

$CH_3COOH + CH_3OH \rightarrow CH_3COOCH_3 + H_2O$
ethanoic acid methanol methyl ethanoate water

40. (a) The reaction is a substitution reaction. The reactants are ethane and bromine, and the products are bromoethane and hydrogen bromide.
(b) The reaction is an addition reaction. The reactants are propene and chlorine, and the product is 1,2-dichloropropane.
(c) The reaction is a substitution reaction. The reactants are benzene and iodine, and the products are iodobenzene and hydrogen iodide.
(d) The reaction is a substitution reaction. The reactants are 1-chlorobutane and hydroxide ion, and the products are butan-1-ol and chloride ion.
(e) The reaction is an esterification reaction. The reactants are propanoic acid and methanol, and the products are methyl propanoate and water.
(f) The reaction is a dehydration reaction. The reactant is ethanol, and the products are ethene and water.
(g) The reaction is a combustion reaction. The reactants are methylbenzene and oxygen, and the products are carbon dioxide and water.
(h) The reaction is an oxidation reaction. The reactant is ethanol, and the product is ethanoic acid.
(i) The reaction is a condensation reaction. The reactants are ammonia and pentanoic acid, and the products are pentanamide and water.
(j) The reaction is a condensation reaction. The reactants are iodomethane and ammonia, and the products are methanamine and hydrogen iodide.

41. (a) A substitution reaction of propane involving chlorine:

$CH_3CH_2CH_3 + Cl_2 \rightarrow CH_3CH_2CH_2Cl + HCl$
propane chlorine 1-chloropropane hydrogen chloride

(b) A halogenation reaction of benzene involving fluorine:

$C_6H_6 + F_2 \rightarrow C_6H_5F + HF$
benzene fluorine fluorobenzene hydrogen fluoride

(c) The complete combustion of ethanol:

$CH_3CH_2OH + 3\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$
ethanol oxygen carbon dioxide water

(d) A dehydration reaction of butan-2-ol:

$CH_3CH_2CH(OH)CH_3 \rightarrow CH_3CHCHCH_3 + H_2O$

butan-2-ol but-2-ene water

(e) The controlled oxidation of butanal:

$CH_3CH_2CH_2CHO + [O] \rightarrow CH_3CH_2CH_2COOH$

butanal butanoic acid

(f) The preparation of pentan-2-one from an alcohol:

$CH_3CH_2CH_2CH(OH)CH_3 + [O] \rightarrow CH_3CH_2CH_2COCH_3 + H_2O$

pentan-2-ol pentan-2-one water

(g) The preparation of hexyl ethanoate from an acid and an alcohol:

$CH_3COOH + CH_3CH_2CH_2CH_2CH_2CH_2OH \rightarrow CH_3COOCH_2CH_2CH_2CH_2CH_2CH_3 + H_2O$

ethanoic acid hexan-1-ol hexyl ethanoate water

(h) The hydrolysis of methyl pentanoate:

$CH_3CH_2CH_2CH_2COOCH_3 + H_2O \rightarrow CH_3CH_2CH_2CH_2COOH + CH_3OH$

methyl pentanoate water pentanoic acid methanol

(i) The controlled oxidation of propan-1-ol:

$CH_3CH_2CH_2OH + [O] \rightarrow CH_3CH_2CHO + H_2O$

propan-1-ol propanal water

(j) Answers may vary. Sample answer: An addition reaction of an alkene to produce an alcohol:

$CH_2CH_2 + H_2O \rightarrow CH_3CH_2OH$

ethene water ethanol

(k) Answers may vary. Sample answer: A condensation reaction of an amine:

