Unit 26

Homologous series, structural formulae and naming of carbon compounds

26.1 A look at molecules of compounds in petroleum

The gaseous fraction from fractional distillation of petroleum contains compounds with low boiling points (less than 40 °C). The hydrocarbon molecules in this fraction contain 1 to 4 carbon atoms. On the other hand, the liquid fractions consist of molecules having from 5 to more than 25 carbon atoms.

Now complete the following discussion to learn more about the physical properties of hydrocarbons.

Worksheet
A worksheet on this activity is available for download from *Jing Kung Chemistry Website.*

Discussion

Refer to page T23.

Table 26.1 shows the boiling points of some hydrocarbons.

Table 26.1 Boiling points of some hydrocarbons

Hydrocarbon	Molecular formula	Boiling point (°C)
Butane	C_4H_{10}	–0.5
Ethane	C_2H_6	–89
Heptane	C_7H_{16}	98
Hexane	C_6H_{14}	69
Methane	CH_4	–162
Octane	C_8H_{18}	126
Pentane	C_5H_{12}	36
Propane	C_3H_8	–42

Chemists often gather data about the physical properties of substances. These data can be organized in many ways. The most useful way is the one that tells us the trends among the data.

1 Propose a useful way to arrange the data in Table 26.1.

2 Reorganize the data table based on your proposal.

You may notice that there is a trend among the molecular formulae and boiling points of the hydrocarbons shown in Table 26.1. These hydrocarbons are members of the homologous series alkanes. So, what is a homologous series? Is there any trend among properties of members in the same homologous series? Can we predict the properties of an unfamiliar member of a homologous series from those of known members, in a way similar to working with elements of the same group of the periodic table?

26.2 Chemistry of carbon compounds

Hydrocarbons and their derivatives are the focus of the branch of chemistry known as chemistry of carbon compounds. These substances are also called 'organic compounds' because early chemists thought that such compounds were made by living things (the word 'organic' means living). Later this was found to be untrue. At present, the name 'carbon compound' is applied to all carbon-containing compounds*.

> * Simple carbon-containing compounds such as oxides of carbon, carbonates, hydrogencarbonates, carbides, cyanides are regarded as inorganic compounds.

Carbon — a unique element

There are millions of different carbon compounds*. The ability of carbon to form so many compounds lies in its unique structural and bonding properties.

> * Carbon forms many more compounds than other elements.

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- Carbon atoms are able to join up with one another to form carbon chains of different sizes. The carbon chains may be short or long; straight, branched or ring-shaped.
- The ability of each carbon atom to form four single covalent bonds allows atoms of other elements to join to a carbon chain or ring.

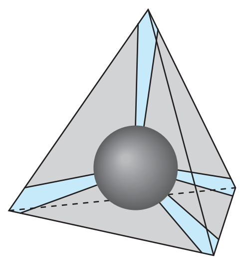
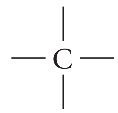


Fig. 26.1 The four covalent bonds of a carbon atom are arranged in a tetrahedral shape

- T e four covalent bonds of a carbon atom are actuall arranged in a tetra edral s ape (Fig. 26.1), as in diamond*. However, for convenience sake, t e bonds are written like t is:



- One carbon atom can also form double and triple covalent bonds wit anot er carbon atom (T able 26.2)*.

*The structure of diamond is a giant network of carbon atoms joined together by strong covalent bonds.

*A carbon atom can also form double and triple covalent bonds with other atoms, e.g.

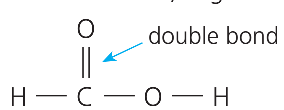
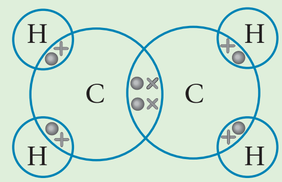
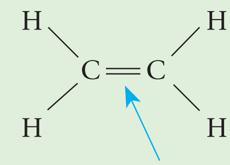
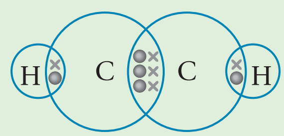
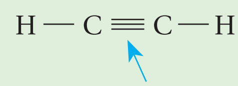


Table 26.2 Compounds containing a double bond or triple bond between two carbon atoms

Compound	Electron diagram	Structure
Ethene		
Ethyne		

26.3 Representing molecular structures of carbon compounds

Structural formulae

We ave learnt t at t e molecular formula of a compound s ows t e number of atoms of different elements in one molecule of t e compound. However, t e molecular formula does not s ow ow t e atoms are arranged in t e molecule.

Consider t e following two compounds: butane and met lpropane.

Butane and met lpropane ave t e same molecular formula * C_4H_{10}, but t e are different compounds. Atoms of t eir molecules link toget er in different wa s.

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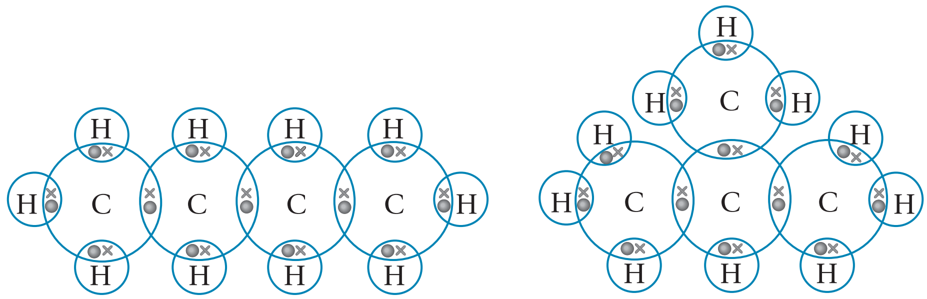
*Compounds with the same molecular formula but with their atoms arranged in different ways are isomers. We will discuss isomers in Topic 8 Chemistry of Carbon Compounds.



butane
(molecular formula C_4H_{10})

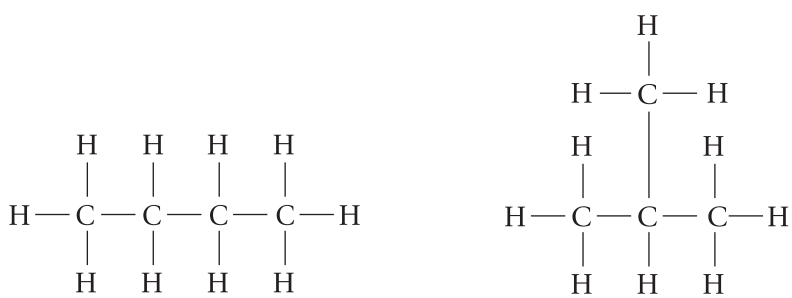
methylpropane
(molecular formula C_4H_{10})

Fig. 26.2 Different compounds with the same molecular formula (only electrons in the outermost shells are shown here)

N1 Refer to page T23.

N2 Refer to page T24.

The **structural formula** of a compound shows how the atoms N1 are linked together. The two compounds above can be represented by the following structural formulae: N2



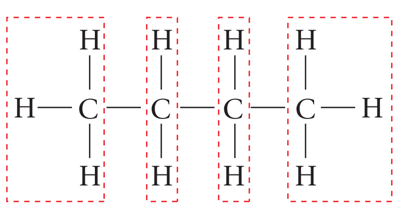
butane

methylpropane

Fig. 26.3 Structural formulae of butane and methylpropane

Condensed structural formulae

Another way for writing the structural formula of a compound is the **condensed structural formula**. This method emphasizes groups of atoms in a compound. For example, the structural formula of butane may be written as:



or $CH_3CH_2CH_2CH_3$
(condensed structural formula)

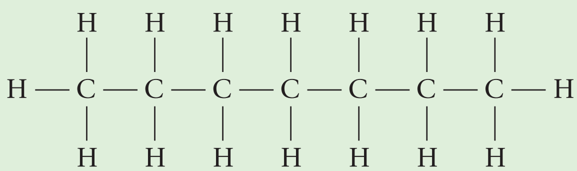
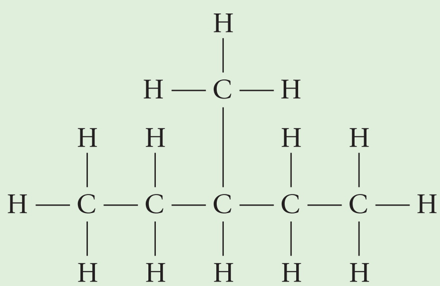
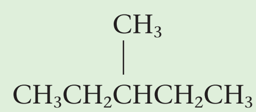
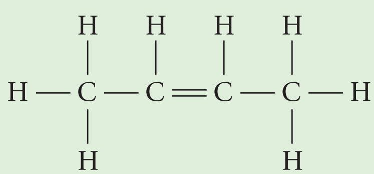
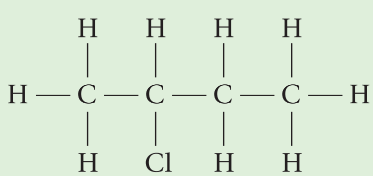
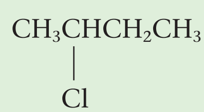
or $CH_3(CH_2)_2CH_3$
(condensed structural formula)

Fig. 26.4 The structural formula of butane can be written in a condensed form

structural formula 結構式 condensed structural formula 簡明結構式

In condensed structural formulae, we omit single bonds (except those joining anything other than hydrogen atoms to the main carbon chain). However, we must write carbon-carbon multiple bonds (that is C=C or C≡C). Table 26.3 shows more examples.

Table 26.3 Some examples of structural formulae and condensed structural formulae

Structural formula	Condensed structural formula
	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$ or $CH_3(CH_2)_5CH_3$
	 or $CH_3CH_2CH(CH_3)CH_2CH_3$
	$CH_3CH{=}CHCH_3$
	 or $CH_3CHClCH_2CH_3$

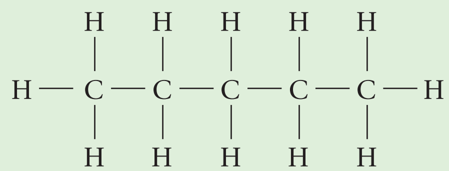
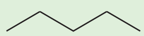
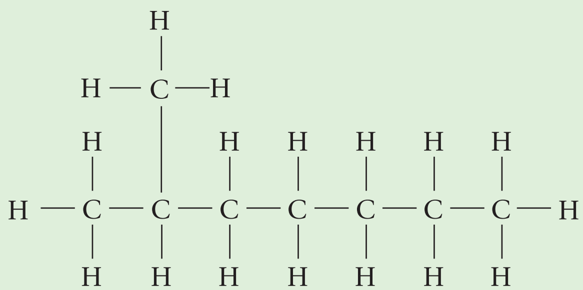
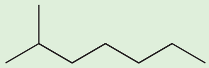
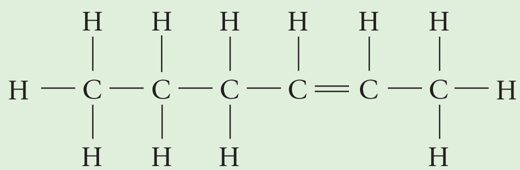
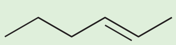
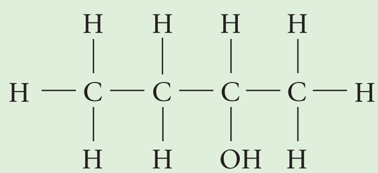
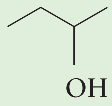
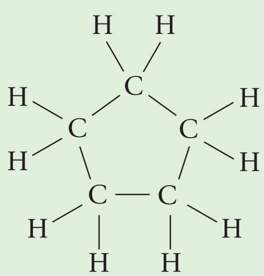
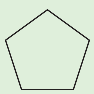
Skeletal formulae

Formulae that show only how the carbon atoms are bonded are called **skeletal formulae**. In these formulae, all the carbon and hydrogen atoms are omitted and only heteroatoms (e.g. oxygen or nitrogen) are shown explicitly.

skeletal formula 骨架式

Skeletal formulae depict the carbon skeleton of a molecule using a *zig-zag line*. Each intersection or end of line represents a carbon atom with the appropriate number of hydrogen atoms. Table 26.4 shows some examples.

