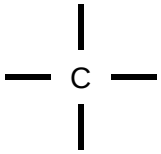
Introduction to Organic Chemistry

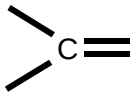
Organic chemistry is the study of carbon compounds. It is such a complex branch of chemistry because carbon form a wide variety of compounds for the following reasons

1) Carbon atoms can form **strong covalent bonds to each other.**
Carbon is an unusual element in that it can form 4 covalent bonds per atom and can form strong covalent bonds to other carbon atoms. This leads to the formation of a vast number of stable carbon compounds. We used the word *Catenation* for the ability to form bonds between atoms of the same element. Other Group 4 elements can also catenate but the stability of the compounds formed are limited due to weaker bond strengths.

2) The carbon-carbon bonds can be **single, double or triple** which leads to the following bond patterns**.**

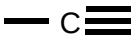


4 single bonds



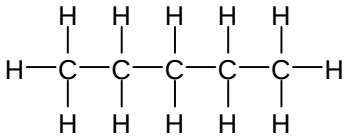
1 double bond
2 single bonds

2 double bonds

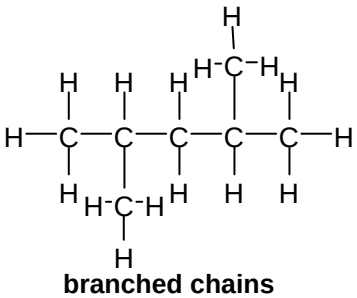


1 triple bond
1 single bond

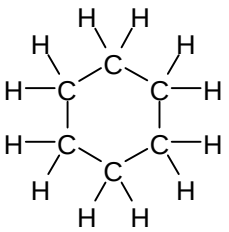
3) Carbon atoms can be arranged in **straight chains, branched chains and rings**



straight chains

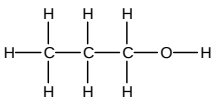


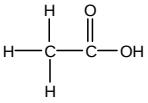
branched chains

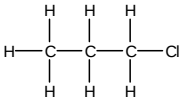


rings

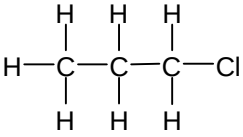
4) **Other atoms or groups of atoms** can be placed on the carbon atoms**.**

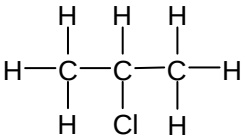






5) Groups can be placed in **different positions on a carbon skeleton.**





Ways of Representing Organic Molecules

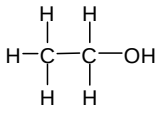
There are a number of different types of formulae that we use to represent organic molecules that show varying degrees of information about the structure of the molecule.

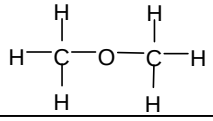
Molecular formula: The formula which shows the actual **number** of **each type** of **atom**

e.g. C_3H_8 or C_2H_6O

This type of formula shows no detail about the structure and several different molecules may have the same molecular formula.

C_2H_6O could be either ethanol or methoxymethane





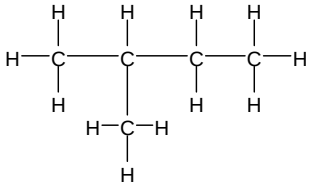
Condensed Structural formula shows the minimal detail that shows the arrangement of atoms in a molecule,

eg for butane: $CH_3CH_2CH_2CH_3$

CH_3CH_2OH for ethanol CH_3OCH_3 for methoxymethane

Bonds are not drawn but it is possible to see what is attached to each carbon.

Displayed formula: show all the covalent bonds present in a molecule

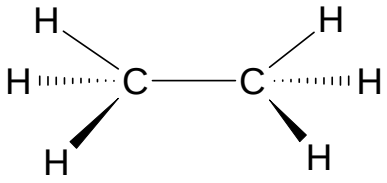


The displayed structural formula shows every bond and atom in a 2D format. It is common to draw the single bonds at 90°. This is done to simplify the representation of the molecule. It is not, however, a truthful representation of the 3D shape

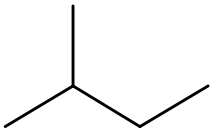
Remember that the shape around the carbon atom in saturated hydrocarbons is tetrahedral and the bond angle is 109.5°

We can represent the 3D shape by using stereochemical formulae

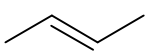
- The solid line represent a bond on the plane of the paper
- The black triangular wedge represents a bond coming in front of the paper
- The striped wedge represents a bond behind the plane of the paper



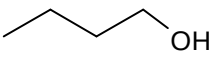
Skeletal formula shows the simplified organic formula, shown by removing hydrogen atoms from alkyl chains, leaving just a carbon skeleton and associated functional Groups.



