TEMASEK JUNIOR COLLEGE
JC2 Preliminary Examination
Higher 3

CANDIDATE NAME						CIVICS GROUP			/	2	0
CENTRE NUMBER	S					INDEX NUMBER					▨

CHEMISTRY

9813/01

Paper 1

21 September 2021

2 hours 30 minutes

Candidates answer on the Question Paper.

Additional Materials: Data Booklet
Insert

READ THESE INSTRUCTIONS FIRST

Write your Centre number, index number, name and CT on all the work you hand in.
Write in dark blue or black pen.
You may use an HB pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

Answer **all** the questions in the spaces provided on the Question Paper. If additional space is required, you should use the pages at the end of this booklet. The question number must be clearly shown.

Section A
Answer **all** questions.

Section B
Answer **two** questions only.

The use of an approved scientific calculator is expected, where appropriate.
A Data Booklet is provided.

The number of marks is given in brackets [ ] at the end of each question or part question.
You are reminded of the need for good English and clear presentation in your answers.

This document consists of **36** printed pages and **1** Insert.

[Turn over

Section A

Answer **all** questions in this section.

1 The information provided in the insert is taken from two published scientific articles.

You should read the whole insert before you start to answer any questions and use the information it contains to answer the questions.

(a) Suggest **two** reasons why current methods of performing allylic oxidation is neither scalable nor sustainable. [2]

………

………

………

………

………

………

………

………

(b) Allylic oxidation usually begins with the formation of an allyl radical. Table 1.1 lists the bond dissociation energy (BDE) of allylic C–H bond and 1º C–H bond in propene and propane respectively.

Table 1.1

	BDE/ kJ mol^{-1}
$H–CH_2CH=CH_2$	372
$H–CH_2CH_2CH_3$	423

Use the concepts of electronic effect and Hammond Postulate to explain why allylic oxidation is more easily achieved than oxidation of the 1º C–H bond of an alkane. [2]

………

………

………

………

………

………

………

………

………

(c) Fig. 1.1 illustrates the reactions occurring during the electrosynthesis of enone from an allylic substrate.

(i) Write balanced half-equations for the reactions occurring at the anode and cathode. [2]

(ii) The allylic substrate does not get oxidised directly at the electrode.

Instead, R_2N–OH is used as the *mediator* and ^{t}BuOOH is used as the *co-oxidant* to produce the enone.

Suggest what you understand by the italicised terms above. [2]

(iii) Construct an equation representing the overall chemical transformation that occurs. [1]

(d) Refer to Fig. 1.2 to answer the following questions.

(i) Use curly arrows to suggest the mechanism for the reduction of TBS-cresol (**D**) to form **E**, given that the reaction begins by a **single electron transfer** from the cathode to the phenyl ring. [3]

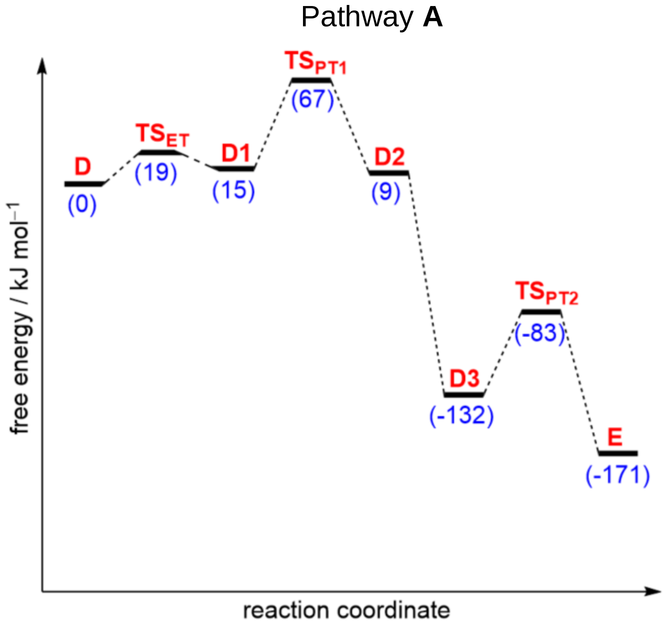
(ii) Write a balanced half-equation for the reaction occurring at the Mg anode. [1]

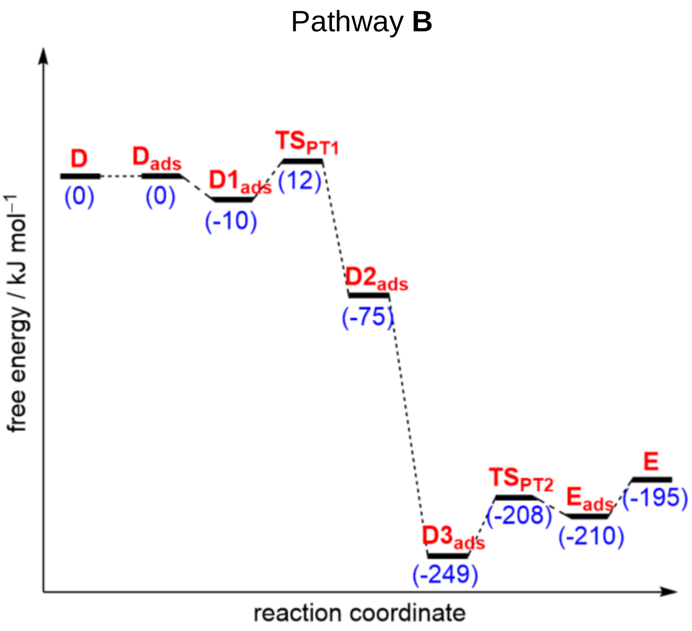
(iii) Suggest a difference in the product if an inert electrode such as Pt is used in place of Mg. [1]

