University of Reading

FIRST YEAR UNDERGRADUATE CHEMISTRY

ORGANIC CHEMISTRY WORKBOOK

HEA PHYSICAL SCIENCES FUNDED PROJECT
PHYSICAL SCIENCES CENTRE
OPEN EDUCATIONAL RESOURCES FUNDED PROJECT
'SKILLS FOR SCIENTISTS'

Dr Elizabeth M. Page, Liz A. Tracey,
Department of Chemistry, University of Reading, Reading, UK. (e.m.page@reading.ac.uk)

Organic Chemistry Workbook

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The workbook contains a selection of typical questions with worked answers on the topics above. Following the example questions are questions which students can attempt themselves of a similar type. Worked answers can be found to the questions at the end of each section.

This self-study workbook was compiled as part of a HEA funded project entitled 'Supporting and Retaining New Students in the Physical Sciences'. Many thanks to Liz Tracey who compiled the workbook, Dr John McKendrick for examples, Chris Searle and Tim Snow for testing the questions. It is made available through the JISC funded Open Educational Resources project 'Skills for Scientists' via an "Attribution-Non Commercial Share Alike" Creative Commons Licence.

Key words: chemistry, organic, first year, undergraduate, university, revision, workbook, self study, skills for scientists.

Section 1

Foundations of Organic Chemistry

Atomic Structure

Much of the basis of organic chemistry hinges upon the understanding of the concept of orbital hybridisation.
Remember from your organic course (also covered in inorganic) that an orbital is a diffuse region around the nucleus where there is a finite probability of finding an electron. In organic chemistry we are concerned with s-orbitals and p-orbitals.
The carbon atom in its ground state has six electrons, occupying the 1s-, 2s- and 2p-orbitals.
Remember that each orbital can hold a maximum of 2 electrons (**Pauli Exclusion Principle**), and that orbitals are filled in order of increasing energy (**Aufbau Principle**).
Applying these rules to carbon, the two lowest-energy electrons are placed in the 1s-orbital, the next two are placed in the 2s-orbital and each of the final two electrons are placed in two of the three available 2p-orbitals.

Remember that the ground state electron configuration of a carbon atom is $1s^2\ 2s^2\ 2p^2$.

Generally speaking, the 1s-orbital can be ignored in organic chemistry. It is of too low an energy level to have any impact on reactivity. Consequently, organic chemistry is concerned with the second shell and the interactions of the 2s-/2p-orbitals.

Exercise 1

Remind yourself of the shapes of the s-orbital and p-orbital. These shapes are important when considering the structure of organic molecules, and consequently are important when considering bonding.

Sketch the three 2p-orbitals below.

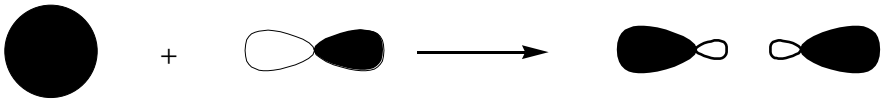
You should appreciate the nature of the each of 2p-orbitals lying along a separate axis, x, y and z. This is extremely important when considering the bonding and reactivity of alkenes and alkynes in particular.

Orbital hybridisation

Hybridization can occur if the component atomic orbitals are close in energy. When carbon forms bonds, one of the two electrons in the 2s-orbital is promoted to a vacant 2p-orbital. This gives carbon an electron configuration of $1s^2\ 2s^1\ 2p^3$. The 2s- and 2p-orbitals can be combined (**hybridized**) to give the same number of Hybrid Atomic Orbitals.

Worked example 1

sp



2s $2p_x$ 2 sp orbitals

a) How many unhybridized p-orbitals are there?
b) In what type of molecule would this hybridization scheme be found?
c) What is the angle between the hybrid orbitals?

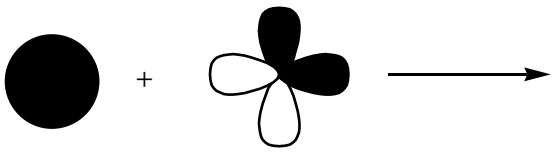
Worked example 1 answers

a) Two ($2p_y$ & $2p_z$)
b) Alkyne
c) 180°

Question 1

sp^2

a) Complete the diagram below to show the hybrid atomic orbitals.



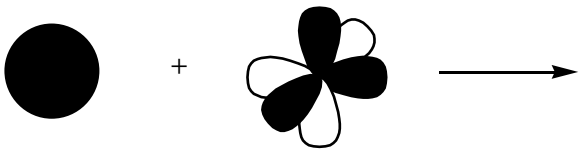
2s $2p_x + 2p_y$

b) How many unhybridized p-orbitals are there?
c) In what type of molecule would this hybridization scheme be found?
d) What are the angles between the hybrid orbitals?

Question 2

sp^3

a) Complete the diagram below to show the hybrid atomic orbitals.

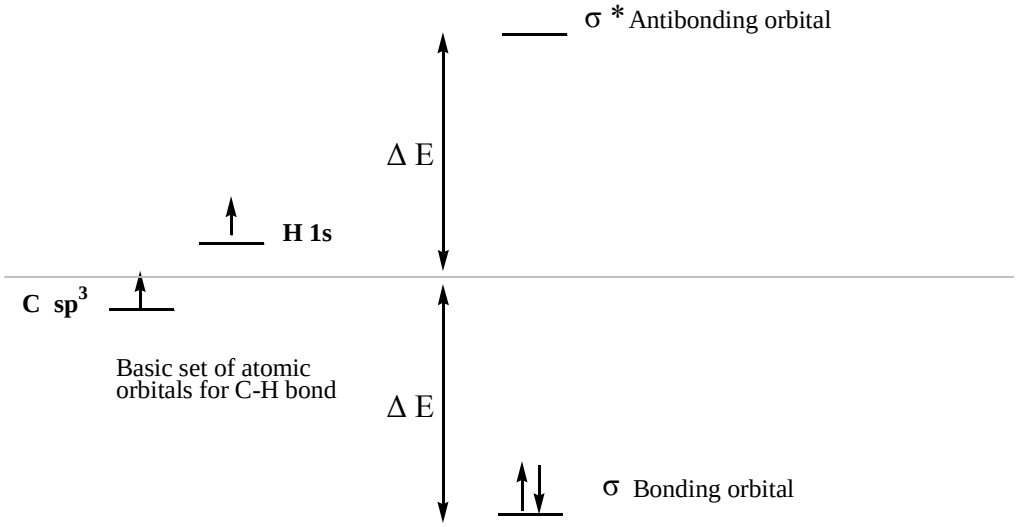


2s $2p_x + 2p_y + 2p_z$

b) How many unhybridized p-orbitals are there?
c) In what type of molecule would this hybridization scheme be found?
d) What are the angles between the hybrid orbitals?

Molecular orbitals

Overlap of two atomic orbitals gives two molecular orbitals, one bonding and one anti-bonding. Overall orbital energy does not change, but the bonding orbital is lower in energy and the anti-bonding orbital correspondingly higher in energy than the original atomic orbital. However, the electrons fill the bonding orbital leaving the anti-bonding orbital empty. Hence the paired electrons in the bond are lower in energy than as unpaired non-bonded electrons. This constitutes the strength of the bond.



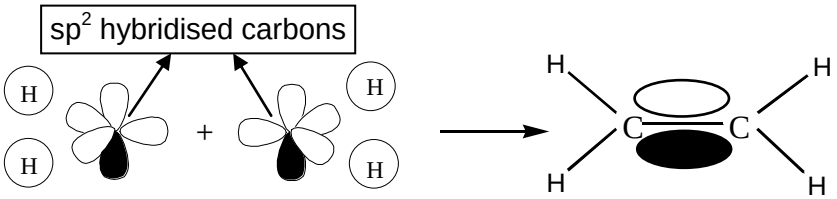
The energies of molecular orbitals in a C-H bond

Worked example 2

Explain (using representation of molecular orbitals) the structure and bonding found in ethane; indicate clearly the structure of the molecule and define the H-C-H and H-C-C bond angles.

Worked example 2 answer

We know that a carbon in an alkene is sp^2 hybridised.



Each of the four hydrogen 1s-orbitals overlaps head-on with a carbon sp^2 orbital to give four C–H σ -bonds.
Unhybridized p-orbitals overlap side-on to give a π-bond.
End-on overlap of an sp^2 orbital from each carbon gives a C–C σ-bond.
H–C–H and C–C–H bond angles are 120°.
All atoms of ethane lie in a plane.
The carbons are **trigonal planar.**

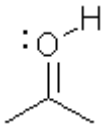
Question 3

Explain (using representation of molecular orbitals) the structure and bonding found in ethyne; indicate clearly the structure of the molecule and define the H-C-H and H-C-C bond angles.

Electron accounting - assigning formal charges

In some molecular species the number of bonds formed by an atom appears to be inconsistent with the number of valence electrons. We can localize an overall charge on that atom using electron-accounting.

Worked example 3



What is the formal charge on the oxygen in the molecule above?

Worked example 3 answer

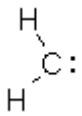
Assign each atom one of the bonding electrons.

C=O Oxygen takes **2** of these electrons.
O-H Oxygen takes **1** of these electrons.
Non-bonding electrons, of which there are **2**, are assigned completely to oxygen.

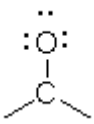
If we compare the number of electrons we have assigned **(5)** with the number of valence electrons in the neutral atom **(6)** we can see that the oxygen above has a **formal charge of +1.**

Question 4

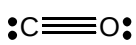
a) What is the formal charge on the carbon atom?



b) What is the formal charge on the oxygen atom?



c) What are the formal charges on the carbon and oxygen atoms?

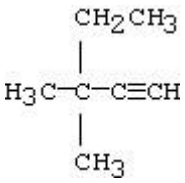


Drawing and naming structures

It is common to show molecular structure by a shorthand notation emphasising bonds and bond angles and not focusing on individual atoms, below this is referred to as a '**schematic structural formula'**.
You should review your notes on naming organic molecules before attempting these questions.

Worked example 4

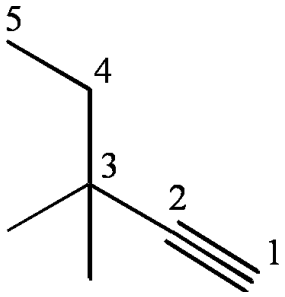
Draw a schematic structural formula (i.e. no C and carbon-attached H atoms shown) for the following molecule and name it using IUPAC conventions.



Worked example 4 answer

To draw the schematic structural formula we follow the rules below

C atoms make up the backbone.
Unspecified positions including the ends are occupied by C atoms.
Each C atom makes 4 bonds.
Any remaining unspecified atoms are H atoms.



To name it

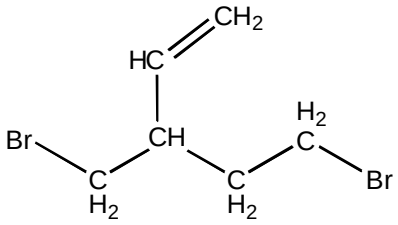
Identify the longest chain (must include both carbons of the triple bond) and name it = **pentyne.**
Number the chain from the end nearest to the triple bond (see above)
Give the position of the triple bond as the lowest number, in this case 1 = **pent-1-yne.**
Name substituent groups and identify their positions on the longest chain = **3,3-dimethyl.**
Put the name together (remember if there is more than 1 type of substituent present they should be arranged alphabetically in the name)

3,3-dimethylpent-1-yne

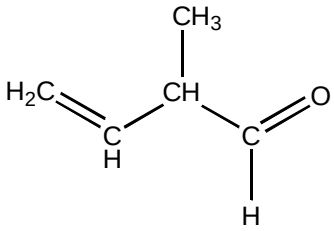
Question 5

Draw a schematic structural formula for the following molecules and name them using the IUPAC convention.

a)



b)



Question 6

Draw the schematic structural formula of the following molecules

a) (E)-3,4,5-trimethylhept-2-ene

b) 3,5-dinitrophenol

c) pentane-2,4-dione

d) hexanoyl chloride

Double bond equivalents

Double bond equivalents (DBE) result from a double bond, triple bond (= 2 DBE) or a ring in a molecule.

Worked example 5

How many double bond equivalents are contained in the following molecule?
C_4H_7N

Worked example 5 answer

We must use the equation below

$$\text{Double bond equivalents} = \frac{\text{H atoms in saturated hydrocarbon} - \text{H atoms in equivalent hydrocarbon}}{2}$$

Find the equivalent hydrocarbon.

Replace all monovalent substituents with a hydrogen. In this example there are no monovalent substituents.
Remove all divalent substituents. In this example there are none.
Remove all trivalent substituents and one hydrogen. Nitrogen is a trivalent substituent (it forms 3 bonds) and so we remove it along with 1 H giving us C_4H_6 = **6 H atoms.**

Find the number of hydrogens in the saturated hydrocarbon

Use C_nH_{2n+2}. For us n = 4
No. of hydrogens = (2 × 4) + 2 = **10 H atoms.**

DBE's = (10 – 6)/ 2 = 4/2 **= 2 double bond equivalents**

Question 7

How many double bond equivalents are contained in the following molecules?

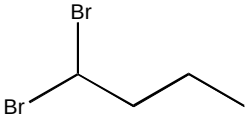
a) C_5H_8 Suggest 3 possible structures for this molecule.
b) C_8H_8NOBr
c) $C_6H_{10}O$

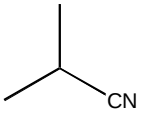
Bond polarization

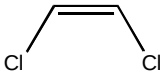
Bond polarization is a property of a heteronuclear bond.

Worked example 6

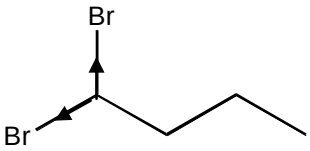
For each of the following molecules, comment on factors that contribute to the direction and magnitude of the molecular dipole moments.



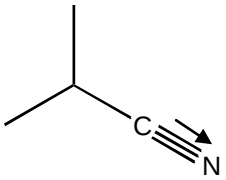




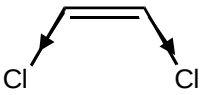
Worked example 6 answer



Bromine is electronegative and has lone pairs.



Nitrogen is electronegative and has lone pairs.



Cl is electronegative and has lone pairs; net dipole moment is the result of two bond dipole moments.

Question 8

a) Draw all the isomers of $C_2H_2Cl_2$
b) How many are polar? Indicate the direction of the dipole moment.

Question 9

Which of the following molecules are polar?

a) CH_3Cl b) SO_3 c) HCHO d) CBr_4

Question 10

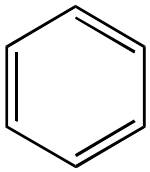
How might values of molecular dipole moments help you to distinguish between (*E*)- and (*Z*)-1,2-dichloroethene?

Aromaticity

Huckel's rule: A molecule is aromatic if it has a cyclic, planar overlapping array of p-orbitals, with 4n+2 π electrons (n is zero or any integer).

Worked example 7

Is benzene aromatic? Give reasoning.



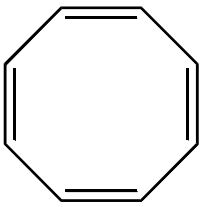
Worked example 7 answer

Yes. Benzene is planar and cyclic. It has 6 π electrons (one from each carbon) and therefore obeys the 4n+2 rule because (4 × 2) + 2 = 6

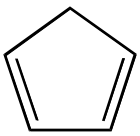
Question 11

Are the following molecules aromatic, according to Huckel's rule?

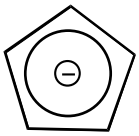
a)



b)



c)



Question 12

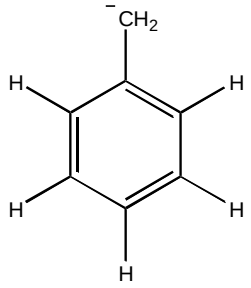
Outline what chemical and physical properties led to the realisation of benzene as an unusual chemical entity.

Resonance

Electrons in a system of adjacent π-orbitals can be delocalized over the whole system. This is known as **resonance**. Resonance structures represent contributing electronic distributions within the π-framework. They are **NOT** distinct entities but electronic extremes (canonical forms) of the **resonance hybrid** which represents the actual state of affairs more accurately but is not convenient for use in curly arrow mechanisms. From the point of view of curly arrow pushing, all contributing electronic forms are equivalent.

Worked example 8

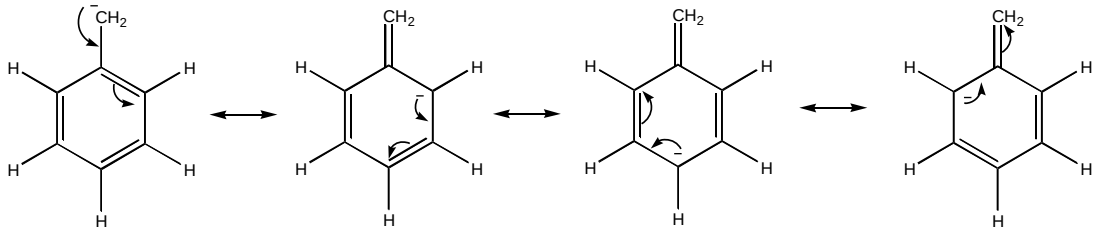
Draw the important resonance forms of $[C_6H_5CH_2]^-$ (where C_6H_5 is a phenyl ring)



Worked example 8 answer

The negative charge can be delocalized over the whole structure due to the adjacent π-orbitals.
There are some important rules to follow when drawing resonance structures.

All resonance structures should have the same number of valence electrons (bonding and lone pairs)
The octet rule must be obeyed.
Atoms do not change position, only electrons.



Major

Double headed arrows show that the structures are resonance canonicals.

