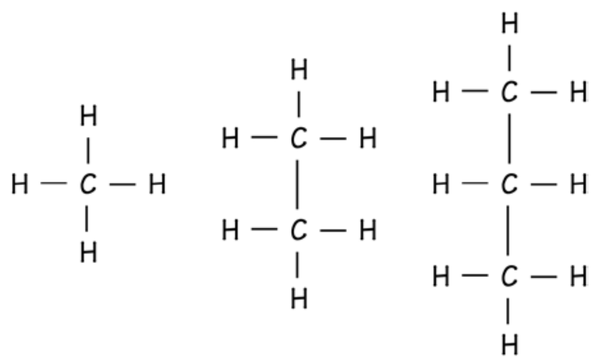
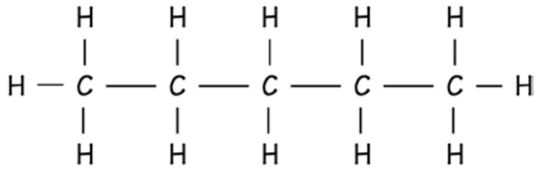
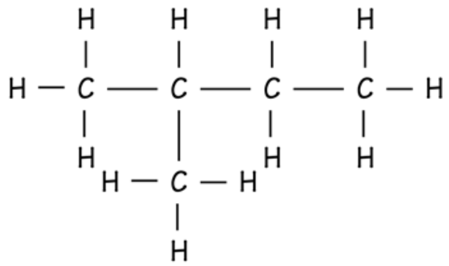
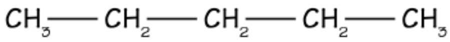
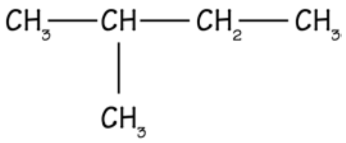
Introduction to Organic Chemistry

What are hydrocarbons?	Contain hydrogen and carbon atoms only
What are the functional groups to know at level 2?	Influence reactivity – give similar chemical and physical properties • alkanes C-C • alkenes C=C • alkynes C≡C • haloalkanes R-X (where X is F, Cl, Br, I) • alcohols R-OH • carboxylic acids R-COOH • amines R-NH_2 R is rest of molecule
What are the prefixes for C 1-8?	# of C atoms in the molecule. 1 meth- 2 eth- 3 prop- 4 but- 5 pent- 6 hex - 7 hept- 8 oct-
What is the general formula for alkanes and what are they saturated hydrocarbons?	C_nH_{2n+2} Each C atom bonded to 4 other atoms; no spare bonds within molecule for further atoms to be added, contain only C-C single bonds; this is called a saturated molecule 

SUMMARY: Organic chemistry is study of compounds containing carbon. Homologous series have fixed functional groups which give the compound its characteristic properties. Alkanes are saturated hydrocarbons having single bonds between carbon atoms.

Types of Formula

What does the molecular formula tell you?	Identifies the number and type of atoms e.g. C_5H_{12}
What does the structural formula show you?	Shows how the atoms are arranged and bonded to each other  
How do we write a structural formula as a condensed structural formula?	 or $CH_3CH_2CH_2CH_2CH_3$ or even $CH_3(CH_2)_3CH_3$  or $CH_3CH(CH_3)CH_2CH_3$

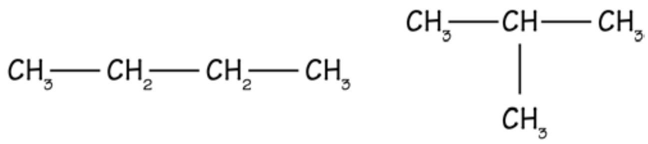
SUMMARY: We can write the formulae of organic molecules in a number of different ways; molecular, structural and condensed structural formula.

Alkanes & Isomers

How do I draw isomers of C_4H_{10}?

C_nH_{2n+2} where n is the # of carbon atoms

Can be straight chain or branched chain



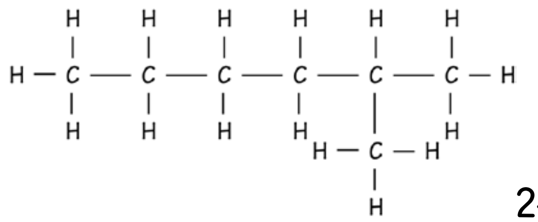
Side chains named methyl (CH_3-), ethyl (C_2H_5-), propyl (C_3H_7-) etc

How are alkanes named using numbers and side chains?

