IB · HL · Chemistry

4 hours 25 questions

Structured Questions

Electron Pair Sharing Reactions

Nucleophilic Substitution / Heterolytic Fission / Electrophilic Addition Reactions / Lewis Acids & Bases (HL) / Lewis Acid & Base Reactions (HL) / Coordination Bonds (HL) / Nucleophilic Substitution in Halogenoalkanes (HL) / Relative Rates of Nucleophilic Substitution (HL) / The Mechanisms of Electrophilic Addition Reactions (HL) / Addition to Unsymmetrical Alkenes (HL) / Electrophilic Substitution in...

Easy (10 questions)	/84
Medium (7 questions)	/67
Hard (8 questions)	/73
Total Marks	**/224**

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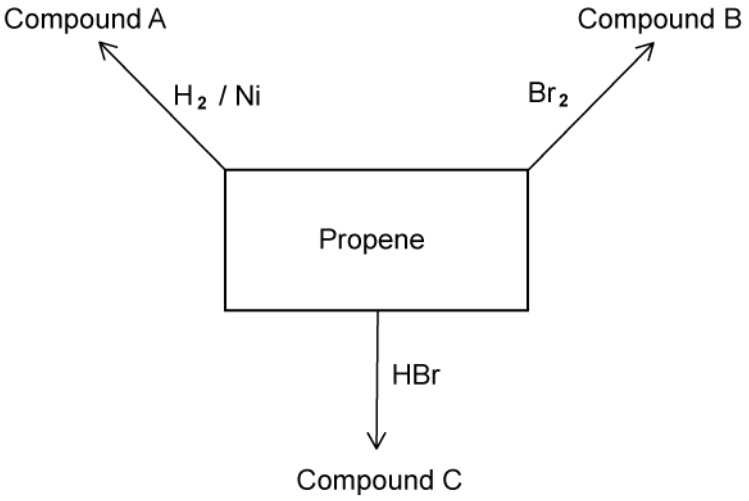
Easy Questions

1 (a) A reaction scheme for propene is shown below.



State the condensed structural formula of propene.

.....

(1 mark)

(b) State the IUPAC names for compounds A, B and C shown in the reaction scheme in part (a)

.....

.....

.....

(3 marks)

(c) Propene will also react to form an alcohol. State the reagents and conditions required for the formation of an alcohol from propene.

.....

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(3 marks)

(d) State the colour change when compound B is formed from propene.

(1 mark)

(e) Propene can form polypropene. Draw the repeating unit that will be formed via the addition polymerisation of propene.

(2 marks)

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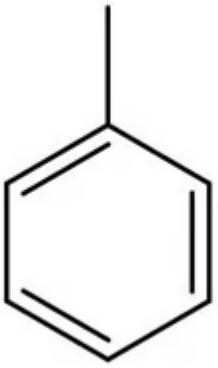
2 (a) Benzene undergoes substitution reactions. State the equation for the reaction of benzene with nitric acid to produce nitrobenzene and water.

.....

.....

(2 marks)

(b) The structure of methylbenzene is shown below.



Draw the structures of the two isomers of choromethylbenzene formed from the reaction of methyl benzene and Cl_2 in the presence of $AlCl_3$.

.....

.....

(2 marks)

(c) State the type of reaction that benzene will typically undergo.

.....

(1 mark)

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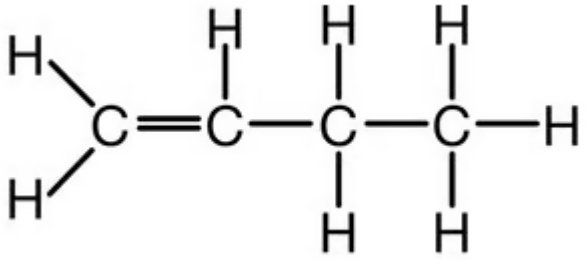
3 (a) The structure of but-1-ene is shown below.



Draw and state the name of the secondary halogenoalkane formed when but-1-ene reacts with HCl.

(2 marks)

(b) Explain why halogenoalaknes are more reactive than alkanes.

