

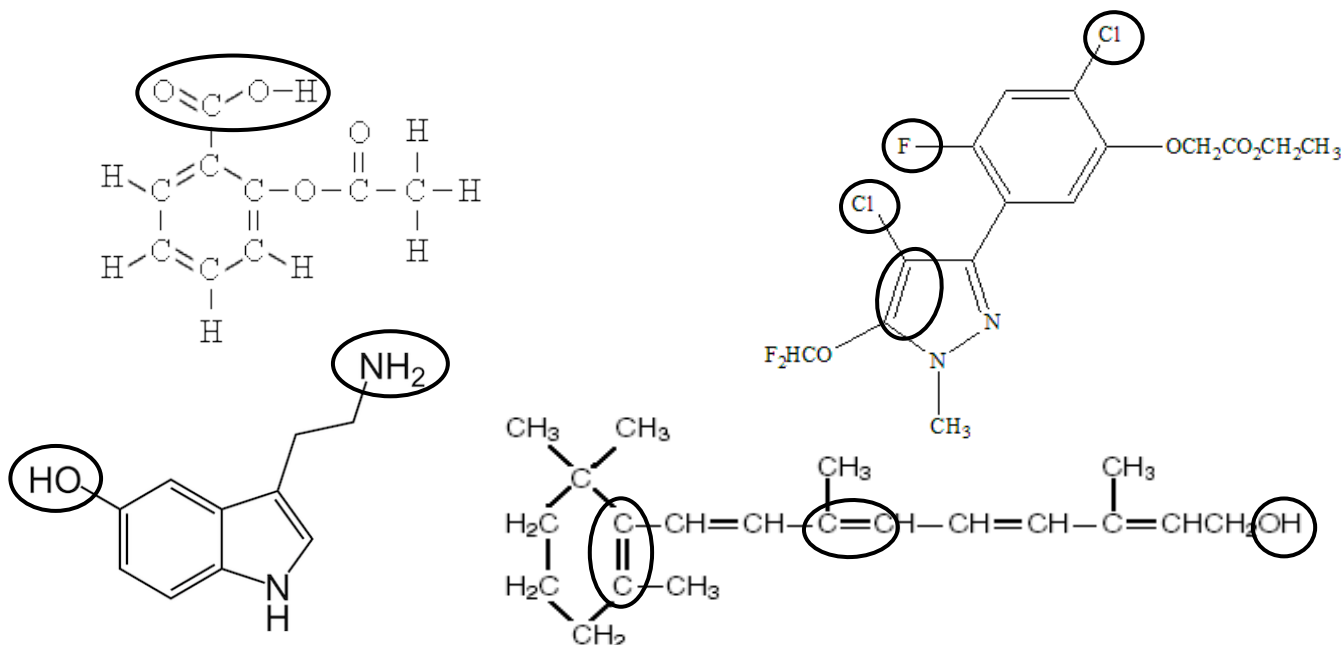
LEVEL 2 ORGANIC CHEMISTRY

Naming (IUPAC nomenclature)

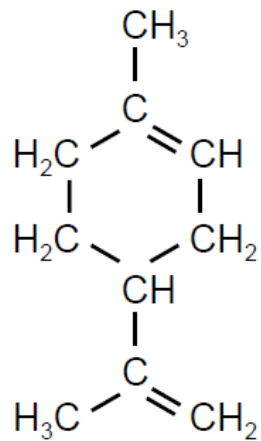
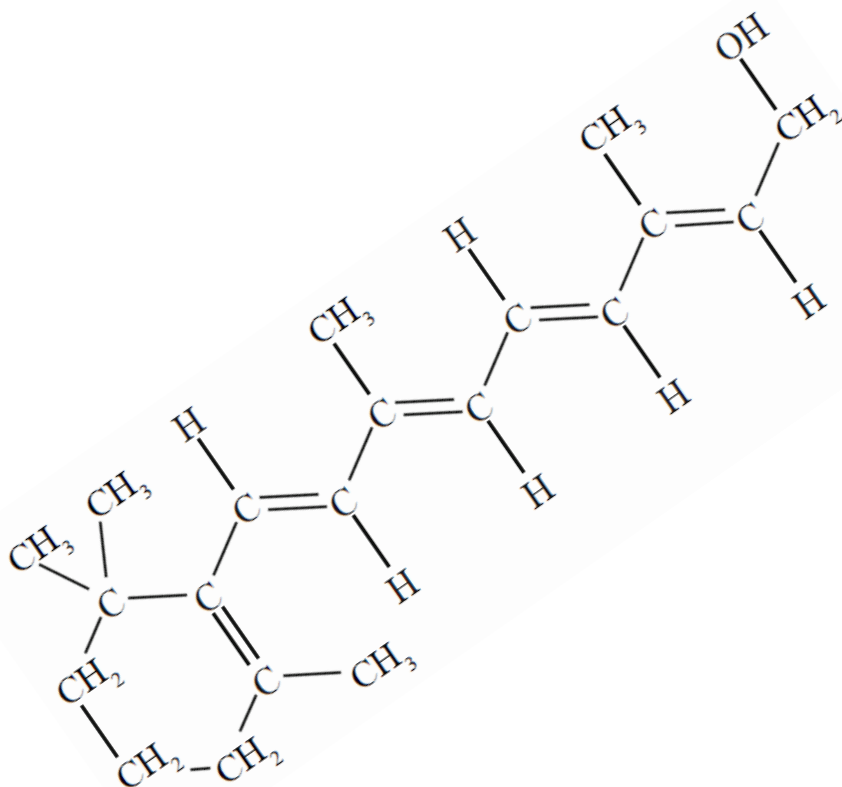
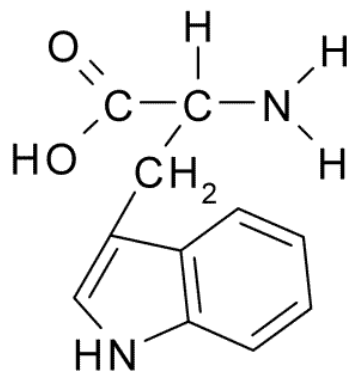
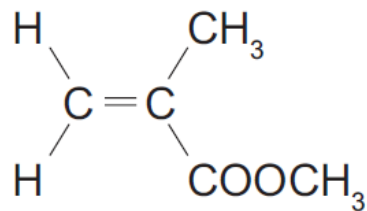
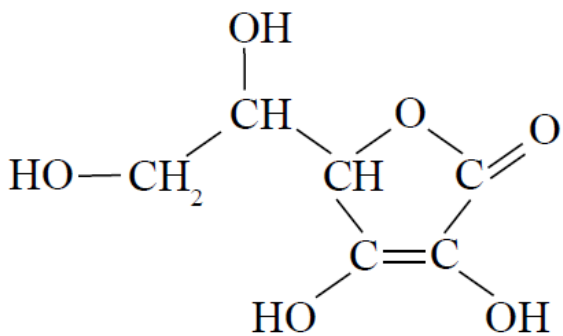
First the functional groups...