(e) The reduction of **D** to **E** shown in Fig. 1.2 was hypothesised to proceed via one of two pathways, **A** or **B**:

- Pathway **A**: Li atoms, generated *in-situ* by the cathode, transfer electrons to **D**.
- Pathway **B**: **D** adsorbed onto the electrode before the electrode transfers electrons to **D**.

The energy profile diagrams for both pathways **A** and **B** are given below. The number in parenthesis is the free energy of the intermediate species or transition state (TS) relative to **L**. TS for steps which are barrierless are not shown for clarity.





(ET – electron transfer; PT – proton transfer; ads – adsorption)

The rate determining step is the step with the largest activation energy. By identifying the rate determining step for each pathway and calculating its activation energy, suggest which pathway the reduction of **D** to **E** undergoes. [2]

……

……

……

……

……

……

……

……

……

……

……

……

(f) Another method of reducing TBS-cresol is the Birch reduction. To reduce 100 g (0.45 mol) of TBS-cresol via the Birch reduction, the reactants required are summarised in Fig. 1.3.

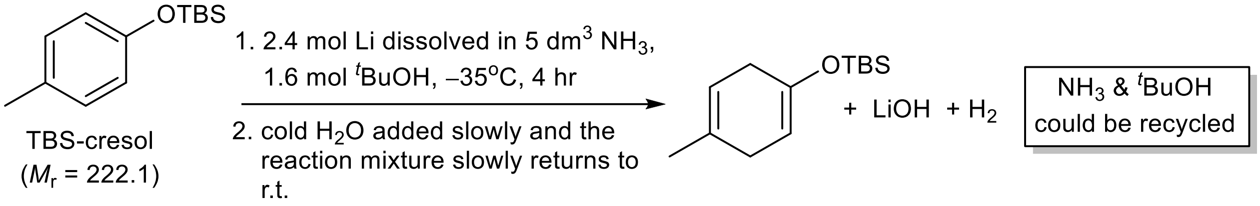


Fig. 1.3

Given that the boiling point of NH_3 is –33 °C, by comparing the reagents and conditions used in both methods, suggest why the Birch reduction is not a feasible method for large-scale reduction of TBS-cresol as compared to the work by Baran and co-workers. [3]

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

(g) The reduction described in Fig. 1.2 is dependent on the rate of transfer of the electrons from the stainless-steel electrode to TBS-cresol.

The rate constant of the electron transfer from the electrode to TBS-cresol, k_{red} could be calculated using equation 1.1.

equation 1.1 $$k_{red} = \frac{I}{F \times A \times [R]_{surface}}$$

I = value of the current supplied in the experiment
F = Faraday's constant
A is the surface area of electrode
$[R]_{surface}$ is the surface concentration of TBS-cresol on the electrode in mol cm^{-2} s^{-1}.

Table 1.2 provides data to a typical experiment.

Table 1.2

mass of TBS-cresol used / g	10.0
dimension of each immersed electrode (length / cm x width / cm)	10.0×4.0
I / A	0.75
duration / hr	16
mass of TBS-cresol reduced / g	7.1

(i) Show that the surface concentration of TBS-cresol (M_r = 222.1) in a typical experiment is 1.39×10^{-8} mol cm^{-2} s^{-1}. [1]

(ii) Hence, calculate the value of k_{red} for the setup. [1]

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

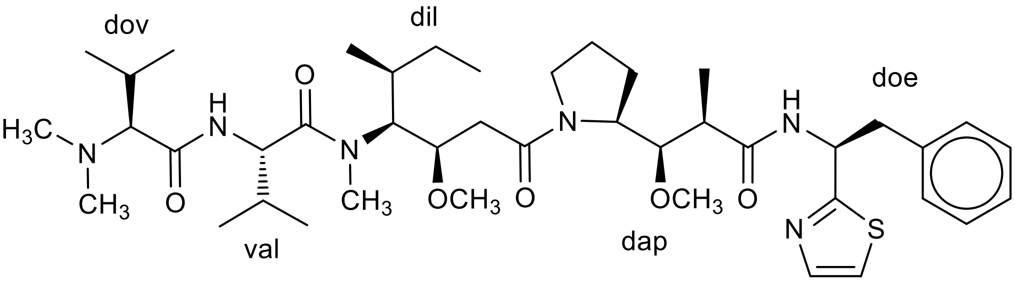
……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

[Total: 21]

2 Dolastatin 10 is a powerful anticancer agent that was isolated from the sea-hare *Dolabella*. It is a linear peptide of five amino acids: dolavaline (dov), valine (val), dolaisoleucine (dil), dolaproline (dap) and dolaphenine (doe).

