TOPIC 1 INTRODUCTION TO ORGANIC CHEMISTRY

Teaching Aims

Functional groups and homologous series

Introduction to organic chemistry

Naming organic compounds (organic nomenclature)

Teaching Plan

1 Introduction: discussion of what organic chemistry is. Discuss why carbon forms so many compounds. Introduce the term 'functional group' and 'homologous series' (most will be familiar with these terms from GCSE).

Resource: *Teacher Notes*

2 Introduce all the functional groups found in the AS specification you are teaching (you will need to look these up).

Resources: *Resource Sheet 1*
Class Sheet 1
Worksheet 1

3 Naming alkanes. Introduce organic nomenclature by showing how to name the alkanes. Show that, despite the way they are drawn, the bond angles of the alkanes are not 90°. Build models if desired. Discuss the meaning of the terms 'structural formula', 'stereochemical formula', 'displayed formula' and 'skeletal formula'. Discuss the term 'isomerism'.

Resources: *Resource Sheet 2*
Resource Sheet 3
Resource Sheet 4
Class Sheet 2
Worksheet 2

4 Naming other organic compounds. Go through each functional group naming the first three or four members of the homologous series. Briefly explain the term *cis–trans* isomerism and what causes it.

Resources: *Class Sheet 3*
Worksheet 3

Timing: 8 lessons

Teacher notes

What is 'organic chemistry'?

Put simply, this is the study of compounds containing carbon–hydrogen bonds. There are over 10 million organic compounds known which, amazingly enough, is more than all the compounds of all the other (112) elements put together.

Why is this branch of chemistry called 'organic chemistry'?

Because the major source of compounds containing carbon and hydrogen is living (animals and plants) or once-living material (coal, oil and gas). For this reason, in the early nineteenth century Berzelius suggested that only substances obtainable from biological sources should be called organic compounds, in contrast to inorganic substances obtained from mineral sources. It was also believed that these compounds contained a 'vital force' that could be transmitted from one plant or animal to another.

It was not until Friedrich Wöhler accidentally prepared the organic compound urea from the inorganic salts potassium cyanate and ammonium sulfate (in an attempt to prepare ammonium cyanate) in 1828 that it was realised that organic compounds were *not* made exclusively by living organisms. However, the name still persists and, as stated above, is now the name applied to that branch of chemistry concerned with the study of compounds containing C–H bonds. This includes the vast majority of carbon compounds, but compounds such as CO, CO_2 and carbonates have been traditionally considered to belong to the field of inorganic chemistry.

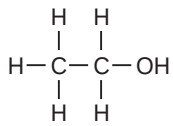
Why study organic chemistry?

Not only are there so many organic compounds, but many of them are very useful and important too.

- Living organisms are carbon based and contain thousands of different organic compounds. In order to understand how living systems work, one needs to know something about organic chemistry. The molecule of life itself, DNA, is an organic molecule.
- A knowledge of organic chemistry allows chemists to develop and manufacture medicines, antiseptics, disinfectants, agricultural chemicals, anaesthetics, plastics, polymers and fuels.

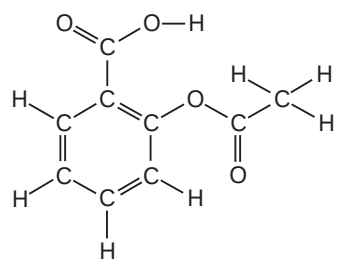
Some interesting organic molecules

- **Ethanol**



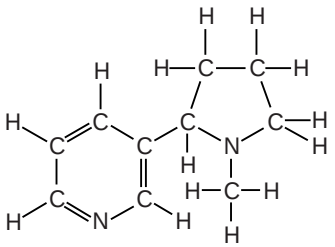
Present in all alcoholic drinks. Slows down the activity of the central nervous system (thus a depressant) so that messages take longer to travel along nerve fibres. As a result, we become slower to react. Interestingly, were alcohol to be discovered today, its sale would never be permitted because of its potentially lethal side-effects.