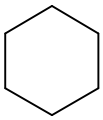
2-methylbutane



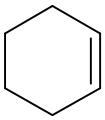
But-2-ene



Butan-1-ol



cyclohexane



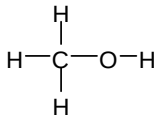
cyclohexene

Skeletal formulae are useful when the molecule is a large complex one

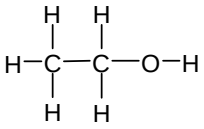
Functional Groups

As organic chemistry is a vast subject with many millions of molecules we separate the molecules into groups of molecules with similar chemical properties. This is usually done by studying compounds which behave in a similar way because they have a particular atom, or group of atoms, (**functional group**) in their structure.

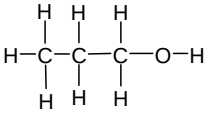
Each functional group has its own distinctive properties



methanol



ethanol



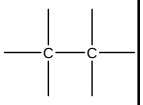
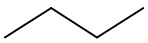
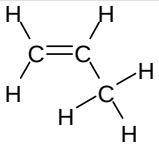
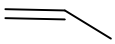
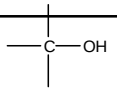
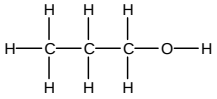
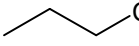
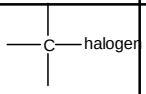
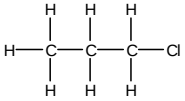
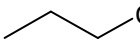
propanol

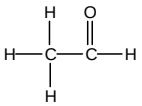
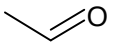
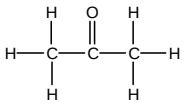
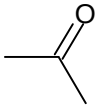
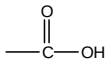
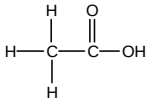
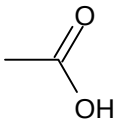
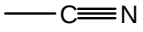
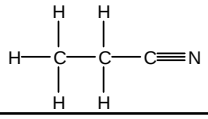
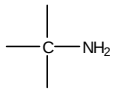
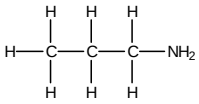
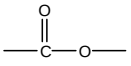
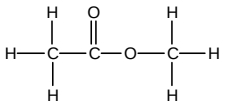
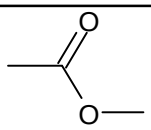
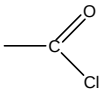
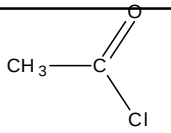
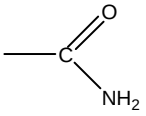
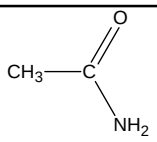
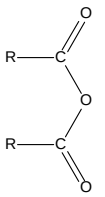
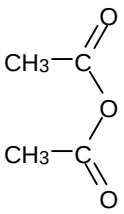
These molecules have similar properties due to the presence of the –O-H group of atoms. We call this functional group a alcohol

We can use the term Homologous series to describe families of organic compounds with the same functional group, (with varying carbon chain length) and the same general formula.

- They show a gradual change in physical properties (e.g. boiling point).
- Each member differs by CH_2 from the last.
- same chemical properties.

Some of the functional groups met at A-level are given in the table below and the next page.

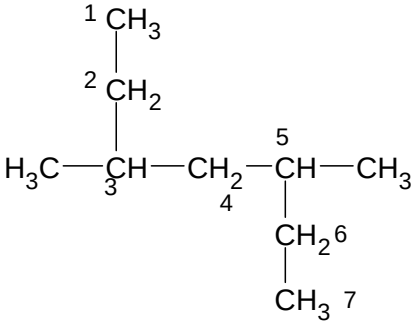
homologous series	functional group	prefix / suffix (* = usual use)	example
Alkane		*-ane*	$CH_3CH_2CH_2CH_3$  Butane
Alkenes		*suffix* **-ene**	  propene
Alcohols		*suffix** **-ol** *prefix* **hydroxy-**	 Propan-1-ol  OH
Halogenoalkanes		*prefix* **chloro-** **bromo-** **iodo-**	 1-chloropropane  Cl

homologous series	functional group	prefix / suffix (* = usual use)	example
aldehydes		*suffix* -**al** *prefix* **formyl-**	  ethanal
ketones		*suffix** -o**ne** *prefix* **oxo-**	  Propanone
carboxylic acids		*suffix* -**oic acid**	  Ethanoic acid
nitriles		*suffix* -**nitrile** *prefix* **cyano-**	 Propanenitrile
amines		*suffix** -**amine** *prefix* **amino-**	 Propylamine Or propan-1-amine
esters		*-yl –oate*	  methylethanoate
Acyl chloride		*-oyl chloride*	 ethanoylchloride
Amide		*-amide*	 ethanamide
Acid Anhydrides		*-oic anhydride*	 Ethanoic anhydride

