Mastering Chemistry

- Book 3B
- Topic 8 Chemistry of Carbon Compounds

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Content

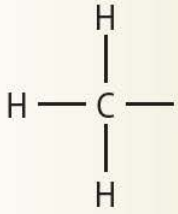
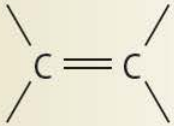
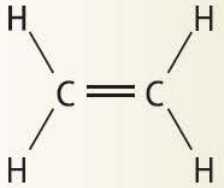
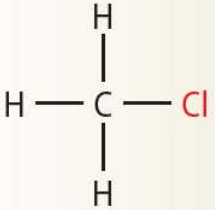
29.1 Functional groups and homologous series (p.2)

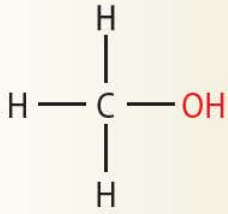
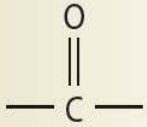
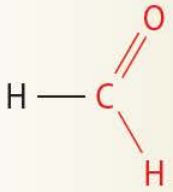
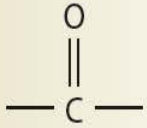
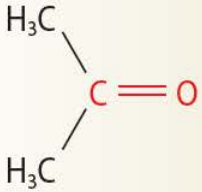
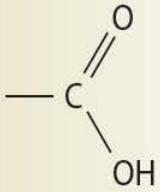
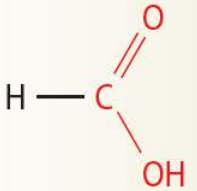
- A functional group is either a single atom or a group of atoms that determines most of the properties of a compound. For example, a carboxyl group gives a compound a sour, acidic taste.
- The family of compounds that has a common functional group, with successive members differing by a '–CH_2–' unit, is called a homologous series.

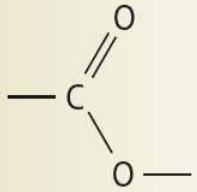
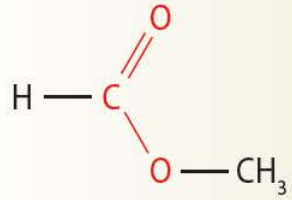
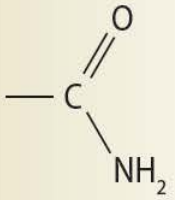
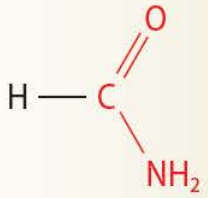
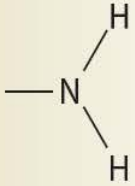
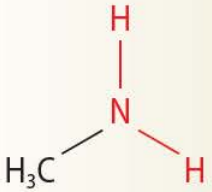
Building molecular models of compounds in different homologous series

29.1 Functional groups and homologous series (p.2)

Table 29.1 Functional groups and general formulae of selected homologous series

Functional group	Homologous series		First member
	General formula	Name	
None	C_nH_{2n+2}	alkanes	 methane
 Carbon-carbon double bond	C_nH_{2n}	alkenes	 ethene
–X where X is a halogen	RX	haloalkanes	 chloromethane

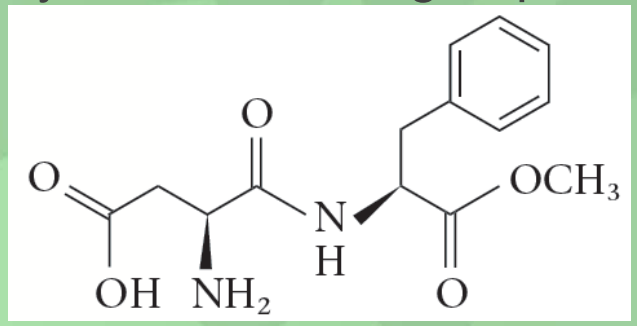
–OH Hydroxyl group	ROH	alcohols	 methanol
 Carbonyl group	(H or R)CHO	aldehydes	 methanal
 Carbonyl group	R_1COR_2	ketones	 propanone
 Carboxyl group	(H or R)COOH	carboxylic acids	 methanoic acid

 Ester group	$(H \text{ or } R_1)COOR_2$	esters	 methyl methanoate
 (unsubstituted amide) Amide functional group	$(H \text{ or } R)CONH_2$	amides	 methanamide
 (primary amine) Amine functional group	RNH_2	amines	 methanamine

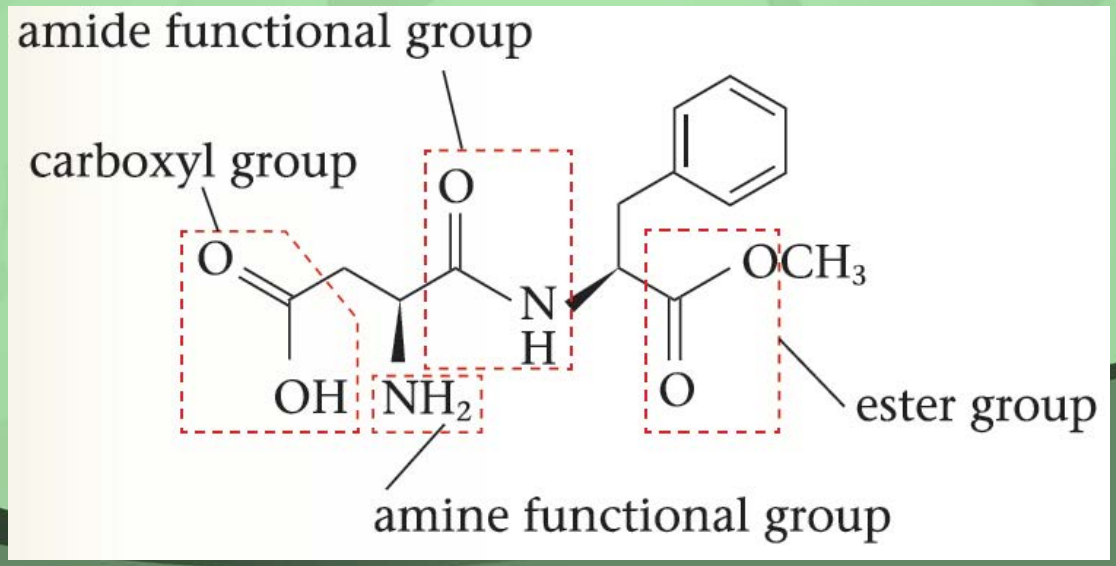
29.1 Functional groups and homologous series (p.2)

Q (Example 29.1)

Aspartame is used as an artificial sweetener. Identify the functional groups present in aspartame (besides the benzene ring).



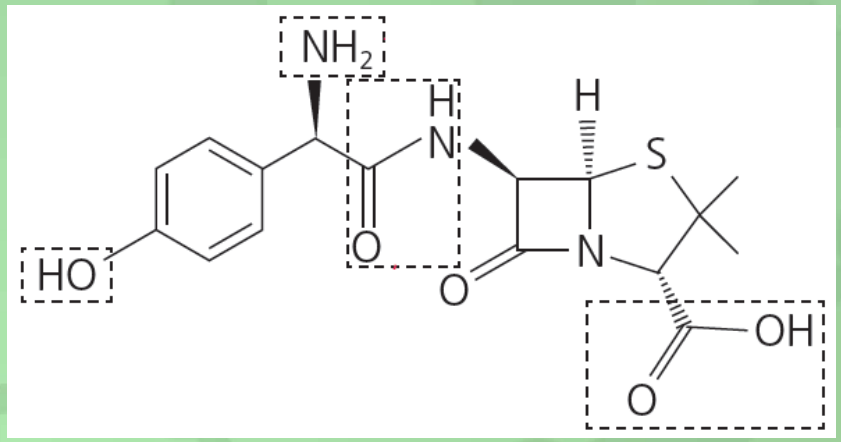
A



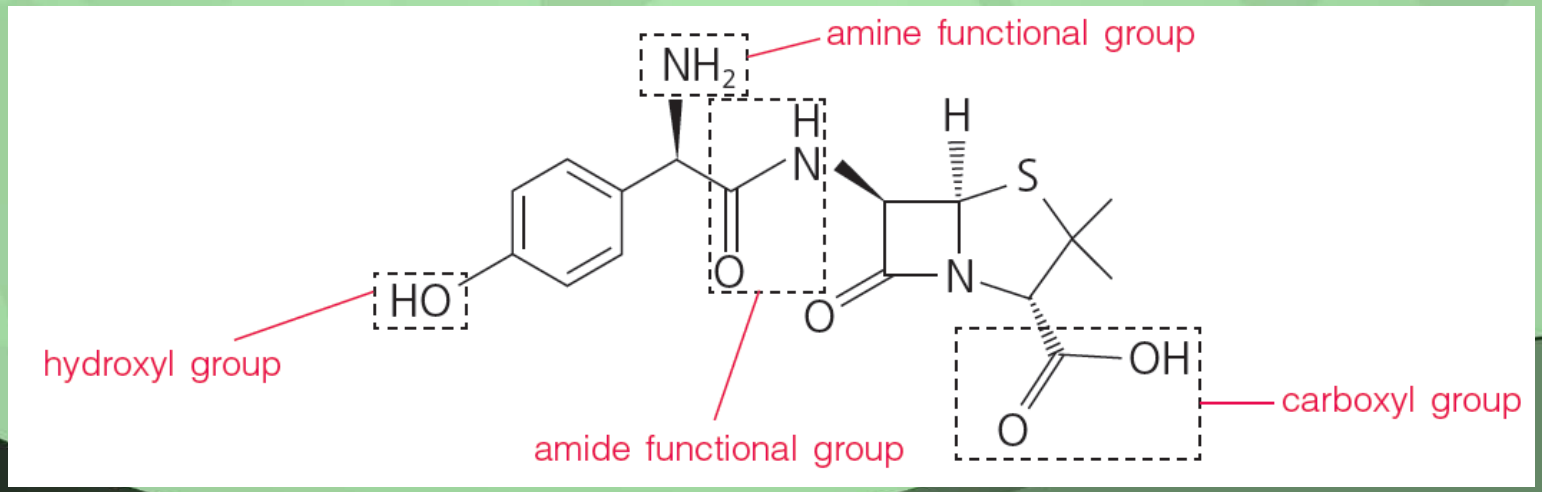
29.1 Functional groups and homologous series (p.2)

Practice 29.1

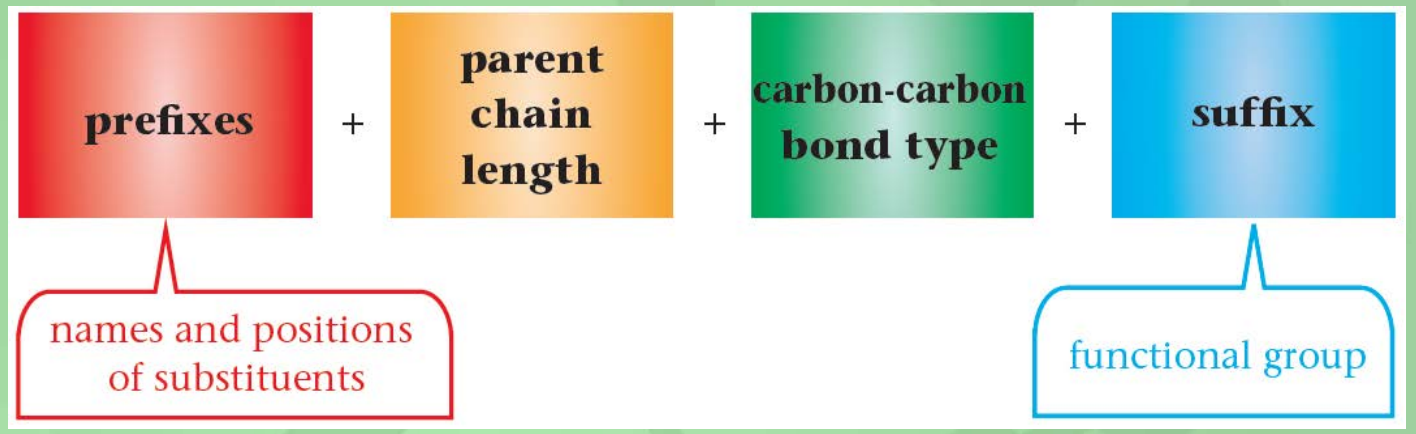
The structure of the antibiotic 'amoxicillin' is shown below:

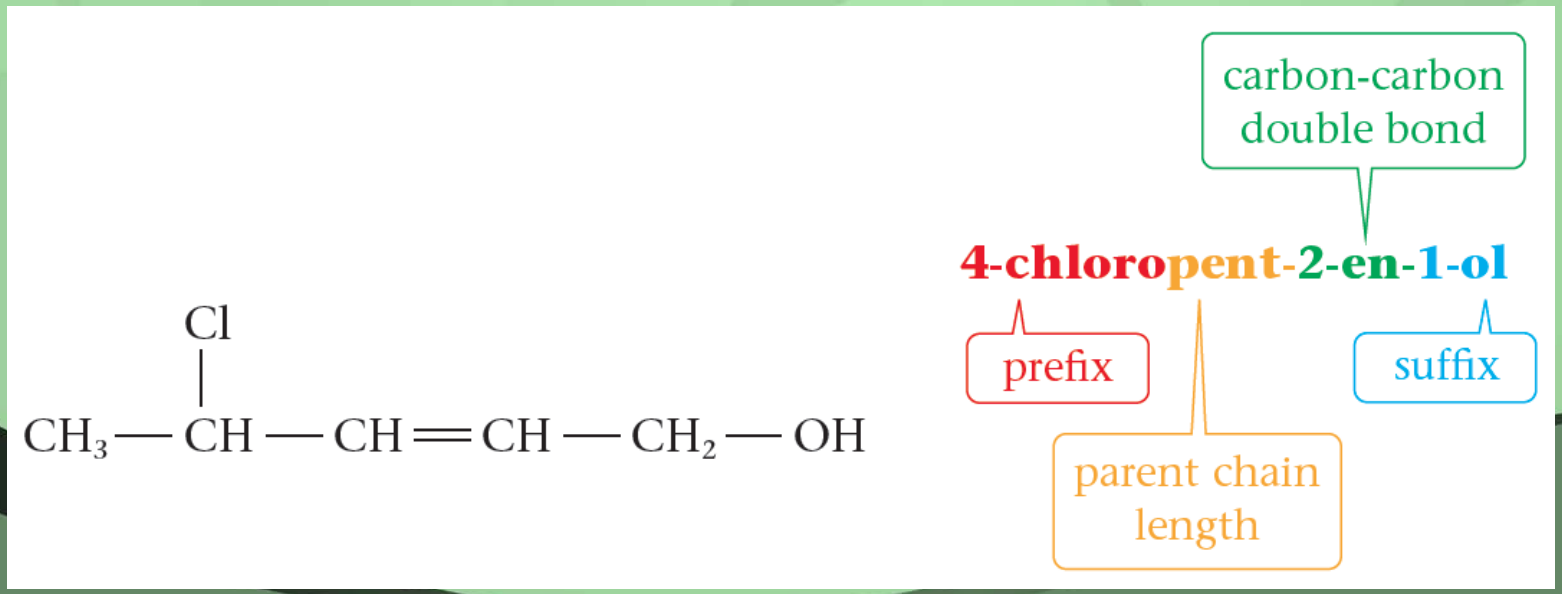


Name the functional groups highlighted.



29.2 Naming carbon compounds with functional group (p.5)





29.2 Naming carbon compounds with functional group (p.5)

Naming compounds with functional groups follows the same basic principles below as for naming alkanes:

1 Name the longest carbon chain. Identify the carbon-carbon bond type in the chain.

2 Identify any functional groups and any substituents, and select the appropriate prefixes or suffixes for them.

3 Add numbers to indicate the positions of functional groups, substituents and carbon-carbon multiple bonds, if any, on the parent chain as appropriate.

29.2 Naming carbon compounds with functional group (p.5)

Table 29.2 Prefixes and suffixes for naming selected homologous series

Homologous series	General formula	Prefix	Suffix
Alkenes	C_nH_{2n} (acyclic)	—	-ene
Haloalkanes	RX where X is a halogen	fluoro- chloro- bromo- iodo-	—
Alcohols	ROH	—	-ol
Aldehydes	(H or R)CHO	—	-al
Ketones	R_1COR_2	—	-one
Carboxylic acids	(H or R)COOH	—	-oic acid
Esters	(H or R_1)$COOR_2$	—	-oate
Unsubstituted amides	(H or R)$CONH_2$	—	-amide
Primary amines	RNH_2	—	-amine

29.3 Trends in physical properties within a homologous series (p.6)

- Members of a homologous series have the same functional group and thus have similar chemical properties.
- There is also gradual trends in their physical properties with increasing carbon chain length.

29.3 Trends in physical properties within a homologous series (p.6)

Boiling point

- Successive member of a homologous series increases by a $-CH_2-$ unit: longer molecule → stronger van der Waals' forces between molecules → increase in b.p.
- At r.t., lower members of a homologous series are generally gases or liquids, while the higher members are more likely to be solids.
- The functional group present influences the boiling point of a carbon compound as well.
  (e.g. functional groups capable of forming hydrogen bonds result in stronger forces between the molecules, giving rise to higher boiling points.)

29.3 Trends in physical properties within a homologous series (p.6)

Solubility in water

Largely determined by two opposing factors related to the two essential parts of a molecule of the compound — the functional group and the carbon skeleton.

- If the functional group present is able to interact with water, for example, by forming hydrogen bonds, this will favour the solubility of the compound in water.
- The carbon skeleton of a molecule is non-polar, and so does not help the solubility of the compound in water. In general, the solubility of carbon compounds decreases with increasing carbon chain length.

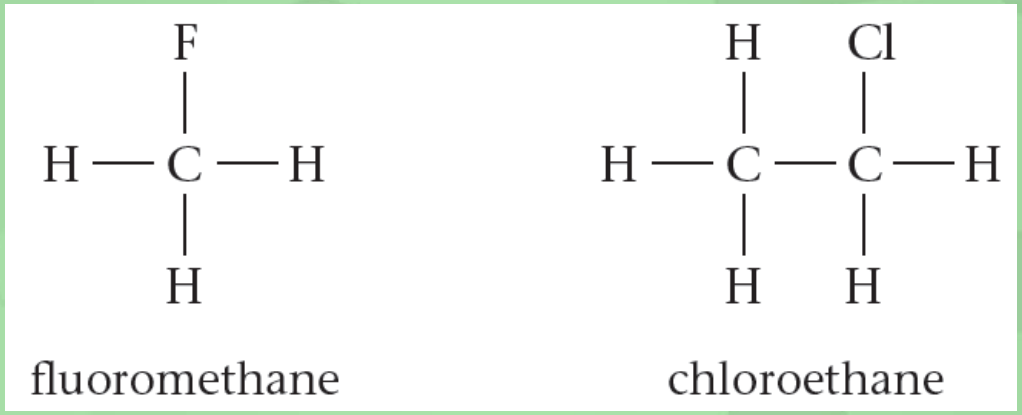
29.3 Trends in physical properties within a homologous series (p.6)

The physical properties (e.g. the boiling point and water solubility) of a carbon compound are affected by

- **the functional group it contains;**
- **the length of the carbon chain in molecule.**

29.4 Haloalkanes (p.7)

- **Haloalkane (鹵烷)**—$C_nH_{2n+1}X$ (where X = F, Cl, B or I)
  one or more of the hydrogen atoms in an alkane molecule is / are replaced by halogen atom(s).

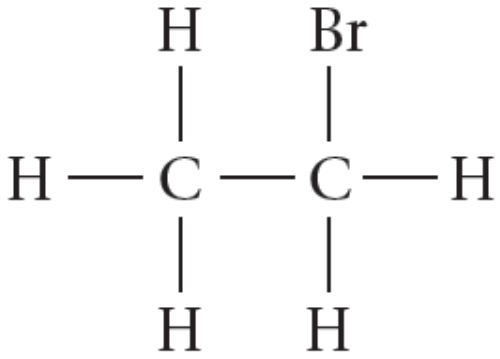


29.4 Haloalkanes (p.7)

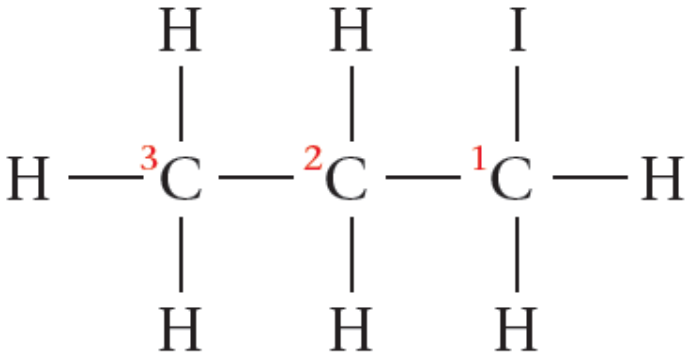
Naming haloalkanes

1 Add the prefix fluoro-, chloro-, bromo- or iodo-.

2 Use lowest number(s) to show the location(s) of the halogens.



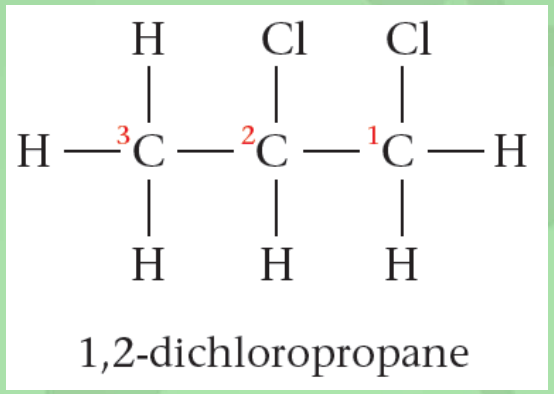
bromoethane



1-iodopropane

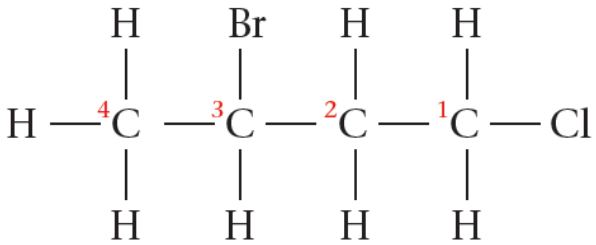
29.4 Haloalkanes (p.7)

3 Use the prefixes di-, tri-, and so on.
(di-, tri- and so on do not count in deciding alphabetical order)



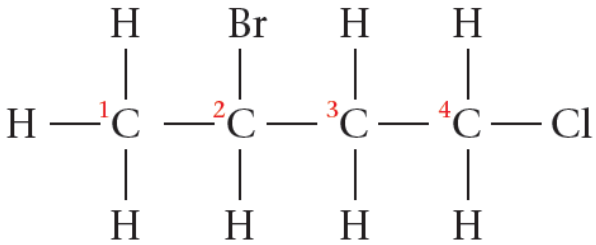
1,2-dichloropropane

4 List different halogens in alphabetical order with lowest numbers.



3-bromo-1-chlorobutane

✔

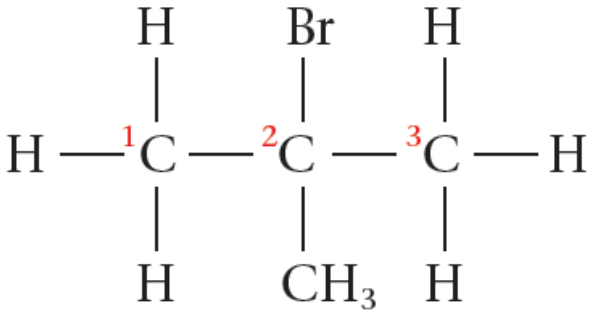


2-bromo-4-chlorobutane

✘

29.4 Haloalkanes (p.7)

5 List an halogen and an alkyl substituent in alphabetical order.



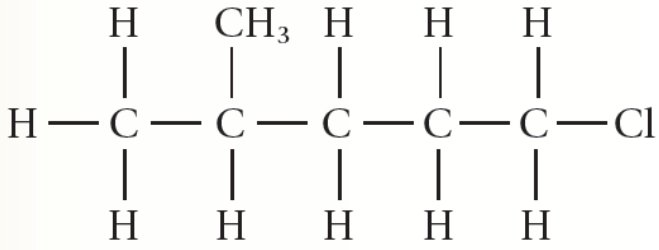
2-bromo-2-methylpropane

29.4 Haloalkanes (p.7)

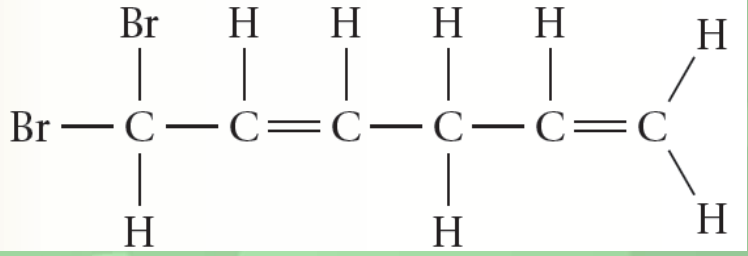
Q (Example 29.2)

Give the systematic names of the compounds shown below.

a)

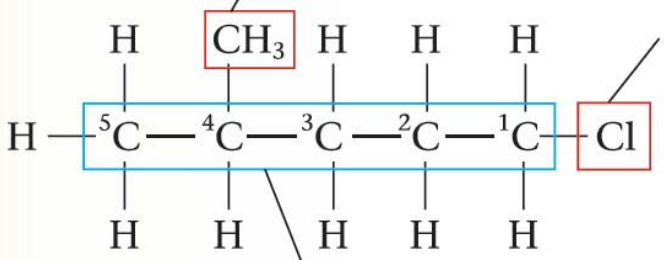


b)



A

a) one methyl group on carbon atom 4, i.e. 4-methyl



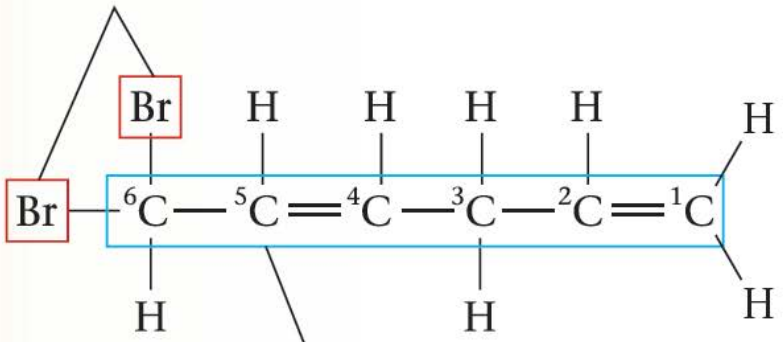
one chlorine atom on carbon atom 1, i.e. 1-chloro

parent chain contains 5 carbon atoms, i.e. pentane

Thus, the systematic name of this compound is 1-chloro-4-methylpentane.