(2 marks)

(c) State the reagents and conditions required for the formation of propan-1-ol from 1-bromopropane.

(3 marks)

(d) The type of reaction outlined in part (c) is *nucleophilic substitution*. State the meaning of the term *nucleophile*.

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.....

(1 mark)

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4 (a) A complex ion contains one Fe^{3+} ion, four ammonia molecules and two chloride ions.

State the formula of this complex ion.

.....

(1 mark)

(b) State **two** characteristic properties of transition elements.

.....

.....

(2 marks)

(c) Transition metals can be used as successful catalysts in a range of reactions.

State what is meant by the term *homogeneous* catalyst.

.....

(1 mark)

(d) Transition metals can form complexes with different ligands.

Identify **one** species from the following list that does not act as a ligand and explain your answer.

CO H_2O SCN^- H_2

.....

.....

(2 marks)

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5 (a) Define the terms Lewis acid and Lewis base and state the type of bond formed between a Lewis acid and base.

(3 marks)

(b) Identify which of the following are Lewis acids, Lewis bases or neither:

NH_3, K^+, SO_4^{2-}, CH_4, BCl_3,

(5 marks)

(c) Explain why aqueous ions of transition metals can act as Lewis acids.

(2 marks)

(d) State an alternative name for a species that acts as a Lewis base in organic chemistry mechanisms.

(1 mark)

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6 (a) Define the term *nucleophile*.

(2 marks)

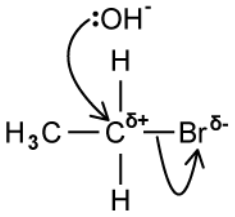
(b) Explain why the hydroxide ion, OH^-, is a stronger nucleophile than water.

(2 marks)

(c) State the two ways a nucleophilic substitution reaction can occur.

(1 mark)

(d) State the the name of the mechanism occurring in the image below which will form ethanol in one step.



(1 mark)

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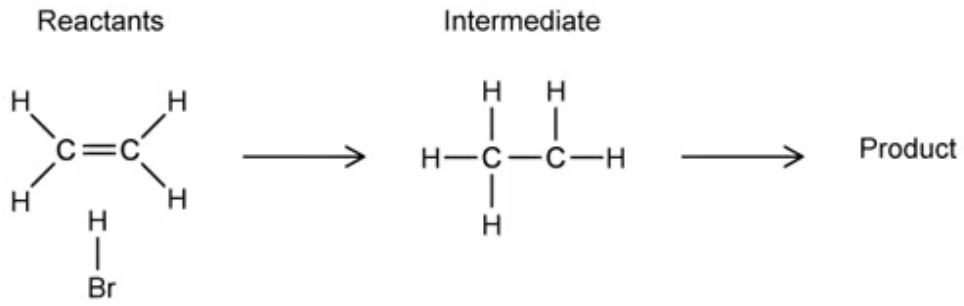
7 (a) The start of the electrophilic addition mechanism for the addition of hydrogen bromide to ethene is shown below:



Complete the mechanism by:

i) Adding **two** curly arrows and the partial charges, δ+ / δ-, to the reactants.

[3]

ii) Adding the correct charge to the carbocation intermediate, adding the anion, including its lone pair, and **one** curly arrow to the intermediate step.

[3]

(6 marks)

(b) Draw the product of the reaction in part a).

(1 mark)

(c) The electrophilic addition of hydrogen bromide to but-1-ene results in two isomeric products - one is a major product and one is a minor product. The first steps of the electrophilic addition mechanism are shown below:

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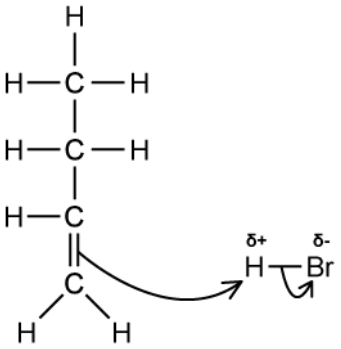

i) Draw the displayed formula of the secondary carbocation intermediate that forms the major product.

[1]

ii) Draw the displayed formula of the primary carbocation intermediate that forms the minor product.

[1]

.....