General rules for naming carbon chains

- Count the longest carbon chain and name appropriately
- Find any branched chains and count how many carbons they contain
- Add the appropriate prefix for each branch chain

Eg $-CH_3$ methyl or $-C_2H_5$ ethyl $-C_3H_7$ propyl



3,5-dimethylheptane

code	no of carbons
meth	1
eth	2
prop	3
but	4
pent	5
hex	6
hept	7
oct	8
non	9
dec	10

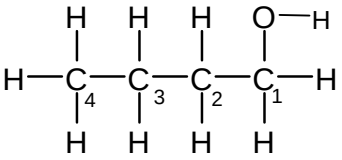
Basic rules for naming functional groups

- When using a suffix, add in the following way :

  If the suffix starts with a vowel- remove the –e from the stem alkane name
  e.g. Propan-1-ol, butan-1-amine, ethanoic acid, ethanoylchloride, butanamide

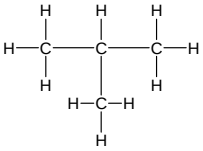
  If the suffix starts with a consonant or there are two or more of a functional group meaning di, or tri needs to be used then **do not remove the the –e** from the stem alkane name
  e.g. Propan**e**nitrile, ethan**e**-1,2-diol, propan**e**dioic acid, propan**e**-1,2,3-triol, Pentan**e**-2,4-dione.

- The position of the functional group on the carbon chain is given by a number – counting from the end of the molecule that gives the functional group the lowest number. For aldehydes, carboxylic acids & nitriles, the functional group is always on carbon 1.



Butan-1-ol

- We only include numbers, however, if they are needed to avoid ambiguity.



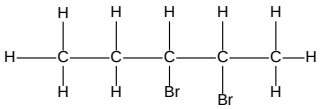
methylpropane

$CHCl_3$ trichloromethane

- The functional groups take precedence over branched chains in giving the lowest number

3-methylbut-1-ene is correct and not 2-methylbut-3-ene

- Where there are two or more of the same groups, *di-*, *tri-* or *tetra* are used. Note the point made above about the addition of 'e' to the stem



2,3-dibromopentane.

- Words are separated by numbers with dashes
- numbers are separated by commas

$CH_2FCCl_2CH_2CH_3$ 2,2-dichloro-1-fluorobutane.

- If there is more than one functional group or side chain, the groups are listed in alphabetical order (ignoring any *di*, *tri*).

$CH_2FCH_2CHBrCH_2CH_3$ 3-bromo-1-fluoropentane

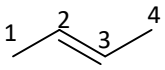
The suffix for alkenes can go in front of other suffixes.

$CH_2OHCHBrCH{=}CH_2$ 2-bromobut-3-en-1-ol

When compounds contain more than one functional group, the order of precedence determines which groups are named with prefix or suffix forms. The highest precedence group takes the suffix, with all others taking the prefix form. However, double and triple C-Cbonds only take suffix form.
Order of priority highest first:
Carboxylic acids >carboxylic acid derivative>nitriles>aldehydes>ketones>alcohols>amines>>alkenes>halogenoalkanes

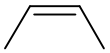
Alkenes

The double bond will be between two carbons. Use the lower number of the two to show the position of the double bond



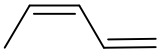
Double bond between C^2 and C^3 so But-2-ene

The name for alkenes may include E or Z at start to show the type of stereoisomer



Z-but-2-ene

If more than one double bond is present then suffix ends **di**ene or **tri**ene. The stem ends in **a**

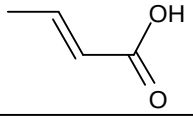


Pent**a**-1,3-diene

The suffix **-en** for alkenes can go in front of other suffixes. The alcohol and carboxylic acid groups have higher priority than the alkene group so take precedence with numbering

$CH_2OHCHBrCH=CH_2$

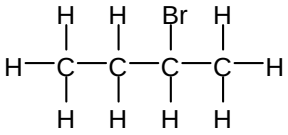
2-bromobut-3-**en**-1-ol



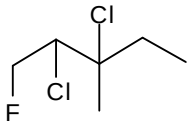
E-but-2-**en**oic acid

Halogenoalkanes

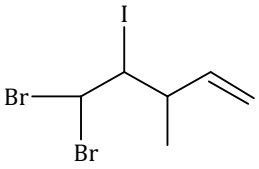
Class the halogen as a substituent on the C chain and use the prefix **-fluoro**, **-chloro**, **-bromo**, or **–iodo**. (Give the position number if necessary)



2-bromobutane



2,3-dichloro-1-fluoro-3-methylpentant



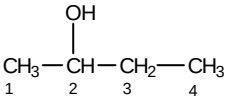
5,5-dibromo-4-iodo-3-methylpent-1-ene

Multiple functional group and side chains are listed in alphabetical order (ignoring any *di*, *tri*).