- **Aspirin**



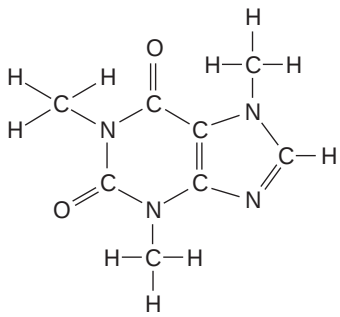
Painkiller. Safer derivative of the painkiller 2-hydroxybenzoic acid (salicylic acid), which was first extracted from willow bark. Not without risks itself. One of the most successful drugs ever made. Around 1.5 billion aspirin tablets are swallowed each year in the UK alone. Works by blocking the enzyme that produces the molecules (the prostaglandins) that help to transmit pain signals. It is now believed to help prevent heart disease.

- **Nicotine**



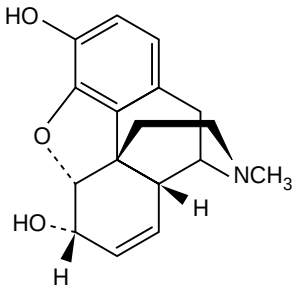
Found in the leaves of the tobacco plant. Highly toxic (2–3 drops of pure nicotine will kill if placed on the tongue). Acts as quickly as cyanide. Addictive.

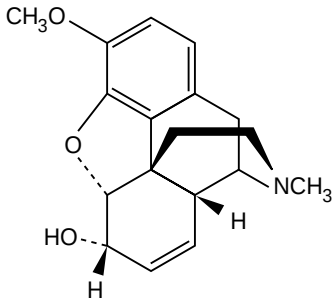
- **Caffeine**

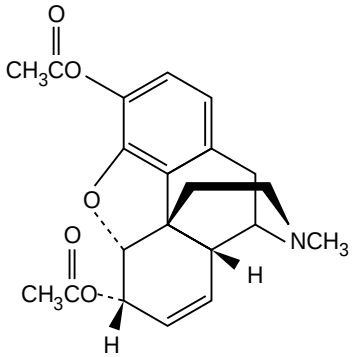


Found in coffee beans, tea leaves, chocolate and cola drinks. Stimulates the central nervous system, causing mental alertness and restlessness.

- **Morphine/codeine/heroin**

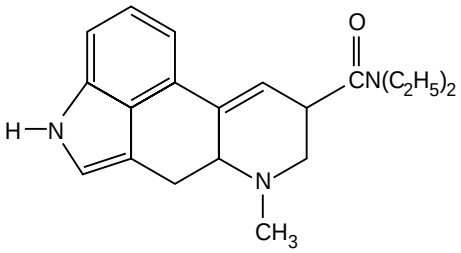






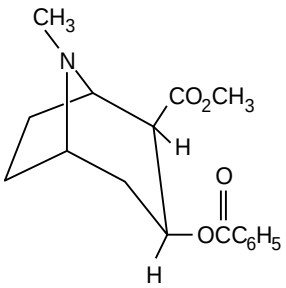
Classic demonstration of how slight differences in structure can change the response of a chemical in the body. Morphine, codeine and heroin are all painkillers and, like ethanol, are depressants. Heroin and morphine are narcotics, which means that they produce feelings of peace and tranquillity. Both are highly addictive. Codeine is only one-sixth as effective a painkiller as morphine, but does not cause addiction; it is used as a cough suppressant.

- **LSD (lysergic acid diethylamide)**



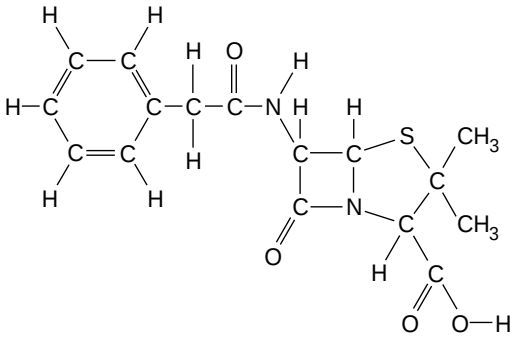
LSD is a hallucinogen. It causes changes in perception, especially visual perception. Causes mental damage as well as possible permanent personality change. Works by disrupting the transmission of nerve impulses to the brain.

