

LEVEL 3 CHEMISTRY

ORGANIC COMPOUNDS

NCEA Workbook

Section One

Basic Skills

This section will test the fundamental skills you're going to need in organic chemistry, including an understanding of naming molecules, their properties, and reactions. You may spend a while memorising information but this is an opportunity for you to get in some good practice!

1. Identifying functional groups, drawing and naming molecules

a. What is a functional group?

Atoms on a molecule, which give it some special properties. They can contain heteroatoms (atoms other than carbon and hydrogen), and double or triple bonds.

b. How many covalent bonds do the following atoms form?

i. Carbon 4 bonds

ii. Oxygen 2 bonds

iii. Nitrogen 3 bonds

iv. Chlorine 1 bond

v. Bromine 1 bond

vi. Fluorine 1 bond

vii. Hydrogen 1 bond

c. Draw out each functional group below. For each, write down the prefix or suffix you would use when naming a molecule with that functional group.

i. Alkene



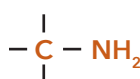
-n-ene

ii. Alkyne



-n-yne

iii. Amine



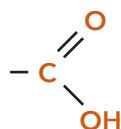
n-amino... or an-n-amine

iv. Alcohol



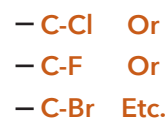
n-hydroxy... or an-n-ol

v. Carboxylic acid



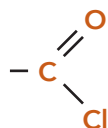
-anoic acid

vi. Haloalkane



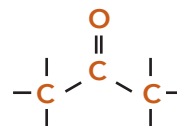
n-chloro..., n-fluoro...n-bromo...

vii. Acyl chloride



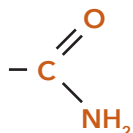
-anoyl chloride

viii. Ketone



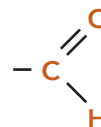
-an-n-one

ix. Amide



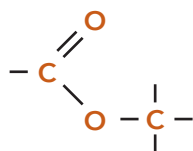
-anamide

x. Aldehyde



-anal

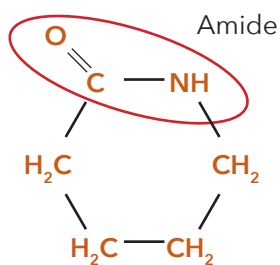
xi. Ester



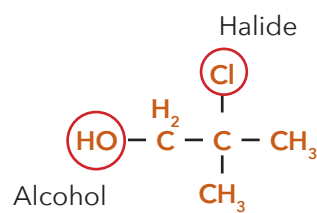
-yl -anoate

d. On the following molecules, circle and label the functional group(s) present.

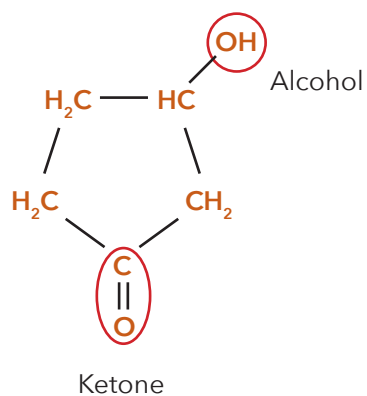
i.



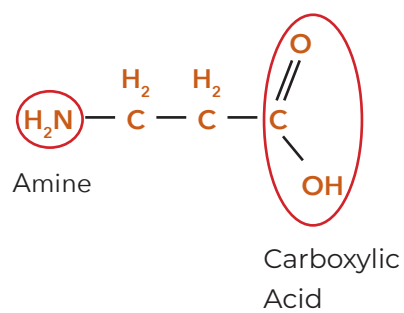
ii.

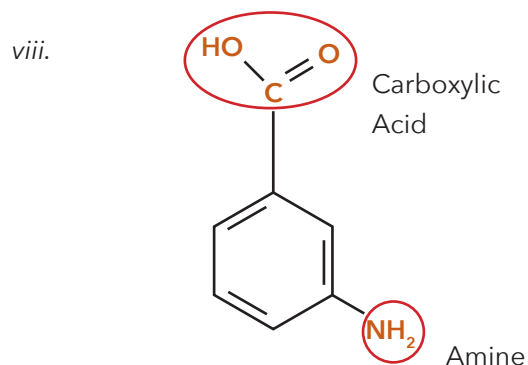
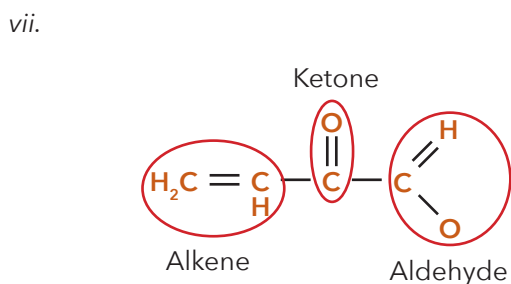
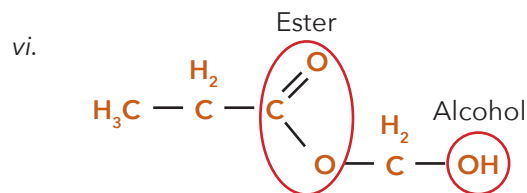
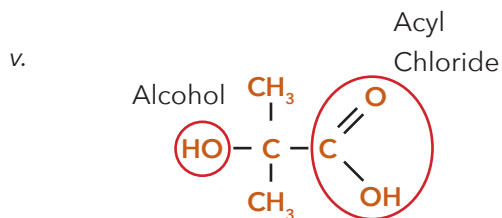


iii.



iv.





- e. What is the difference between an aldehyde and a ketone functional group? What are they collectively known as?

An aldehyde has a double-bonded oxygen on the end of the carbon chain whereas a ketone has the double-bonded oxygen in the middle of the chain. A carbon double bonded to an oxygen is collectively known as a carbonyl group.

- f. What is the difference between an ester and amide functional group?

An amide has a nitrogen atom where an ester would have an oxygen atom.

- g. What is the difference between a carboxylic acid and acyl chloride functional group?

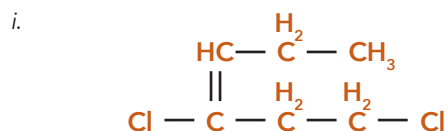
An acid chloride has a chlorine atom where the carboxylic acid would have an OH (hydroxyl) group.

- h. Complete the following table to show what name to use for each length that the main carbon chain in a molecule can have.

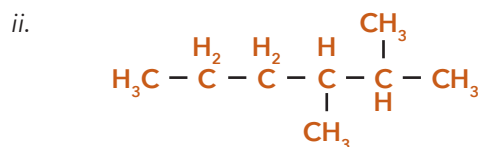
Main carbon chain has:	Use the following name:
1 carbon	Meth-
2 carbons	Eth-
3 carbons	Prop-
4 carbons	But-
5 carbons	Pent-
6 carbons	Hex-

Main carbon chain has:	Use the following name:
7 carbons	Hept-
8 carbons	Oct-
9 carbons	Non-
10 carbons	Dec-

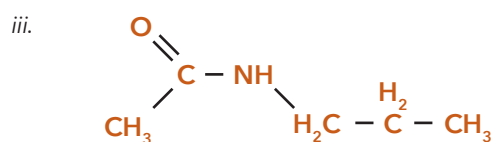
i. Name the following molecules using IUPAC rules:



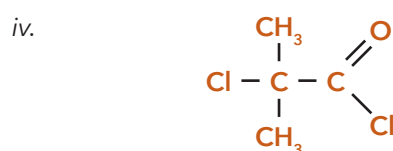
Name: 1,3-dichlorohex-3-ene



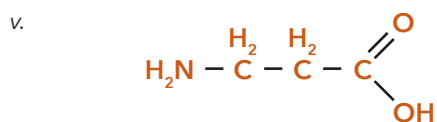
Name: 2,3-dimethylhexane



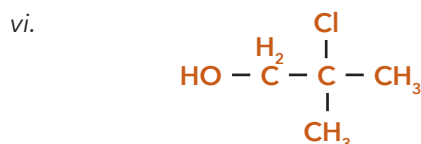
Name: Propyl ethanamide



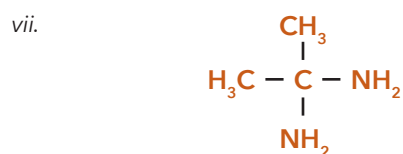
Name: 2-chloro-2-methylpropanoyl chloride



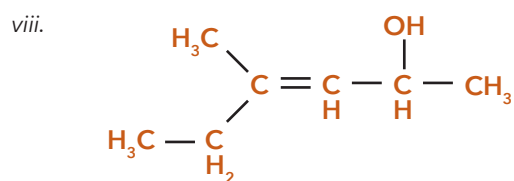
Name: 3-amino propanoic acid



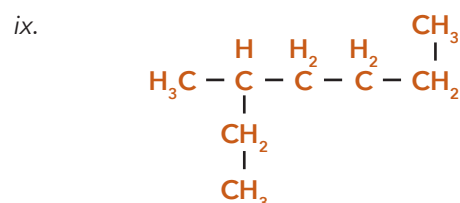
Name: 2-chloro-2-methylpropan-1-ol



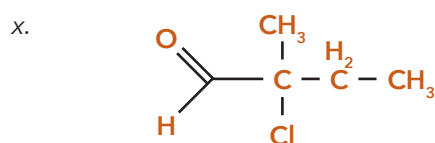
Name: 2,2-diamino propane



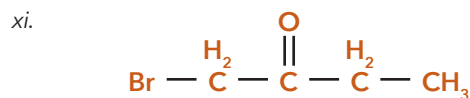
Name: 2-hydroxyl-4-methyl hex-3-ene



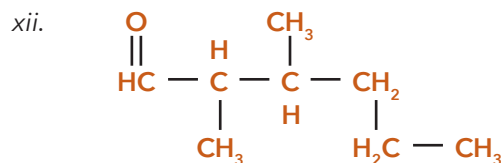
Name: 3-methylheptane



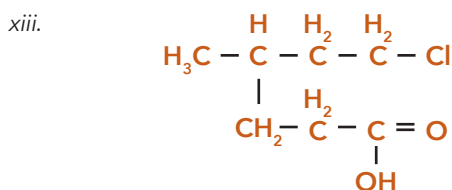
Name: 2-chloro-2-methylbutanal



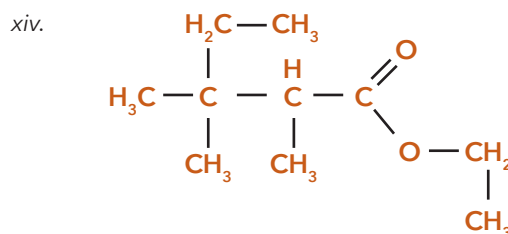
Name: 1-bromo-butan-2-one



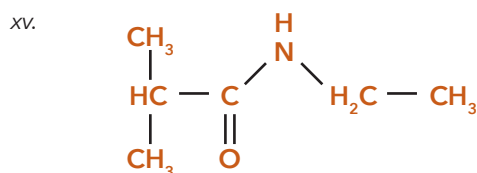
Name: 2,3-dimethylhexanal



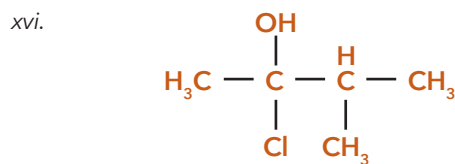
Name: 6-chloro-4-methylhexanoic acid



Name: 3,3,4-trimethyl-ethyl pentanoate



Name: ethyl-2-methylpropanamide



Name: 2-chloro-3-methyl butan-2-ol

j. Describe the process of naming a molecule, in your own words.

Identify the longest straight carbon chain which runs through the functional groups on the molecule. Circle this chain if helpful.

Starting from the end of the carbon chain closest to the functional groups, number each of the carbons. Carbonyl groups take priority.

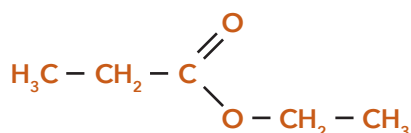
At the start of the name, say the number for each side chain/group, a dash, and then the name of the side chain. List these in order.

Name the main chain with meth-, eth- etc depending on how many carbons are in it

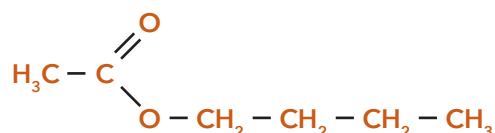
Add a suffix appropriate to the functional group present.

k. Draw the following molecules based on their IUPAC names.

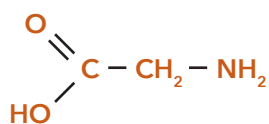
i. Ethyl propanoate



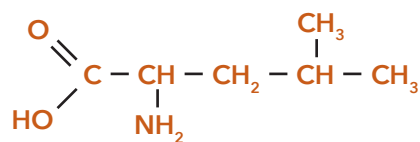
ii. Butyl ethanoate



xvii. 2-amino ethanoic acid



xviii. 2-amino, 4-methyl pentanoic acid



- l. Describe the process of drawing a molecule based on its name, in your own words.

Draw the main chain based on the number of carbons indicated (meth-, eth-, etc.). Add on a functional group to the end if indicated in the name. Add the functional groups to the positions indicated in the name.

- m. What is the difference between a primary, secondary, and tertiary functional group when it comes to alcohols and haloalkanes?

In a primary alcohol/haloalkane, the carbon that the functional group is attached to is itself attached to only one other carbon. A secondary is attached to two other carbons, and a tertiary is attached to three others.

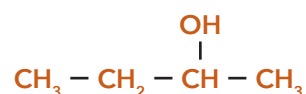
- n. An alcohol with molecular formula C₄H₁₀O could either be a primary, secondary, or tertiary alcohol. Give the name and structure of:

i. The primary alcohol:



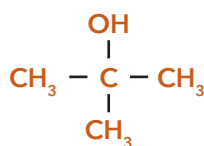
Name: butan-1-ol

ii. The secondary alcohol:



Name: The secondary alcohol
butan-2-ol

iii. The tertiary alcohol:



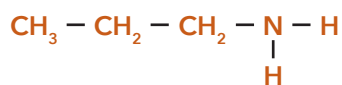
Name: The tertiary alcohol
2-methylpropan-2-ol

- o. What is the difference between a primary, secondary, and tertiary functional group when it comes to amines and amides?

In a primary amine, there is one carbon attached to the nitrogen. In a secondary amine, there are two carbons attached to the nitrogen and in a tertiary one there are three carbons attached to the nitrogen. Amides can only exist as primary as the amide functional group must exist at the end of a primary chain.

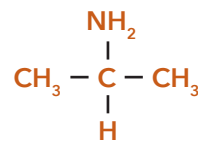
p. An amine with molecular formula C_3H_9N could either be a primary or secondary. Give the name and structure of:

i. The primary amine:



Name: The primary amine
propan-1-amine

ii. The secondary amine:



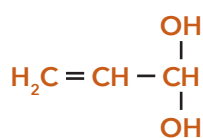
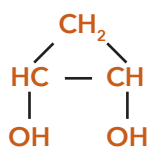
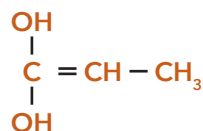
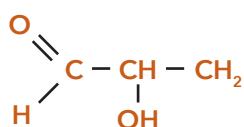
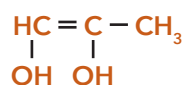
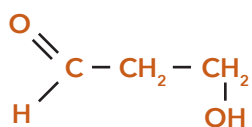
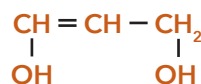
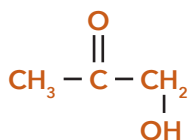
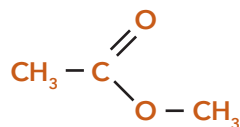
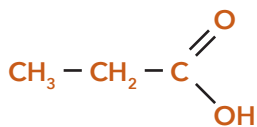
Name: The secondary amine
2-aminopropane

2. Isomers

a. What are constitutional (a.k.a. structural) isomers?

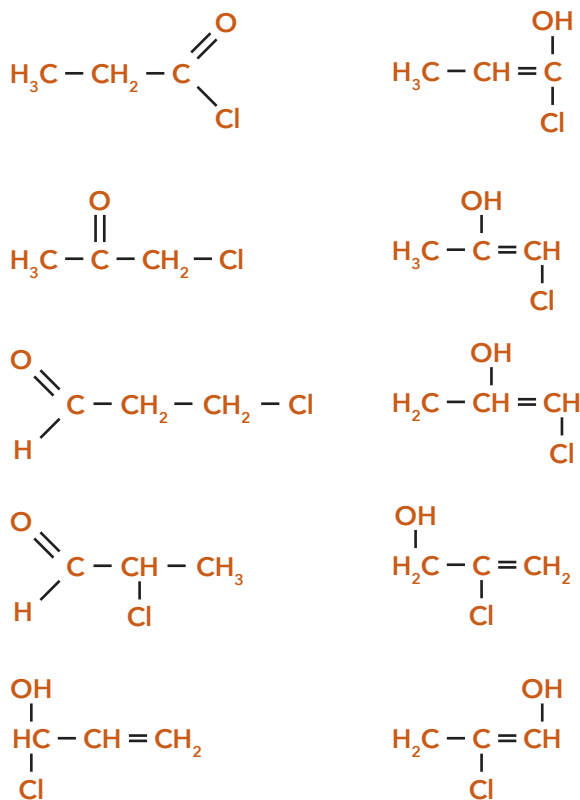
Two molecules with the same chemical formula (same numbers of each atom) but with different connections between those atoms.

b. Draw the structural isomers for a compound with the molecular formula $C_3H_6O_2$. Try and draw as many different functional groups as you can.