.....

(2 marks)

(d) Explain why the secondary carbocation is more stable than the primary carbocation.

.....

(1 mark)

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8 (a) Name the type of mechanism that benzene will undergo in order to form nitrobenzene.

.....

(1 mark)

(b) State the reagents required to form nitrobenzene from benzene.

.....

(1 mark)

(c) Outline the mechanism for the formation of nitrobenzene from benzene.

.....

.....

.....

(3 marks)

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9 (a) 2-chloro-2-methylpropane is reacted with aqueous sodium hydroxide in ethanol and heated under reflux.

i) Deduce the class of halogenoalkane that 2-chloro-2-methylpropane belongs to.

[1]

ii) State the name of the product formed in this reaction.

[1]

iii) State the type of mechanism that this reaction will favour.

[1]

.....

.....

.....

(3 marks)

(b) Outline the mechanism for the reaction given in part a).

.....

.....

.....

.....

(4 marks)

(c) State the type of bond breaking that occurs in this mechanism.

.....

(1 mark)

(d) A student stated that changing the halogenoalkane for the reaction in part a) to 2-iodo-2-methylpropane, the reaction would be quicker. Is the student correct? Explain your answer.

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(3 marks)

10 (a) Propan-1-ol can be synthesised from alkene P in the following synthetic route:

alkene P $\xrightarrow{\text{Step 1}}$ halogenoalkane Q $\xrightarrow{\text{Step 2}}$ propan-1-ol

i) State the identity of halogenoalkane Q.

[1]

ii) Give the reagents and conditions needed for Step 2.

[2]

.....

.....

.....

(3 marks)

(b) Give the name and structure of alkene P.

.....

.....

(2 marks)

(c) Give a reagent that could be used to convert P to Q and outline why this synthesis of propan-1-ol might not be very efficient.

.....

.....

.....

(3 marks)

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(d) This question is about alkene P and Step 1.

i) Give the empirical formula of P.

[1]

ii) Give the reagents and conditions needed for Step 1.

[2]

iii) State the type of reaction mechanism.

[1]

.....

.....

.....

.....

(4 marks)

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Medium Questions

1 (a) Benzene, C_6H_6, typically undergoes *electrophilic substitution*

i) State the meaning of the term *electrophile*.

[1]

ii) Write an equation for the reaction between benzene and concentrated nitric acid.

[1]

iii) Identify the electrophile in the reaction and show, by means of an equation, how it is generated.

[2]

(4 marks)

(b) Benzene is a highly unsaturated molecule.

i) Discuss why benzene undergoes substitution reactions rather than addition reactions.

[3]

ii) Show, by means of an equation, the reaction of benzene with chlorine and state any necessary conditions.

[2]

(5 marks)

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(c) An aromatic organic compound with molecular formula C_7H_8 reacts with bromine in the presence of UV light to produce a compound with molecular formula C_7H_7

i) Name the type of reaction taking place.

[1]

ii) Deduce the structures of the reactant and product.

[1]

iii) Give the formula of an additional organic product that could be obtained in the reaction.

[1]

.....

.....

.....

(3 marks)

(d) The same aromatic compound in part (c), C_7H_8, can be reacted with concentrated nitric acid to produce a multiple substituted product, with molecular formula $C_7H_5N_3O_6$.

i) Deduce the systematic IUPAC name for this compound.

[1]

ii) Draw the structure of $C_7H_5N_3O_6$.

[1]

iii) Name a use for the product.

[1]

.....

.....

.....

(3 marks)

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2 (a) Iron(III) ions can react with cyanide ions to form ferricyanide ion via the following equation

$$Fe^{3+} + 6CN^{-} \rightarrow [Fe(CN)_6]^{3-}$$

State which of the reactants is behaving as a Lewis base and justify your answer.

.....

.....

(2 marks)

(b) State the definition of a Brønsted-Lowry acid and the equation which demonstrates how ethanoic acid, CH_3COOH (aq) , behaves as a Brønsted-Lowry acid when reacting with ammonia, NH_3 (aq).

.....

.....