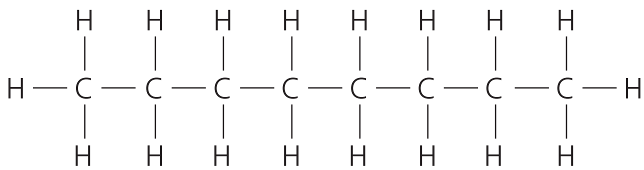
Table 26.4 Some examples of structural formulae and skeletal formulae

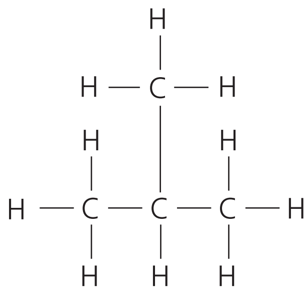
Structural formula	Skeletal formula
	
	
	
	
	

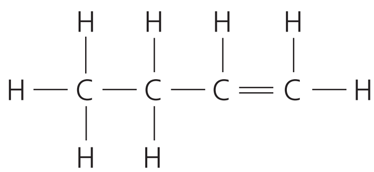
zig-zag line 鋸齒形線

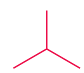
Checkpoint

1 Draw the condensed structural formulae and skeletal formulae of the following compounds.

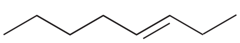
a) 

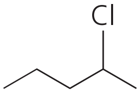
b) 

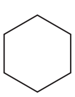
c) 

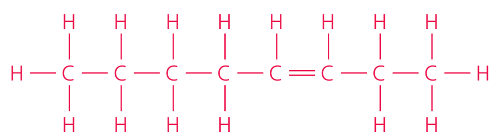
	Condensed structural formula	Skeletal formula
(a)	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$ or $CH_3(CH_2)_6CH_3$	
(b)	CH_3CHCH_3 with CH_3 on the middle C, or $CH_3CH(CH_3)CH_3$	
(c)	$CH_3CH_2CH=CH_2$	

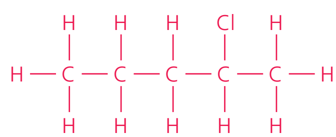
2 Draw the structural formulae of the following compounds.

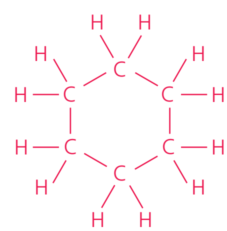
a) 

b) 

c) 

a) 

b) 

c) 

Animation
Molecular model

26.4 Molecular models

The molecular structures of carbon compounds are actually three-dimensional*. It is useful to use molecular models to show the exact molecular structures and shapes of carbon compounds. The simplest models are ball-and-stick models (Fig. 26.5a). To get a more accurate idea of how close together different atoms are in a compound, we use space-filling models (Fig. 26.5b).

* We have discussed molecular shapes in Topic 6 Microscopic World II.

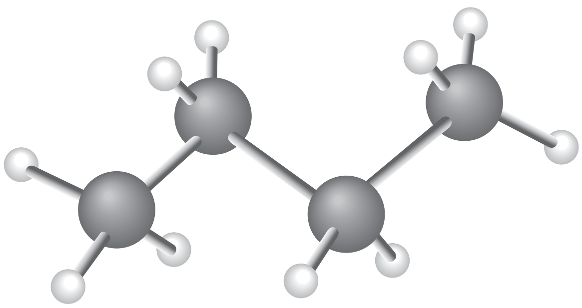


Fig. 26.5a A ball-and-stick model of a carbon compound

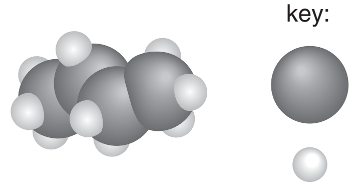
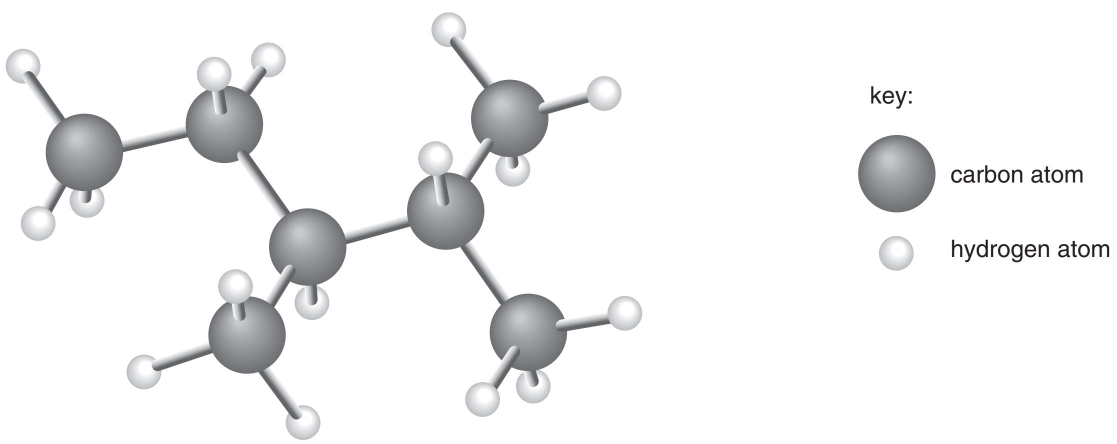


Fig. 26.5b A space-filling model of a carbon compound

Checkpoint

The molecular model of a compound is shown below.



a) Write the molecular formula of the compound.

C_7H_{16}

b) Draw the condensed structural formula and the skeletal formula of the compound.

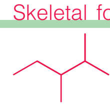
Condensed structural formula:

$$\begin{array}{l}\quad\quad\ \ CH_3CH_3\\ \quad\quad\quad\ |\quad |\\ CH_3CH_2CHCHCH_3\end{array}$$

or

$CH_3CH_2CH(CH_3)CH(CH_3)CH_3$

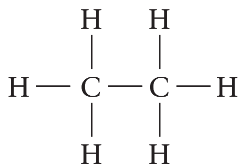
Skeletal formula:



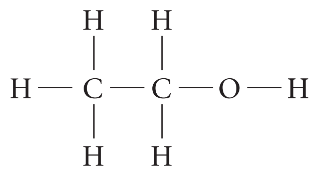
26.5 Functional groups

Most of the compounds discussed so far are hydrocarbons. However, there are many carbon compounds with atoms other than hydrogen joined to the main carbon chain.

Consider two compounds — ethane and ethanol. Their structural formulae are:



ethane



ethanol

Ethane and ethanol have similar molecular structures except that one hydrogen atom in ethane is replaced by a hydroxyl group –O–H in ethanol. However, they have very different properties (Table 26.5).

Table 26.5 Some properties of ethane and ethanol

Property	Ethane	Ethanol
State at room temperature and pressure	gas	liquid
Reaction with sodium	no reaction	reacts to give hydrogen gas

Clearly, the hydroxyl group –O–H in ethanol has a great effect in modifying the properties of the ethane skeleton. The hydroxyl group –O–H in ethanol is an example of a **functional group**.

> A functional group is an atom, or a group of atoms, which determines most of the properties of a compound.

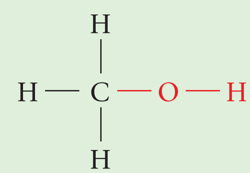
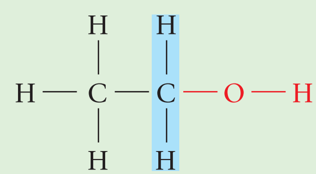
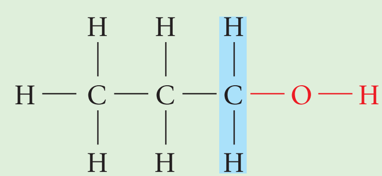
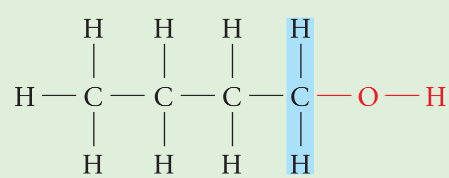
A given functional group, such as –O–H, has similar effect whatever the size and shape of the hydrocarbon skeleton it is attached to. This greatly simplifies the study of carbon compounds because we can regard all compounds containing the same functional group to be members of the same family with similar properties. Compounds containing the hydroxyl group –O–H are alkanols.

functional group 官能基

26.6 Homologous series

A family of compounds containing the same functional group is called a **homologous series**. Methanol, ethanol, propan-1-ol and butan-1-ol are the first four members of the homologous series of alkanols (Table 26.6). Their structural formulae show that each alkanol differs from the next by a $-CH_2-$ unit.

Table 26.6 The first four members of the homologous series of alkanols

Name	Molecular formula	Structural formula
Methanol	CH_3OH	
Ethanol	C_2H_5OH	
Propan-1-ol	C_3H_7OH	
Butan-1-ol	C_4H_9OH	

The properties of an alkanol are affected by the hydroxyl group and the size of the hydrocarbon portion. Therefore members of a homologous series show a steady gradation in properties as the size of the hydrocarbon portion increases.

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CE 2005 Paper 1 Q5(a)
CE 2007 Paper 2 Q4

Members in a homologous series show the following characteristics:

1 They have the same **general formula**. For example, the general formula of alkanols is $C_nH_{2n+1}OH$, where n = 1, 2, 3, 4, etc.

homologous series 同系列 general formula 通式

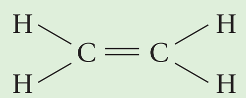
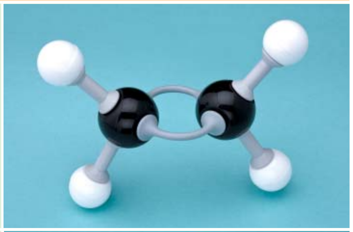
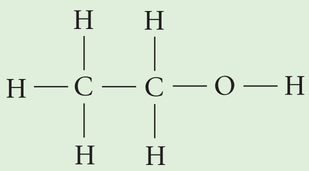
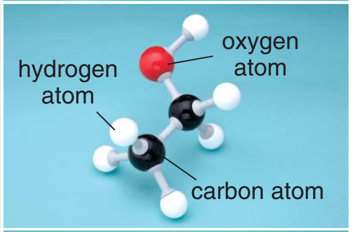
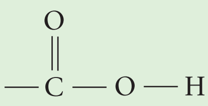
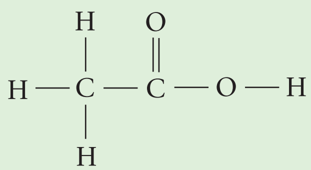
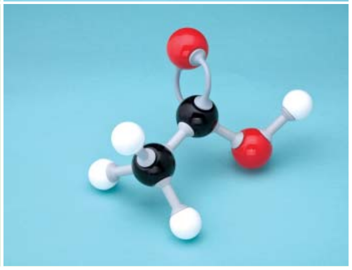
2 Each member in a homologous series differs from the next by a $-CH_2-$ unit.