- **Cocaine**



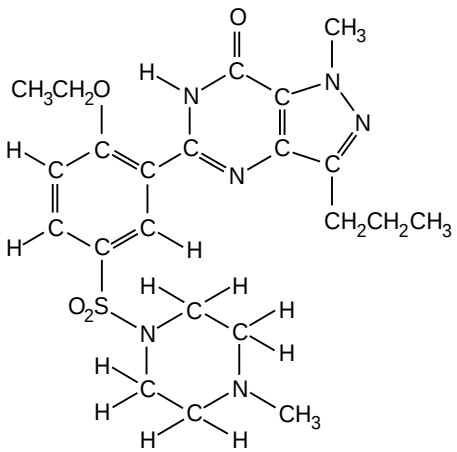
Once used as a local anaesthetic in dentistry and in so-called tonic wines – Queen Victoria was reputed to be very partial to these. It is still widely used as a drug of abuse. Causes nausea, weight loss, insomnia and psychological dependence. Was never present in Coca-Cola®!

- **Penicillin G**



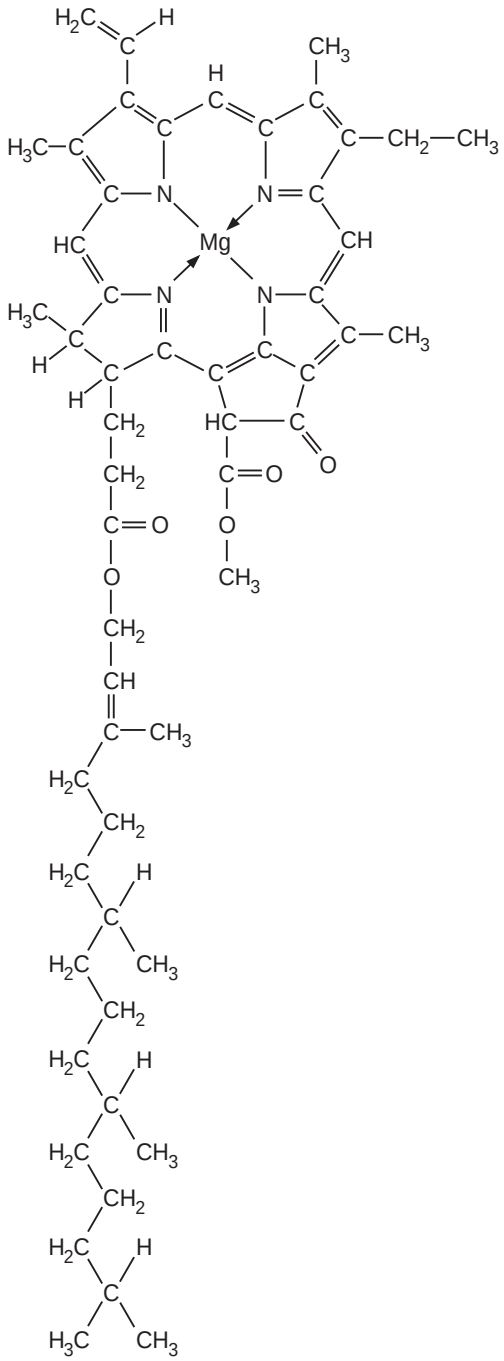
One of a family of compounds (discovered accidentally by Alexander Fleming in 1928), which have brought relief to millions since their introduction. They are 'antibiotics', i.e. fight bacterial infections (*not* viral infections) by blocking the enzyme responsible for building the cell wall of a new bacterium. Because of this inhibition, the enzyme never satisfactorily completes the cell wall and, eventually, the contents of the cell wall burst out and the bacterium dies. Worryingly, bacteria ('super bugs') are starting to appear that are resistant to even the most powerful antibiotics.