Place in a molecule where a reaction takes place. Compounds with the same functional group – homologous series - have similar properties.

alkane -ane	alkene -ene	alkyne -yne	haloalkane bromo, chloro etc
$ \begin{array}{cccc} \text{H} & \text{H} & \text{H} & \text{H} \\ & & & \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ & & & \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array} $	$ \begin{array}{c} \text{H} & \text{H} \\ & \diagdown \quad \diagup \\ & \text{C}=\text{C} \\ & \diagup \quad \diagdown \\ \text{H} & \text{H} \end{array} $	$ \text{H}-\text{C}\equiv\text{C}-\begin{array}{c} \text{H} \\ \\ \text{C} \\ \\ \text{H} \end{array}-\begin{array}{c} \text{H} \\ \\ \text{C} \\ \\ \text{H} \end{array}-\text{H} $	$ \begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H}-\text{C}-\text{Br} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H} \end{array} $
alcohol -anol	carboxylic acid -anoic acid	amine amino	C-C C=C C≡C R-X R-OH R-COOH R-NH ₂
$ \begin{array}{ccccccc} & & \text{H} & & & & \\ & & & & & & \\ \text{H} & \text{H} & \text{O} & \text{H} & \text{H} & & \\ & & & & & & \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \end{array} $	$ \begin{array}{c} \text{H} & \text{H} & & \text{O} \\ & & & \\ \text{H}-\text{C}-\text{C}-\text{C} & & \text{O} \\ & & / \\ \text{H} & \text{H} & \text{H} \end{array} $	$ \begin{array}{c} \text{H} & \text{H} & \text{H} \\ & & \\ \text{H}-\text{C}-\text{C}-\text{N} \\ & & \\ \text{H} & \text{H} & \text{H} \end{array} $	

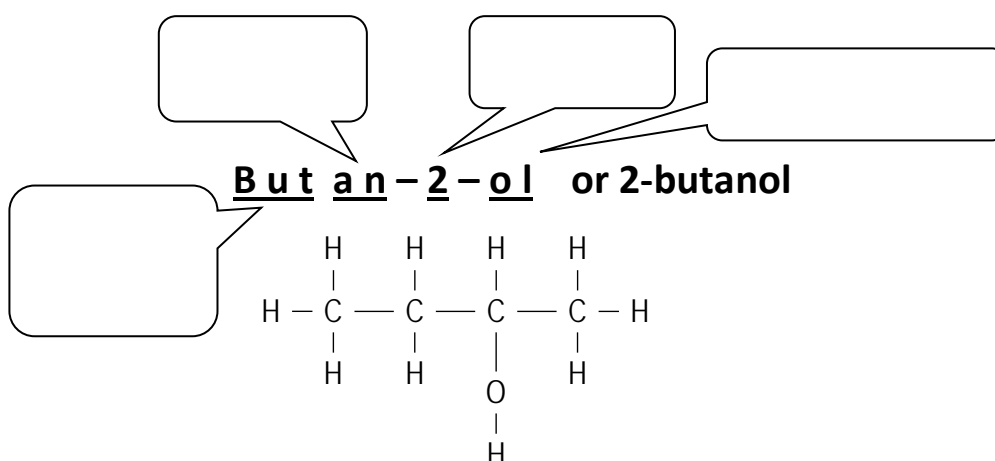


What functional groups can you identify here?

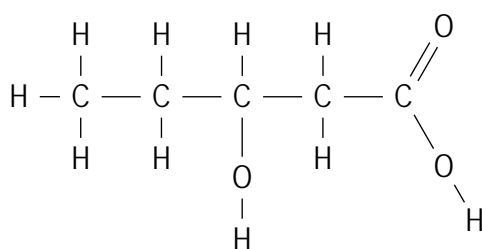


NAMING

No. of carbons	Alkane name	Prefix	Side chain
1	methane	meth-	methyl-
2	ethane	eth-	ethyl-
3	propane	prop-	propyl-
4	butane	but-	butyl-
5	pentane	pent-	
6	hexane	hex-	
7	heptane	hept-	
8	octane	oct-	



- Find longest carbon chain – base name on the parent alkane
- Number the C atoms in the chain to indicate position of any side chains or functional groups (number from end to give the lowest numbers)
- Give names and positions of functional groups eg 3-bromo, and 4-chloro (alphabetically)
- Where there's more than one functional group there is priority order for naming - ol > halo- -anoic acid > halo -anoic acid > hydroxy (-OH)



___ - hydroxy ____anoic acid

Name me...	Draw me...
$\text{CH}_3\text{CH}_2\text{C}\equiv\text{CCH}_3$	3-chlorobutan-1-ol
$ \begin{array}{cccc} \text{H} & \text{H} & \text{H} & \text{H} \\ & & & \\ \text{H}-\text{C} & -\text{C}- & \text{C}- & \text{N} \\ & & & \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array} $	2-chloro-3-methylbutanoic acid
$ \begin{array}{ccccccc} \text{CH}_3 & -\text{CH}_2 & -\text{CH} & -\text{CH}_2 & -\text{Cl} \\ & & & & \\ & & \text{Cl} & & \end{array} $	2-methyl propan-1,2-diol
$ \begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & & & \\ & & & & & & \\ \text{N} & -\text{C} & -\text{C} & -\text{C} & -\text{H} & & \\ & & & & & & \\ \text{H} & \text{H} & \text{H} & \text{H} & & & \end{array} $	pentan-2-ol
$ \begin{array}{ccccccc} \text{CH}_3 & -\text{CH}_2 & -\text{CH} & -\text{CH}_2 \\ & & & \\ & & \text{Br} & \text{Br} \end{array} $	4-methylpent-2-yne
$ \begin{array}{ccc} \text{CH}_3 & -\text{C} & =\text{CH}_2 \\ & & \\ & \text{Br} & \end{array} $	3-chloropropan-1-ol
$ \begin{array}{cccc} \text{H} & \text{H} & \text{H} & \text{H} \\ & & & \\ \text{H}-\text{C} & -\text{C}- & \text{C}- & \text{N} \\ & & & \\ \text{H} & \text{H} & \text{H} & \text{H} \end{array} $	2-amino-2-methyl propane
$ \begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & & & \\ & & & & & & \\ \text{H}-\text{C} & -\text{C}- & \text{C}- & \text{C}- & \text{H} & & \\ & & & & & & \\ \text{H} & \text{H} & \text{H}-\text{C} & -\text{H} & & & \\ & & & & & & \\ & & \text{H} & & & & \end{array} $	pent-2-ene

FORMULAE

General Formula

C_nH_{2n+2} alkanes

C_nH_{2n} alkenes

C_nH_{2n-2} alkynes

$C_nH_{2n+1}OH$ alkanols (alcohols)

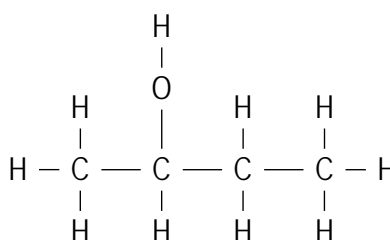
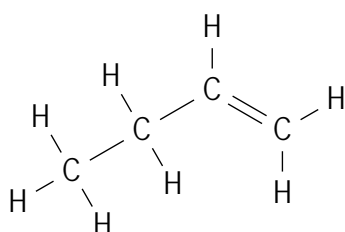
$C_nH_{2n+1}Cl$ chloroalkanes

$C_nH_{2n+1}NH_2$ amines

$C_nH_{2n+1}COOH$ carboxylic acids

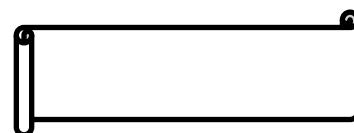
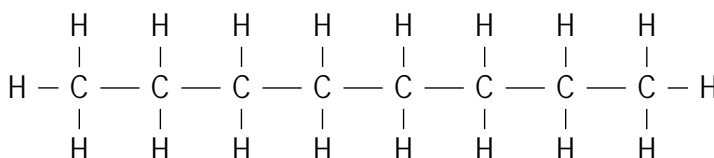
Molecular formula – gives the number of each type of atom in a molecule

Structural formula – gives the arrangement of atoms in a molecule, indicating how atoms are bonded together.