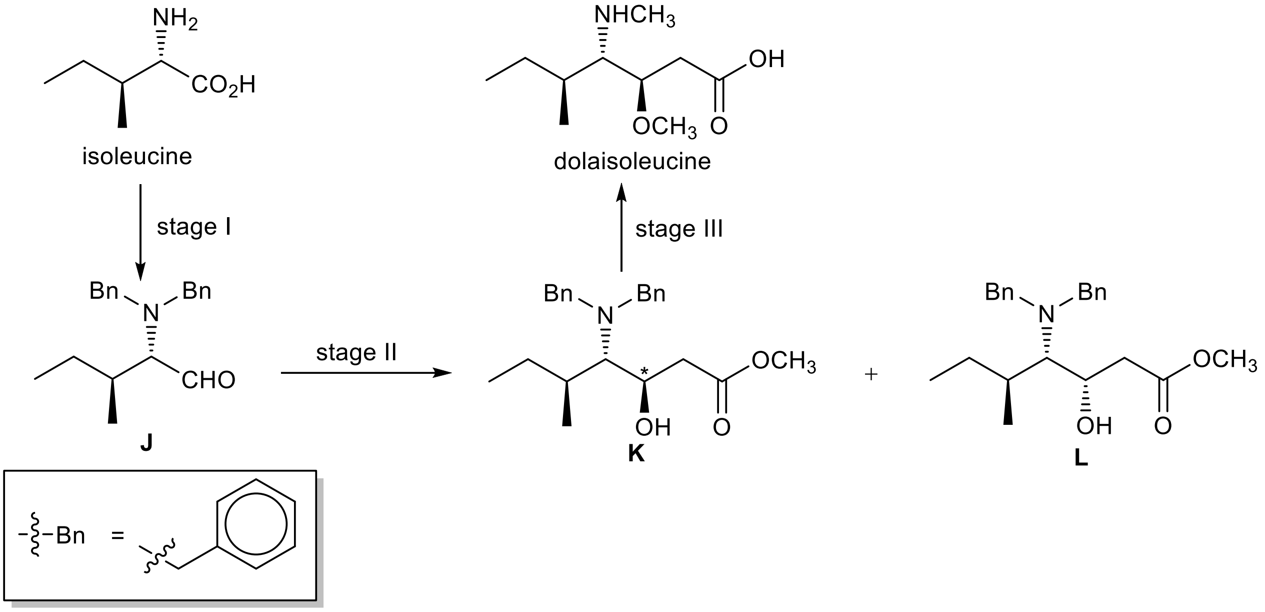


dolastatin 10

(a) Draw the structures of the organic compounds formed when dolastatin 10 is heated under reflux with NaOH(aq) for several hours.

Assume that the methyl ether ($–OCH_3$) groups and the thiazole (N- and S- containing ring) in the dolaphenine residue do not react under these conditions. [3]

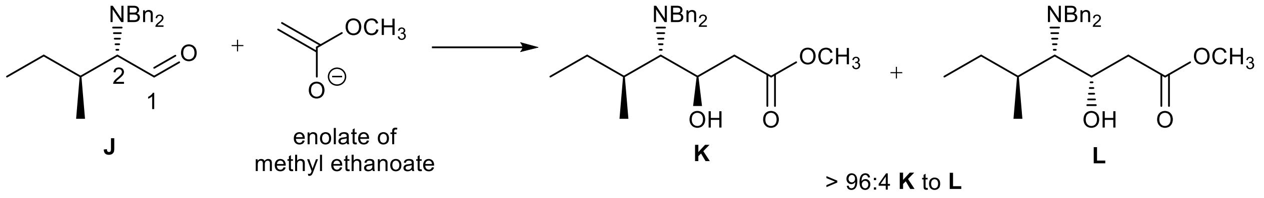
(b) One of the amino acids in dolastatin 10, dolaisoleucine, can be synthesised from isoleucine in three stages as shown below.



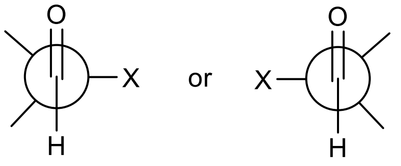
(i) Suggest, in no more than three steps, how isoleucine can be converted to compound **J** in stage I. Draw structures for the intermediates and state reagents and conditions needed for each step. [3]

(ii) Using the *R* and *S* convention, assign the absolute configuration of the chiral centre labelled with asterisk (*) in compound **K**. Your answer should include priority assignments as defined by the Cahn-Ingold-Prelog rules. [1]

(c) Stage II of the synthesis of dolaisoleucine in **(b)** is a stereoselective aldol reaction between **J** and the enolate of methyl ethanoate.

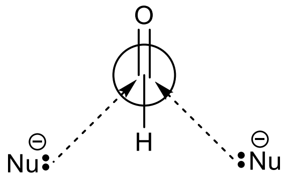


In such instances of stereoselective nucleophilic addition reactions, the carbonyl compound assumes conformations that have the largest substituent, X, perpendicular to the plane of the carbonyl group as shown below.