- **Viagra®**



Treatment for male erectile dysfunction. The process of erection follows the release of nitric oxide (NO), which produces the compound guanosine monophosphate. Guanosine monophosphate is a messenger compound that relaxes muscle and allows blood to flow into the penis. Viagra® works by blocking an enzyme that is responsible for breaking down the guanosine monophosphate into an inactive form, thus leading to much higher levels of guanosine monophosphate than would normally be the case.

- **Chlorophyll *a***

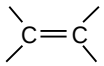
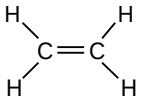
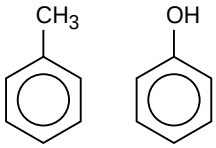
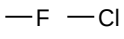
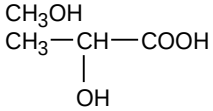
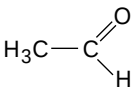
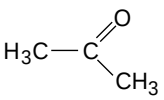
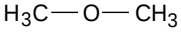
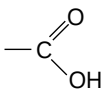
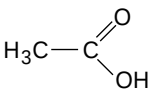
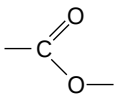
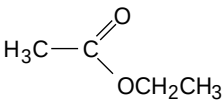
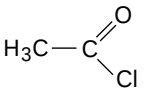
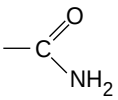
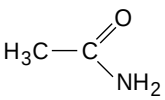
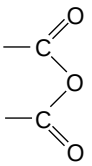
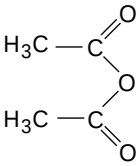


Essential molecule in the process of photosynthesis. Life would not be possible if plants were not able to trap energy from the sun using this molecule. Note the central magnesium ion bonded to four nitrogen atoms. Changes in the energies of electrons in this part of the molecule enable it to absorb light very strongly, giving it its intense green colour. When vegetation is cooked, the central magnesium is replaced with a hydrogen ion. This changes the colour of the leaves (often to a very insipid green).

Reading list and other resources

Atkins, P.W. (1991) *Molecules*, Scientific American Library.
Emsley, J. (1999) *Molecules at an Exhibition*, Oxford University Press.
Emsley, J. (1998) *The Consumer's Good Chemical Guide*, Oxford University Press.
Hancock, J. (1999) *The Right Chemistry*, Hodder and Stoughton.
Mann, J. (1992) *Murder, Magic and Medicine*, Oxford University Press.
Selinger, B. (2000) *Why the Watermelon Won't Ripen in Your Armpit*, Allen and Unwin.

The functional groups

Functional group	Family name	Name clues	Examples	Structure
	Alkene	-ene	Ethene	
	Alkyne	-yne	Ethyne	
	Arene	benz- phen-	Methylbenzene Phenol	
	Haloalkane	fluoro- chloro- bromo- iodo-	Chloromethane 1-Bromopropane	CH_3Cl $CH_3CH_2CH_2Br$
	Alcohol	-ol hydroxy-	Methanol 2-hydroxypropanoic acid	CH_3OH 
	Aldehyde	-al	Ethanal	
	Ketone	-one	Propanone	
	Ether	-oxy-	Methoxymethane	
	Carboxylic acid	-oic acid	Ethanoic acid	
	Ester	-oate	Ethyl ethanoate	
	Acid chloride	-oyl chloride	Ethanoyl chloride	
	Acid amide	-amide	Ethanamide	
	Acid anhydride	anhydride	Ethanoic anhydride	
	Nitrile	-nitrile	Propanenitrile	$CH_3CH_2C{\equiv}N$
	Amine	-amine	Ethylamine Phenylamine	$CH_3CH_2NH_2$ $C_6H_5NH_2$

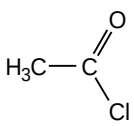
Class Sheet 1

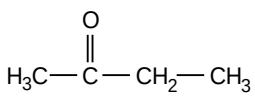
Functional groups

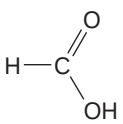
1 Complete the table below by drawing out the structures of the appropriate functional groups.