Find longest carbon chain.

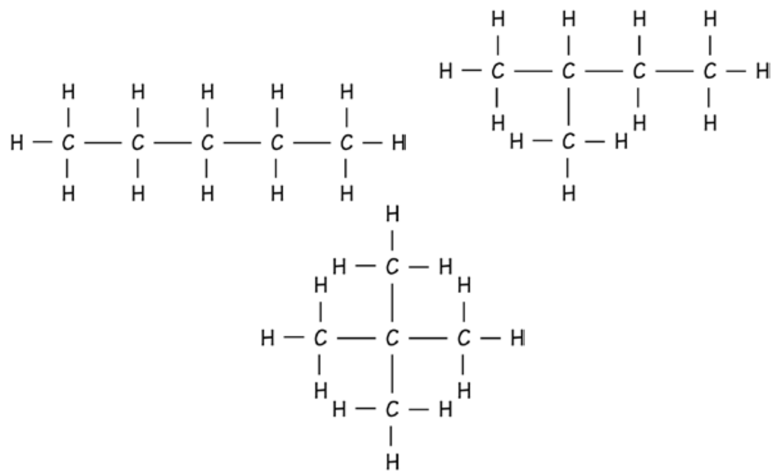
Find side chain and name it based on # of C atoms, using yl

Count from end that gives lowest number for the side chain



2-methylhexane

Have the same molecular formula but different structures e.g.



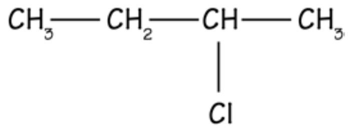
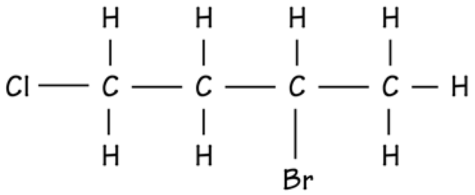
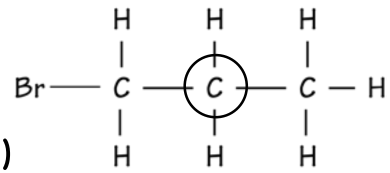
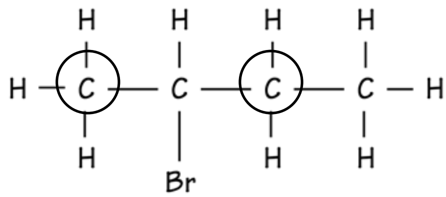
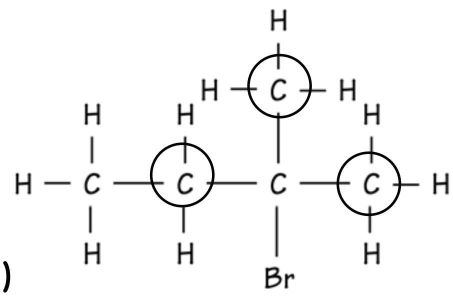
SUMMARY: Alkanes with general formula C_nH_{2n+2} can be straight or branched. They are named based on the longest carbon chain, with numbers used to show the position of the side chains, numbering from the end so as to give the side chain position the lowest possible number. Structural isomers have the same molecular formula but have different physical structures. They are also known as conformational isomers.

Alkane physical properties & chemical reactions

How and why do m.pt. and b.pt. increase as alkanes increase in size?	Melting and boiling points increase in a regular way as the length of the carbon chain increases. @ room temperature C1 – 4 are gases, C5 upwards are liquids; larger alkanes are solids e.g. candle wax Forces of attraction between molecules increases as carbon chain length increases, which means that more energy is needed overcome these forces to change the substances state.
What happens to alkanes in water and why?	Alkanes (non polar) are insoluble in water – a polar solvent. Form 2 layers – are immiscible in water.
How are alkanes used as fuels and what affects how well they burn?	Are used extensively as fuels Plentiful oxygen – complete combustion to produce CO_2, H_2O and max. amount of energy. Limited oxygen – incomplete combustion to produce C and CO and H_2O and less energy. C (soot) is dirty, CO is colourless, odourless, very toxic. CO_2 linked to global warming / climate change.
How do alkanes react with bromine water – and what special conditions are needed?	React slowly with Br_2 water in presence of UV light and/or heat. Orange bromine colour is slowly decolourised. Is a substitution reaction. Two products are made. $C_6H_{14} + Br_2 \rightarrow C_6H_{13}Br + HBr$ (The reaction would continue with further substitution but for this exam you only need to write an equation for monosubstitution).