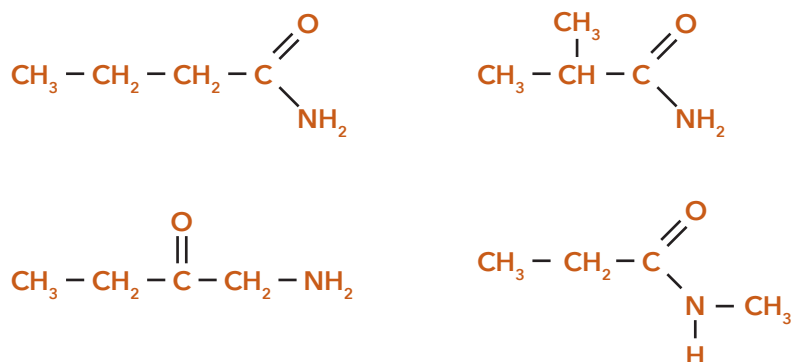
Other answers with the correct numbers of each atom are also acceptable. Tip: if the number of hydrogens is 2x the number of carbon atoms (e.g. C_3H_6), then a double bond or ring has to be present. If it is 2x carbon + 2 (e.g. C_3H_8) then no double bonds are present. Also, notice how you can easily make more structural isomers by shifting the functional groups and side chains around the main chain - this will be very helpful for when it comes to doing exam questions!

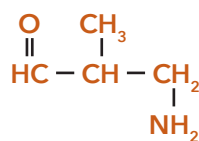
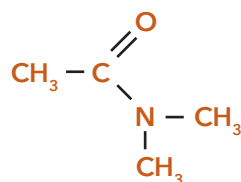
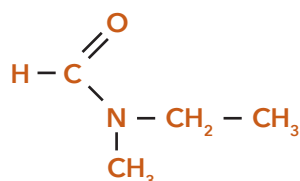
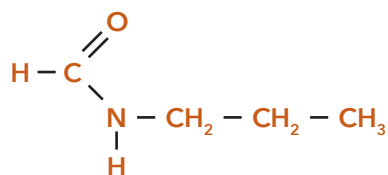
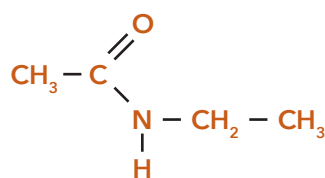
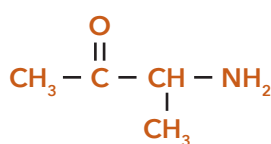
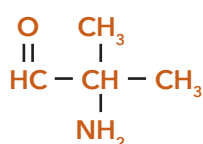
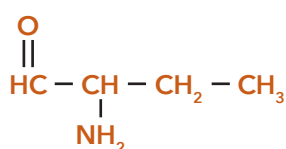
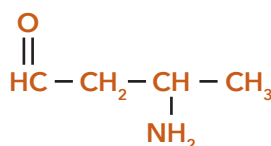
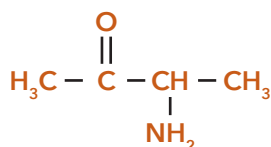
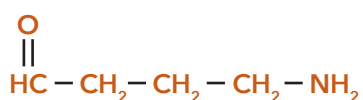
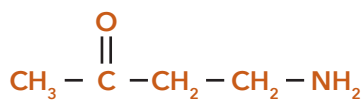
- c. Draw the structural isomers for a compound with the molecular formula C_3H_5OCl . Try and draw as many different functional groups as you can.



Other answers may be possible as well. To double-check if your answer is correct, double-check that the molecule has 3 carbons, 5 hydrogens, 1 oxygen and 1 chlorine atom. Secondly, make sure that you only have 4 bonds around each carbon!

- d. Draw the structural isomers for a compound with the molecular formula C_4H_9ON . Try and draw as many different functional groups as you can.





Other answers are also possible. To double-check if your answer is correct, double-check that the molecule has 4 carbons, 9 hydrogens, 1 oxygen and 1 nitrogen atom. Secondly, make sure that you only have 4 bonds around each carbon!

- e. What are optical isomers (also known as enantiomers)?

Two molecules which have the same atoms connected in the same way, but are non-superimposable mirror images of each other.

- f. What are the requirements for a molecule to exist as enantiomers? This is also known as being _____ active.

It must contain at least one carbon to which four different groups are attached. This is also called the chiral carbon. Also known as being **optically** active.

- g. How do you draw the enantiomers of a molecule when given a molecule?

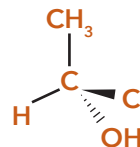
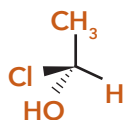
Draw the chiral carbon at the centre of a tetrahedral shape, and draw the groups attached to it around the outside. Then, draw the mirror image of that tetrahedron.

h. How can two enantiomers be physically distinguished?

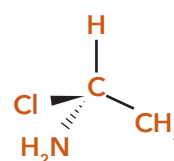
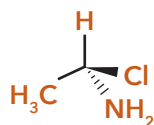
One enantiomer will rotate the plane of a polarised light source in one direction, and the other enantiomer will rotate the plane in the other direction.

i. For the following molecules, draw its corresponding enantiomer:

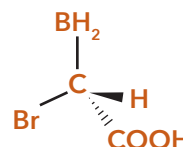
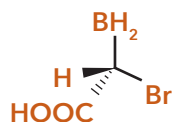
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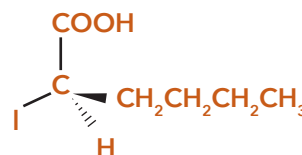
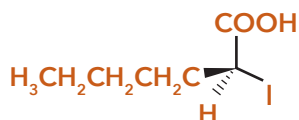
ii.



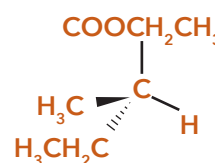
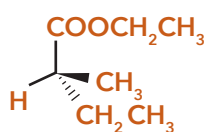
iii.



iv.

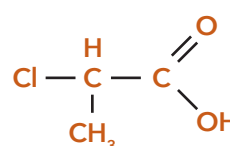
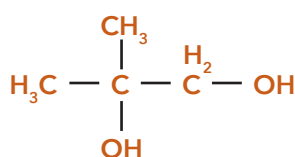


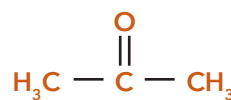
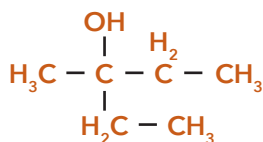
v.



Notice what you're doing; you're just drawing the mirror images of the first molecule with the functional groups in the mirroring positions.

j. For the following molecules, state which ones will be optically active. For each one which is, explain why and draw its two enantiomers.





Only the second molecule will be optically active. This is because only it has a chiral carbon, to which four different groups are attached. Its enantiomers can be drawn by placing the chiral carbon in the middle of a tetrahedron, placing the attached groups on the outside, and then drawing the mirror image.



An answer which places these groups at different places around the tetrahedron is also correct, as long as the two enantiomers are **mirror images** of each other:



- k. What do two enantiomers of a molecule have in common? How do they differ?

The enantiomers have the same physical and chemical properties - they have the same polarity, melting/boiling point, and undergo the same reactions. They differ in their rotation of plane-polarised light, and in their interactions with other chiral molecules such as enzymes.

3. Addition and Elimination Reactions

- a. What occurs during an addition reaction?

One bond in a carbon-carbon double bond is broken, and a new atom is added onto each of the carbon atoms.

- i. What types of molecules can undergo addition reactions?

Any molecule with a carbon-carbon double or triple bond (alkenes, alkynes)

- ii. What reagents can be used to perform addition, and what do they add to the product?

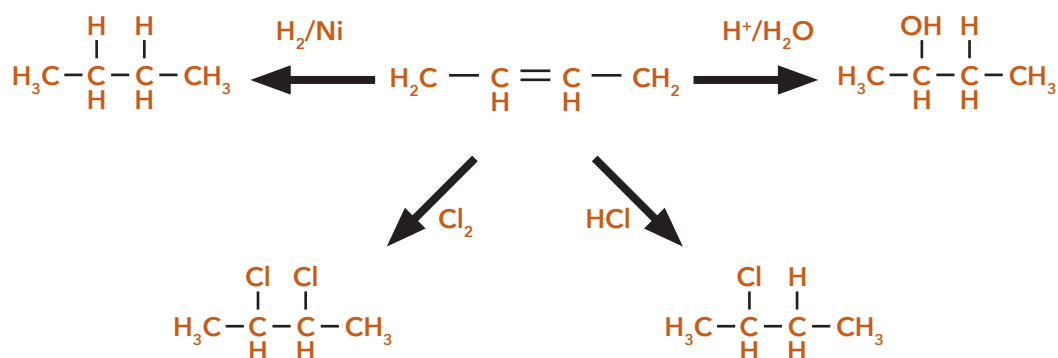
H_2/Ni - adds 2 hydrogen atoms, one to each carbon

HCl or HBr - adds 1 hydrogen atom and 1 halogen atom (Cl or Br)

Cl_2 or Br_2 - adds 2 halogen atoms, one to each carbon

$\text{H}^+/\text{H}_2\text{O}$ or dilute H_2SO_4 - adds H_2O ; OH onto one carbon, H onto the other. The acid acts as a catalyst.

- b. The molecule below can undergo an addition reaction, and the product depends on the reagent used. Complete the diagram to show what the products would be:



Note: Showing the hydrogens 'sticking out' of the chain is just for reference showing where they've been added on - in your actual answer it's not necessary.

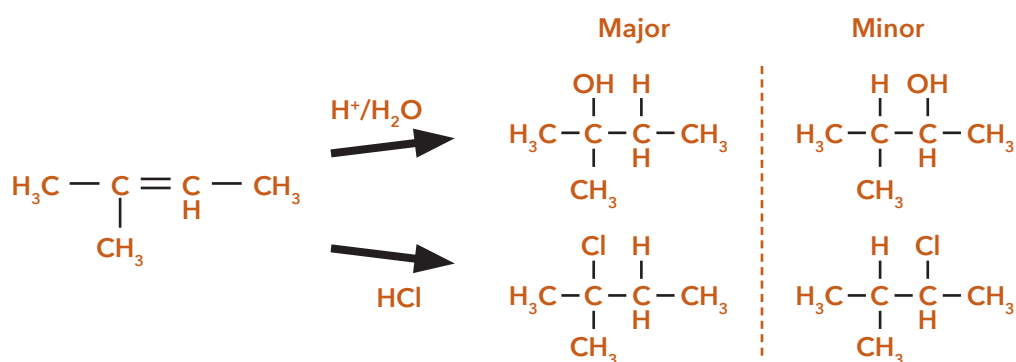
- c. When is it possible to have two different products (major and minor) from an addition reaction? Explain why.

If you have an asymmetric alkene, and the reaction is going to place a hydrogen atom on one of the carbons and a different atom on the other, then you will have two possible products. This is because placing the hydrogen on one atom produces a different product than if you placed it on the other atom.

- i. Of the two possible products, how do you determine which will be the major and minor product?

Use Markovnikov's rule, also known as the 'rich get richer' rule: the carbon with more hydrogens will preferentially gain the hydrogen, and the carbon with fewer hydrogens will get the other atom. Make sure you don't just say 'the rich get rich'-you need to explain what is going on in the reaction, and how this results in 2 possible products, one made in a larger quantity than the other.

- ii. Complete the following reactions with the major and minor products:



- d. What occurs during an elimination reaction?

A functional group and the hydrogen on the carbon next to it leave their respective carbon atoms. The two carbon atoms that have been left will form a double bond with each other.

- i. Which types of molecules can undergo elimination reactions? What types of molecules are produced?

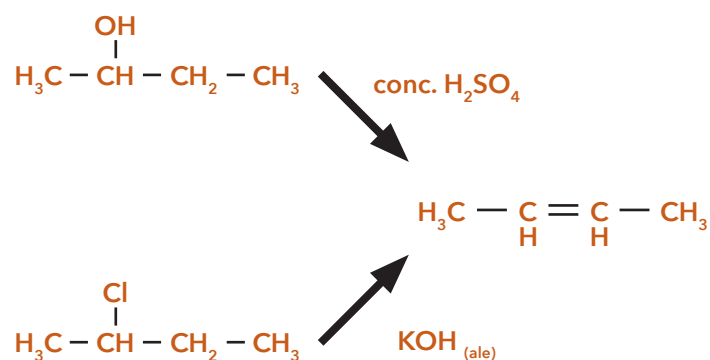
Alcohols and haloalkanes can undergo elimination, and alkenes are produced.

- ii. What reagents can be used in elimination reactions, and when are they used?

$\text{KOH}_{(\text{alc})}$ - used to do elimination in haloalkanes. (The OH^- acts as a base to remove the hydrogen. An alcoholic solution is necessary, otherwise the OH^- would substitute into the place of the halogen instead).

Concentrated H_2SO_4 - used to do elimination in alcohols. (The acid acts as a catalyst. Concentrated acid rather than dilute acid is necessary as it 'dehydrates' the alcohol, removing OH off one carbon and H off of the other).

- e. Complete the reaction scheme below by drawing the two possible reactants that can result in the product shown:



Instead of Cl , could have F , Br , or I in place.

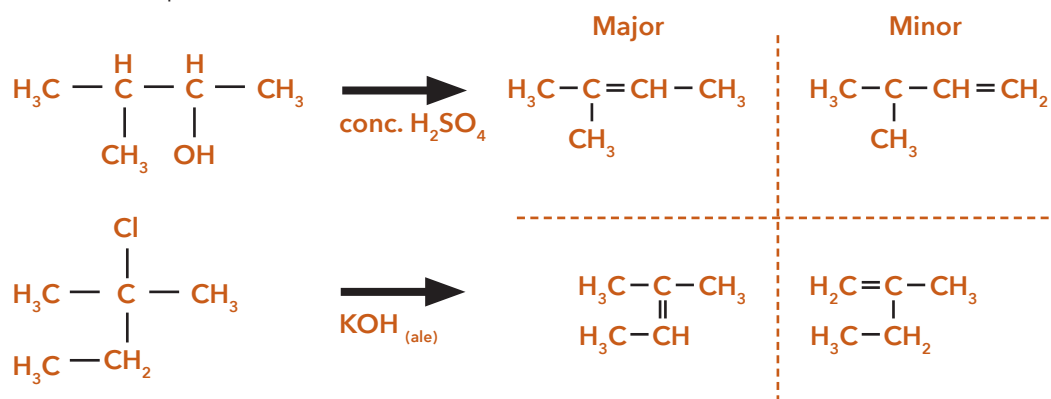
- f. When is it possible to have two different products (major and minor) from an elimination reaction? Explain why.

When you have an asymmetric secondary or tertiary alcohol/haloalkane, there are two or three different adjacent hydrogens which could get removed. Depending on where the hydrogen gets removed from, there could be multiple different products.

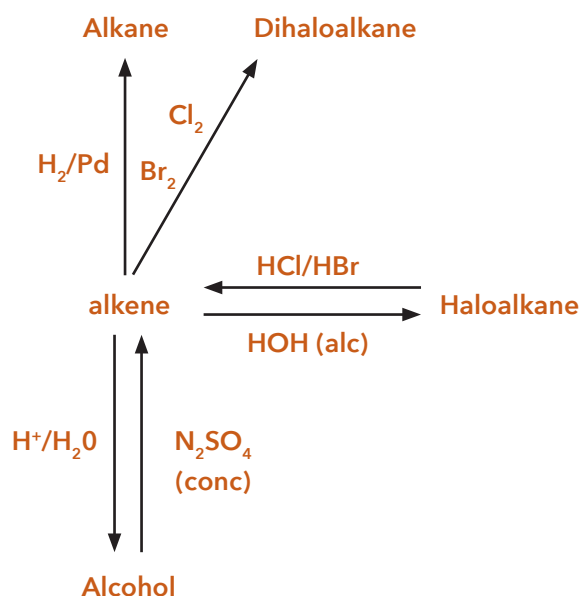
- i. Of the two possible products, how do you determine which will be the major and minor product?

Using Zaytsev's (Sayteff/Saytev's-you know what we mean) rule, or the 'poor get poorer' rule: the carbon with the fewest hydrogens will preferentially lose the hydrogen atom. Don't just say 'the poor get poorer' though, you need to explain what is going on in the reaction, and relate it to the amount of each product that is produced i.e. the major product will be made in larger quantities than the minor product.

- g. Complete the following elimination reactions by indicating the reagent. Draw and indicate the major and minor products.



- h. Propose a reaction scheme for the reactions which you've just learned. One reaction has been completed for you.



This is just one possible way to arrange the reactions, though it's a good idea to use a layout similar to this because of how the other reactions will fit in later.

4. Oxidation and Reduction Reactions

- a. What occurs during oxidation reactions?

Unlike in the redox internal; an alcohol group is converted to a carbonyl, and a carbonyl is converted to a carboxylic acid. A carbon-carbon double bond can also be turned into a diol.