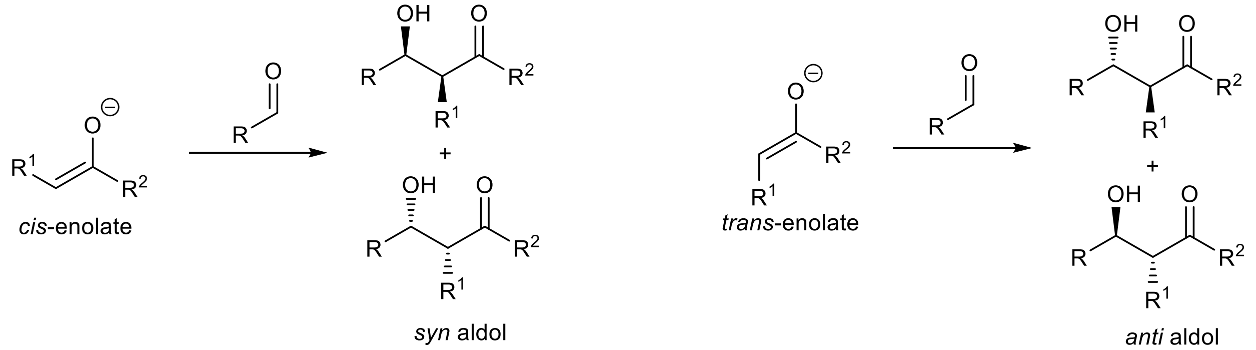
(i) By viewing along the C^1–C^2 bond in the chiral aldehyde **J**, draw the **two** possible Newman projections which would satisfy the above condition. [2]

(ii)

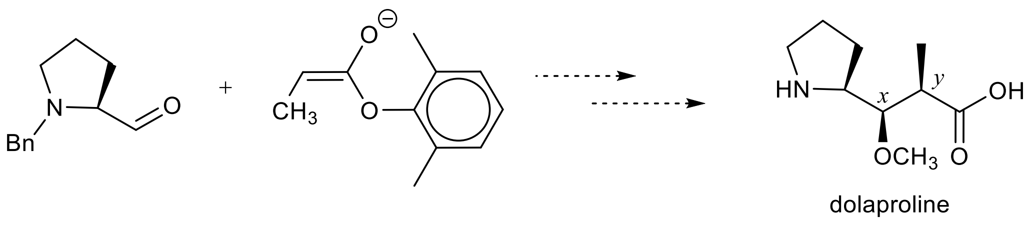


Given that a nucleophile attacks about 107° from either side of the C=O bond as shown above, rationalise why **K** is formed almost exclusively by using the Newman projections you have drawn in **(c)(i)**. You may represent the enolate nucleophile as :Nu$^-$. [3]

When substituted enolates are used in the aldol reaction, *cis*-enolates give *syn* aldol products, while *trans*-enolates give *anti* aldol products as shown. For each enolate used, the major diastereoisomer formed also depends on the stereochemistry of the aldehyde, as described in **(c)(i)**.



(iii) Using all of the above information, deduce whether the following pair of aldehyde and enolate is able to give the desired configuration of chiral centres *x* and *y* in dolaproline. [2]



[Total: 14]

3 Methylene blue (**MB**), also known as methylthioninium chloride, is a salt used as a medication and dye. Its structure and IR spectrum are shown in Fig. 3.1.