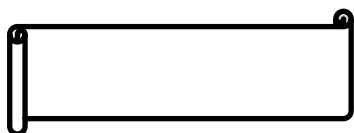


• **Expanded**

• **Condensed**



is $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$ or $CH_3(CH_2)_6CH_3$





Structural isomers

- **Same number and type of atoms but arranged in different ways**

Structural isomers have the same molecular formula but they differ in the sequence in which the atoms are joined together.

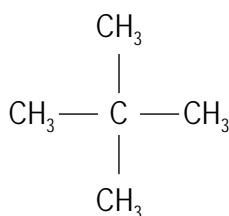
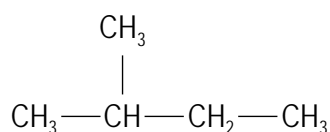
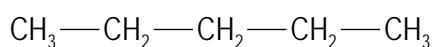
Structural

- Chain/branched chain
- Positional
- Functional group

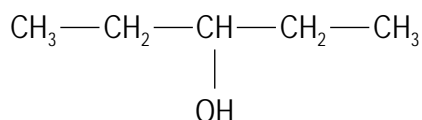
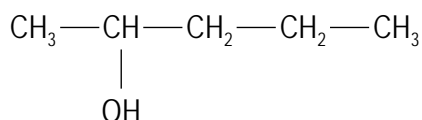
Geometric

- Cis
- Trans

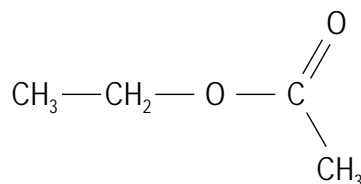
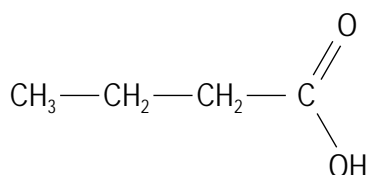
Chain/branched chain



Positional



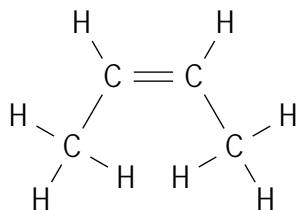
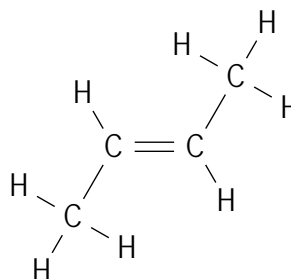
Functional group



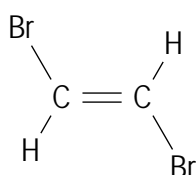
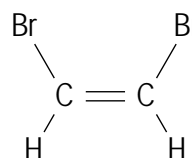
- **Geometric**

C=C double bond in alkenes is fixed and cannot be rotated (“is no free rotation about the C=C double bond”). This allows for different arrangements of the atoms/groups of atoms **in space**.

- groups on same side, cis-
- groups on opposite sides, trans

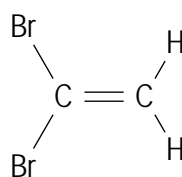
*cis-*and *trans-*

Cis-trans (geometric) isomers exist where there is a C=C which **cannot freely rotate**. If there are two different groups bonded to the Cs of the double bond, two arrangements are possible.

*trans-*and *cis-*

1,2-dibromoethene meets these requirements since each C of the double bond has –H and –Br, i.e. different groups.

However, 1,1-dibromoethene does not meet these requirements since the two groups on the Cs of the double bond are the same, ie one C has two –H and the other two –Br.



Example Question

But-2-ene can exist as geometric (*cis-trans*) isomers, whereas but-1-ene cannot. Explain this difference, using structural formulae to illustrate your answer.

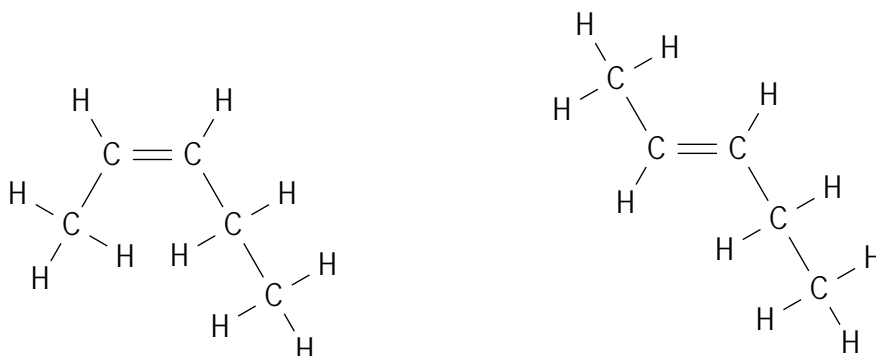
Cis-trans isomers can occur in molecules that have double bonds, because rotation of the atoms about the axis of the carbon to carbon double bond is restricted. They must also have two different groups attached to each of the carbons involved in the double bond.

<i>Cis</i> -but-2-ene	<i>Trans</i> -but-2-ene	But-1-ene

Drawing cis- and trans- isomers

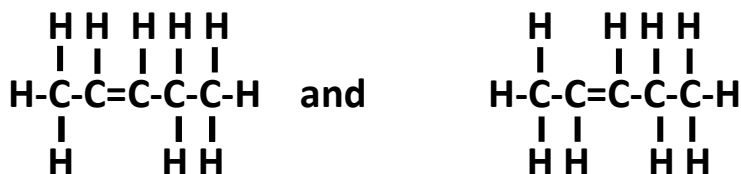
Always start from a  shape!!

Right 😊



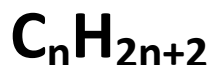
and

Wrong 😞



Using the top way, you will clearly see the effect on the shape of the molecule.

ALKANES



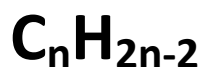
- single C-C bonds
- are saturated (no more H atoms can be added to their molecules)

ALKENES



- contain a C=C double bond
- are unsaturated (more H atoms (or other atoms) can be added to their molecules)

ALKYNES



- contain a C≡C triple bond
- are unsaturated (more H atoms (or other atoms) can be added to their molecules)

Physical properties

- as no. of C↑ go from being gas to liquid to solid at room temperature
- smell – have weak intermolecular forces
- low m.pt & b.pt – have weak intermolecular forces
- insoluble in water – hydrocarbons are non-polar
- good solvents for fats & oils – non-polar substances dissolve other non-polar substances
- don't conduct electricity – no electrons that are free to move

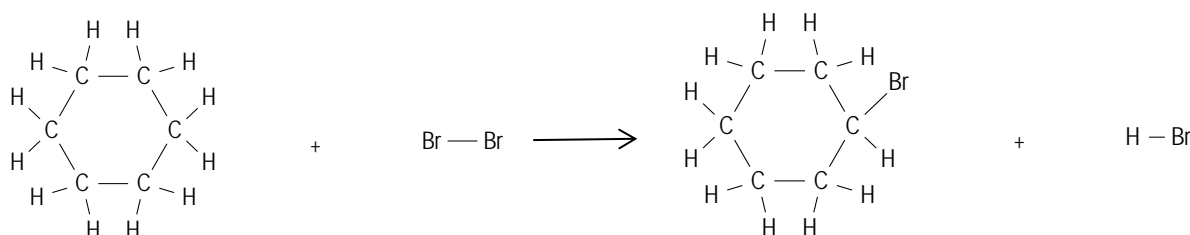


ALKANES

- Fairly unreactive (only C-C); reactions need heat and/or UV light.
- But they do BURN well – used as fuels ☺ see below

Substitution reactions: chlorination / bromination.