SUMMARY: Alkanes are non-polar molecules that are insoluble in water. Their m.pt and b.pt increase as the number of carbon atoms in the molecule increase. Their two most important chemical reactions are combustion reactions (complete and incomplete) and substitution reaction with orange bromine.

Haloalkanes

What are haloalkanes (halogenoalkanes / alkyl halides)?	Molecules when H atom or H atoms in an alkane are replaced by X, where X is a halogen (F, Cl, Br, I)
How are haloalkanes named?	Fluoro, chloro, bromo, iodo (listed alphabetically if a molecule contains more than one type of halogen).  2-chlorobutane Naming similar to naming branched alkanes with numbering from end to give smallest number.  3-bromo-1-chlorobutane
How do you decide if a haloalkane is classified as primary, secondary or tertiary?	Primary (1°), secondary (2°) and tertiary (3°) used to classify haloalkanes. Identify the carbon atom bonded to the halogen and count the number of C atoms directly bonded to that C atom. (1°)  (2°)  (3°) 

SUMMARY: Haloalkanes contain halogen atom(s) in place of H atoms and can be classified as primary, secondary or tertiary depending on how many carbon atoms are directly bonded to the carbon atom that has the halogen bonded to it.

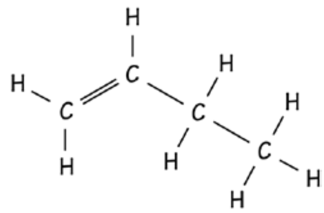
Alkenes

What are the first 3 alkenes and what is the alkene functional group?

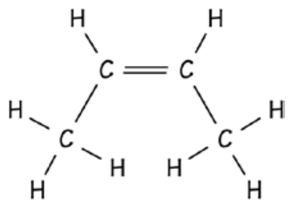
C_nH_{2n} ethene, propene, butene etc. Hydrocarbon molecules with one (or more) double covalent bonds between carbon atoms (C=C)

C=C functional group makes them more reactive than alkanes. The C=C means more atoms can be added to the molecule which is described as unsaturated; not every C atom is bonded to 4 other atoms.

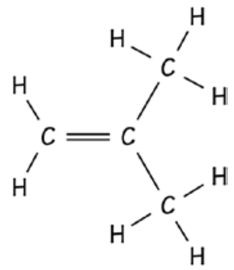
How can alkenes have structural and geometrical isomers?



but-1-ene



but-2-ene

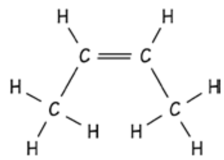


methylpropene

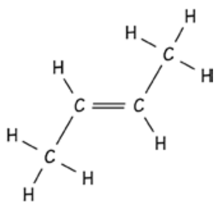
But-1-ene, but-2-ene and methylpropene are structural isomers (same molecular formula, different arrangement of carbon atoms)

What two things are needed for geometrical isomerism?

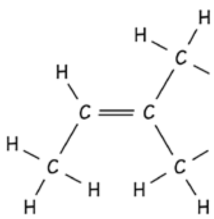
The C=C bond prevents rotation and so atoms / groups of atoms attached to either side of C=C are fixed in position. Alkenes with same molecular formula can be cis or trans. This is geometric isomerism.



cis-but-2-ene



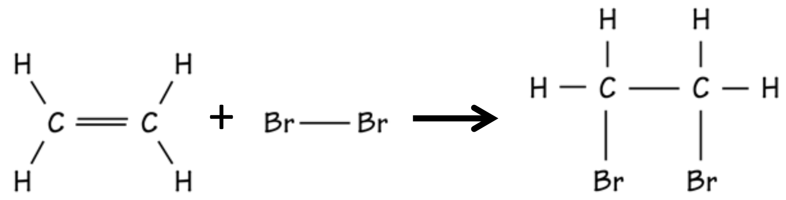
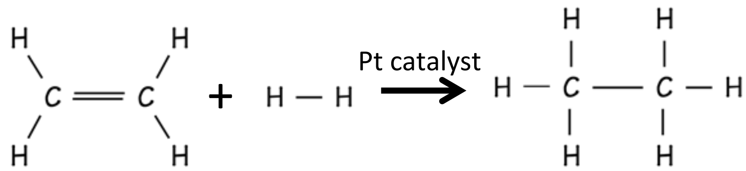
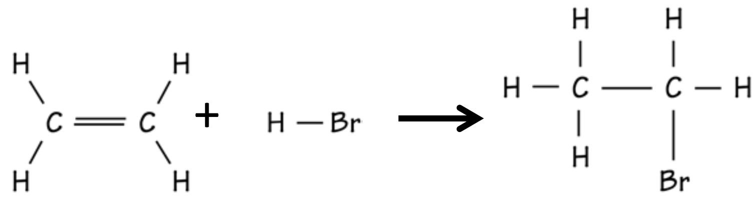
trans-but-2-ene