29.4 Haloalkanes (p.7)

b) two bromine atoms on carbon atom 6, i.e. 6,6-dibromo



parent chain contains 6 carbon atoms,
with the double bonds between carbon atoms 1 and 2,
and carbon atoms 4 and 5, i.e. hexa-1,4-diene

Thus, the systematic name of this compound is 6,6-dibromohexa-1,4-diene.

29.4 Haloalkanes (p.7)

Q (Example 29.3)

Write the structural formula of the compound: 2-bromo-1,1-difluoropropane

A

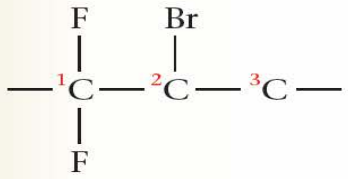
'2-bromo' indicates one bromine atom on carbon atom 2

'1,1-difluoro' indicates two fluorine atoms on carbon atom 1

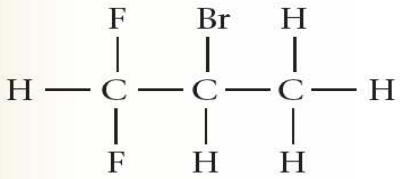
2-bromo-1,1-difluoropropane

'propane' indicates an alkane with 3 carbon atoms

Numbering this straight carbon chain from left to right establishes the locations of the halogen atoms.



Thus, the structural formula of 2-bromo-1,1-difluoropropane is:

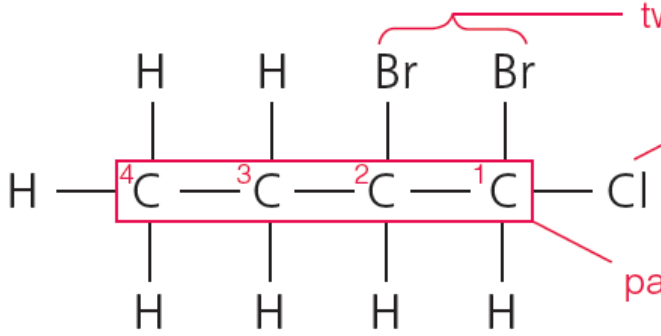


29.4 Haloalkanes (p.7)

Practice 29.2

1 Give the systematic names of the compounds below.

a)



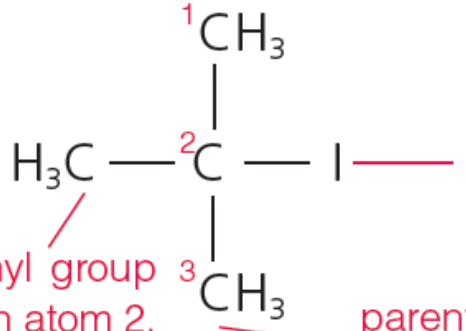
two bromine atoms on carbon atoms 1 and 2, i.e. 1,2-dibromo

one chlorine atom on carbon atom 1, i.e. 1-chloro

parent chain containing 4 carbon atoms, i.e. butane

Thus, the systematic name of this compound is 1,2-dibromo-1-chlorobutane.

b)



one iodine atom on carbon atom 2, i.e. 2-iodo

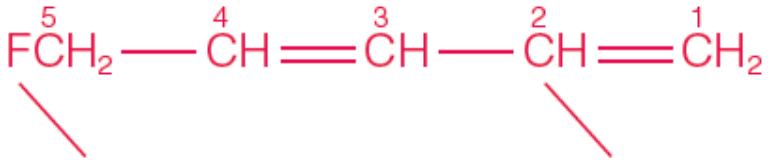
one methyl group on carbon atom 2, i.e. 2-methyl

parent chain containing 3 carbon atoms, i.e. propane

Thus, the systematic name of this compound is 2-iodo-2-methylpropane.

29.4 Haloalkanes (p.7)

c) $FCH_2-CH=CH-CH=CH_2$

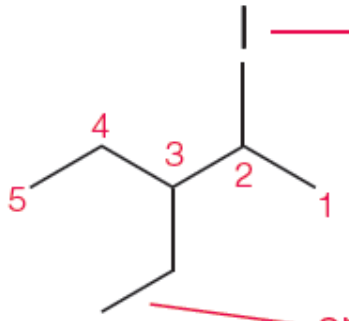


one fluorine atom on carbon atom 5, i.e. 5-fluoro

parent chain containing 5 carbon atoms, with the double bonds between carbon atoms 1 and 2 and carbon atoms 3 and 4, i.e. penta-1,3-diene

Thus, the systematic name of the compound is 5-fluoropenta-1,3-diene.

d)



one iodine atom on carbon atom 2, i.e. 2-iodo

parent chain containing 5 carbon atoms, i.e. pentane

one ethyl group on carbon atom 3, i.e. 3-ethyl

Thus, the systematic name of this compound is 3-ethyl-2-iodopentane.

29.4 Haloalkanes (p.7)

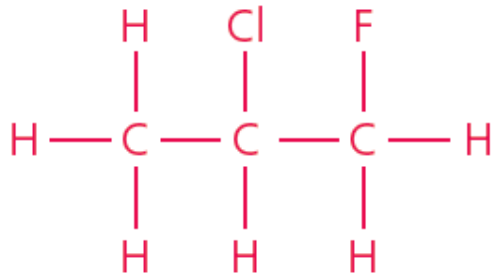
2 Write the structural formulae of the compounds below.

a) 2-chloro-1-fluoropropane

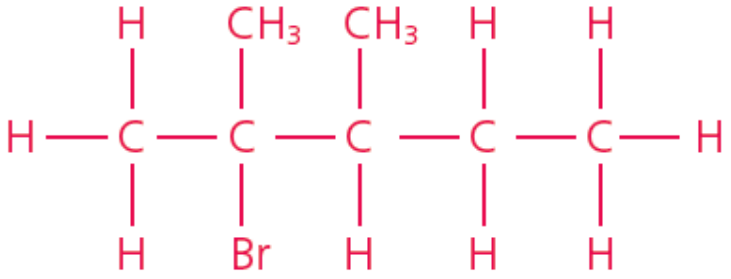
b) 2-bromo-2,3-dimethylpentane

c) 2-chlorobut-2-ene

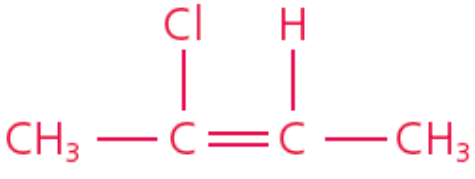
a)



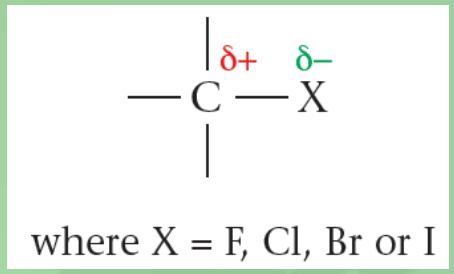
b)



c)



29.4 Haloalkanes (p.7)



where X = F, Cl, Br or I

Physical properties of haloalkanes

Boiling point

- The carbon-halogen bond in a haloalkane is polar.
- The main intermolecular forces in haloalkanes are van der Waals' forces.
  - b.p. increases with the carbon chain length;
  - b.p. rises from each chloroalkane to the corresponding iodoalkane.
- The larger the size of a molecule, the stronger are the van der Waals' forces between molecules. More heat is needed to separate the molecules during boiling.

29.4 Haloalkanes (p.7)

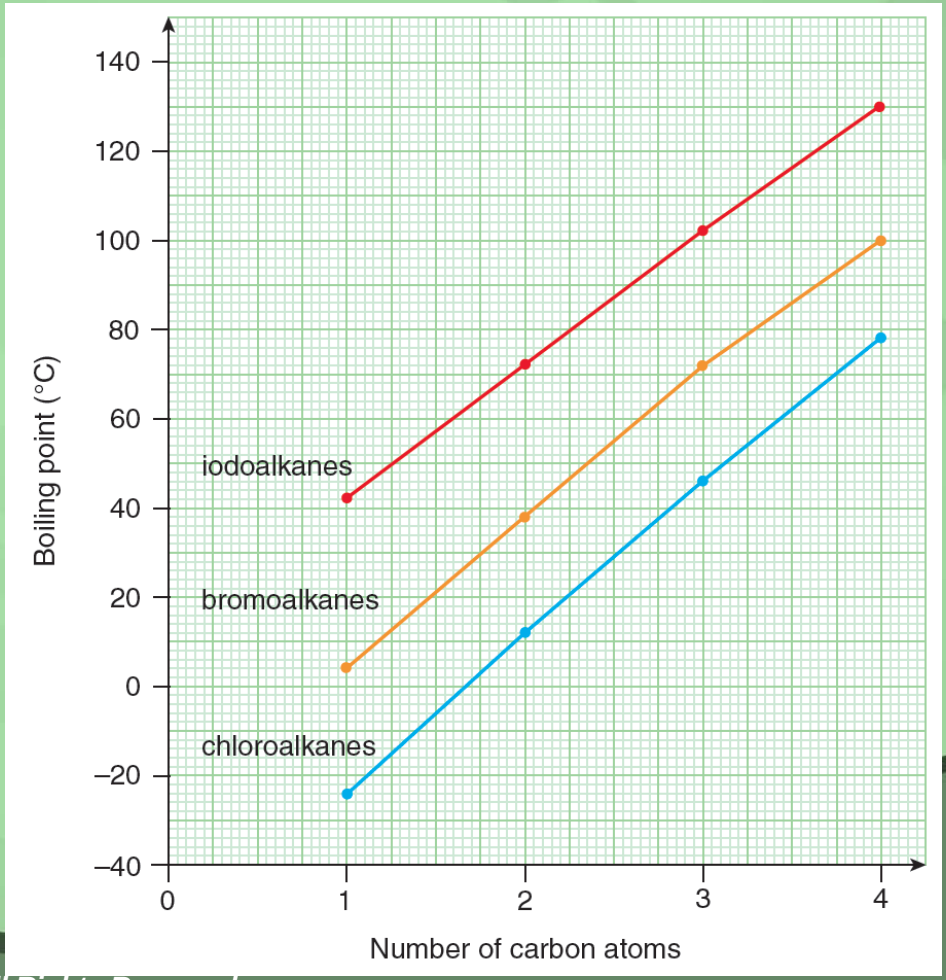
Table 29.3 Boiling points of some haloalkanes

Chloroalkane	Boiling point (°C)	Bromoalkane	Boiling point (°C)	Iodoalkane	Boiling point (°C)
Chloromethane CH_3Cl	−24	bromomethane CH_3Br	4	iodomethane CH_3I	43
Chloroethane CH_3CH_2Cl	13	bromoethane CH_3CH_2Br	38	iodoethane CH_3CH_2I	72
1-chloropropane $CH_3CH_2CH_2Cl$	47	1-bromopropane $CH_3CH_2CH_2Br$	71	1-iodopropane $CH_3CH_2CH_2I$	102
1-chlorobutane $CH_3CH_2CH_2CH_2Cl$	79	1-bromobutane $CH_3CH_2CH_2CH_2Br$	101	1-iodobutane $CH_3CH_2CH_2CH_2I$	130

boiling point increasing

29.4 Haloalkanes (p.7)

- The boiling points of chloroalkanes, bromoalkanes and iodoalkanes increase with the number of carbon atoms in their molecules.



29.4 Haloalkanes (p.7)

- Chloromethane, bromomethane and chloroethane are gases at room temperature, but most other haloalkanes are colourless liquids.
- Their boiling points are higher than that of the parent alkanes because the polar carbon-halogen bond leads to stronger intermolecular forces.

29.4 Haloalkanes (p.7)

Solubility in water

- The polar haloalkane molecules can interact with water molecules. However, they cannot form hydrogen bonds with water molecules. Hence haloalkanes are only very slightly soluble in water.

29.5 Alcohols (p.14)

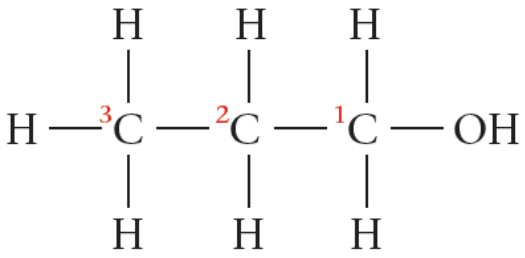
R — OH

where R = an alkyl or aryl group

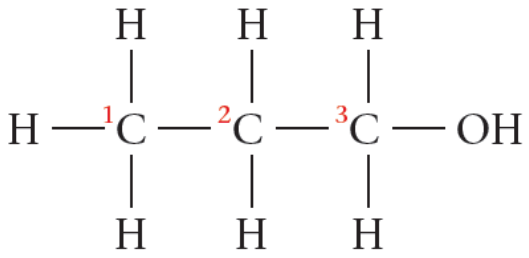
- **Acohols (醇)** are carbon compounds containing one or more **hydroxyl group(s) (–OH) (羥基)**.

Naming haloalkanes

- IUPAC rules name an alcohol by replacing the ‘e’ at the end of the name of the corresponding alkane with the suffix -ol.
- Use the lowest number to indicate the location of the –OH.



propan-1-ol ✔

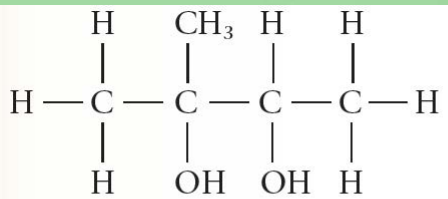


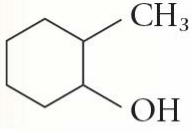
propan-3-ol ✘

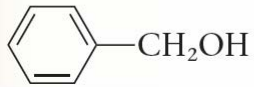
29.5 Alcohols (p.14)

Q (Example 29.4)

Give the systematic names of the compounds shown.

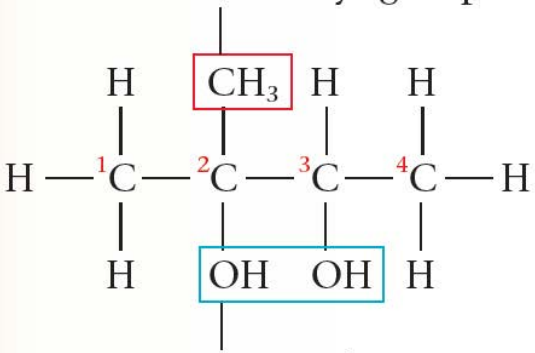
a)


b)


c)


A

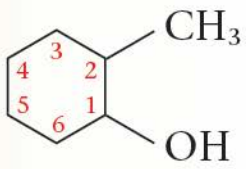
a) a methyl group on carbon atom 2, i.e. 2-methyl



parent chain containing 4 carbon atoms, and two –OH groups on carbon atoms 2 and 3, i.e. butane-2,3-diol

Thus, the systematic name of the compound is 2-methylbutane-2,3-diol.

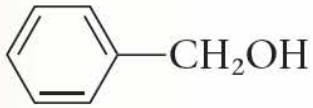
29.5 Alcohols (p.14)

b) 

This alcohol has a ring structure with 6 carbon atoms, so it is a cyclohexanol.

There is a methyl group on carbon atom 2.

Thus, the systematic name of the compound is 2-methylcyclohexanol.

c) 

This alcohol is derived from methanol with one of the hydrogen atoms replaced by a phenyl group.

When a $-C_6H_5$ group is attached to an alkyl chain with a functional group, the prefix 'phenyl' is used in the name.

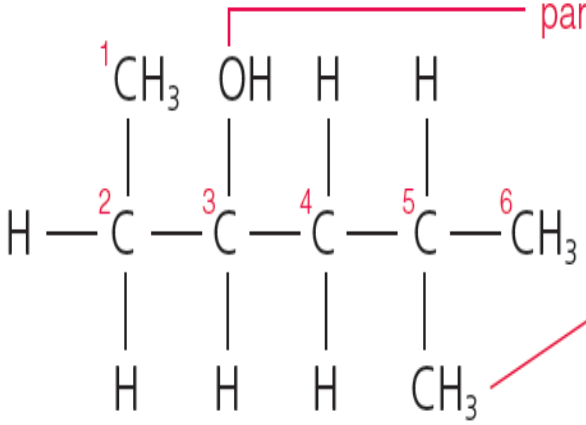
Thus, the systematic name of the compound is phenylmethanol.

29.5 Alcohols (p.14)

Practice 29.3

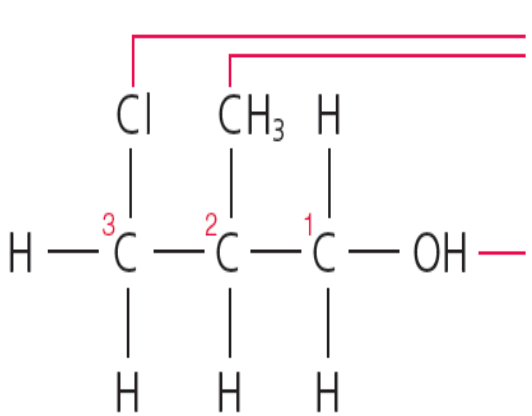
1 Give the systematic names of the compounds below.

a)



Thus, the systematic name of the compound is 5-methylhexan-3-ol.

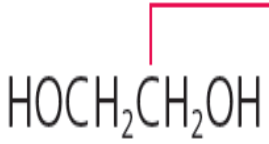
b)



Thus, the systematic name of the compound is 3-chloro-2-methylpropan-1-ol.

29.5 Alcohols (p.14)

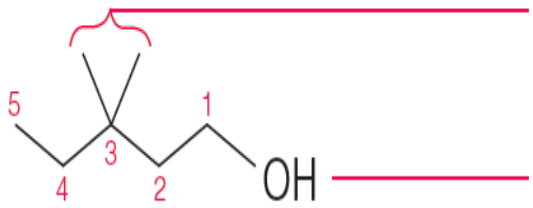
c)



parent chain containing 2 carbon atoms, and two –OH groups on carbon atoms 1 and 2

Thus, the systematic name of the compound is ethane-1,2-diol.

d)



two methyl groups on carbon atom 3, i.e. 3,3-dimethyl

parent chain containing 5 carbon atoms, with a –OH group on carbon atom 1, i.e. pentan-1-ol

Thus, the systematic name of the compound is 3,3-dimethylpentan-1-ol.

29.5 Alcohols (p.14)

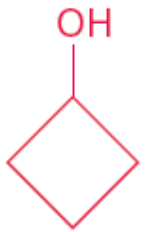
2 Write the structural formulae of the compounds below.

a) Cyclobutanol

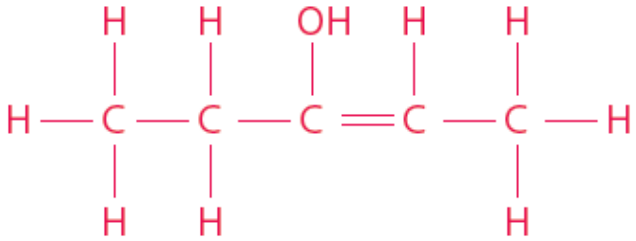
b) Pent-2-en-3-ol

c) 4-phenylbutan-1-ol

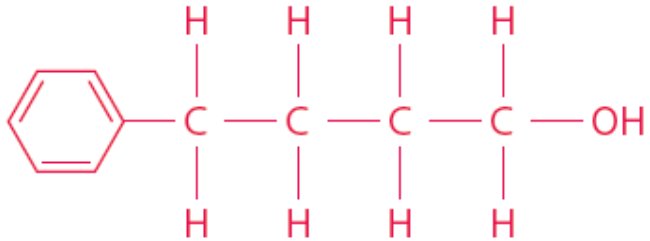
a)



b)



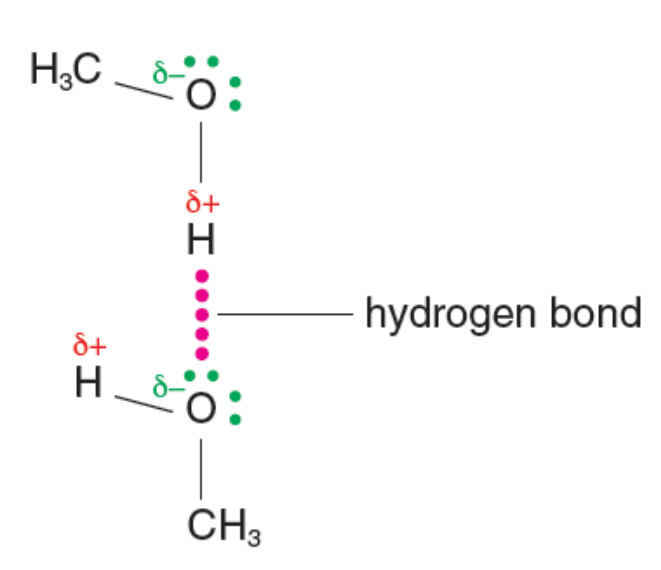
c)

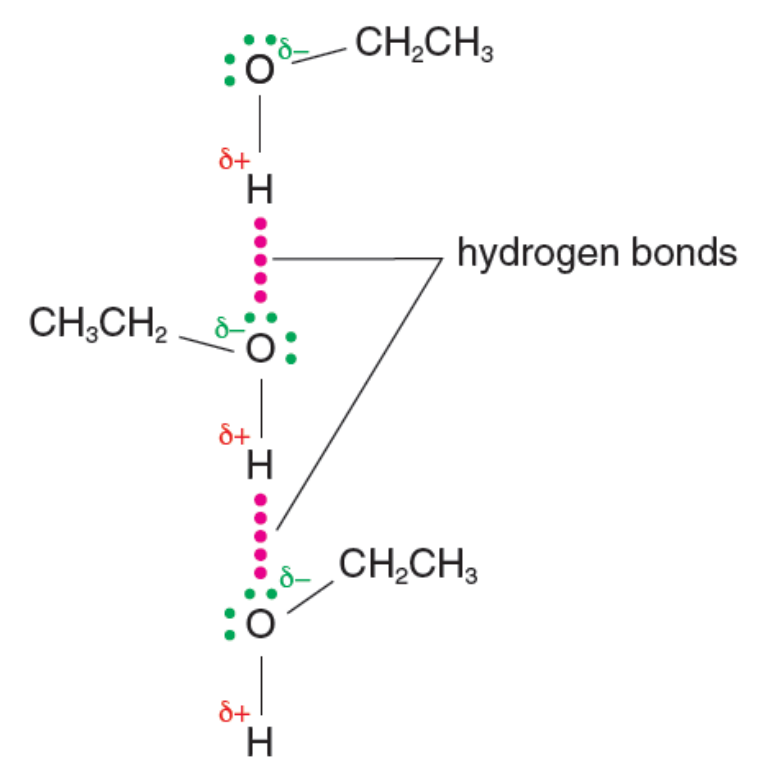


29.5 Alcohols (p.14)

Boiling point

- There are two types of intermolecular forces operating between alcohol molecules — hydrogen bonds and van der Waals' forces.