- React in presence of UV light and/or heat.



- The reaction is slow. Orange bromine is slowly decolourised.
- Chlorine reacts in a similar way.
- The reaction continues but normally we only write equations for “monosubstitution”.
- It is called a SUBSTITUTION reaction because one of the hydrogen atoms in the molecule is replaced by a bromine atom.

Molecules that undergo substitution reactions have carbon to carbon single bonds and form molecules with carbon to carbon single bonds. In a substitution reaction an atom or group of atoms is replaced by another atom or group of atoms.

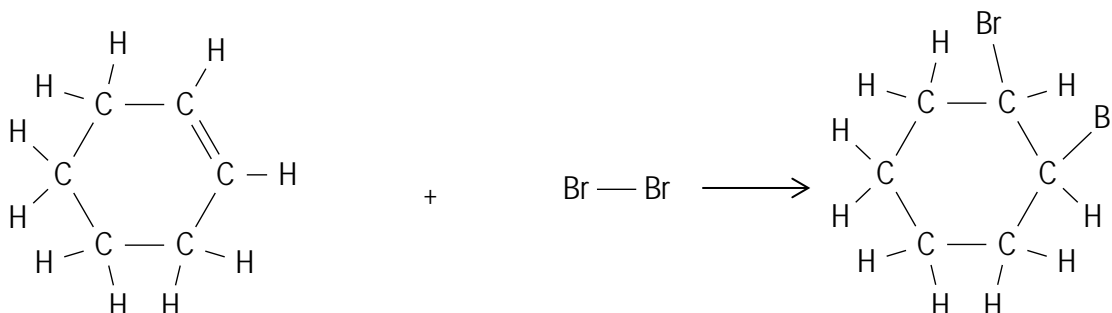
Combustion

- Complete; plentiful O_2 . Products CO_2 & H_2O and lots of energy
- Incomplete; limited O_2 . Products C (soot), CO & CO_2 & H_2O and less energy

ALKENES...

- More reactive than alkanes because of C=C
- Undergo ADDITION reactions
- C=C double bond replaced with C-C bond
& 2 new bonds are made.

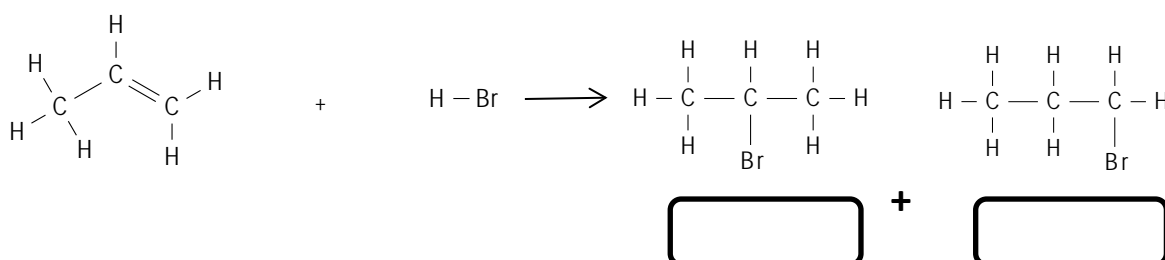
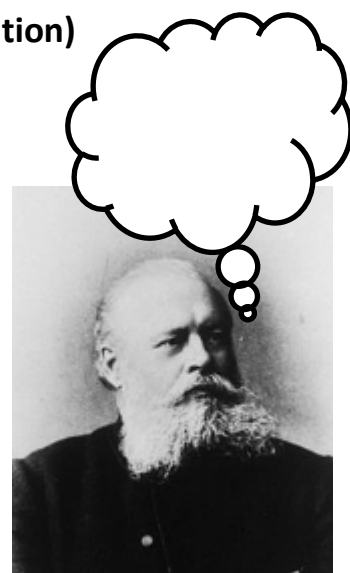
Molecules that undergo **addition** reactions have carbon to carbon double bonds and form molecules with carbon to carbon single bonds. In an addition reaction the reaction involves breaking a double bond between the carbon atoms and forming a single bond in its place as well as forming two new single bonds.



- Addition reactions can occur with
 - Hydrogen, H_2 , Pt catalyst – hydrogenation
 - Water, conc H_2SO_4 then water & heat – hydration
 - Halogens, Cl_2 & Br_2 – halogenation (chlorination, bromination)
 - Hydrogen halides, HBr – hydrohalogenation
 - Themselves, monomer \rightarrow polymer, polymerisation

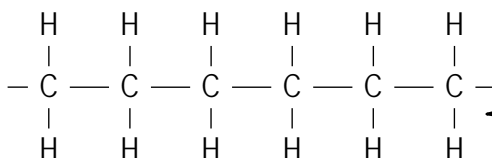
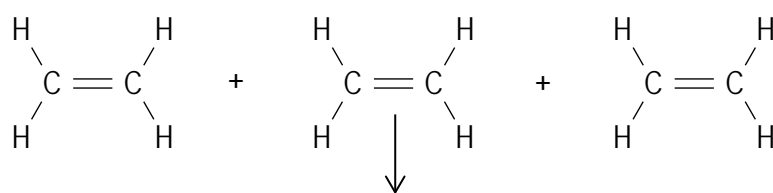
Markownikoff's rule

- Addition of an unsymmetrical reagent (eg HCl, HBr, H_2O (H-OH)) to an unsymmetrical alkene eg propene or but-1-ene
- 2 possible products, one major one minor
- Predict using "the rich get richer"
- H atom adds to the C of the C=C that already has most H atoms

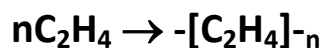


POLYMERISATION

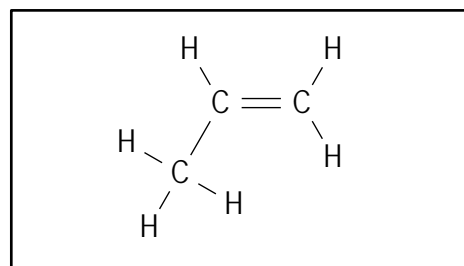
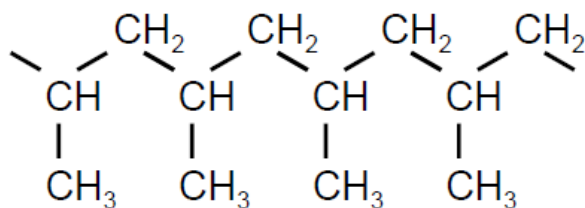
- Need high temperatures, pressure & catalyst
- Many monomer molecules → polymer molecule
- Addition reaction – called “addition polymerisation”
- E.g. ethene → polyethene, propene → polypropene
- Feature that allows this is the C=C double bond



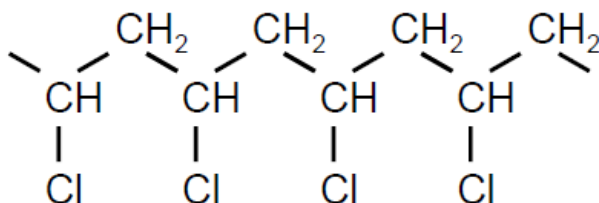
Now a saturated molecule but still called polyethene