- i. What molecules can undergo oxidation and what kinds of molecules are produced?

Primary alcohols can undergo oxidation into aldehydes.
 Aldehydes can undergo oxidation into carboxylic acids.
 Secondary alcohols can undergo oxidation into ketones.
 Alkenes can undergo oxidation into diols.

ii. How do oxidising agents work?

Effectively, oxidising agents 'provide oxygen' to turn an alcohol to a carbonyl then a carbonyl to carboxylic acid; your oxidising agents will have a lot of oxygen i.e. $\text{H}^+/\text{Cr}_2\text{O}_7^{2-}$ and $\text{H}^+/\text{MnO}_4^-$.

iii. What reagents can be used to perform oxidation reactions? When are each of them used?

Strong oxidising agents: $\text{H}^+/\text{Cr}_2\text{O}_7^{2-}$ and $\text{H}^+/\text{MnO}_4^-$ can be used to oxidise alcohols to aldehydes or ketones and aldehydes to carboxylic acids.

$\text{H}^+/\text{MnO}_4^-$ is used to oxidise alkenes to diols.

Weak oxidising agents: Tollen's reagent and Fehling's reagent can be used to oxidise aldehydes to carboxylic acids.

iv. For each oxidising agent, describe and explain the observation when they undergo oxidation.

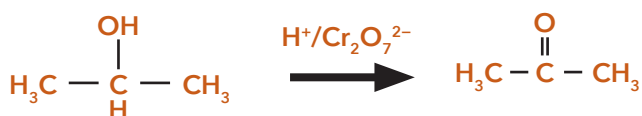
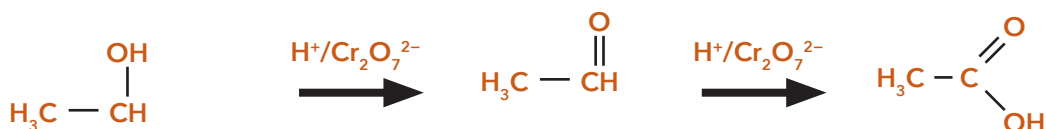
$\text{H}^+/\text{Cr}_2\text{O}_7^{2-}$: Solution goes from orange (due to dichromate ions) to blue/green (due to chromate ions).

$\text{H}^+/\text{MnO}_4^-$: Solution goes from purple (due to permanganate ions) to colourless (due to manganese ions).

Tollen's reagent: Silver mirror is formed on the test tube, due to $\text{Ag}^+_{(\text{aq})}$ being reduced to $\text{Ag}_{(\text{s})}$ and depositing on the sides of the tube.

Fehling's reagent: Solution goes from blue (from Cu^{2+}) to red-brown (from Cu^+).

b. Complete the following reaction scheme:



Tollen's or Fehling's can also be used to turn the aldehyde into the carboxylic acid.

- c. How do the products that can be made by oxidising primary, secondary, and tertiary alcohols differ? Explain.

Oxidising a primary alcohol makes an aldehyde, because the OH is at the end of the carbon chain. It can be further oxidised to a carboxylic acid because it can make a bond to another oxygen. A secondary alcohol makes a ketone, because the OH is in the middle of the carbon chain. Ketones cannot be further oxidised because the carbon's other two bonds are taken up; it cannot make any more bonds to oxygen. A tertiary alcohol cannot be oxidised because all three of the carbon's bonds are taken up; it cannot make any more bonds to oxygens.

- d. What occurs during a reduction reaction?

The opposite of an oxidation reaction; a carboxylic acid is converted to a carbonyl, and carbonyls are converted to alcohols.

- i. What molecules can undergo reduction, and what molecules are produced?

Aldehydes can be reduced to primary alcohols.
Ketones can be reduced to secondary alcohols.

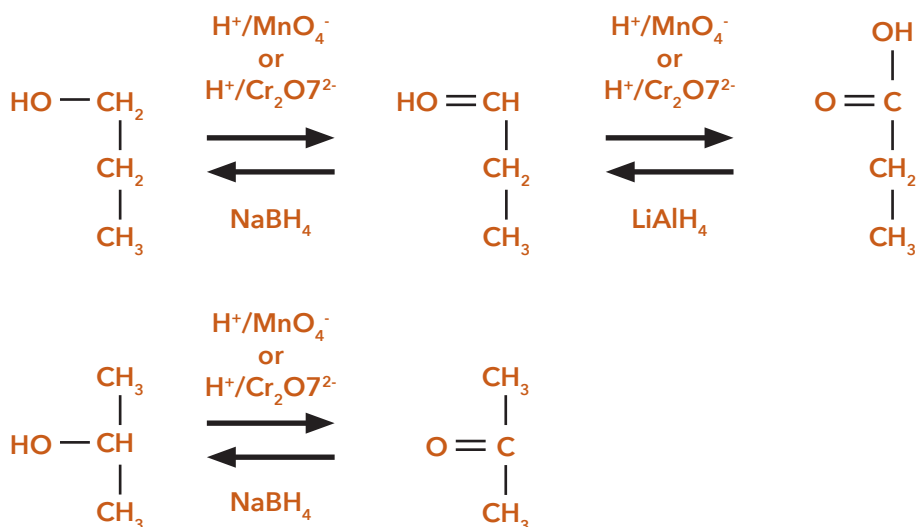
- ii. How do reducing agents work?

Reducing agents 'provide hydrogen' to turn a carboxylic acid to a carbonyl, then a carbonyl to an alcohol; your reducing agents will have a lot of hydrogens i.e. NaBH_4 or LiAlH_4

- iii. What reagent(s) can be used in reduction?

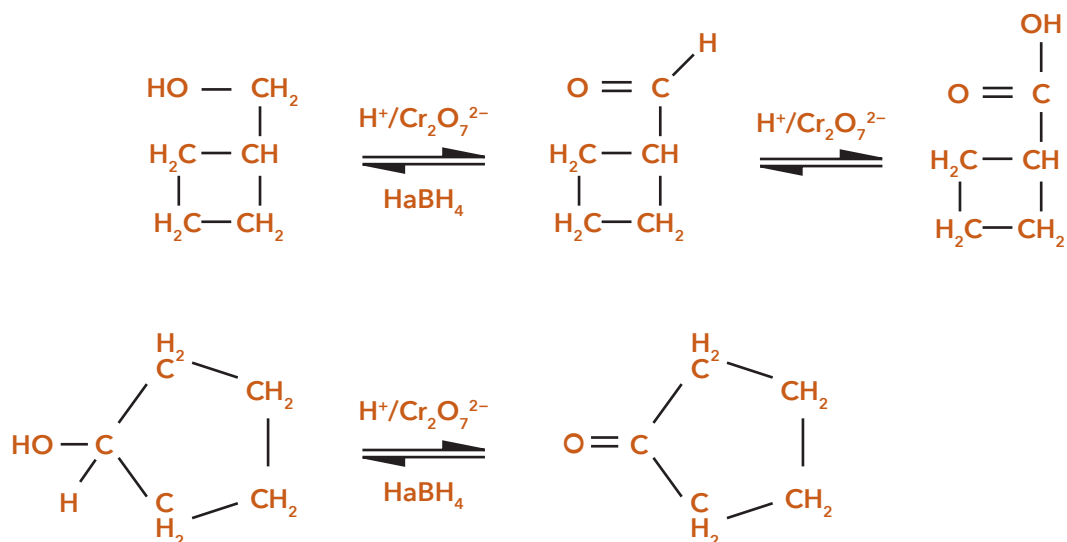
NaBH_4 or LiAlH_4

- e. Complete the following reaction scheme, filling in reagents:



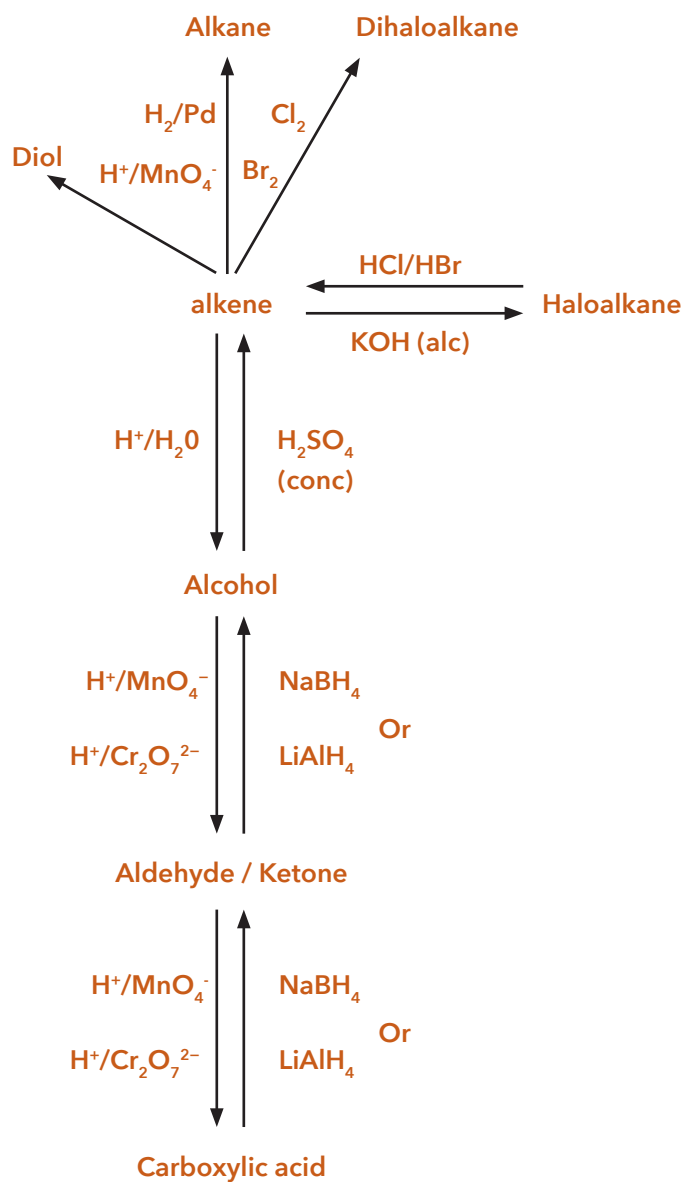
Tollen's or Fehling's can also be used to turn the aldehyde into the carboxylic acid.

f. Complete the following reaction scheme, filling in the missing molecules:



Tollen's or Fehling's can also be used to turn the aldehyde into the carboxylic acid.

g. Using the reactions you've learned over the last two sections, propose a reaction scheme.



This layout is just one way you can do it. Think of this one like a 'tree' - the reduction and oxidation reactions are the trunk and the addition/elimination reactions are the branches and leaves.

5. Substitution Reactions

a. What occurs during a substitution reaction?

A functional group is 'kicked off' the molecule, and a new functional group replaces it.

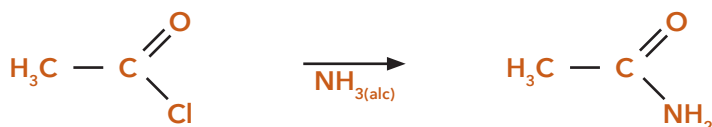
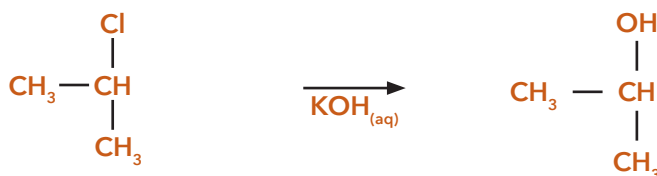
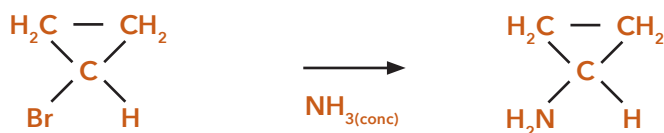
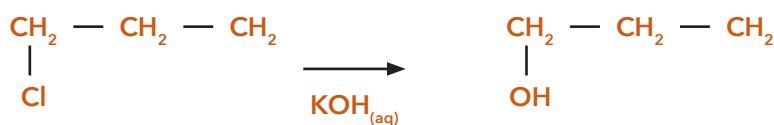
i. What reagents can be used for substitution reactions? For each one, briefly describe how they work including what kinds of molecules are produced.

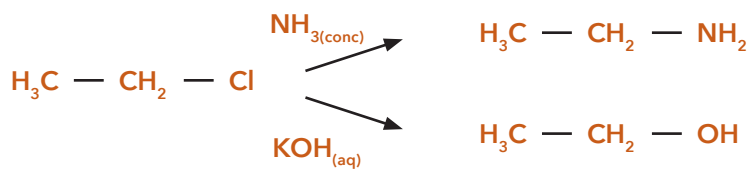
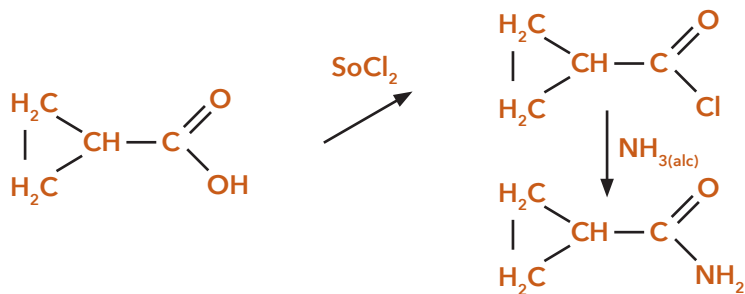
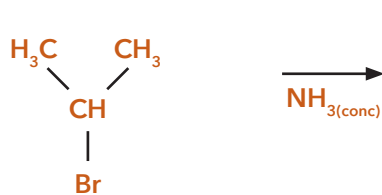
$\text{KOH}_{(\text{aq})}$ produces OH^- ions, which add onto a haloalkane, pushing off the halogen and making an alcohol.

$\text{NH}_{3(\text{alc})}$ or $\text{NH}_{3(\text{conc})}$ provides NH_3 , which adds onto a haloalkane, pushing off the halogen and making an amine. It can also push Cl off of an acid chloride, making an amide.

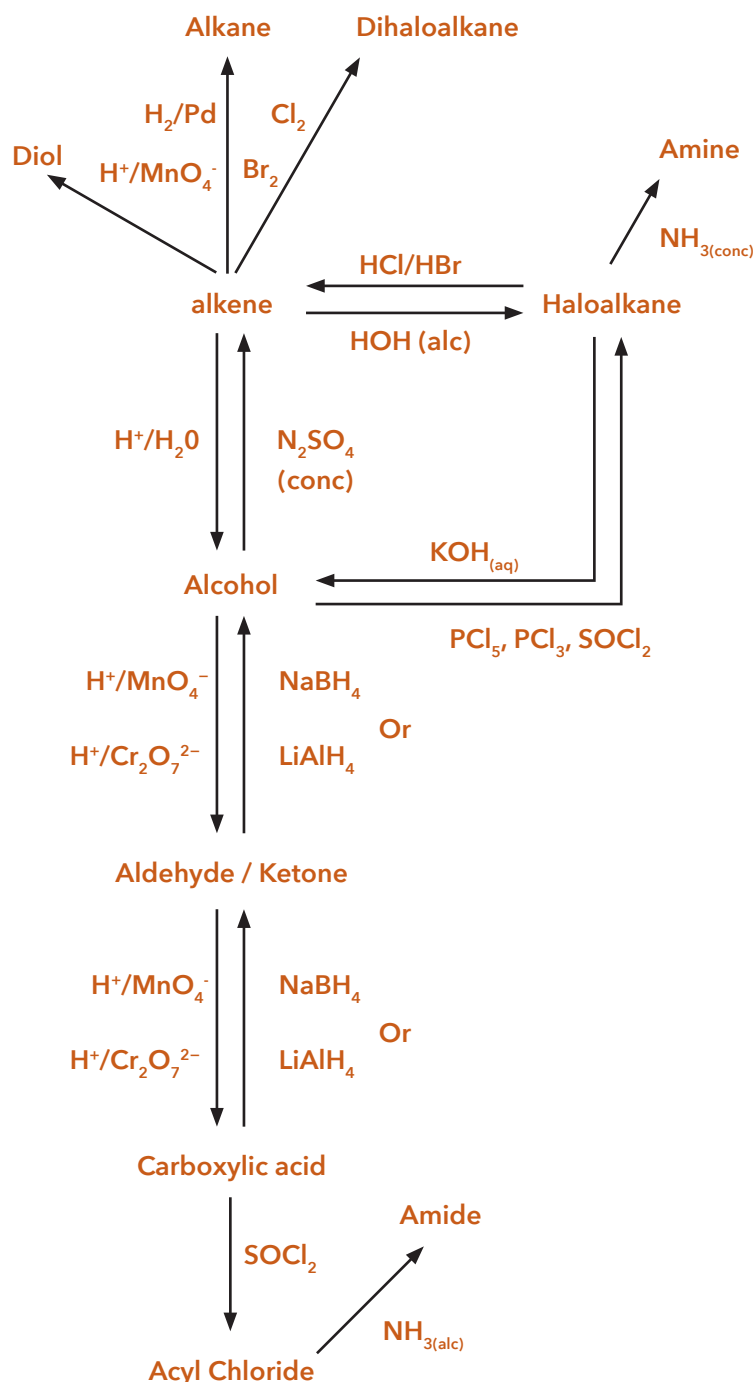
SOCl_2 , PCl_3 , and PCl_5 provide Cl, which adds onto an alcohol, pushing off the OH and making a haloalkane. They can also push the OH off a carboxylic acid, making an acid chloride.

b. Complete the following reactions with either the product, reagent, or reactant.





c. Use the reactions you've learned over the past three sections to propose a reaction scheme.