Question 13

Write resonance structures for the following

a) $[CH_3CHOCHCH_2]^+$
b) $[CH_3CH_2OCHCHCH_2]^+$
c) $[CH_3COCH_2]^-$
d) $[CH_2CHCHCHCH_2]^+$

Tautomerism

Tautomers are isomeric structures that interconvert by movement of an atom or group of atoms (most commonly a proton)

Question 14

What is the major difference between tautomerism and resonance?

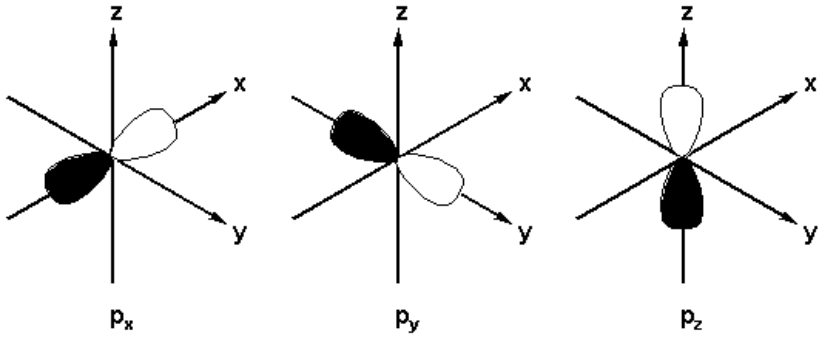
Question 15

a) Draw the possible tautomeric forms of propanal.
b) Draw the enol form of cyclohexanone.
c) Provide a curly arrow mechanism for the acid catalysed enolization of propanone.

Section 1 Answers:

Exercises

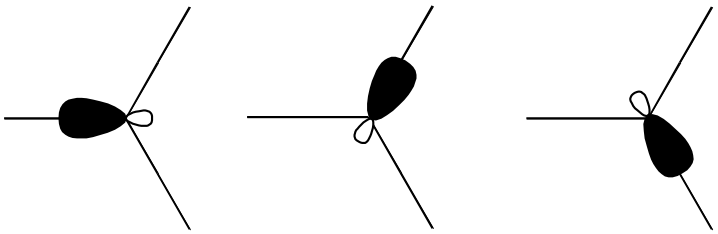
1.



Questions

1.

a)

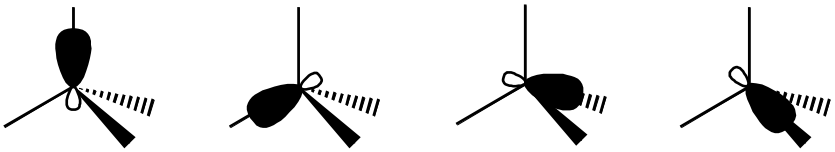


sp^2 hybrid orbitals

b)1 ($2p_z$) c) Alkene d)120°

2.

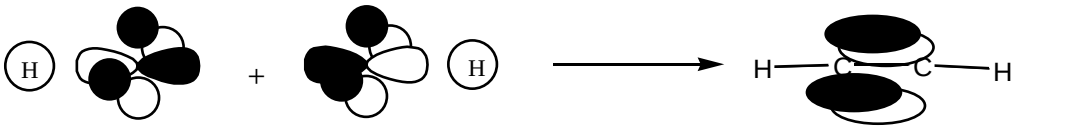
a)



sp^3 hybrid orbitals

b) 0 c) Alkane d) 109.4°

3.



2 sp hybridised carbon atoms
$2p_y$ and $2p_z$ orbitals remain

Linear σ bond form skeleton
Two perpendicular π bonds

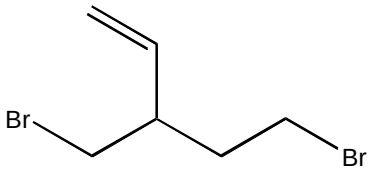
Bond angles are 180°

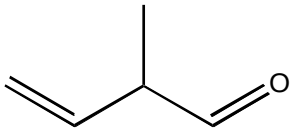
4.

a) 0 b) – 1 c) C = - 1, O = + 1

5.

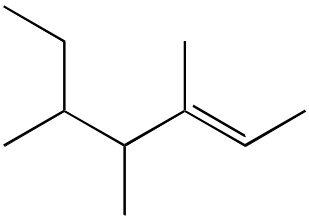
a) 5-bromo-3-(bromomethyl)pent-1-ene b) 2-methylbut-3-enal



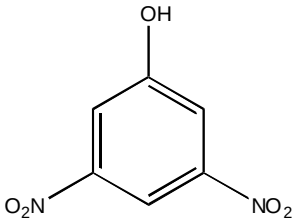


6.

a)



b)



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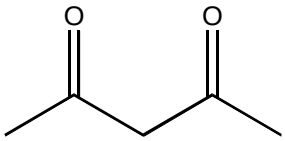

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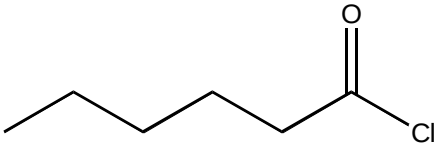
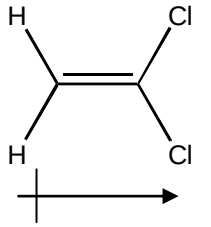


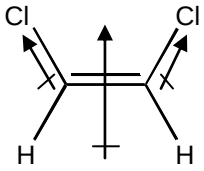
7. a) 2 (1-pentyne, 2-pentyne or cyclopentene) b) 5 c) 2

8.

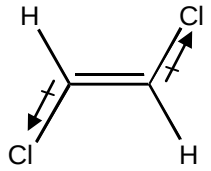
a) & b) There are 3 isomers of $C_2H_2Cl_2$, but only 2 are polar. Dipole moments are shown



1,1-dichloroethene
Polar- There is an overall dipole moment



Cis-1,2-dichloroethene
Polar- There is an overall dipole moment



Trans-1,2-dichloroethene
Non-polar- equal and opposite dipole moments cancel out

9.

a) Yes b) No c) Yes d) No

10.

E-isomer is non-polar, *Z*-isomer is polar

11.

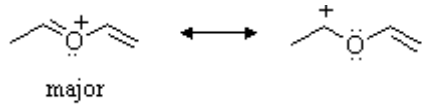
a) No. 8 π electrons so does not obey 4n+2 rule. Ring not planar
b) No. 4 π electrons so does not obey 4n +2 rule. Localized bonding.
c) Yes. Cyclopentadienyl anion is planar has 6 π electrons and delocalized bonding.

12.

Unlike alkenes, benzene undergoes substitution rather than addition with electrophilic reagents. All carbon-carbon bond lengths are identical. The heat of hydrogenation of benzene is significantly less than for 1,3,5-hexatriene or than would be predicted for a theoretical cyclohexatriene. !,2-Disubstituted benzenes only exist as one isomer.

13.

a)



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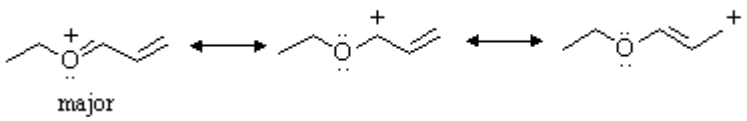

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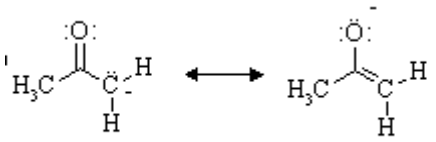

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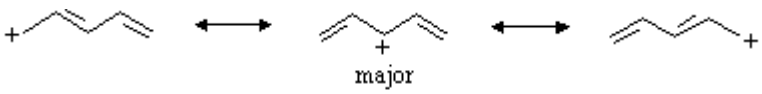
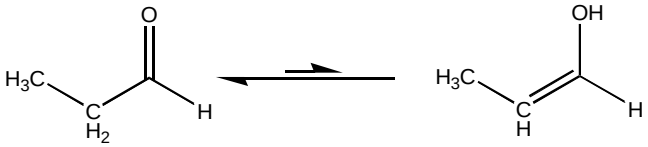


14.

Tautomerism involves movement of atoms, resonance involves movement of electrons.

15.

a)



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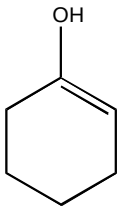
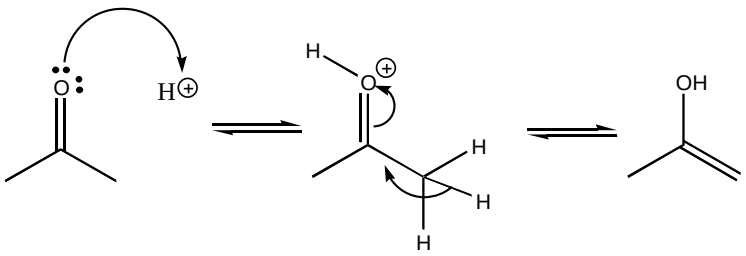


c)



Section 2

Nucleophilic Substitution

Lewis acids and bases

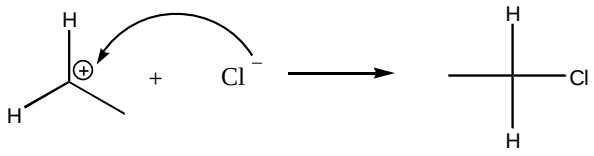
Worked example 1

Complete the reaction scheme between the Lewis acid-base pair (showing all bonds). Indicate electron flow by means of curved arrows. Explain your answer.

$CH_3CH_2^+ + Cl^- \longrightarrow$

Worked example 1 answer

The trivalent carbon atom in the ethyl cation has an empty orbital in its valence shell, and, therefore, is the Lewis acid. The chloride ion is the Lewis base because it is capable of donating an electron pair.



Question 1

a) How do the terms Lewis acid and Lewis base relate to the terms electrophile and nucleophile?
b) Predict the structure of the product formed by reaction of the Lewis acid-base pairs below (showing all bonds). Indicate electron flow by means of curved arrows. Explain your answer and indicate the charge on the product.

i. $BF_3 + NH_3$
ii. $(CH_3CH_2)_3B + OH^-$
iii. $Br^- + AlBr_3$

Nucleophiles and electrophiles

An **electrophile** is an electron-deficient species and reacts by accepting electrons to attain a filled valence shell.
A **nucleophile** has electrons available for donation to electron deficient centres.

Question 2

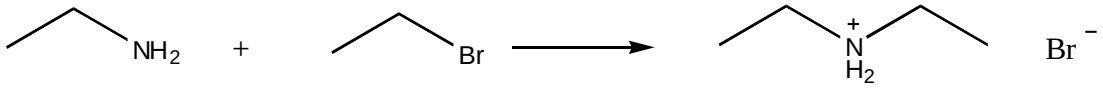
Classify the following compounds as electrophilic or nucleophilic, giving your reasoning in each case.

a) R-SH
b) $CH_3CH_2NH_2$
c) EtCHO
d) CH_3MgBr

Nucleophilic Substitution reactions

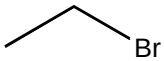
Worked example 2

a) Denote the substrate, nucleophile and leaving group in the reaction below.

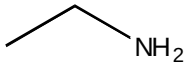


b) Will this reaction occur via an S_N1 or S_N2 mechanism?
c) What happens to the stereochemistry of the centre undergoing substitution during an S_N2 reaction? Explain your answer.

Worked example 2 answers

a) Substrate = 

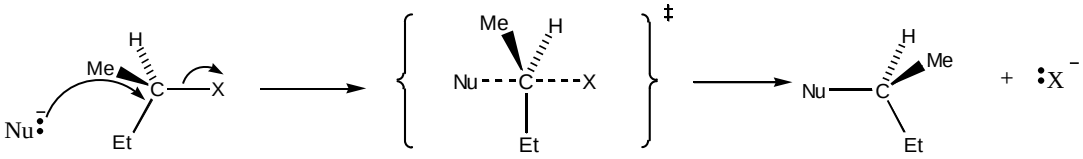
The C-Br bond is polar. This means that the C atom has a δ+ charge and is susceptible to attack by a nucleophile.

Nucleophile = 

The N of the amine has a non-bonding pair of electrons, which can attack the electrophilic C of the halogenoalkane.

Leaving group= Br^-

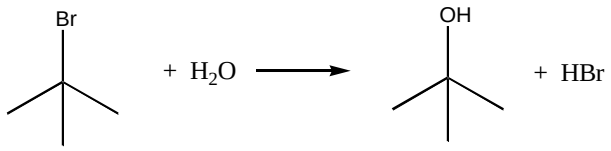
b) The reaction will happen via an S_N2 mechanism because the substrate is a primary halogenoalkane.
c) Inversion of stereochemistry occurs because of the backside attack of the nucleophile ie. The nucleophile attacks from the opposite side to which the leaving group is departing.



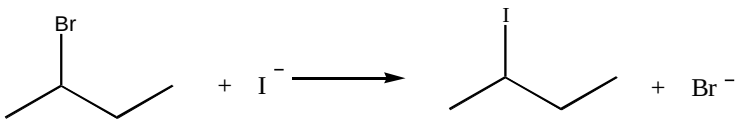
Question 3

a) Denote the substrate, nucleophile and leaving group in the reactions below.

i.



ii.

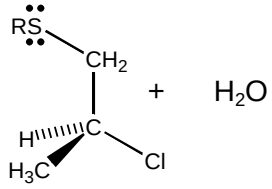


b) For reactions i and ii state whether an S_N1 or S_N2 mechanism will take place and explain why.

c) What happens to the stereochemistry of the centre undergoing substitution during an S_N1 reaction? Explain your answer.
d) Explain why the products formed during an S_N1 reaction are unlikely to be present in an exact 1:1 ratio.

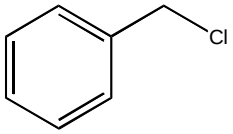
Question 4

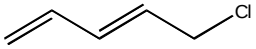
Give the product of the reaction below explaining the stereochemical outcome.



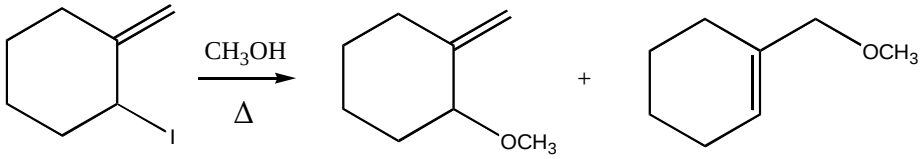
Question 5

a) Explain why the following substrates are likely to undergo nucleophilic substitution via an S_N1 reaction.



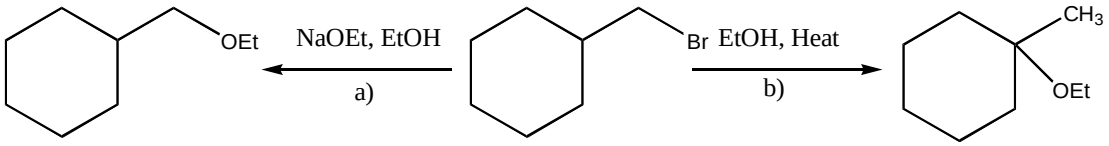


b) Explain why S_N2 reactions on allyl bromide proceed faster than corresponding reactions on ethyl bromide.
c) Provide a detailed, stepwise mechanism for the reaction shown below. Show resonance structures of any carbocation intermediates formed.



Question 6

(Bromomethyl)cyclohexane reacts as shown below; provide mechanisms that account for the formation of the products isolated.



Section 2 Answers

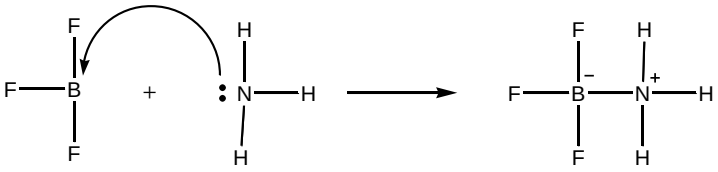
Questions

1.

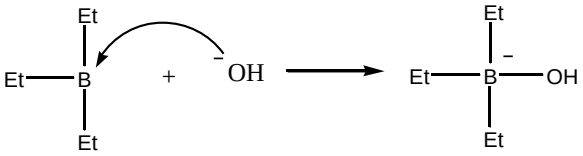
a) A Lewis acid is an electrophile. A Lewis base is a nucleophile.

b)

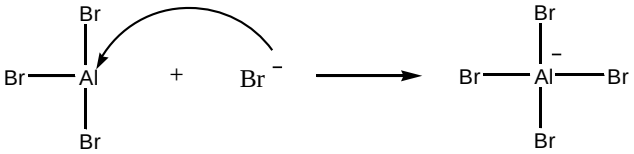
i. BF_3 has an empty orbital in the valence shell of boron and is the Lewis acid (electrophile). NH_3 has an unshared pair of electrons on nitrogen and is the Lewis base (nucleophile). In this example, each atom takes on a formal charge; the resulting structure, however, has no net charge.



ii. $(CH_3CH_2)_3B$ has an empty orbital in the valence shell of boron and is the Lewis acid. OH^- has a non-bonding pair of electrons on O and is the Lewis base. The product has an overall negative charge



iii. $AlBr_3$ has an empty orbital in the valence shell of Al and is the Lewis acid. Br^- has a non-bonding pair of electrons and is the Lewis base. The product has an overall negative charge



2.

a) Nucleophile due to the presence of lone pairs of electrons on the sulphur.
b) Nucleophile due to the presence of a lone pair of electrons on the nitrogen.
c) Electrophile. The carbonyl carbon has a δ + charge.
d) Nucleophilic. This is a Grignard reagent which is formed when magnesium metal reacts with an alkyl halide. Electrons from the Mg-Alkyl bond attack an electrophilic centre.