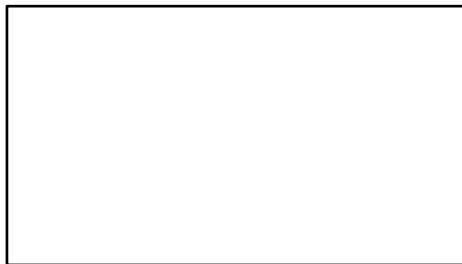
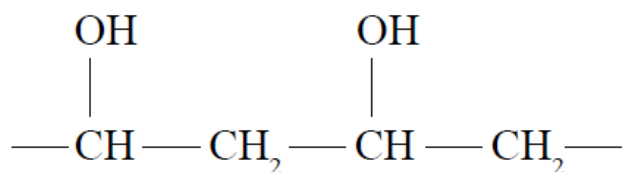
Polypropene



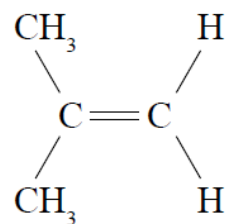
Polyvinyl chloride (PVC)



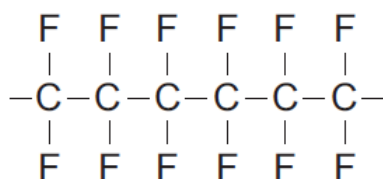
Polyvinyl alcohol



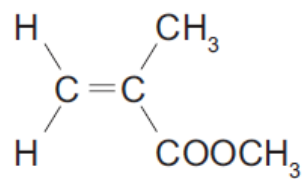
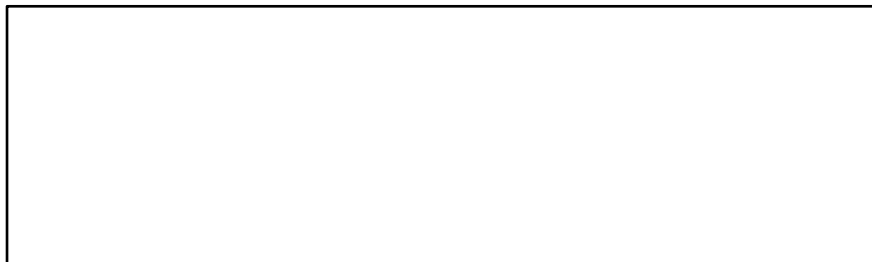
Polymethylpropene



Polytetrafluoroethene (PTFE)



Perspex





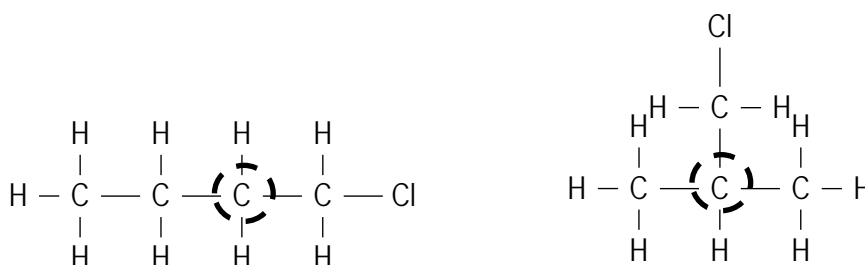
- R-X
- $C_nH_{2n+1}X$
- X – is F, Cl, Br or I (halogen)

Formed by

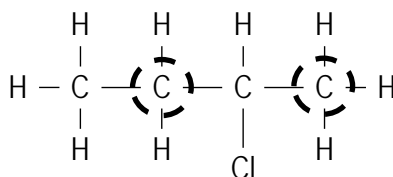
- Substitution of an alkane (needs *uv* light and or heat)
- Addition of HX to an alkene
- Addition of X_2 to an alkene
- Reaction of an alcohol with a hydrogen halide, PCl_3 , PCl_5 or $SOCl_2$

Classification – based on position of the halogen group

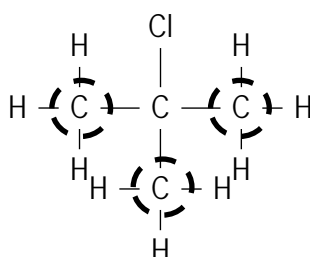
- Primary



- Secondary



- Tertiary



How many C are attached to the C that has the halogen attached to it?

Reactions of haloalkanes

Substitution reactions

NH_3 : haloalkane \rightarrow amine

$\text{R-X(l)} + \text{NH}_3(\text{alc}) \rightarrow \text{R-NH}_2 + \text{HX(alc)}$; the must be dissolved in alcohol, not in H_2O (which would produce NH_4^+ and OH^- : OH^- would react with the R-X instead of the NH_3).

KOH or NaOH(aq) : haloalkane \rightarrow alcohol

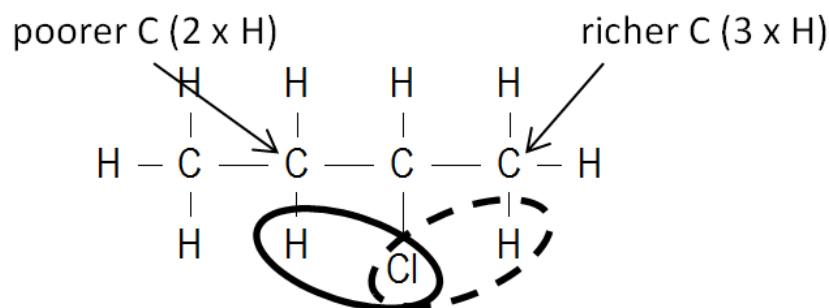
$\text{R-X(l)} + \text{NaOH(aq)} \rightarrow \text{R-OH} + \text{NaX(aq)}$

Elimination reactions:

Haloalkanes \rightarrow alkenes, $\text{R-X} \rightarrow \text{R=C} + \text{HX}$

This uses KOH dissolved in alcohol, usually ethanol which we write as KOH(alc) or $\text{OH}^-(\text{alc})$

- KOH(alc) or NaOH(alc) - dissolved in alcohol to prevent substitution by OH^- (forming the alcohol)
- 3° haloalkanes $>$ 2° haloalkanes $>$ 1° haloalkanes to undergo elimination
- **Saytzeff** 's rule applies: *the poor get poorer*. (reverse of Markovnikov's rule)
- Will get a major & minor products if unsymmetrical/asymmetric haloalkane

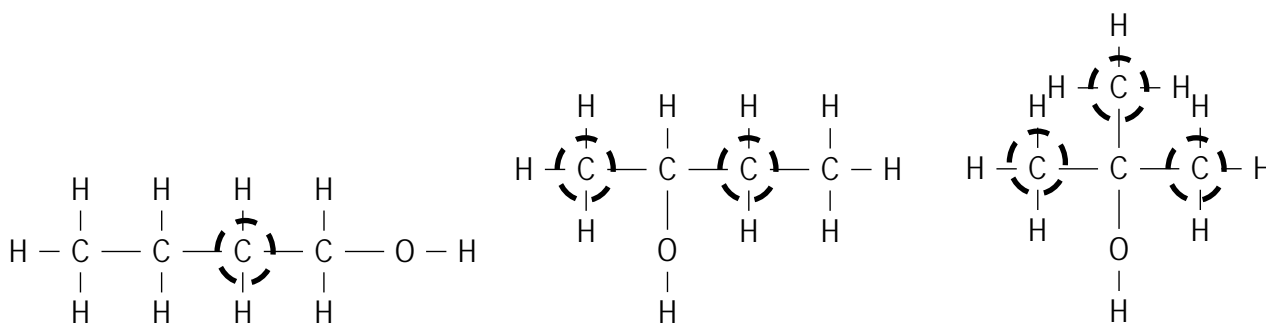


Molecules that undergo elimination reactions have carbon to carbon single bonds and form molecules with carbon to carbon double bonds. In an elimination reaction two atoms or small groups are removed from a molecule forming a carbon to carbon double bond.