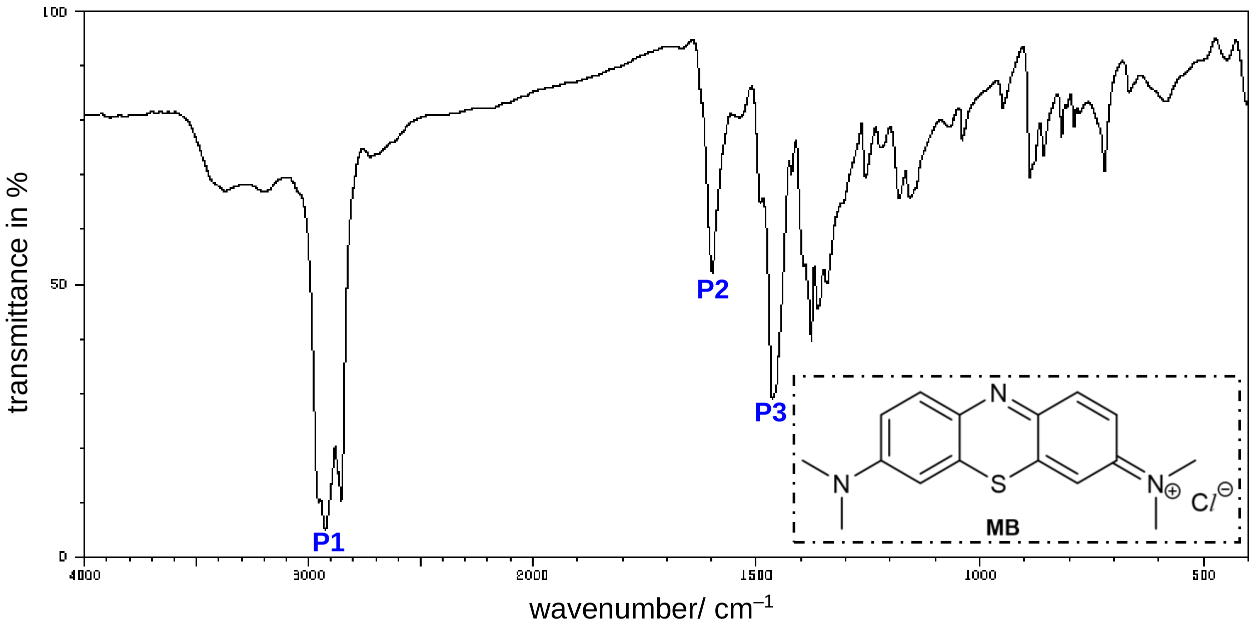


Fig. 3.1

(a) **(i)** Outline the principles underlying IR spectroscopy. [2]

(ii) Suggest the bonds and their modes of vibrations giving rise to each of the labelled peaks. [2]

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

(b) **MB** (M_r = 319.6) has a λ_{max} of 665 nm.

A sample of **MB**(aq) was prepared by dissolving 0.095 g of **MB** in 250 cm^3 of water. A 1.0 cm^3 sample of this solution is made up to 100 cm^3 with water. The diluted solution was found to have an absorbance of 0.88 at 665 nm in a cell with a path length of 1.0 cm.

Calculate the molar extinction coefficient, ε, for **MB** at 665 nm. [2]

………

………

………

………

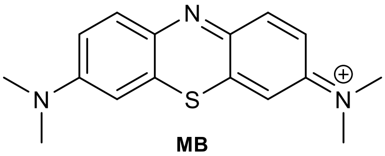
………

………

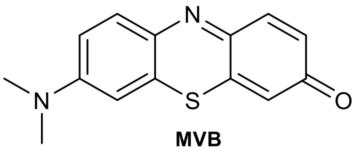
………

………

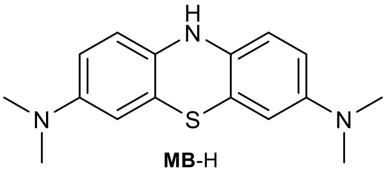
(c) **MB** reacts readily with NaOH(aq) to give **MVB** (λ_{max} = 525 nm), a red-coloured compound. A closely related compound, **MB**-H (λ_{max} = 256 nm) was found to be colourless.



MB



MVB



MB-H

(i) By drawing out appropriate resonance structures, explain why **MVB** and **MB**-H have different λ_{max} values. [2]

(ii) Suggest the type of reaction **MB** undergoes to give **MVB** and give the by-product of the reaction. [1]

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

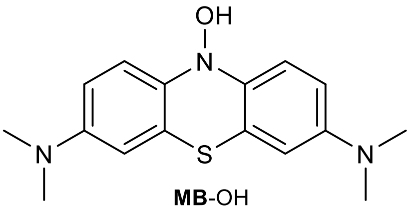
……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

(d) **MB**-OH was originally proposed to be the structure of the red-coloured compound produced from **MB** and NaOH(aq).



MB-OH

The nitrogen atom in the central ring of **MB** was postulated to be electrophilic since one of the resonance structures of **MB** contains a +1 formal charge. The formation of **MB**-OH from **MB** would then involve a nucleophilic attack by HO⁻ onto this nitrogen atom.

(i) By drawing out the said resonance structure, explain why the above postulate is not likely to be valid. [1]

(ii) By using the information in **(c)**, suggest one further reason why **MB**-OH is not likely to be the structure of the red-coloured compound. [1]

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

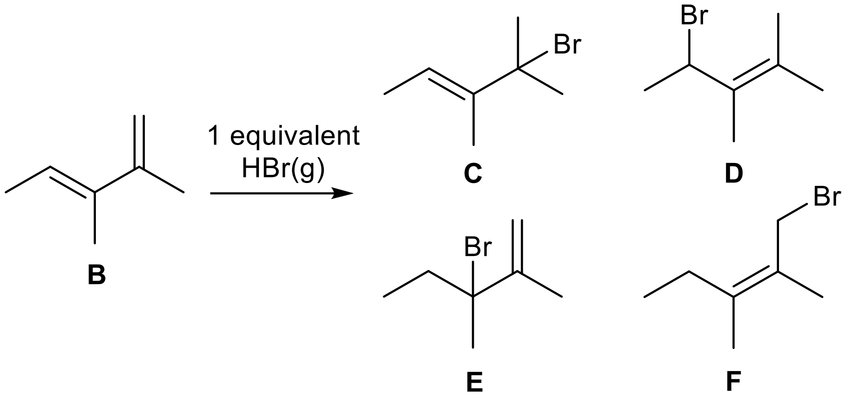
....

....

....

[Total: 11]

4 **(a)** When **B** is subjected to one equivalent of HBr, products **C**, **D**, **E** and **F** are obtained in different ratios under four different temperature conditions as shown in Fig. 4.1.