(2 marks)

(c) Sketch a graph to indicate the change in pH during a titration of 25.0 cm^3 of 0.100 mol dm^{-3} hydrochloric acid, HC*l* (aq) , with 0.100 mol of ammonia, NH_3 (aq).

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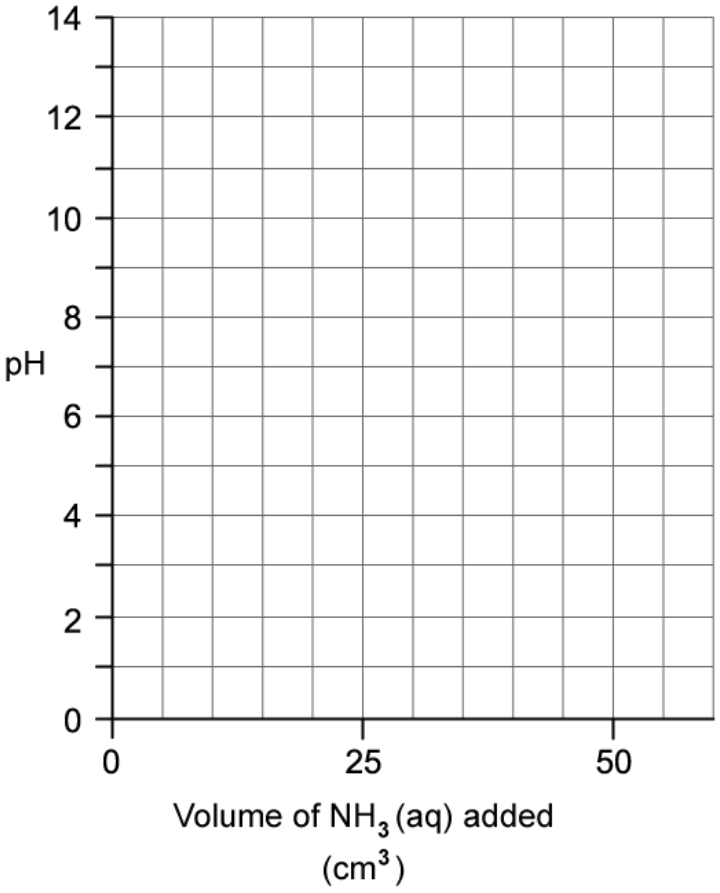

(2 marks)

(d) The endpoint in a titration can be identified using a suitable indicator.

i) Using Section 18 of the Data Booklet, select a suitable indicator that could be used for this titration and justify your choice.

[2]

ii) Describe how an acidic indicator works.

[3]

(5 marks)

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3 (a) The results of a series of experiments performed to determine the order of reaction between an isomer of bromobutane, C_4H_9Br, and aqueous sodium hydroxide are shown.

Experiment	$[C_4H_9Br]$ / mol dm^{-3}	$[OH^-]$ / mol dm^{-3}	Initial rate / mol dm^{-3} s^{-1}
1	0.10	0.20	2.90×10^{-4}
2	0.15	0.20	4.35×10^{-4}
3	0.30	0.40	8.70×10^{-4}

Determine, explaining your method, the rate expression for the reaction of the bromobutane isomer with aqueous sodium hydroxide.

(3 marks)

(b) Use your answer to (a) to deduce the type of mechanism for the reaction of the bromobutane isomer with aqueous sodium hydroxide, explain your reasoning.

(2 marks)

(c) Sketch the mechanism, using curly arrows to represent the movement of electrons.

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.....

.....

(4 marks)

(d) State, giving your reason, the role of the hydroxide ion in the nucleophilic substitution.

.....

(1 mark)

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4 (a) The starting materials for many products are alkenes such as propene.

State the type of reaction that occurs when propene is converted into chloropropane.

.....

(1 mark)

(b) Two possible isomeric products can be formed in the conversion of propene to chloropropane.

State the type of isomerism that is exhibited by these chloropropane products.

.....

(1 mark)

(c) Explain the mechanism of the reaction that forms the major product when propene is converted to chloropropane using curly arrows to represent the movement of electron pairs.

.....

.....

.....

.....

(4 marks)

(d) Outline why the major product is formed.