doesn't exist as cis or trans as right hand C of C=C has 2 groups the same

SUMMARY: Alkenes are unsaturated hydrocarbons containing a C=C double bond. The bond does not allow rotation and can give rise to cis and trans isomers as long as each carbon joined by the double bond has 2 different atoms/groups attached to it.

Addition reactions of alkenes

Define 'addition' reaction	C=C makes alkenes reactive. One of the bonds in the double bond breaks and atoms / groups of atoms can join to make a new molecule.
How do alkenes react with bromine water, hydrogen, HX, water, and themselves?	Addition reaction with bromine water. Orange bromine water is rapidly decolourised: Useful test for C=C / unsaturation Halogenation – e.g. addition of Br_2 or Cl_2  There is one product which is saturated (C-C). Other addition reactions Hydrogenation  Addition of HX – e.g. HCl or HBr  Hydration – addition of water. H^+, H_2O, heat – to form an alcohol Polymerisation (ethene → polyethene)

SUMMARY: Alkenes undergo addition reactions where one bond of the C=C double bond opens up and atoms join to the carbon atoms. The one product molecule is now unsaturated.

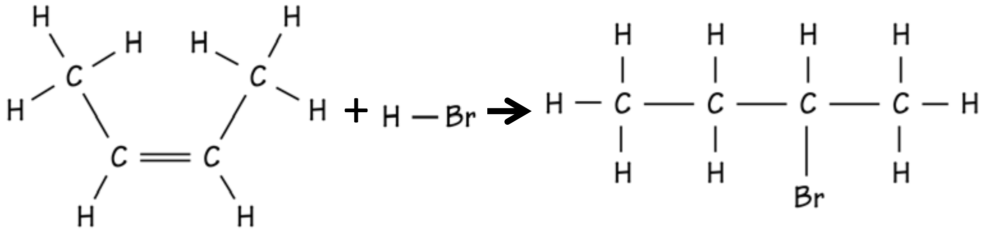
Shaking a small amount of bromine water with an alkane and an alkene lets you easily distinguish between them as the bromine water decolourises instantly with the alkene (and only very slowly with the alkane in uv light).

Markovnikov's Rule

What happens when an unsymmetrical reagent e.g. H-OH or HCl undergoes an addition reaction with an unsymmetrical alkene e.g. propene?

Reaction of HX or H_2O with alkenes.

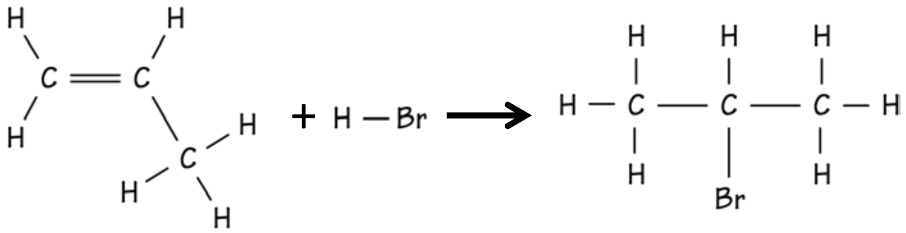
For symmetrical alkenes (even # of C atoms and C=C in middle of molecule) there is only one possible product.