3.

a)

i. Substrate = $(CH_3)_3CBr$, Nucleophile = H_2O, Leaving group = Br^-
ii. Substrate = $CH_3CHBrCH_2CH_3$, Nucleophile = I^-, Leaving group = Br^-

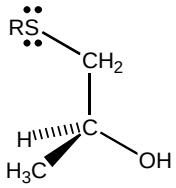
b)

i. S_N1- substrate is a tertiary halide- therefore intermediate tertiary carbocation is stabilized by hyperconjugation.
ii. S_N2- substrate is a secondary halide- although it is somewhat sterically hindered, this is overcome by I- being a good nucleophile.

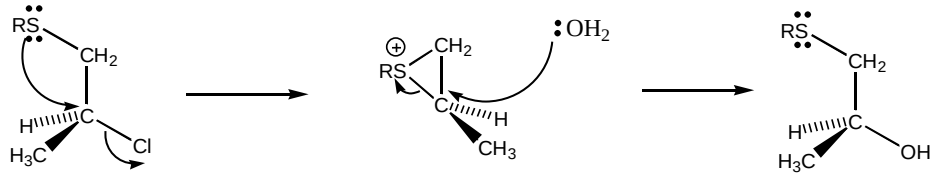
c) Both inversion and retention of stereochemistry occurs (both R and S enantiomers are formed). S_N1 reactions are stereochemically non-specific because the planar transition state carbocation can be attacked from either side of the plane.

d) If the nucleophile reacts rapidly with the carbocation, it is likely to react with an intimate ion pair (carbocation and leaving group), this means that one side will be protected by the leaving group and will therefore be less likely to be attacked.

4.

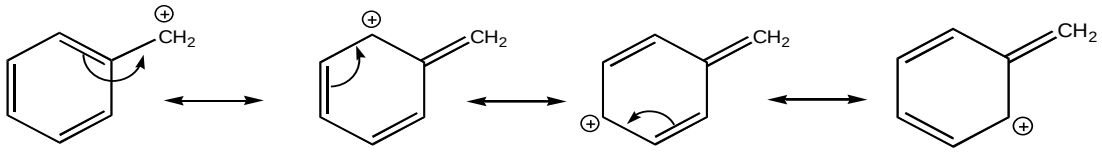


This is called retention of configuration. Retention of configuration is brought about by neighbouring group participation (anchimeric assistance) and involves a double inversion of stereochemistry.



5.

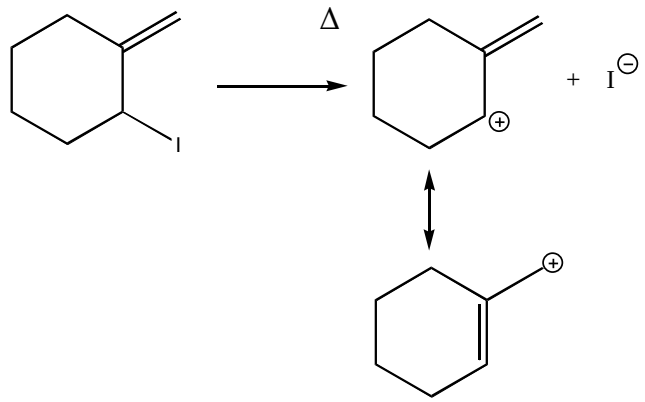
a) The primary carbocation formed on loss of Cl^- will be stabilised by conjugation.

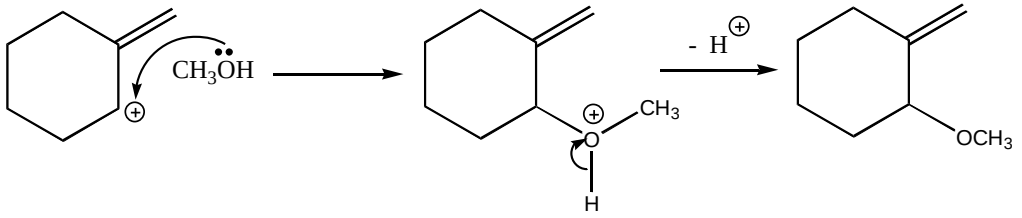


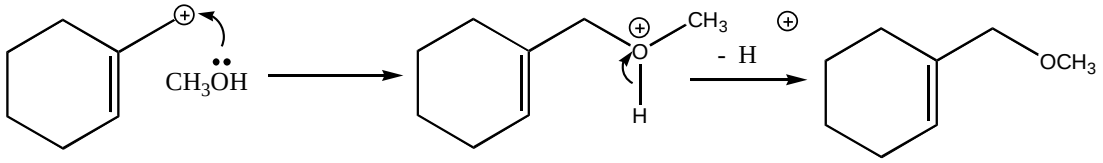
In the case of the benzylic system, the π system of the benzene ring can stabilise an adjacent carbocation by donating electron density through resonance.
Resonance also stabilises the carbocation of the diene via conjugation.

b) When the substrate is allylic, resonance stabilization through conjugation with the adjacent π bond occurs in the transition state. This delocalization lowers the energy of the transition state and results in an enhanced rate.

c)

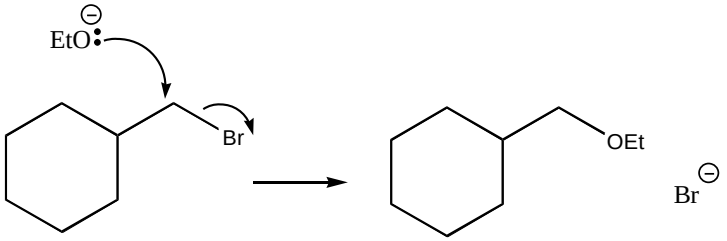




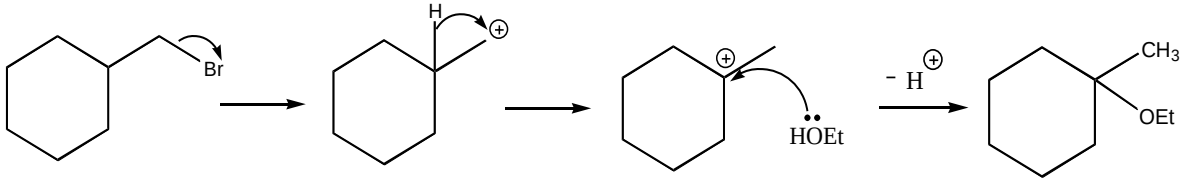


6.

a) The ethoxide ion is a good nucleophile and favours an S_N2 mechanism.



b) Although the initial carbocation formed is primary, ethanol is a weaker nucleophile and so an S_N1 mechanism is favoured. The reaction involves a 1,2-hydride shift to give the more stable tertiary carbocation.



Section 3

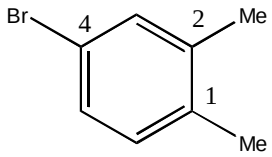
Aromatic Chemistry

Nomenclature

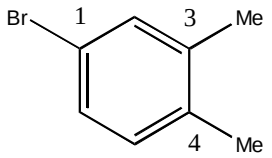
Worked example 1

Name the molecules below.

a)



b)



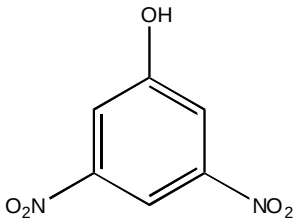
Worked example 1 answer

We number the carbons in the ring to keep the total sum of the numbers as low as possible ie. a) is correct not b). When putting the name together substituents still go in alphabetical order. The molecule is called 4-bromo-1,2-dimethylbenzene.

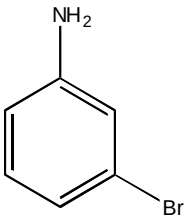
Question 1

Name the following molecules.

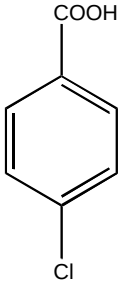
a)



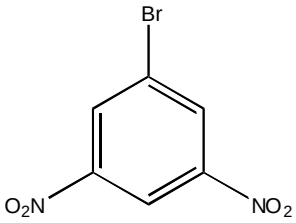
b)



c)



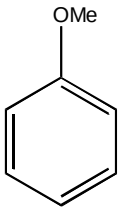
d)

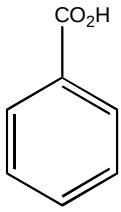


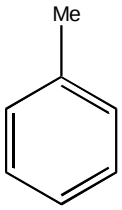
Electrophilic Aromatic Substitution

Question 2

a) Outline the EAS mechanism (Electrophilic Aromatic Substitution) through which aromatic compounds (such as benzene) react with electrophiles.
b) Will this process be faster or slower if the benzene is substituted with either
   i. A nitro (NO2) group?
   ii. A methoxy (OMe) group?
c) Predict the structures of the nitration products with the following substrates and briefly give your reasoning.

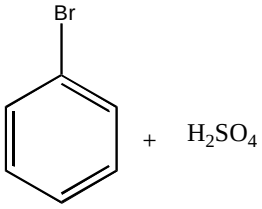
i. 

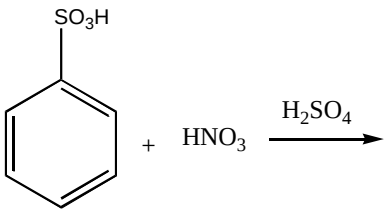
ii. 

iii. 

Question 3

Complete the following electrophilic aromatic substitution reactions. Where you predict *meta* substitution, show only the *meta* product. Where you predict *ortho-para* substitution, show both products.

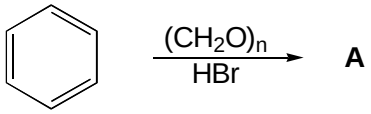
a) 

b) 

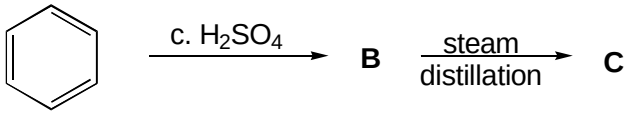
Question 4

Predict the products of the following reactions.

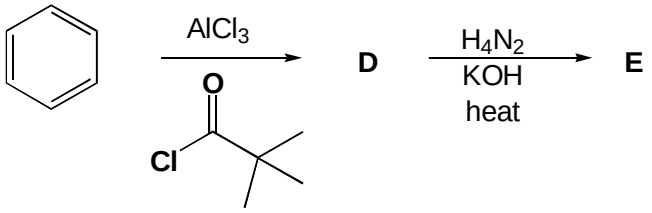
a)



b)



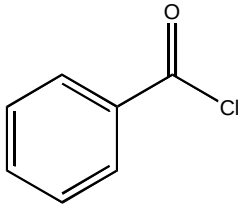
c)



Question 5

Write structural formulas for the products you expect from Friedel-Crafts alkylation or acylation of benzene with either

a) Benzyl chloride $C_6H_5CH_2Cl$
b) Benzoyl chloride



Question 6

a) Reaction of aniline with aqueous Br_2 gives a multi-substituted product. Explain why.
b) Is the amine group *ortho-para* or *meta* directing? Explain why using resonance structures.
c) What could we do to make sure we get the mono-substituted product?

Question 7

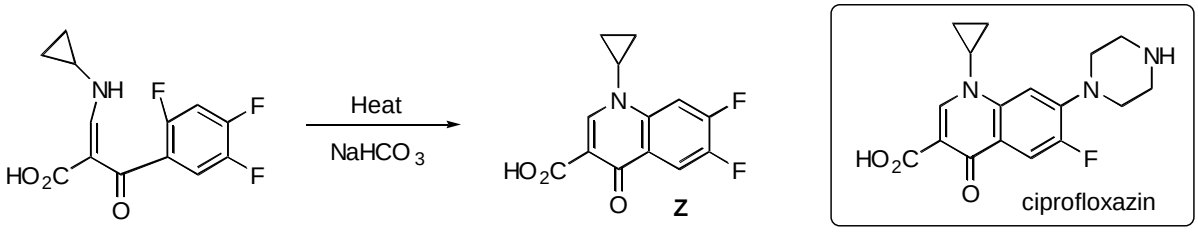
Give reagents and outline the mechanisms for the following conversions.

a) Benzene to benzenesulphonic acid ($C_6H_5SO_3H$)
b) Benzene to isopropylbenzene (C_6H_5-$CH(CH_3)_2$)
c) Benzene to 1-phenyl-1-propanone (C_6H_5-CO-CH_2-CH_3)
d) Explain why reaction c) can be considered to be more controlled than reaction b)

Nucleophilic Aromatic Substitution

Question 8

a) Give the product and provide a mechanism for the reaction of 2,4-dinitrochlorobenzene with sodium hydroxide at 100°C followed by protonation.
b) The synthesis of ciprofloxazin, a quinoline anitibiotic, incorporates the reaction shown below.

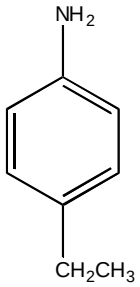


i. Provide a mechanism that accounts for the formation of the product drawn.
ii. A final reaction is required to complete the synthesis. Provide the reagent required to convert Z into ciprofloxazin and explain why the nucleophilic aromatic substitution replaces only one fluorine selectively.

Azo coupling

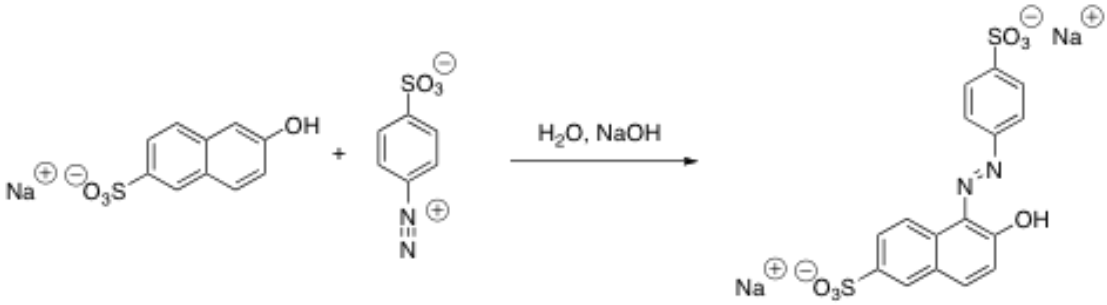
Question 9

a) Give the product of the reaction below and provide mechanisms.



With $NaNO_2$ and HCl

b) A substance used in the food industry, FD&C #6, can be prepared via an azo coupling reaction from the following components. Provide a mechanism that accounts for the product given.

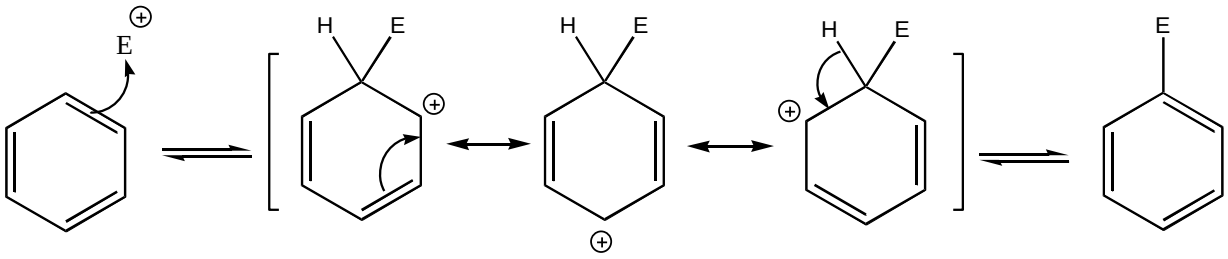


Section 3 Answers

Questions

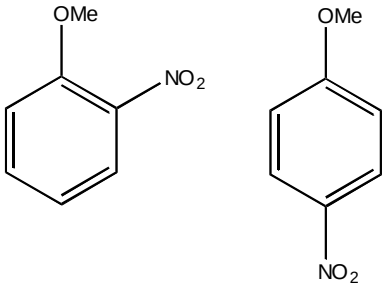
1.
a) 3,5-dinitrophenol
b) 3-bromoaniline
c) *Para*-chlorobenzoic acid or 4-chlorobenzoic acid
d) 1-bromo-3,5-dinitrobenzene

2.
a)



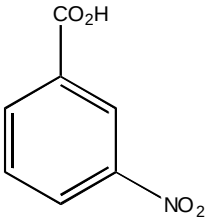
b)
i. Slower because the nitro group is electron withdrawing via resonance. This reduces the nucleophilicity of the ring.
ii. Faster. Although the methoxy group is electron withdrawing via inductive effects, this is only a very small effect and is outweighed by electron donation via resonance.

c)
i.



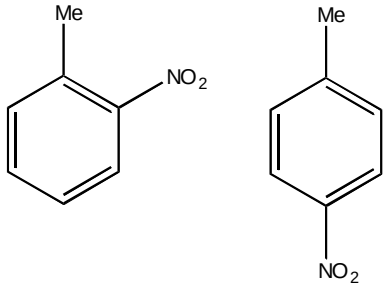
Ortho/para substitution gives 4 resonance structures whereas *meta* substitution gives just 3. *Ortho/para* substitution is favoured.

ii.

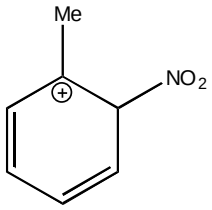


Meta substitution is favoured because *ortho/para* substitution puts a cation on the ipso carbon, immediately adjacent to the electron withdrawing carboxyl group (unfavourable).

iii.

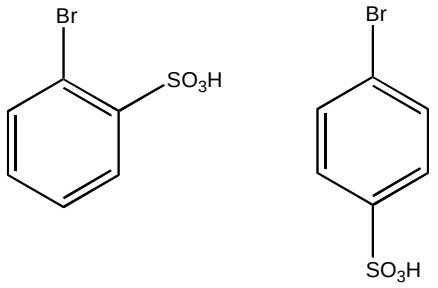


Ortho/para substitution gives a tertiary carbocation intermediate e.g. which is more stable.