T/ °C	(**C**+**E**):(**D**+**F**)
–25	85:15
0	60:40
40	20:80
70	5:95

Fig 4.1

(i) Suggest mechanism leading to **C**, **D**, **E** and **F**. [2]

(ii) Products **C** and **E** are often termed as the *kinetic products* whereas products **D** and **F** are termed as the *thermodynamic products*. By considering the stability of the transition states leading to the products as well as the stability of the products, suggest an explanation to the terms in italics. [3]

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

(b) The atomic orbitals of electronegative atoms are lower in energy (i.e. more stable) than those of less electronegative atoms.

The difference in electronegativity distorts the energies of the molecular orbitals formed by the overlap of atomic orbitals on two adjacent atoms. Fig. 4.2 shows the molecular orbitals (MOs) of π symmetry in ethene and methanal.

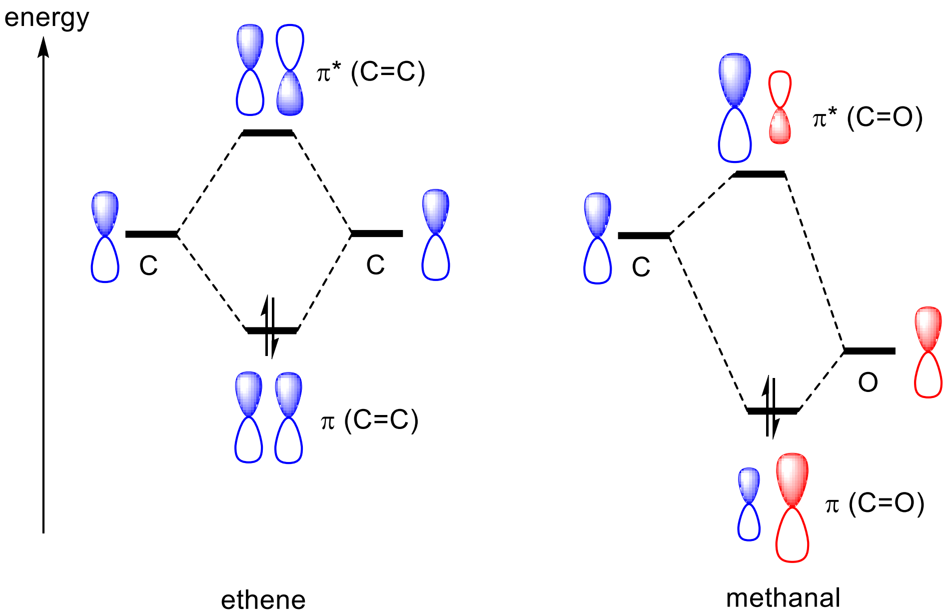
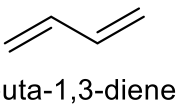
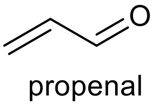


Fig. 4.2

(i) The four MOs of π symmetry of buta-1,3-diene may be constructed by applying linear combination to the π and π* of two C=C.

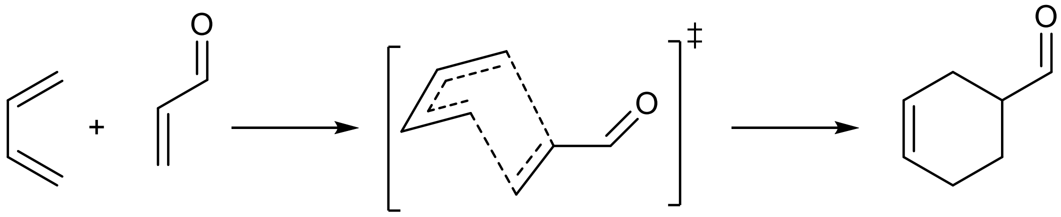
The four MOs of π symmetry of propenal may be constructed similarly, but by using the π and π* of C=C and C=O instead.


buta-1,3-diene


propenal

Use the above information and Fig. 4.2 to construct the MOs of π symmetry of buta-1,3-diene and propenal, similar to the one depicted in Fig. 4.2. Label the HOMO and LUMO in your diagram. [3]

(ii) Buta-1,3-diene and propenal undergoes the Diels-Alder reaction in one concerted step as shown.



The reaction can be understood by using the MOs of π symmetry constructed in **(a)(i)** where the HOMO of buta-1,3-diene interacted with the LUMO of propenal in the transition state. By copying the shape of the transition state and drawing in the appropriate MOs, explain why the two reactants approach in the above manner and how this leads to the formation of the two new σ bonds. [2]

(c) Biphenyl **G** is an example of a molecule exhibiting atropisomerism (isomerism arising due to hindered rotation about C_a and C_b). The potential energy diagram associated with various conformations rotated through C_a and C_b is given in Fig. 4.3 below.