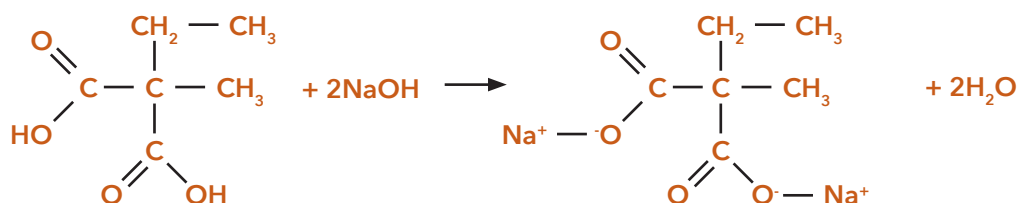
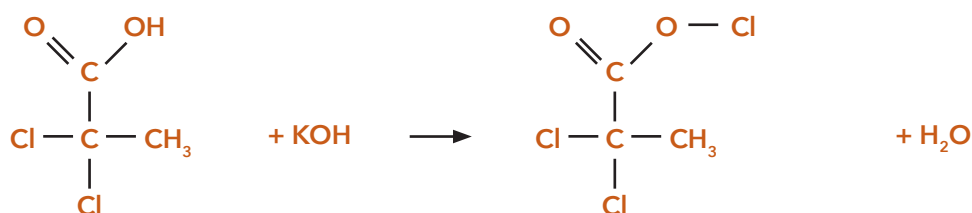
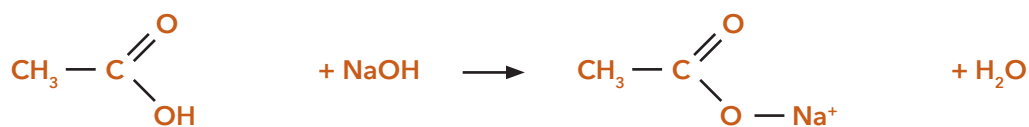
Right about now the number of reactions and reagents will really start to get overwhelming. Make sure you're not trying to just memorise the reagents, think about how they work (for example, SOCl_2 is used to substitute chlorine onto something).

6. Acid and Base Reactions

a. Which organic molecules will act as an acid? What happens to them during a neutralisation reaction?

Carboxylic acids. They can donate a hydrogen ion off of the OH on part of the functional group, turning into O^- , which can bond to the positive ion of the base it reacted with.

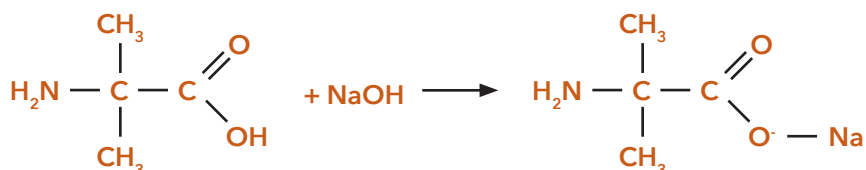
i. Complete the following reactions with either the product or reactant.



b. Which organic molecules will act as a base? What happens to them during a neutralisation reaction?

Amines. They can accept a hydrogen ion onto the NH_2 part of the functional group, turning into NH_3^+ , which can bond to the negative ion of the acid it reacted with.

i. Complete the following reactions with either the product or reactant.



7. Condensation and Hydrolysis Reactions

- a. Describe what occurs during a condensation reaction.

A carboxylic acid or acyl chloride, plus an alcohol or amine join together. Water (or hydrochloric acid) is removed from the ends of the molecules and they join.

- i. Why are condensation reactions called condensation reactions?

Water is removed from the reactants, so when doing the reaction 'condensation' (i.e. water vapor) will appear on the walls of the reacting vessel.

- ii. Which functional groups are capable of undergoing condensation reactions?

Acyl chlorides can undergo condensation with amines and alcohols. Carboxylic acids can undergo condensation with alcohols if under reflux and with an acid catalyst.

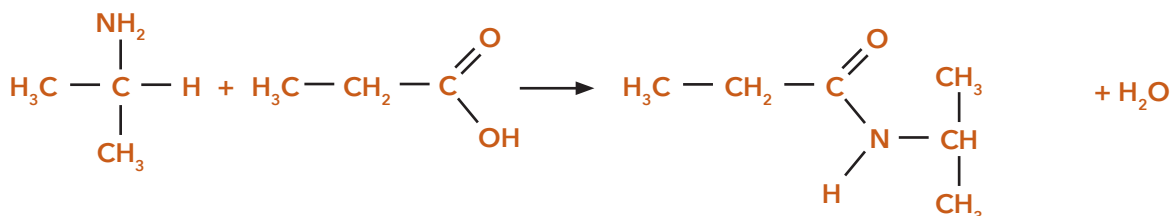
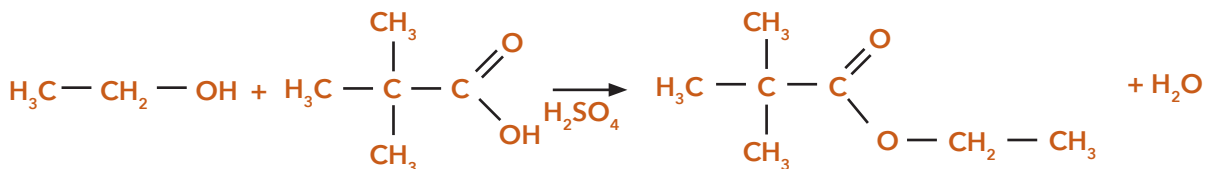
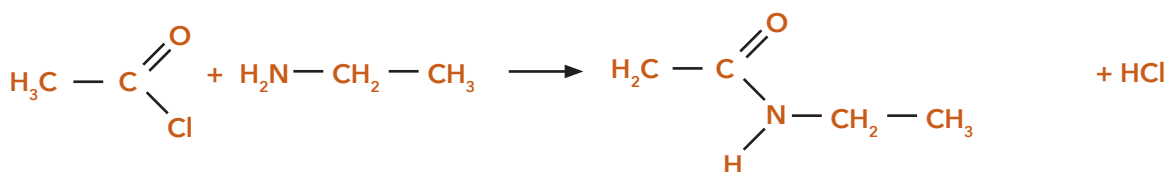
- iii. How does the product of a condensation reaction depend on its reactants?

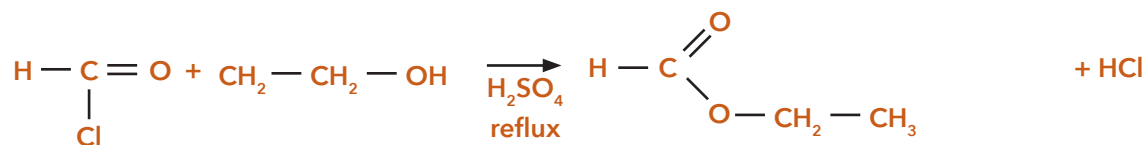
If an alcohol is used, there is an oxygen linking the two original molecules together and this is called an ester. If an amine is used, there is a nitrogen linking the two original molecules together and this is called an amide.

- iv. What is the difference between an acyl chloride and a carboxylic acid in terms of their ability to do condensation reactions? How does this affect the reaction conditions that they require?

An acyl chloride is very reactive and easily forms an ester or amide. A carboxylic acid is less reactive and will need reflux with an acid catalyst to form an ester.

- b. Complete the following reactions with either the product or reactants.





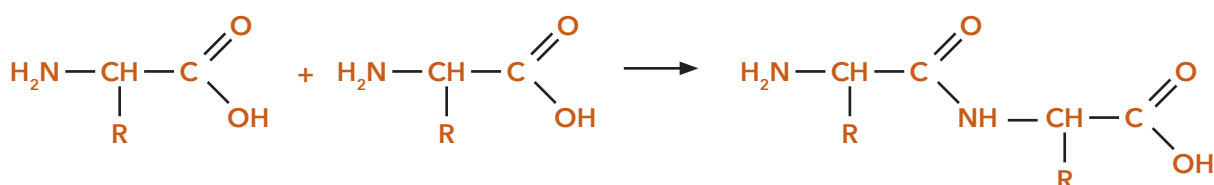
c. What are polymers?

Long molecules made of repeating monomer units.

i. How can polymers be formed by condensation reactions?

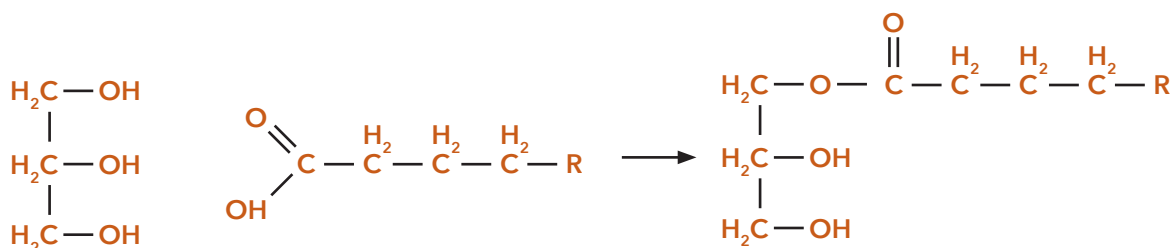
If a monomer has two functional groups either end that are both capable of undergoing a condensation reaction, then multiples of those monomers can be joined together infinitely to form a polymer.

d. What is the structure of an amino acid? How are they able to form polymers? Use a diagram for your answer.



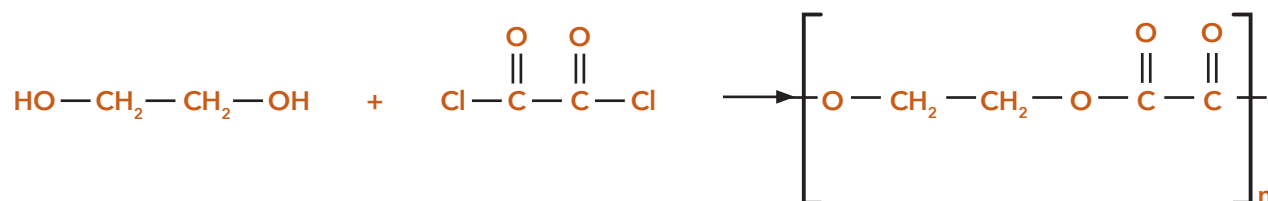
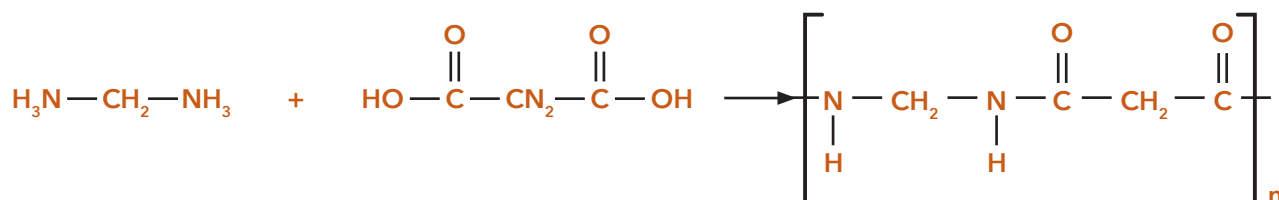
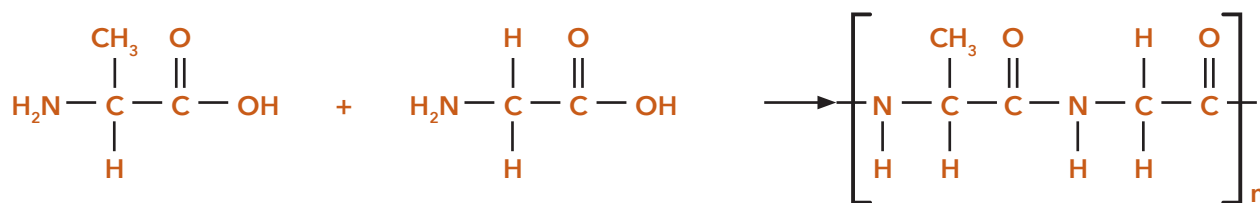
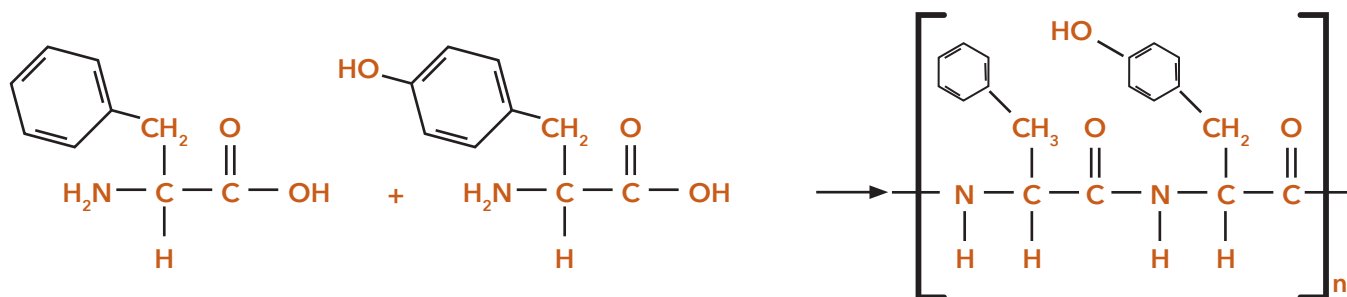
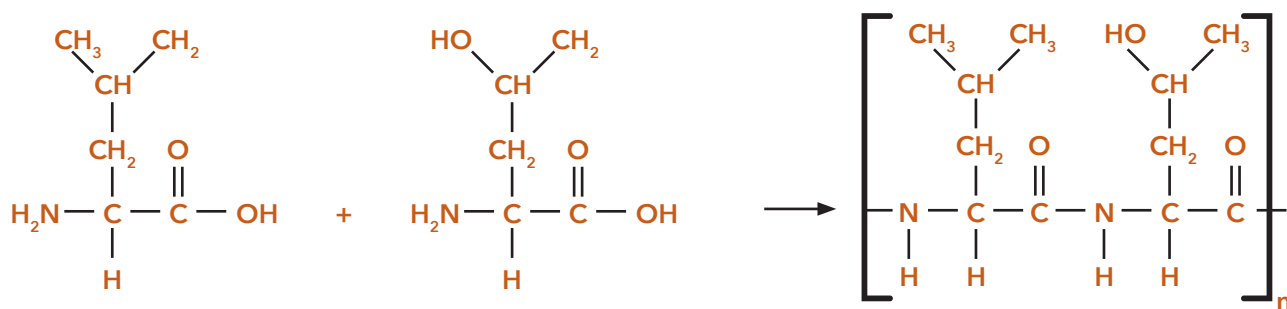
An amino acid is a biological monomer, with a carboxylic acid on one end and an amine on the other end. Amide linkages can form between monomers and these monomers can be joined together continuously. There are many different amino acids, which are differentiated by the side-chain they have at the "R" group. This side chain can be anything from a long carbon chain to another acid group.

e. What are the structures of fatty acids and glycerol? How are they able to form triacylglycerides? Use a diagram for your answer.

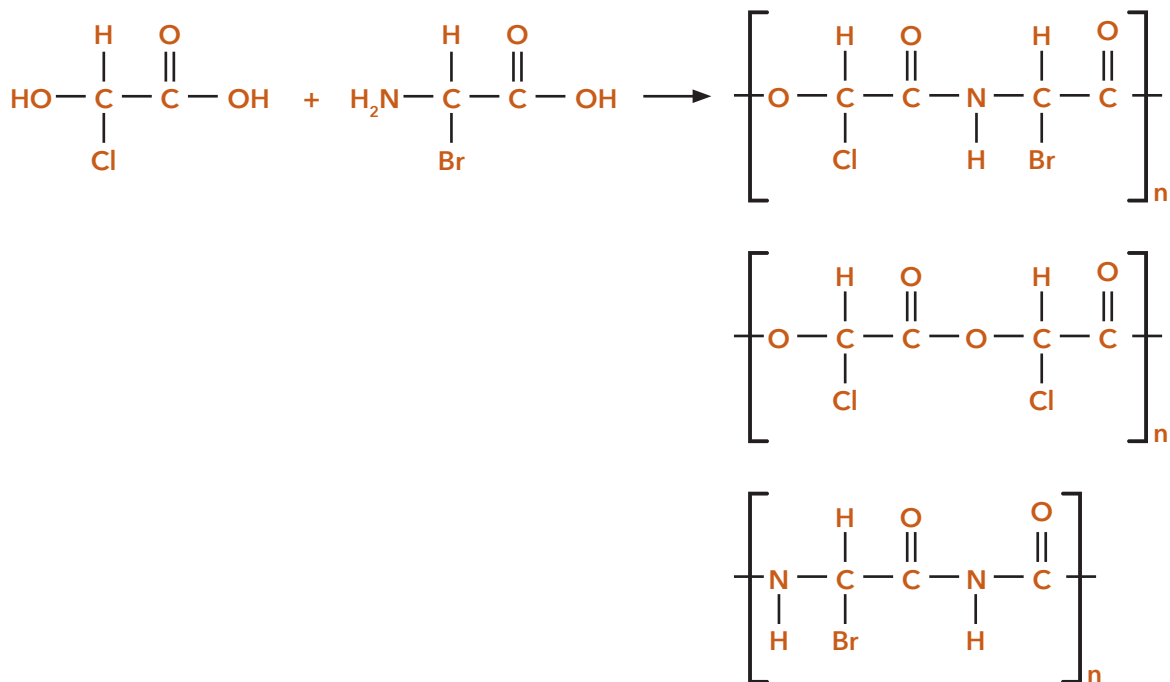


Glycerol is a tri-ol (triple alcohol group) with three carbons. A fatty acid is a long, nonpolar hydrocarbon chain with a carboxylic acid group at the very end. The alcohol on the glycerol and the carboxylic acids can undergo a condensation reaction and join together via an ester linkage. Each glycerol molecule can join to three fatty acids. (these are the lipids that your cell membranes are made of, any fat in your body, and also any oil that you use!)