The alkene group has higher priority than the halogenoalkane group so it takes the lowest number on the carbon chain

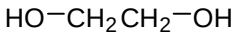
Alcohols

These have the ending **-ol** and if necessary the position number for the OH group is added between the name stem and the –ol

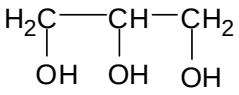


Butan-2-ol

If there are two or more -OH groups then di, tri are used.
Add the **'e'** on to the stem name though.

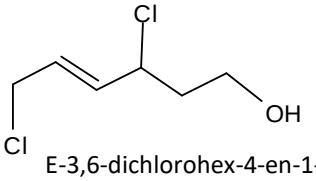


Ethan**e**-1,2-diol



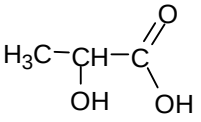
propan**e**-1,2,3-triol

The OH group has a higher priority than the halogenoalkane group and alkene so takes precedence in numbering. The OH is on carbon 1



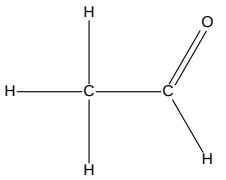
E-3,6-dichlorohex-4-en-1-ol

If the compound has an –OH group in addition to another functional group with a higher priority. The priority group gets the suffix ending and the OH can be named with the prefix **hydroxy-**:



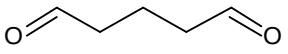
2-hydroxypropanoic acid

Aldehydes
An aldehyde's name ends in **–al**
It always has the C=O bond on the first carbon of the chain so it does not need an extra number. It is by default number one on the chain.



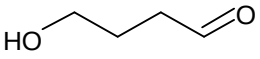
Ethan**al**

If two aldehyde groups then **di** is put before **–al** and an **e** is added to the stem.



pentanedial

Aldehydes have a higher priority than alcohol so the –OH group uses the hydoxy prefix.

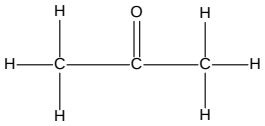


4-hydroxybutanal

Ketones

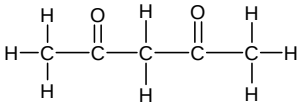
Ketones end in **-one**

When ketones have 5C's or more in a chain then it needs a number to show the position of the double bond. E.g. pentan-2-one



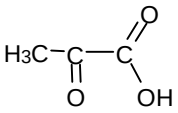
Propan**one**

If two ketone groups then **di** is put before **–one** and an **e** is added to the stem.



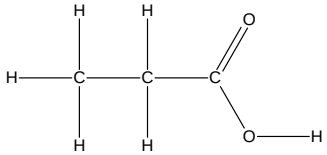
Pentan**e**-2,4-dione

The prefix oxo- should be used for compounds that contain a ketone group in addition to a carboxylic acid or aldehyde



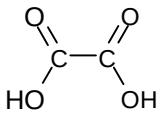
2-oxopropanoic acid

Carboxylic acids
These have the ending **-oic acid** but no number is necessary for the acid group as it must always be at the end of the chain. The numbering always starts from the carboxylic acid end.



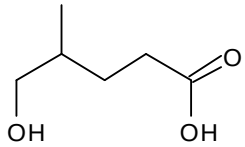
Propan**oic acid**

If there are carboxylic acid groups on both ends of the chain then it is called a - dioic acid



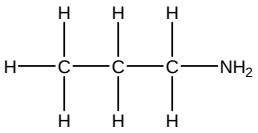
Ethan**edioic acid**

Note the **e** in this name



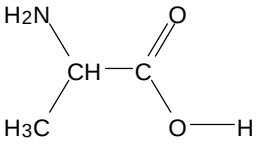
5-hydroxy-4-methylpentanoic acid

Amines
These end in **–amine**.
There is, however, rather confusingly two ways of using this suffix.
The exam boards tend to use the common version where the name stem ends in **-yl** prop**yl**amine.
The IUPAC version of the same chemical is propan-1-amine. (This is used in the same way as naming alcohols)



prop**yl**amine
Or propan-1-amine

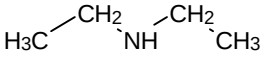
If there is another priority functional group as well as the amine group then the prefix amino is used.