ALCOHOLS

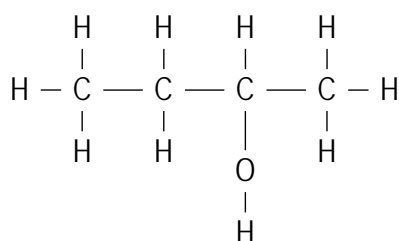
important fuels
and solvents

- -OH functional group
- $C_nH_{2n+1}OH$ or R-OH
- Position of -OH group decides primary, secondary or tertiary

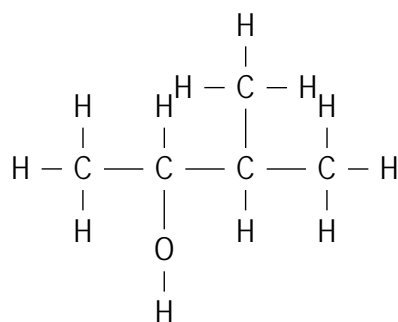


- Polar molecules due to -OH group; small ones (C 1 -3) are water soluble, larger ones not.

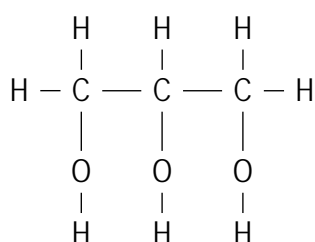
Naming - name or draw



propan-2-ol

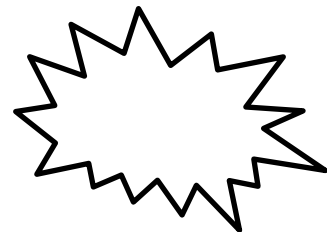


ethan-1,2-diol



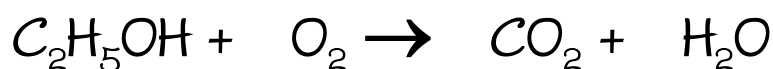
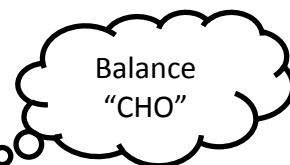
2-chloro-butan-2-ol

Reactions of alcohols



Combustion

Burn with a clean almost colourless flame, good fuels



OXIDATION

Primary alcohols can be oxidised by heating them with either:

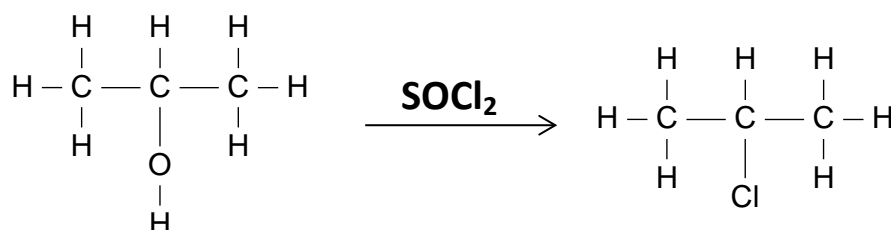
- Acidified dichromate ($\text{H}^+/\text{Cr}_2\text{O}_7^{2-}$):
colour change $\text{Cr}_2\text{O}_7^{2-}$ _____ to Cr^{3+} _____
- Acidified permanganate ($\text{H}^+/\text{MnO}_4^-$):
colour change MnO_4^- _____ to Mn^{2+} _____

The alcohols are oxidised to carboxylic acid ($-\text{COOH}$ functional group)

SUBSTITUTION REACTIONS – to form chloroalkanes

Chloroalkanes are important for the formation of many other organic chemicals.

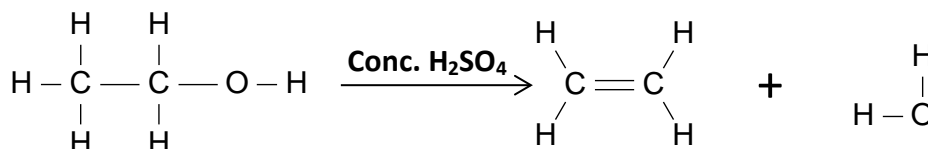
- Can use PCl_3 , PCl_5 or SOCl_2 (SOCl_2 being the most effective for primary, secondary & tertiary alcohols).



(+ SO_2 + HCl)

Elimination of water – essentially dehydration where –OH is removed with –H from an adjacent C atom – to produce a C=C (alkene)

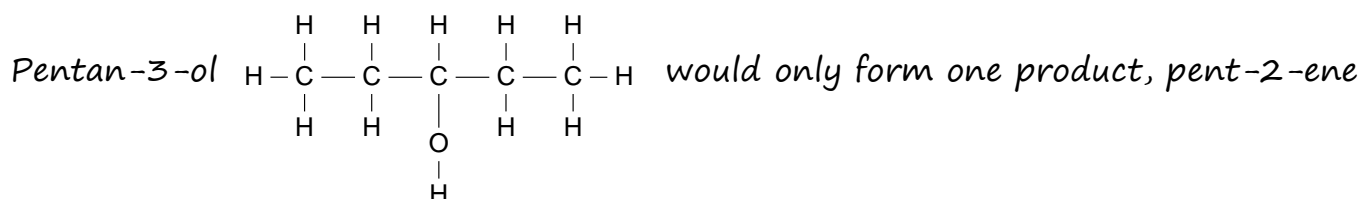
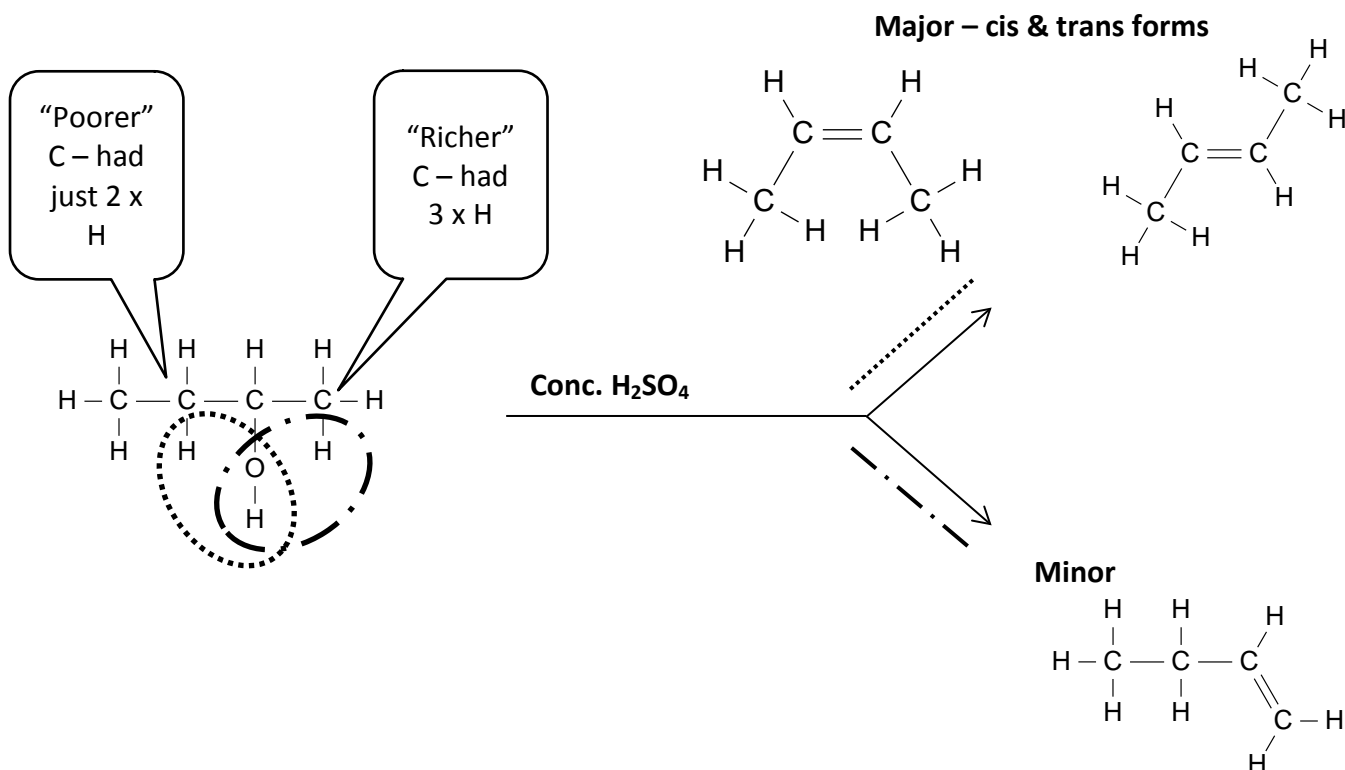
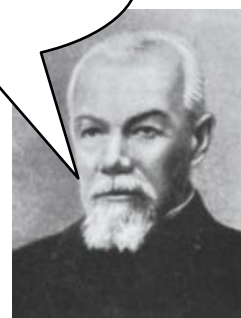
Reagent: conc H_2SO_4