- f. Complete the following polymerisation reactions with either the product or reactant. Where you would draw a polymer, draw the repeating unit that would be made with two monomers.



- g. From a mixture of the two following monomers, you can form a polymer by joining the two different molecules together repeatedly. You can also form a polymer by just repeatedly joining molecules of the first monomer together, or by repeatedly joining molecules of the second monomer together. This gives three possible monomers that you could form. Draw all three, showing two monomer units each.



The first and second monomers can be linked by an amide bond, then an ester bond, then an amide bond, etc... to make the first polymer.

The first monomer can repeatedly form ester linkages with other identical monomers, producing the second polymer down.

The second monomer can repeatedly form amide linkages with other identical monomers, producing the third polymer down.

h. What occurs during a hydrolysis reaction?

In an ester or amide linkage, the bond between the carbonyl carbon and the nitrogen or oxygen is broken. Water (which is why it's called hydrolysis) is used; the OH from the water joins onto the carbonyl carbon to make a carboxylic acid, and the H goes onto the oxygen or nitrogen to remake the alcohol or amide.

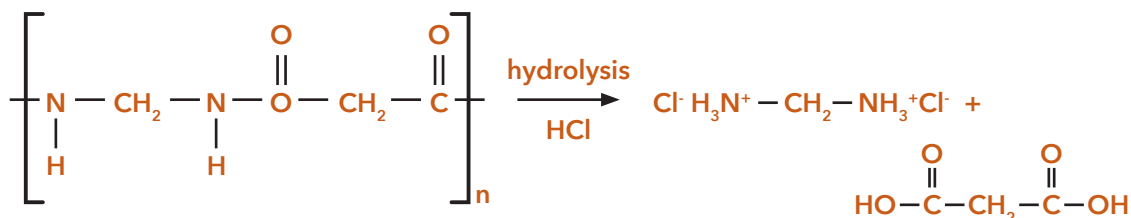
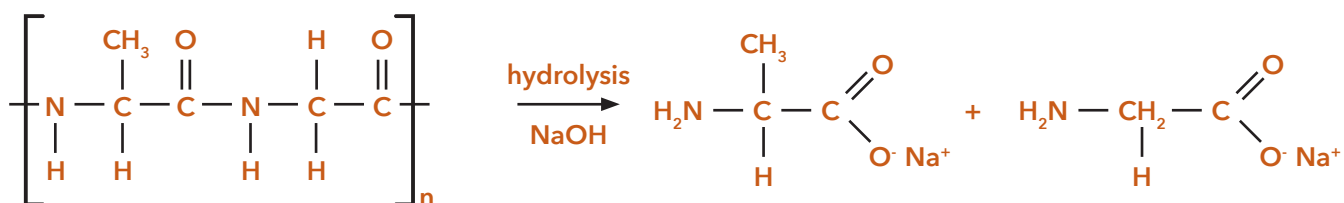
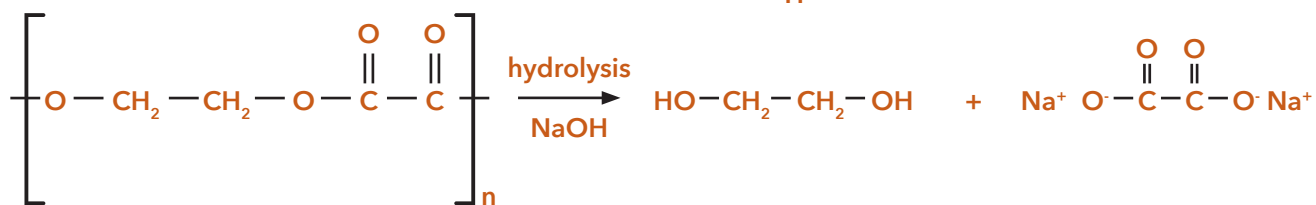
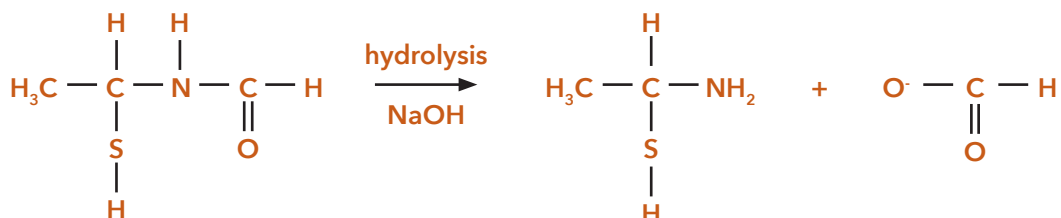
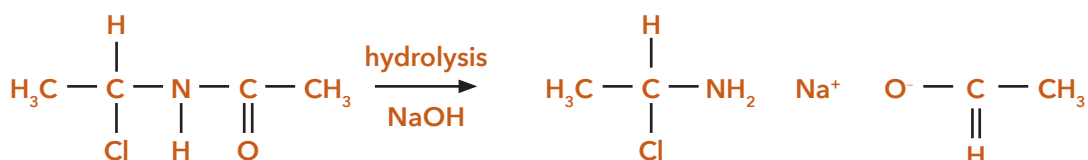
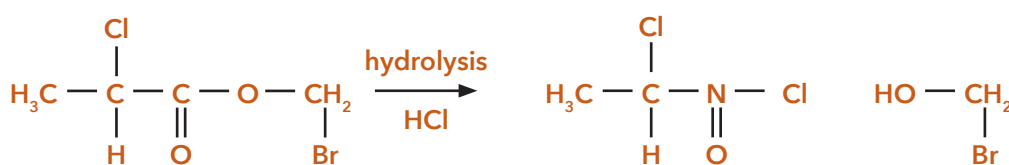
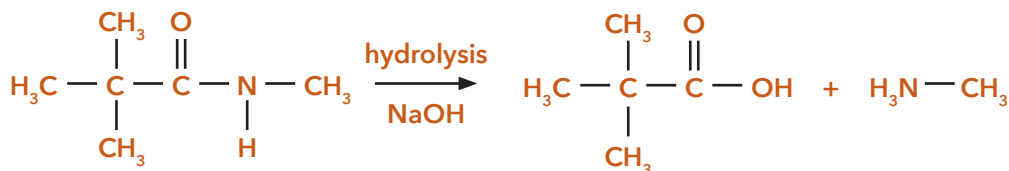
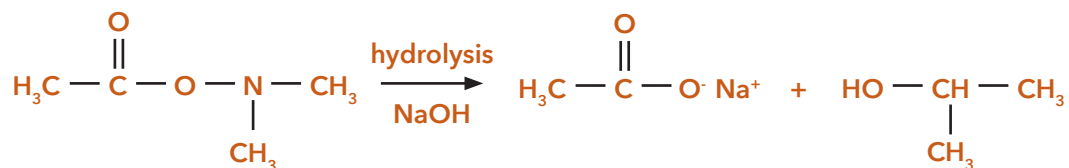
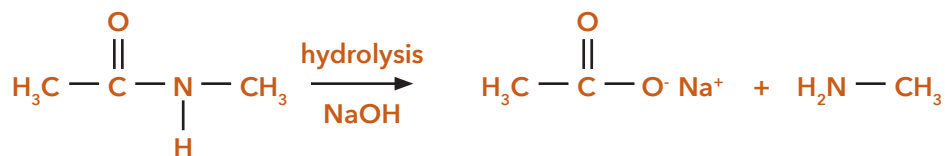
i. What occurs during basic/alkaline hydrolysis?

Alkaline hydrolysis is done in a basic solution. Any carboxylic acid groups which are produced by the hydrolysis will react with the base, turning the OH part of the COOH into an O⁻ and joining onto the positive ion from the base.

ii. What occurs during acid hydrolysis?

Acidic hydrolysis is done in an acidic solution. Any basic (i.e. amine) groups which are produced by hydrolysis will react with the acid, turning the NH₂ part of the amine into a NH₃⁺ and joining onto the negative ion from the acid.

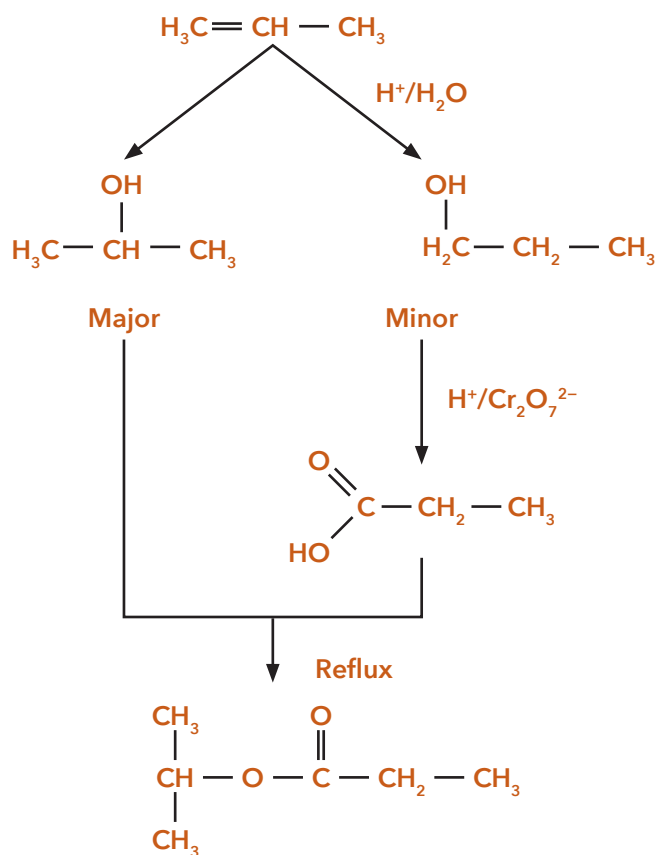
i. Complete the following reactions with either the product or reactant. Where you would draw a polymer, draw two of the repeating units.



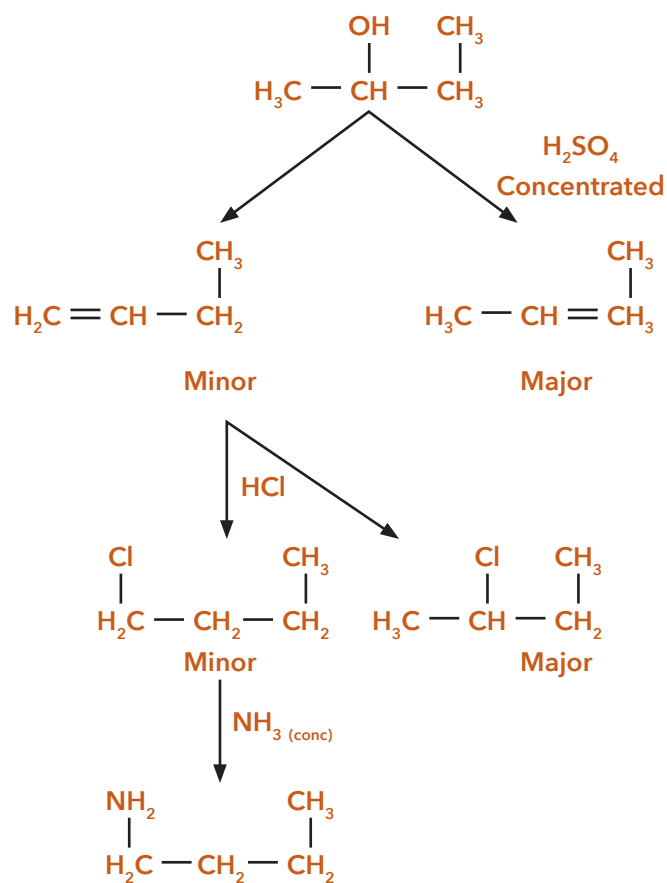
8. Reactions Practice

a. Complete the following reaction schemes with reagents, conditions, and structures.

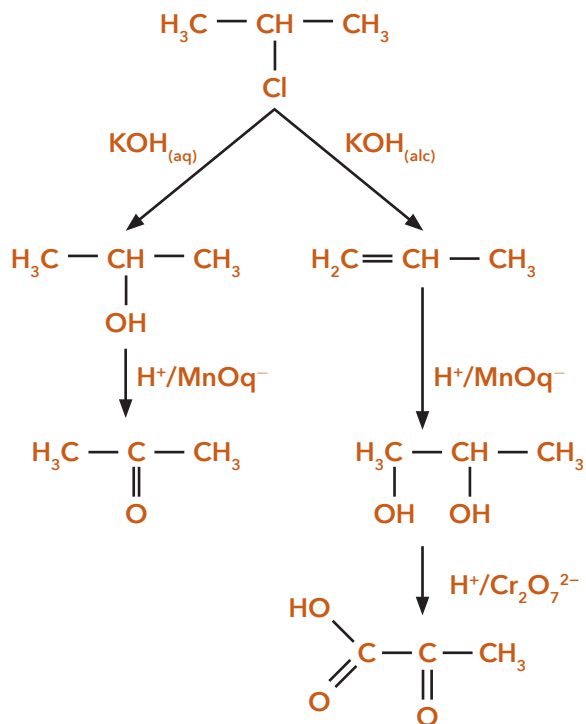
i.



ii.

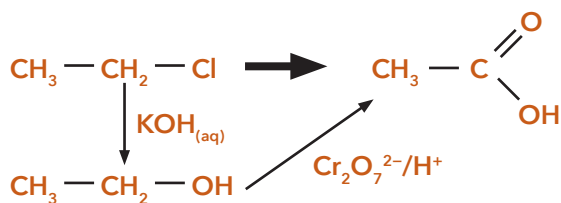


iii.

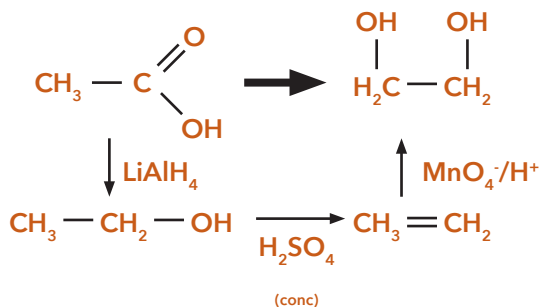


b. For the following pairs of molecules, suggest a series of reactions to get from the first molecule to the second.

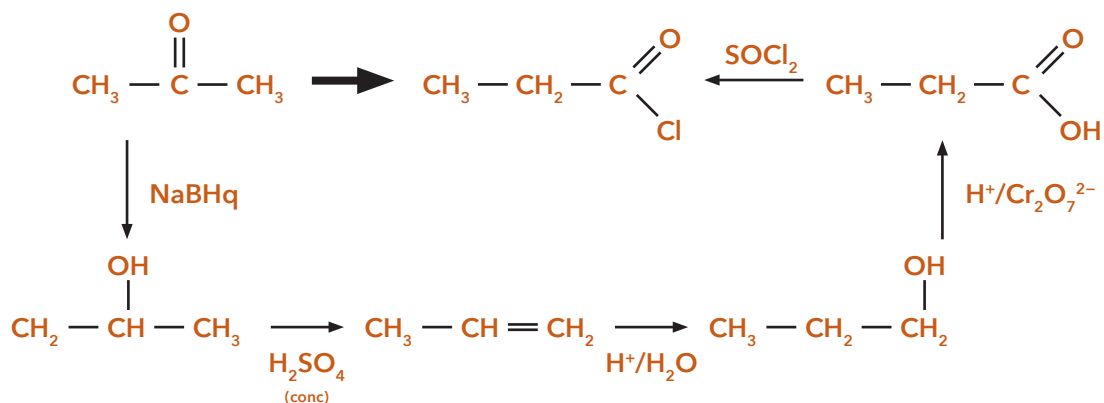
i.



ii.



iii.



9. Molecule Properties

- a. What determines whether an organic compound is polar or nonpolar?

If an organic molecule only has hydrogen and carbon atoms (is a hydrocarbon), it is nonpolar. Functional groups such as alcohols, carboxylic acids, and (to a lesser extent) halides are polar. The more functional groups a molecule has, the more polar it is. If most of the molecule is nonpolar, it will be mostly nonpolar.

- i. How does polarity affect solubility?

Like dissolves like: If a molecule is polar, it will dissolve in polar solvents (e.g. water) and won't dissolve in nonpolar solvents (e.g. hexane, oil). If a molecule is nonpolar, it will dissolve in nonpolar solvents but not polar solvents.