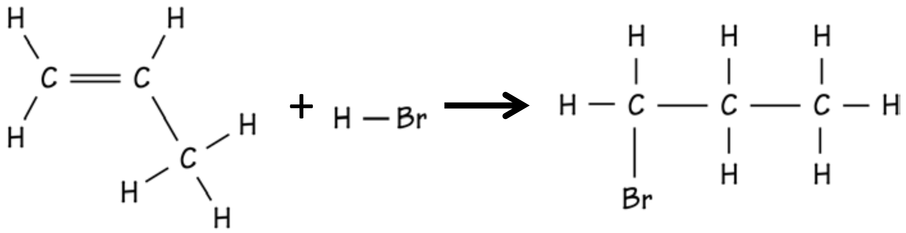
2-bromobutane

HBr is an unsymmetrical reagent (as is HCl, and H_2O - think of it as H-OH). When it reacts with an unsymmetrical alkene there are 2 possible products. Most common = major product, least common = minor product.

e.g.



major product



minor product

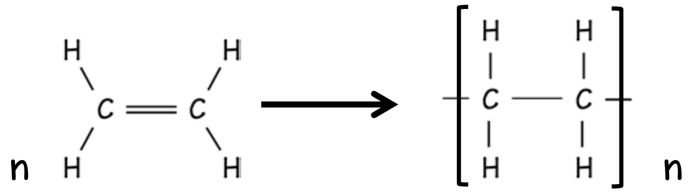
What is the easy way to remember Markovnikov's rule?

Major product - The H atom adds on to the C atom in the C=C that had most H atoms already attached.

Sometimes remembered as "the rich get richer" rule

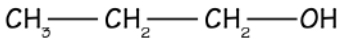
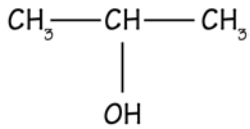
SUMMARY: Addition of an unsymmetrical reagent to an unsymmetrical alkene produces 2 products, a major and a minor, which can be predicted by applying Markovnikov's rule

Addition Polymerisation

Define addition polymerisation. Explain how the structure of the monomer allows the polymer to form.	Linking together of many alkene molecules; Can react with each other because of C=C bonds. Monomer is the single molecule building block; Polymer is a macromolecule (very large molecule) made from many linked monomers. n =large number. Polymerisation reaction needs heat + catalyst.  ethene monomers section of polyethene Polythene is long molecule – solid at room temperature. Unreactive polymer as now saturated C-C. Resistant to attack by chemicals.
Name 2-3 different polymers and give a use for each.	Propene → polypropene; rope, carpet, crates, clothing Vinylchloride → PVC; raincoats, pipes, wire insulation Tetrafluoroethene → PTFE; non stick pans, waterproofing

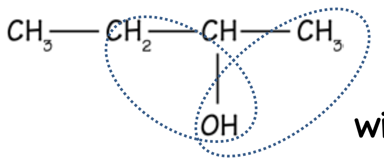
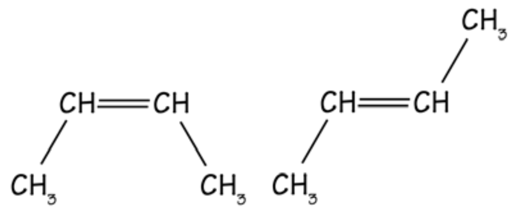
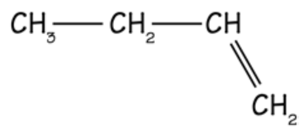
SUMMARY: Addition polymers are made from alkene monomers which can join together in a polymerisation reaction to make large solid molecules, the polymer molecules. Different polymers with different properties are made from different monomers. Their different properties give them different uses but they are now all unreactive as they are saturated.

Alcohols

What is the alcohol general formula?	Alkane chain with –OH group replacing a H atom. $C_nH_{2n+1}OH$ Names based on # of C atoms, methanol, ethanol, propanol etc.
Show how to draw poropan-1-ol and propan-2- ol	For alcohols with more than 3 C atoms it is necessary to show the C atom that the –OH group is attached to.   propan-1-ol / 1-propanol $CH_3CH_2CH_2OH$ propan-2-ol / 2-propanol $CH_3CH(OH)CH_3$
How are alcohols classified as 1°, 2° or 3°?	Classified as 1°, 2°, or 3°. Identify the carbon atom bonded to the -OH and count the number of C atoms directly bonded to that C atom. e.g. $CH_3CH(OH)CH_3$ is a secondary alcohol
How do m.pt and b.pt of alcohols change as they increase in size and why?	As # of carbon atoms increases, the m.pt. and b.pt of alcohols increase. As the molecules get bigger the intermolecular attractions between the molecules get stronger so more heat energy is needed to separate the molecules to bring about a change in state. Alcohols have higher m.pt. and b.pt than their corresponding alkanes because of the polar nature of the –OH group.
How does the solubility of alcohols change as they increase in size and why?	As # of carbon atoms increases, the solubility of alcohols decreases. C1-3 are soluble in water, C4 onwards are not because the longer non polar hydrocarbon regions.