$CH_3CH_2Br + H_2NCH_3 \rightarrow CH_3CH_2NHCH_3 + HBr$

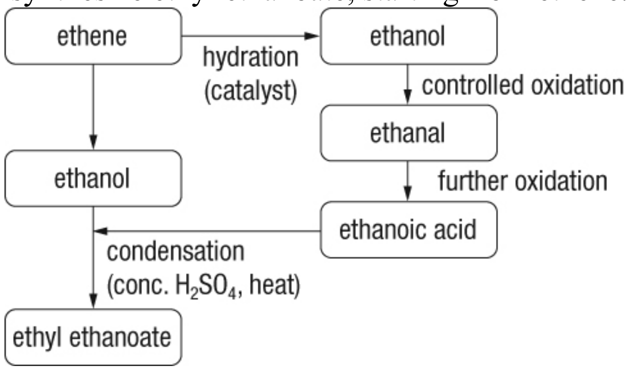
bromoethane methanamine *N*-methylethanamine hydrogen bromide

Analysis and Application

42. Answers may vary. Sample answer: A procedure that could be used to separate a mixture of alcohols containing methanol, ethanol, and hexan-1-ol is as follows: Since methanol (64.7 °C), ethanol (78.4 °C), and hexan-1-ol (156 °C), are liquids with distinct boiling points, the mixture of these three alcohols can be separated by fractional distillation. During fractional distillation, the temperature of a mixture of hydrocarbons is slowly increased. As the boiling point of each alcohol is reached, each alcohol boils out of the mixture. The vapour is collected and then condensed back to the alcohol with that particular boiling point.

43. Answers may vary. Sample answer: The empirical formula $C_5H_{12}O$ is likely an alcohol with a 5-carbon chain and a hydroxyl group (–OH). When this compound is oxidized in a controlled way with potassium permanganate, $KMnO_4(aq)$, it is converted to a ketone that has the empirical formula $C_5H_{10}O$. So, the unknown compound should be a secondary alcohol. The possible isomers of this compound would be pentan-2-ol with the formula $CH_3CH_2CH_2CH(OH)CH_3$, pentan-3-ol with the formula $CH_3CH_2CH(OH)CH_2CH_3$, and 3-methylbutan-2-ol with the formula $CH_3CH(CH_3)CH(OH)CH_3$. Among these compounds, 3-methylbutan-2-ol is less likely to be oxidized because the hydroxyl group in the molecule is less available for oxidation due to the large methyl group in the neighbouring carbon.

44. Answers may vary. Sample answer: The following flow chart shows the steps needed to synthesize ethyl ethanoate, starting from ethene.



45. Answers may vary. Students' answers should include a table with the suggested headings and have all columns filled for the following types of compounds discussed in this chapter: alkanes, alkenes, alkynes, aldehydes, ketones, carboxylic acids, amines, and amides. They should also include some others such as aromatic compounds, thiols, ethers, or esters.

46. Answers may vary. Sample answer:

Organic compound	**Structure**	**Reactions**
alkane	saturated hydrocarbon	undergo substitution reactions to form compounds such as alkyl halides and alcohols
alkene	hydrocarbon with at least 1 double carbon–carbon bond	undergo halogenation, dydrohalogenation, hydration, hydrogenation to form larger molecules
alkyne	hydrocarbon with at least 1 triple carbon–carbon bond	
aromatic hydrocarbons	unsaturated with a ring structure	some undergo substitution reactions
alcohol	include a hydroxyl group	formed by hydration reactions
ether	include an oxygen atom between 2 carbon atoms in a chain	can be synthesized from two alcohols in a condensation reaction
aldehyde	include a carbonyl group, bonded to at least one hydrogen atom	synthesized by controlled oxidation of an alcohol can undergo hydrogenation to produce a primary alcohol
ketone	include a carbonyl group bonded to 2 carbon atoms	
carboxylic acid	includes a carboxyl group	can be formed by the oxidation of aldyhydes
ester	includes a group similar to a carboxyl group, but with an alkyl group instead of a hydrogen atom	formed by a condensation reaction of a carboxylic acid and an alcohol, called esterification

Evaluation

47. (a) Answers may vary. Sample answer: Glucose molecules have five hydroxyl groups, glycerol molecules have three, and ethylene glycol molecules have only two, so glucose molecules are more polar than glycerol molecules, which are more polar than ethylene glycol molecules. The hydroxyl groups in the molecules of glucose, glycerol, and ethylene glycol are able to form hydrogen bonds with one another and with water. Therefore, the compounds in order of increasing melting points and boiling points are ethylene glycol, glycerol, glucose.