3 They show a gradual change in physical properties.

4 They show similar chemical properties.

Table 26.7 shows some common functional groups and homologous series.

Table 26.7 Some common functional groups

Functional group		Homologous series		Example	
Formula	**Name**	**General formula**	**Name**		
$>C=C<$	—	C_nH_{2n}	alkene	 ethene	
$-O-H$	hydroxyl group	$C_nH_{2n+1}OH$	alkanol	 ethanol	
	carboxyl group	$C_nH_{2n+1}COOH$	alkanoic acid	 ethanoic acid	

CE 2003 Paper 2 Q8

In the following activity, you are going to build molecular models of alkenes, alkanols and alkanoic acids.

Activity 26.1

Building molecular models of alkenes, alkanols and alkanoic acids.

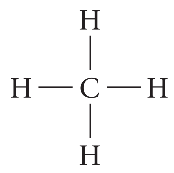


Fig. 26.6 Structural formula of methane

26.7 The alkanes

CE 1998 Paper 2 Q3

The major component of natural gas is methane. Each methane molecule contains one carbon atom and four hydrogen atoms (Fig. 26.6). Methane is the simplest member of the homologous series of alkanes.

The general formula of members of the alkane series is C_nH_{2n+2}, where n = 1, 2, 3, 4, etc. It is possible to have alkanes with straight or branched chains (Fig. 26.7).

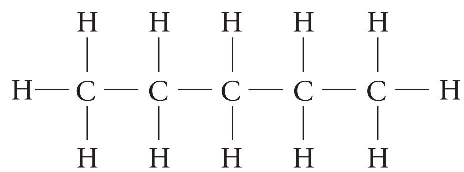


Fig. 26.7a A straight-chain alkane

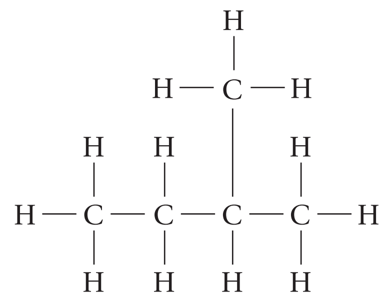


Fig. 26.7b A branched-chain alkane

Table 26.8 shows the condensed structural formulae of some simple straight-chain alkanes. Notice that each member differs from the next by a $-CH_2-$ unit.

Table 26.8 Condensed structural formulae of some simple straight-chain alkanes

Name	Molecular formula	Condensed structural formula
Methane	CH_4	CH_4
Ethane	C_2H_6	CH_3CH_3
Propane	C_3H_8	$CH_3CH_2CH_3$
Butane	C_4H_{10}	$CH_3CH_2CH_2CH_3$
Pentane	C_5H_{12}	$CH_3CH_2CH_2CH_2CH_3$
Hexane	C_6H_{14}	$CH_3CH_2CH_2CH_2CH_2CH_3$
Heptane	C_7H_{16}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$
Octane	C_8H_{18}	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$

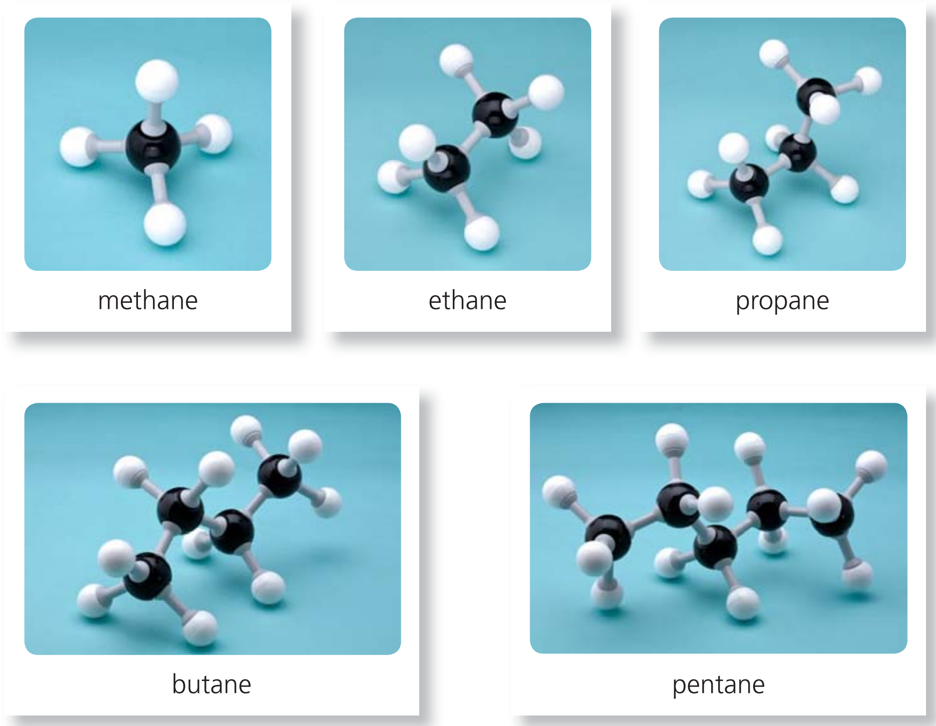


Fig. 26.8 Molecular models of the first five members of the alkane series

In the following activity, you are going to build molecular models of alkanes.

Activity 26.2

Building molecular models of alkanes.

26.8 Naming straight-chain and branched-chain alkanes

A systematic way of naming carbon compounds is used throughout the world. It is known as the IUPAC (International Union of Pure and Applied Chemistry) system. We will learn how to name alkanes and other carbon compounds using this system.

Straight-chain alkanes

To name straight-chain alkanes, use a **prefix** to show how many carbon atoms are in the straight chain, followed by the **suffix** -ane. Table 26.9 shows the names and prefixes for the first eight alkanes.

Reference Website

Refer to the following website for tutorials and exercises on the nomenclature of carbon compounds: http://cd1.edb.hkedcity.net/cd/science/chemistry/resource/naming/t4_main.htm

prefix 詞首　suffix 詞尾

Table 26.9 Prefixes and names for the first eight alkanes

Structural formula of alkane	Number of carbon atoms per molecule	Prefix	Name of alkane
CH_4	1	meth–	methane
CH_3CH_3	2	eth–	ethane
$CH_3CH_2CH_3$	3	prop–	propane
$CH_3CH_2CH_2CH_3$	4	but–	butane
$CH_3CH_2CH_2CH_2CH_3$	5	pent–	pentane
$CH_3CH_2CH_2CH_2CH_2CH_3$	6	hex–	hexane
$CH_3CH_2CH_2CH_2CH_2CH_2CH_3$	7	hept–	heptane
$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	8	oct–	octane

Branched-chain alkanes

To name branched-chain alkanes, consider them as straight-chain alkanes with hydrogen atoms replaced by alkyl groups*.

* Alkyl groups are often represented by the symbol R–. They have a general formula C_nH_{2n+1}–, where n = 1, 2……

Alkyl groups are derived from alkanes by the removal of a hydrogen atom. Name an alkyl group by replacing the suffix -ane of the parent alkane by -yl. Table 26.10 gives the names and the formulae of the first four alkyl groups.

Table 26.10 Names and formulae of the first four alkyl groups

Name	Formula
Methyl	CH_3–
Ethyl	C_2H_5–
Propyl	C_3H_7–
Butyl	C_4H_9–

The IUPAC name for a branched-chain alkane consists of two parts:

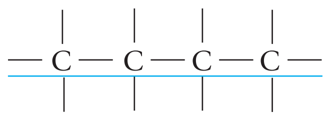
Prefixes — identify the alkyl groups and give their locations

Parent — describes the main carbon chain

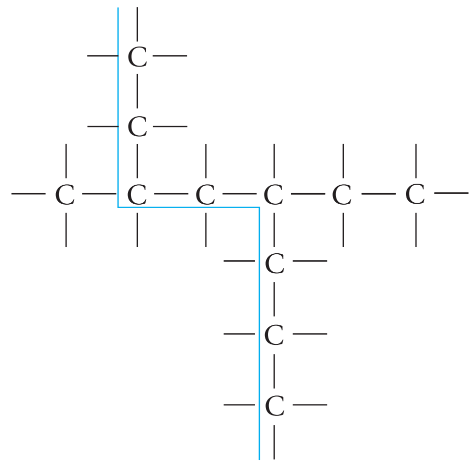
The IUPAC rules for naming branched-chain alkanes are as follows:

1 Locate the longest continuous chain of carbon atoms. This is the parent chain. Use the IUPAC system to name the parent chain. Notice that the longest continuous carbon chain may not appear in a straight line.

Examples:

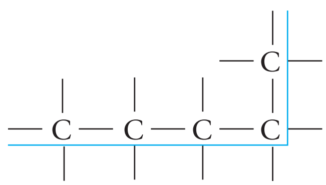


butane parent chain



octane parent chain

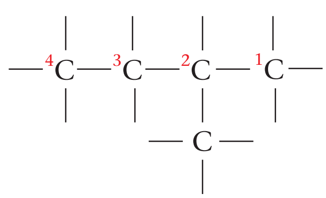
ASL 2006 Q11(a)(i)



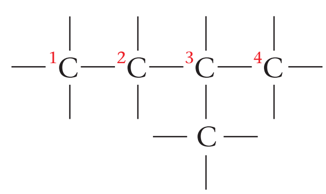
pentane parent chain

2 Number the parent chain, starting from the end nearest to the alkyl group(s).

Example:



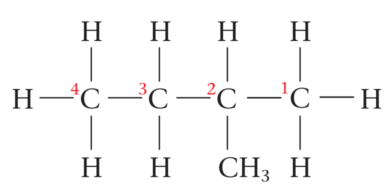
✓



✗

3 Name each alkyl group. Assign a number to each alkyl group, matching the number of the carbon atom where it attaches to the parent chain. Place the number in front of the name of each alkyl group, followed by a hyphen.

Example:

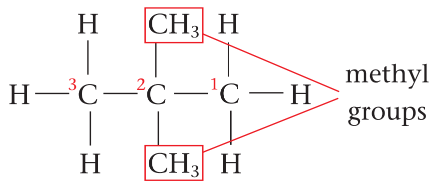


2-methylbutane

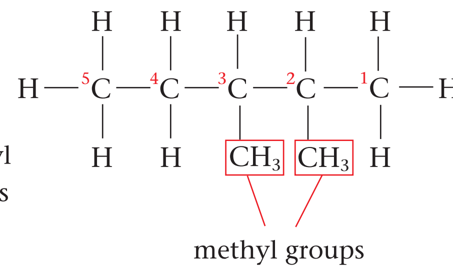
4 If two or more identical alkyl groups are attached to the parent chain, specify this by numerical prefixes.

Number of identical alkyl groups	Numerical prefix
2	di–
3	tri–
4	tetra–

Examples:



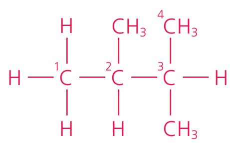
2,2-dimethylpropane*



2,3-dimethylpentane N3

> * Separate two numbers by a comma ','.