.....

(1 mark)

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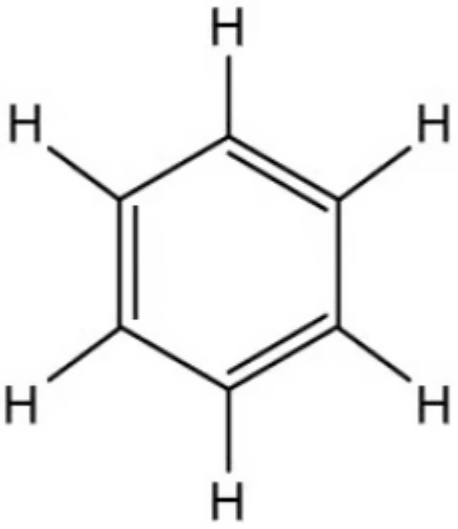
5 (a) Kekulé proposed the following structure of benzene.



Discuss the physical and chemical evidence to suggest that the Kekulé structure of benzene is incorrect.

(3 marks)

(b) State the reagents and the name of the mechanism used to convert benzene into nitrobenzene.

(2 marks)

(c) Using your answer to (b), formulate the equation for the formation of the nitronium ion.

(1 mark)

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(d) Using curly arrows to indicate the movement of electron pairs, explain the mechanism for the nitration of benzene.

(4 marks)

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6 (a) State a halogenoalkane reactant that can be used to **slowly** produce butan-1-ol by reacting with aqueous sodium hydroxide.

.....

(1 mark)

(b) Butan-1-ol can also be formed by the catalytic reduction of butanal. State the reagents for this reduction to occur

.....

(1 mark)

(c) State the reagent required to reduce butanoic acid to butan-1-ol.

.....

(1 mark)

(d) Using your answer to (c), write the equation for the reduction reaction of butanoic acid.

.....

(1 mark)

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7 (a) 1-bromobutane and 2-bromo-2-methylpropane are isomers. State the type of structural isomerism that they exhibit, explaining your reasoning.

(2 marks)

(b) Using curly arrows to indicate the movement of electron pairs, explain the mechanism for the reaction of 1-bromobutane with aqueous sodium hydroxide.

(4 marks)

(c) Consider the reactions of 1-bromobutane and 2-bromo-2-methylpropane with aqueous sodium hydroxide.

Compare and contrast the mechanisms for these reactions.

(3 marks)

(d) Explain why an inversion of configuration occurs during the reaction described in (c).

(1 mark)

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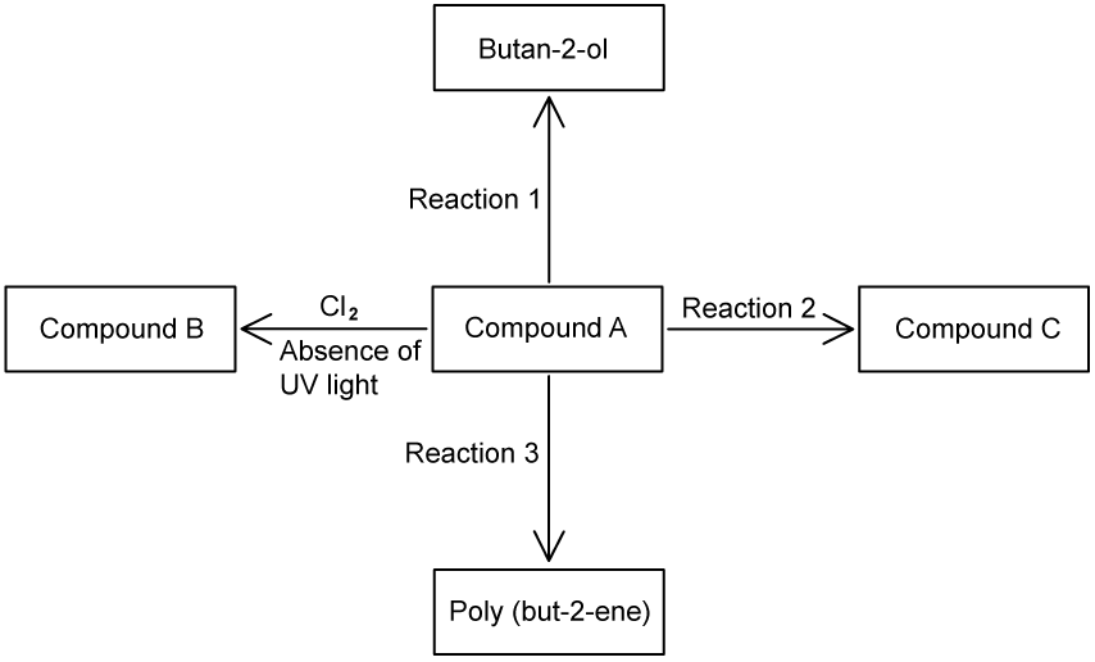
Hard Questions