Here, we may need to apply the **Saytzeff's rule**:

the poor get poorer if the alcohol is **ASYMMETRIC**. The double bond starts on the carbon which had the –OH, but the other end of that double bond goes to the carbon atom which had the fewer hydrogen atoms.

e.g. butan-2-ol

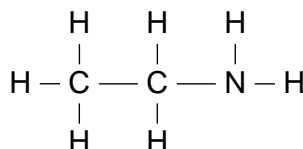


AMINES –NH₂ amino group



Essentially NH₃ with 1, 2 or 3 H atoms replaced with alkyl group(s)

- naming based on alkane so C₂H₅NH₂ is aminoethane (IUPAC) but also often called ethylamine

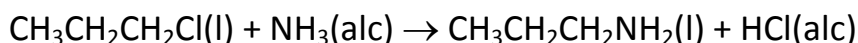


Physical properties

- Methylamine and ethylamine are gases; others low m.pt. volatile liquids; C > 5 are usually solids
- Characteristic “fishy” smell (actually they stink!!)
Low mass amines are soluble in water – as form hydrogen bonds with water; larger ones insoluble.




Preparation

Primary amines can be prepared by the substitution of a haloalkane by alcoholic ammonia.



Acid-base reactions of amines.

- Amines are bases - like ammonia.
- Amines are **weak bases** since proton acceptors, $\text{R-NH}_2 + \text{H}_2\text{O} \rightleftharpoons \text{R-NH}_3^+ + \text{OH}^-$
 - $\text{NH}_3 + \text{H}_2\text{O} \rightleftharpoons \text{NH}_4^+ + \text{OH}^-$
 - $\text{R-NH}_2 + \text{H}_2\text{O} \rightleftharpoons \text{R-NH}_3^+ + \text{OH}^-$

They turn damp  litmus paper 
and green universal indicator solution/paper blue. 

Reaction with HCl

As bases, amines react with acids such as HCl to form salts.

- $\text{NH}_3(\text{g}) + \text{HCl}(\text{g}) \rightarrow \text{NH}_4^+\text{Cl}^-(\text{s})$
- $\text{CH}_3\text{NH}_2(\text{g}) + \text{HCl}(\text{g}) \rightarrow \text{CH}_3\text{NH}_3^+\text{Cl}^-(\text{s})$ methyl ammonium chloride

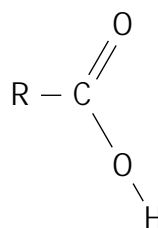
These salts are colourless, crystalline solids, soluble in water and have no smell.

Carboxylic acids – count the “C”s 😊

HCOOH methanoic acid

CH₃COOH ethanoic acid





C₂H₅COOH propanoic acid

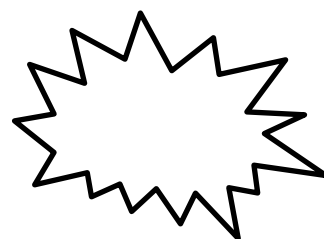


- contain the –COOH functional group
- the -COOH group is very polar; C1-3 are soluble in water, C4 and above not (due to long hydrocarbon portion)
- Higher m.pt. and b.pt. than alcohols of similar mass due to stronger intermolecular attractions
- are weak acids – only partly ionised when placed in water

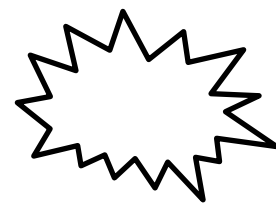
$$\text{CH}_3\text{COOH} + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{COO}^- + \text{H}_3\text{O}^+$$
- are poor conductors of electricity as aq. solutions (as weak acids)

Reactions as acids

- turn  blue litmus red 
- turn  green UI paper orange  pH 3-4
- $\text{RCOOH} + \text{H}_2\text{O} \rightleftharpoons \text{RCOO}^- + \text{H}_3\text{O}^+$ ie release H_3O^+ ions
- “Typical acids reactions”
 - acid + metal → salt + hydrogen eg Mg or Zn to produce bubbles of H₂ gas
 - acid + base → salt + water eg NaOH
 - acid + carbonate → salt + water + carbon dioxide eg Na₂CO₃ and CaCO₃ & hydrogen carbonates NaHCO₃ to produce bubbles of CO₂ gas



TYPES OF REACTIONS



The list may look long & bewildering but that's just because some reactions can be called a number of things.....

All of this has been previously covered in separate sections. The "must knows" are highlighted