N3

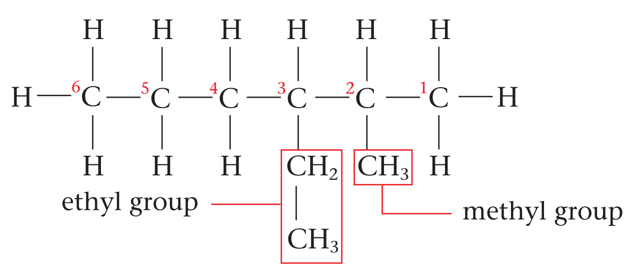


The IUPAC name of the above alkane is 2,3-dimethylbutane.

5 If two or more different alkyl groups are attached to the parent chain, list them in alphabetical order (for example, ethyl before methyl).

CE 2005 Paper 2 Q1
ASL 2008 Paper 2 Q2(a)(i)
AL 2008 Paper 2 Q5(a)(i)

Example:



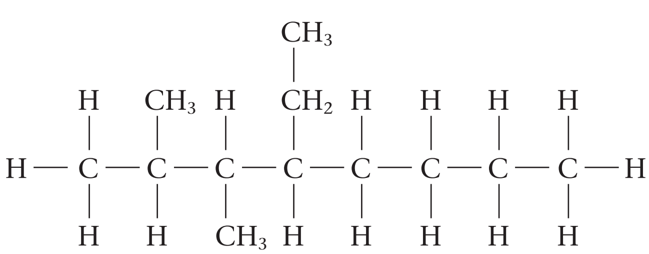
3-ethyl-2-methylhexane*

> * Use hyphen '–' between a number and a letter. Notice that 'ethyl' is listed before 'methyl' although the methyl group is attached to the second carbon atom and the ethyl group to the third atom.

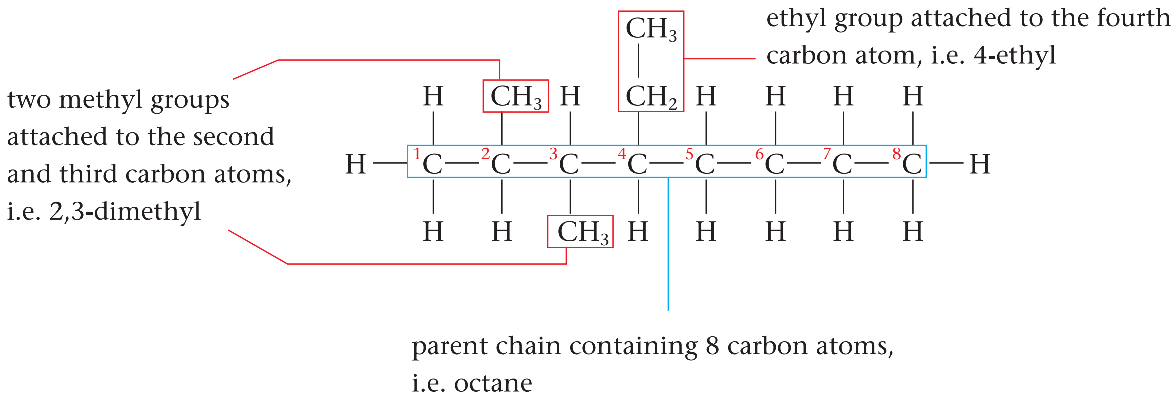
Example

26.1 Naming a branched-chain alkane

Name the ollo ing ompound y the UPAC system



Solution

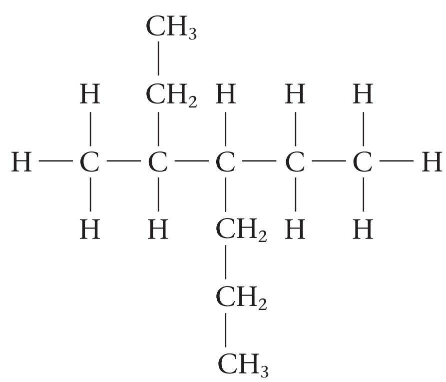


The name of the compound is 4-ethyl-2,3-dimethyloctane*.

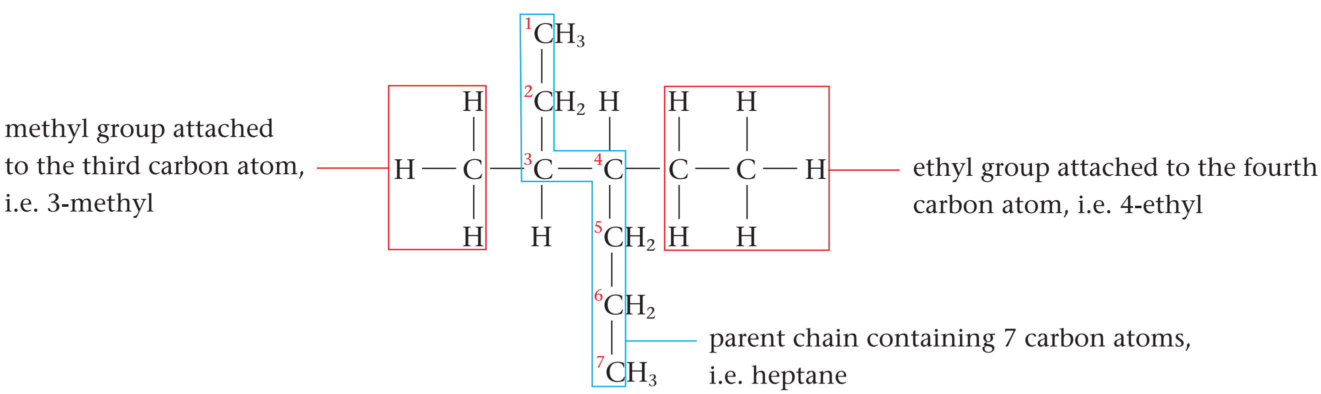
> * Notice that when deciding the alphabetical order of the prefixes, such as 'ethyl' and 'methyl', we ignore the numerical prefixes, such as 'di' and 'tri'.

26.2 Naming a branched-chain alkane

Name the following compound by the IUPAC system.



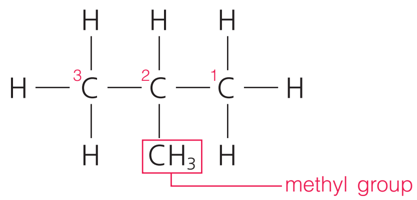
Solution



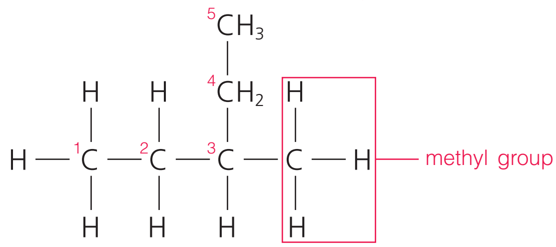
The name of the compound is 4-ethyl-3-methylheptane.

Checkpoint

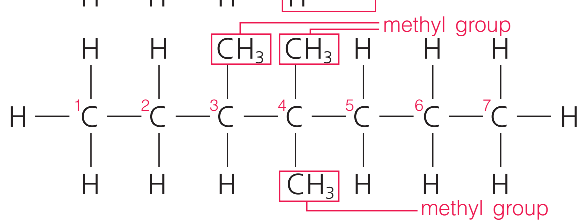
1 Name the following compounds by the IUPAC system.

a)


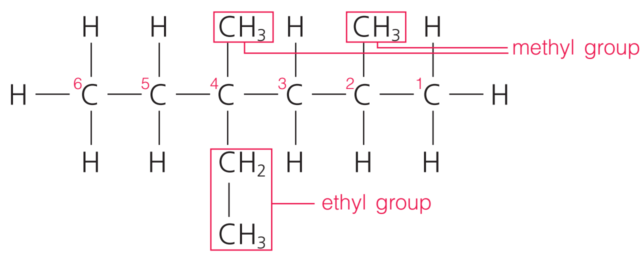
methylpropane

b)


3-methylpentane

c)


3,4,4-trimethylheptane

d)


4-ethyl-2,4-dimethylhexane

e) $\overset{1}{C}H_3\overset{2}{C}H_2\overset{3}{C}H_2\overset{4}{C}H\boxed{(CH_3)}\overset{5}{C}H_2\overset{6}{C}H_2\overset{7}{C}H_2\overset{8}{C}H_3$

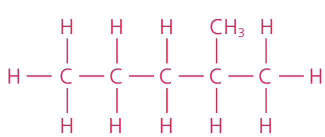
methyl group

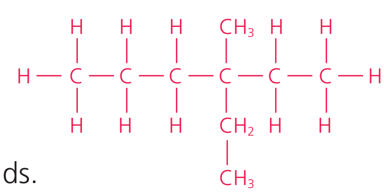
4-methyloctane

2 Draw the structural formulae of the following compounds.

a) 2-methylpentane

b) 3-ethyl-3-methylhexane

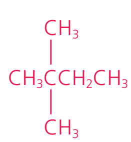
2 a)


b)


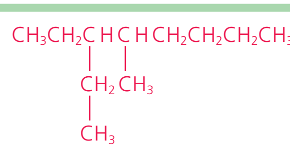
3 Draw the condensed structural formulae of the following compounds.

a) 2,2-dimethylbutane

b) 3-ethyl-4-methyloctane

3 a)


or $CH_3C(CH_3)_2CH_2CH_3$

b)


or $CH_3CH_2CH(C_2H_5)CH(CH_3)(CH_2)_3CH_3$

Cycloalkanes

The alkanes considered so far all have open-chain molecules. It is also possible for alkane molecules to have ring structures. These compounds are cycloalkanes. The general formula is C_nH_{2n}, where n = 3, 4, 5, 6, etc. Cycloalkanes are named by using the prefix cyclo-. Some cycloalkanes are shown in Table 26.11.

* Skeletal formulae are often used for ring compounds.

Table 26.11 Some examples of cycloalkanes

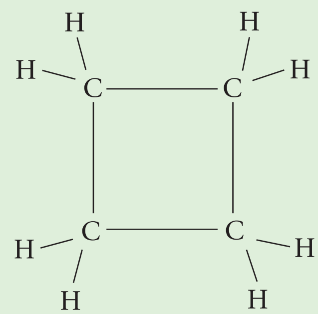
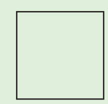
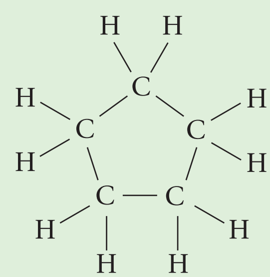
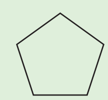
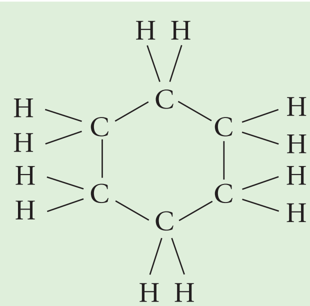
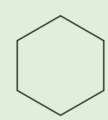
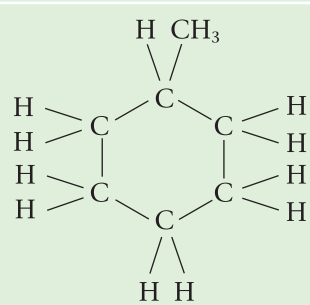
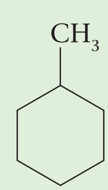
	Structural formula	Skeletal formula*
Cyclobutane (C_4H_8)		
Cyclopentane (C_5H_{10})		
Cyclohexane (C_6H_{12})		
Methylcyclohexane (C_7H_{14})		

Fig. 26.9 shows the various types of hydrocarbon.