29.5 Alcohols (p.14)

- –OH group for hydrogen bonding;
- b.p. increases with carbon chain length (stronger van der Waals' forces between longer molecules)

Table 29.4 Boiling points of five straight-chain alcohols

Alcohol	Condensed structural formula	Boiling point (°C)
Methanol	CH_3OH	65
Ethanol	CH_3CH_2OH	78
Propan-1-ol	$CH_3CH_2CH_2OH$	97
Butan-1-ol	$CH_3CH_2CH_2CH_2OH$	118
Pentan-1-ol	$CH_3CH_2CH_2CH_2CH_2OH$	138

boiling point increasing

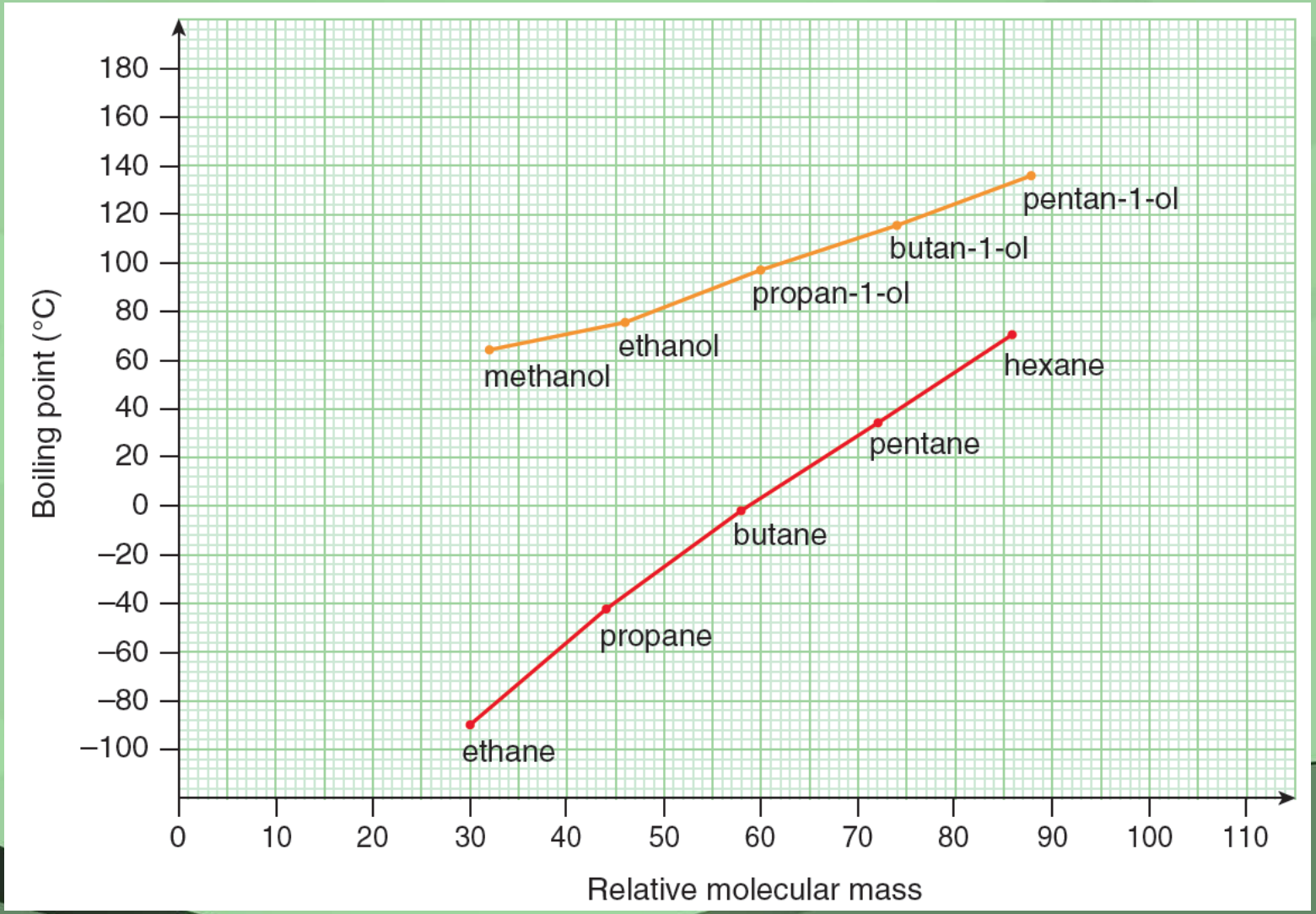
29.5 Alcohols (p.14)

- methane and ethane: gases at room temperature
  methanol and ethanol: liquids at room temperature
- b.p. of alcohol > b.p. of alkane of a similar molecular size
- since hydrogen bonding between –OH groups in an alcohol is much stronger than the van der Waals' forces in an alkane

Table 29.5 Boiling points of alcohols and alkanes of similar relative molecular masses

Straight-chain alcohol			Straight-chain alkane		
Formula	Relative molecular mass	Boiling point (°C)	Formula	Relative molecular mass	Boiling point (°C)
CH_3OH	32	65	C_2H_6	30	–89
C_2H_5OH	46	78	C_3H_8	44	–42
C_3H_7OH	60	97	C_4H_{10}	58	–0.5
C_4H_9OH	74	118	C_5H_{12}	72	36
$C_5H_{11}OH$	88	138	C_6H_{14}	86	69

29.5 Alcohols (p.14)



29.5 Alcohols (p.14)

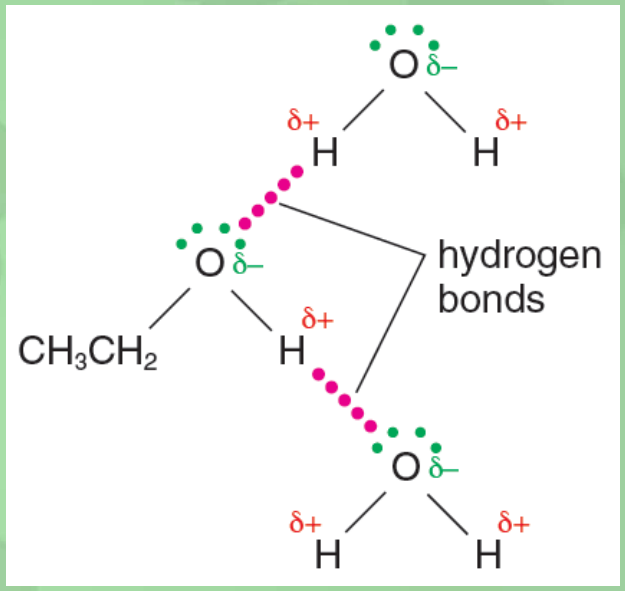
Water solubility

Table 29.6 Water solubilities of some alcohols

Alcohol	Condensed structural formula	Solubility (g per 100 g of water)
Methanol	CH_3OH	infinite
Ethanol	CH_3CH_2OH	infinite
Propan-1-ol	$CH_3CH_2CH_2OH$	infinite
Butan-1-ol	$CH_3CH_2CH_2CH_2OH$	7.9
Pentan-1-ol	$CH_3CH_2CH_2CH_2CH_2OH$	2.3

29.5 Alcohols (p.14)

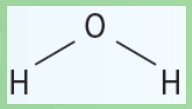
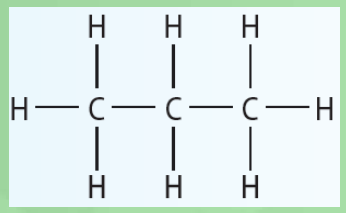
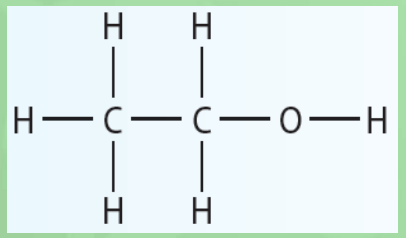
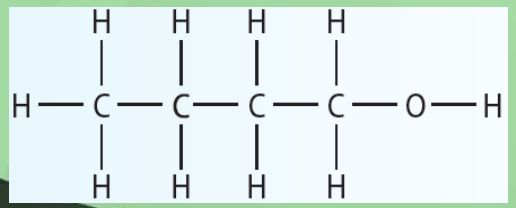
- Lower members: all miscible with water in all proportions
- Due to the hydrogen bonding between alcohol molecules and water molecules
- Alcohols dissolve in water to form neutral solutions.
- As the carbon chain length increases,
  - the molecule becomes longer;
  - the influence of the –OH group becomes less important;
  - the water solubility of longer chain alcohols become more like that of the corresponding alkanes;
  - solubility decreases.



29.5 Alcohols (p.14)

Practice 29.4

The table below shows the boiling points and relative molecular masses of four substances.

Substance		Boiling point	Relative molecular mass
Water		100	18.0
Propane		–42	44.0
Ethanol		78	46.0
Butan-1-ol		118	74.0

29.5 Alcohols (p.14)

Use ideas about intermolecular forces to explain why

a) ethanol has a higher boiling point than propane;

The hydrogen bonding between –OH groups in ethanol is much stronger than the van der Waals' forces in propane.

As a result, ethanol has a higher boiling point than propane.

b) water has a higher boiling point than ethanol;

A water molecule has two lone pairs of electrons on the oxygen atom together with two hydrogen atoms.

This means that it can form two hydrogen bonds per molecule on average whereas ethanol can only form one hydrogen bond per molecule.

This means that the hydrogen bonding in water is more extensive.

As a result, water has a higher boiling point than ethanol.

c) butan-1-ol has a higher boiling point than ethanol.

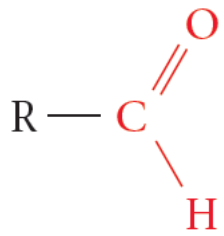
Both butan-1-ol and ethanol have one –OH group for hydrogen bonding. Hydrogen bonds in the two alcohols are of comparable strengths.

The carbon chain length of butan-1-ol is longer than that of ethanol. Van der Waals' forces between longer molecules are stronger.

As a result, butan-1-ol has a higher boiling point than ethanol.

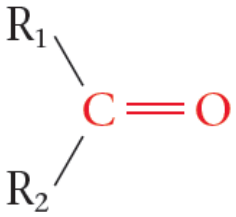
29.6 Aldehydes and ketones (p.21)

- **Aldehydes (醛)**, RCHO

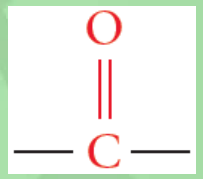


where R = an alkyl or aryl group or H

Ketones (酮), R_1COR_2



where R_1 and R_2 = alkyl or aryl groups

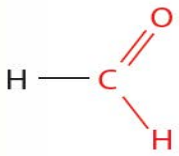
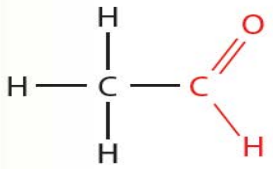
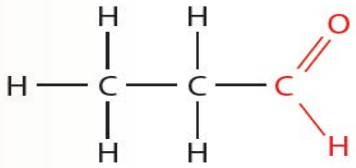
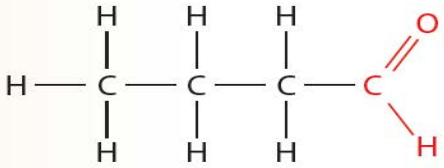
- contain the **carbonyl group (羰基)** ().

- Aldehydes and ketones are structurally quite similar. However, their properties differ considerably and they are considered two different homologous series.

29.6 Aldehydes and ketones (p.21)

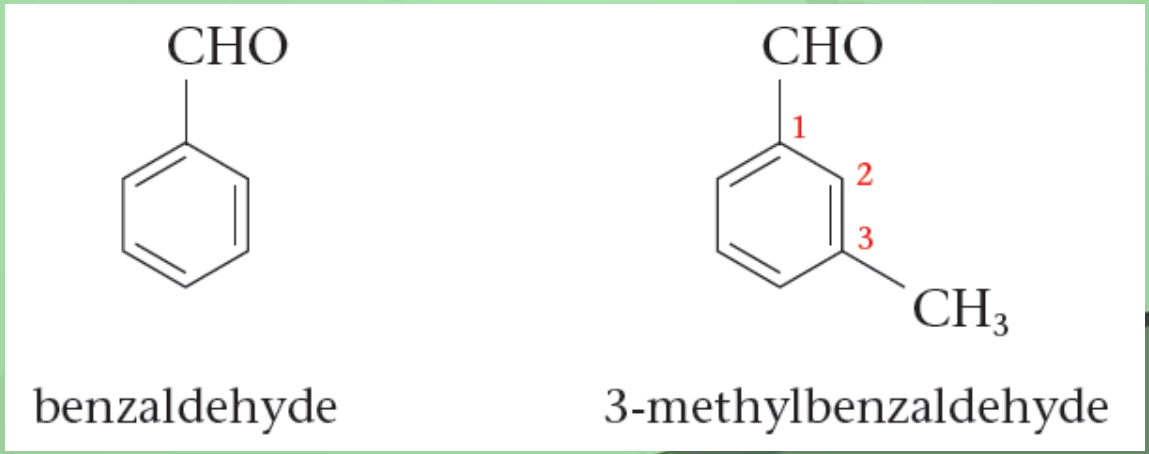
Naming aldehydes

- Replace the ‘e’ in the name of the corresponding alkane with the suffix -al.

Name	Structural formula	Condensed structural formula
Methanal		$HCHO$
Ethanal		CH_3CHO
Propanal		CH_3CH_2CHO
Butanal		$CH_3CH_2CH_2CHO$

29.6 Aldehydes and ketones (p.21)

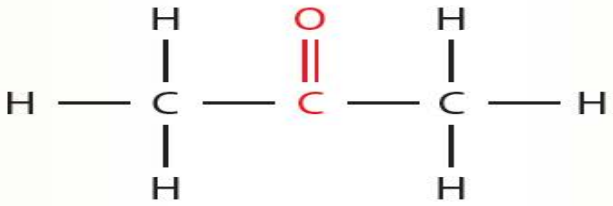
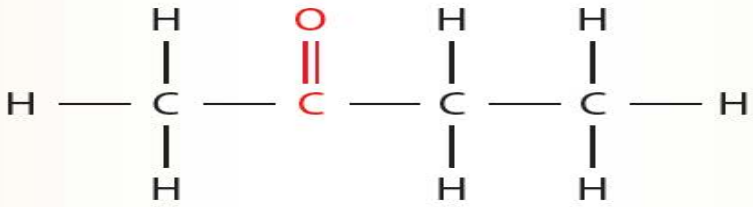
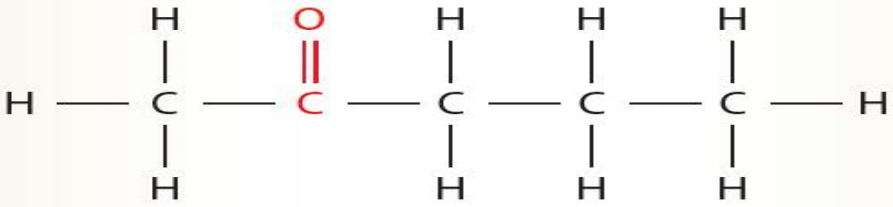
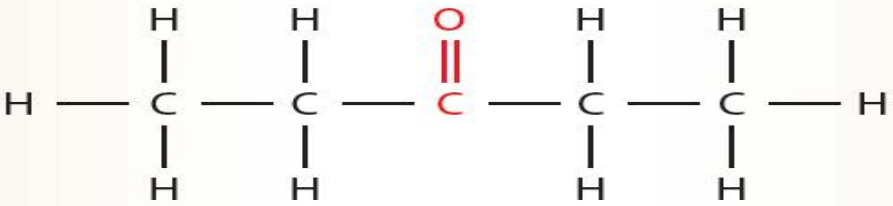
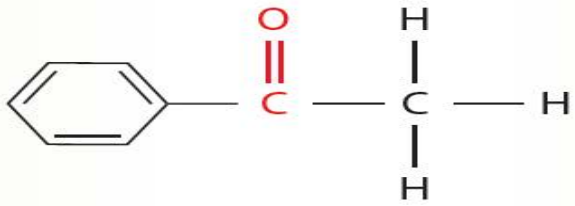
- Aldehydes do not need a positional number for the location of the carbonyl group as it is always at the end of the carbon chain and this is carbon number one, if there are other substituents on the chain.
- Aldehydes with the –CHO group directly attached to a benzene ring are called benzaldehydes. The carbon attached to this group is assigned number 1.



29.6 Aldehydes and ketones (p.21)

Naming ketones

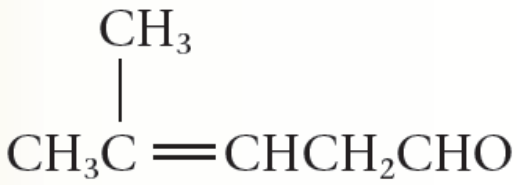
- Replace the ‘e’ in the name of the corresponding alkane with the suffix -one.
- Give the carbonyl group the lowest number.
  e.g. pentan-2-one

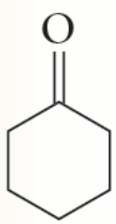
Ketone	Structural formula	Condensed structural formula
Propanone		CH_3COCH_3
Butanone		$CH_3COCH_2CH_3$
Pentan-2-one		$CH_3COCH_2CH_2CH_3$
Pent-3-one		$CH_3CH_2COCH_2CH_3$
Phenylethanone		$C_6H_5COCH_3$

29.6 Aldehydes and ketones (p.21)

Q (Example 29.5)

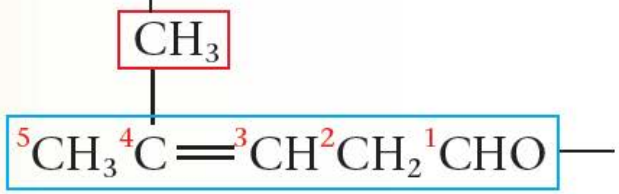
Give the systematic names of the compounds shown below.

a) 

b) 

A

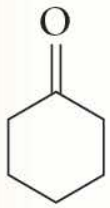
a) a methyl group on carbon atom 4, i.e. 4-methyl



an aldehyde containing 5 carbon atoms, with the C=C bond between carbon atoms 3 and 4, i.e. pent-3-enal

Thus, the systematic name of this compound is 4-methylpent-3-enal.

29.6 Aldehydes and ketones (p.21)

b) 

Name this compound by replacing the 'e' at the end of the name of cyclohexane with the suffix -one.

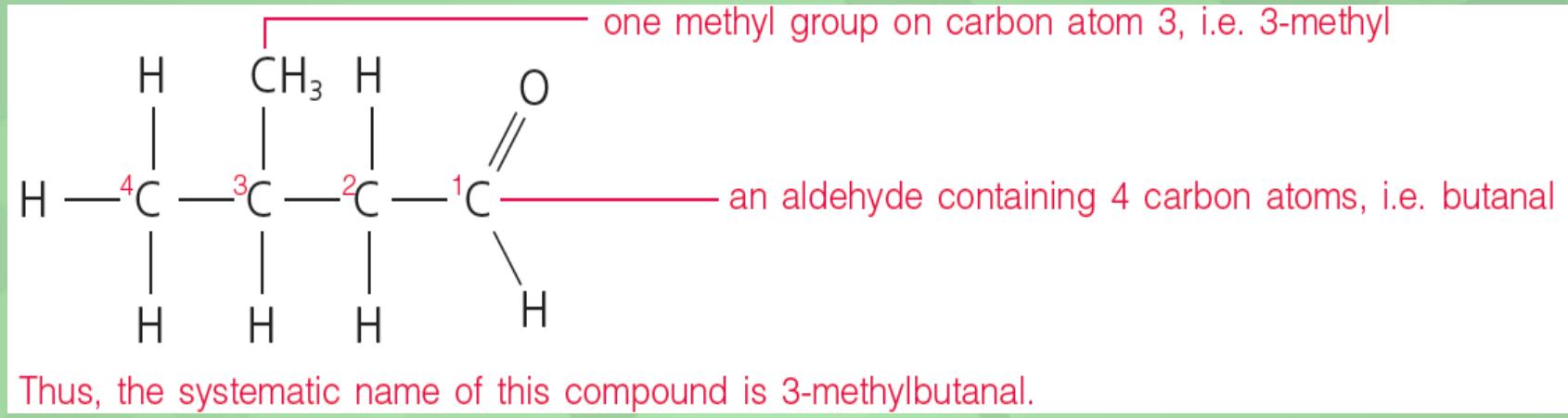
Thus, the systematic name of the compound is cyclohexanone.

29.6 Aldehydes and ketones (p.21)

Practice 29.5

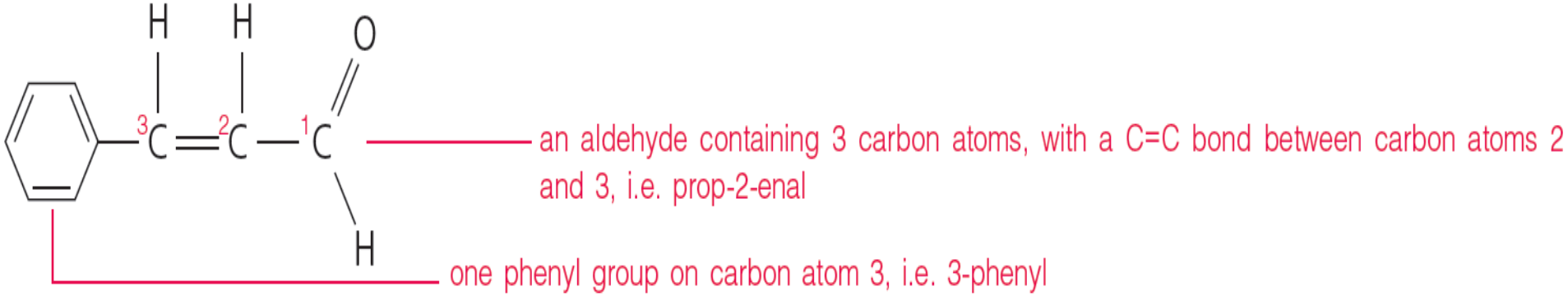
1 Give the systematic names of the compounds below.

a)



Thus, the systematic name of this compound is 3-methylbutanal.

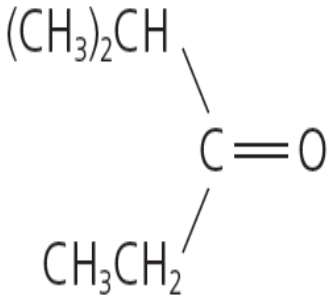
b)



Thus, the systematic name of the compound is 3-phenylpropan-2-enal.

29.6 Aldehydes and ketones (p.21)

c)



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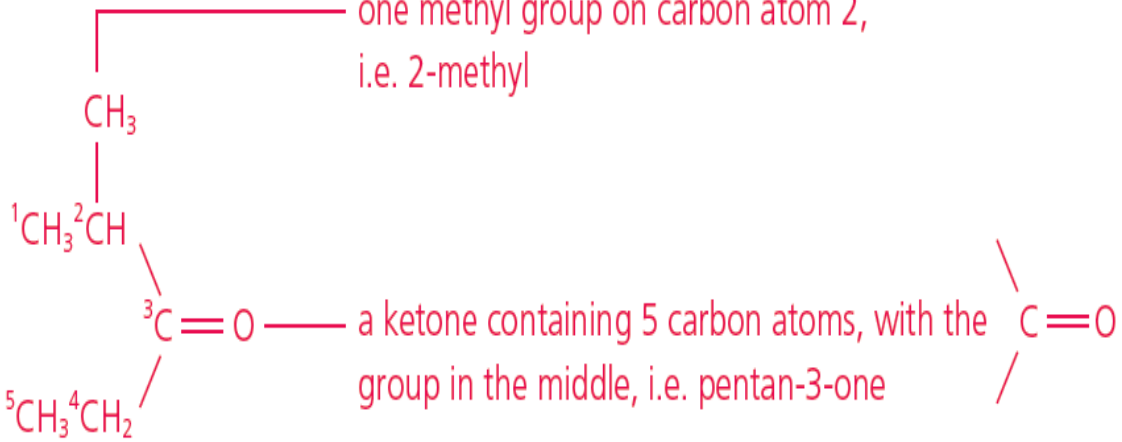
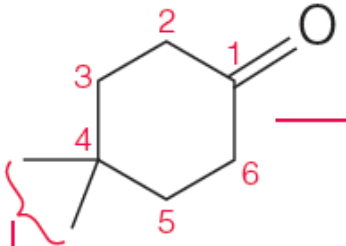


d)



a cyclic ketone containing 6 carbon atoms, i.e. cyclohexanone

two methyl groups on carbon atom 4, i.e. 4,4,-dimethyl

Thus, the systematic name of the compound is 4,4-dimethylcyclohexanone.

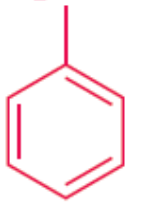
29.6 Aldehydes and ketones (p.21)

2) Write the structural formulae of the compounds below.

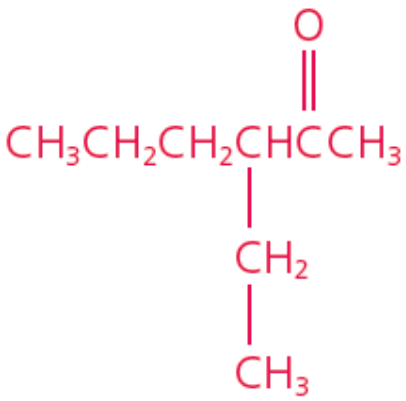
a) 2-phenylbutanal

b) 3-ethylhexan-2-one

a) CH_3CH_2CHCHO



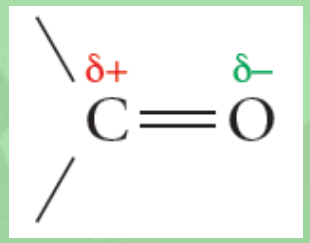
b)



29.6 Aldehydes and ketones (p.21)

Physical properties of aldehydes and ketones

- Oxygen is more electronegative than carbon, making the carbonyl group polar.



- Aldehydes have distinctive smells.
  - Those with short carbon chains have unpleasant smells (butanal smells of rancid butter).
  - Some of those with long carbon chains have very pleasant smells and are used in expensive perfumes (nonanal, with nine carbon atoms per molecule, smells like roses).

29.6 Aldehydes and ketones (p.21)

- The smells of the lower ketones, especially propanone, remind most people of solvents. In fact, propanone is widely used as a solvent, including *nail varnish remover*.