2-aminopropanoic acid.

If the amine is secondary and has two alkyl groups attached to the nitrogen, then each chain is named and the smaller alkyl group is preceded by an –N which plays the same role as a number in positioning a side alkyl chain

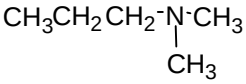
$CH_3CH_2CH_2NHCH_3$
N-methylpropylamine (common name)
N-methylpropan-1-amine (IUPAC name)



In the common naming version if the chain lengths are the same an –N is not used

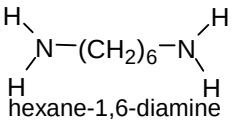
Diethylamine (common name- does not use N if chains are same length)
N-ethylethanamine (IUPAC name does still use N)

If a tertiary amine similar rules apply, and each alkyl side group is given an N



N,N-dimethylpropylamine (common name)
N,N-dimethylpropan-1-amine (IUPAC name)

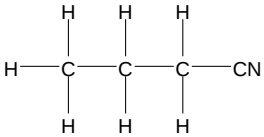
If there are two amine groups then it is easiest to use amino prefix



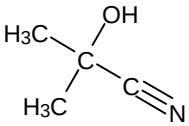
hexane-1,6-diamine

It could also be named
1,6-diaminohexane

Nitriles
These end in **–nitrile**, but the C of the CN group counts as the first carbon of the chain. Note the stem of the name is different : but**ane**nitrile and not butannitrile.



butanenitrile



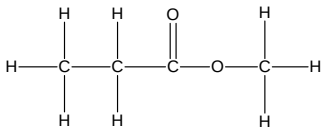
2-hydroxy-2-methylpropanenitrile

Carboxylic acid derivatives

Esters

Esters have two parts to their names

The bit ending in **–yl** comes from the alcohol that has formed it and is next to the single bonded oxygen.
The bit ending in **–anoate** comes from the carboxylic acid. (This is the chain including the C=O bond)



methylpropanoate

Acid Anhydrides

This is called **ethanoic anhydride.** It is ethanoic because it is two ethanoate groups joined together.
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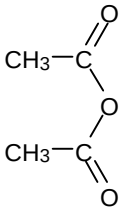
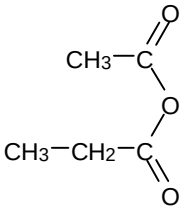
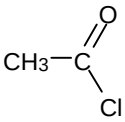


If the alkyl groups are of different lengths then each one is named
e.g. ethanoic propanoic anhydride

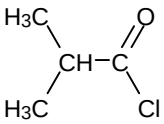


Acyl Chlorides

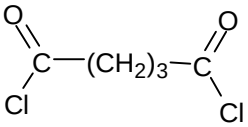
add **–oyl chloride** to the stem name



ethanoyl chloride



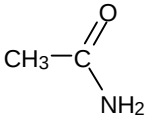
2-methylpropanoyl chloride



Pentan**e**dioyl dichloride

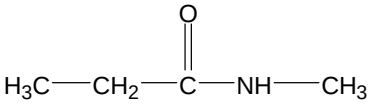
Amides

Add **–amide** to the stem name

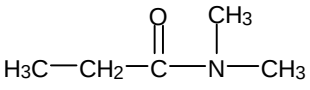


ethanamide

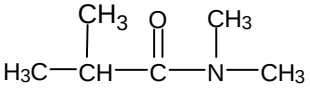
Secondary and tertiary amides are named differently to show the two (or three) carbon chains. The smaller alkyl group is preceded by an –N which plays the same role as a number in positioning a side alkyl chain



N-methylpropanamide



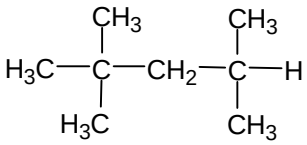
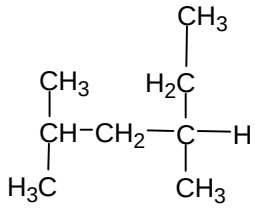
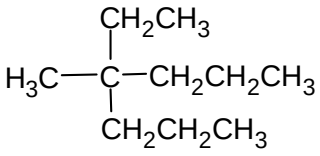
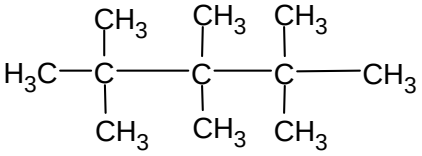
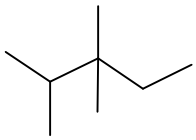
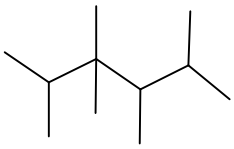
N,*N*-dimethylpropanamide