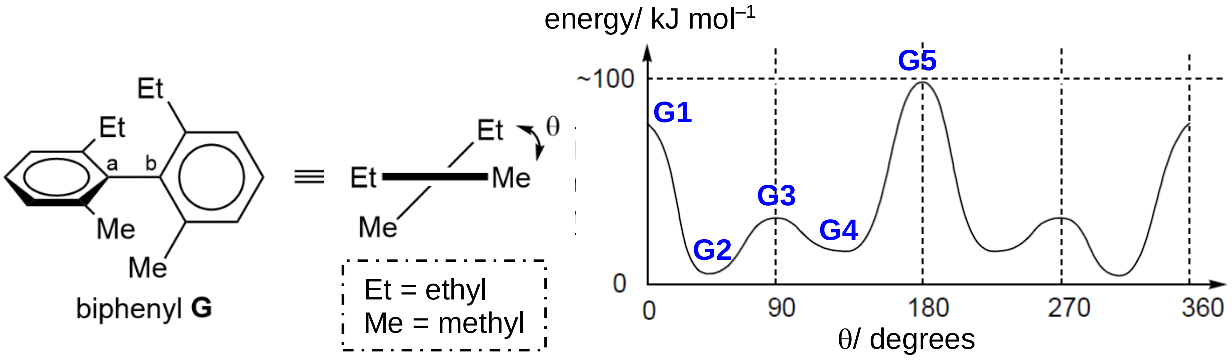


Fig. 4.3

(i) Electronic effect alone favours θ = 0° and 180° whereas steric effect alone favours θ = 90°. However, conformations taking these θ end up as the local maximum points in the potential energy diagram. The local minimum points were instead found to be at θ = 45° and 135°.

Use the concepts of steric effect and delocalisation to explain the observations above. [3]

(ii) State the stereochemical relationship between the conformations at θ = 90° and 270°. [1]

[Total: 14]

Section B

Answer **two** questions from this section.

5 **(a)** Compound **Q** is an essential oil extracted from cloves that is widely used as a flavoring. **Q** is a multi-substituted aromatic compound that contains only C, H and O. The molecular ion peak in its mass spectrum is m/z = 164 and the ratio of the peak heights of the M and M+1 peak is 54:6.

Table 5.1 shows the peaks in the ^1H NMR spectrum of **Q**. The peak at δ 5.53 disappears in the presence of D_2O.

Table 5.1

chemical shift δ / ppm	integration	multiplicity
3.29	2	doublet
3.81	3	singlet
5.04	2	multiplet
5.53	1	broad singlet
5.91	1	multiplet
6.66	1	singlet
6.67	1	doublet
6.82	1	doublet

(i) Deduce the molecular formula of **Q**, showing your reasoning. [2]

(ii) Explain the use of TMS in ^1H NMR spectroscopy. [1]

(iii) With reference to the chemical shifts of the peaks and their observed splitting pattern, deduce a structure for **Q** and explain your answer. [4]

(iv) Compound **R** is a positional isomer of **Q**. In the ^1H NMR spectrum of **R**, the peak that disappears in the presence of D_2O was found to be at a lower chemical shift compared to that of **Q**.

Suggest a possible reason for this. [1]

....

....

....

....

....

....

....

....

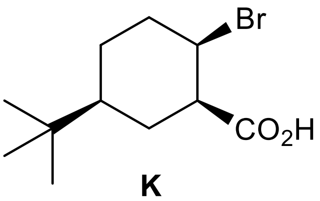
....

....

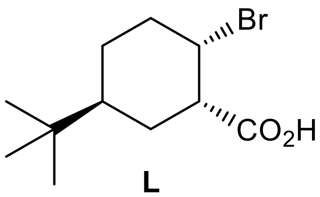
....

DO NOT WRITE IN THIS MARGIN DO NOT WRITE IN THIS MARGIN DO NOT WRITE IN THIS MARGIN DO NOT WRITE IN THIS MARGIN DO NOT WRITE IN THIS MARGIN

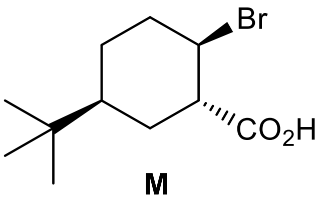
(b) When three stereoisomers **K**, **L** and **M** with the molecular formula $C_{11}H_{19}BrO_2$ are reacted with excess sodium ethoxide, different rates of reaction and products are observed.



K



L



M

(i) Draw the alkenes formed from the elimination of HBr from **K**. Explain which alkene is the major product. [2]

(ii) Draw the lowest energy conformations of **K**, **L** and **M**. [2]

(iii) **K** and **L** undergo E2 reactions at different rates. Draw the relevant ring conformation of **L**, using stereochemical projections and curly arrows for the E2 reaction, to explain

- the stereochemistry of the reactions, and
- the relative rate of E2 reaction of **K** compared to **L**. [2]

(iv) The reaction of **M** with sodium ethoxide gives rise to the formation of $C_{10}H_{18}$ and other by-products. Suggest the structure of $C_{10}H_{18}$ and a mechanism to show its formation. [2]

(v) **K** reacts with thionyl chloride to give an acid chloride.