SUMMARY: Alcohols have the –OH functional group, with –OH replacing the H of an alkane. Their melting and boiling points increase as the molecules get bigger due to stronger intermolecular attractions but their solubility in water decreases as the non-polar portion of the molecule increases in length. They can be classified as primary, secondary or tertiary depending on how many carbon atoms are directly bonded to the carbon atom that has the –OH group bonded to it.

Alcohol reactions

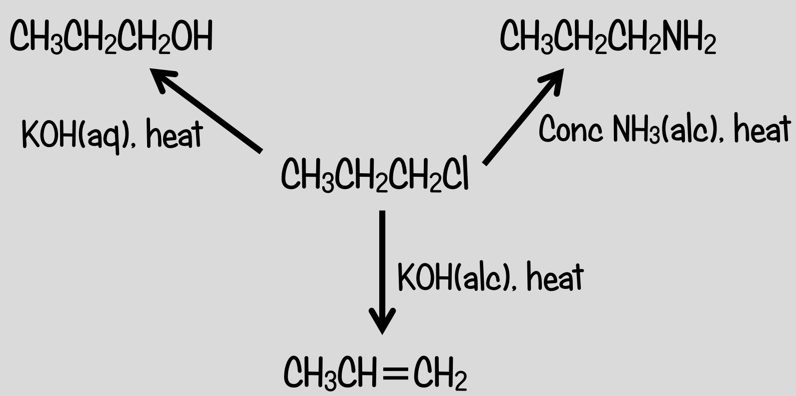
How do alcohols burn?	Alcohols are flammable and make good fuels, burning with complete combustion forming CO_2 and H_2O. Need more O_2 because as # of C increase so combustion becomes more incomplete.
What brings about substitution of –OH for –Cl?	$SOCl_2$ (as well as PCl_3 or PCl_5 or hydrogen halides) will convert R-OH to R-Cl. e.g. $CH_3CH_2CH_2OH \xrightarrow{SOCl_2} CH_3CH_2CH_2Cl$
What brings about dehydration of an alcohol to create an alkene C=C and why is this elimination?	Conc. H_2SO_4 and heat will dehydrate an alcohol to an alkene. Remove –OH and an –H from an adjacent (next door) carbon atom. If unsymmetrical may get 2 products (poor get poorer). In this elimination reaction 2 atoms or groups are removed from adjacent C atoms, creating a C=C bond.  will be dehydrated to a mixture of  and  major* minor *major would be include a mixture of cis and tans forms
What brings about the conversion of a primary alcohol to a carboxylic acid?	Heating with $H^+/Cr_2O_7^{2-}$ (colour change orange to green) or H^+/MnO_4^- (colour change purple to colourless) will oxidise a primary alcohol to a carboxylic acid.

SUMMARY: Alcohols burn well, making good fuels particular the smaller molecules. Alcohols can be substituted with $SOCl_2$ (R-OH to R-Cl), dehydrated with conc. sulfuric acid, creating a C=C functional group, or oxidised (if they are primary alcohols) to carboxylic acids by heating with an oxidising agent.

Haloalkane reactions

Why are reactions of haloalkanes so useful?	Haloalkanes are useful as they can be converted to alcohols, alkenes and amines in three different reactions. Often need to know for "conversion" questions.
What are the two substitution reactions of haloalkanes?	Haloalkane heated with KOH*(aq) will undergo a substitution reaction, forming an alcohol. (*or NaOH (aq)) $CH_3CH_2CH_2Cl \xrightarrow{KOH(aq),\ heat} CH_3CH_2CH_2OH$ Haloalkane heated with conc. NH_3(alc) will undergo a substitution reaction, forming an amine. $CH_3CH_2CH_2Cl \xrightarrow{Conc\ NH_3(alc),\ heat} CH_3CH_2CH_2NH_2$
What is the elimination reaction of haloalkanes?	Haloalkane heated with KOH(alc) will undergo an elimination reaction, forming an alkene. (*or NaOH (alc)) – a hydrogen halide is eliminated $CH_3CH_2CH_2Cl \xrightarrow{KOH(alc),\ heat} CH_3CH{=}CH_2$
How do you predict major and minor elimination products from a haloalkane?	If the structure of the haloalkane is such that it can undergo elimination in two different ways, then the more highly substituted alkene (having lesser number of hydrogen atoms on the doubly bonded carbon atoms) is the major product of elimination. (Poor get poorer, Saytzeff's rule) $CH_3CH_2CHBrCH_3 \xrightarrow{KOH(alc),\ heat} \underset{major}{CH_3CH{=}CHCH_3} + \underset{minor}{CH_3CH_2CH{=}CH_2}$