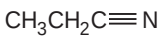
Functional group	Structure	Functional group	Structure
Alkene		Benzene	
Nitrile		Ketone	
Alcohol		Acid chloride	
Epoxide		Chloroalkane	
Aldehyde		Ester	
Carboxylic acid		Acid anhydride	
Acid amide		Amine	

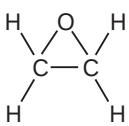
2 Identify the functional group present in the following organic molecules:

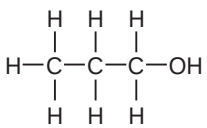
(a) 

(b) 

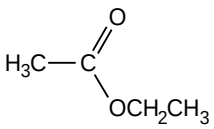
(c) 

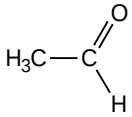
(d) 

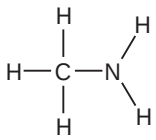
(e) 

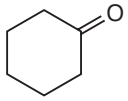
(f) 

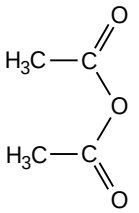
Class Sheet 1

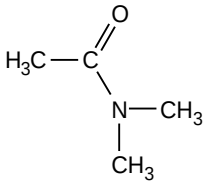
(g) 

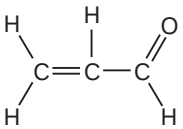
(h) 

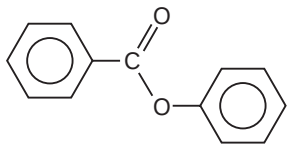
(i) 

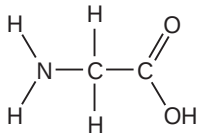
(j) 

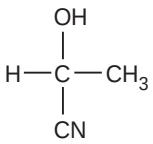
(k) 

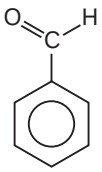
(l) 

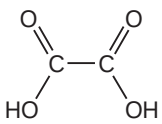
(m) 

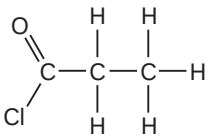
(n) 

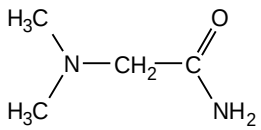
(o) 

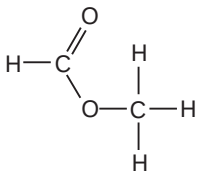
(p) 

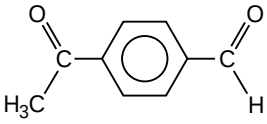
(q) 

(r) 

(s) 

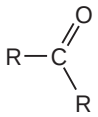
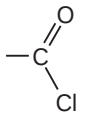
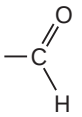
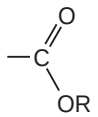
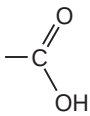
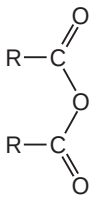
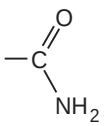
(t) 

(u) 

(v) 

Sheet 1

1

Functional group	Structure	Functional group	Structure
Alkene		Benzene	
Nitrile		Ketone	
Alcohol		Acid chloride	
Epoxide		Chloroalkane	
Aldehyde		Ester	
Carboxylic acid		Acid anhydride	
Acid amide		Amine	

2 (a) Acid chloride
(b) Ketone
(c) Carboxylic acid
(d) Nitrile
(e) Epoxide
(f) Alcohol
(g) Ester
(h) Aldehyde
(i) Amine
(j) Ketone
(k) Acid anhydride
(l) Acid amide
(m) Alkene + aldehyde
(n) Benzene + ester
(o) Amine + carboxylic acid
(p) Alcohol + nitrile
(q) Benzene + aldehyde
(r) Carboxylic acid
(s) Acid chloride
(t) Amine + acid amide
(u) Ester
(v) Ketone + benzene + aldehyde