1 (a) The following scheme shows reactions of Compound **A.**



i) Deduce the structural formula of compound **A**.

[1]

ii) Apply IUPAC rules to name compound **B**.

[1]

.....

.....

(2 marks)

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(b) Reaction **1** forms an alcohol when reacted with concentrated sulfuric acid, H_2SO_4 and steam.

i) State the conditions required for this reaction.

[1]

ii) Deduce the structure of the intermediate in this reaction.

[1]

.....

.....

(2 marks)

(c) Butan-2-ol can also be directly formed from a halogenoalkane.

i) State the name of of the type of reaction occurring in this conversation.

[2]

ii) State the conditions for this reaction.

[1]

.....

.....

.....

(3 marks)

(d) Identify the structure of the repeating unit of poly(but-2-ene).

.....

(1 mark)

(e) Compound A reacts with hydrogen bromide to form compound C. A student suggested a possible formula of compound C is $CH_2(Br)CH_2CH_2CH_3$.

State whether the student is correct and justify your answer.

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(1 mark)

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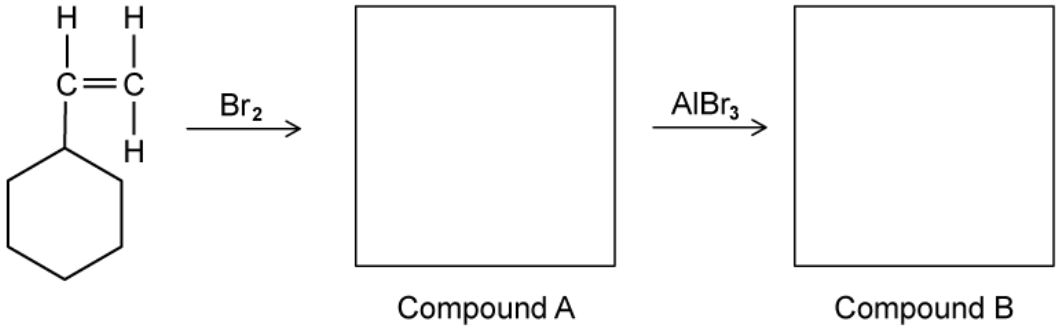
2 (a) A student investigated two reactions of phenylethene, $C_6H_5CHCH_2$. First she reacted phenylethene with excess bromine at room temperature to form Compound **A**. She then added aluminium bromide, $AlBr_3$ to the reaction mixture to form Compound **B.**

Draw the structure of Compound **A** and identify one the isomers of $C_8H_7Br_3$ formed in the second reaction.