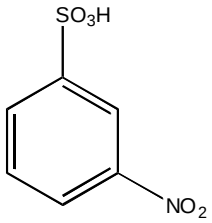


3.

a) Bromine is *ortho-para* directing and weakly activating.

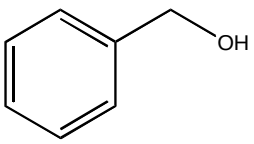


b) The sulfonic acid group is *meta* directing and moderately deactivating.

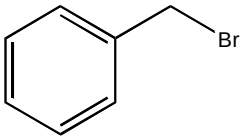


4.

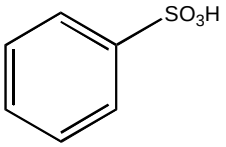
i. $(CH_2O)_n$ is paraformaldehyde, which breaks down to give formaldehyde. Electrons from the benzene ring attack the δ+ carbon of formaldehyde via an electrophilic substitution reaction to give an alcohol.



An S_N2 substitution then takes place to give the product A

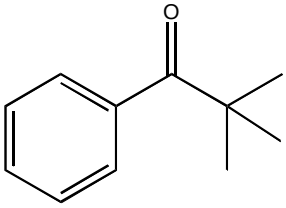


ii. Conc. H_2SO_4 forms the electrophile HSO_3^+. EAS leads to product B

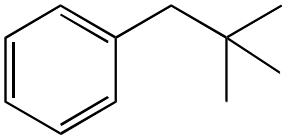


Steam and distillation merely removes the group to give benzene

iii. The first reaction is a Friedel Crafts Acylation reaction. Under Lewis acid conditions (with $AlCl_3$), an electrophilic acylium ion is formed.
The product is

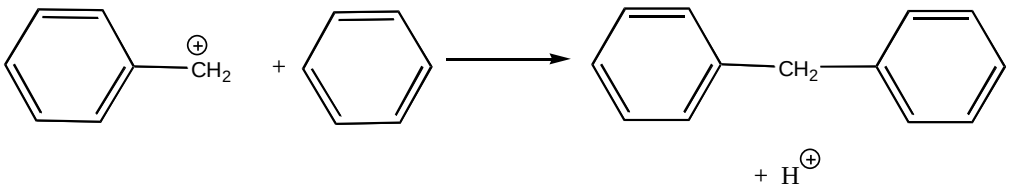


The next reaction is a Wolff-Kishner reduction, which proceeds via a hydrazone.
The product is

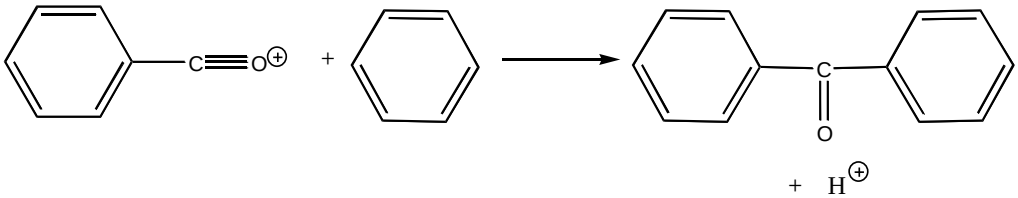


5.

a) Benzyl chloride in the presence of a Lewis acid catalyst gives the benzyl cation, which then attacks benzene followed by loss of H^+ to give diphenylmethane. In this example, the benzyl cation, although primary, cannot rearrange.



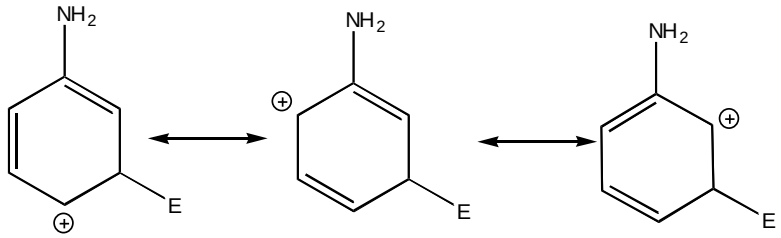
b) Treatment of benzoyl chloride with aluminium chloride gives an acyl cation, an electrophile, which then attacks benzene to give benzophenone, a ketone.



6.

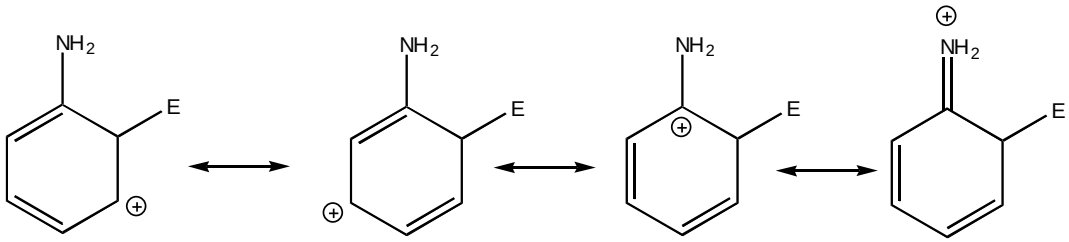
a) The amine group is strongly electron donating via resonance. In fact nitrogen is more activating than oxygen. Electrophilic substitutions occur readily leading to multi-substituted products. In this case a tribromination occurs.

b) We must consider the resonance structures of intermediates.
Meta substitution results in only three resonance structures.

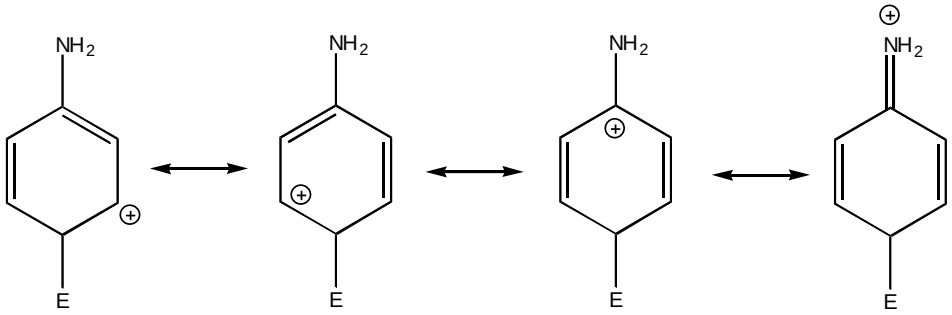


Ortho substitution results in four resonance structures, as does *para* substitution. This is due to stabilisation of the ipso carbocation by the lone pair from nitrogen.

Ortho

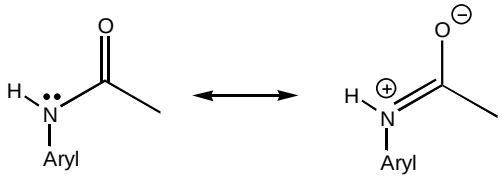


Para



The amine group is therefore *ortho/para* directing.

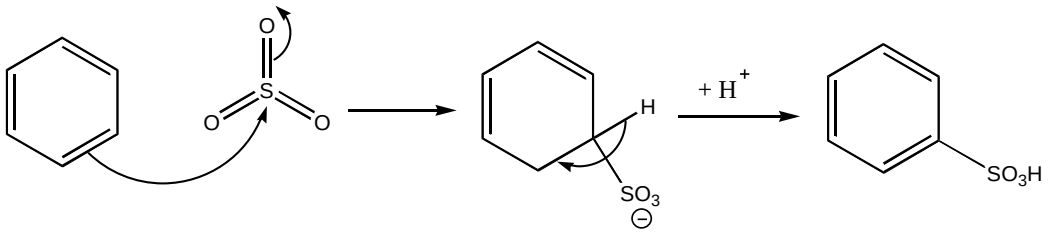
c) We can acetylate using Ac_2O, which reduces the reactivity of the nitrogen lone pair (see below) leading to mono-bromination. Mono-bromination will occur at the *para* position due to steric hindrance at the *ortho* position.



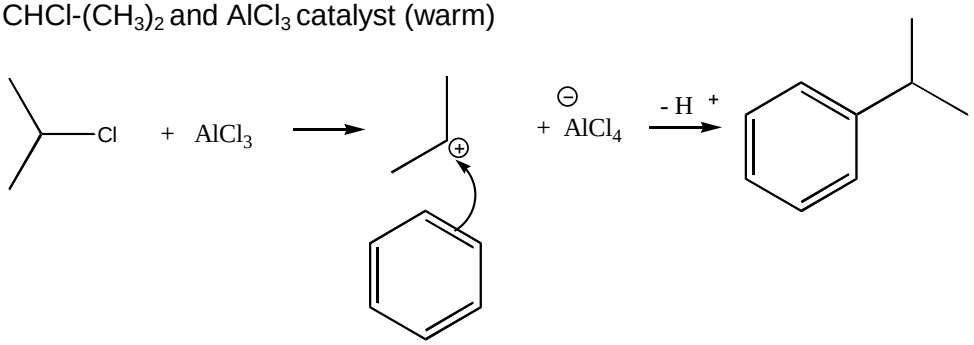
Once we have performed the EAS we can hydrolyse off the acetyl group.

7.

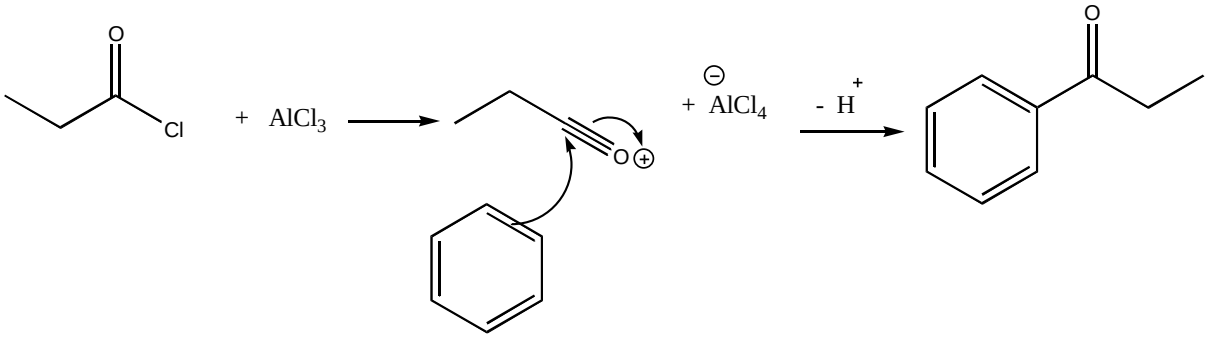
a) Conc. H_2SO_4 and reflux



b) $CHCl\text{-}(CH_3)_2$ and $AlCl_3$ catalyst (warm)



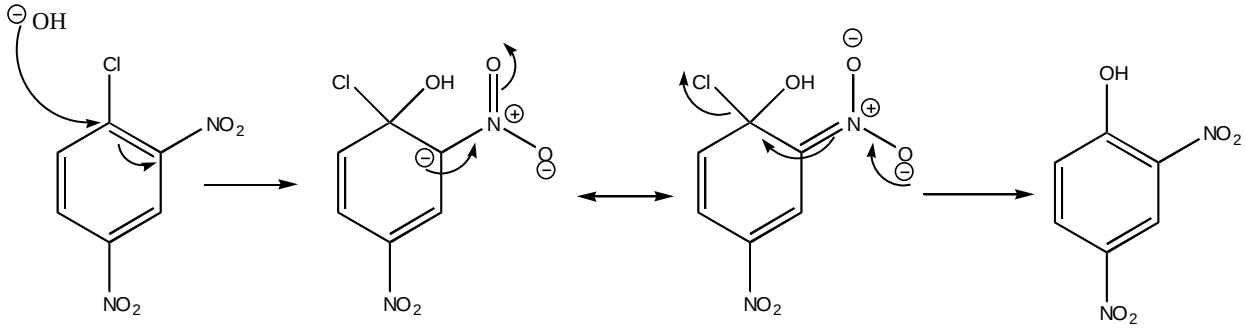
c) Propanoyl chloride and $AlCl_3$ catalyst



d) Alkylation of benzene (reaction b) suffers from 2 drawbacks: i) the product of the initial alkylation step is more reactive cf. benzene, because of the presence of an alkyl substituent- polyalkylation therefore occurs and ii) since the reaction proceeds via a carbocation intermediate rearrangements can occur leading to the incorrect products.

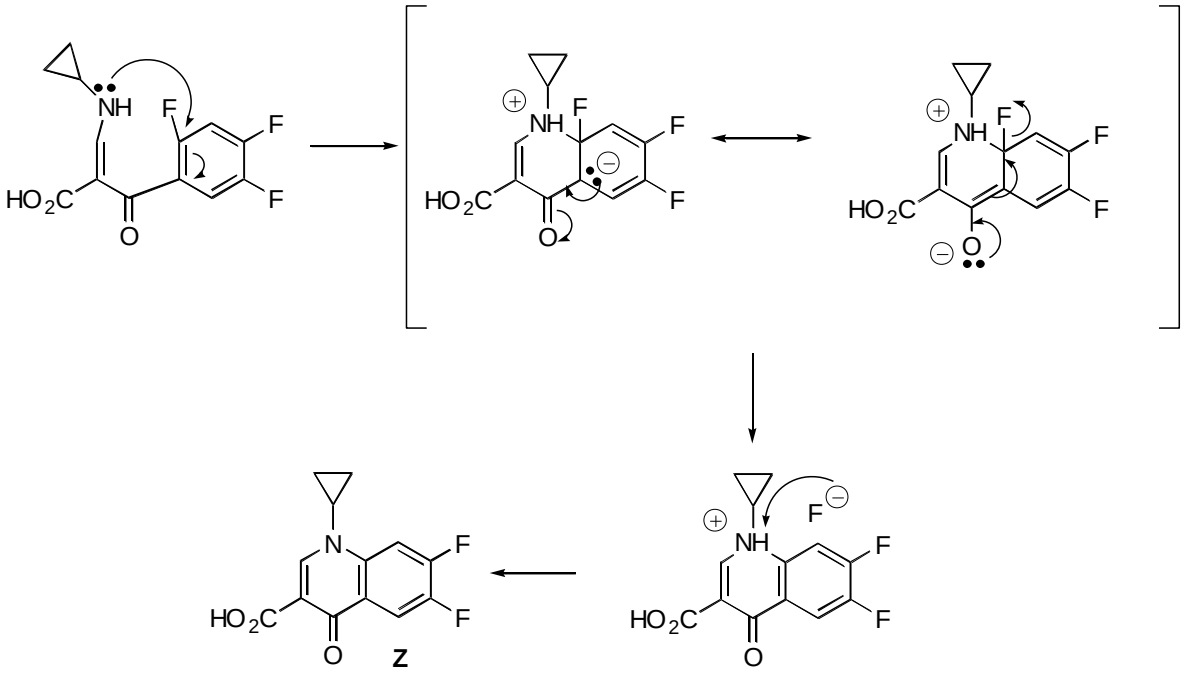
8.

a) Product is 2,4-dinitrophenol

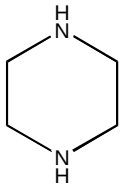


b)

i. This is an addition/elimination reaction, which swaps the leaving group for the nucleophile



ii. Reagent required to convert Z into ciprofloxazin

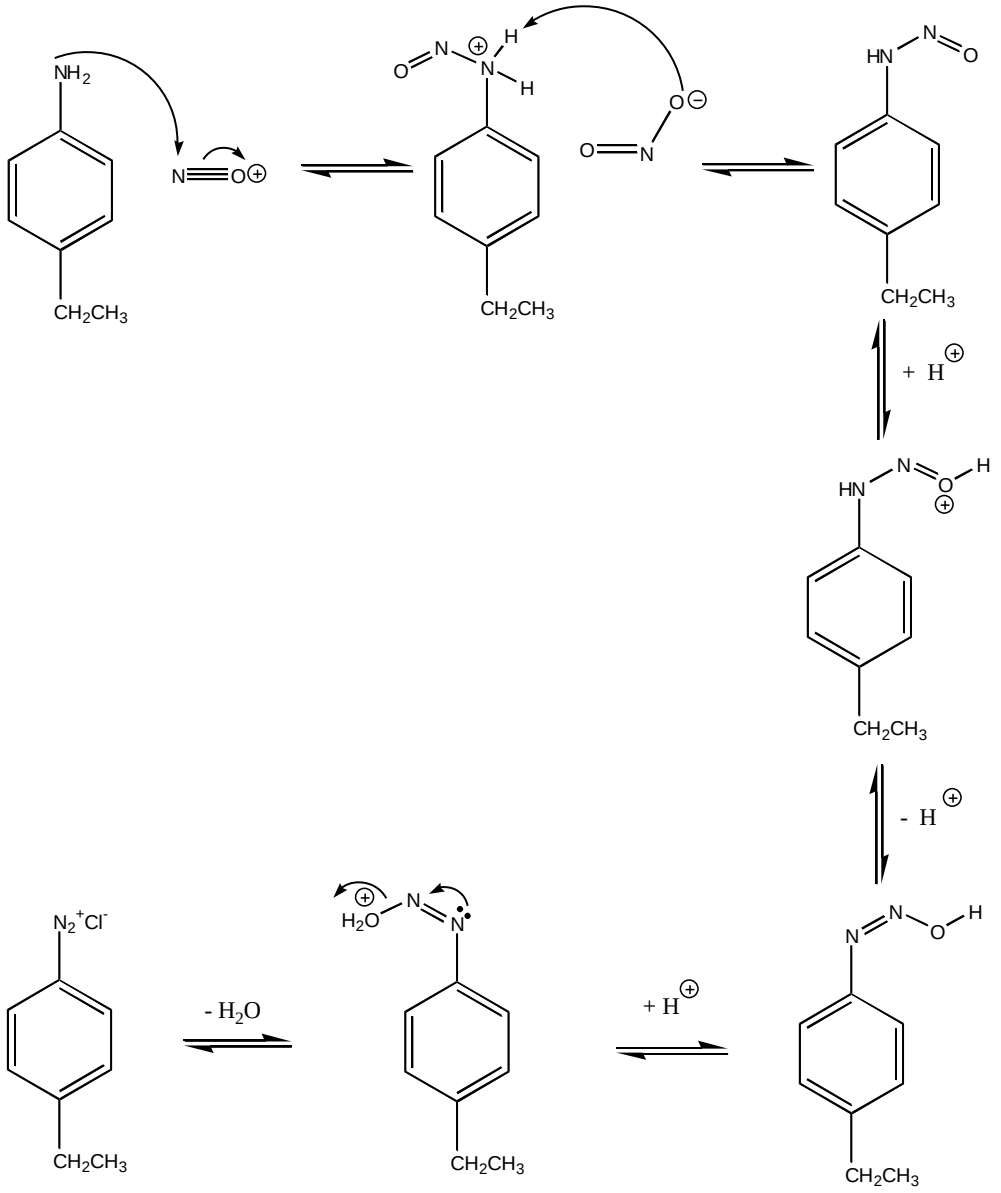


For nucleophilic aromatic substitution to occur there should be an electron withdrawing group (EWG) *ortho* and/or *para* to the leaving group. We require this relative position to achieve resonance stabilisation of the intermediate anion by the EWG. EWG's could include carbonyl, nitro or cyanide groups.