N,*N*,2-trimethylpropanamide

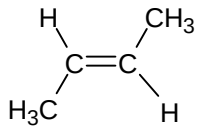
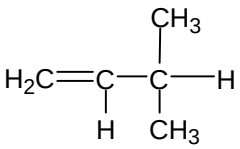
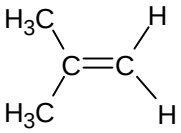
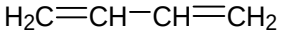
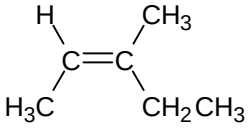
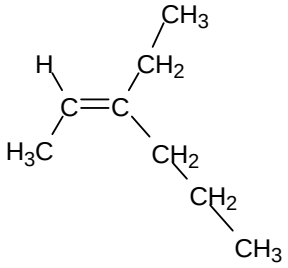
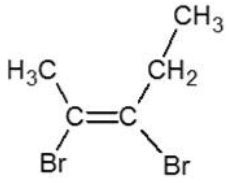
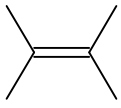
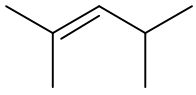
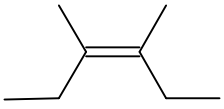
Naming Alkanes

1. Draw the displayed formula for 2,2-dimethylpropane
2. Draw the skeletal formula for 2,3-dimethylbutane
3. Draw the displayed formula for 3-ethylhexane
4. Draw the skeletal formula for $(CH_3)_3CCH_2CH_3$ and name the compound
5. Name the following compounds

a) 	b) 
c) 	d) 
e) 	f) 

Naming Alkenes

1. Draw the displayed formula for but-2-ene
2. Draw the skeletal formula for pent-2-ene
3. Draw the skeletal formula for 2-methylpent-2-ene
4. Draw the skeletal and displayed formula for cyclopentene
5. Name the following compounds

a) $CH_3CH_2CH=CH_2$	b) $(CH_3)_2C=CHCH_3$
c) 	d) 
e) 	f) 
g) 	h) 
i) 	j) 
k) 	l) 

Naming Halogenoalkanes

1. Draw the displayed formula for 2,2-dichlorohexane

2. Draw the skeletal formula for 2,3,3,3-tetrafluoropropene

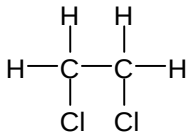
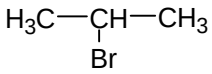
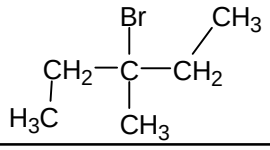
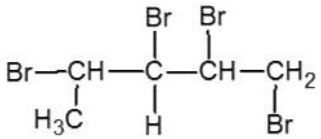
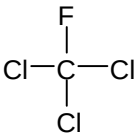
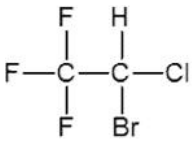
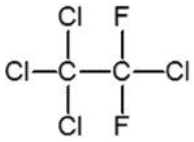
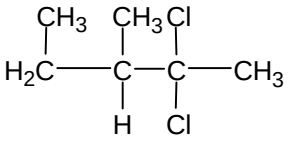
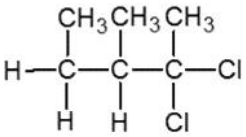
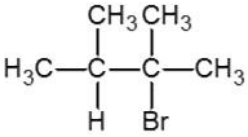
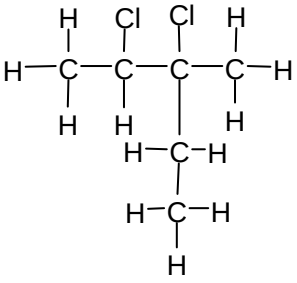
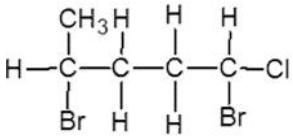
3. Draw the skeletal formula for 2,2-dichloro-3-methylpentane

4. Draw the displayed formula for 1,2-dichloro-2-methylpropane.

5. Draw the skeletal formula for 1,1,1-trichloro-2,2-difluoroethane

6. Draw the displayed formula for 5-chloro-2,2-dimethylhexane

7 Name the following compounds

a) $CH_3CH_2CH_2CH_2Cl$	b) CH_3CHICH_3
c) 	d) 
e) 	f) 
g) 	h) 
i) 	j) 
k) 	l) 
m) 	n) 