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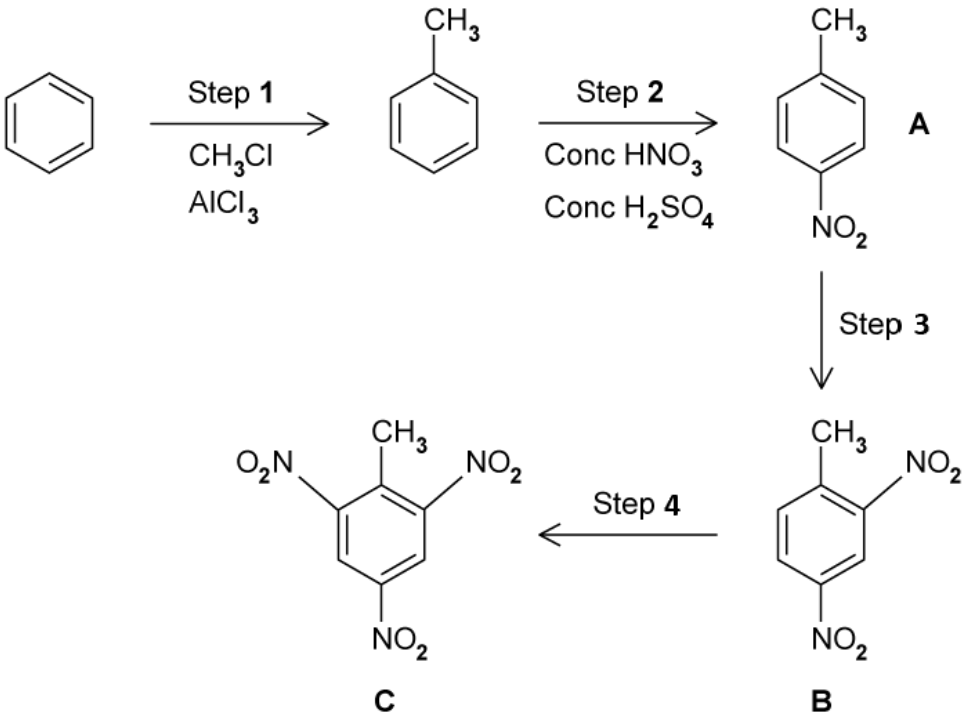
(2 marks)

(b) 2,4,6-trinitrotoluene (TNT) can be manufactured from benzene as shown below.



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5.00 g of benzene was used in step 1. Use section 6 of the data booklet to determine the theoretical yield for step 1.

(2 marks)

(c) Step 2 involves the formation of a nitronium ion for the nitration of Toluene, as shown in the following equation:

$$HNO_3 + 2H_2SO_4 \rightarrow NO_2^+ + 2HSO_4^- + H_3O^+$$

i) Explain the role of the nitric acid in the formation of the electrophile.

[2]

ii) Explain the role of the sulphuric acid in the overall nitration reaction.

[1]

(3 marks)

(d) Explain why the product of step 2 is most likely to have the nitro group bonded to the second or fourth carbon atom.

(1 mark)

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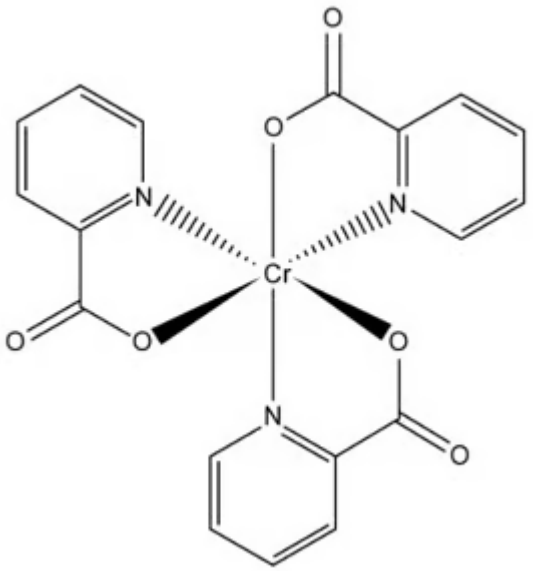
3 (a) Chromium (III) picolinate, shown below, is often used in tablets as a nutritional supplement for chromium.



i) Draw the structure of the ligand in chromium(III) picolinate.

[1]

ii) State the coordination number of chromium in chromium(III) picolinate.

[1]

.....

.....

(2 marks)

(b) A complex of cobalt has the following composition by mass:

Co, 21.98%; N, 31.35%; H, 6.81%; Cl, 39.86%

i) Calculate the empirical formula of this complex.

[2]

ii) The formula of this cobalt complex can be expressed in the form $[Co(L)_m]^{x+}(Cl^-)_n$. Suggest the chemical formula of $[Co(L)_m]^{x+}$.