Worksheet 1

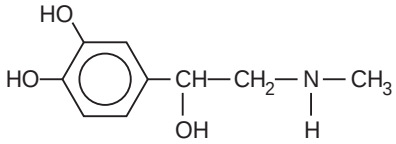
Introducing organic chemistry (I)

1 (a) Define the terms:
(i) functional group
(ii) homologous series

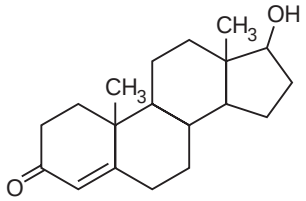
(b) Explain why, on going down a particular homologous series (increasing the number of carbon atoms), the chemical properties of the molecules may remain very similar, yet there is a gradual change in the physical properties of these same molecules.

2 Identify and name the functional groups in the following molecules:

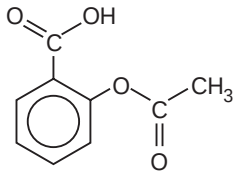
(a) Epinephrine (adrenaline)



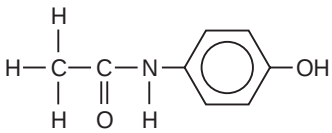
(b) Testosterone (male sex hormone)



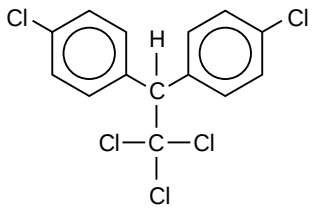
(c) Aspirin (a painkiller)



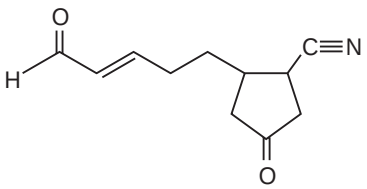
(d) Paracetamol (a painkiller)



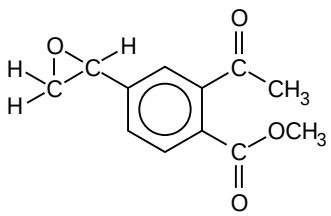
(e) DDT (a pesticide)



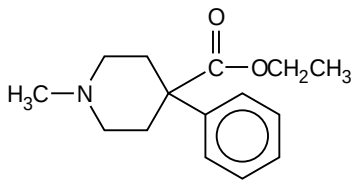
(f)



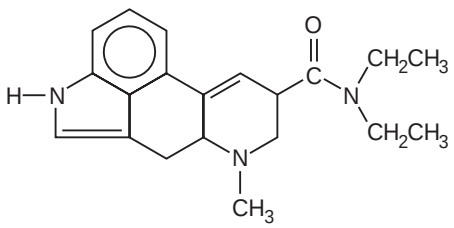
(g)



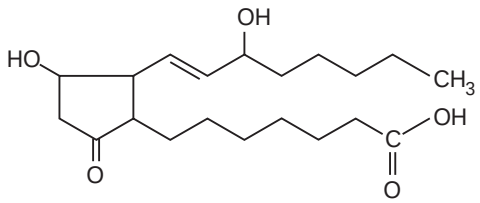
(h) Pethidine (a painkiller)



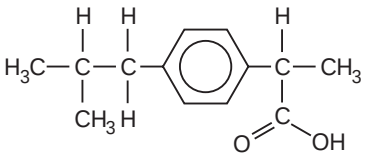
(i) LSD (a dangerous narcotic)



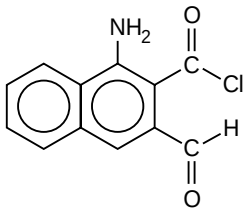
(j) Prostaglandin E_1



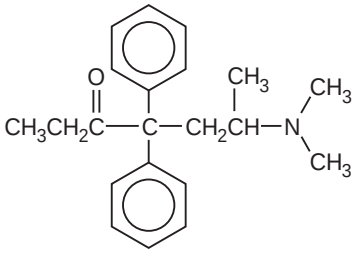
(k) Ibuprofen (a painkiller)