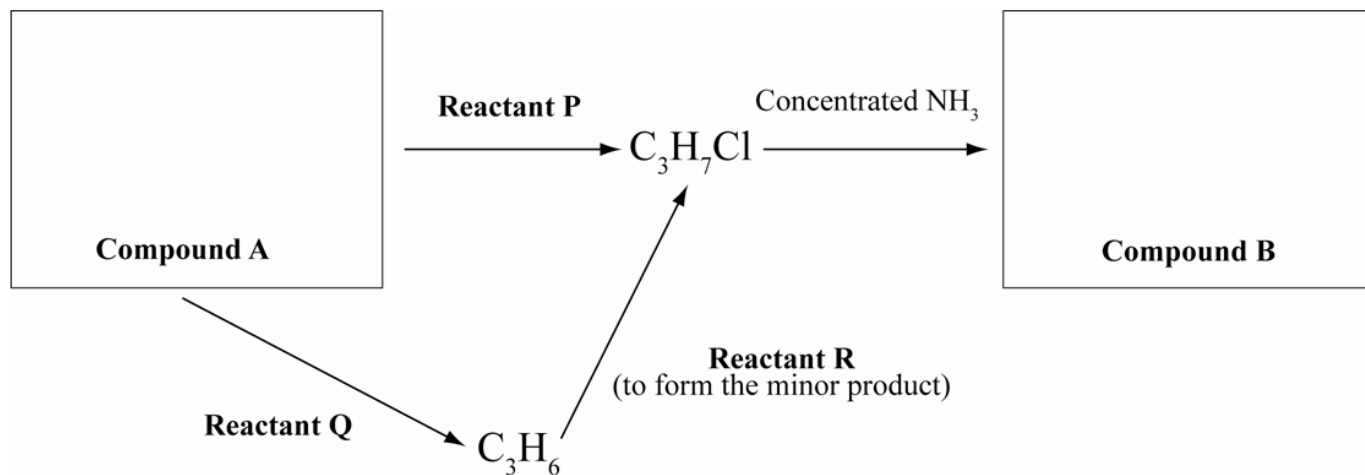
- **acid-base**
 - reaction involving a carboxylic acid & a base e.g. NaOH OR
 - reaction involving a carboxylic acid & a carbonate/hydrogen carbonate e.g. NaHCO₃
 - reaction involving an amine & an acid
 - these are neutralisation reactions
- **addition**
 - involves a small molecule joining across the C=C double bond of an unsaturated molecule (alkene/yne). The molecule becomes saturated.
 - no other product is made
- **bromination**
 - addition of bromine
- **chlorination**
 - addition of chlorine
- **dehydration**
 - the removal of water (H and OH on adjacent C atoms) to form a C=C bond
 - heat with conc. H₂SO₄ or pass over Al₂O₃ catalyst
 - since it involves removal it is also an elimination reaction
- **elimination**
 - -H & -OH / water / removed from neighbouring C atoms in an alcohol. Also known as dehydration
 - H-X / hydrogen halide removed from neighbouring C atoms in a haloalkane.

A C=C double bond forms / forms an alkene / the molecule becomes unsaturated.

- **halogenation** (halogens are Cl_2 , Br_2 etc)
 - halogen added across the double bond of alkene (or $\text{C}\equiv\text{C}$ of alkyne)
 - since it involves adding atoms it is also an addition reaction
 - chlorination, bromination & iodination are all halogenation reactionsOR
 - halogen swapped for an H on an alkane (alkane & halogen & UV light and/or heat)
 - since it involves replacing atoms it is also a substitution reaction
- **hydration**
 - water added across the double bond of alkene (alkene \rightarrow alcohol)
 - since it involves adding atoms H and OH it is also an addition reaction
- **hydrogenation**
 - hydrogen added across the double bond of alkene (or $\text{C}\equiv\text{C}$ of alkyne)
 - needs a Pt or Ni catalyst
 - since it involves adding atoms it is also an addition reaction
- **oxidation**
 - conversion of primary alcohol to carboxylic acid using heat and $\text{H}^+/\text{Cr}_2\text{O}_7^{2-}$ or $\text{H}^+/\text{MnO}_4^-$ (both oxidising agents)
 - conversion of an alkene to a diol using $\text{H}^+/\text{MnO}_4^-$ (no heat needed)
- **polymerisation** (limited to addition polymerisation @ level 2)
 - unsaturated monomers joined to make a polymer (saturated)
 - it is an addition reaction as the monomers add (and no other product made)
- **substitution** – one atom is removed and replaced with another atom
 - e.g. Cl_2 and an alkane: one hydrogen atom will be removed from the molecule and one chlorine atom will take its place. UV light is required for the process. HCl also formed.

REACTION FLOW CHARTS

The secret is that you don't have to start at the beginning! Looking for clues and working backwards often works very well.



Compound A has a molecular formula C_3H_8O . It reacts readily with acidified potassium dichromate solution.

Clues!

A had the molecular formula C_3H_8O – only 1 x O so an alcohol with a $-OH$ group.

A reacts with acidified dichromate – more evidence for it being an alcohol.

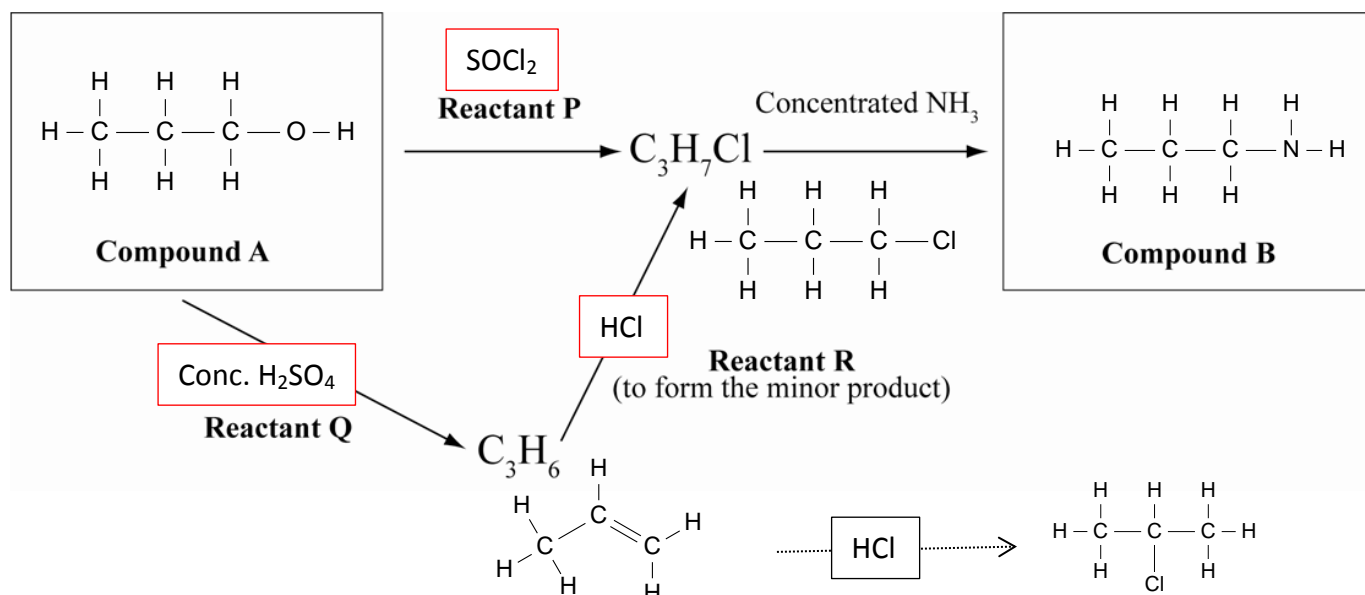
C_3H_7Cl reacts with ammonia – B must be an amine (a substitution reaction) with $-Cl$ off and $-NH_2$ on.

$C_3H_6 \rightarrow C_3H_7Cl$; must be the addition of HCl ; so C_3H_6 had to be an alkene ($C=C$), and an unsymmetrical one since there is a reference to the "minor" product.

A, $C_3H_8O \rightarrow C_3H_6$ involves the loss of 2 x H and 1 x O, i.e. H_2O . This is an elimination or dehydration reaction, and needs conc. H_2SO_4 .

A, $C_3H_8O \rightarrow C_3H_7Cl$ needs substitution of $-OH$ for $-Cl$, best done using $SOCl_2$.

Since the C_3H_7Cl is the minor product with the $-Cl$ on the end, the $-OH$ and $-NH_2$ must also be there.



This would be the major product