SUMMARY:

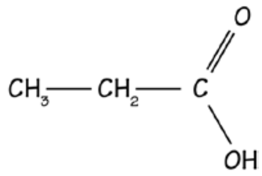
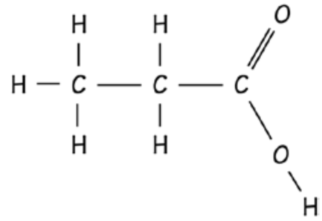


HOW TO IDENTIFY SOME ORGANIC COMPOUNDS

Solubility in water.	Alcohols C1 – C3, amines C1 – C5 & carboxylic acids C1 – C3 are soluble in water. Miscible/mix totally. Why? Attraction (hydrogen bonding) between –OH of alcohols, $-NH_2$ of amines and –COOH of carboxylic acids and water molecules. Same attraction does not occur between the non-polar hydrocarbon regions and water. Alcohols, amines and carboxylic acids with $\geq$ 4 carbon atoms are increasingly insoluble in water. Immiscible (form two layers). All alkanes, alkenes, alkynes, haloalkanes are insoluble.
pH / acid-base character o indicators o carbonates/hydrogen carbonates o reactive metals e.g. Mg	To measure pH substance must be soluble in water. • Alcohols are (virtually) neutral o IU paper / solution is unchanged o Red litmus STAYS red, blue litmus STAYS blue • Amines are weak bases o IU paper / solution TURNS blue o Red litmus TURNS blue, blue litmus STAYS blue • Carboxylic acids are weak acids o IU paper / solution TURNS orange o Red litmus STAYS red, blue litmus TURNS red o Produce gas with carbonates / hydrogen carbonates [CO_2] and reactive metals [H_2]
Reaction with Br_2 water	Orange Br_2 water decolourises rapidly with alkenes and alkynes [addition rxn], but only slowly by saturated hydrocarbons & other unsaturated organic compounds, needing uv light and/or heat [substitution rxn].
Reaction with H^+/MnO_4^- (no heat needed)	H^+/MnO_4^- changes from purple to colourless when shaken with alkenes [oxidation reaction].
Reaction with H^+/MnO_4^-, heat OR $H^+/Cr_2O_7^{2-}$, heat	H^+/MnO_4^- changes from purple to colourless, and $H^+/Cr_2O_7^{2-}$ from orange to green when heated with primary (and secondary) alcohols. [oxidation reaction].

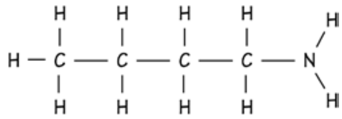
SUMMARY: Solubility in water (or lack of), indicators, carbonates and reactive metals, bromine water, MnO_4^- and $Cr_2O_7^{2-}$ can be used to help identify organic "unknowns" Reactions are acid-base, addition, substitution and oxidation.

Carboxylic acids & their reactions

How are carboxylic acids named?	IUPAC suffix is "oic acid" e.g. butanoic acid
How are they written/ drawn?	CH_3CH_2COOH / C_2H_5COOH (propanoic acid)  
What types of reactions are needed at level 2?	At level 2 the reactions of carboxylic acids are restricted to those acting as weak acids (proton donors)
How do they react with water?	$RCOOH + H_2O \rightleftharpoons RCOO^- + H_3O^+$ • Reaction with water / ionisation is incomplete • $RCOO^-$ is carboxylate ion e.g. CH_3COO^- is ethanoate ion • Turn UI solution / paper orange (pH≈3-5) depending on the acid and its concentration of course • Turn blue litmus paper red
How do they react with carbonates / hydrogen carbonates?	$RCOOH + NaHCO_3 \rightarrow RCOO^-Na^+ + H_2O + CO_2$ $RCOO^-Na^+$ is the sodium salt of the carboxylic acid. Can also be written Na^+RCOO^- See bubbles of colourless gas / effervescence
How do they react with bases?	$RCOOH + NaOH \rightarrow RCOO^-Na^+ + H_2O$ No gas produced.
How do they react with (reactive) metals?	$2RCOOH + Mg \rightarrow (RCOO^-)_2Mg^{2+} + H_2$ See bubbles of colourless gas / effervescence
Other useful clues to their identity	Methanoic, ethanoic and propanoic acid are soluble in water; C4 and upwards are not. Ethanoic acid = acetic acid; has vinegar smell. Butanoic acid smells like rancid (off) butter.