(b) Answers may vary. Sample answer: Since the hydroxyl groups in the molecules of glucose, glycerol, and ethylene glycol are able to form hydrogen bonds with one another and with water and since glucose has the most hydroxyl groups in its molecules, the compounds in order of increasing solubility in water are: ethylene glycol, glycerol, glucose. Gasoline is a non-polar solvent. Since like dissolves like, polar compounds dissolve in polar solvents (such as water), so the solubility of the three compounds glucose, glycerol, and ethylene glycol in gasoline should be poor. In order of increasing solubility, they would be glucose, glycerol, ethylene glycol.

(c) Answers may vary. Sample answer: A possible explanation for the toxicity of ethylene glycol is that it becomes converted into toxic metabolites when ingested. Due to its sweet taste, it is possible to mistake it for a non-poisonous substance and consume enough for its metabolites accumulate to toxic concentrations.

(d) Answers may vary. Sample answer: The structures of these three compounds seem to support the hypothesis because the compounds all taste sweet and have the same functional group—the hydroxyl group.

48. (a) Answers may vary. Sample answer: Artificial vanilla flavouring and vanilla extracted from a vanilla bean are not identical. Natural vanilla extract would also contain many other compounds that were present in the vanilla bean, while artificial vanilla flavouring is purified. Therefore artificial vanilla flavouring and vanilla extracted from a vanilla bean are not identical.

(b) Answers may vary. Sample answer: Food companies should be required to distinguish between a "natural" flavouring and an "artificial" flavouring on a food product label, because the ingredients in these products are different and they are prepared by different methods. People may have allergic reactions to certain chemicals involved, so they need to be informed of all the ingredients in a product.

(c) Answers may vary. Sample answer: A taste test with a survey could be used to determine whether people can tell the difference between synthetic vanilla and natural vanilla, and people's preference.

Reflect on Your Learning

49. Answers may vary. Students' answers should relate to their understanding of the organic compounds in this chapter, their properties, and their reactions.

50. Answers may vary. Students' answers should provide examples explaining the common errors when naming certain organic compounds. Sample answer: I find that it is easy to make an error in naming the alkyl groups in amines. The groups may be attached to the parent alkyl chain or the nitrogen atom. To avoid the naming error, I would draw the structure using the compound name to check if it is the same as the original structure to be named.

51. Answers may vary. Sample answer: I have difficulty understanding the structures and properties of fats and oils, and their chemistry. To improve my understanding, I could compare their functional groups with similar functional groups in compounds that I am more familiar with, I could use the Internet to research their structures and properties, and I could learn about some possible reactions in which these compounds are involved.
52. Answers may vary. Students' answers should include information from the chapter about organic entities and their reactions that affect everyday life. For example, a variety of organic entities are used as fuels, as lubricants, as solvents, and as flavouring agents. In these roles, they can affect our everyday lives, our health, society, and the environment.