29.6 Aldehydes and ketones (p.21)

Boiling point

- Aldehydes and ketones have only van der Waals' forces (no hydrogen bonding) between their molecules.
- As the length of carbon chain increases, the boiling point of an aldehyde increases.
  - The larger a molecule, the greater is the number of electrons, and hence the stronger are the van der Waals' forces between the molecules.
- The boiling points of the ketones increase similarly.

29.6 Aldehydes and ketones (p.21)

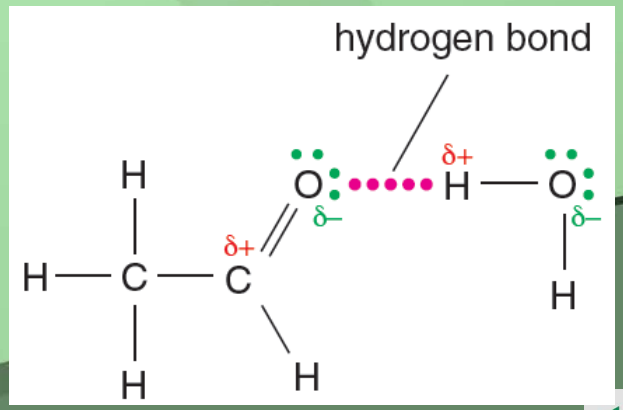
Table 29.9 Boiling points of some aldehydes and ketones

Name	Formula	Boiling point (°C)	
Aldehyde			boiling point increasing ↓
Methanal	$HCHO$	−21	
Ethanal	CH_3CHO	21	
Propanal	CH_3CH_2CHO	49	
Butanal	$CH_3CH_2CH_2CHO$	76	
Pentanal	$CH_3CH_2CH_2CH_2CHO$	102	
Ketone			boiling point increasing ↓
Propanone	CH_3COCH_3	56	
Butanone	$CH_3COCH_2CH_3$	80	
Pentan-2-one	$CH_3COCH_2CH_2CH_3$	102	
Pentan-3-one	$CH_3CH_2COCH_2CH_3$	102	

29.6 Aldehydes and ketones (p.21)

Solubility in water

- Short chain aldehydes and ketone — such as methanal, ethanal and propanone — are miscible with water in all proportions.
- This solubility is due to hydrogen bonding between the lone pair of electrons on the δ– oxygen atom in the carbonyl group and the δ+ hydrogen atom in a water molecule.
- The water solubility of aldehydes and ketones decrease with increasing carbon chain length.

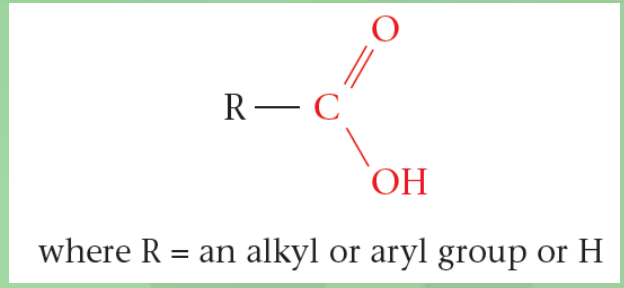


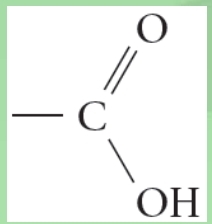
29.6 Aldehydes and ketones (p.21)

Table 29.10 Water solubilities of some aldehydes and ketones

Name	Formula	Solubility (g per 100 g of water)
Aldehyde		
Methanal	$HCHO$	infinite
Ethanal	CH_3CHO	infinite
Propanal	CH_3CH_2CHO	31
Butanal	$CH_3CH_2CH_2CHO$	7.1
Pentanal	$CH_3CH_2CH_2CH_2CHO$	1.2
Ketone		
Propanone	CH_3COCH_3	infinite
Butanone	$CH_3COCH_2CH_3$	22
Pentan-2-one	$CH_3COCH_2CH_2CH_3$	4.3
Pentan-3-one	$CH_3CH_2COCH_2CH_3$	5.0

29.7 Carboxylic acids (p.28)



- **Carboxylic acid (羧酸)**, RCOOH, contains the **carboxyl group (羧基)** ().

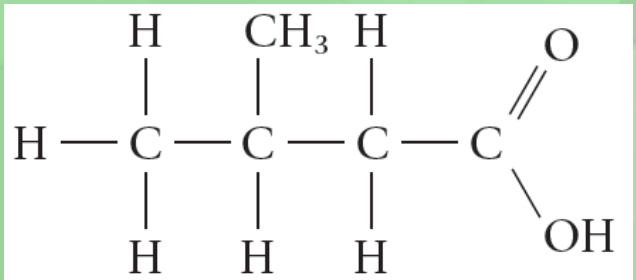
- Carboxylic acids are present in many foods. Ethanoic acid is responsible for the sharp taste of vinegar. Ethanedioic acid (HOOC–COOH) is found in the leaves of many plants including *rhubarb.*

The leaves of rhubarb are rich in ethanedioic acid

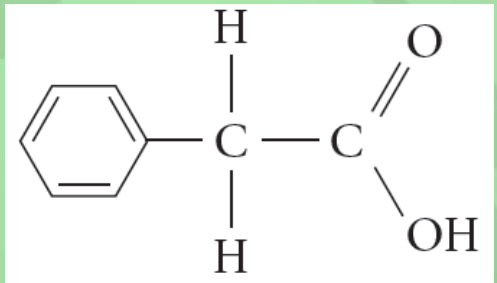
29.7 Carboxylic acids (p.28)

Naming carboxylic acids

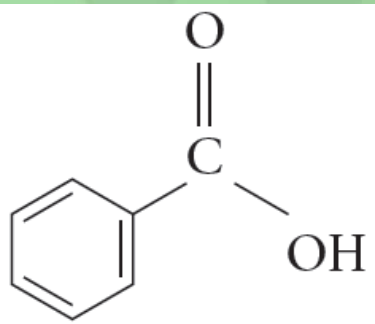
- A carboxylic acid is named by replacing the ‘e’ at the end of the name of the corresponding alkane with the suffix -oic acid.
- Substituents on the parent chain are named in the usual way. Remember that the carbon atom of the carboxyl group is always assigned number 1.



3-methylbutanoic acid



phenylethanoic acid



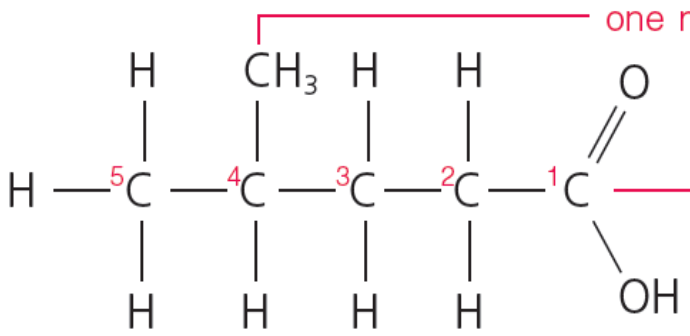
benzoic acid

29.7 Carboxylic acids (p.28)

Practice 29.6

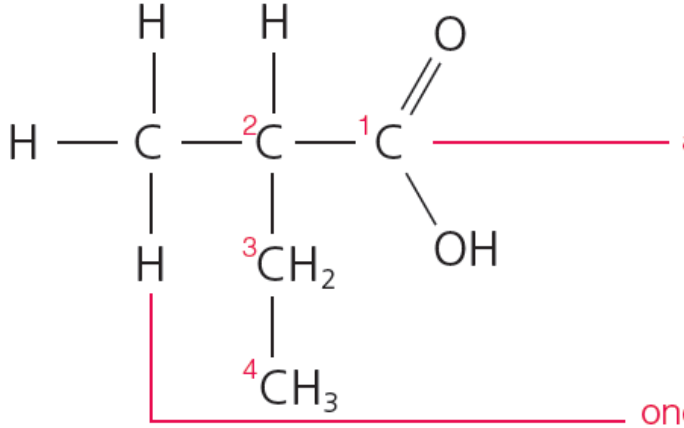
1 Give the systematic names of the carboxylic acids below.

a)



Thus, the systematic name of the compound is 4-methylpentanoic acid.

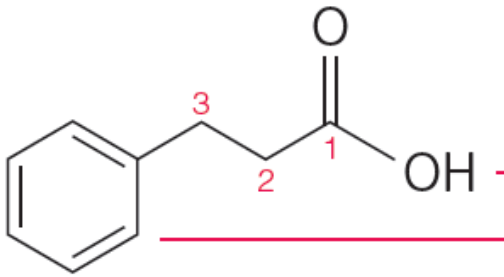
b)



Thus, the systematic name of the compound is 2-methylbutanoic acid.

29.7 Carboxylic acids (p.28)

c)

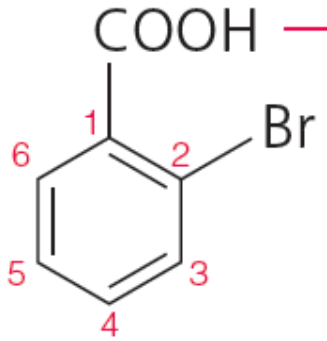


a carboxylic acid containing 3 carbon atoms, i.e. propanoic acid

one phenyl group on carbon atom 3, i.e. 3-phenyl

Thus, the systematic name of the compound is 3-phenylpropanoic acid.

d)



benzoic acid

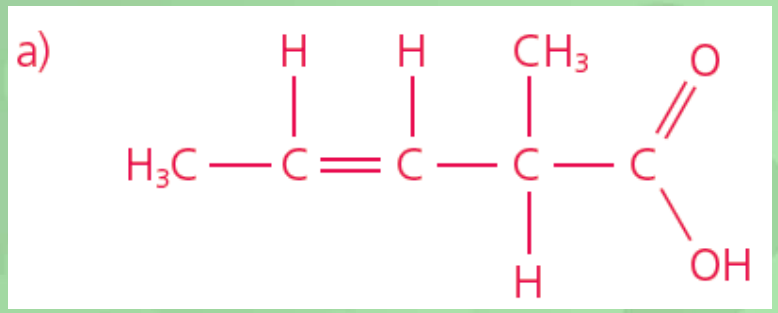
one bromine atom on carbon atom 2, i.e. 2-bromo

Thus, the systematic name of the compound is 2-bromobenzoic acid.

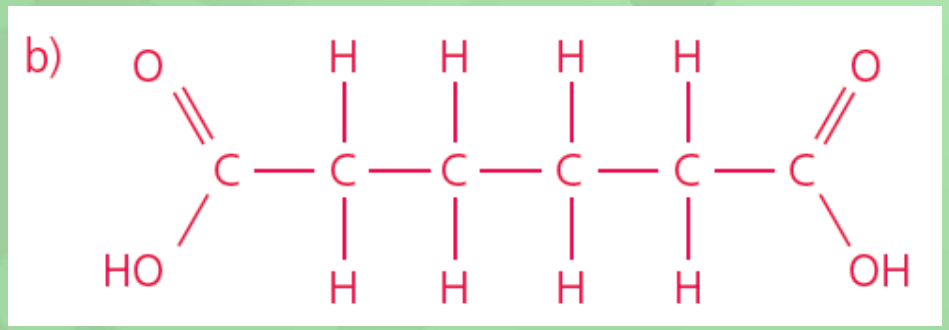
29.7 Carboxylic acids (p.28)

2) Write the structural formulae of the carboxylic acids below.
   a) 2-methylpent-3-enoic acid
   b) Hexanedioic acid

a)



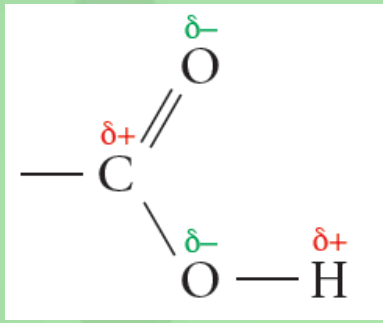
b)



29.7 Carboxylic acids (p.28)

Physical properties of carboxylic acids

- Oxygen is more electronegative than either carbon or hydrogen. Hence both the C=O and O–H bonds in the –COOH group are polar.



- A carboxylic acid molecule can form hydrogen bonds with other carboxylic acid molecules and water molecules.

29.7 Carboxylic acids (p.28)

Boiling point

- Most carboxylic acids are liquids at room temperature.
- The boiling point increases from methanoic acid to pentanoic acid as the length of carbon chain increases.

Table 29.11 Boiling points of five carboxylic acids

Carboxylic acid	Formula	Boiling point (°C)
Methanoic acid	$HCOOH$	101
Ethanoic acid	CH_3COOH	118
Propanoic acid	CH_3CH_2COOH	141
Butanoic acid	$CH_3CH_2CH_2COOH$	164
Pentanoic acid	$CH_3CH_2CH_2CH_2COOH$	187

boiling point increasing

29.7 Carboxylic acids (p.28)

- The boiling point of a carboxylic acid is higher than that of an alcohol of a similar relative molecular mass.

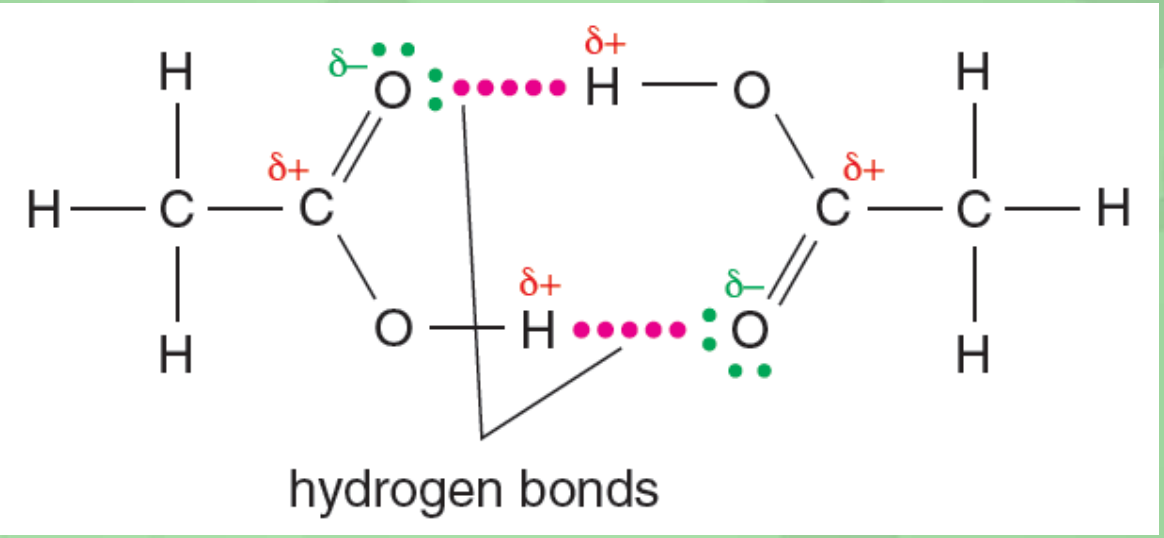
Table 29.12 Boiling points of ethanoic acid and propan-1-ol

Substance	Formula	Relative molecular mass	Boiling point (°C)
Ethanoic acid	CH_3COOH	60.0	118
Propan-1-ol	$CH_3CH_2CH_2OH$	60.0	97

- Both ethanoic acid and propan-1-ol have hydrogen bonds between their molecules.
- However, ethanoic acid molecules, in addition, forms **dimers (二聚物)**.

29.7 Carboxylic acids (p.28)

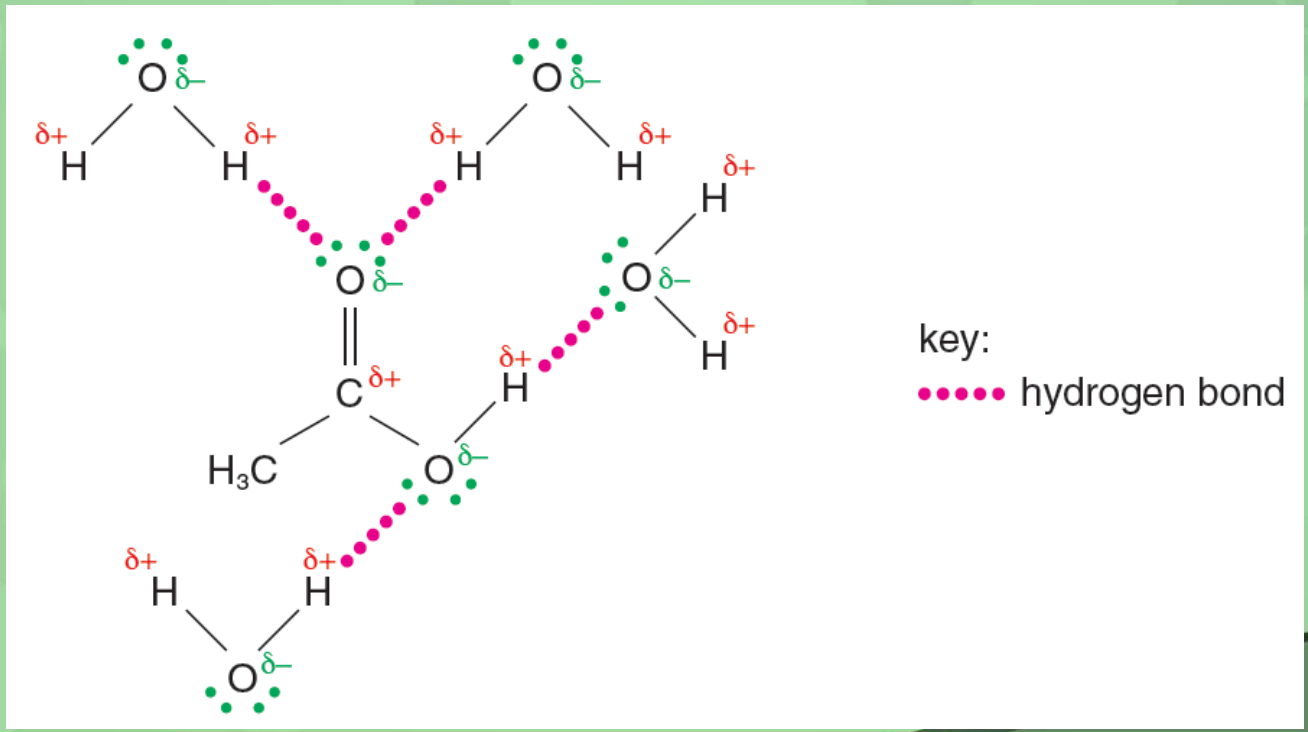
- This doubles the size of the molecule and increases the van der Waals' forces between the dimers, resulting in a higher boiling point.



29.7 Carboxylic acids (p.28)

Solubility in water

- The carboxyl groups in carboxylic acids allow the acid molecules to form hydrogen bonds with water molecules.



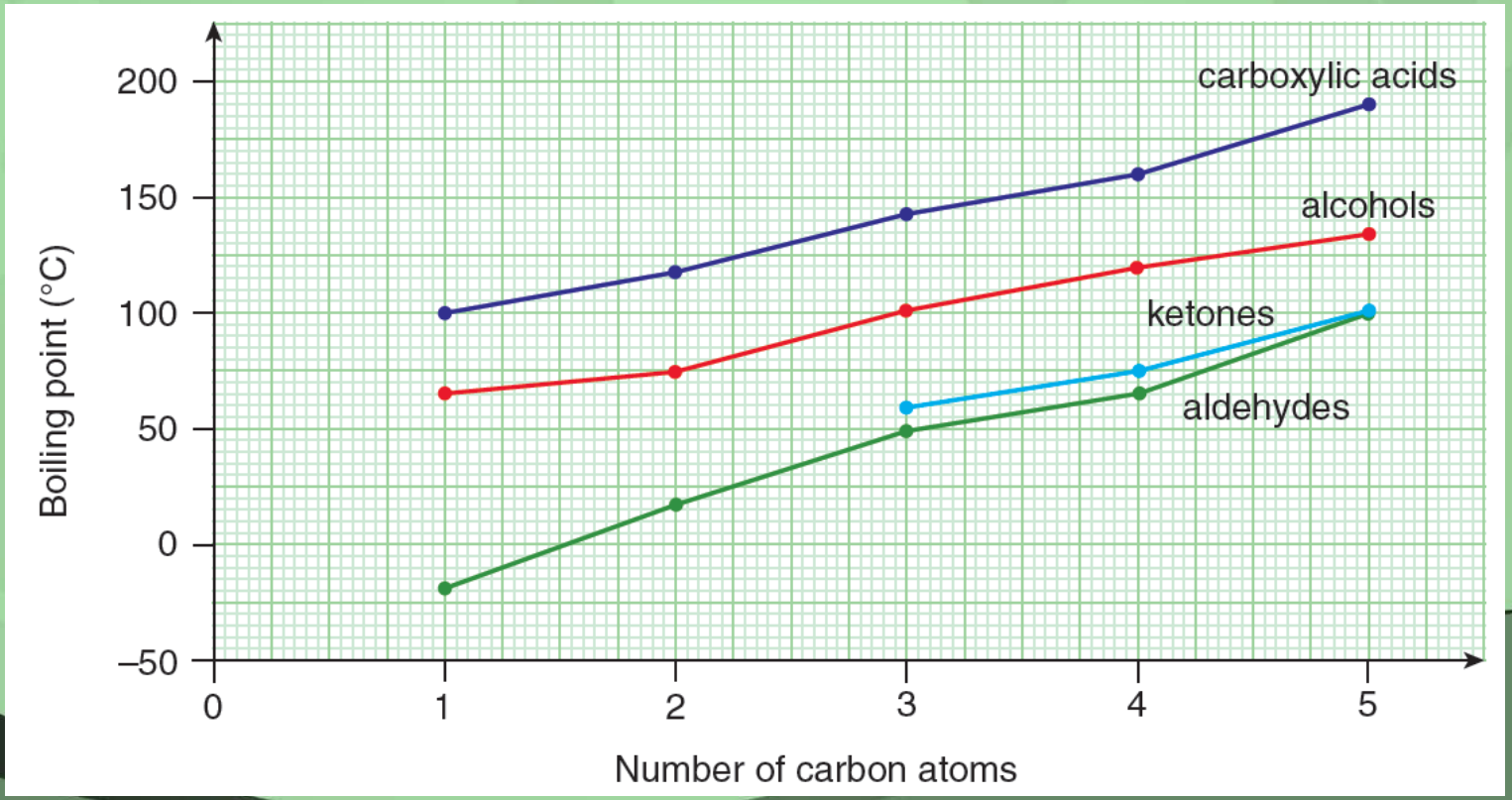
29.7 Carboxylic acids (p.28)

- Carboxylic acids with up to four carbon atoms are miscible with water in all proportions.
- The water solubility decreases with increasing carbon chain length.
- The water solubility of carboxylic acid is higher than that of alcohol with the same number of carbon atoms per molecule. This is because the molecules of carboxylic acid can form more hydrogen bonds with water molecules.

29.7 Carboxylic acids (p.28)

Practice 29.7

1 The following graph compares the boiling points of carbonyl compounds, alcohols and carboxylic acids with the same number of carbon atoms per molecule.



29.7 Carboxylic acids (p.28)

Explain why

a) the boiling point of methanal is lower than that of ethanal.

Aldehydes have only van der Waals' forces between their molecules.
The larger the size of a molecule, the stronger the van der Waals' forces between the molecules. Thus, the van der Waals' forces in ethanal are stronger than those in methanal. As a result, the boiling point of ethanal is higher than that of methanal.

b) the boiling points of alcohols are higher than those of carbonyl compounds with the same number of carbon atoms per molecule.

Alcohols have both hydrogen bonds and van der Waals' forces between their molecules.
Carbonyl compounds have only van der Waals' forces between molecules.
Hydrogen bonds are stronger than van der Waals' forces. As a result, the boiling points of alcohols are higher than those of carbonyl compounds with the same number of carbon atoms per molecule.

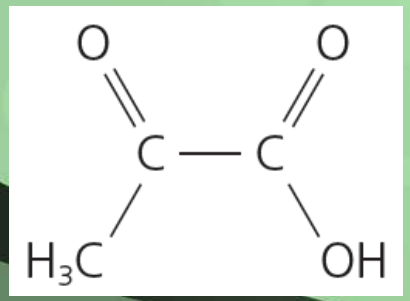
29.7 Carboxylic acids (p.28)

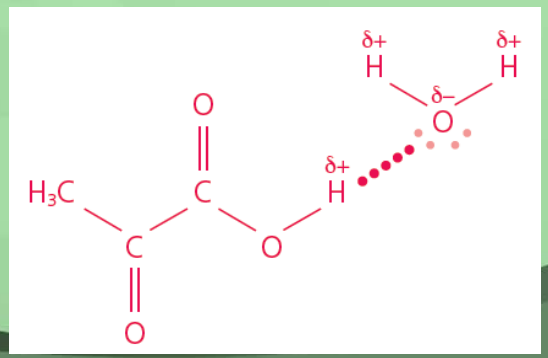
c) the boiling points of carboxylic acids are higher than those of alcohols with the same number of carbon atoms per molecule.

Alcohols and carboxylic acids have both hydrogen bonds and van der Waals' forces between their molecules.
However, unique to carboxylic acids, hydrogen bonding can occur between two molecules to produce a dimer. The presence of dimers increases the strength of van der Waals' forces, resulting in a higher boiling point.