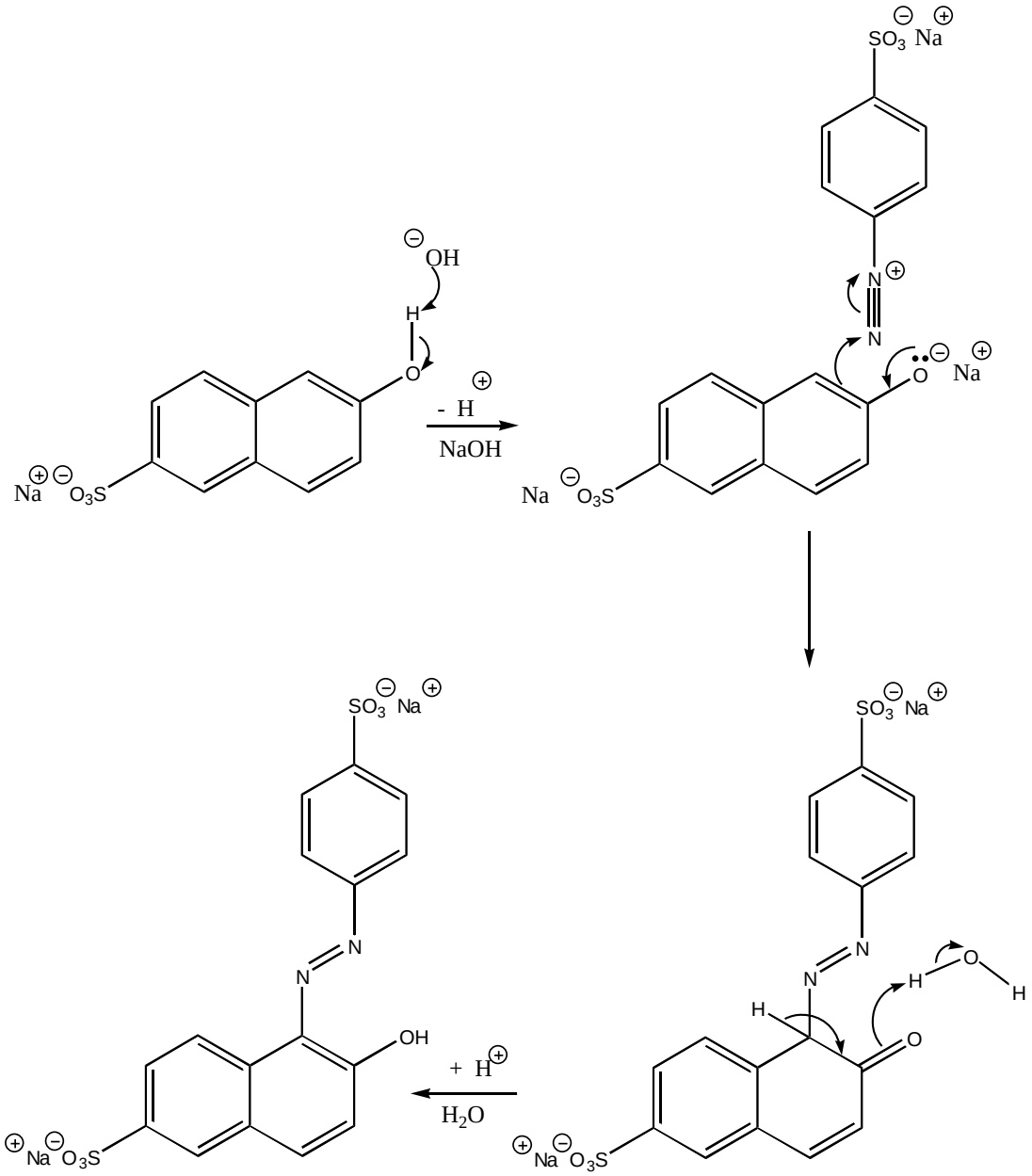
Only one fluorine is replaced during the reaction because it is the only position which obeys this rule. The EWG in this case is a carbonyl group at the *para* position. The EWG is *meta* to the alternative fluorine atom and so nucleophilic aromatic substitution does not occur at this position.

9.

a) Diazonium salt



b)



Section 4:

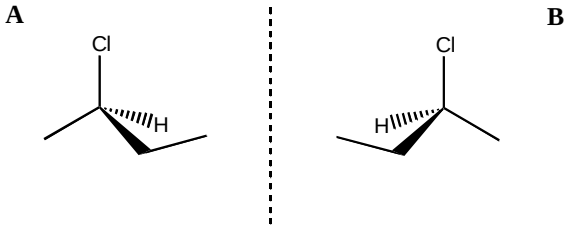
Isomerism and Organic Chemistry

You should recall that isomers are different compounds that have the same molecular formula. There are many categories of isomers. **Constitutional isomers** have the same molecular formula but different connectivity of atoms. **Stereoisomers** are isomers of identical constitution but differing in the arrangement of atoms in space. Stereoisomers which have non-superimposable mirror image forms are called **Chiral** molecules.

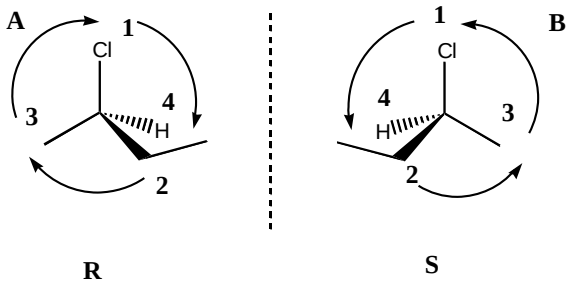
Drawing enantiomers and assigning *R* or *S* to stereocentres

Worked example 1
Draw stereorepresentations for 2-chlorobutane. Assign each structure as *R* or *S*.

Worked example 1 answer
First we must draw the structure showing wedged and hashed bonds.
Next we imagine a mirror plane and draw the mirror image of the molecule.



Determine the order of priority of groups according to atomic number. In this case Cl > CH_2CH_3 > CH_3 > H.
Make sure that the group of lowest priority projects back into the plane of the paper. In this case it already does. If this was not the case, rotate the molecule until it does.
Determine whether the remaining 3 substituents decrease in priority in a clockwise direction (*R*) or in an anticlockwise direction (*S*).



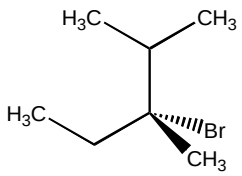
Question 1
a) Draw stereorepresentations of the following molecules. Identify the *R* stereoisomer in each case.

i. 1,2-propanediol

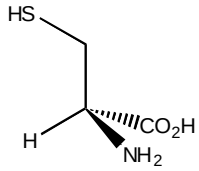
ii. 3-chlorocyclohexene

b) Assign the following stereocentres as *R* or *S.*

i.

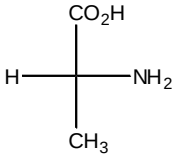


ii.



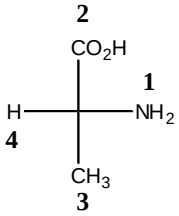
Worked example 2

Showing your working, assign the stereocentre in the following molecule as either *R* or *S.*

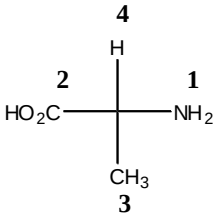


Worked example 2 answer

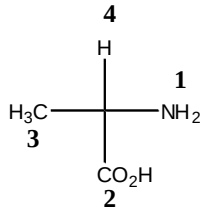
Rank the four substituents according to C.I.P rule.



Exchange two groups so that the lowest priority group is at the top.



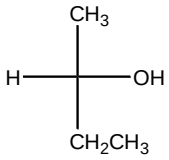
Exchange any other pair to ensure absolute configuration is unchanged.



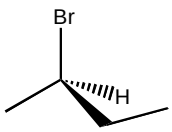
Priority groups 1,2,3 descend clockwise. The configuration is *R*.

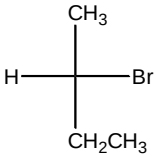
Question 2

a) Showing your working, assign the stereocentre in the following molecule as either *R* or *S.*



b) Assign the configuration of the stereocentres below and state whether the molecules are the same compound, diastereoisomers or enantiomers.

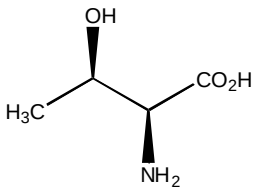




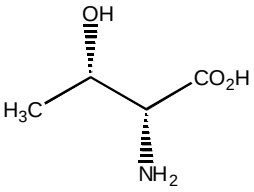
Stereochemical relationships

Worked example 3

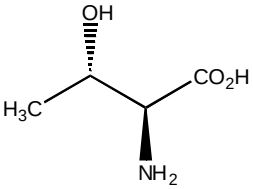
What are the stereochemical relationships between compounds **A** and **B** and **A** and **C**?



A



B



C

Worked example 3 answer

A and B are enantiomers because both stereocentres have been inverted. They are non-superimposable mirror image forms of each other.

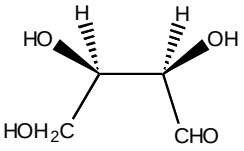
A and C are diastereoisomers because only one stereocentre has been inverted. They are not mirror images of each other.

Remember for a compound with n stereocentres there are a maximum of 2^n stereoisomers.

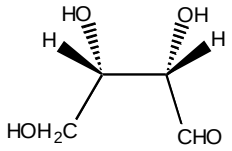
Remember to look out for the possibility of meso compounds. A meso compound is an achiral member of a set of diastereosiomers that includes at least one chiral member.

Question 3
What are the stereochemical relationships between compounds **A** + **B**, **A** + **C**, **C** + **D** and **B** + **C**

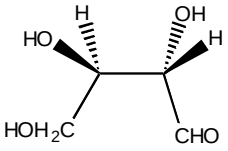
A



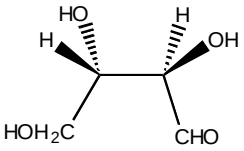
B



C

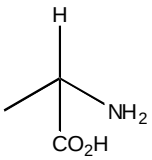


D

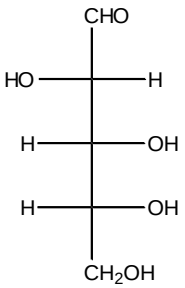


Question 4
Mark each stereocentre on the following molecules with an asterisk. How many stereoisomers are possible for each molecule?

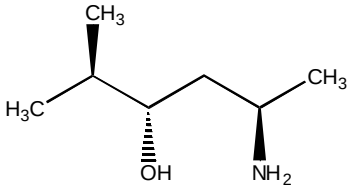
a)



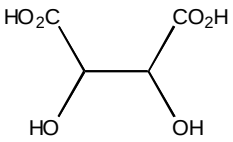
b)



c)

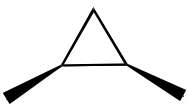


d)



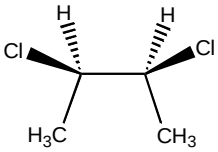
Question 5
Which of the following are meso compounds?

a)



b) *trans*-1,2-cyclopentanediol

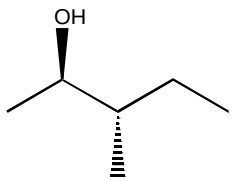
c)

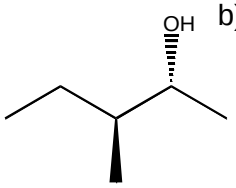


Question 6

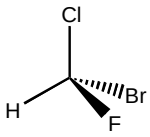
What is the stereochemical relationship between the molecules in the pairs below?

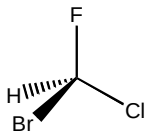
a)



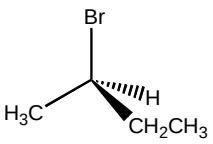


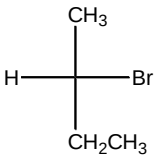
b)





c)

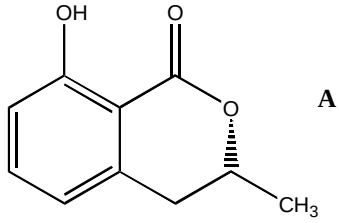




Optical and Specific rotation

Worked example 4

Given the data below calculate the specific rotation of compound A



A

A solution of 50mg of A in 5ml of $CHCl_3$ was transferred to a 1 dm cell and placed in a polarimeter. The α was measured as -0.96 ° at 20 °C at the sodium D line.

Worked example 4 answer

$$[\alpha]^{t}_{\lambda} = \frac{100\ \alpha}{c\ l}$$

α = the measured optical rotation.
c = the concentration in g $100ml^{-1}$
l = the pathlength of the cell in dm .
t = the temperature at which the measurement was made.
λ = the wavelength at which the measurement was made.

50 mg in 5 ml therefore c = 20 x 0.05 = 1 g/100ml

$$[\alpha]^{20}_{D} = \frac{100 \text{ x} - 0.96}{1 \text{ x } 1} = -96$$

The specific rotation is recorded as: $[\alpha]^{20}_{D} = -96$ (*c* = 1 , $CHCl_3$).

Question 7

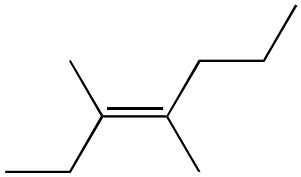
a) A newly isolated natural product was shown to be optically active. If a solution of 2.0 g in 10 ml of ethanol in a 5 cm tube gives a rotation of + 2.57°, what is the specific rotation of this natural product?

b) (-)-Lactic acid has a specific rotation of – 3.8°. What is the specific rotation of a solution containing 7.5g of (-)-lactic acid and 2.5 g of (+)-lactic acid?

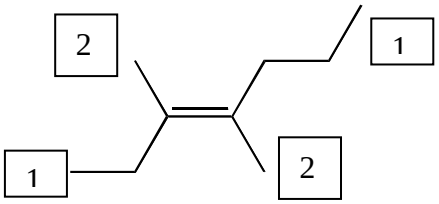
c) Calculate the observed rotation of a solution of 0.5245g of (*S*)-1-amino-1-phenylethane diluted to a volume of 10.0 ml with methanol at 20°C, using the sodium D line and 1 dm cell. Specific rotation of this material is – 30.0°.

Other types of stereoisomers

Worked example 5
Showing your working, assign the double bond in the following molecule as either *E* or *Z.*



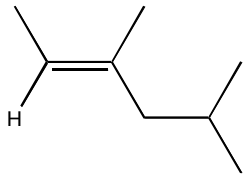
Worked example 5 answer
Double bond isomers are another form of stereoisomer.
First we must rank the substituents at either end of the double bond as 1 or 2 using C.I.P rules.
In this case-



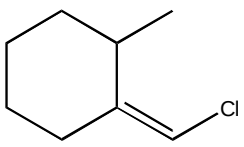
The two highest ranked substituents are on opposite sides of the double bond and so the stereochemistry is designated as *E*.

Question 8
Showing your working, assign the double bonds in the following molecules as either *E* or *Z.*

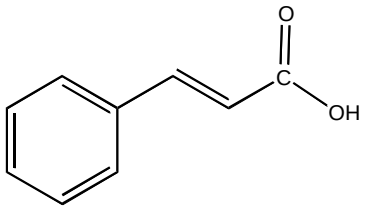
a)



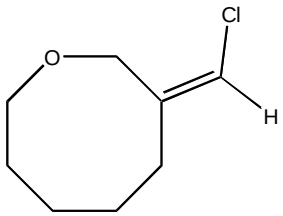
b)



c)



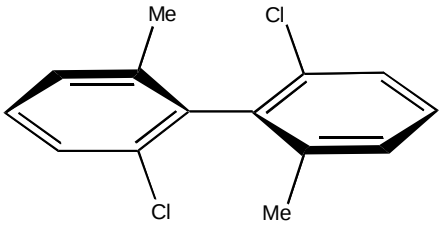
d)



Question 9

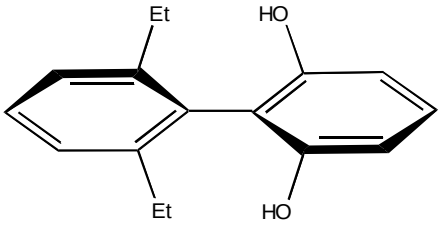
Assign the following molecules as chiral or achiral.

a)

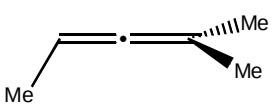


b)

c)



d)



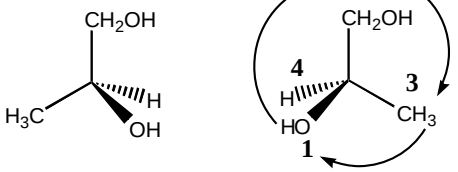
Section 4 Answers

Questions

1.