Naming Alcohols

1. Draw the displayed formula for Hexan-1-ol

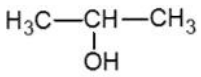
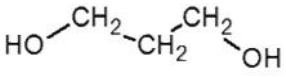
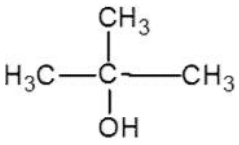
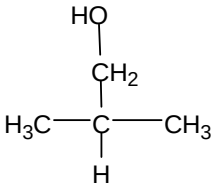
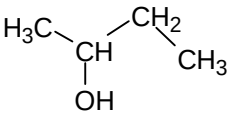
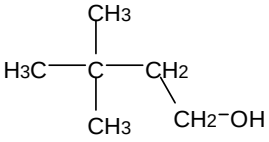
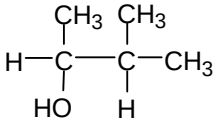
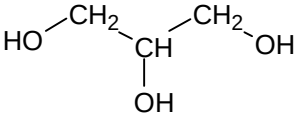
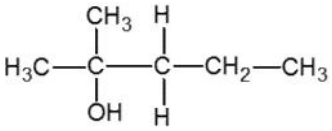
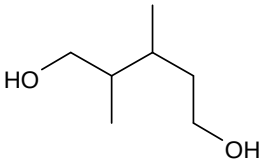
2. Draw the displayed formula for prop-2-en-1-ol

3. Draw the skeletal formula for 3-methylpentan-2-ol

4. Draw the skeletal formula for 2,3-dimethylbutan-1-ol

5 Draw the displayed and skeletal formula for cyclohexanol

6 Name the following compounds

a) 	b) 
c) 	d) 
e) 	f) 
g) 	h) 
i) 	j) 

Naming Carbonyls

1) Draw the displayed formula for butanone

2) Draw the skeletal formula for hexan-3-one

3) Draw the displayed formula for propanal

4) Draw the skeletal formula for 2-methylbutanal

5) Name the following compounds

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 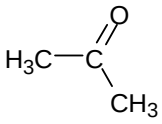 </td><td>b) HCHO</td></tr>
<tr><td>c) $CH_3CH(OH)CH_2CHO$</td><td>d) $CH_3(CH_2)_2CHO$</td></tr>
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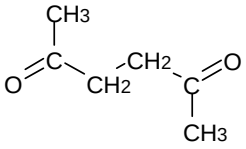
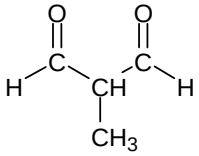
  </td><td>f)
  </td></tr>
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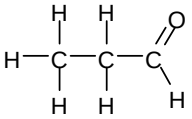
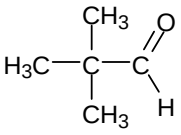
  </td><td>h)
  </td></tr>
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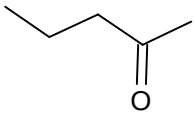
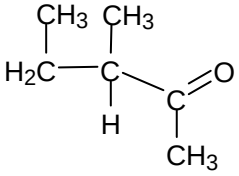
  </td><td>j)
  </td></tr>
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Naming Carboxylic Acids

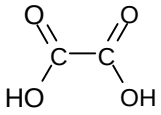
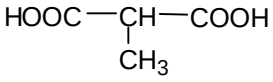
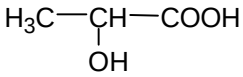
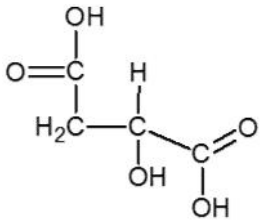
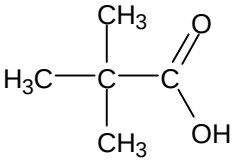
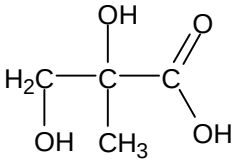
1) Draw the displayed formula for propanoic acid

2) Draw the skeletal formula for 3-methylpentanoic acid

3) Draw the displayed formula for 3-hydroxypropanoic acid

4) Draw the skeletal formula for 2,3-dichlorobutanoic acid

5) Name the following compounds

a) HCOOH	b) 
c) $CH_3CH_2CH_2COOH$	d) 
e) 	f) 
g) 	h) 