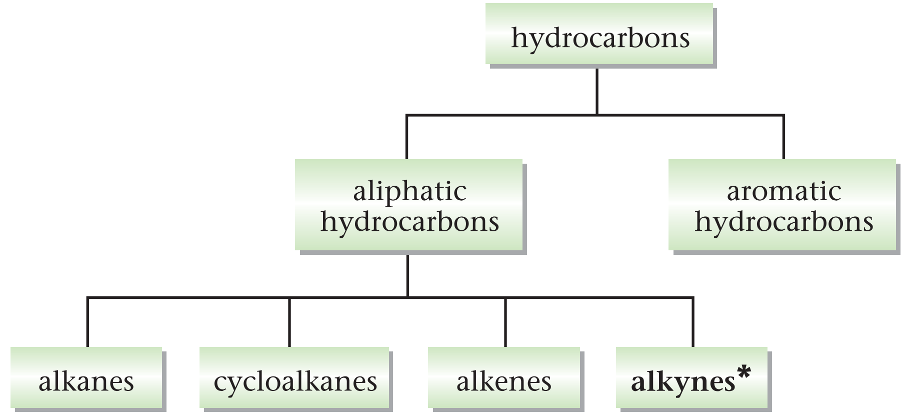


Fig. 26.9 Various types of hydrocarbon

* Alkynes are hydrocarbons containing carbon-carbon triple bonds (C≡C).

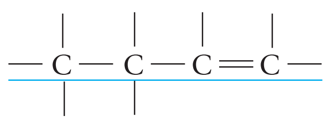
26.9 Naming alkenes

Alkenes have the general formula C_nH_{2n}, where n = 2, 3, 4, etc. Name the compounds with the rules as if for alkanes, but using the suffix –ene instead of –ane.

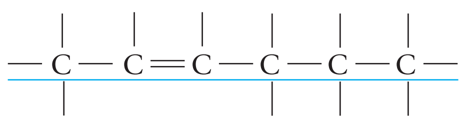
The IUPAC rules for naming alkenes are as follows:

1 Locate the longest continuous carbon chain that contains the double bond. Determine the parent name by changing the ending of the name of the alkane of identical length from –ane to –ene.

Examples:



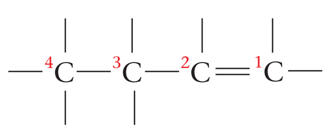
butene parent chain



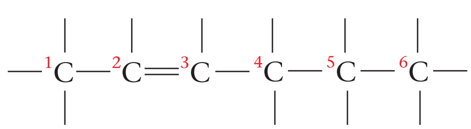
hexene parent chain

2 Number the parent chain, starting from the end nearest to the double bond. Indicate the position of the double bond by the number of the first carbon atom of the double bond. Place the number in front of the suffix –ene.

Examples:

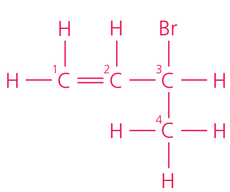


but-1-ene N4
(not but-3-ene)



hex-2-ene
(not hex-4-ene)

N4

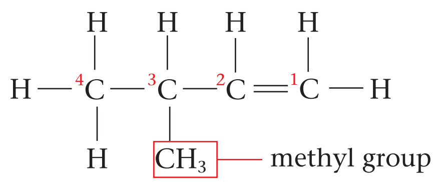


The IUPAC name of the above compound is 3-bromobut-1-ene.

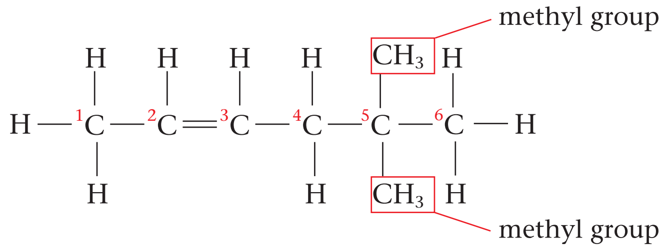
alkyne 炔

3 Name each alkyl group. State the number of the carbon atom to which each alkyl group attaches to the parent chain.

Examples:



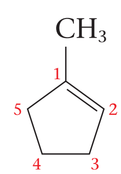
3-methylbut-1-ene



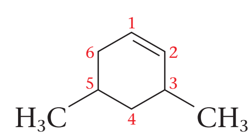
5,5-dimethylhex-2-ene

4 For a cycloalkene with attached alkyl group(s), number the carbon atoms of the double bond the 1 and 2 positions. Give the alkyl group(s) the lower number(s) as well.

Examples:



1-methylcyclopentene*



3,5-dimethylcyclohexene*

* It is not necessary to specify the position of the carbon double bond since it will always at the first and second carbon atoms.

Table 26.12 shows the condensed structural formulae and names of some simple alkenes.

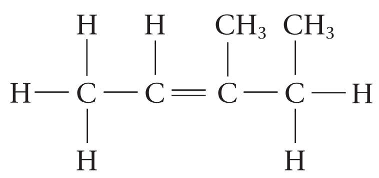
Table 26.12 Condensed structural formulae and names of some simple alkenes

Condensed structural formula of alkene	Name
$CH_2=CH_2$	ethene
$CH_3CH=CH_2$	propene
$CH_3CH_2CH=CH_2$	but-1-ene
$CH_3CH=CHCH_3$	but-2-ene
$CH_3CH_2CH_2CH=CH_2$	pent-1-ene
$CH_3CH_2CH_2CH_2CH=CH_2$	hex-1-ene

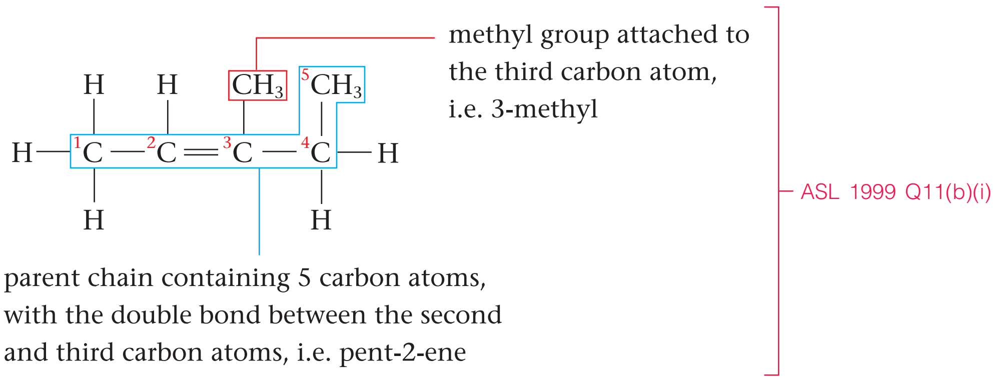
Example

26.3 Naming an alkene

Name the following compound by the IUPAC system.



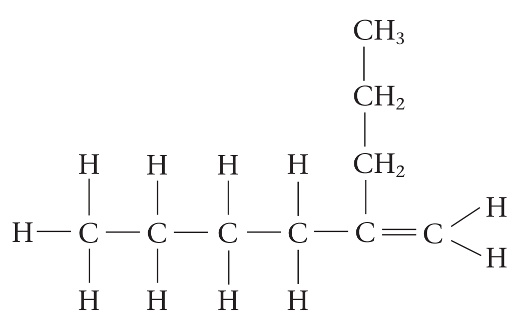
Solution



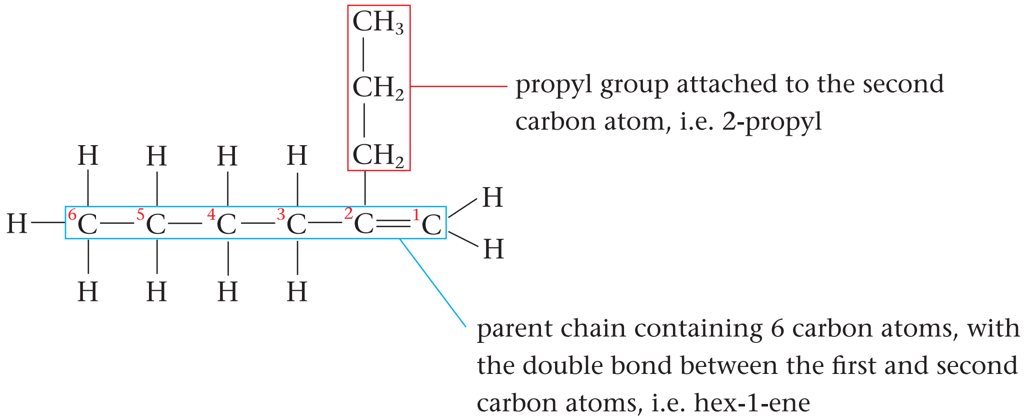
The name of the compound is 3-methylpent-2-ene.

26.4 Naming an alkene

Name the following compound by the IUPAC system.



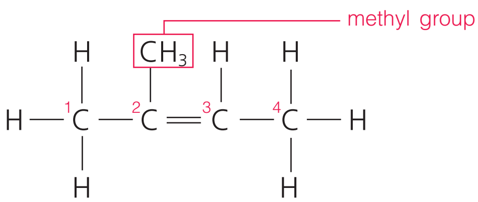
Solution



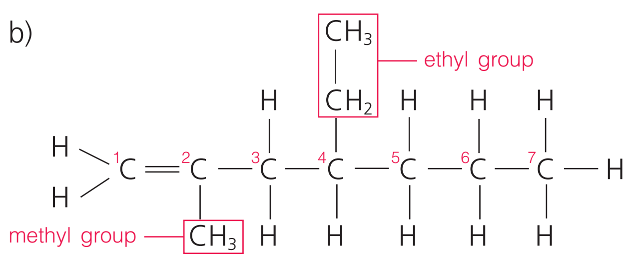
The name of the compound is 2-propylhex-1-ene.

Checkpoint

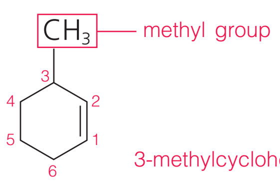
1 Name the following compounds by the IUPAC system.

a) 

2-methylbut-2-ene

b) 

4-ethyl-2-methylhept-1-ene

c) 

3-methylcyclohexene

d) $\overset{5}{C}H_3\overset{4}{C}H_2\overset{3}{C}H=\overset{2}{C}H\overset{1}{C}H_3$

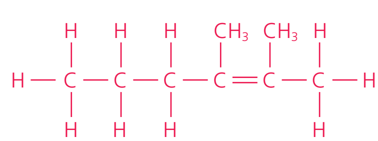
pent-2-ene

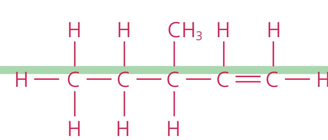
2 Write the structural formulae of the following compounds.

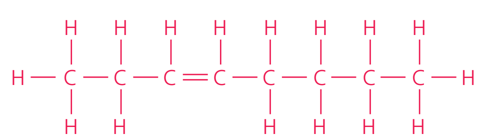
a) 2,3-dimethylhex-2-ene

b) 3-methylpent-1-ene

c) oct-3-ene

2 a) 

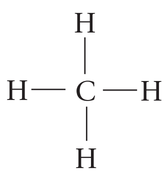
b) 

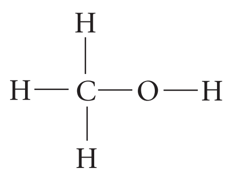
c) 

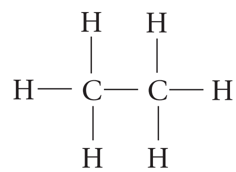
26.10 Naming alkanols

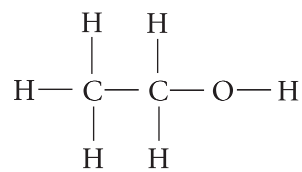
Alkanols have the general formula $C_nH_{2n+1}OH$, where n = 1, 2, 3, 4, etc. The C_nH_{2n+1}– is an alkyl group while the hydroxyl group –O–H is the functional group.