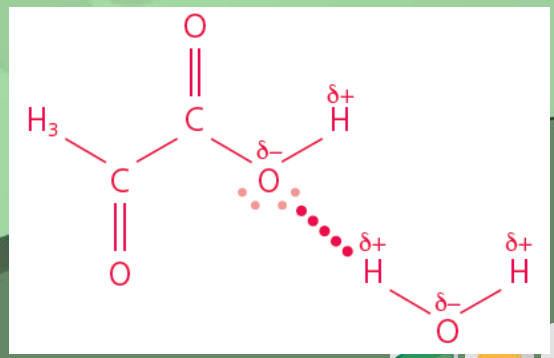
2 Pyruvic acid, as shown below, is a carbon compound that has a smell similar to that of ethanoic acid. It is extremely soluble in water. Explain why pyruvic acid is soluble in water. Use a labelled diagram to support your answer.

Pyruvic acid molecules can form hydrogen bonds with water molecules.

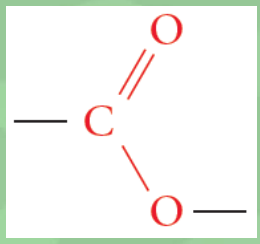


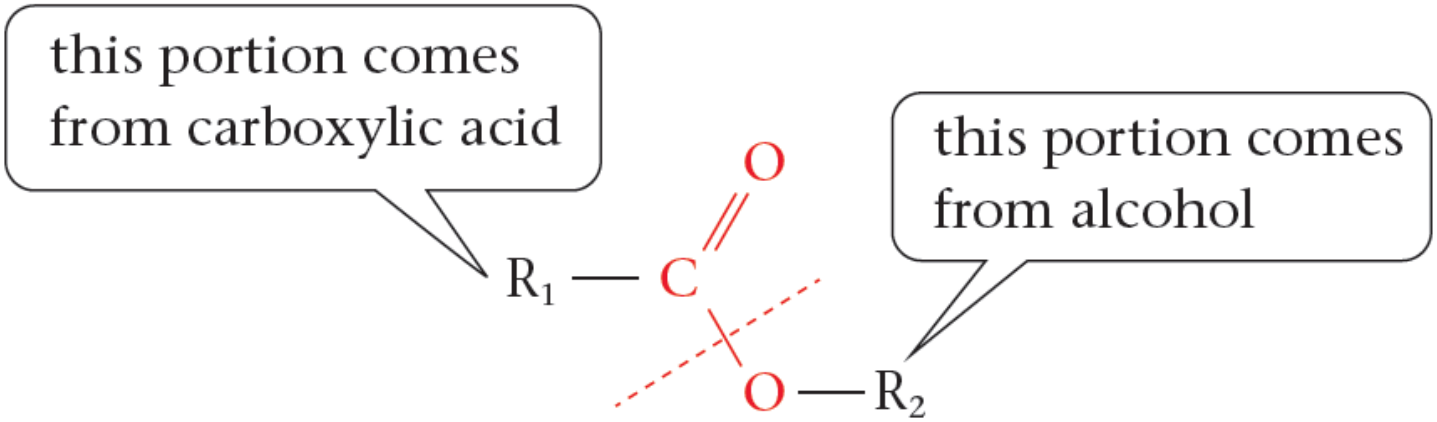


or



29.8 Esters (p.33)

- Carboxylic acids react with alcohols in the presence of an acid catalyst to produce esters.
- **Esters (酯)**, R_1COOR_2, contain the ester group ().



where R_1 = an alkyl or aryl group or H
where R_2 = an alkyl or aryl group

29.8 Esters (p.33)

Naming esters

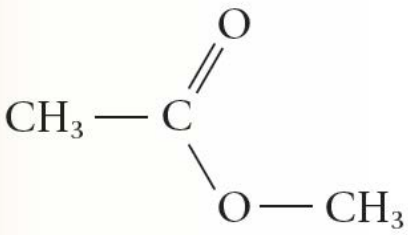
- The name of an ester is derived from the names of the carboxylic acid and the alcohol from which it is formed.
  - The alcohol portion is named first and has the suffix -yl.
  - The carboxylic acid portion is named with the '-oic acid' ending replaced by -oate.

29.8 Esters (p.33)

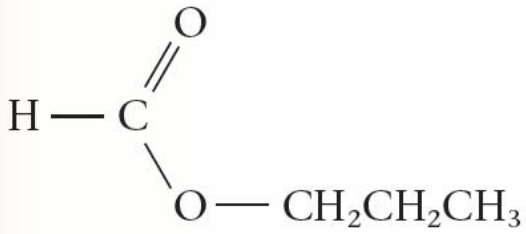
Q (Example 29.6)

Give the systematic names of the esters below.

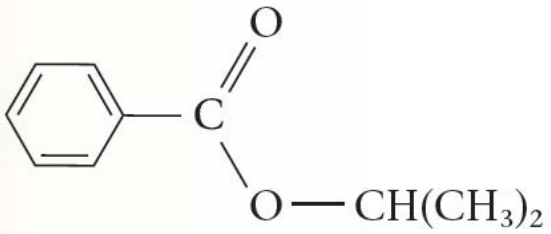
a)



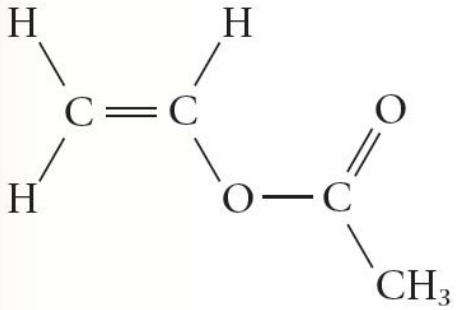
b)



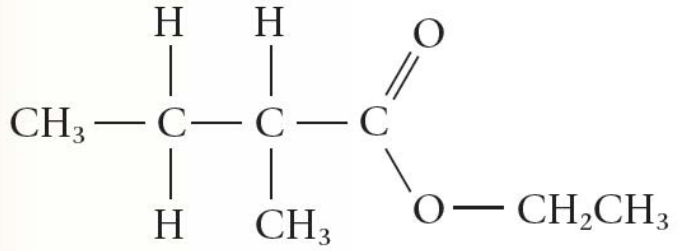
c)



d)

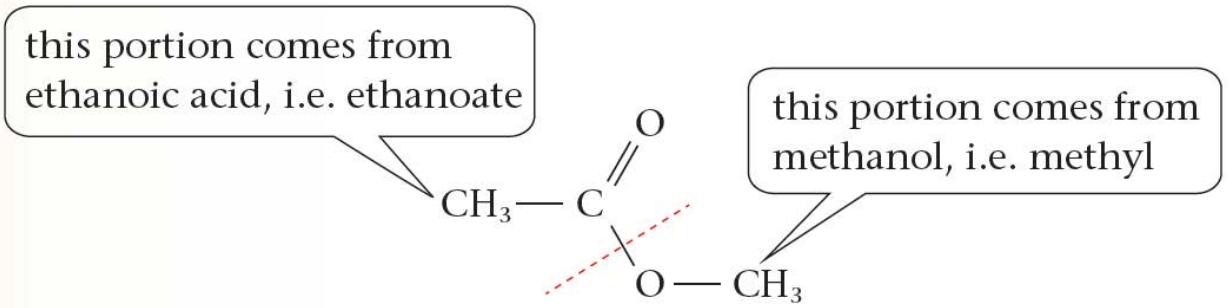


e)



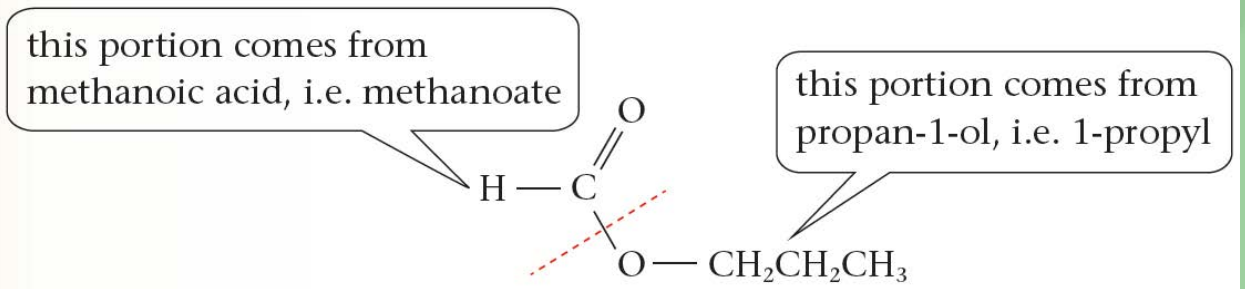
A

a)



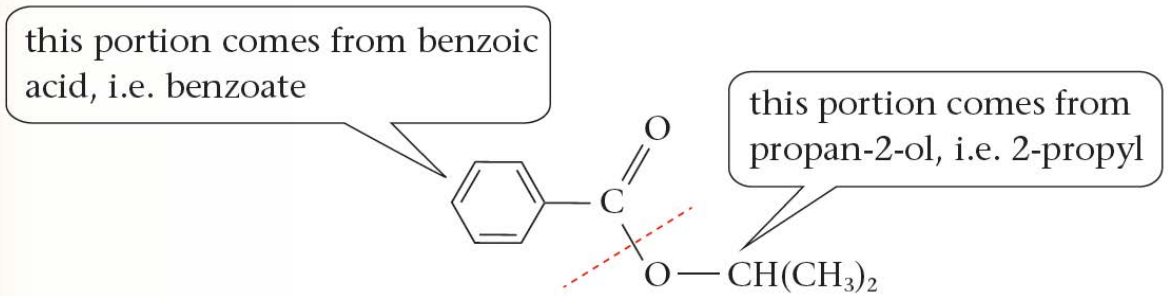
Thus, the systematic name of the ester is methyl ethanoate.

b)



Thus, the systematic name of the ester is 1-propyl methanoate.

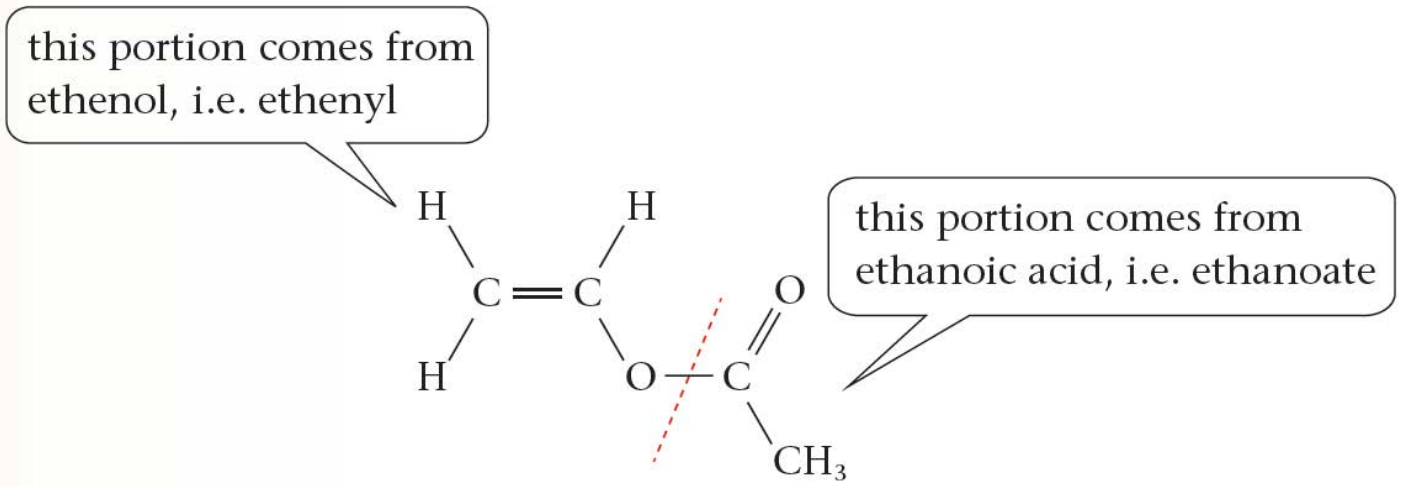
c)



Thus, the systematic name of the ester is 2-propyl benzoate.

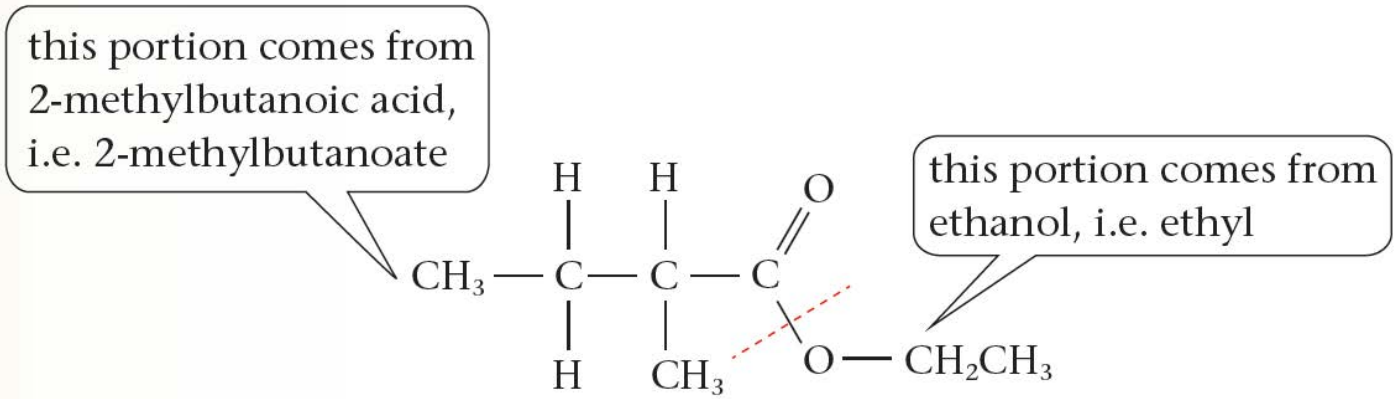
29.8 Esters (p.33)

d)



Thus, the systematic name of the ester is ethenyl ethanoate.

e)



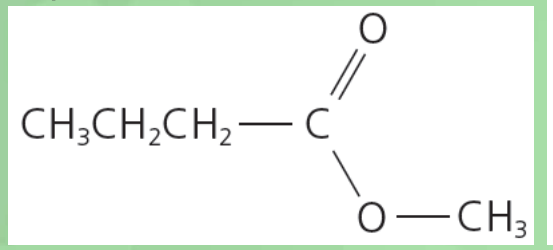
Thus, the systematic name of the ester is ethyl 2-methylbutanoate.

29.8 Esters (p.33)

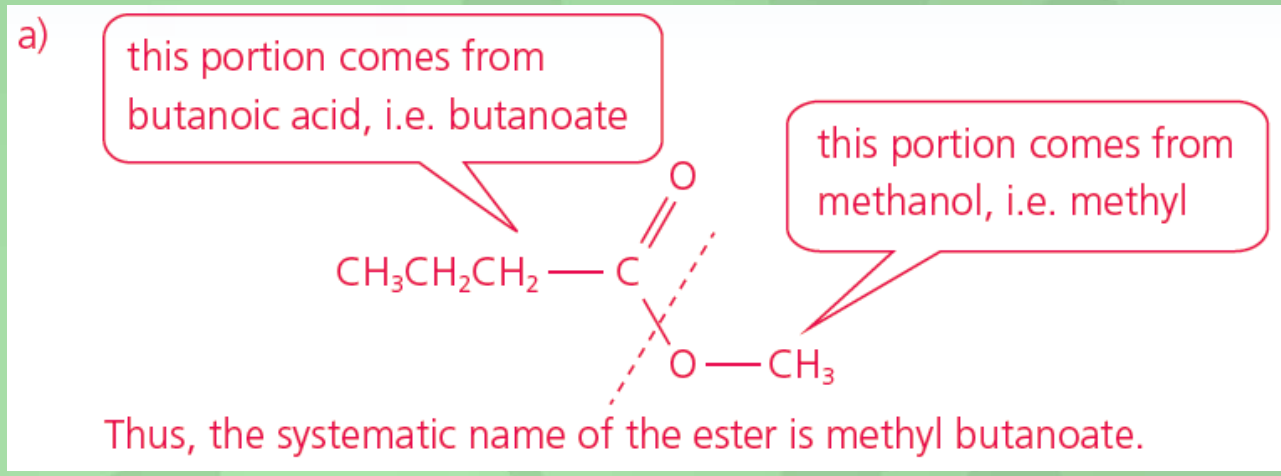
Practice 29.8

1 Give the systematic names of the esters:

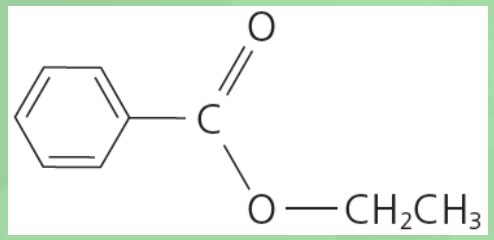
a)



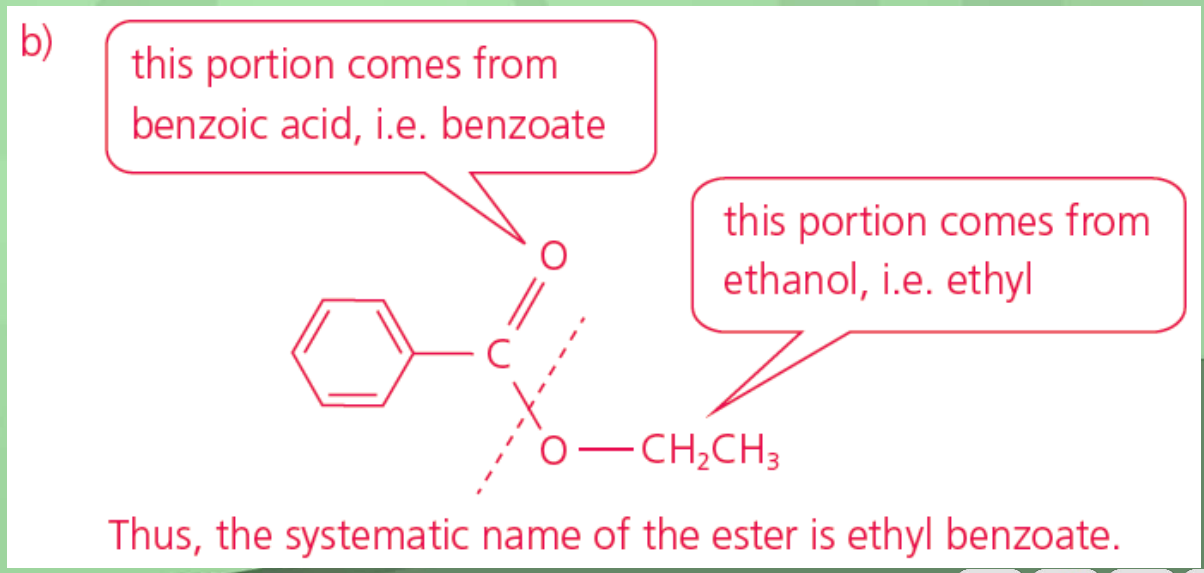
a)



b)

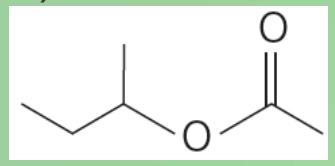


b)



29.8 Esters (p.33)

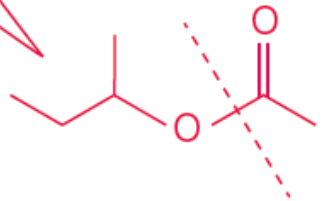
c)



c)

this portion comes from butan-2-ol, i.e. 2-butyl

this portion comes from ethanoic acid, i.e. ethanoate



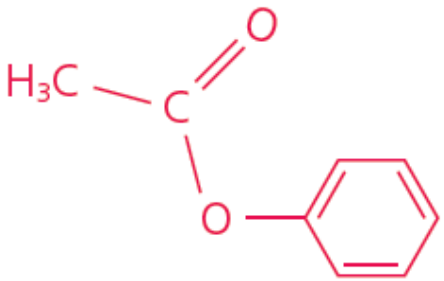
Thus, the systematic name of the ester is 2-butyl ethanoate.

2) Write the structural formulae of the esters below.

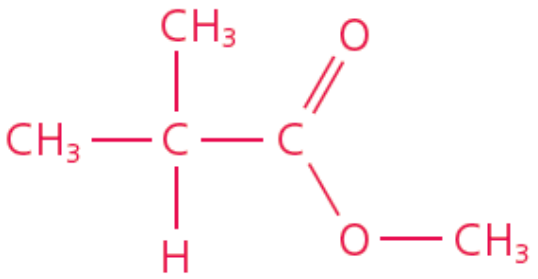
a) Phenyl ethanoate

b) Methyl methylpropanoate

a)



b)



29.8 Esters (p.33)

Physical properties of esters

- Many esters are liquids with sweet and fruity smells. Mixtures of natural esters are responsible for the sweet smells you get from many fruits.
- Esters with low relative molecular masses find many uses as solvents for paints and *varnishes*.
- Some of the naturally-occurring esters are now made synthetically and used as artificial flavourings in foodstuffs.

29.8 Esters (p.33)

Boiling point

- Esters are colourless liquids with relatively low boiling temperatures.
- Only van der Waals' forces exist in esters. Hence the boiling points of esters are lower than those of alcohols and carboxylic acids of similar relative molecular masses.

29.8 Esters (p.33)

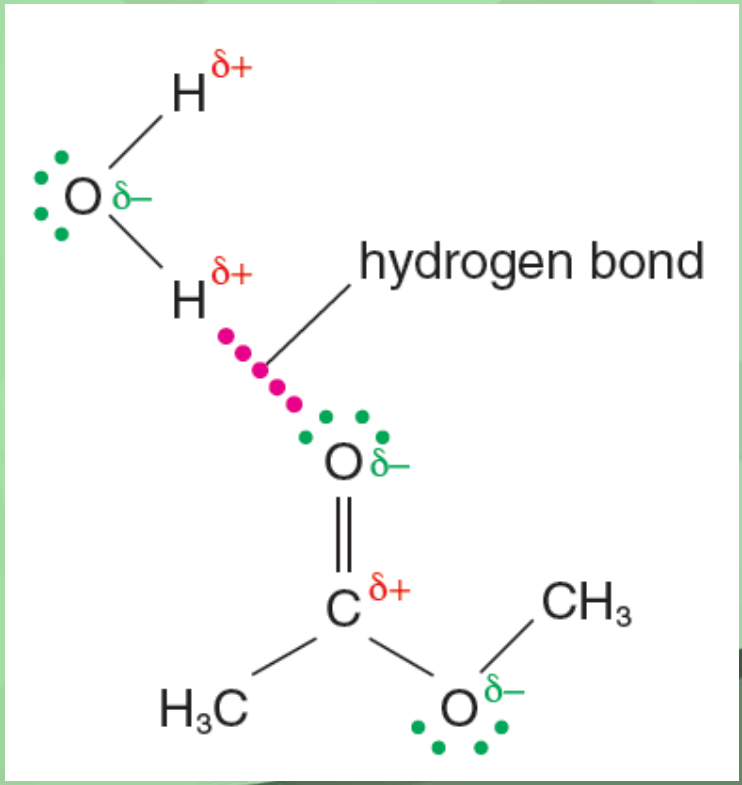
Table 29.14 Boiling points of six esters

Ester	Condensed structural formula	Boiling point (°C)
Methy methanoate	$HCOOCH_3$	32
Ethyl methanoate	$HCOOCH_2CH_3$	54
Methyl ethanoate	CH_3COOCH_3	57
Ethyl ethanoate	$CH_3COOCH_2CH_3$	77
1-propyl ethanoate	$CH_3COOCH_2CH_2CH_3$	102
Ethyl propanoate	$CH_3CH_2COOCH_2CH_3$	99

29.8 Esters (p.33)

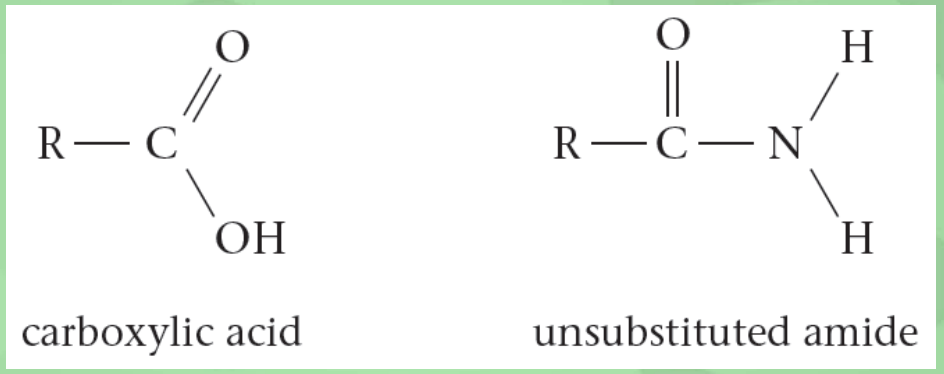
Solubility in water

- Ester molecules can form hydrogen bonds with water molecules. Hence simple esters, such as methyl methanoate and methyl ethanoate, are very soluble in water.