Research
53. Answers may vary. Students' answers should follow the guidelines to answer the different parts of the question in the format of their choice. Sample answer:
Acetylsalicylic acid (ASA) is an ester-containing compound. It is synthesized by the esterification between salicylic acid
(2-hydroxybenzoic acid, an acid that contains the –OH group) and acetic acid (ethanoic acid, a carboxylic acid). The acetic acid component is added to salicylic acid at its hydroxyl group by acetylation using acetic anhydride.
Willow bark contains salicin, a bitter-tasting compound. This compound is metabolized into salicylic acid inside the body and acts to relieve pain and inflammation. Salicylic acid could also be taken directly, but it still has an unpleasant taste and causes stomach irritation. Converting salicylic acid into acetylsalicylic acid in the laboratory results in a compound that is less irritating, an advantage over salicylic acid. The use of ASA eliminates some disadvantages of herbal medications. It is easy to synthesize, it provides the correct dose information and instruction, its use is regulated by governments, and its interactions with other drugs are known.
54. Answers may vary. Students' answers should be presented in the form of a poster or electronic slide show. The poster or electronic slide show should include at least five examples of compounds whose names indicate that they are organic compounds, the chemical structures of these compounds, how they are produced, and what their functions are in the products in which they are used. Sample answer: Five common organic compounds in foods or beverages are ethanol, sucrose (sugar), citric acid, starch, and lactic acid.
Ethanol is found in alcoholic beverages. It is an alcohol with the chemical formula CH_3CH_2OH. It is produced by the fermentation of sugar. Ethanol contributes to the smell and taste of alcoholic drinks. The characteristics of ethanol are due to the –OH group in the compound.
Sucrose is a disaccharide, a composition of the two monosaccharides glucose and fructose. It has the chemical formula $C_{12}H_{22}O_{11}$. Sucrose, best known as table sugar, is derived from plant sources. It is produced by extracting the juices from sugar canes or sugar beets. Sucrose is commonly added to sweeten foods.
Citric acid (2-hydroxypropane-1,2,3-tricarboxylic acid) is a carboxylic acid containing three carboxyl groups, with the chemical formula $HO_2CCH_2C(OH)(CO_2H)CH_2CO_2H$. It shares the properties of other carboxylic acids, and makes foods and soft drinks taste sour. Oranges, lemons, and tomatoes are all foods that naturally contain citric acid. In its

production, cultures of *Aspergillus niger* are fed on sucrose to produce citric acid which is then purified.

Starch has the appearance of a white powder. The basic chemical formula of the starch molecule is $(C_6H_{10}O_5)_n$. Starch is a polysaccharide made up of glucose repeat units. Plants synthesize starch as a way to store glucose. Cereals, breads, potatoes, grains, peas, and beans all contain starch. In humans and other animals, starch is broken down into its constituent sugar molecules, which then supply energy to the tissues.

Lactic acid is a carboxylic acid with the chemical formula $CH_3CH(OH)COOH$. In industry, lactic acid fermentation is performed by lactic acid bacteria. Lactic acid is found in sour dairy products, such as yogurt and sour cream, and other fermented foods such as pickles and sauerkraut.

55. Answers may vary. Students' answers should follow the guidelines to answer the different parts of the question, and be presented in the form of an infomercial or poster. The presentation should include at least four of the organic compounds in gasoline. The following information may be included: Gasoline is largely a mixture of hydrocarbons with 4 to 12 carbon atoms in their molecules. Four organic compounds that are found in gasoline are heptane (n-heptane),
2-methylhexane(isoheptane), 2-methylheptane, and 2,2,4-trimethylpentane (isooctane).
The structural formulas of these compounds are:

heptane: $H_3C–CH_2–CH_2–CH_2–CH_2–CH_2–CH_3$

2-methylhexane: $H_3C–CH(CH_3)–CH_2–CH_2–CH_2–CH_3$

2-methylheptane: $(CH_3)_2CH(CH_2)_4CH_3$

2,2,4-trimethylpentane: $(CH_3)_3CCH_2CH(CH_3)_2$

The "octane rating" of gasoline is a measure of its ability to avoid engine knocking. The name comes from isooctane (2,2,4-trimethylpentane), an anti-knocking agent based on which the octane rating is measured. Engine knocking occurs when some of the fuel detonates rather than burning steadily, leading to noise and rattling. Different fuels have different octane ratings. For example, premium fuel has a higher octane rating than regular fuel. Different vehicles may require fuels with different ratings depending on their engine performance. Persistent knocking due to low-octane fuel usage may result in engine damage.