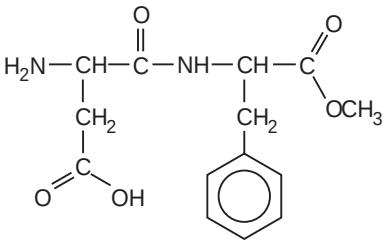
(l)



(m) Methadone



(n) Aspartame (an artificial sweetener)



3 A compound **X** has a relative molecular mass of 58 and percentage composition by mass C: 62.04%; H: 10.41%; O: 27.55%.

(a) Calculate the molecular formula of **X**.

(b) Draw two possible structural formulae for the isomers of **X**.

4 An organic compound **Y** has a relative molecular mass of 264 and percentage composition by mass C: 54.50%; H: 9.10%; O: 36.40%.

(a) Calculate the empirical formula of **Y**.

(b) Deduce its molecular formula.

5 A compound **Z** contains 62.1% carbon, 10.3% hydrogen and 27.6% oxygen by mass. When vaporised, 0.125 g of **Z** produced 66 cm^3 of dry vapour measured at 100°C and atmospheric pressure (101 kPa). $R = 8.314$ J $K^{-1}mol^{-1}$.

(a) Calculate the empirical formula of **Z**.

(b) Calculate the molecular formula of **Z**.

Sheet 1

1 (a) *Functional group* A single atom or group of atoms largely responsible for determining the chemical properties of the molecule or class of organic compounds.
Homologous series A family of organic compounds containing the same functional group. They can be represented by a general formula and each member of the series differs from the next one by a single CH_2 group. The compounds in a particular homologous series have similar chemical properties but gradually changing physical properties.

(b) The chemical properties of a particular homologous series depend upon the particular functional group present. On going down the homologous series (increasing the number of carbon atoms), the functional group does not change, so the chemical properties may remain very similar. However, on going down the homologous series, the molecules become bigger and bigger as successive CH_2 groups are added. This will have effects on the physical properties of the molecules, such as melting and boiling points, since these are determined by molecular size.

2 (a) Alcohol group (OH)
Benzene ring
Amine group (N–H)

(b) Alkene group (C=C)
Ketone group (C=O)
Alcohol group (OH)

(c) Benzene ring
Carboxylic acid group (COOH)
Ester group (COOR)

(d) Benzene ring
Alcohol group (OH)
Amide group (CONH)

(e) Benzene ring
Chloroalkane (Cl)

(f) Nitrile group (CN)
Aldehyde group (CHO)
Alkene group (C=C)
Ketone group (C=O)

(g) Epoxide group
Benzene ring
Ketone group ($COCH_3$)
Ester group ($COOCH_3$)

(h) Amine group ($N–CH_3$)
Ester group (COOR)
Benzene ring

(i) Benzene ring
Alkene group (C=C)
Amine group (N–H) and ($N–CH_3$)
Amide group ($CON(CH_2CH_3)_2$)

(j) Alcohol group (OH)
Ketone group (C=O)
Alkene group (C=C)
Carboxylic acid group (COOH)

(k) Benzene ring
Carboxylic acid group (COOH)

(l) Benzene ring
Amine group (NH_2)
Acid chloride group (COCl)
Aldehyde group (CHO)

(m) Ketone group (C=O)
Benzene ring
Amine ($N(CH_3)_2$)

(n) Amine group (NH_2)
Carboxylic acid group (COOH)
Amide group (CONH)
Ester group (COOR)
Benzene ring

3 (a) Empirical formula = C_3H_6O but r.m.m. = 58. Therefore, empirical formula = molecular formula.
(b) CH_3COCH_3 and CH_3CH_2CHO

4 (a) Empirical formula = C_2H_4O
(b) Empirical formula = C_2H_4O (mass = 44) but r.m.m. = 264. Therefore, actual compound is 264/44 = 6 times bigger, i.e. $(C_2H_4O) \times 6 = C_{12}H_{24}O_6$.