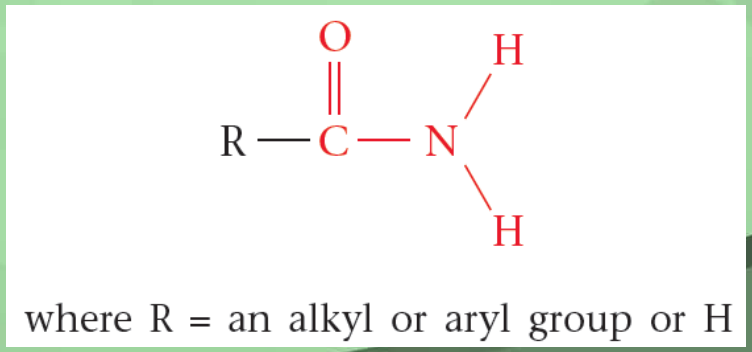


29.9 Amides (p.38)

- **Amides (酰胺)** are nitrogen compounds derived from carboxylic acids. An unsubstituted amide results when the –OH group in a carboxylic acid is replaced with an $–NH_2$ group.



- Unsubstituted amides have the general formula $RCONH_2$:

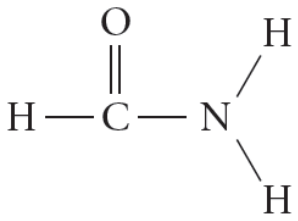


29.9 Amides (p.38)

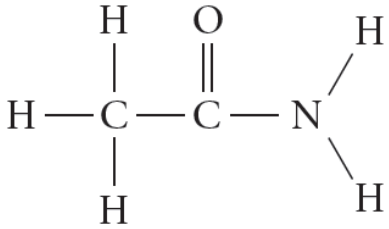
Naming amides

- An unsubstituted amide is named by replacing the '-oic acid' at the end of the name of the corresponding carboxylic acid with the suffix -amide.
- Substituents on the parent chain are named in the usual way. Remember that the carbon atom of the amide functional group is always assigned number 1.

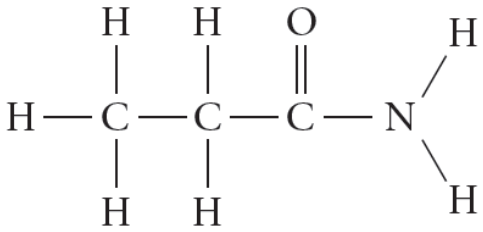
29.9 Amides (p.38)



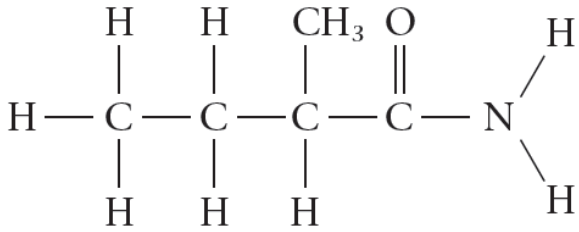
methanamide



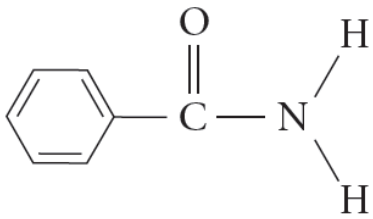
ethanamide



propanamide



2-methylbutanamide



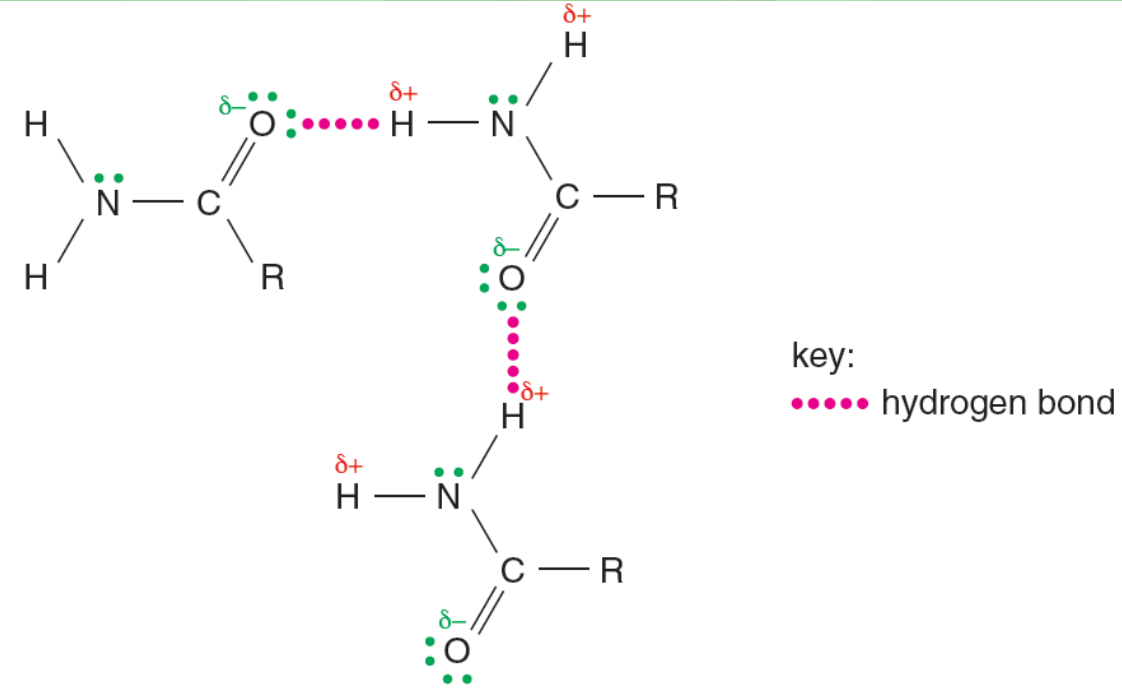
benzamide

29.9 Amides (p.38)

Physical properties of amides

Boiling point

- Amides have higher boiling points than expected for carbon compounds of a similar relative molecular masses. This is because amide molecules can form extensive hydrogen bonds.



29.9 Amides (p.38)

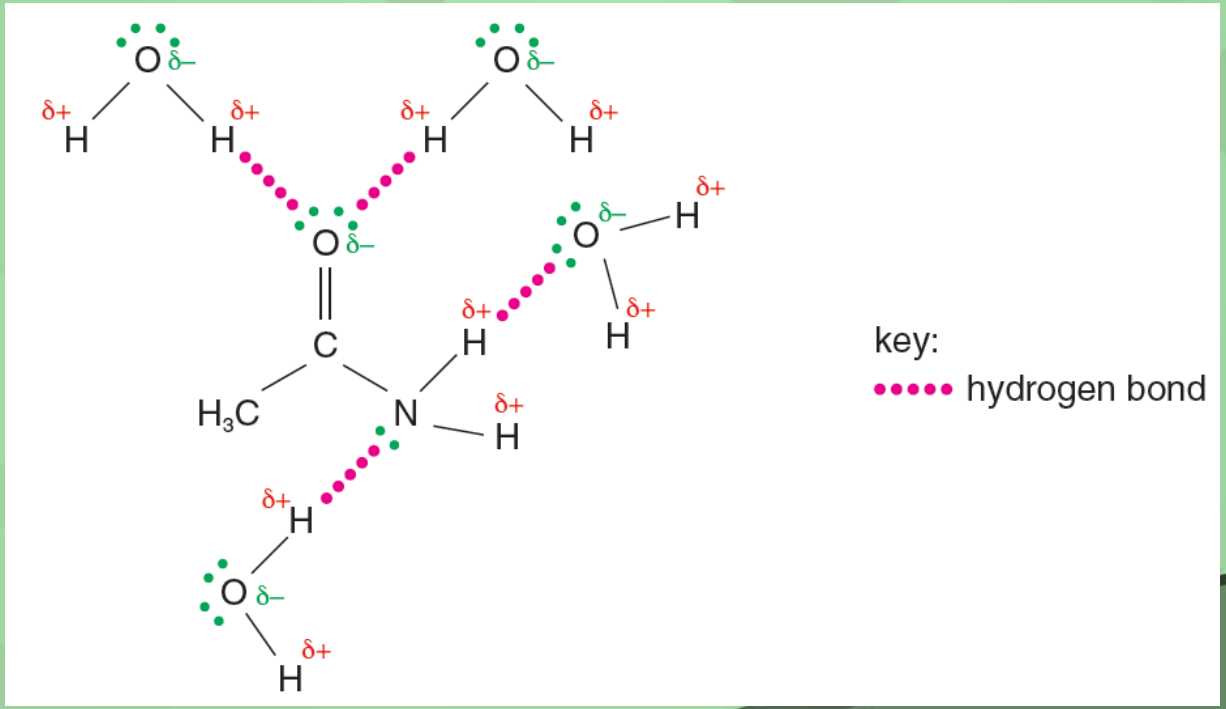
Table 29.15 Boiling points of five amides

Amide	Formula	Boiling point (°C)
Methanamide	$HCONH_2$	210
Ethanamide	CH_3CONH_2	221
Propanamide	$CH_3CH_2CONH_2$	213
Butanamide	$CH_3CH_2CH_2CONH_2$	216
Pentanamide	$CH_3CH_2CH_2CH_2CONH_2$	232

29.9 Amides (p.38)

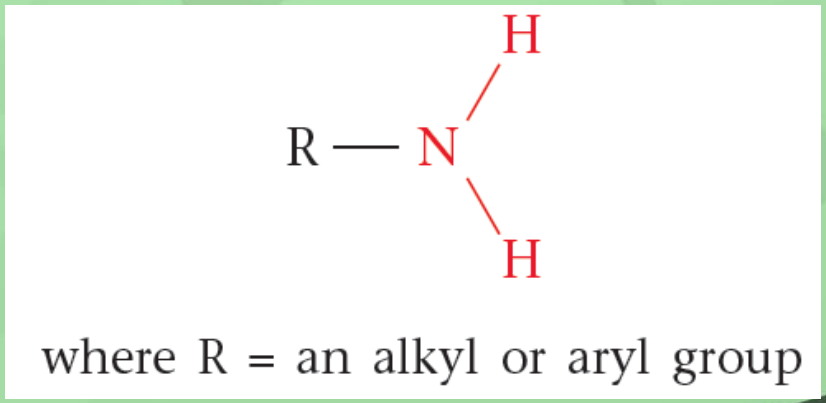
Solubility in water

- Unsubstituted amides with one to five carbon atoms are soluble in water because they can form hydrogen bonds with water.



29.10 Amines (p.41)

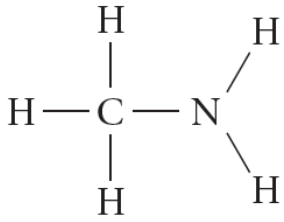
- **Amines (胺)**, RNH_2, have fish smell.
- Amines can be thought of as substituted ammonia molecules. When one of the hydrogen atoms of an ammonia molecule has been replaced by an alkyl or aryl group, you obtain a molecule of a primary amine.
- Primary amines have the general formula RNH_2:



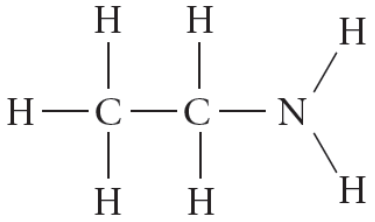
29.10 Amines (p.41)

Naming amines

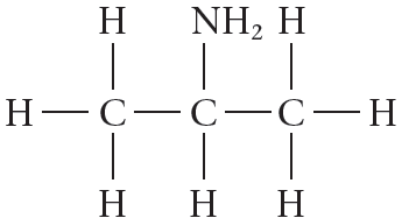
- A primary amine is named by replacing the last letter ‘e’ in the name of the corresponding alkane with the suffix -amine.



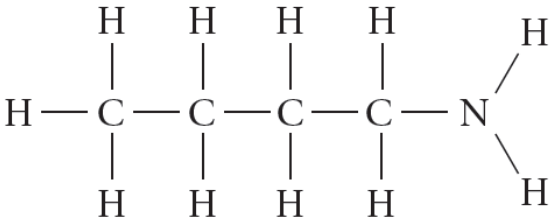
methanamine



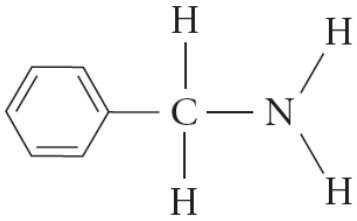
ethanamine



propan-2-amine



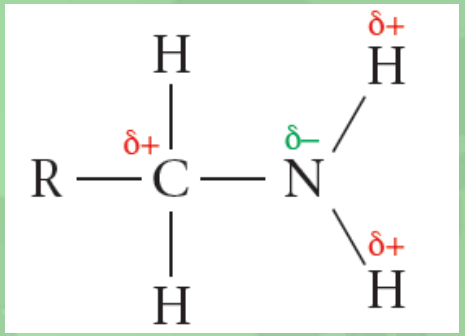
butan-1-amine



phenylmethanamine

29.10 Amines (p.41)

Physical properties of amines

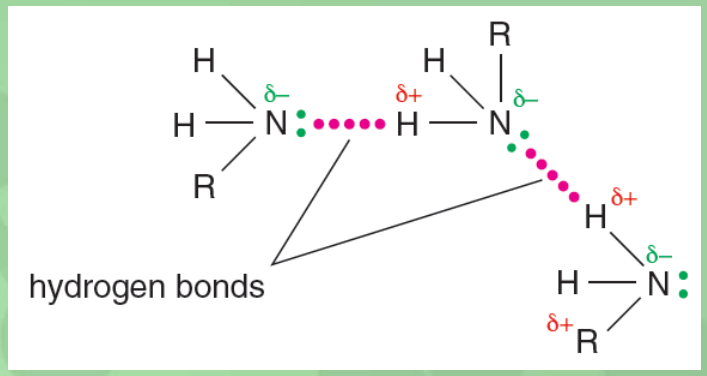


- Amines are polar. Nitrogen is more electronegative than either carbon or hydrogen.
- The physical properties of the simplest amines are similar to those of ammonia. Methanamine and ethanamine are gases at room temperature and they smell like ammonia, though with a fishy character.

The smell of fish is partly due to ethanamine

29.10 Amines (p.41)

Boiling point



- Amines with low relative molecular masses are gases or volatile liquids.
- A primary amine molecule can form hydrogen bonds with other primary amine molecules.

Table 29.16 Boiling points of five primary amines

Amine	Formula	Boiling point (°C)
Methanamine	CH_3NH_2	–6
Ethanamine	$CH_3CH_2NH_2$	17
Propan-1-amine	$CH_3CH_2CH_2NH_2$	49
Butan-1-amine	$CH_3CH_2CH_2CH_2NH_2$	78
Pentan-1-amine	$CH_3CH_2CH_2CH_2CH_2NH_2$	103

29.10 Amines (p.41)

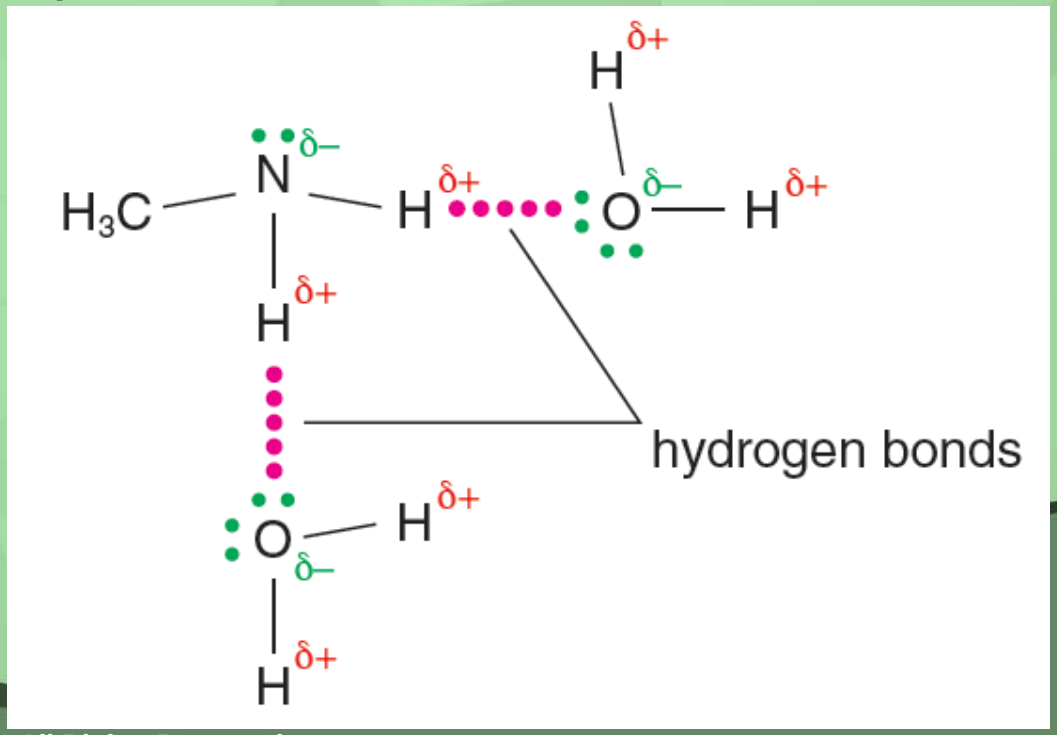
- The boiling point of a primary amine is lower than that of a primary alcohol of a similar relative molecular mass.
- Propan-1-amine and propan-1-ol have a similar relative molecular mass. Both have hydrogen bonds between their molecules.
- Nitrogen is less electronegative than oxygen, thus the N–H bond in propan-1-amine is less polar than the O–H bond in propan-1-ol. As a result, the hydrogen bonds in propan-1-amine are not as strong as those in propan-1-ol.

Substance	Formula	Relative molecular mass	Boiling point (°C)
Propan-1-amine	$CH_3CH_2CH_2NH_2$	59.0	49
Propan-1-ol	$CH_3CH_2CH_2OH$	60.0	97

29.10 Amines (p.41)

Solubility in water

- Like ammonia, primary amines can form hydrogen bonds with water. Because of this strong attraction between primary amine molecules and water molecules, primary amines with small alkyl groups are soluble in water.

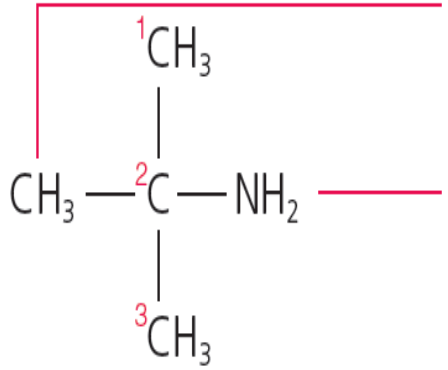


29.10 Amines (p.41)

Practice 29.9

1 Give the systematic names of the compounds below.

a)

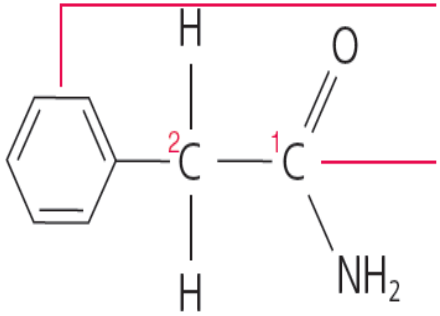
a) 

one methyl group on carbon atom 2, i.e. methyl
(There is no need to assign a number to indicate the position of the methyl group as it can be in one position only.)

an amine containing 3 carbon atoms, with the $-NH_2$ group on carbon atom 2, i.e. propan-2-amine

Thus, the systematic name of the compound is methylpropan-2-amine.

b)

b) 

a phenyl group on carbon atom 2, i.e. phenyl
(There is no need to assign a number to indicate the position of the phenyl group as it can be in one position only.)

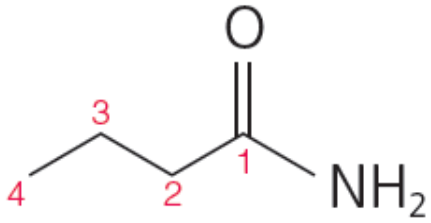
an amide containing 2 carbon atoms, i.e. ethanamide

Thus, the systematic name of the compound is phenylethanamide.

29.10 Amines (p.41)

c)

c)

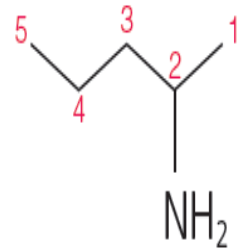


——— an amide containing 4 carbon atoms, i.e. butanamide

Thus, the systematic name of the compound is butanamide.

d)

d)



——— an amine containing 5 carbon atoms, with the $-NH_2$ group on carbon atom 2, i.e. pentan-2-amine

Thus, the systematic name of the compound is pentan-2-amine.

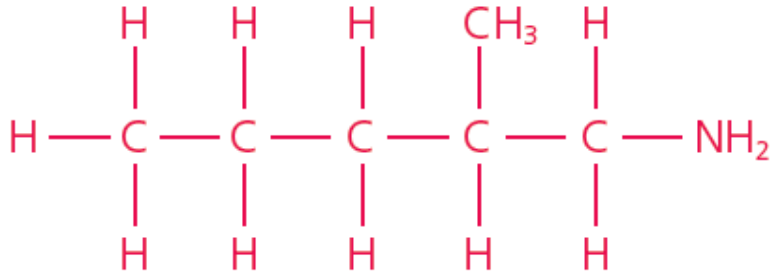
29.10 Amines (p.41)

2 Write the structural formulae of the compounds below.

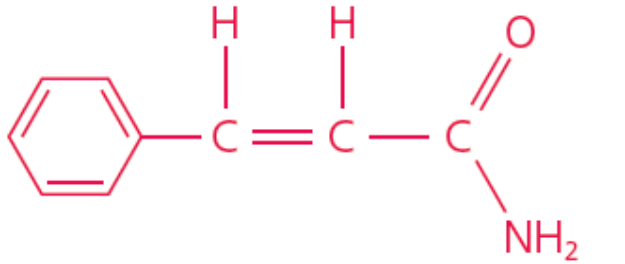
a) 2-methylpentan-1-amine

b) 3-phenylprop-2-enamide

a)



b)



29.11 Common name of carbon compounds (p.45)

- Before the IUPAC system of naming, whenever new carbon compounds were discovered, individual names were assigned to them based on their origins or certain properties. These names are called **trivial / common names (通俗名稱)**.
- Ant stings and bites contain methanoic acid. Its trivial name is *formic acid* since the Latin word for ant is *formica*. The common name for 2-hydroxypropanoic acid ($CH_3CH(OH)COOH$) is lactic acid. It derives its name from the Latin word for milk (*lactis*).

29.11 Common name of carbon compounds (p.45)

- Many trivial names continue to be used because their IUPAC names are considered too cumbersome for everyday use. For example, *tartaric acid*, a compound found in wine, has a systematic name of *2,3-dihydroxybutanedioic acid*.

Key terms (p.46)

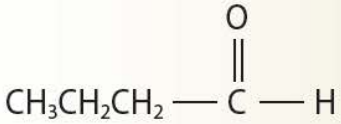
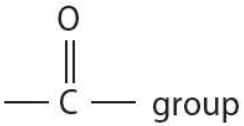
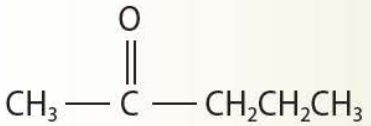
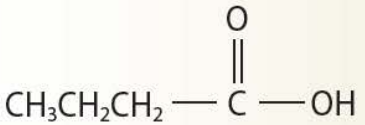
alkyl group	烷基	carboxylic acid	羧酸
aryl group	芳基	carboxyl group	羧基
haloalkane	鹵烷	dimer	二聚物
Alcohol	醇	ester	酯
hydroxyl group	羥基	amide	酰胺
aldehyde	醛	amine	胺
ketone	酮	trivial / common name	通俗名稱
carbonyl group	羰基		

Summary (p.47)

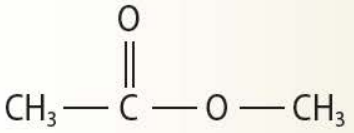
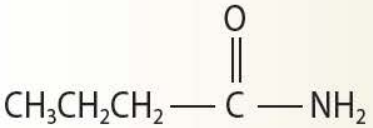
1 The following table summarises the naming of compounds in various homologous series.

Homologous series	General formula	Naming	Example	
			Structural formula	Systematic name
Alkanes	C_nH_{2n+2}	add appropriate prefix to -ane	$CH_3CHCH_2CH_3$ (with CH_3 branch)	2-methylbutane
Alkenes	C_nH_{2n}	replace 'ane' in the name of the corresponding alkane with -ene; insert a number to indicate the location of the C=C bond	$CH_3CH_2CH=CH_2$	but-1-ene
Haloalkanes	RX (X = F, Cl, Br or I)	add the name of halogeno functional group as prefix to the name of the corresponding alkane; insert a number to indicate the location of the halogeno group	$CH_3-CH(Cl)-CH_2CH_3$	2-chlorobutane

Summary (p.47)

Alcohols	ROH	replace the 'e' at the end of the name of the corresponding alkane with -ol; insert a number to indicate the location of the −OH group	$CH_3CH_2CH_2CH_2OH$	butan-1-ol
Aldehydes	RCHO	replace the last letter 'e' at the end of the name of the corresponding alkane with -al		butanal
Ketones	$RCOR_1$	replace the last letter 'e' at the end of the name of the corresponding alkane with -one; insert a number to indicate the location of the  group		pentan-2-one
Carboxylic acids	RCOOH	replace the last letter 'e' at the end of the name of the corresponding alkane with -oic acid		butanoic acid

Summary (p.47)

Homologous series	General formula	Naming	Example	
			Structural formula	Systematic name
Esters	$RCOOR_1$	the name consists of two separate words; the first word comes from the alcohol; the second word comes from the carboxylic acid		methyl ethanoate
Amides (unsubstituted)	$RCONH_2$	replace the 'oic acid' at the end of the name of the corresponding acid by -amide		butanamide
Amines (primary)	RNH_2	replace the last letter 'e' in the name of the corresponding alkane with -amine; insert a number to indicate the location of the $-NH_2$ group	$CH_3CH_2CH_2CH_2NH_2$	butan-1-amine

Summary (p.47)

2 The physical properties (e.g. the boiling point and water solubility) of a carbon compound are affected by
a) the functional group it contains;
b) the length of the carbon chain in molecule.