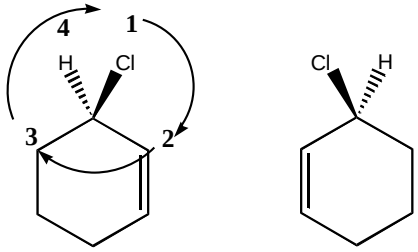
a)

i.



R

ii.

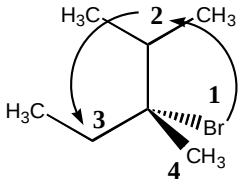


R

Double and triple bonds are treated as if they were split into two or three single bonds respectively. In this example the double bond takes priority over the single bond in the ring.

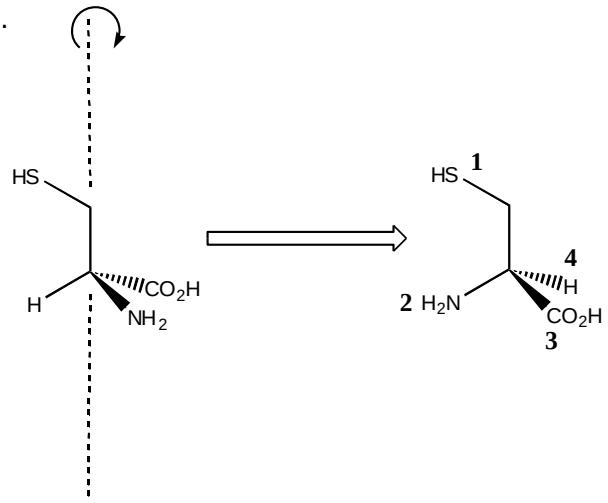
b)

i.



Priority of groups descends anticlockwise, but the lowest ranked group is forward therefore we assign this as ***R***.

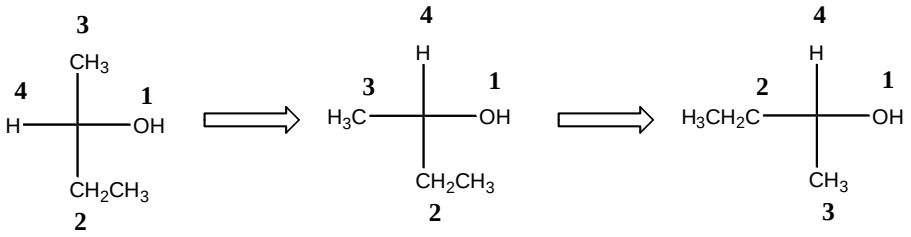
ii.



Lowest ranked group is in the plane of the paper. Rotate around the other bond which is in the plane of the paper until the lowest ranked group projects back into the paper. The molecule is assigned as ***S***.

2.

a) (*S*)-2-butanol



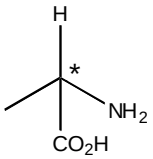
b) *R* and *S* respectively therefore enantiomers

3.

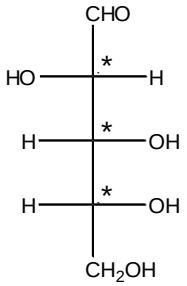
A + **B** = enantiomers, **A** + **C** = diastereoisomers, **C** + **D** = enantiomers, **B** + **C** = diastereoisomers

4.

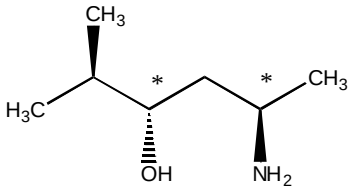
a) 1 stereocentre therefore 2^1 stereoisomers



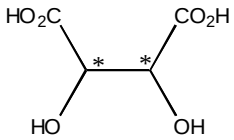
b) 3 stereocentres therefore 2^3 stereoisomers = 8



c) 2 stereocentres therefore 4 stereoisomers.



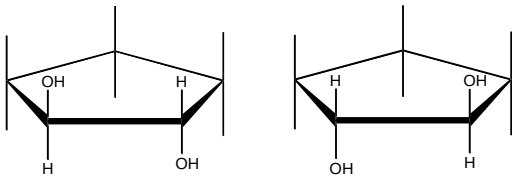
d) 2 stereocentres. We would expect 4 stereoisomers, but the presence of a mirror plane results in a meso compound. Only 3 stereoisomers.



5.

a) Meso, as molecule has a mirror plane.

b) Not meso, molecule is *trans* therefore no mirror plane.



c) Meso, molecule has a mirror plane.

6.

a) Same molecule.
b) Same molecule.
c) Enantiomers.

7.

a) + 25.7°
b) -1.9°
c) Solve the specific rotation equation for observed rotation. Answer is -1.57°

8.

a) *E (trans)*
b) *Z (cis)*
c) *E (trans)*
d) *Z (cis)*

9.

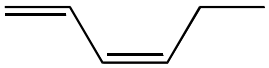
a) Chiral
b) Chiral
c) Achiral
d) Achiral

Section 5

Synthesis and Reaction of Alkenes

Nomenclature

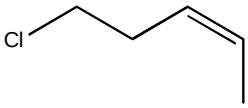
Worked example 1
Give a systematic name for the compound below.



Worked example 1 answer
The name must indicate the number of carbon atoms in the chain and the position of the alkene functionality.
The chain is numbered to place the unsaturation at the lowest position.
The double bond at carbon 1 does not have an *E* or *Z* geometry because both substituents at carbon 1 are H atoms.

Molecule is (3*Z*)-hexa-1,3-diene.

Worked example 2
Provide the proper IUPAC name for the alkene shown below.

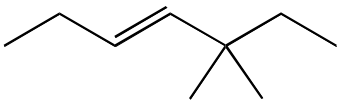


Worked example 2 answer
As for Worked example 1 we number the chain to place the unsaturation at the lowest position.
The chain has 5 carbons, therefore the stem is pent.
There is a chlorine atom on carbon 5.
The double bond is *Z* (*cis*).

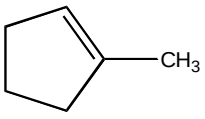
Molecule is (*Z*)-5-chloropent-2-ene.

Question 1
Give systematic names for the compounds a-d.

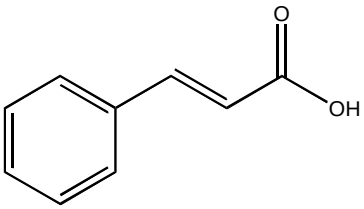
a)

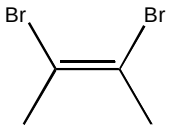


b)



c)

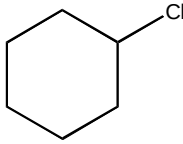


d) 

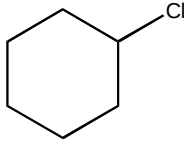
Synthesis of Alkenes- Elimination reactions

Elimination vs Substitution

Worked example 3
Complete the indicated reactions.

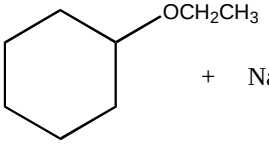
a) 

+ $CH_3CH_2O^-Na^+$ $\xrightarrow[CH_3CH_2OH]{\text{subsitution}}$

b) 

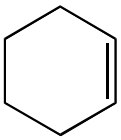
+ $CH_3CH_2O^-Na^+$ $\xrightarrow[CH_3CH_2OH]{\text{Elimination}}$

Worked example 3 answers
Elimination and nucleophilic substitution are competing processes. Nucleophiles can often act as bases and vice versa.

a) 

+ NaCl

During the substitution reaction chlorine is lost and the ethoxide ion takes its place.

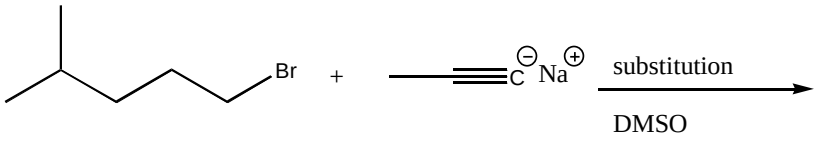
b) 
+ CH_3CH_2OH + NaCl

During the elimination reaction both chlorine and a proton from an adjacent carbon atom are removed. The electrons from the C-H bond now form the C-C double bond.

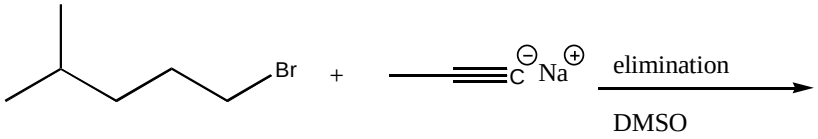
Question 2

Complete the indicated reactions.

a)



b)



Question 3

a) What factors would favour an elimination reaction occurring over a substitution reaction? Explain your answer.

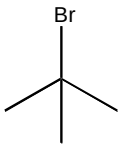
b) Which base, ammonia (NH_3) or triethylamine [$(CH_3CH_2)_3N$], would be a better choice for use in converting 1-chlorohexane to hex-1-ene? Explain briefly.

E1 and E2 eliminations

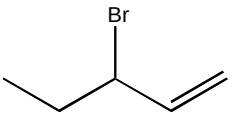
Worked example 4

Treatment of each of the following halogenoalkanes with EtO^- promotes elimination by an E1 mechanism; what would you expect to be the predominant products? Give a mechanism in each case.

a)

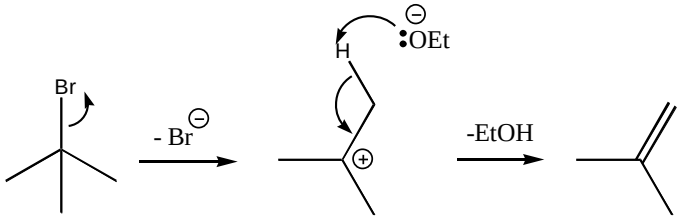


b)



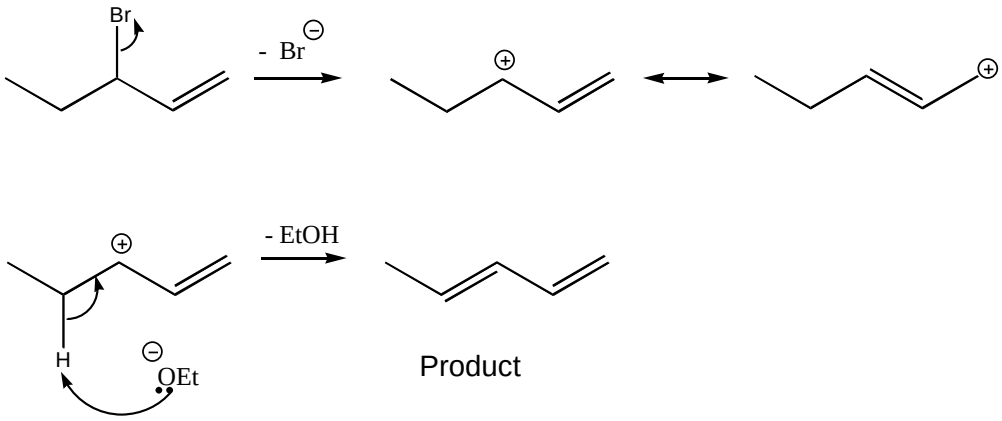
Worked example 4 answers

a) The ethoxide ion is a strong base and promotes elimination of HBr from the molecule. Only one product can be formed from this reaction.



Product

b) The product is a 1,3-diene. Only one product can be formed from this reaction.

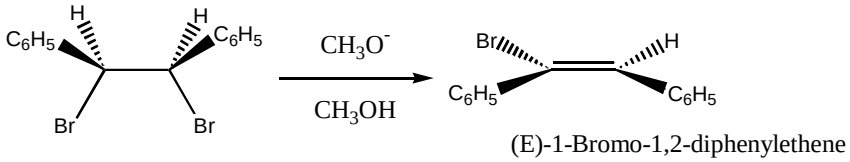


Question 4

What factors promote unimolecular as opposed to bimolecular elimination (E1 over E2)?

Question 5

a) Account for the stereospecificity of the reaction below.

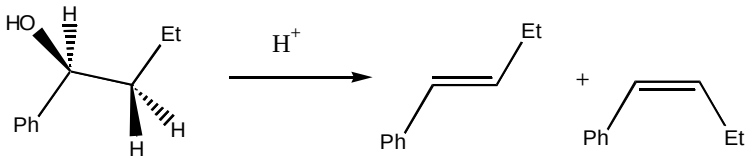


(E)-1-Bromo-1,2-diphenylethene

b) The above substrate is meso. What would happen if we performed the same reaction with a racemic mixture of the substrate?

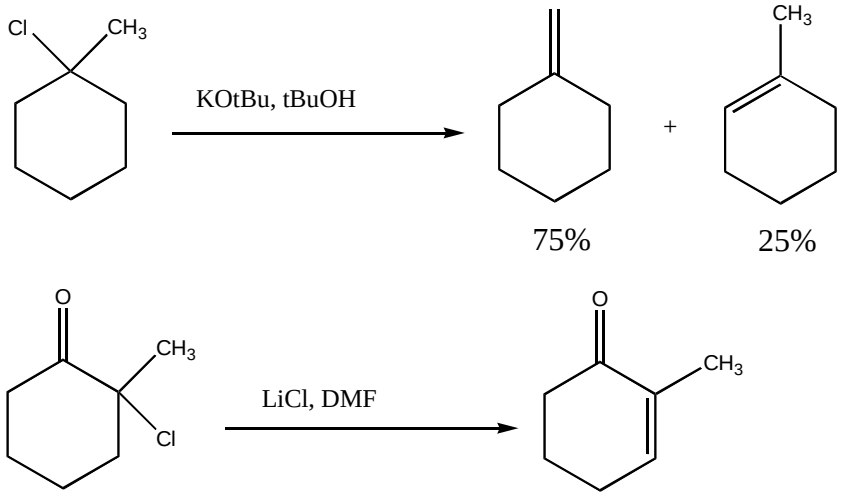
Question 6

Account for the stereoselectivity of the reaction below.



Major product

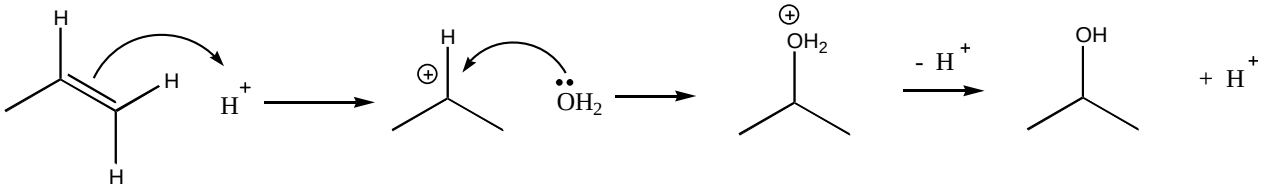
Question 7
Account for the product distribution of the following two reactions (explain your reasoning).



Reactions of alkenes

Worked example 5
Give the reagents and outline the mechanism for the formation of propan-2-ol from propene ($CH_3CH=CH_2$).

Worked example 5 answer



The reaction is an acid catalysed addition. The reaction obeys the Markovnikov rule, which means that the proton becomes attached to the carbon which has the most hydrogens attached to it in the alkene starting material. This forms a more stable carbocation intermediate and gives us a secondary alcohol.

Question 8
Give the reagents and outline the mechanism for the formation of the following compounds from propene ($CH_3CH=CH_2$).
a) 2-bromopropane
b) Propan-1-ol
c) 1-bromopropane

Question 9
Using structural diagrams, explain the exclusive formation of the trans (*E*) 1,2-dibromo geometrical isomer from the reaction of cyclopentene with bromine.

Question 10

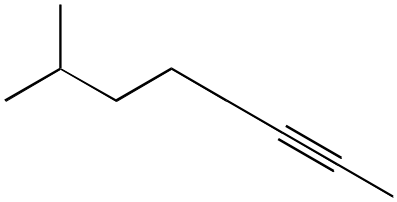
For reactions a) and b) state the products of the following reactions and outline the mechanism in each case. For reaction c) state the product only.

a) Cyclopentene + osmium tetroxide and water (do not include mechanism of hydrolysis)
b) Cyclopentene + m-CPBA (followed by treatment with aqueous acid)
c) But-2-ene + ozone (with DMS)

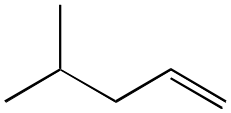
Section 5 Answers

1.
a) (*E*)-5,5-dimethylhept-3-ene
b) 1-methylcyclopentene
c) (*E*)-3-phenylpropenoic acid
d) (*Z*)-2,3-dibromobut-2-ene

2.
a)



b)



3.
a) Elimination reactions are favoured by:

Performing the reaction at high temperature: In an elimination reaction, two molecules become three new molecules, whereas in a substitution reaction, two molecules become two new molecules. The entropy increases during an elimination reaction.
A reaction where the entropy change is positive is more favourable at higher temperatures ($\Delta G = \Delta H - T\Delta S$)
Using strong bases: Strong bases attack protons rather than carbon atoms, and this leads to elimination rather than substitution.
Presence of bulky groups on a substrate and use of a bulky base: This prevents the base acting as a nucleophile and attacking carbon, due to steric hindrance.

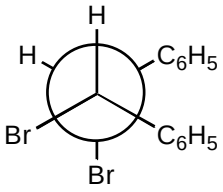
b) Triethylamine. Amines can act as both nucleophiles and as bases in reactions with alkyl halides. Increasing the steric bulk about the nitrogen reduces the undesirable nucleophilicity while allowing the amine to continue to function effectively as a base.