Naming Carboxylic Acids Derivatives

1) Draw the displayed formula for methyl propanoate

2) Draw the skeletal formula for ethyl butanoate

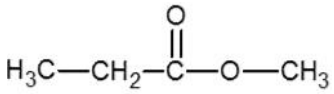
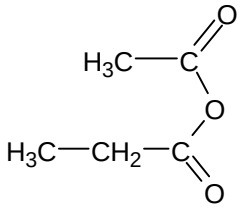
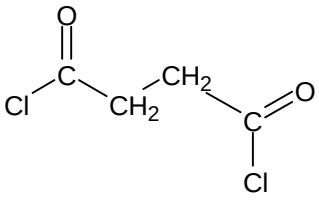
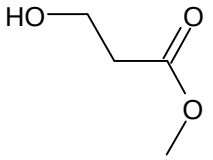
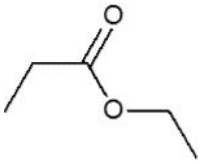
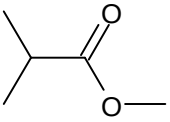
3) Draw the displayed formula for Ethanoic anhydride

4) Draw the skeletal formula for Methyl pentanoate

5) Draw the skeletal formula for 2-methylpropanoyl chloride

6) Draw the displayed formula for Methyl-2-methylpropenoate

7) Name the following compounds

a) CH_3CH_2COCl	b) $HCOOCH_2CH_3$
c) $(CH_3CH_2CO)_2O$	d) 
e) 	f) 
g) $CH_3COOCH_2CH_2CH_3$	h) 
i) 	j) 

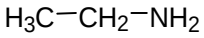
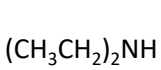
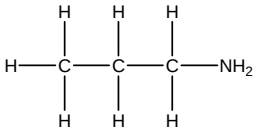
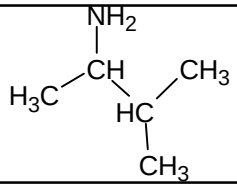
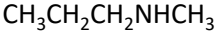
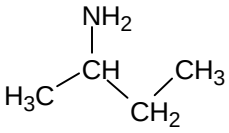
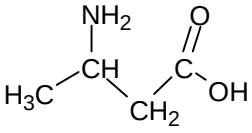
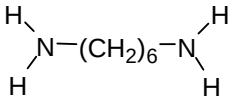
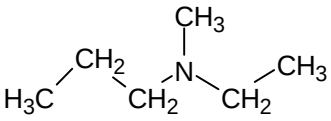
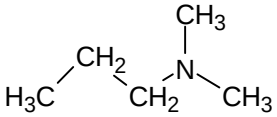
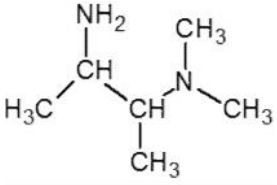
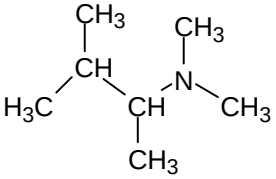
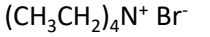
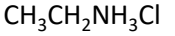
Naming Amines and ammonium salts

1) Draw the displayed formula for Methanamine or Methylamine

2) Draw the skeletal formula for butan-2-amine

3) Draw the displayed formula for 2,6-diaminohexanoic acid

4) Name the following compounds

a) 	b) 
c) 	d) 
e) 	f) 
g) 	h) 
i) 	j) 
a) 	l) 
m) 	) 

Naming Amides and Nitriles

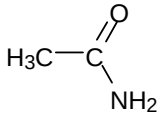
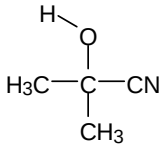
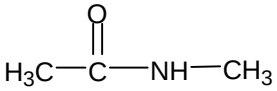
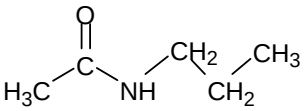
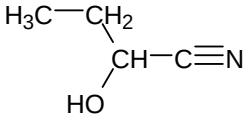
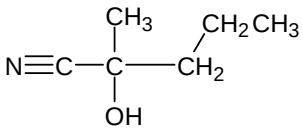
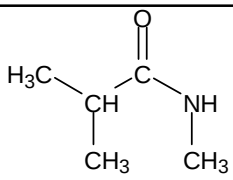
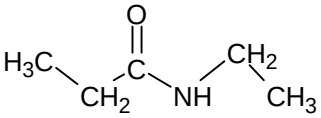
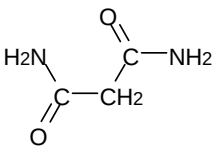
1) Draw the displayed formula for Propanenitrile

2) Draw the skeletal formula for propanamide

3) Draw the displayed formula for N-ethylpropanamide

4) Draw the skeletal formula for 2-bromobutanenitrile

5) Name the following compounds

a) CH_3CN	b) 
c) 	d) 
e) $CH_3CH_2CONH_2$	f) 
g) 	h) 
i) 	j) 
k) 	l)