3 The table below summarises trends of boiling points of members of some homlogous series.

Homologous series	Intermolecular forces in the substance	Boiling point trend
Haloalkanes	• van der Waals' forces between molecules	• boiling points increase with the length of carbon chain
Alcohols	• hydrogen bonding between molecules	• boiling points increase with the length of carbon chain • boiling points much higher than those of alkanes of similar relative molecular masses
Aldehydes and ketones	• van der Waals' forces between molecules	• boiling points increase with the length of carbon chain
Carboxylic acids	• hydrogen bonding between molecules	• the hydrogen bonding leads to dimer formation, so boiling points higher than those of alcohols of similar relative molecular masses
Esters	• van der Waals' forces between molecules	• boiling points lower than those of alcohols and carboxylic acids of similar relative molecular masses
Amides (unsubstituted)	• hydrogen bonding between molecules	• boiling points are high
Amines (primary)	• hydrogen bonding between molecules of primary amines; hydrogen bonding less strong than that in alcohols	• boiling points lower than those of alcohols of similar relative molecular masses

Summary (p.47)

4 The table below summarises information about water solubilities of members of some homologous series.

Homologous series	Interaction with water molecules	Solubility in water
Haloalkanes	• polar molecules can interact with water molecules	• slightly soluble in water
Alcohols	• hydrogen bonding between alcohol molecules and water molecules	• alcohols with less carbon atoms are miscible with water in all proportions • alcohols with long carbon chains are much less soluble in water
Aldehydes and ketones	• hydrogen bonding between aldehyde / ketone molecules and water molecules	• aldehydes and ketones with small molecules are miscible with water in all proportions
Carboxylic acids	• hydrogen bonding between acid molecules and water molecules; more extensive than that between alcohol molecules and water molecules	• the first four acids are miscible with water in all proportions • water solubility higher than those of alcohols of similar relative molecular masses
Esters	• hydrogen bonding between ester molecules and water molecules	• simple esters are very soluble in water
Amides (unsubstituted)	• hydrogen bonding between amide molecules and water molecules	• simple amides are soluble in water
Amines (primary)	• hydrogen bonding between amine molecules and water molecules	• simple primary amines are soluble in water

Unit Exercise (p.50)

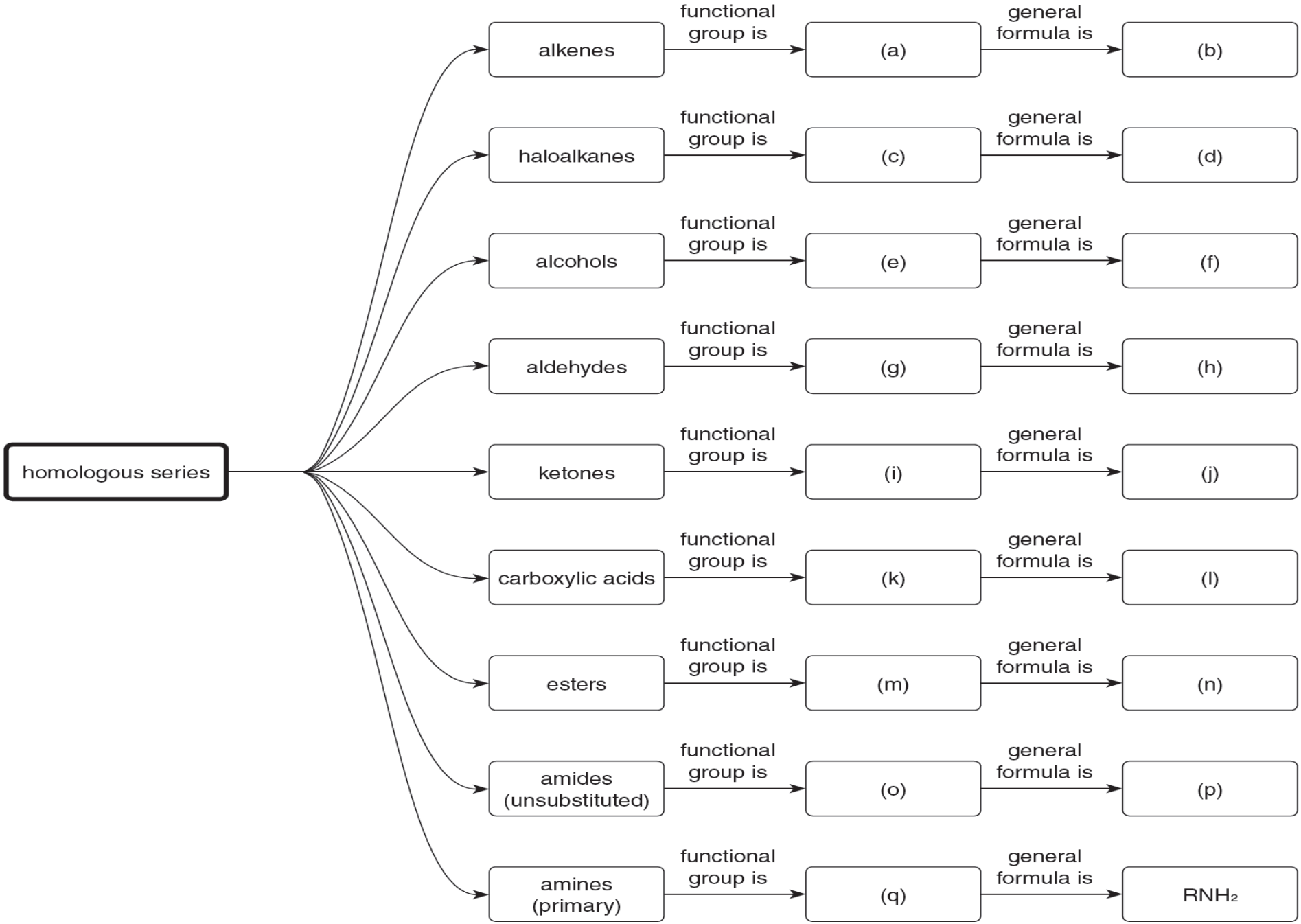
Note: Questions are rated according to ascending level of difficulty (from 1 to 5):

 **question targeted at level 3 and above;**
 **question targeted at level 4 and above;**
 **question targeted at level 5.**
‘ * ’ indicates 1 mark is given for effective communication.

Unit Exercise (p.50)

PART I KNOWLEDGE AND UNDERSTANDING

1 Complete the following concept map.



Unit Exercise (p.50)

a) C=C

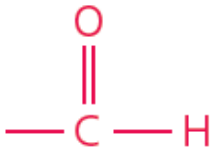
b) C_nH_{2n}

c) –X where X is a halogen

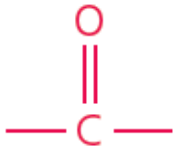
d) RX

e) –OH

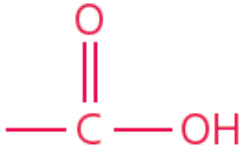
f) ROH

g) 

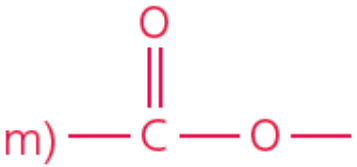
h) (H or R) CHO

i) 

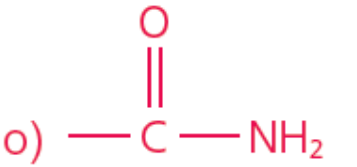
j) R_1COR_2

k) 

l) (H or R) COOH

m) 

n) (H or R_1) $COOR_2$

o) 

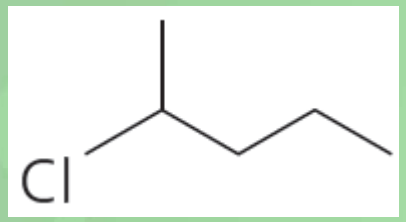
p) (H or R) $CONH_2$

q) $-NH_2$

Unit Exercise (p.50)

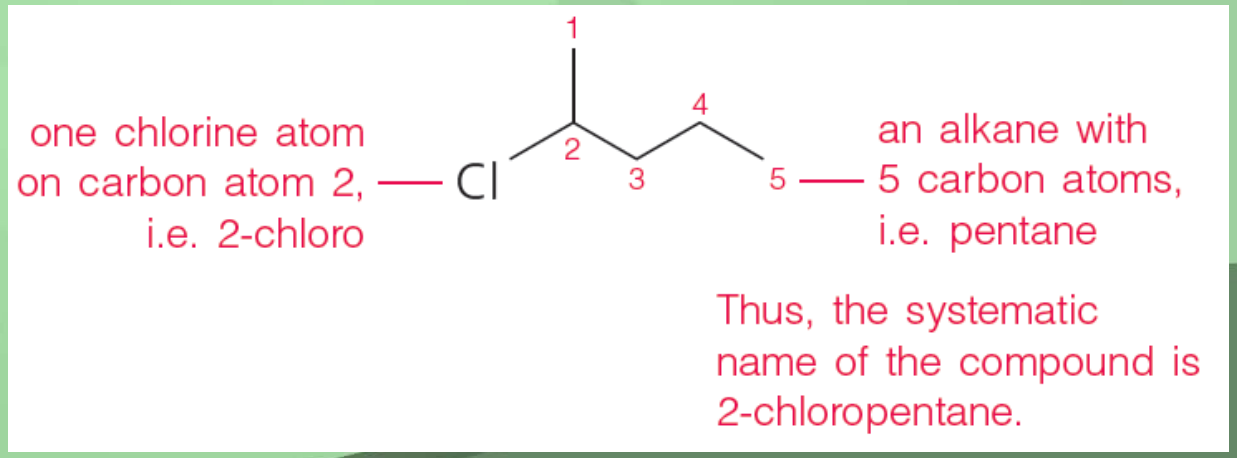
PART II MULTIPLE CHOICE QUESTIONS

2 What is the systematic name of the compound below?



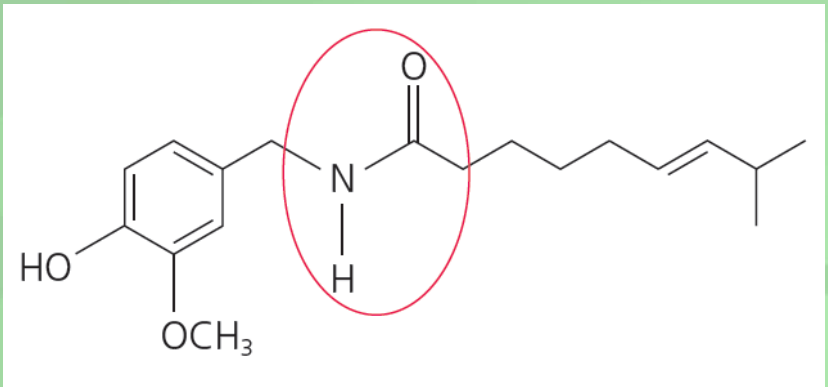
A 1-chloro-1-methylbutane
B 1-chloro-2-methylbutane
C 2-chloropentane
D 4-chloropentane

Answer: C



Unit Exercise (p.50)

3 Capsaicin is commonly used in food products to give them added spice. The structure of it is shown below:



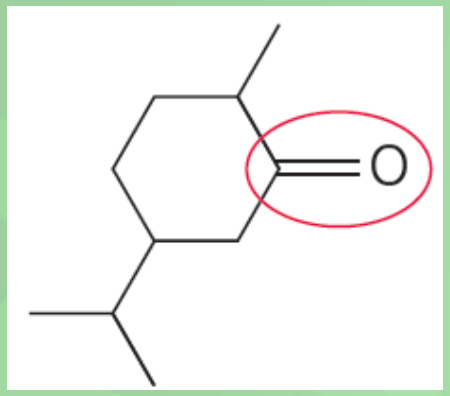
Which of the following functional groups is present in capsaicin?

A Amide functional group
B Amine functional group
C Carboxyl group
D Ester group

Answer: A

Unit Exercise (p.50)

4 The compound shown below has the smell of peppermint.
What functional group does the compound contain?

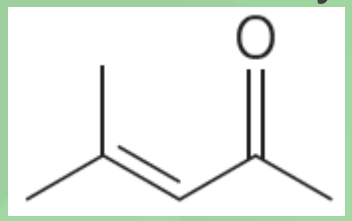


A Carbonyl group
B Carboxyl group
C Hydroxyl group
D Methyl group

Answer: A

Unit Exercise (p.50)

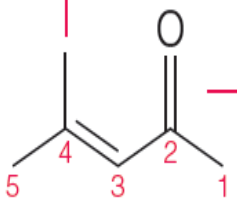
5 What is the systematic name of the compound below?



A 2-methylpenten-4-one
B 4-methylpent-3-en-2-one
C 2-methylpentenal
D 4-methylpent-3-enal

Answer: B

one methyl group at carbon atom 4, i.e. 4-methyl



a ketone containing 5 carbon atoms, with the carbon atom of the C=O group at position 2, and a C=C bond between carbon atoms 3 and 4, i.e. pent-3-en-2-one

Thus, the systematic name of the compound is 4-methylpent-3-en-2-one.

Unit Exercise (p.50)

6 The boiling points of the haloethanes are shown below.

Haloethane	Boiling point (°C)
Fluoroethane	–37
Chloroethane	13
Bromoethane	38
Iodoethane	72

Answer: D

The change in boiling point is due to an increase in

A hydrogen bonding.
B hydrogen bonding and van der Waals' forces.
C polarity of the carbon-halogen bond.
D van der Waals' forces.

(CEA Advanced Subsidiary GCE, Unit 2, Module 2, Jun. 2016, 2)

Unit Exercise (p.50)

7 Which of the following compounds has the highest boiling temperature?

A CH_4
B CH_3Cl
C HCHO
D CH_3OH

Answer: D

(Edexcel Advanced Subsidiary GCE, Unit 2, Jan. 2013, 5)

Explanation:
Hydrogen bonds exist between molecules of CH_3OH, but NOT between molecules of other compounds.

Unit Exercise (p.50)

Directions: Questions 8 and 9 concern the following carbon compounds:

A CH_3CH_2OH
B CH_3CHO
C CH_3COOH
D $HCOOCH_3$

8 Which of the compounds has a fruity smell? Answer: D

Explanation:
$HCOOCH_3$ is an ester.

9 Which of the compounds has the highest boiling point? Answer: C

Explanation:
Hydrogen bonding can occur between two molecules of CH_3COOH to produce a dimer. The presence of dimers increases the strength of van der Waals' forces, resulting in a higher boiling point.

Unit Exercise (p.50)

10 Which of the following compounds has the highest boiling point?

A $CH_3CH_2CH_2CH_3$
B $CH_3CH_2CH=CH_2$
C $CH_3CH_2CH_2CHO$
D $CH_3CH_2CH_2CH_2NH_2$

Answer: D

Explanation:
Hydrogen bonds exist between molecules of $CH_3CH_2CH_2CH_2NH_2$, but NOT between molecules of the other compounds.

Unit Exercise (p.50)

11 The boiling point of propan-1-amine is 49 °C while that of ethanamine is 17 °C. Why is the boiling point of propan-1-amine higher than that of ethanamine?

Answer: C

A The hydrogen bonds in propan-1-amine are stronger than the hydrogen bonds in ethanamine.

B The van der Waals' forces in propan-1-amine are stronger than the hydrogen bonds in ethanamine.

C The van der Waals' forces in propan-1-anime are stronger than the van der Waals' forces in ethanamine.

D The C–H bonds in propan-1-amine are stronger than the C–H bonds in ethanamine.

Unit Exercise (p.50)

12 The boiling point of butan-1-ol is 118 °C while that of methylpropan-2-ol is 82 °C. Why is the boiling point of butan-1-ol higher than that of methylpropan-2-ol?

A Butan-1-ol has stronger van der Waals' forces because it has more electrons per molecule.
B Butan-1-ol has stronger van der Waals' forces because its molecule has a longer shape.
C Butan-1-ol can form hydrogen bonds while methylpropan-2-ol cannot.
D Butan-1-ol is polar while methylpropan-2-ol is not.

Answer: B

Unit Exercise (p.50)

13 Hexan-1-ol is less soluble than ethanol in water. The best explanation for this is that

A hexan-1-ol molecules cannot form hydrogen bonds with water molecules but ethanol molecules can.
B van der Waals' forces between hexan-1-ol molecules are stronger than those between ethanol molecules.
C the C–H bonds in hexan-1-ol are stronger than the C–H bonds in ethanol.
D the C–C bonds in hexan-1-ol are stronger than the C–C bonds in ethanol.

Answer: B

Unit Exercise (p.50)

Directions: Questions 14 and 15 concern the alcohol shown, which is present in sperm whale oil.

18 11→17 10 9 2→8 1

$CH_3(CH_2)_7CH=CH(CH_2)_7CH_2OH$

14 The systematic name of the alcohol is

A octadec-8-en-1-ol.
B octadec-9-en-1-ol.
C octadec-8-en-18-ol.
D octadec-9-en-1-ol.

Answer: B

Explanation:
The compound is an alcohol containing 18 carbon atoms, with the –OH group on carbon atom 1, and a C=C bond between carbon atoms 9 and 10. Thus, the systematic name of the compound is octadec-9-en-1-ol.

15 What forces are present between the alcohol molecules?

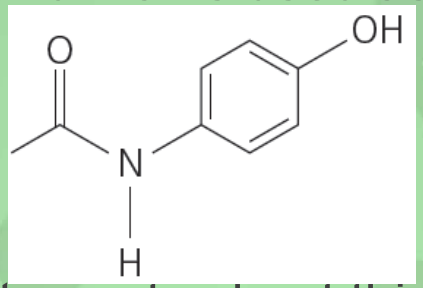
(1) Covalent bonds
(2) Hydrogen bonds
(3) Van der Waals' forces

A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

Answer: C

Unit Exercise (p.50)

16 The structure of a compound that is used as a pain reliever is shown below:



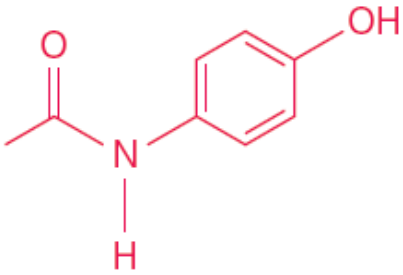
Which of the following statements about this compound is / are correct?

(1) Its molecular formula is $C_8H_9NO_2$.
(2) It contains an amine functional group.
(3) It contains a carbonyl group.

Answer: A

A (1) only
B (2) only
C (1) and (3) only
D (2) and (3) only

(1)



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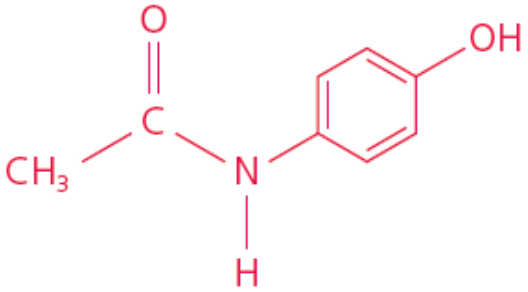


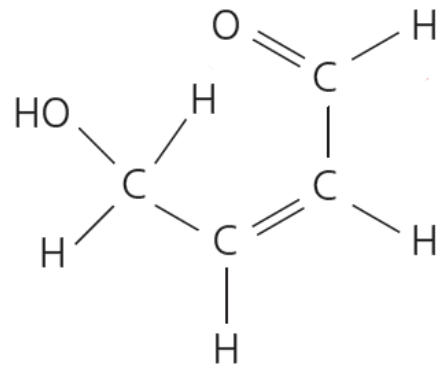
Thus, its molecular formula is $C_8H_9NO_2$.

Unit Exercise (p.50)

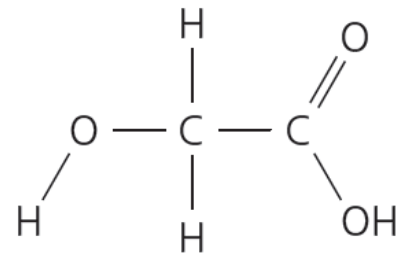
PART III STRUCTURED QUESTIONS

17 Identify the functional groups in the following compounds.

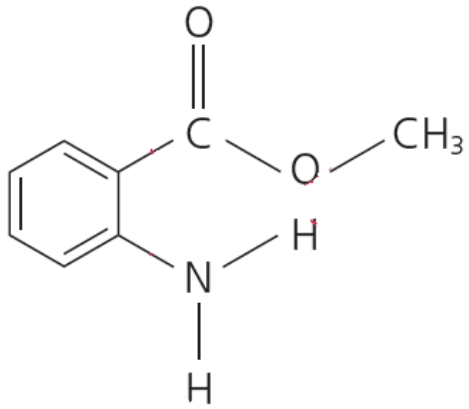
a)



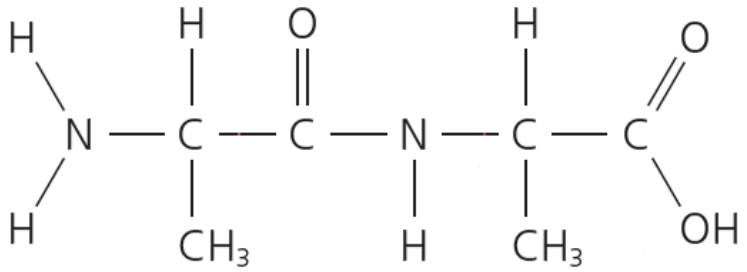
b)



c)

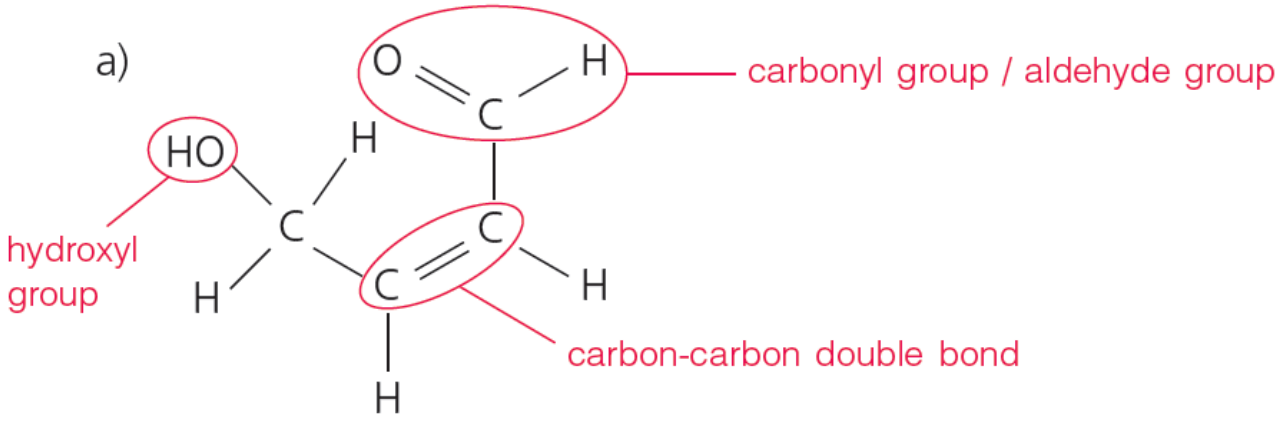


d)



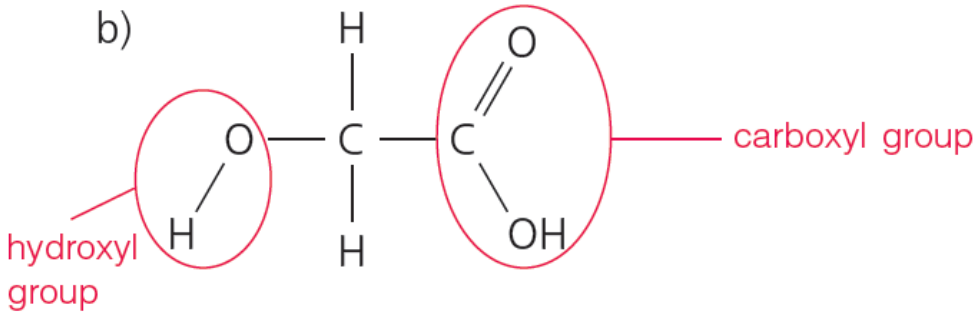
Unit Exercise (p.50)

a)



(1+1+1)

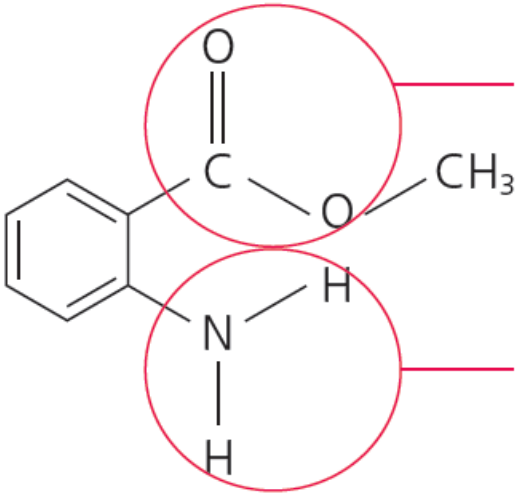
b)



(1+1)

Unit Exercise (p.50)

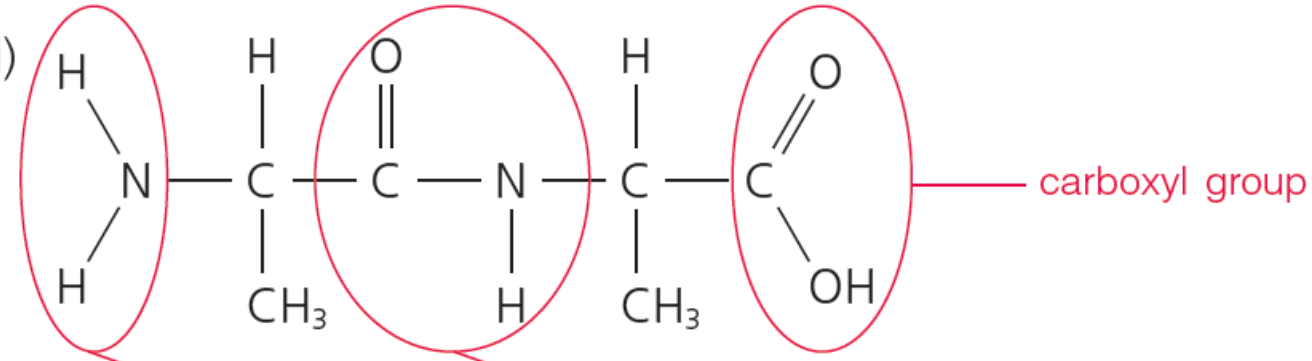
c)



ester group (1+1)

amine functional group

d)



carboxyl group

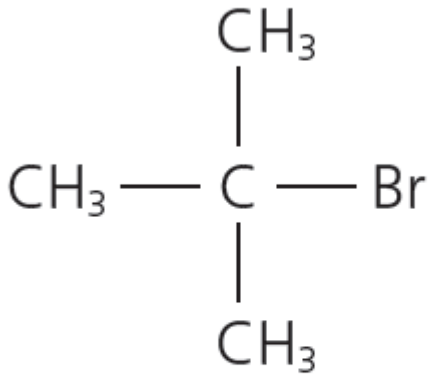
amine functional group

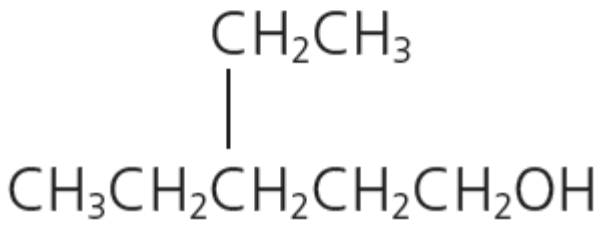
amide functional group (1+1+1)

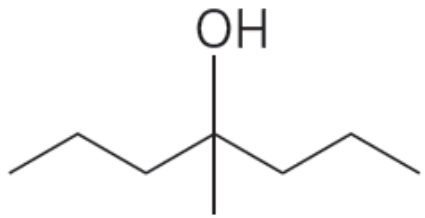
Unit Exercise (p.50)

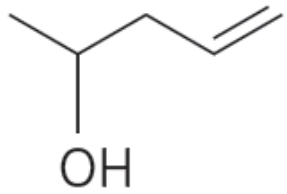
18 Give the systematic names of the compounds below.