4. E1 is favoured over E2 if:

There is an alkyl group in the substrate that will give a relatively stable carbocation E.g. tertiary alkyl group
There is another group that will stabilise the carbocation e.g. Allylic, Benzylic or α-Hetero substituted.
A good ionising solvent is used.
A poor leaving group is present.

5.

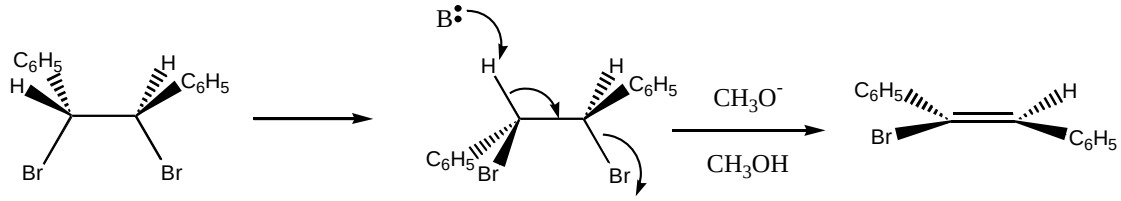
a) In this case the reaction occurs by an E2 pathway. It is a requirement for an E2 reaction that H and X (Br) be anti-periplanar. Rotation of the left carbon in the substrate by 60° brings H and Br into an anti-periplanar relationship.



Although this conformation places the two bulky phenyl groups on the same side of the molecule, the reaction has only one course to follow due to the requirement for an anti-periplanar arrangement.

As this is the only anti-periplanar relationship possible, the reaction is stereospecific. Stereospecific reactions lead to production of a single isomer as a direct result of the mechanism and the stereochemistry of the starting material. The *E* alkene results.

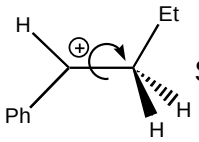
b)



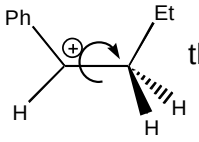
E2 reaction of either enantiomer will give the (*Z*)- alkene as this places the two bulky phenyl groups on opposite sides of the double bond, meaning that the Z alkene is lower in energy.

6.

The reaction is acid catalysed and proceeds via an E1 mechanism.
The geometry of the product is determined at the point when the proton is lost from the intermediate carbocation.
The new π bond can only form if the vacant p-orbital of the carbocation and the breaking C-H bond are aligned parallel.
Bond rotation in the carbocation intermediate can occur.



Sterically favoured because the phenyl and ethyl groups are on opposite sides



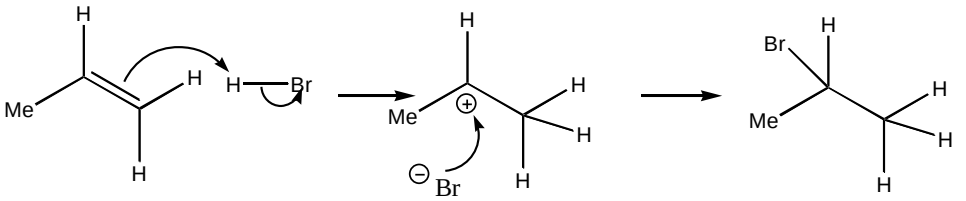
Sterically hindered because phenyl and ethyl groups are on the same side.

E1 reactions favour *E* alkenes because the intermediates that lead to them are lower in energy than for *Z* alkenes.

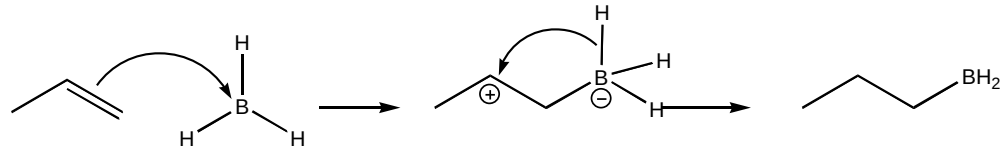
7.
If the substrate has a choice of β-hydrogen atoms available for effecting elimination, it is possible to obtain more than one alkene (regioisomers). The second reaction occurs by an E1 mechanism and so the most thermodynamically stable product (the most substituted alkene) is formed.

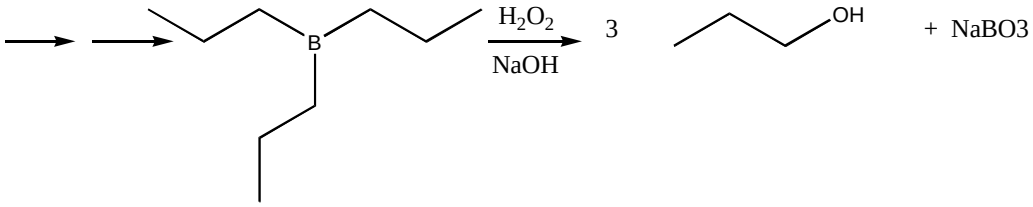
The first reaction occurs by an E2 mechanism. E2 reactions become more regioselective for the less substituted alkene with more hindered bases. The t-butyl base cannot approach the hydrogen on the ring carbon as well as it can approach the hydrogen on the methyl group. Removal of the hydrogen on the methyl group is therefore favoured, giving us a double bond outside the ring.

8.
a)



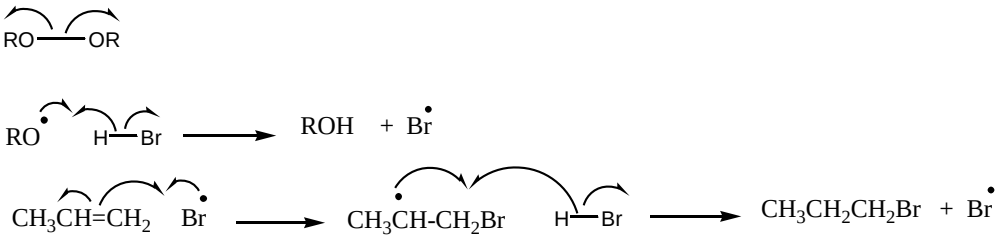
b)





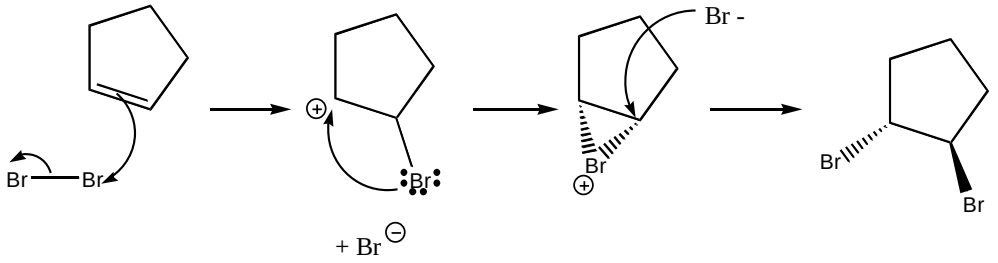
This reaction is anti-Markovnikov's rule. This is because Hydrogen has not become attached to the carbon of the alkene that had the most hydrogens.

c)



This reaction is also anti-Markovnikov. The Br radical formed can then abstract a hydrogen radical from another molecule of HBr, to generate the product and another Bromine radical. It is a chain reaction mechanism.

9.

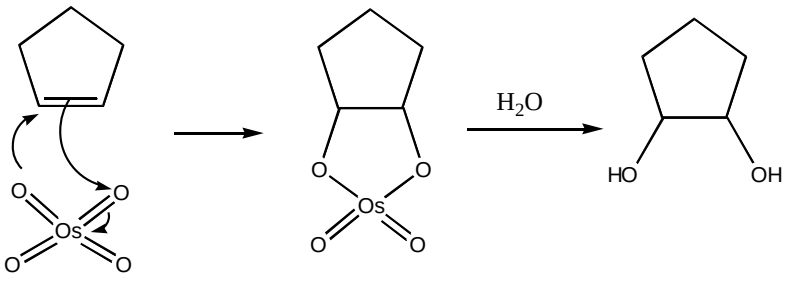


Step 1 **Step 2** **Step 3**

Step 1: Unconjugated alkenes are like nucleophiles and can react with electrophiles. Br_2 is a polarisable electrophile.
Step 2: Lone pairs from Br can attack the resulting carbocation to give a bromonium ion.
Step 3: Attack of Br^- on the bromonium ion occurs via a normal S_N2 reaction to give the dibromoalkane. You will remember that S_N2 reactions always occur with backside attack of the carbon, resulting in inversion of stereochemistry. This factor determines the geometry of the product (*trans*).

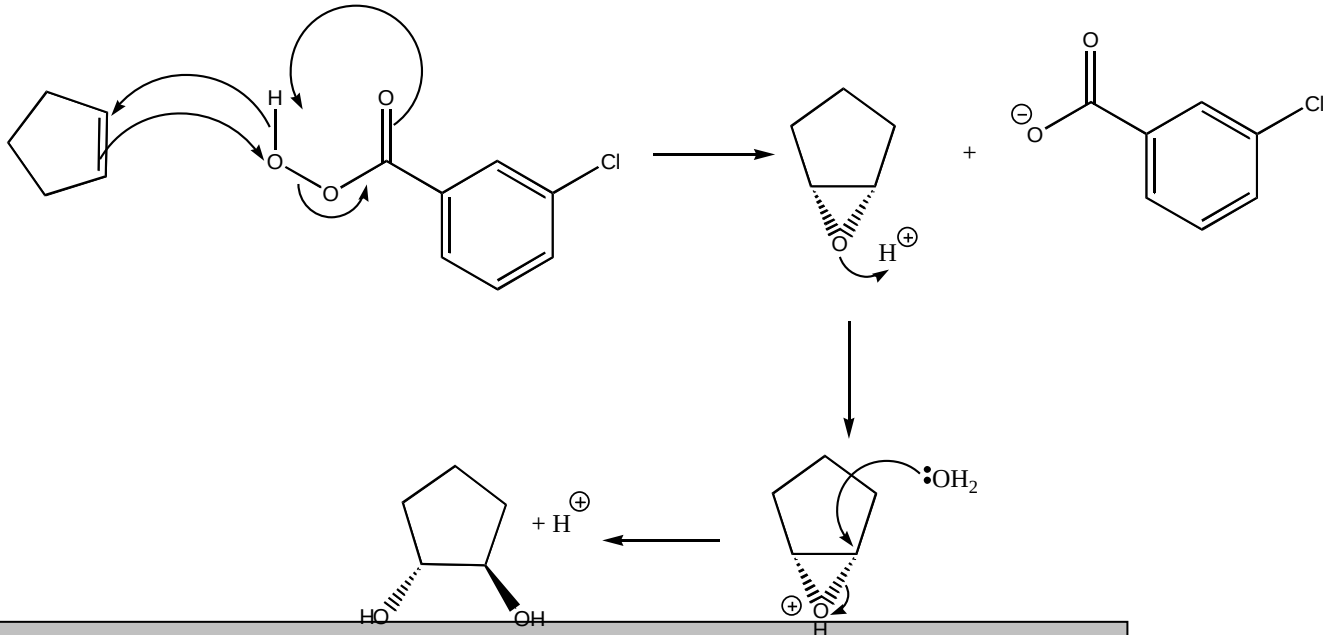
10.

a) 1,2-cis dihydroxycyclopentane

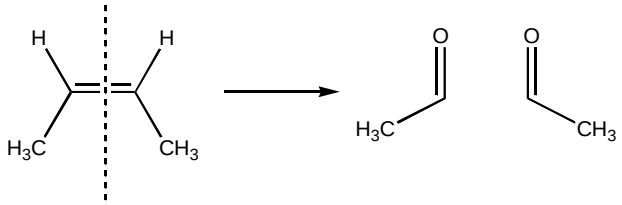


Osmate ester

b) 1,2-trans dihydroxycyclopentane



c) Two molecules of ethanal.



Section 6
Carbonyl Chemistry

Orbitals and Trajectories

Question 1

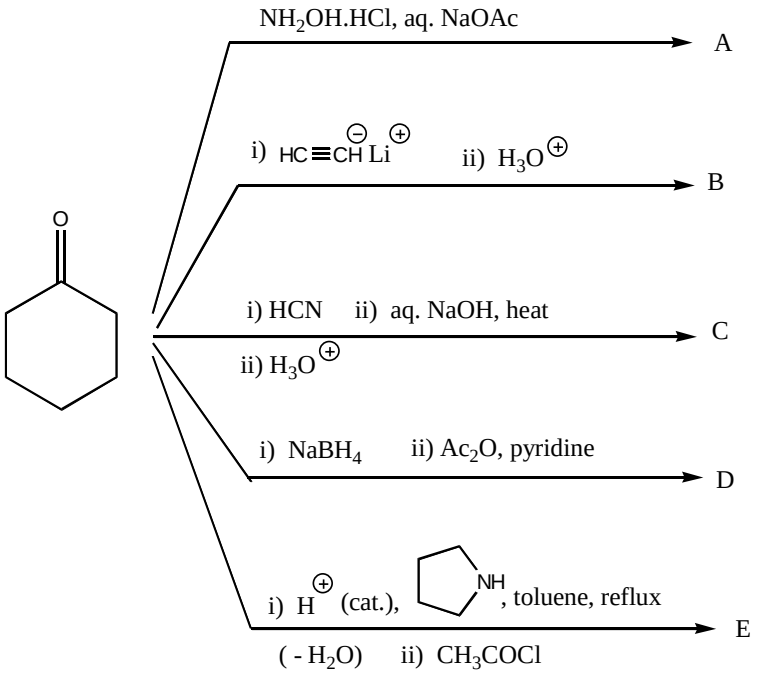
a) Explain why nucleophiles attack the carbon of a carbonyl group and electrophiles attack the oxygen.

b) Explain why a nucleophile attacks the carbon of a carbonyl group at an angle of 107°.

Reaction Mechanism Pathways

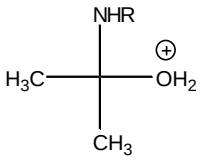
Question 2

Write down structural formulae for the organic products expected from the following reaction sequences.

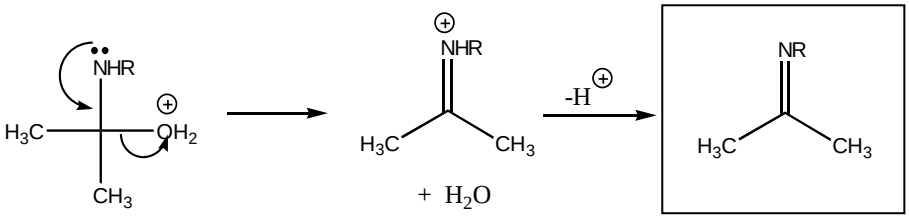


Worked Example 1

What is the product expected on collapse of the following tetrahedral intermediate to an sp^2 hybridised species?



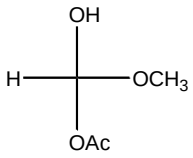
Worked example 1 answer



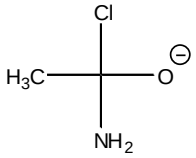
Question 3

What are the products expected on collapse of the following tetrahedral intermediates to sp^2 hybridised species?

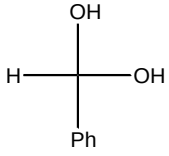
a)



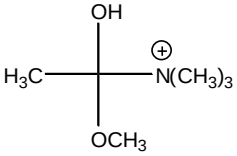
b)



c)



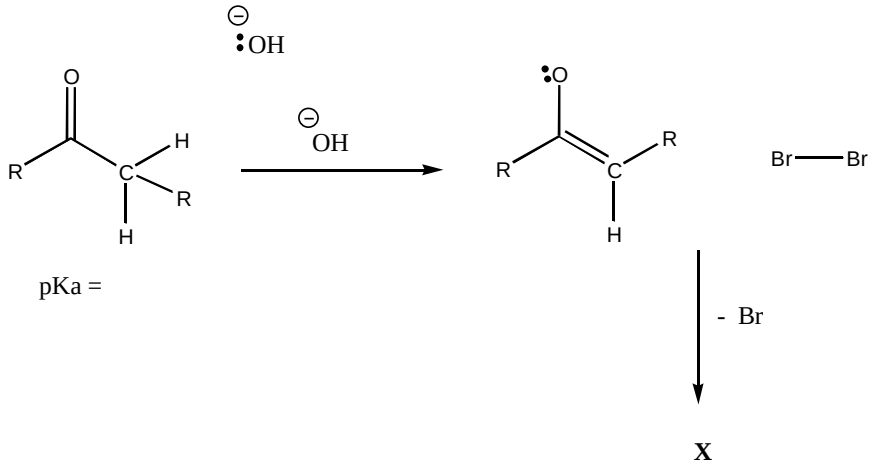
d)



Question 4

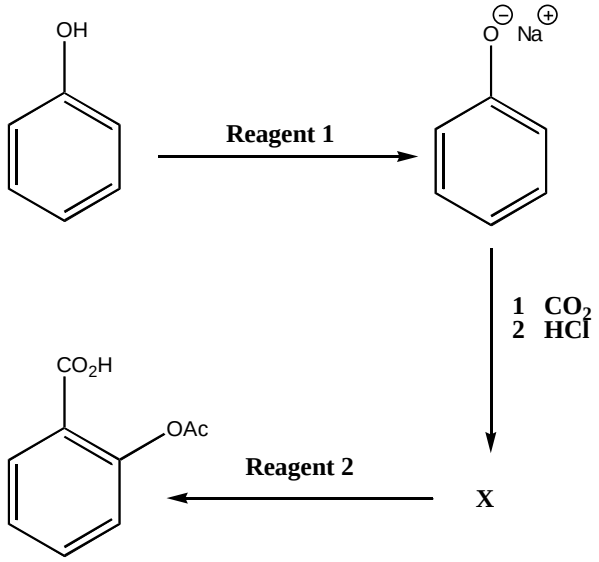
Complete the reaction mechanism by drawing curly arrows to describe electron pair movements, assign any required charges and give the structure of the overall product of the reaction, X. Indicate an approximate pKa for the initial carbonyl compound.