Alkanols are named by the IUPAC system as derivatives of the parent alkane. The last letter 'e' of the corresponding alkane is replaced by the suffix –ol. For example, methanol is derived from methane and ethanol from ethane.


methane


methanol


ethane

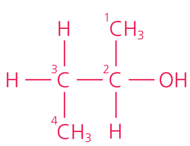

ethanol

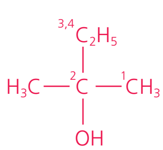
The IUPAC rules for naming alkanols are as follows:

1 Locate the longest continuous carbon chain to which the –O–H group is attached. Change the name of the corresponding alkane by replacing the last letter 'e' by the suffix –ol.

2 Number the parent chain, starting from the end nearest to the –O–H group. Indicate the position of the –O–H group by a number in front of the suffix –ol.

N5


The IUPAC name of the above compound is butan-2-ol.


The IUPAC name of the above compound is 2-methylbutan-2-ol.

Examples:

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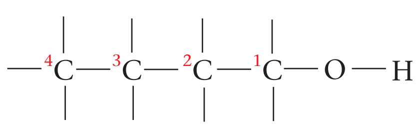
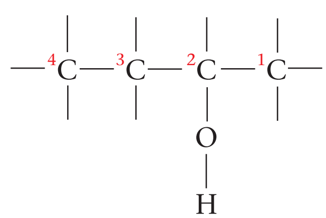
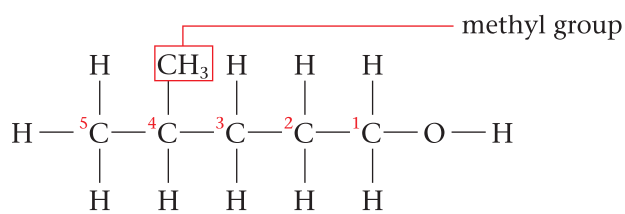

butan-1-ol


butan-2-ol N5

3 Name each alkyl group. State the number of the carbon atom to which each alkyl group attaches to the parent chain.

Example:



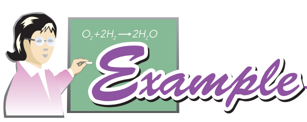
4-methylpentan-1-ol

alkanol 烷醇

Table 26.13 shows the names and condensed structural formulae of six simple alkanols.

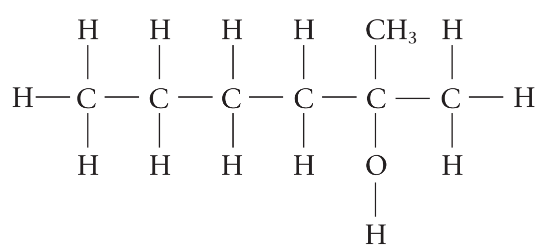
Table 26.13 Names and condensed structural formulae of six simple alkanols and their corresponding alkanes

Condensed structural formula of alkanol	Name	Corresponding alkane
CH_3OH	methanol	methane (CH_4)
CH_3CH_2OH	ethanol	ethane (CH_3CH_3)
$CH_3CH_2CH_2OH$	propan-1-ol	propane ($CH_3CH_2CH_3$)
$CH_3CH_2CH_2CH_2OH$	butan-1-ol	butane ($CH_3CH_2CH_2CH_3$)
$CH_3CH_2CH_2CH_2CH_2OH$	pentan-1-ol	pentane ($CH_3CH_2CH_2CH_2CH_3$)
$CH_3CH_2CH_2CH_2CH_2CH_2OH$	hexan-1-ol	hexane ($CH_3CH_2CH_2CH_2CH_2CH_3$)

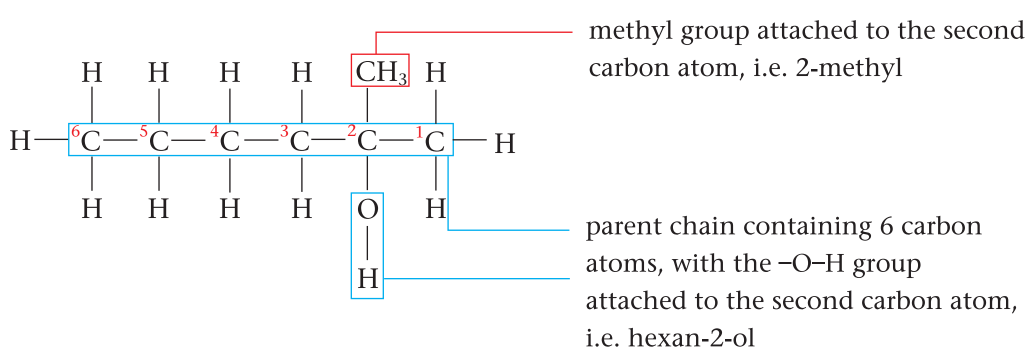


26.5 Naming an alkanol

Name the following compound by the IUPAC system.



Solution



The name of the compound is 2-methylhexan-2-ol.

26.11 Naming alkanoic acids

Alkanoic acids have the general formula RCOOH, where R is an alkyl group or a hydrogen atom. The carboxyl group $-\overset{\displaystyle O}{\overset{\|}{C}}-O-H$ is the functional group.

Name an alkanoic acid by replacing the last letter ‘e’ in the corresponding alkane by a suffix –oic acid. The carbon atom of the carboxyl group is assigned number 1. Table 26.14 shows the condensed structural formulae and names of six simple alkanoic acids.

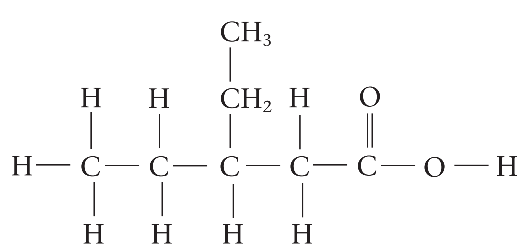
Table 26.14 Condensed structural formulae and names of six simple alkanoic acids and their corresponding alkanes

Condensed structural formula of alkanoic acid	Name	Corresponding alkane
$HCOOH$	methanoic acid	methane (CH_4)
CH_3COOH	ethanoic acid	ethane (CH_3CH_3)
CH_3CH_2COOH	propanoic acid	propane ($CH_3CH_2CH_3$)
$CH_3CH_2CH_2COOH$	butanoic acid	butane ($CH_3CH_2CH_2CH_3$)
$CH_3CH_2CH_2CH_2COOH$	pentanoic acid	pentane ($CH_3CH_2CH_2CH_2CH_3$)
$CH_3CH_2CH_2CH_2CH_2COOH$	hexanoic acid	hexane ($CH_3CH_2CH_2CH_2CH_2CH_3$)

Example

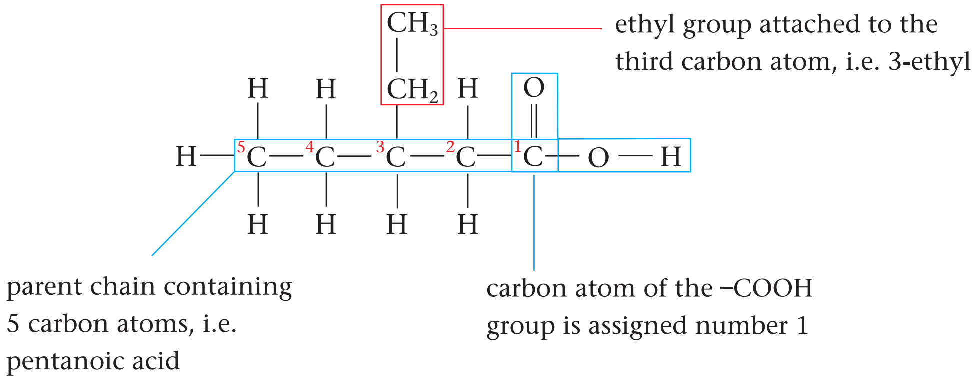
26.6 Naming an alkanoic acid

Name the following compound by the IUPAC system.



alkanoic acid 烷酸

Solution

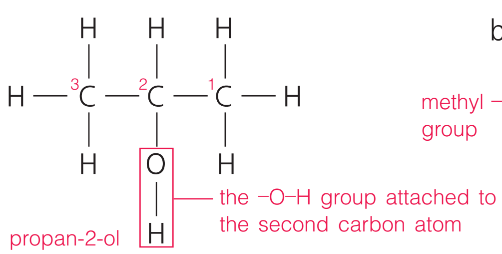


The name of the compound is 3-ethylpentanoic acid.

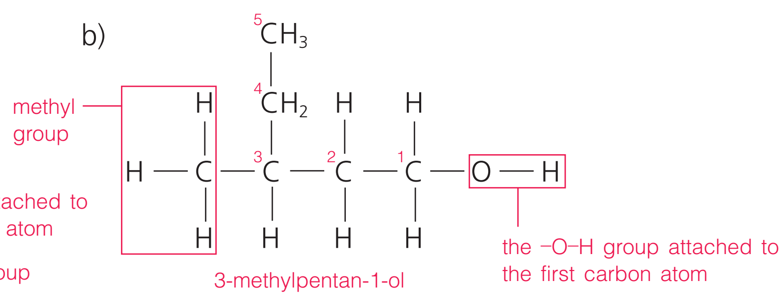
Checkpoint

1 Name the following compounds by the IUPAC system.

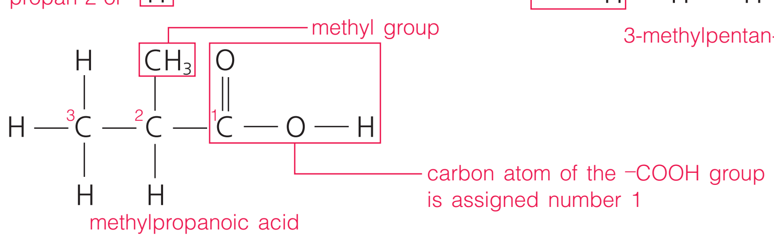
a)



b)



c)

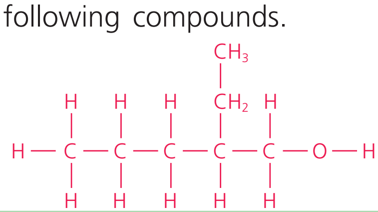


2 Write the structural formulae of the following compounds.

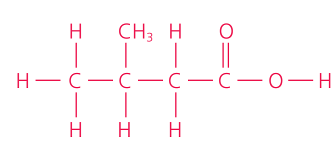
a) 2-ethylpentan-1-ol

b) 3-methylbutanoic acid

2 a)



b)



26.12 Physical properties of alkanes

Table 26.15 shows some physical properties of several straight-chain alkanes.