SUMMARY: Carboxylic acids are weak acids, their reaction with water being incomplete so the $[H_3O^+]$ concentration is not very high / pH not very low. They give characteristic colours with UI & litmus and a visible sign of reaction (gas) with carbonates/hydrogen carbonates & reactive metals, forming salts.

Amines & their reactions

How are amines named? How are they written/ drawn?	IUPAC suffix is "amine" e.g. butan-1-amine  Sometimes also named as 1-aminobutane
How are they made?	Substitution reaction of haloalkane with ammonia (alc) $RX + NH_3 \rightarrow RNH_2 + HX$
What types of reactions are needed at level 2?	At level 2 the reactions of amines are restricted to those acting as weak bases (proton acceptors). The easiest way to think of amines is as near relatives of ammonia, NH_3.
How do they react?	$RNH_2 + H_2O \rightleftharpoons RNH_3^+ + OH^-$ • Reaction with water / ionisation is incomplete • When an amine reacts with HCl or H_2SO_4, an acid-base reactions occur. Amines are bases and as a result amines accept protons from acids. $RNH_2 + HCl \rightarrow RNH_3^+Cl^-$
Other useful clues to their identity	• Turn UI solution / paper blue (pH≈9-11) depending on the amine and its concentration of course • Turn red litmus paper blue Solubility falls off as the hydrocarbon chains get longer - noticeably so after 5 carbons. They form alkaline solutions that affect indicators (as above). The small amines smell very similar to ammonia but as the amines get bigger, they tend to smell more "fishy", or of decay. Or perhaps we should put it the other way around: Decaying fish give off odorous amines.

SUMMARY: Amines are weak bases, their reaction with water being incomplete so the $[OH^-]$ concentration is not very high / pH not very high. They give characteristic colours with UI & litmus and many have unpleasant fishy or decay-like smells.

Types of chemical reactions

Addition – the double bond breaks and TWO atoms and/or groups being added.

- Addition reactions include hydration, halogenation, hydrohalogenation, hydrogenation and polymerisation.

Substitution – an atom or group of atoms is replaced with another atom or group of atoms.

- Reaction of alkane with a halogen in presence of light and/or heat.
- Reaction of alcohol with PCl_5 is a substitution reaction. The hydroxyl group (-OH) of butan-1-ol is replaced by a chloro group (–Cl). The product is $CH_3CH_2CH_2CH_2Cl$. The functional group in the product is a chloro group / chloroalkane (haloalkane).
- Reaction of haloalkane with NH_3(alc) to form an amine.
- Reaction of haloalkane with KOH(aq) to form an alcohol.

Elimination reactions – a C to C double bond forms and TWO atoms and/or groups being removed.

- Reaction of an alcohol with concentrated H_2SO_4. A hydrogen atom and the –OH group on (an adjacent) carbon atoms are removed forming a (carbon-to-carbon) double bond. The functional group in the product is a (carbon-to-carbon) double bond / alkene. Although this is a dehydration reaction you should classify it as an elimination reaction.
- Reaction of a haloalkane with KOH(alc). A hydrogen atom and the halogen atom on (an adjacent) carbon atoms are removed forming a (carbon-to-carbon) double bond. The functional group in the product is a (carbon-to-carbon) double bond / alkene.

Acid-base reactions - should be called acid-base (and not 'neutralisation').

- When propanoic acid reacts with sodium carbonate, an acid-base reaction occurs in which sodium propanoate, water and carbon dioxide are formed. It is acid-base because the propanoic acid donates a proton, forming the propanoate ion.
- When propanamine reacts with HCl or H_2SO_4, acid-base reactions occur. Amines are bases and as a result amines accept protons from acids. E.g. $CH_3CH_2CH_2NH_2 + HCl \rightarrow CH_3CH_2CH_2NH_3^+Cl^-$

Oxidation

- Reaction of an butan-1-ol with $H^+/Cr_2O_7^{2-}$ or H^+/MnO_4^- is oxidation as butan-1-ol is oxidised to a carboxylic acid. The functional group in the product is carboxylic acid.
- When H^+/MnO_4^- reacts with an alkene, the alkene is oxidised to a diol.