Alpha substitution reaction



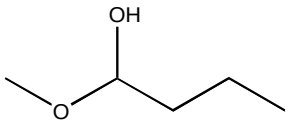
Question 5

Insert appropriate reagents and identify compound X for the formation of aspirin from phenol.



Question 6

a) Write a mechanism for the acid-catalysed decomposition of the hemiacetal below to the aldehyde and alcohol.



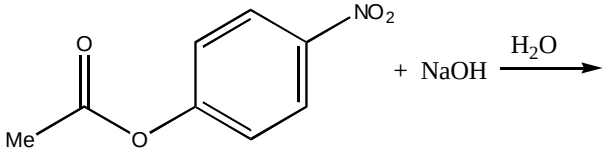
b) Write a mechanism for the base-catalysed reaction between methanol and propanal to give a hemiacetal.

Esters and Amides

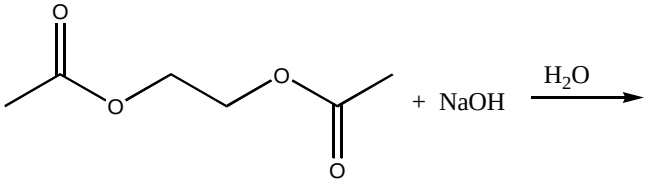
Question 7

Complete and balance equations for the complete hydrolysis of each ester in aqueous sodium hydroxide. Show all products as they are ionized under the indicated experimental conditions.

a)



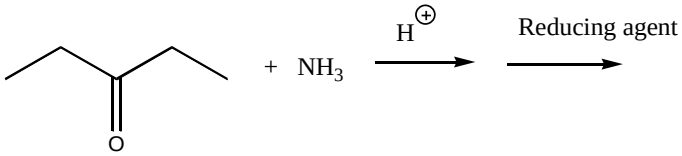
b)



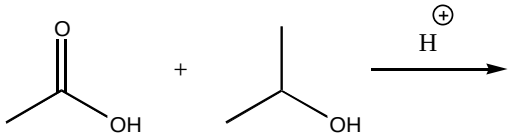
Question 8

Suggest products for the following reactions and give mechanisms.

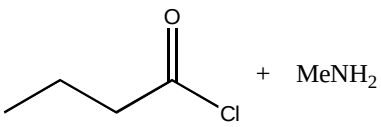
a)



b)



c)



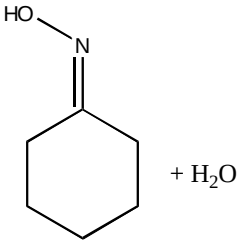
Section 6 Answers

1.
a) The nucleophile is electron rich. The lone pair of electrons from the nucleophile (Highest Occupied Molecular Orbital) are placed in the Lowest Unoccupied Molecular Orbital of the carbonyl, which is the π^* anti-bonding orbital. In the carbonyl group the largest LUMO (largest orbital co-efficient) occurs on the carbon atom and so carbon is attacked by a nucleophile.
The oxygen of the carbonyl group possesses a lone pair of electrons. This is the HOMO of the carbonyl group and will attack the LUMO of the electrophilic reagent.

b) The angle (called the Burgi-Dunitz angle) is a combined effect of two factors. Firstly, the nucleophile wants to obtain maximum overlap with the π^*, and secondly, electronic repulsion from the filled π orbital forces the nucleophile to attack from an obtuse angle.

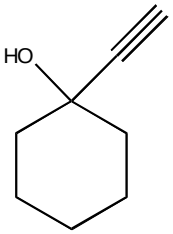
2.

A

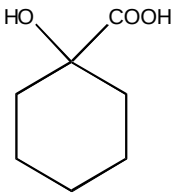


+ H_2O

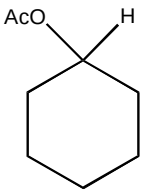
B



C



D



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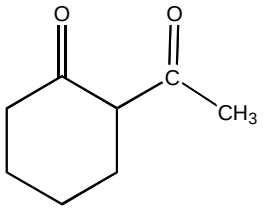
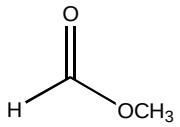


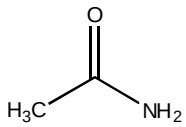
3.

a)



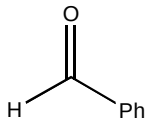
+ AcOH

b)



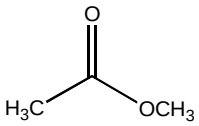
+ Cl^-

c)



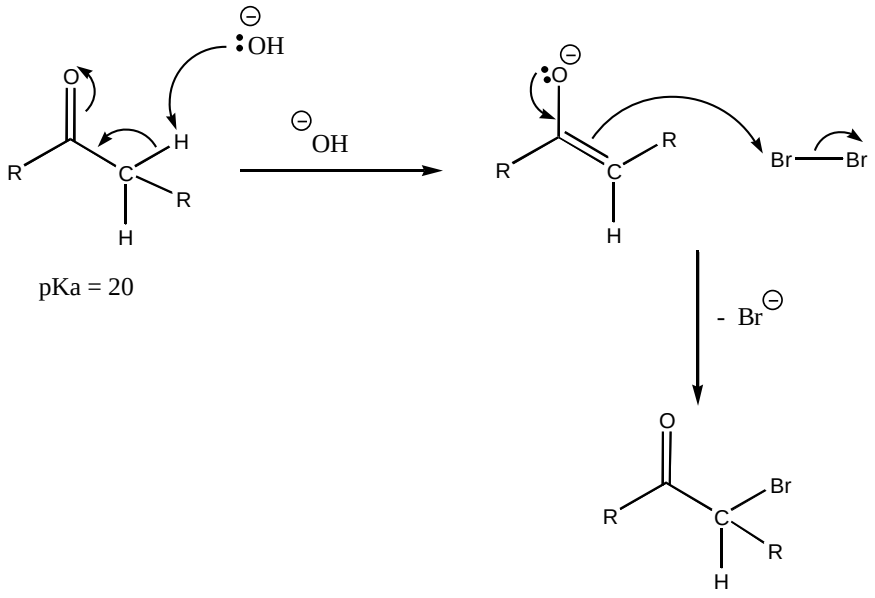
+ H_2O

d)

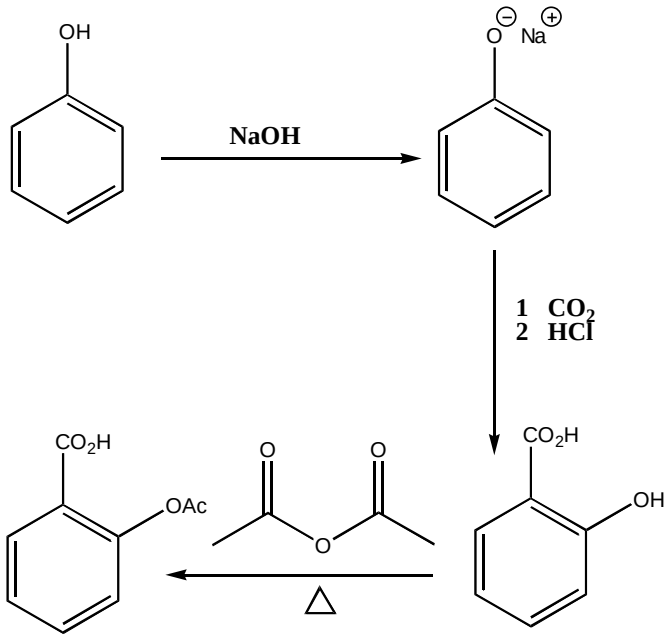


+ $N(CH_3)_3$ + H^+

4.

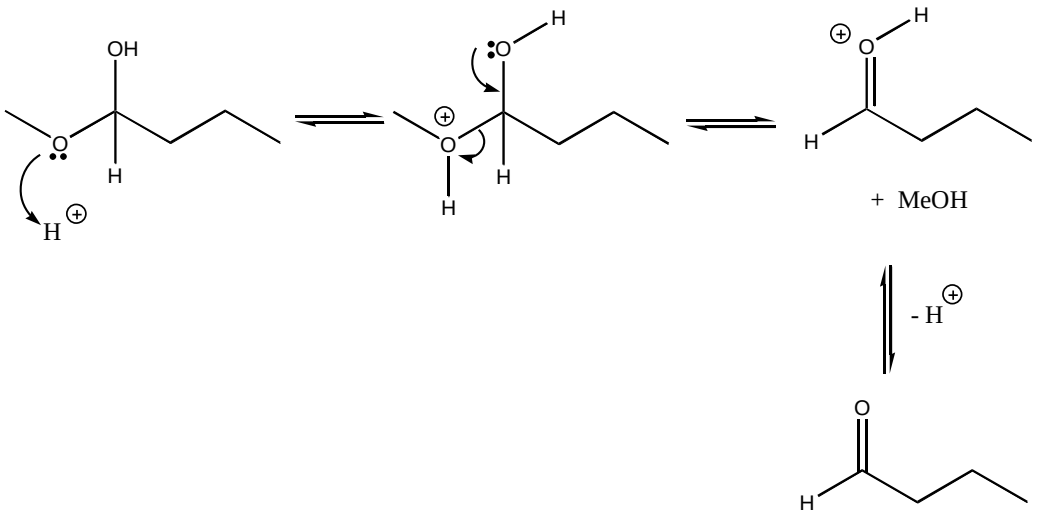


5.

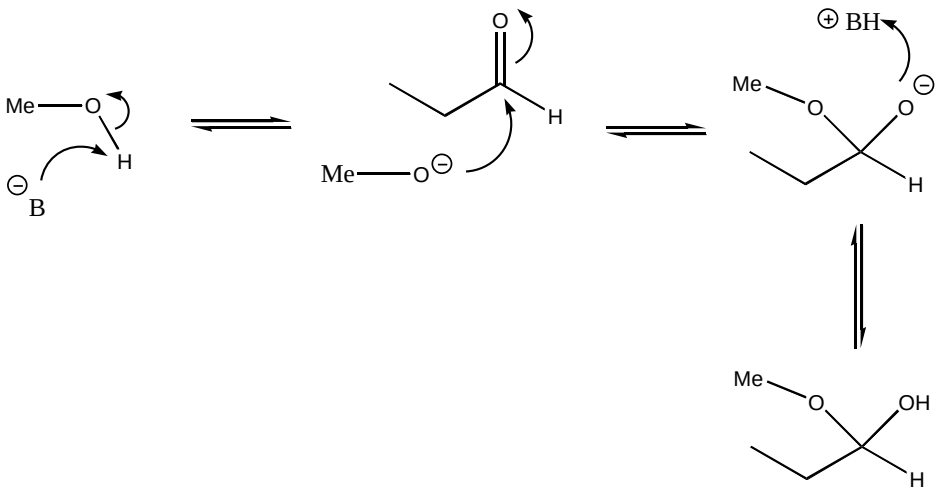

OH
NaOH
O Na
1 CO2
2 HCl
CO2H
OAc
O
O
O
CO2H
OH
△

6.

a)

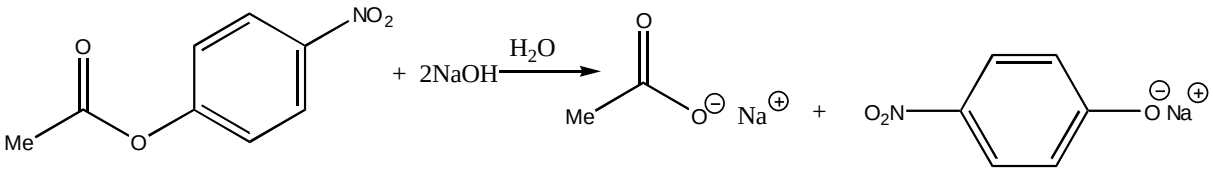

OH
O
H
H
O
H
O
H
H
O
H
H
+ MeOH
- H
O
H

b)


Me
O
H
B
O
H
Me
O
BH
Me
O
O
H
Me
O
OH
H

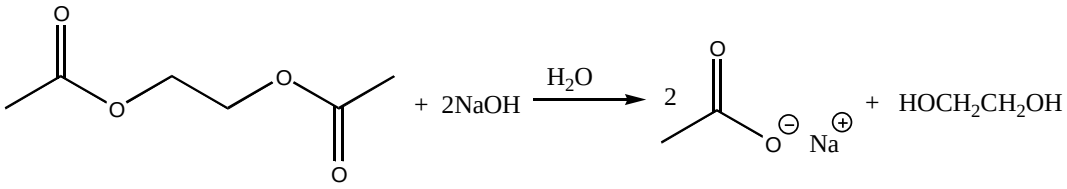
7.

a)



Each product is converted to its sodium salt, therefore 2 moles of NaOH are required for hydrolysis of 1 mole of the ester.

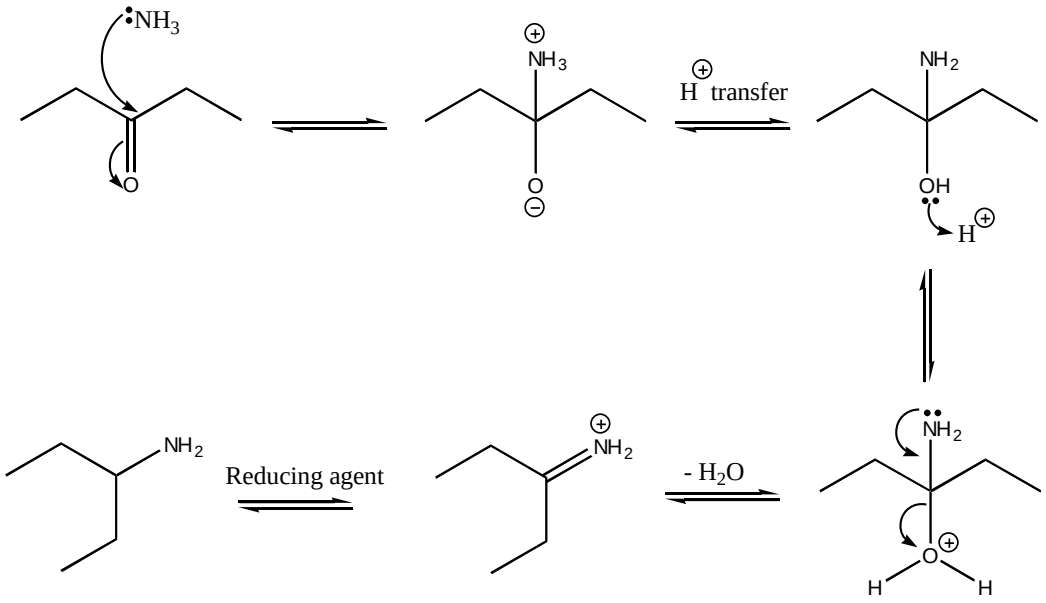
b)



The diester of ethylene glycol requires two moles of NaOH for complete hydrolysis of one mole of reactant.

8.

a)



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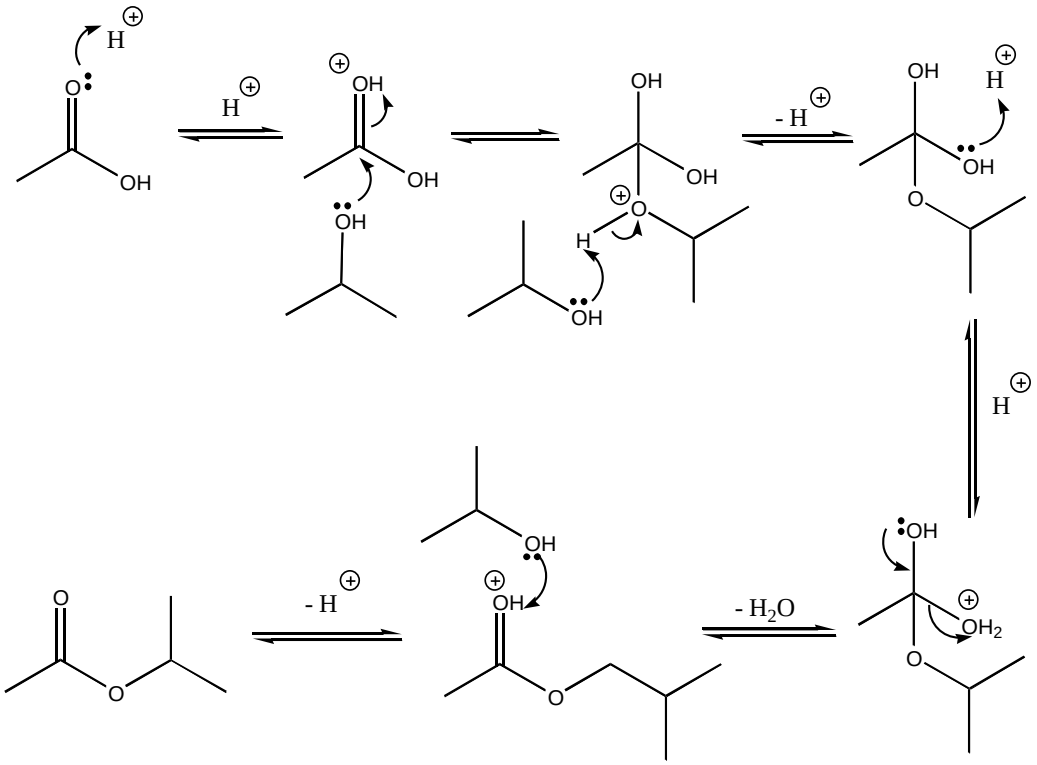

c)