Table 26.15 Some physical properties of several straight-chain alkanes

Name	Molecular formula	Melting point (°C)	Boiling point (°C)	State at room temperature and pressure
Methane	CH_4	–182	–162	gas
Ethane	C_2H_6	–183	–89	
Propane	C_3H_8	–190	–42	
Butane	C_4H_{10}	–138	–0.5	
Pentane	C_5H_{12}	–130	36	liquid
Hexane	C_6H_{14}	–95	69	
Heptane	C_7H_{16}	–91	98	
Octane	C_8H_{18}	–57	126	
⋮	⋮	⋮	⋮	
Heptadecane	$C_{17}H_{36}$	22	302	
Octadecane	$C_{18}H_{38}$	28	316	solid
Nonadecane	$C_{19}H_{40}$	32	330	

An alkane molecule becomes larger and heavier as the number of carbon atoms in the molecule increases. The number of electrons in the molecule also increases. Hence the attractive forces (van der Waals' forces*) between the molecules increase. Therefore more heat is needed to separate the molecules during melting and boiling. Thus, the melting points and boiling points of alkanes rise as the number of carbon atoms in the alkane molecules increases (Fig. 26.10).

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* We have discussed van der Waals' forces in Topic 6 Microscopic World II.

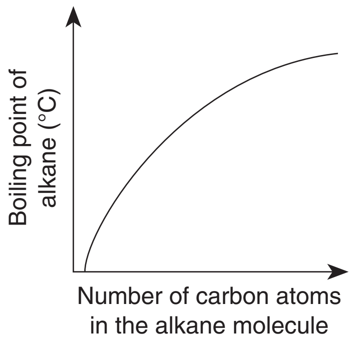


Fig. 26.10 The boiling points of alkanes rise as the number of carbon atoms in the alkane molecules increases

Alkanes are insoluble in water. All liquid alkanes are less dense than water, and thus float on it. On the other hand, alkanes are soluble in many organic solvents.

Example

26.7 Factors affecting the viscosity of a liquid

Explain why heptadecane ($C_{17}H_{36}$) found in diesel oil is more viscous than heptane (C_7H_{16}) found in petrol.

Solution

A heptadecane molecule has a larger molecular mass / size (or a greater number of electrons) than a heptane molecule. Therefore heptadecane has stronger intermolecular forces than heptane.

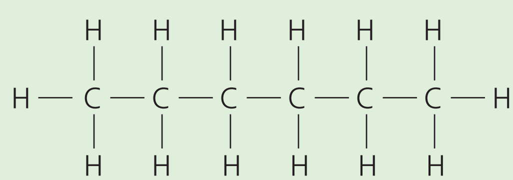
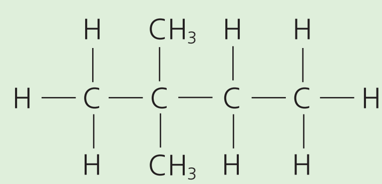
Also heptadecane molecules in the form of long chains can become entangled. Hence the relative motion between the molecules will be hindered.

Therefore heptadecane is more viscous than heptane.

Checkpoint

Refer to page T24.

1 The structural formulae and boiling points of hexane and 2,2-dimethylbutane are shown below. Both substances have the same molecular formula, C_6H_{14}.

	Hexane	**2,2-dimethylbutane**
Structural formula		
Boiling point (°C)	69	50

a) Why does hexane have a higher boiling point than 2,2-dimethylbutane?

b) 2-methylpentane is another compound with the molecular formula, C_6H_{14}. How do you think its boiling point will be when compared with these two substances? Explain your answer.

2 Would you expect pentane to have a higher density than 2,2-dimethylpropane? Explain your answer.

Summary

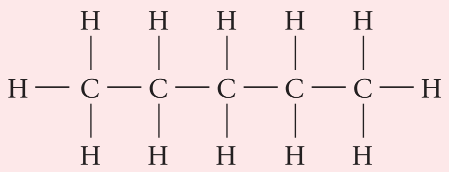
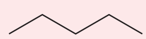
1 The unique nature of carbon are as follows:

a) carbon atoms are able to join up to form chains;

b) atoms of other elements can join to a carbon chain or ring;

c) one carbon atom can form double and triple covalent bonds with another carbon atom.

2 Carbon compounds can be represented by structural formulae, condensed structural formulae and skeletal formulae.

Structural formula	Condensed structural formula	Skeletal formula
	$CH_3(CH_2)_3CH_3$	

3 A functional group is an atom, or a group of atoms, which determines most of the properties of a compound.

4 A family of compounds containing the same functional group is called a homologous series.

Members in a homologous series show the following characteristics:

a) have the same general formula;

b) each member differs from the next by a $-CH_2-$ unit;

c) show a gradual change in physical properties; and

d) show similar chemical properties.

5 Alkanes have the general formula C_nH_{2n+2}. The IUPAC name for a branched-chain alkane consists of two parts:

Prefixes ↑ identify the alkyl groups and give their locations

Parent ↑ describes the main carbon chain

6 Alkenes have the general formula C_nH_{2n}. Name the compounds with the rules as if for alkanes, but using the suffix –ene instead of –ane.

7 Alkanols have the general formula $C_nH_{2n+1}OH$. Name the compound by replacing the last letter 'e' of the corresponding alkane by the suffix –ol.

8 Alkanoic acids have the general formula RCOOH where R is an alkyl group or a hydrogen atom. Name the compound by replacing the last letter 'e' of the corresponding alkane by the suffix –oic acid. The carbon atom of the carboxyl group is assigned number 1.

9 The following table gives condensed structural formulae and names of some carbon compounds from different homologous series.

Homologous series	Condensed structural formula of compound	Name
Alkane	$CH_3(CH_2)_2CH_3$	butane
Alkene	$CH_3CH_2CH{=}CH_2$ $CH_3CH{=}CHCH_3$	but-1-ene but-2-ene
Alkanol	$CH_3CH_2CH_2CH_2OH$ $CH_3CH_2CH(OH)CH_3$	butan-1-ol butan-2-ol
Alkanoic acid	$CH_3CH_2CH_2COOH$	butanoic acid

10 a) The melting points and boiling points of alkanes rise as the number of carbon atoms in the alkane molecules increases.

b) Alkanes are insoluble in water.

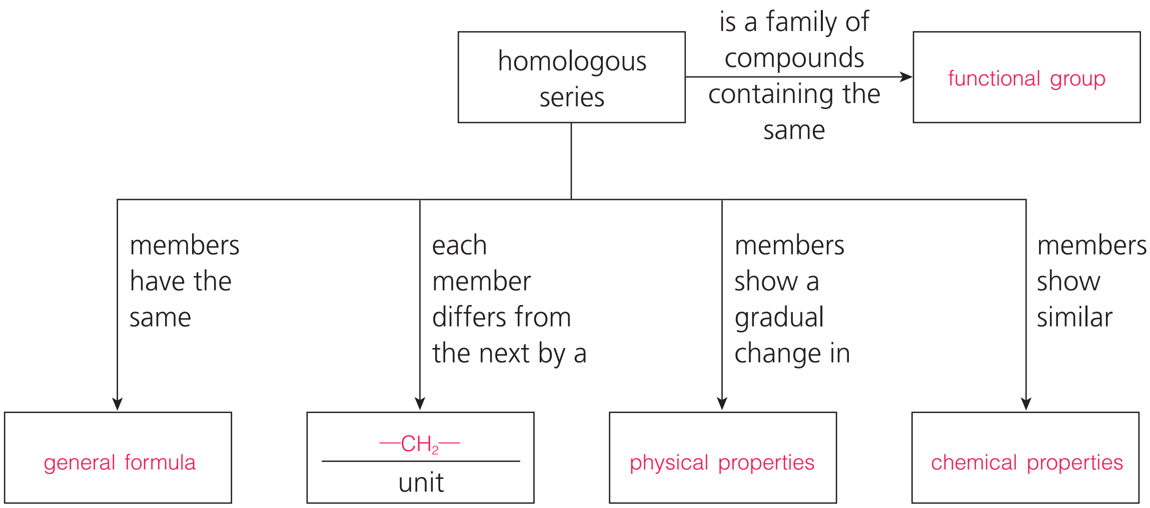
Summary

Exercise

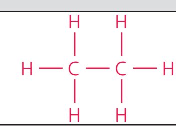
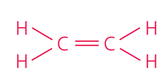
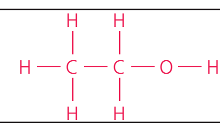
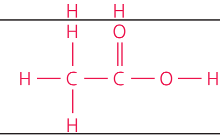
Note: The symbol 🌶 indicates the level of difficulty of a question.

Part I Knowledge and understanding

1 Complete the following concept map.



2 Complete the following table.

Name of homologous series	Functional group	General formula	Example	
			Name	Structural formula
Alkane	—	C_nH_{2n+2}	ethane	
Alkene	$>C=C<$	C_nH_{2n}	ethene	
Alkanol	—O—H	$C_nH_{2n+1}OH$	ethanol	
Alkanoic acid	—C(=O)—O—H	$C_nH_{2n+1}COOH$	ethanoic acid	

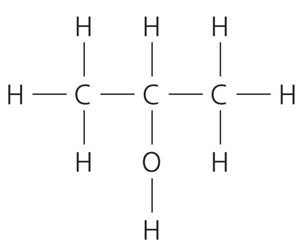
3 Complete the following table concerning some simple straight-chain alkanes.

Name	Molecular formula	Condensed structural formula
Methane	CH_4	CH_4
Ethane	C_2H_6	CH_3CH_3
Propane	C_3H_8	$CH_3CH_2CH_3$
Butane	C_4H_{10}	$CH_3(CH_2)_2CH_3$
Pentane	C_5H_{12}	$CH_3(CH_2)_3CH_3$
Hexane	C_6H_{14}	$CH_3(CH_2)_4CH_3$
Heptane	C_7H_{16}	$CH_3(CH_2)_5CH_3$
Octane	C_8H_{18}	$CH_3(CH_2)_6CH_3$

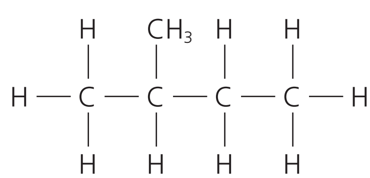
4 Complete the following table concerning some simple alkenes.

Name	Molecular formula	Condensed structural formula
Ethene	C_2H_4	$CH_2{=}CH_2$
Propene	C_3H_6	$CH_3CH{=}CH_2$
But-1-ene	C_4H_8	$CH_3CH_2CH{=}CH_2$
But-2-ene	C_4H_8	$CH_3CH{=}CHCH_3$
Pent-1-ene	C_5H_{10}	$CH_3CH_2CH_2CH{=}CH_2$
Pent-2-ene	C_5H_{10}	$CH_3CH_2CH{=}CHCH_3$

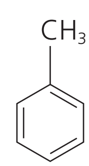
5 The question is about the compounds A — F shown below.



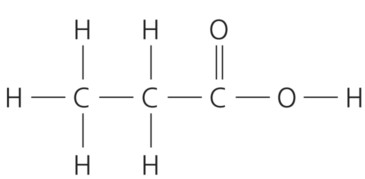
A



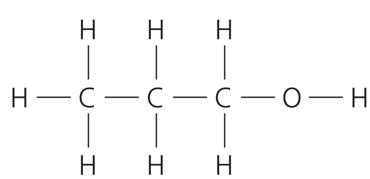
B



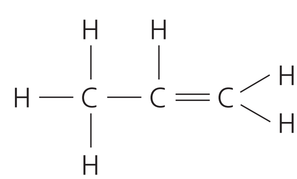
C



D



E



F

Exercise

a) Which one is a branched-chain alkane?
B

b) Which one is an aromatic compound?
C

c) Which one is an alkene?
F

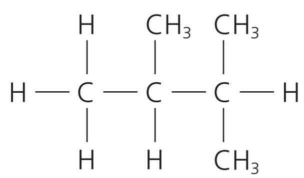
d) Which two are members of the same homologous series?
A and E

Part II Multiple choice questions

6 Which of the following molecular formulae represents an alkanoic acid?

A CH_2O
B CH_2O_2
C $C_2H_2O_2$
D $C_2H_6O_2$ *(HKCEE 2005)*

7 What is the systematic name of the following hydrocarbon?



A 1,1,2-trimethylpropane
B 2,3,3-trimethylpropane
C 1,2-dimethylbutane
D 2,3-dimethylbutane *(HKCEE 2005)*

8 Which of the following statements concerning members of a homologous series is / are correct?

(1) They contain carbon and hydrogen only.
(2) They can be represented by the same general formula.
(3) They have similar chemical properties.