- ii. What happens when a compound is insoluble?

It won't 'mix' - it will stay as globs and sit in a separate layer from the solvent.

- b. What determines the melting and boiling points of an organic compound?

The functional groups and size: Carboxylic acid, alcohol, and amine groups are capable of hydrogen bonding. Molecules with these functional groups will have high boiling/melting points. Haloalkanes are slightly polar and will have slightly higher boiling points than alkanes, which have no permanent dipoles. Bigger molecules (more atoms) have higher melting points. Linear (straight-chained) molecules have higher boiling points than molecules with lots of side chains.

10. Identification Tests

- a. How can acidic organic compounds be identified?

Blue litmus paper will go red when added to (acidic) carboxylic acids. Carboxylic acids will also react with other bases, such as with a carbonate to form carbon dioxide gas bubbles.

- i. How can basic organic compounds be identified?

Red litmus paper will go blue when added to (basic) amines.

- b. How can primary, secondary, and tertiary alcohols be distinguished from each other?

Primary and secondary alcohols can be oxidised to aldehydes and ketones respectively. This will cause their oxidising agent to change colour. Tertiary alcohols will not be oxidised, so no colour change will occur.

c. How can aldehydes be identified?

Aldehydes readily oxidise to carboxylic acids, which can be identified with Tollen's or Fehling's reagent. This will cause the formation of a silver mirror (Tollen's) or orange precipitate (Fehling's).

d. How can an acyl chloride be identified?

Acyl chlorides are very reactive and will violently react, fizzing when added to water.

e. How can alkanes and alkenes be distinguished from each other?

Add bromine water to both; an alkene is more reactive than water and the orange bromine will quickly go colourless due to an addition reaction. An alkane is less reactive and the bromine will go colourless slowly, and only in the presence of UV light.

f. For the following pairs of molecules, describe how you might distinguish one from the other. Explain what you would observe in each case.

i. Butanone and butanal.

Add an oxidising agent which changes colour upon oxidising the reactant; butanone is a ketone and cannot undergo oxidation, whereas butanal is an aldehyde and can be oxidised to a carboxylic acid. You could use Tollen's (observe a silver mirror forming), Fehling's (observe a blue solution changing to red precipitate), dichromate (observe orange solution going to blue/green solution), or permanganate (observe purple solution going to colourless solution)

ii. Propanoic acid and propan-1-ol

Add blue litmus paper to both; propanoic acid is a carboxylic acid which is acidic and will turn the litmus paper red, whereas propan-1-ol is an alcohol and neutral and no change will be observed.

iii. Ethanoyl chloride and propanone

Add water to both; ethanoyl chloride is an acid chloride and will react with water violently with fizzing, and propanone is a ketone so it will not.

iv. Pentene and pentane

Add bromine water to both; pentene is an alkene and will rapidly turn the orange solution colourless due to an addition reaction. Pentane is an alkane and the orange solution will turn colourless slowly and only with UV light.

v. Ethanol and hexane

Add water to both; ethanol is an alcohol and is polar so it will dissolve in water. Hexane is an alkane and nonpolar so it won't dissolve.

vi. Hexan-1-amine and hexan-1-ol

Add red litmus paper to both; hexan-1-amine is an amine and basic so it will turn the red litmus paper blue. Hexan-1-ol is an alcohol and neutral so no change will be observed.

vii. Butan-1-al and butan-1-ol

Add a weak oxidising agent (Tollen's reagent or Fehling's reagent) to both. Butan-1-al is an aldehyde and will be easily oxidised to a carboxylic acid, causing the Tollens' reagent to form a silver mirror on the test tube. If Fehling's was used, the blue solution will turn into a brick-red precipitate. Butan-1-ol is an alcohol and will not be as easily oxidised, so change will occur.

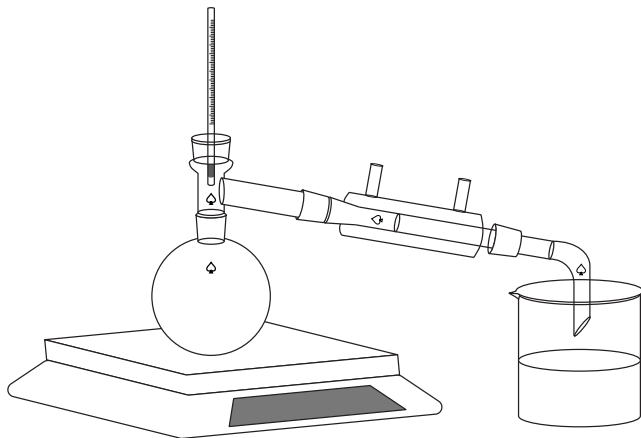
viii. Propanamide and propanamine

Add red litmus paper to both; propanamine is an amine and basic so it will turn the red litmus paper blue. Propanamide is an amide and not basic so no change will occur.

11. Apparatus

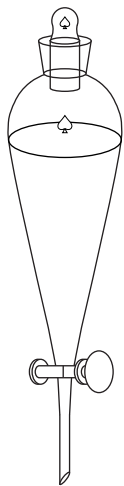
- a. Identify which of the diagrams represent a distillation setup, which one represents a reflux setup, and which one is a separating funnel.

i.



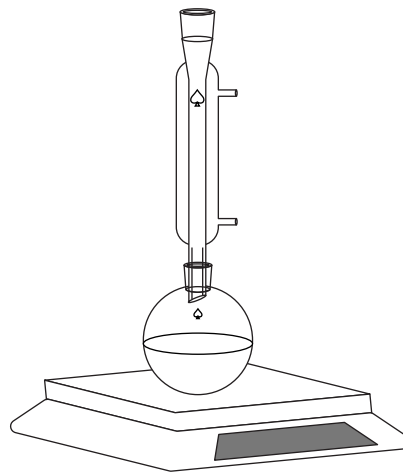
Distillation setup

ii.



Separating funnel

iii.



Reflux setup

b. What is a distillation setup used for? How does it work?

Distillation is used to separate two substances which are dissolved with each other. This is used to purify the desired product (get the one substance and nothing else). The two substances/molecules will almost always have different boiling points, so if the mixture is heated to the lower of the two boiling points then one of the liquids will be boiled off. It is collected and turned back into a liquid for collection via the condenser.

c. What a reflux setup used for? How does it work?

It is used to carry out reactions at temperatures higher than the boiling points of the reactants, allowing them to go faster. A condenser column is placed above the reaction mixture, so any reactants which get boiled off get condensed back down into the reaction mixture.

d. For which reactions is reflux necessary?

Reflux is needed to speed up reactions between unreactive molecules: these include:

- condensation reaction when a carboxylic acid is being used
- oxidation of alcohols to carboxylic acids
- Substitution with $\text{KOH}_{(\text{aq})}$ or $\text{SOCl}_2/\text{PCl}_3/\text{PCl}_5$
- Elimination with $\text{KOH}_{(\text{alc})}$

e. What is a separating funnel used for? How does it work?

It is used to separate two liquids which are not soluble with each other. This is used for purifying a product. It's a clear funnel, and the more dense liquid will sit in a layer below the other liquid. A tap at the bottom can be opened and closed to let out the bottom layer and leave behind the top.

f. Identify the most appropriate piece of equipment to use in the following situations. Briefly justify your choices.

i. I want to separate a mixture of butanol and water

Distillation, because these two substances are soluble with each other.

ii. I want to separate a mixture of hexane and water

Separating funnel, because these two substances are insoluble.

iii. I want to make an ester out of ethanoic acid and propanol

Reflux; making an ester out a carboxylic acid and alcohol is a type of reaction that requires reflux.

iv. I've just carried out a reaction to convert ethanal to ethanoic acid, and want a pure sample of ethanoic acid.

Distillation; ethanal, ethanoic acid, and the oxidising agent are likely all soluble with each other.

v. I want to purify the orange globs from the purple liquid in my lava lamp.

Separating funnel; the fact that they're 'globs' means that they're insoluble.

vi. A sample of ethanol is 40% ethanol and 60% water, and it needs to be purified to be 80% ethanol.

Distillation; ethanol and water are soluble.

Section Two

Exam Skills & Mixed Practice

Those are your basics out of the way for now. Aside from naming molecules, you probably won't get an exam question exactly like the ones you did just now. You might have to use several skills at once, such as knowing how to figure out the structure of a molecule from its name while also figuring out what reactions you need to do to obtain it. This section will be all about how to break down and answer a real exam question. We'll start by breaking down some examples of real exam questions and figuring out how to attack it, then you'll be given some parts of exam questions to work through.

Compared to NCEA level 2 chemistry, level 3 places the emphasis on new reactions you've learned - these are oxidation, reduction, making esters and amides, and hydrolysis. There are a few types of question which usually get asked:

- "Name these molecules" or "Draw these molecules using their names"
- "How do you identify these compounds?"
- "Complete the reaction scheme"
- "Based on the monomer(s), draw the polymer"
- "Based on the polymer/amide/ester, draw the acid/base hydrolysis products"
- "Draw and talk about the enantiomers for this molecule"
- "How would you get from this molecule to that molecule?"

Compared to other standards, there aren't many long answer questions in organic chemistry. They do come up, and they're mainly questions on identifying molecules, but otherwise it's all about knowing how a reaction works and how to draw the reactants and products correctly.

Let's try some example exam questions:

1. Identifying functional groups, drawing and naming molecules

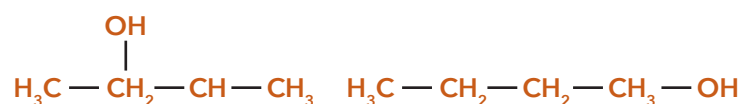
a. Complete the following table with either the name or structure of the molecule.

Name	Structure
2-methylpropanal	$\begin{array}{c} \text{O} \\ \parallel \\ \text{H} - \text{C} - \text{C} - \text{CH}_3 \\ \\ \text{CH}_3 \end{array}$
ethyl ethanamide	$\begin{array}{c} \text{O} \\ \parallel \\ \text{H}_3\text{C} - \text{C} \\ \\ \text{N} - \text{CH}_2 - \text{CH}_3 \\ \\ \text{H} \end{array}$
4-methylpropanamide	$\begin{array}{c} \text{CH}_3 \\ \\ \text{H}_3\text{C} - \text{CH} - \text{CH}_3 - \text{CH}_2 - \text{C} \\ \parallel \\ \text{NH}_2 \end{array}$
3-chloropentan-2-one	$\begin{array}{c} \text{O} \\ \parallel \\ \text{H}_3\text{C} - \text{C} - \text{CH} - \text{C} - \text{CH}_3 \\ \\ \text{Cl} \end{array}$

2. Isomers

a. Out of butan-2-ol and butan-1-ol, which is optically active? Explain your choice.

i. Draw the structures of butan-2-ol and butan-1-ol



ii. What are the other names for being optically active?

A molecule which is optically active is also said to have enantiomers or optical isomers.

iii. What are the requirements for being optically active?

There must be a carbon atom to which four different groups are attached. Remember that a 'group' means anything past the bond so a one-carbon chain is a different group from a two-carbon chain.

iv. Is butan-2-ol or butan-1-ol optically active? Why?

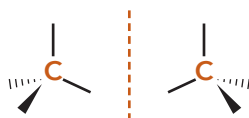
Butan-2-ol is optically active because it has a carbon (carbon 2) to which four different groups are attached, and butan-1-ol does not.

1. CH_3CH_2-
2. CH_3-
3. $-\text{OH}$
4. $-\text{H}$

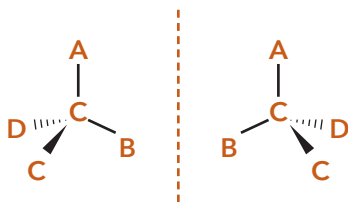
b. Draw the two enantiomers of that optically active molecule.

i. How do you draw enantiomers?

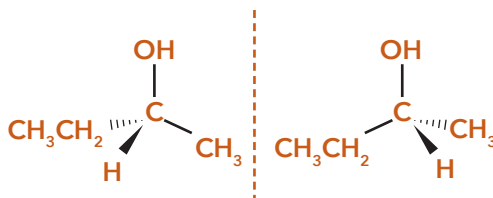
Start by drawing a carbon at the center of a tetrahedron shape. Then, draw the mirror image of that tetrahedron.



Once your tetrahedrons are done, add the four different groups to each bond on one tetrahedron. Do the mirror of that arrangement for the enantiomer.



ii. Draw the two enantiomers for the molecule you selected.

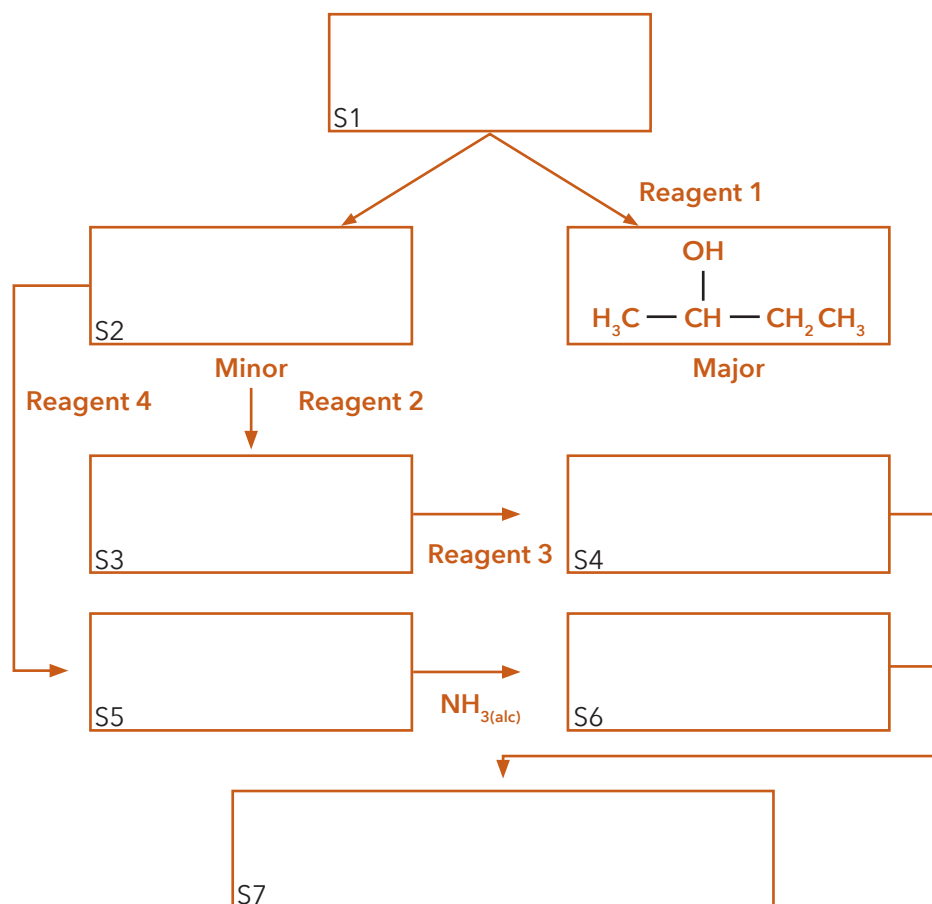


c. How can these two enantiomers be distinguished? Explain your answer.

Shine plane-polarised light into the molecule. This is because one enantiomer will rotate the plane of the polarised light one direction, and the other will rotate the plane the other direction.

3. Reactions

- a. Complete the following reaction scheme with reagents and structures.



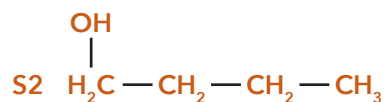
- i. What are S1 and Reagent 1 likely to be?

We can see that there was a major and minor product for this first reaction, so it must've been an addition or elimination reaction. One of the products is an alcohol, so it must've been an addition reaction. Recall that the reagent for addition to make an alcohol is $\text{H}^+/\text{H}_2\text{O}$, so that's Reagent 1. S1 will have a $\text{C}=\text{C}$ double bond. It must've been between the first and second carbons, because if it was between the second and third then the alkene would be symmetrical and there wouldn't be major and minor products.



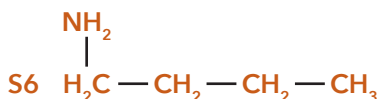
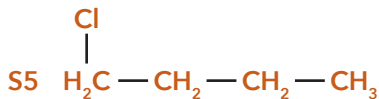
- ii. What is S2 likely to be?

Given that S1 is an alkene and the major product had an $-\text{OH}$ added to the second carbon and the $-\text{H}$ added to the first, S2 must be the minor product with the $-\text{OH}$ added to the first carbon and $-\text{H}$ added on the second.



iii. What are Reagent 4, S5, and S6 likely to be?

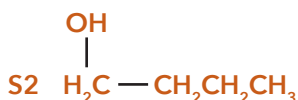
The clue with this series of reactions is that they must be substitution or oxidation/reduction reactions. The reagent for taking S5 to S6 is NH_3 (alc) which you hopefully remember as being used to kick off a Cl to convert a haloalkane into an amine. This means that S5 must be a haloalkane and S6 is an amine, something along these lines:



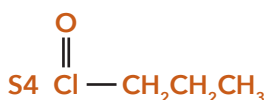
In order to get to the haloalkane S5 from the alcohol we have at S2, we need to do a substitution and put a Cl on while kicking off an -OH. This will need to be PCl_5 , PCl_3 , or SOCl_2 . Any of these can be our Reagent 4

iv. What are Reagent 2, S3, Reagent 3, and S4 likely to be?