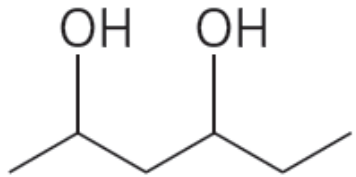
a) $CH_3CHClCHClCH_2CH_3$

b)


c)


d)


e)


f)


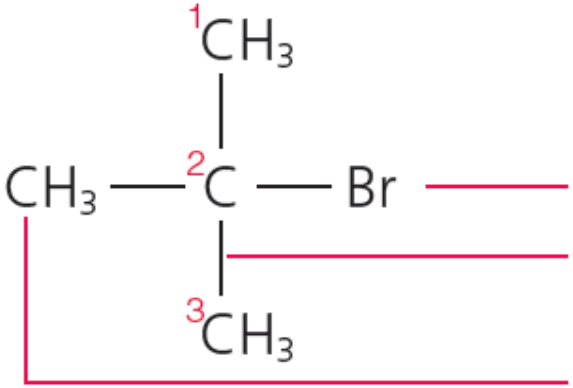
Unit Exercise (p.50)

a) $\overset{1}{C}H_3\overset{2}{C}HCl\overset{3}{C}HCl\overset{4}{C}H_2\overset{5}{C}H_3$

- an alkane containing 5 carbon atoms, i.e., pentane
- two chlorine atoms on carbon atoms 2 and 3, i.e. 2,3-dichloro

Thus, the systematic name of the compound is 2,3-dichloropentane. (1)

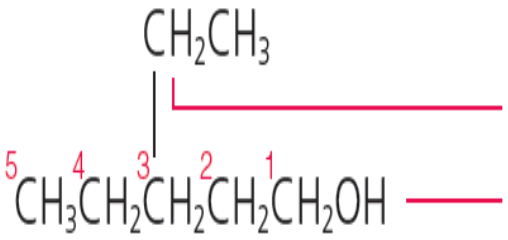
b)



- one bromine atom on carbon atom 2, i.e. 2-bromo
- parent chain containing 3 carbon atoms, i.e. propane
- one methyl group on carbon atom 2, i.e. 2-methyl

Thus, the systematic name of this compound is 2-bromo-2-methylpropane. (1)

c)

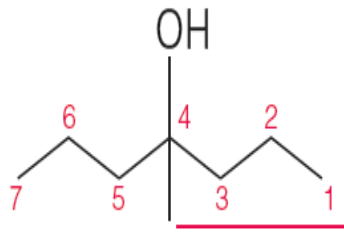


- one ethyl group on carbon atom 3, i.e. 3-ethyl
- an alcohol containing 5 carbon atoms, with the –OH group on carbon atom 1, i.e. pentan-1-ol

Thus, the systematic name of the compound is 3-ethylpentan-1-ol. (1)

Unit Exercise (p.50)

d)

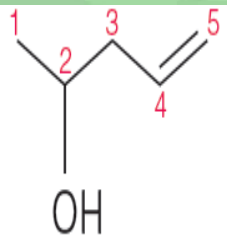


——— an alcohol containing 7 carbon atoms, with the –OH group on carbon atom 4, i.e. heptan-4-ol

——— one methyl group on carbon atom 4, i.e. 4-methyl

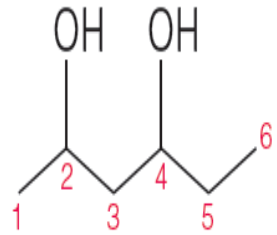
Thus, the systematic name of the compound is 4-methylheptan-4-ol. (1)

e)



This is an alcohol containing 5 carbon atoms, with the –OH group on carbon atom 2, and a C=C bond between carbon atoms 4 and 5. Thus, the systematic name of the compound is pent-4-en-2-ol. (1)

f)



This is an alcohol containing 6 carbon atoms, with two –OH groups on carbon atoms 2 and 4. Thus, the systematic name of the compound is hexane-2,4-diol. (1)

Unit Exercise (p.50)

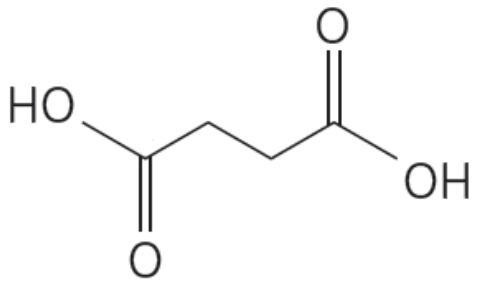
19 Identify the functional groups in the following compounds.

a) $CH_3CH_2CH_2CHO$

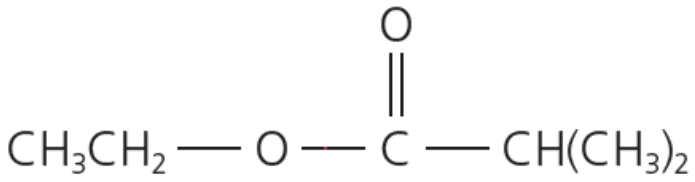
b) $CH_3CH_2COCH_2CH_3$

c) $CH_3CH(CH_3)COCH_3$

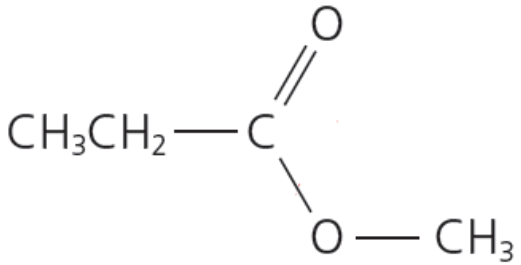
d)



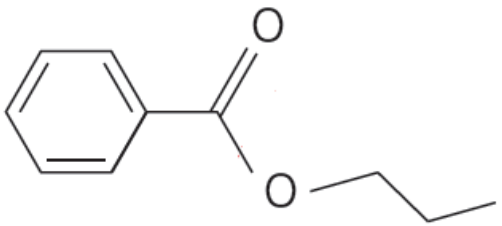
e)



f)



g)



Unit Exercise (p.50)

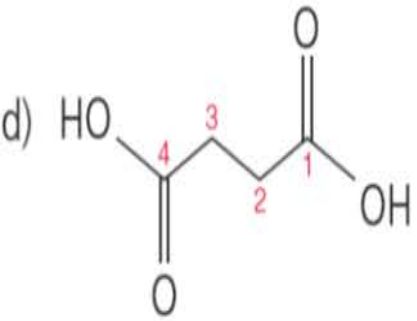
a) $CH_3CH_2CH_2CHO$ This is an aldehyde containing 4 carbon atoms. Thus, the systematic name of the compound is butanal. (1)

b) $CH_3CH_2COCH_2CH_3$ This is a ketone containing 5 carbon atoms, with the $C{=}O$ group in the middle. Thus, the systematic name of this compound is pentan-3-one. (1)

c) $CH_3\overset{4}{C}H(\overset{3}{C}H_3)\overset{2}{C}O\overset{1}{C}H_3$ — a ketone containing 4 carbon atoms, with the carbon atom of the $C{=}O$ group at position 2, i.e. butan-2-one

— one methyl group on carbon atom 3, i.e. 3-methyl

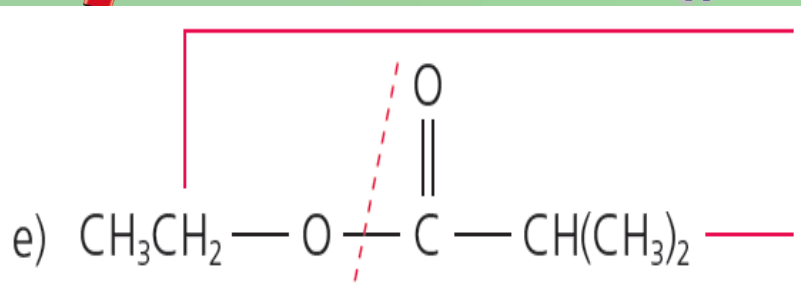
Thus, the systematic name of this compound is 3-methylbutan-2-one. (1)

d) 

Thus, the systematic name of this compound is 3-methylbutan-2-one. (1)

This is a carboxylic acid containing 4 carbon atoms, with two –COOH groups. Thus, the systematic name of this compound is butanedioic acid. (1)

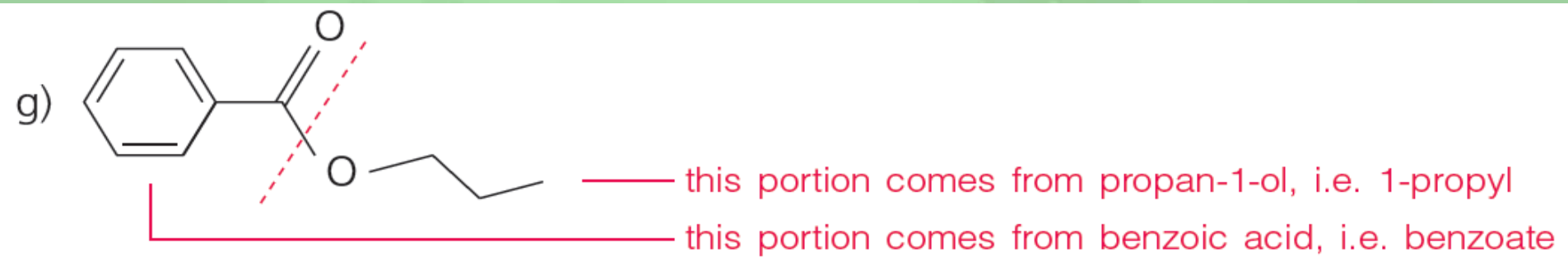
Unit Exercise (p.50)

e) 

Thus, the systematic name of the ester is ethyl methylpropanoate. (1)

f) 

Thus, the systematic name of this ester is methyl propanoate. (1)

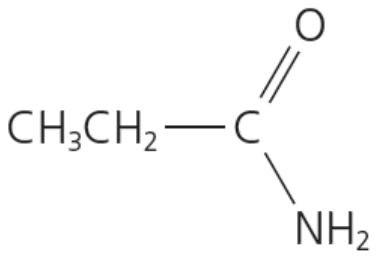
g) 

Thus, the systematic name of this ester is 1-propyl benzoate. (1)

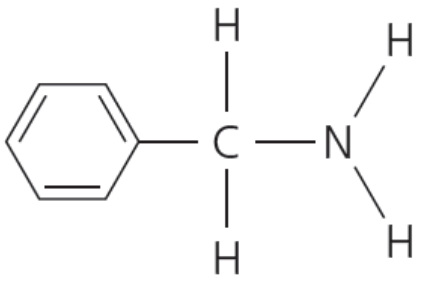
Unit Exercise (p.50)

20 Give the systematic names of the compounds below.

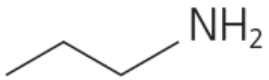
a)



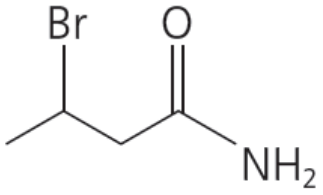
b)



c)

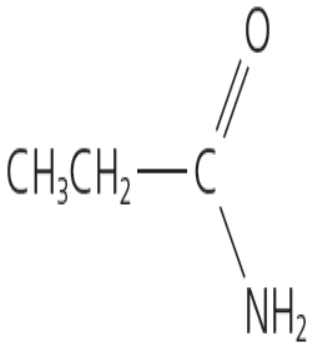


d)



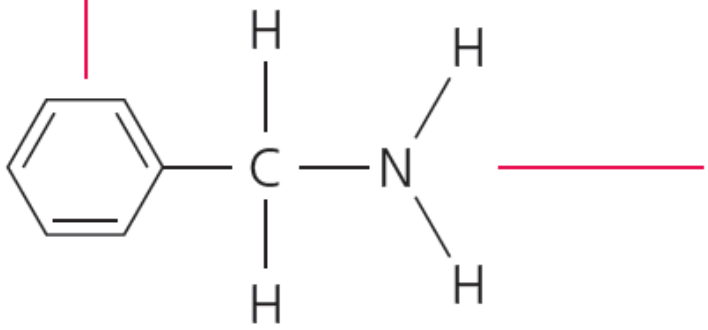
Unit Exercise (p.50)

a)



This is an amide containing 3 carbon atoms. Thus, the systematic name of the compound is propanamide. (1)

b)

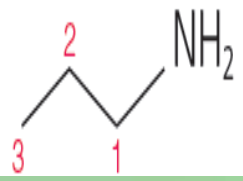


a phenyl group

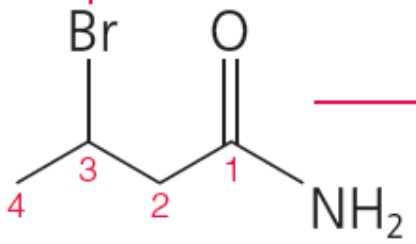
an amine containing 1 carbon atom, i.e. methanamine

Thus, the systematic name of the compound is phenylmethanamine. (1)

Unit Exercise (p.50)

c) 

This is an amine containing 3 carbon atoms, with the $-NH_2$ group on carbon atom 1. Thus, the systematic name of the compound is propan-1-amine. (1)

d) 

one bromine atom on carbon atom 3, i.e. 3-bromo

an amide containing 4 carbon atoms, i.e. butanamide

Thus, the systematic name of the compound is 3-bromobutanamide. (1)

Unit Exercise (p.50)

21 Write the structural formulae of the compounds below.

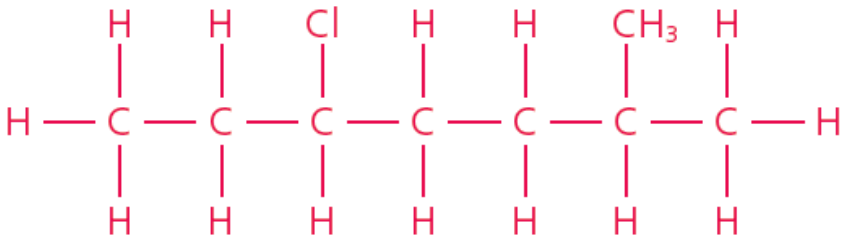
a) 5-chloro-2-methylheptane

b) butane-1,3-diol

c) 2-chloro-3-methylpentanoic acid

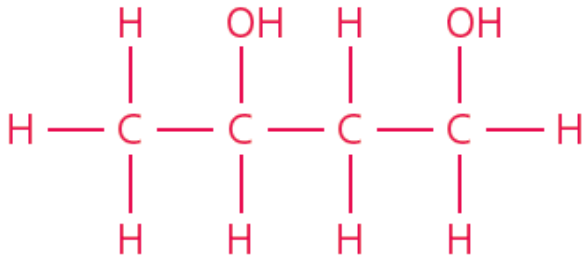
d) 2-bromobenzoic acid

a)

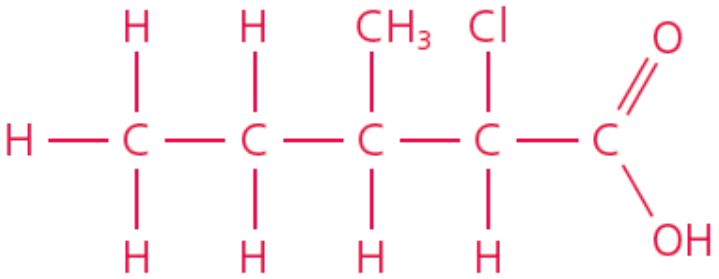


(1)

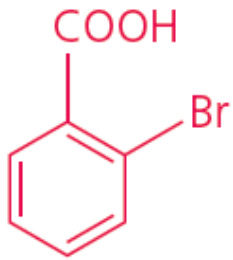
b)



c)



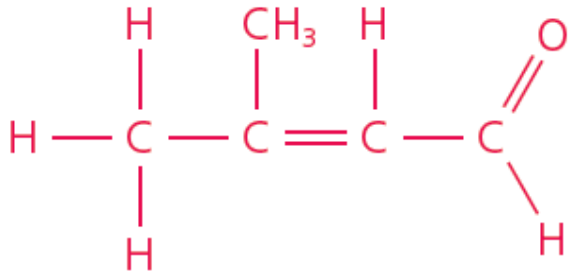
d)



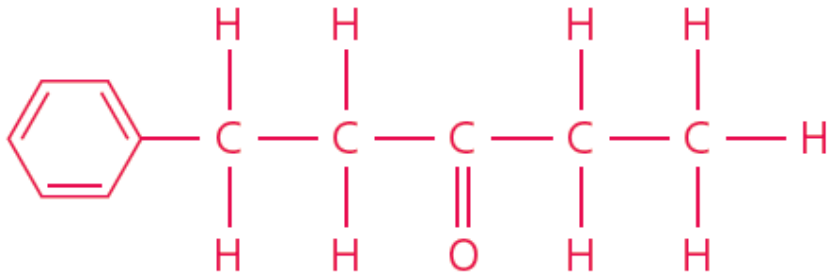
Unit Exercise (p.50)

e) 3-methylbut-2-enal
f) 1-phenylpentan-3-one
g) 2-methylpentanamide
h) 2,3-dimethylbutan-2-amine

e)

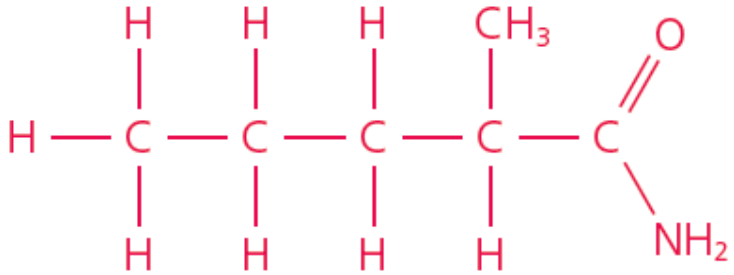


f)

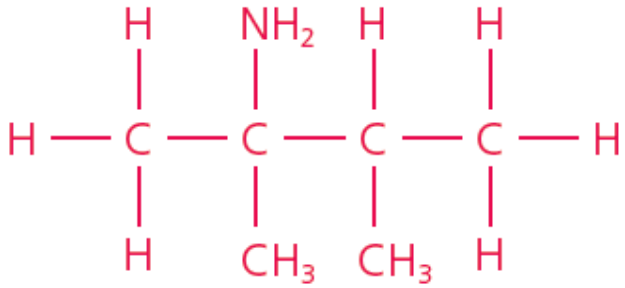


(1)

g)



h)



(1)

Unit Exercise (p.50)

22 Compound X shown below is an intermediate in the synthesis of a variety of substances.

$CH_3CH(OH)CH_2NH_2$

Explain why compound X is very soluble in water. Use a diagram in your answer.

Molecules of compound X can form hydrogen bonds with water molecules. (1)
Diagrams to show hydrogen bonding:

- between –OH group of compound X and lone pair on oxygen atom of water molecule (1)
- between $–NH_2$ group of compound X and lone pair on oxygen atom of water molecule (1)

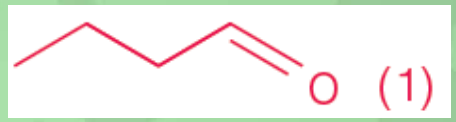
Unit Exercise (p.50)

23 Butanal and butanone have the same molecular formula.

a) Name the functional group common to butanal and butanone.

Carbonyl group (1)

b) Write the skeletal formula of butanal.



(1)

c) Explain why the boiling point of butanal is higher than that of propanal.

The carbon chain length of butanal is longer than that of propanal. (1)
Van der Waals' forces between the longer molecules are stronger. (1)
As a result, butanal has a higher boiling point than propanal.

d) Explain why butanone is soluble in water.

Butanone molecules can form hydrogen bonds with water molecules. (1)

Unit Exercise (p.50)

24 The table lists some properties of the first five carboxylic acids.

Carboxylic acid	Molecular formula	Boiling point (°C)
Methanoic acid	CH_2O_2	101
Ethanoic acid	$C_2H_4O_2$	118
Propanoic acid	$C_3H_6O_2$	141
Butanoic acid	$C_4H_8O_2$	?
Pentanoic acid	$C_5H_{10}O_2$	187

a) i) How does the boiling points of these carboxylic acids vary with the number of carbon atoms per molecule? The boiling points of carboxylic acids increase with increasing number of carbon atoms per molecule. (1)

ii) Suggest a value for the boiling point of butanoic acid.

Boiling point of butanoic acid is between 160 and 170 °C (actual value 164 °C). (1)

b) Explain the trend in water solubilities of carboxylic acids as the number of carbon atoms per molecule increases.

The water solubilities of carboxylic acids decrease with increasing number of carbon atoms per molecule. (1)

Molecules of carboxylic acids become larger with increasing number of carbon atoms per molecule. Large molecules of carboxylic acids cannot form hydrogen bonds with water molecules easily. (1)

Unit Exercise (p.50)

25 Arrange the following compounds in order of increasing boiling point. Explain your answer.

CH_3COCH_3 $CH_3CH_2CH_2CH_2OH$

$CH_3COCH_2CH_3$ $CH_3CH_2CH_2CONH_2$

The order of increasing boiling point of the compounds is:

$CH_3COCH_3 < CH_3COCH_2CH_3 < CH_3CH_2CH_2OH < CH_3CH_2CH_2CONH_2$ (1)

Hydrogen bonds exist in both $CH_3CH_2CH_2OH$ and $CH_3CH_2CH_2CONH_2$ while only van der Waals' forces exist in CH_3COCH_3 and $CH_3COCH_2CH_3$. (1)

Thus, the boiling points of $CH_3CH_2CH_2OH$ and $CH_3CH_2CH_2CONH_2$ are higher.

The carbon chain length of $CH_3COCH_2CH_3$ is longer than that of CH_3COCH_3. Van der Waals' forces between longer molecules are stronger. (1)

Thus, the boiling point of $CH_3COCH_2CH_3$ is higher than that of CH_3COCH_3.

The boiling point of $CH_3CH_2CH_2CONH_2$ is higher than that of $CH_3CH_2CH_2OH$ as $CH_3CH_2CH_2CONH_2$ can form more extensive hydrogen bonds. (1)

Communication mark (1)