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

(1) Members of some homologous series do NOT contain carbon and hydrogen only. For example, alkanols contain the –O–H group.

9 Which of the following statements concerning the compounds C_2H_4, C_3H_8 and C_4H_{10} is / are correct?

(1) They belong to the same homologous series.
(2) They are gases at room temperature and pressure.
(3) They have the same physical properties.

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

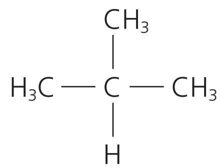
Compound	Name	Homologous series to which it belongs	State at room temperature and pressure
C_2H_4	ethene	alkene	gas
C_3H_8	propane	alkane	gas
C_4H_{10}	butane	alkane	gas

(1) C_2H_4 is an alkene while C_3H_8 and C_4H_{10} are alkanes. The compounds belong to *different* homologous series.

Exercise

10 The structure of two carbon compounds are shown below:

$CH_3CH_2CH_2CH_3$



Which of the following statements concerning the compounds are correct?

(1) Both compounds are members of the same homologous series.
(2) Both compounds have the same molecular formula.
(3) Both compounds have the same boiling point.

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

(1) Both compounds are alkanes.
(2) Both compounds have the same molecular formula, C_4H_{10}.

Part III Structured questions

11 Draw the structural formulae of the following compounds: Refer to page T25.

a) 2-methylpropane

b) butane

c) 2,3-dimethylhexane

d) 3-ethyl-2-methylpentane

e) but-1-ene

f) pent-2-ene

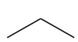
g) 3-methylhex-2-ene

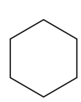
h) propan-2-ol

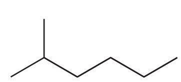
i) 2-methylbutan-1-ol

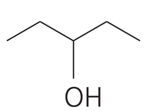
j) pentanoic acid

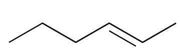
12 The skeletal formulae of some compounds are shown below: Refer to page T26.

a) 

b) 

c) 

d) 

e) 

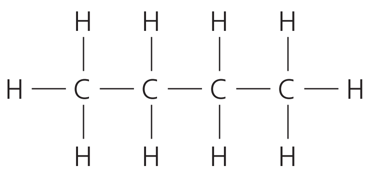
For each compound,

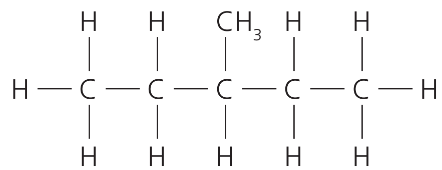
i) draw the structural formula;

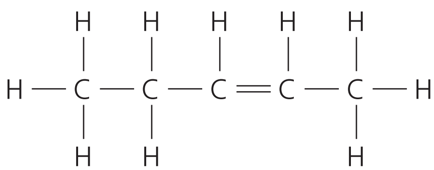
ii) give its systematic name.

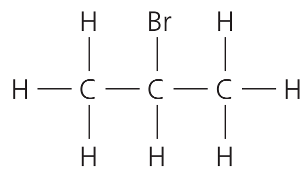
13 Draw the condensed structural formulae and skeletal formulae of the following compounds.

Refer to page T27.

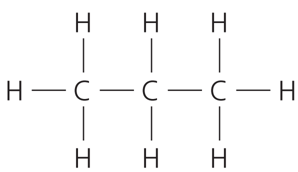
a) 

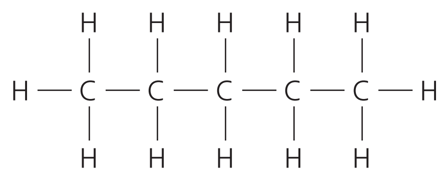
b) 

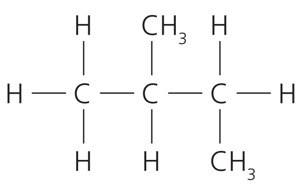
c) 

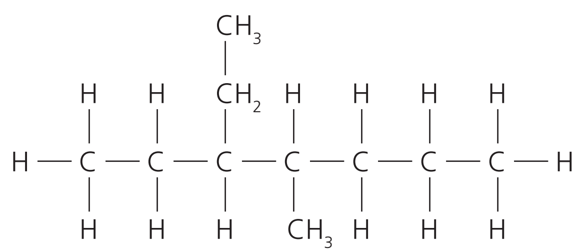
d) 

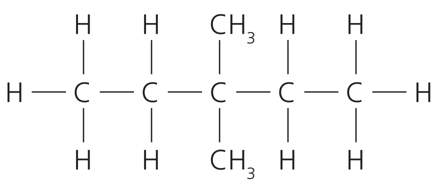
14 Name the following compounds by the IUPAC system.

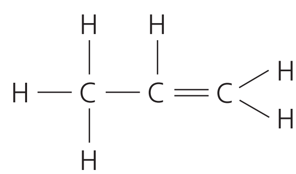
a) 

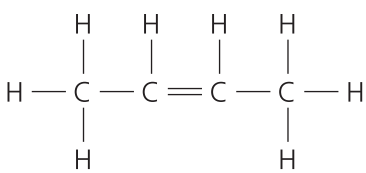
b) 

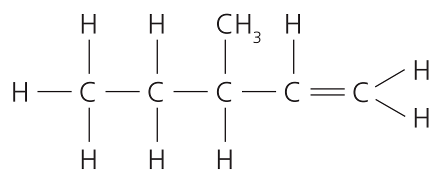
c) 

d) 

e) 

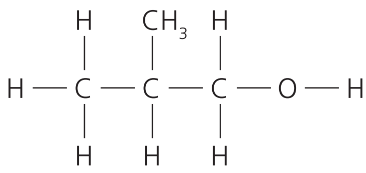
f) 

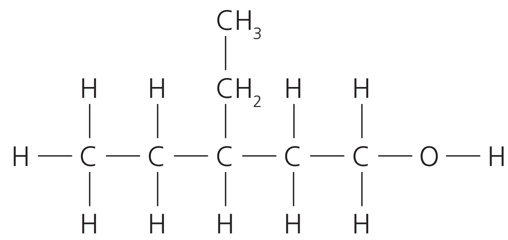
g) 

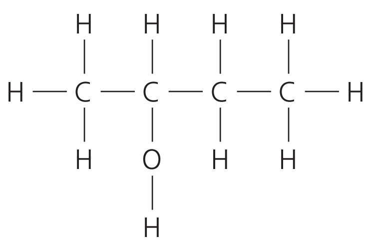
h) 

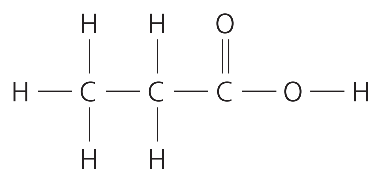
a) propane
b) pentane
c) 2-methylbutane
d) 3-ethyl-4-methylheptane
e) 3,3-dimethylpentane
f) propene
g) but-2-ene
h) 3-methylpent-1-ene

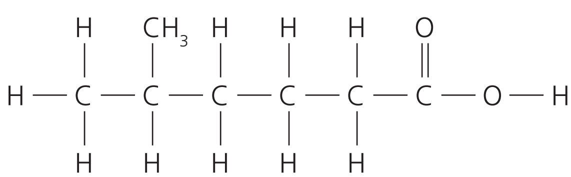
15 Name the following compounds by the IUPAC system.

a) 

b) 

c) 

d) 

e) 

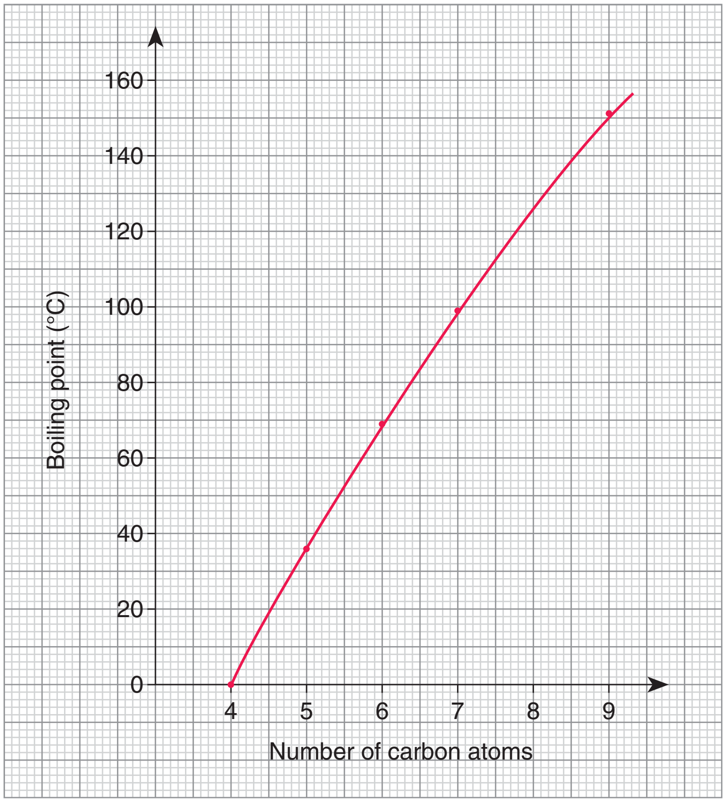
a) 2-methylpropan-1-ol
b) 3-ethylpentan-1-ol
c) butan-2-ol
d) propanoic acid
e) 5-methylhexanoic acid

16 The table shows the formulae and boiling points of some hydrocarbons.

Hydrocarbon	Formula	Boiling point (°C)
Butane	C_4H_{10}	0
Pentane	C_5H_{12}	36
Hexane	C_6H_{14}	69
Heptane	C_7H_{16}	99
Octane	C_8H_{18}	
Nonane	C_9H_{20}	151

a) i) Plot the boiling points of these hydrocarbons on the grid.

ii) Draw a curve through the points.



iii) Describe how the boiling point of a hydrocarbon is linked to the number of carbon atoms in its molecule.

The boiling point of a hydrocarbon increases with the number of carbon atoms in its molecule.

iv) Use your graph to predict the boiling point for octane.

~126 °C

b) Octane is a hydrocarbon in petrol.

i) What is meant by the term 'hydrocarbon'?

A hydrocarbon is a compound that contains only atoms of carbon and hydrogen.

ii) When octane is burned completely, two products are formed. What are the two products from this complete combustion?

Carbon dioxide and water

iii) In a car engine the hydrocarbons in petrol do not burn completely. The exhaust gases from a car engine are dangerous. Explain why.

When incomplete combustion occurs, the carbon in the hydrocarbons forms carbon monoxide. Carbon monoxide is a very poisonous gas.

(OCR GCSE Science, Double Award A, Chemistry (Higher Tier), Jun. 2007)