We've got a whole series of reactions with no clue until we get to the very end here. We've got S6 and S4 combining to make a new molecule. Whenever we have two molecules coming together, this will be a condensation reaction to make either an ester or amide. We know that S6 is an amine, so it must be an amide we're making. We can only make an amide with an acid chloride as the other component, so S4 must be an acid chloride. S2 is an alcohol, so how do we get from an alcohol to an acid chloride in two reactions? We could oxidise the alcohol to a carboxylic acid and then react with SOCl_2 to put a chlorine on. This means Reagent 2 will be a strong oxidising agent like $\text{H}^+/\text{Cr}_2\text{O}_7^{2-}$. S2 will be a carboxylic acid like this:

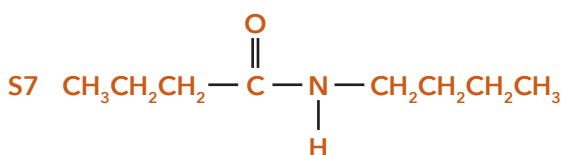


Reagent 3 must be SOCl_2 , and S4 will be the acid chloride that it makes:



v. What is S7 likely to be?

S7 will just be the result of the condensation of S4 and S6. Remember that the H from the amine's NH_2 will leave, and the Cl from the acid chloride will leave to form HCl. The carbonyl carbon and the N will join together to form the new molecule.



b. Suggest a series of reactions to go from propanone to propanoic acid. Include reagents.

i. What kinds of reactions can we use to get to propanoic acid? What will our reactants for these reactions need to be?

This is where the reaction scheme is especially handy: to get to propanoic acid, we could do hydrolysis on an ester or amide. On the other hand, we could get there by oxidising an aldehyde (propanal) or primary alcohol (propan-1-ol).

ii. What kinds of reactions can propanone do? How can the products of these reactions link up with the reactants we need to get propanoic acid?

Propanone is a ketone so it can't really do much aside from getting reduced to a secondary alcohol (propan-2-ol). This is similar to one of the reactants that we can get to propanoic acid; the primary alcohol propan-1-ol. However, it's not quite the same.

How can we get from propan-2-ol to propan-1-ol? We're effectively shifting the functional group one carbon over. Well, we could do an elimination reaction on propan-2-ol to get propene. Then we could do addition to it to get the -OH on the correct carbon as one of the products. Using an alkene as a way to get to the correct functional group is a very common thing you can use in level 3 organic chemistry so make note of this!

iii. Suggest the series of reactions to go from propanone to propanoic acid. Include reaction equations, reagents, and any minor or major products.

Here's where we put the whole series of reactions together. Here's where it's really important to remember how each reaction works and what reagent to use.

1. Propanone can be reduced using NaBH_4 to make propan-2-ol



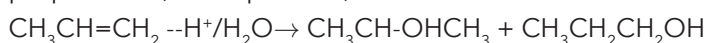
(Remember that a reducing agent turns a $\text{C}=\text{O}$ into a $\text{C}-\text{OH}$. It adds an H so that means it's something with lots of hydrogens: NaBH_4)

2. Propan-2-ol can undergo elimination with concentrated H_2SO_4 to make propene.



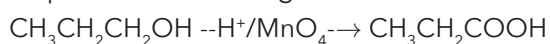
(Remember that conc. H_2SO_4 is a dry 'dehydrating agent' to remove OH and H)

3. Propene can undergo addition with $\text{H}^+/\text{H}_2\text{O}$ to make propan-2-ol (major product) and propan-1-ol (minor product)

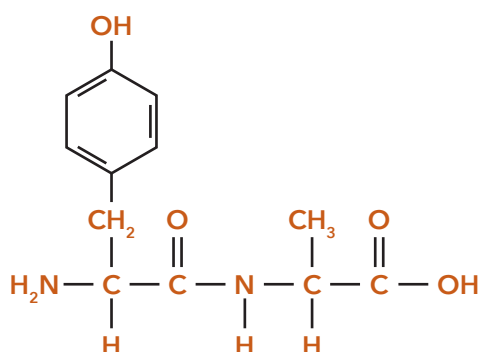
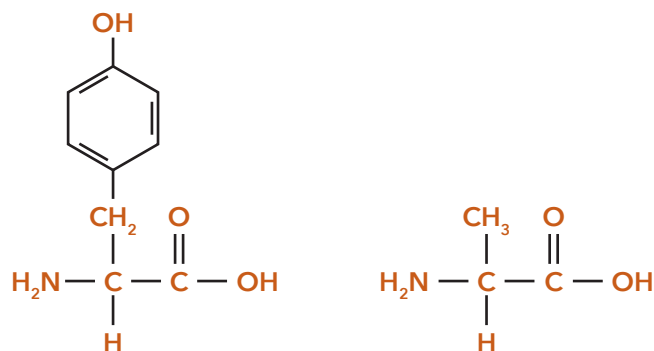


(Remember that in this reaction, OH gets added onto one of the double bonded carbons and H gets added onto the other. The major and minor depend on markovnikov's rule, or the 'rich get richer' rule.)

4. Propan-1-ol can undergo oxidation with acidified permanganate to make propanoic acid



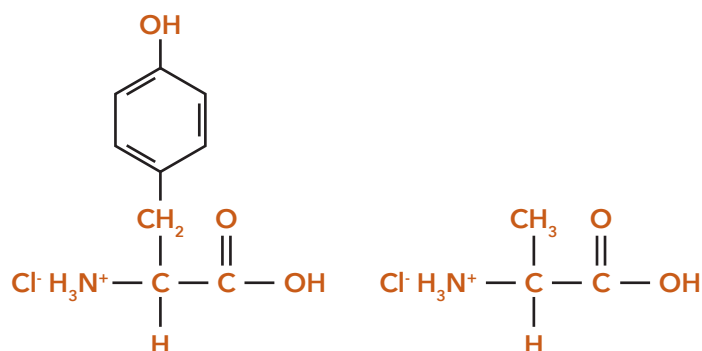
- c. The amino acids tyrosine and alanine can join together. Draw the structure of the dipeptide that results. Explain the reaction that is occurring.



This is a condensation reaction, because two molecules are coming together. The OH from the carboxylic acid group on the tyrosine and the H from the amine on the alanine combine together to form H_2O and leave. The remaining carbonyl and nitrogen bond to each other, forming an amide linkage.

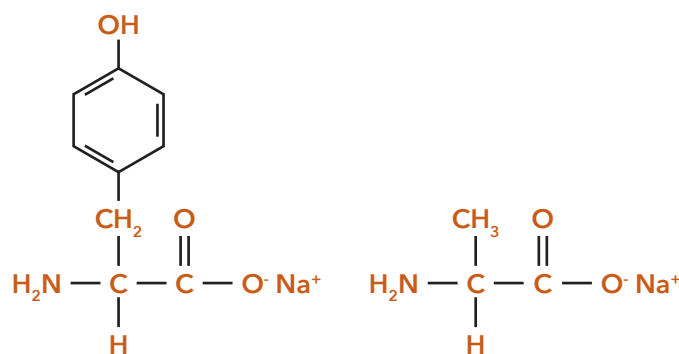
- d. Draw the products of the acidic and basic hydrolysis of this dipeptide. Explain why these products are formed.

i. Acidic hydrolysis in HCl



During hydrolysis, an H_2O splits the two molecules up. OH adds onto the carbonyl, forming a carboxylic acid and making it break off from the nitrogen. H adds onto the nitrogen, forming an amine and making it break off from the carbonyl. The hydrolysis is occurring in an acidic HCl solution, so the basic amine functional groups will react, gaining a proton to form NH_3^+ and bonding to the Cl^- ions.

ii. Basic hydrolysis in NaOH



During hydrolysis, an H₂O splits the two molecules up. OH adds onto the carbonyl, forming a carboxylic acid and making it break off from the nitrogen. H adds onto the nitrogen, forming an amine and making it break off from the carbonyl. The hydrolysis is occurring in a basic NaOH solution, so the acidic carboxylic acid functional groups will react, losing a proton to form COO⁻ and bonding to the Na⁺ ions.

e. A chemist wants to make methyl ethanoate directly from a carboxylic acid. What reactants, reagents and conditions will they need to create and purify this molecule?

i. Write the equation for the formation of methyl ethanoate from a carboxylic acid.



ii. What conditions/reagents are needed to carry out this reaction?

Reflux and H₂SO₄ catalyst.

iii. What apparatus would be used to purify the product? Explain how it would work.

A distillation setup would be used. The mixture could be heated to the boiling point of methyl ethanoate, causing it to be boiled off while leaving the other compounds in the mixture. The methyl ethanoate can then be condensed in the condensing column to yield the pure compound.

4. Identification Tests

a. Explain how you would distinguish between methanoic acid, hexane, cyclohexene, and methanal using moist litmus paper, Tollen's reagent, and bromine water. Include the observations and equations occurring for any reactions where relevant.

i. How would you identify methanoic acid?

Add moist blue litmus paper to each beaker; the methanoic acid is the only acidic compound and will be the one to turn the paper red.

ii. How would you identify methanal?

Add Tollen's reagent to each remaining beaker and heat; the methanal is the only aldehyde and will be oxidised from methanol to methanoic acid. A silver mirror will form on the vessel.
 $\text{CH}_2\text{O} \rightarrow \text{COOH}$.

iii. How would you identify cyclohexene?

Add bromine water to the two remaining beakers; the cyclohexene will rapidly react because it is an alkene with a reactive double bond. The orange bromine water will go colourless quickly.
 $\text{CH}=\text{CHCH}_2\text{CH}_2\text{CH}_2\text{CH}_2 \rightarrow \text{CHBrCHBrCH}_2\text{CH}_2\text{CH}_2\text{CH}_2$

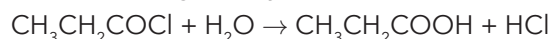
iv. How would you identify hexane?

It will be the last remaining beaker.

b. Explain how you would distinguish between 2-aminopentane, N-methyl propanamide, ethanol, propanoyl chloride using water, acidified potassium dichromate, and moist litmus paper. Include the observations and equations occurring for any reactions where relevant.

i. How would you identify propanoyl chloride?

Add water to each beaker; the propanoyl chloride is the only one which is reactive with water and will fizz vigorously.



ii. How would you identify 2-aminopentane?

Add moist red litmus paper to the remaining beakers; 2-aminopentane is the only one which is basic and will turn the litmus paper blue.

iii. How would you identify ethanol?

Add acidified dichromate to the remaining beakers. Ethanol is the only one which can be oxidised to an aldehyde and then a carboxylic acid. $\text{CH}_3\text{CH}_2\text{OH} \rightarrow \text{CH}_3\text{COOH}$. This will cause the solution to go from orange/red to blue/green.

iv. How would you identify N-methyl propanamide?

It will be the last remaining beaker.

c. Molecule X has the molecular formula $C_4H_8O_3$. It turns moist blue litmus paper red, and reacts with calcium carbonate to make carbon dioxide gas. When heated with acidified dichromate, molecule X turns the orange solution green/blue. Molecule X can also react with concentrated H_2SO_4 to make molecule Y. When added to bromine water, molecule Y rapidly turns it colourless. What is the structure of molecule X?

i. Molecule X turns blue litmus paper red. What does this tell us about its structure?

It must have a carboxylic acid group; $-COOH$ (these are the only groups that give a molecule acidic properties).

ii. It also causes a colour change when reacted with acidified dichromate, what does this tell us about its structure?

It must have an alcohol group or an aldehyde group. Acidified dichromate is the strong oxidising agent, and the colour change means it has oxidised something. Alcohol and aldehydes are groups which can be oxidised.

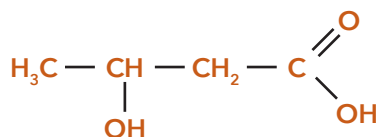
iii. When added to bromine water, molecule Y goes colourless. What does this tell us about molecule Y's structure?

Molecule Y must have a $C=C$ double bond, also known as an alkene group. Alkenes are the only functional group which can rapidly turn bromine water colourless, which it does through the addition reaction of the Br_2 onto either carbon involved in the double bond.

iv. When reacted with concentrated H_2SO_4 , molecule X makes molecule Y. What does this tell us about its structure?

Molecule X must contain an alcohol functional group. We know molecule Y has an alkene functional group, and to arrive at an alkene using concentrated H_2SO_4 as the reagent we must have started with an alcohol group.

v. Looking at the evidence, what is a possible structure for molecule X?



We know a few things about molecule X: It has the molecular formula $C_4H_8O_3$. It must have a carboxylic acid group. It also must have an aldehyde or alcohol group. However, we know for sure that there's an alcohol group because of what happened in parts iii) and iv). We've only got three oxygens in this structure - two would be taken up by the carboxylic acid group, and one is taken up by the alcohol. That means there's no aldehyde. Let's try to draw a molecule with these traits.

The $-OH$ could actually go on either carbon 2,3, or 4 and these would all be correct.

Section Three

Practice Exam

Now's the time where you get to show off how far you've come - we've got a full, proper, NCEA-style exam for you to do here. It's really important that you do this under exam conditions. That means giving yourself a quiet environment, setting a timer for one hour, and studying to get yourself confident with the content beforehand.

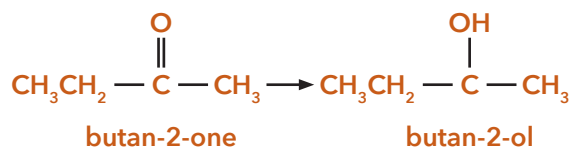
This is important because it's going to train you to work under those conditions, and let you see how you're going to actually perform. Doing the practice exam after a bit of studying is also really important because it lets you do retrieval learning on the content, helping you remember it.

Question One

- a. i. Complete the table below to show either the structural formula or the IUPAC (systematic) name for each organic molecule.

Structural formula	IUPAC name
$\text{H}_3\text{C}-\text{C}_2-\text{C} \begin{array}{l} \text{=O} \\ \text{O} \end{array} \text{O}-\text{C}_2-\text{C}-\text{CH}_3$	Propyl propanoate
$\begin{array}{c} \text{H} \\ \\ \text{CH}_3-\text{C}-\text{C} \begin{array}{l} \text{=O} \\ \text{OH} \end{array} \\ \\ \text{Cl} \end{array}$	2-chloropropanoic acid
$\begin{array}{c} \text{O} \\ \\ \text{C}-\text{C} \begin{array}{l} \text{H} \\ \\ \text{Cl} \end{array} -\text{CH}_3 \\ \\ \text{H} \end{array}$	2-chloropropanal
$\begin{array}{c} \text{CH}_3 \quad \text{O} \\ \quad \\ \text{H}_3\text{C}-\text{C}-\text{C}-\text{CH}_3 \\ \\ \text{H} \end{array}$	3-methylbutan-2-one
$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2-\text{C} \begin{array}{l} \text{=O} \\ \text{NH}-\text{CH}_3 \end{array}$	methyl pentanamide

- ii. Butan-2-ol can be formed from the reduction of a molecule. Write the equation for this reaction including any reagents. This reaction may need to take place at a temperature higher than the boiling point of the reactants. Describe and explain how this can be dealt with.

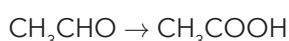


The reagent required is NaBH_4 or LiAlH_4 . Use a reflux set up: the reaction mixture will have a condensing column with cold water placed above it. Whenever any reactants boil off, they'll be re-condensed down into the reaction mixture allowing the reaction to be done at a higher temperature and speeding it up.

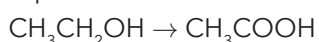
b. Four unlabelled test tubes each contain ethanoic acid, ethanol, 2-methyl propan-2-ol, and ethanal. Describe and explain how you would determine what each test tube contains using only moist litmus paper, acidified potassium dichromate, and Tollen's reagent. Your answer should include:

- Reagents and conditions required.
- Observations.
- The reaction type and structural formulae of any products.

First, add Tollen's reagent to a sample of every test tube. Ethanal is the only aldehyde, so it's the only which will react with Tollen's reagent. It undergoes an oxidation reaction to form ethanoic acid. When added to the test tube with ethanal, Tollen's reagent will form a silver mirror on the test tube surface. The reaction equation is:



Next, add acidified potassium dichromate (an oxidising agent) to a new sample of the remaining three test tubes. Ethanoic acid cannot be oxidised any more, and 2-methylpropan-2-ol is a tertiary alcohol and cannot undergo oxidation. So, ethanol will be the only molecule that can undergo oxidation. The orange solution will turn blue/green if it has ethanol in it, and the reaction equation is:



To the remaining two test tubes, add moist blue litmus paper. Only ethanoic acid is acidic whereas 2-methylpropan-2-ol is not, so when added to the ethanoic acid the litmus paper will turn from blue to red. The 2-methylpropan-2-ol will be last remaining test tube.

c. Molecule A has the molecular formula $\text{C}_3\text{H}_6\text{O}$. When combined with acidified potassium permanganate, it will turn the solution from purple to colourless and turn into molecule B. Molecules A and B can be combined under reflux with acid to make molecule C, a sweet-smelling compound. Molecule A can also be reacted with concentrated sulfuric acid to produce molecule D.