[1]

.....

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(3 marks)

(c) $Ni(ClO_4)_2$ reacts with water to form the complex ion $[Ni(H_2O)_6][ClO_4]_2$.

Explain this reaction in terms of an acid-base theory.

(2 marks)

(d) Nickel(II) forms a complex ion with water, $[Ni(H_2O)_6]^{2+}$

i) Outline how the bond is formed between Ni^{2+} and H_2O during the formation of the complex.

[1]

ii) State the geometry of the complex formed.

[1]

(2 marks)

4 (a) Ammonia reacts with boron trifluoride to form an adduct, a molecule made from the combination of two others.

$$NH_3 + BF_3 \rightarrow NH_3BF_3$$

Identify the Lewis acid and base and the type of bond formed between a Lewis acid and base.

(2 marks)

(b) Explain the role of water, in terms of Lewis acid-base theory, in the following equations:

$$NH_3\,(aq) + H_2O\,(l) \rightleftharpoons NH_4^+\,(aq) + OH^-\,(aq)$$
$$HCl\,(aq) + H_2O\,(l) \rightarrow H_3O^+\,(aq) + Cl^-\,(aq)$$

(2 marks)

(c) 'All Brønsted-Lowry acids are Lewis acids but not all Lewis acids are Brønsted Lowry acids.'

Evaluate whether this statement is true, giving an appropriate example.

(4 marks)

(d) In the nitration of benzene, identify a species which acts as a Lewis base.

(1 mark)

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5 (a) Halogen molecules can react with alkenes to produce halogenoalkanes which contain two halogen atoms. Explain why halogen molecules can react with alkenes.

(2 marks)

(b) Outline the mechanism for the reaction between 1-methylcyclohex-1-ene and hydrogen bromide, HBr, to form the major product.

(3 marks)

(c) Explain why a major product and minor product are produced in the reaction outlined in part b).

(3 marks)

(d) The major product from the reaction of part b) forms an alcohol when reacted with water. Predict the type of mechanism for this reaction and the structure of the alcohol.

i) State the type of mechanism that will occur.

[1]

ii) Give the structure of the alcohol formed.

[1]

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(2 marks)

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6 (a) $C_5H_{11}Cl$ is a chiral molecule.

Draw the three-dimensional shape of each enantiomer of this isomer showing their spatial relationship to each other

(2 marks)

(b) One of these enantiomers undergoes alkaline hydrolysis and approximately 75 % of the product formed shows an inversion of configuration.

Outline the mechanism that causes approximately 100% of the inversion of configuration.

(3 marks)

(c) Explain why the inversion of configuration is 75%.

(2 marks)

(d) Explain what would happen to the rate of the mechanism in part b) if the concentration of alkali is doubled.

(1 mark)

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(e) Comment on the rate if ammonia was reacted with $C_5H_{11}Cl$ compared to alkaline hydrolysis.

.....

.....

(2 marks)

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7 (a) The theoretical molecule cyclohexa-1,3,5-triene reacts differently with bromine than benzene.

Benzene will react with bromine in the presence of aluminium bromide. Outline the mechanism for this reaction.

(3 marks)

(b) State the name of the mechanism that occurs during the reaction between cyclohexa-1,3,5-triene and bromine.

(1 mark)

(c) The nitration of benzene is the first important step in the manufacture of dyes and explosives.

i) Outline the generation of the electrophile for the nitration of benzene by writing an equation.

[1]

ii) Indicate in your equation which reactant is acting as a Brønsted Lowry base.

[1]

iii) Explain your answer and identify the conjugate acid and base pairs in the reaction.

[1]

(3 marks)

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(d) Explain why benzene can only undergo substitution reactions.

(3 marks)

8 (a) Benzene and cyclohexene are two hydrocarbons that are able to react with bromine. State the type of reactions in each case.

(2 marks)

(b) Benzene can be converted into nitrobenzene in a one step reaction. State the names of the reagents needed for the reaction and the formula of the electrophile in the reaction.

(2 marks)

(c) Outline the mechanism of the reaction between benzene and the electrophile in part c)

(4 marks)

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