5 (a) Empirical formula = C_3H_6O.
(b) Using $PV = nRT$ (where $P = 101 \times 10^3$ Pa, $V = 6.6 \times 10^{-5}$ m^3, $R = 8.314\,\text{J K}^{-1}\text{mol}^{-1}$, $T = 373$ K), $n = 2.15 \times 10^{-3}$. Therefore, r.m.m. of **Z** = 58.15. Therefore, molecular formula of **Z** = C_3H_6O.

Sheet 2

1 (a) Propane
(b) Heptane
(c) 2-Methylbutane
(d) Hexane
(e) 2,2-Dimethylbutane
(f) 2,4-Dimethylhexane
(g) 2-Methylbutane
(h) 3-Methylpentane
(i) 3-Ethylheptane
(j) Methylcyclohexane
(k) 2,2-Dimethylpropane
(l) 1,2-Dimethylcyclopentane

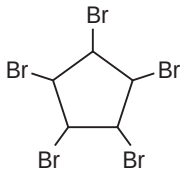
2 (a) $CH_3CH_2CH_2CH_2CH_3$
(b) $CH_3CH_2CH(CH_3)CH_2CH_2CH_3$
(c) $CH_3CH(CH_3)CH(CH_3)CH_2CH_2CH_3$
(d) $CH_3C(CH_3)_2CH(CH_3)CH_3$
(e) $CH_3CH(CH_3)CH_2CH(CH_3)CH(CH_3)CH_2CH_3$
(f) $CH_3CH(CH_3)CH(CH_2CH_3)CH(CH_3)CH_2CH_3$
(g) $CH_3CH(CH_3)CH(CH_3)CH(CH_3)CH_3$
(h) $CH_3C(CH_3)_2C(CH_3)(CH_2CH_3)CH_2CH_2CH_2CH_3$
(*Note* Full structural formulae have not been shown.)

3 (a) 2-Methylbutane
(b) 3-Ethylhexane
(c) 3,3,4-Trimethylhexane
(d) 3-Methylhexane
(e) 4-Ethyl-2,2-dimethylhexane (or 3-ethyl-5,5-dimethylhexane)
(f) 4-Ethyl-3,5-dimethyloctane
(g) 2,3-Dimethylhexane
(h) 2,2-Dimethylbutane

4 (a) Hexane
(b) 2-Methylbutane
(c) 2,2-Dimethylpentane
(d) 3-Methylpentane
(e) 2,2,3-Trimethylbutane
(f) 2,2,3,3-Tetramethylpentane

5 (a) 2-Iodopropane
(b) 2,2-Diiodobutane
(c) 1,2-Dibromopropane
(d) 2,3-Dichloropentane
(e) 1,1-Dibromopropane
(f) Dichloromethane
(g) 2-Bromo-3-chloro-6-methylheptane
(h) 1-Fluoro-2-methylpropane
(i) 1,1,1-Triiodoethane
(j) 2-Bromo-3-methylpentane
(k) 1-Chloro-2-methylcyclopentane
(l) 2,4-dichloro-4-methylhexane
(m) Dibromochlorofluoromethane
(n) 1-Bromo-1-chloro-2,2,2-trifluoroethane
(o) 1,2,3,4,5,6-Hexachlorocyclohexane

6 (a) $CH_3CHICH_2CH_3$
(b) $CH_3CHClCH(CH_3)CH_2CH_2CH_3$
(c) $CH_3CHClCHBrCH_2CH_2CH_2CH_3$
(d) FCH_2CHFCH_2F
(e)



(f) $ICH_2CH_2CHICH(CH_3)CH_3$

(*Note* Full structural formulae have not been shown in every case.)