Draw and give the IUPAC names for molecules A to D.

	Structural formulae	IUPAC name
A	$\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \text{OH}$	Propan-1-ol
B	$\text{CH}_3 - \text{CH}_2 - \text{C} \begin{array}{l} \text{=O} \\ \text{OH} \end{array}$	Propanoic acid
C	$\text{CH}_3 - \text{CH}_2 - \text{C} \begin{array}{l} \text{=O} \\ \text{O} - \text{CH}_3 - \text{CH}_2 - \text{CH}_2 \end{array}$	Propyl propanoate
D	$\text{CH}_3 - \text{CH} = \text{CH}_2$	Propene

Explanation: The molecular formula C_3H_6O means it must be either an alcohol, aldehyde or ketone functional group. If molecule A is able to cause a colour change in the oxidising agent acidified potassium permanganate, that means it must be able to be oxidised. So, molecule A must be either a primary alcohol, secondary alcohol, or aldehyde. This also means molecule B must be either a carboxylic acid, ketone, or carboxylic acid respectively (because it's the product of the oxidation of molecule A).

The next part is key: molecules A and B can be combined to make a new molecule, and only amides (made by amine + acid chloride) and esters (made by alcohol + carboxylic acid or acid chloride) can be made by combining two carbon-containing molecules. Which of these options are possible? Well, we haven't started with or introduced any chlorine or nitrogen atoms so it must be an ester made out of an alcohol and carboxylic acid. Look at our previously-established options for molecule A and B:

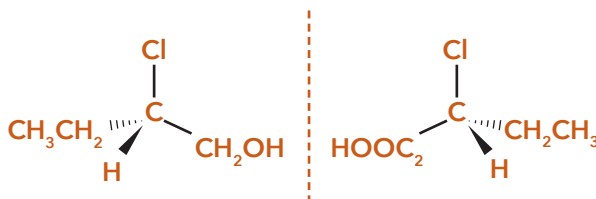
A	B
Primary alcohol	Carboxylic acid
Secondary alcohol	Ketone
Aldehyde	Carboxylic acid

This means it must be the first option; we've got an alcohol and carboxylic acid there. For molecule D, it's the product of the reaction of the primary alcohol with conc. H_2SO_4 . That's an elimination reaction and makes an alkene. Now we've figured out the functional groups, you can just string together the right number of carbons in the main chain and draw the functional groups in the appropriate places.

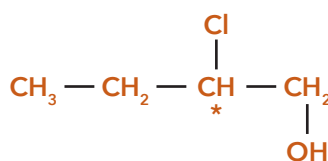
Question Two

a. 2-chlorobutan-1-ol can exist as enantiomers.

i. Draw the enantiomers of 2-chlorobutan-1-ol in the box below.



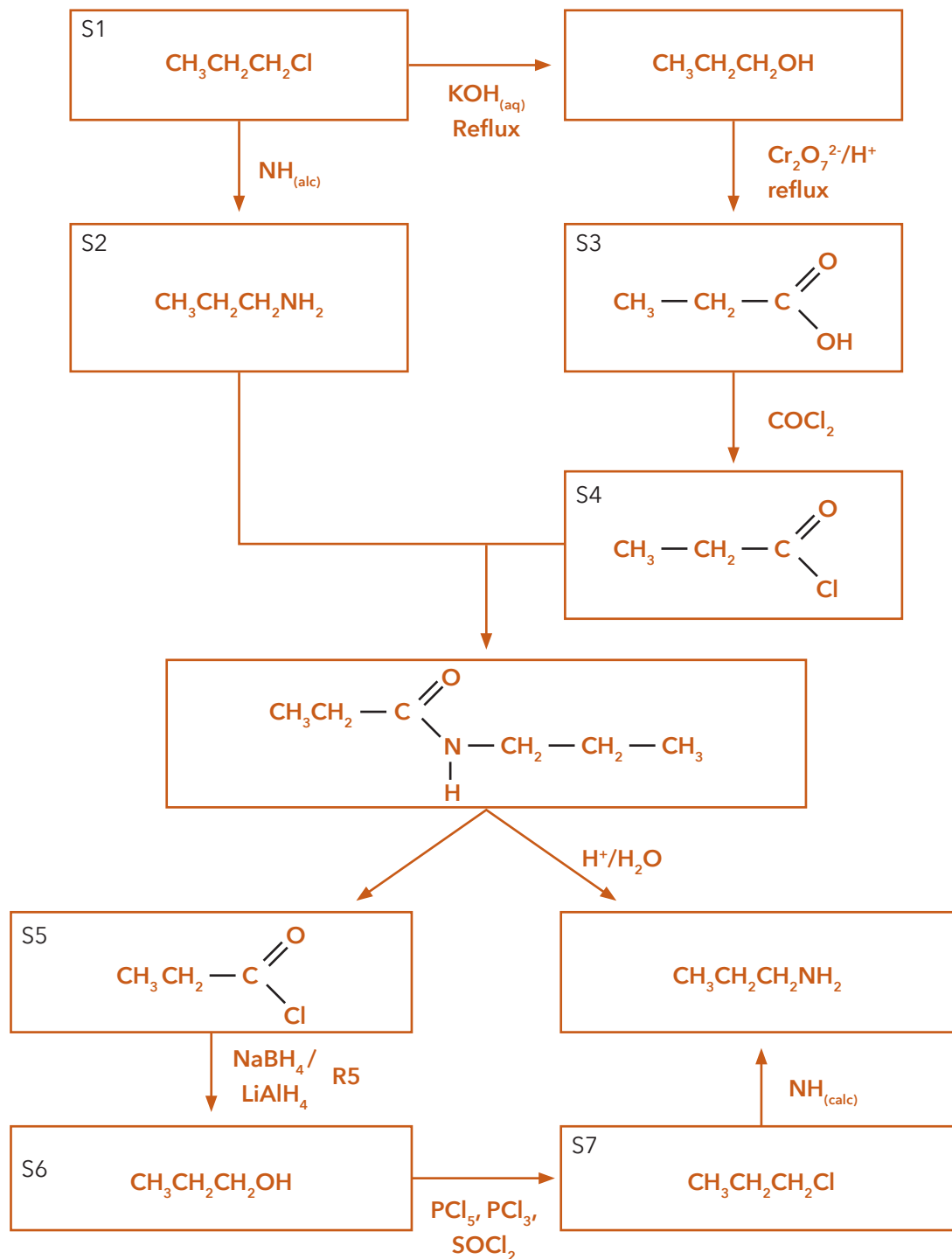
If you're having trouble, first draw out the structure of 2-chlorobutan-1-ol and identify the carbon to which four different groups are attached. That carbon will be in the middle of the tetrahedral shape, and place the groups attached to it around the outside then do the mirror image.



ii. Explain how the two enantiomers of 2-chlorobutan-1-ol could be distinguished.

Shine a ray of plane-polarised light into the molecule. One enantiomer will rotate the plane one direction (a given angle), and the other enantiomer will rotate the plane the same angle in the other direction.

b. Complete the following reaction scheme with structures and reagents.



Explanation: This one is one where the most information is actually near the middle of the scheme, so we should start there. We've got an amide being made by two molecules (above it) and then being split into two molecules (below it).

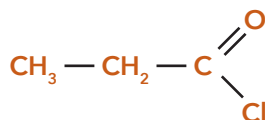
In the top half, we can see that some molecule (S1) is treated with conc. NH_3 and then that (S2) goes to make the amide. We know that an amide requires an amine and a carboxylic acid, and that conc. NH_3 is what you add to a haloalkane to make an amine. That means S2 must be an amine, and by looking at the structure of the amide we can see that it must have a three-carbon chain. Knowing that S2 is an amine, produced by substitution of a haloalkane using conc. NH_3 , that means S1 must be the corresponding haloalkane - we've used Cl for the halogen here.

To the right of the haloalkane we've got an alcohol, and remember that to go from a haloalkane to an alcohol you can do substitution with $\text{KOH}_{(\text{aq})}$ so that will be R1. Now we've got a few blank steps, but remember that we're trying to make an amide at the end by combining with an amine. The other component for making an amide is an acid chloride, so S4 must be the acid chloride. Looking at the structure of the amide, we can see that that acid chloride must have three carbons too. Now we've got an alcohol and an acid chloride with one step in between. Recall that to get to an acid chloride, you've got to add SOCl_2 to a carboxylic acid. So, R3 will be SOCl_2 and S3 will be a three-carbon carboxylic acid. S3 is a carboxylic acid and above it, you have a primary alcohol, and the reagent to oxidise the alcohol is either acidified dichromate or acidified permanganate - this will be R2.

On the bottom half, we've got the amide splitting - you could use either NaOH (for basic hydrolysis) or $\text{H}^+/\text{H}_2\text{O}$ (for acid hydrolysis) as R4. You've got the three-carbon amine component on the left, so on the right for S5 you must have the three-carbon carboxylic acid component. Now you've got another series of blank reactions, so maybe try to look at where you're going. The reactions cycle back to the amine, with conc. NH_3 as the reagent again. Again, conc. NH_3 is the reagent to do substitution on a haloalkane and get an amine. This means S7 must be the corresponding three-carbon haloalkane. Next bit's a bit tricky, how you get from a carboxylic acid to a haloalkane? Well, you could do a reduction with NaBH_4 or LiAlH_4 for R5, making a three-carbon alcohol S6. Then, to go from that alcohol to the haloalkane remember you can do substitution with PCl_5 , PCl_3 , or SOCl_2 for R6 to replace that OH with a Cl.

- c. A molecule with the molecular formula $\text{C}_3\text{H}_6\text{OCl}$ can have structural isomers. Draw and name structural isomers of that molecule which will behave in the following ways:

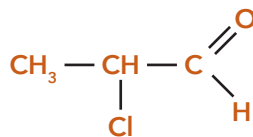
- i. Will react violently and fizz when added to water.



Propanoyl chloride.

(Acid chlorides are known to react violently with water, so it must have that functional group).

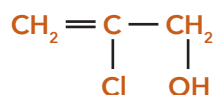
- ii. Will react with Tollen's reagent to produce a silver mirror.



2-chloropropanal (also can draw and name 3-chloropropanal)

(To undergo an oxidation reaction and form a silver mirror from Tollen's reagent, the molecule must have an aldehyde functional group. The chlorine could either go on the middle carbon or the carbon on the other end of the molecule).

iii. Will turn rapidly bromine water from orange to colourless.

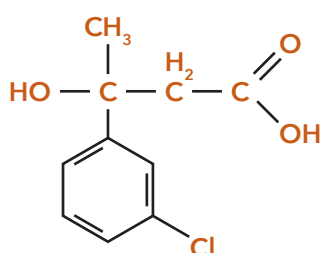


2-chloro, 3-hydroxy prop-1-ene. Many others are possible as well.

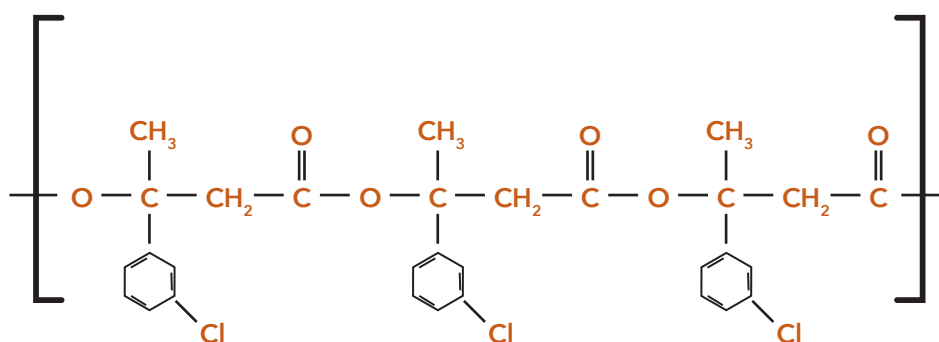
(To turn bromine water colourless via a rapid addition reaction, the molecule must have a carbon-carbon double bond. With the molecular formula $\text{C}_3\text{H}_6\text{OCl}$, there are now too many hydrogens to be able to have a $\text{C}=\text{O}$ group so it must be an alcohol group now. The alcohol and chlorines could both be placed anywhere along the carbon chain, the one above is just one example).

Question Three

a. The following molecule can be used to make polymers.



i. In the box below, draw three repeating monomer units of the polymer.

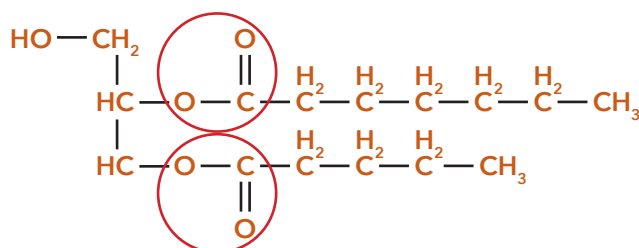


ii. Name the type of reaction that takes place to make the polymer. Explain your choice.

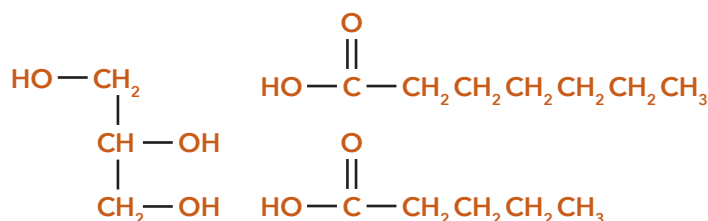
Condensation reaction. A polymer can be made in this case because one end of the molecule has a carboxylic acid group and the other end has an alcohol group. When the carboxylic acid group of one molecule comes in contact with the alcohol group of another molecule, an OH from the carboxylic acid and H from the alcohol combine to form water and leave, causing the carbonyl carbon and oxygen to bond together to form an ester bond. This is a condensation reaction.

b. Diacylglycerides are a type of molecule which is produced when animals digest dietary fats. Below is the structure of a diacylglyceride.

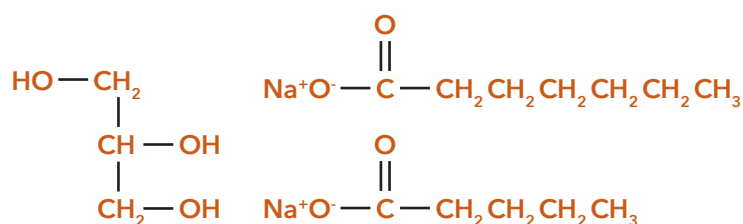
i. Circle the ester functional groups present.



ii. Acid hydrolysis is performed on diacylglycerides in the stomach of animals. Draw the products of the acidic hydrolysis of the ester bonds in this molecule.



iii. Draw the products of the alkaline hydrolysis of the ester bonds in this molecule with NaOH.



iv. Compare and contrast the acidic and basic hydrolysis of the diacylglyceride. In your answer you should include:

- An explanation of the hydrolysis reaction, including the differences in the products between acidic and basic hydrolysis.
- The reagents and conditions required.

Hydrolysis is the breakage of the ester (or amide in other cases) bond by the addition of water. Water splits into OH and H, and the OH goes onto the carbonyl, reforming a carboxylic acid group and breaking it off from the other oxygen atom. The H goes onto the O, reforming the alcohol.

Acidic hydrolysis requires heating the diacylglyceride in an acidic solution. Any basic functional groups (amines) will react with the acid to accept a proton and gain a positive charge. Basic hydrolysis requires heating the diacylglyceride in a basic solution e.g. NaOH. Any acidic functional groups (carboxylic acids) will react with the base to lose a proton from the OH part of their functional group and gain a negative charge. This negative charge may bond to the Na⁺ ion.

c. Suggest a reaction scheme to go from 2-chlorobutane to butanamide. For each step include:

- The reagents and conditions.
- The structural formula for the reactants and products of each step, including major and minor products.

We've explained it a bit more here than you might be expected to. For this question, you don't need to state the type of reaction or name the molecules, just the structures and the reagents/conditions. When it comes to breaking this down, remember to think about the reactions you can go through to get from one functional group to another. As mentioned before, the problem of changing the position of a functional group (from a Cl at carbon 2 to an amide carbon 1) is a common problem so remember the trick of elimination to make an alkene then addition!

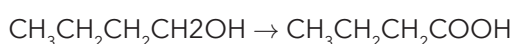
First, add $\text{KOH}_{(\text{alc})}$ with reflux to the 2-chlorobutane. This is an elimination reaction which will make but-1-ene as a minor product and but-2-ene as a major product:



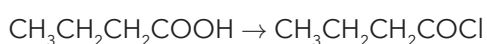
Then, add $\text{H}^+/\text{H}_2\text{O}$ with heating to the but-1-ene. This is an addition reaction which will make butan-1-ol as a minor product and butan-2-ol as the major product.



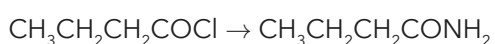
Then, add $\text{H}^+/\text{Cr}_2\text{O}_7^{2-}$ with reflux to the butan-1-ol. This is an oxidation reaction which will make butanoic acid.



Then, add SOCl_2 to the butanoic acid. This is a substitution reaction which will make butanoyl chloride.



Finally, add $\text{NH}_{3(\text{alc})}$ to the butanoyl chloride. This is a substitution reaction which will make butanamide.



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