State the molecular formulae of the species responsible for the M, M+2 and M+4 peaks in the mass spectrum of the acid chloride and calculate their relative intensities. [2]

………………………………………………………………………………………………………

………………………………………………………………………………………………………

………………………………………………………………………………………………………

………………………………………………………………………………………………………

………………………………………………………………………………………………………

………………………………………………………………………………………………………

………………………………………………………………………………………………………

………………………………………………………………………………………………………

………………………………………………………………………………………………………

………………………………………………………………………………………………………

………………………………………………………………………………………………………

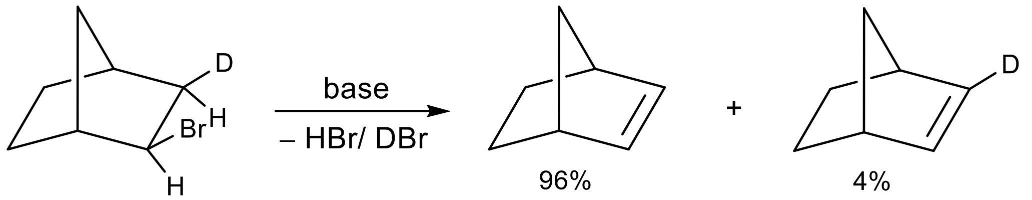
………………………………………………………………………………………………………

………………………………………………………………………………………………………

………………………………………………………………………………………………………

………………………………………………………………………………………………………

(c) The base-catalysed elimination of HBr / DBr from deuterated norbornyl bromide is given below.



N **P**

(i) State a method that will distinguish between compounds **N** and **P**, and describe the measurements needed to distinguish them. [1]

(ii) Explain why **N** is the major product of these elimination reactions. [1]

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

[Total: 20]

6 **(a)** Table 6.1 presents the data obtained for the nucleophilic substitution of bromomethane with various nucleophiles.

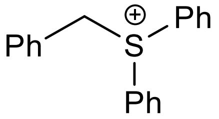
Table 6.1

nucleophile	H_2O	$CH_3CO_2^-$	Cl^-	PhO^-	HO^-	PhS^-
relative rate	1	900	1100	2000	1.2×10^4	5.0×10^7

(i) Explain the difference in the strength of nucleophiles, PhO^- and PhS^-. [1]

(ii) Deduce whether bromomethane undergoes S_N1 or S_N2 pathway. Justify your deduction, using the information in Table 6.1. [1]

Table 6.2 presents the data obtained for the nucleophilic substitution of benzyl sulfonium salt, **Y** with various nucleophiles.



benzyl sulfonium salt, **Y**

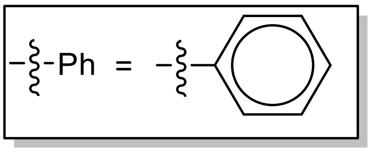
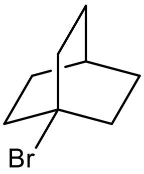


Table 6.2

nucleophile	$CH_3CO_2^-$	Cl^-	PhO^-	HO^-	PhS^-
relative rate	1.0	1.0	1.0	18.5	27.0

(iii) Deduce the most probable pathway **Y** undergoes with **each** of the five nucleophiles. Justify your deductions, using the information in Table 6.2. [2]

(iv) Cage halide **X** does not react with nucleophiles either by S_N1 or by S_N2.



X

Suggest reasons why this is so. [2]

………

………

………

………

………

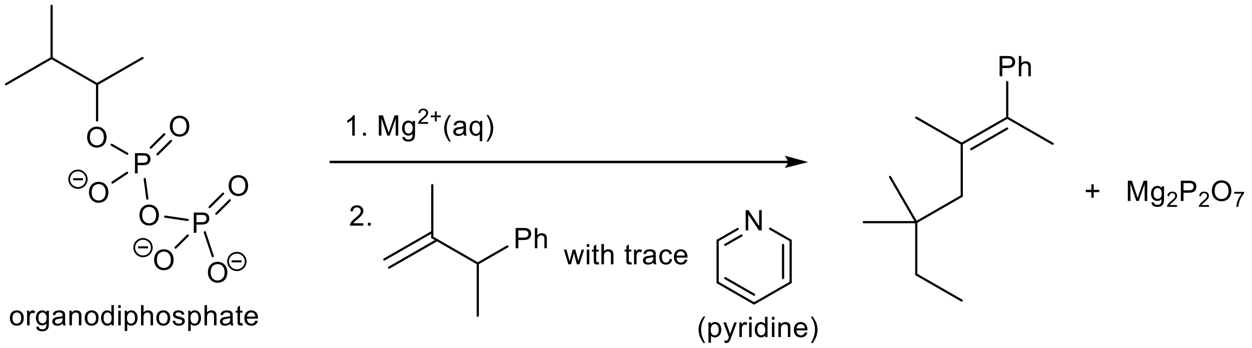
………

………

………

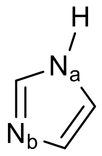
(b) In biological substitution reactions, the most common substrate which reacts with nucleophiles is organodiphosphate rather than alkyl halide.

One such reaction takes place as shown below.



(i) Suggest two reasons why an S_N1 reaction takes place very readily in the presence of **aqueous** Mg^{2+} ions. [2]

(ii) In place of pyridine, imidazole can also be used in step 2.



imidazole

With reference to the basicity of the two nitrogen atoms in imidazole, explain which nitrogen atom, N_a or N_b, reacts similarly as the nitrogen atom in pyridine. [2]

(iii) Starting from the carbocation in step 1, propose a suitable mechanism for step 2. Show clearly the movement of electrons using appropriate curly arrows and charges present. [3]

……

……

……

……

……

……

……

……

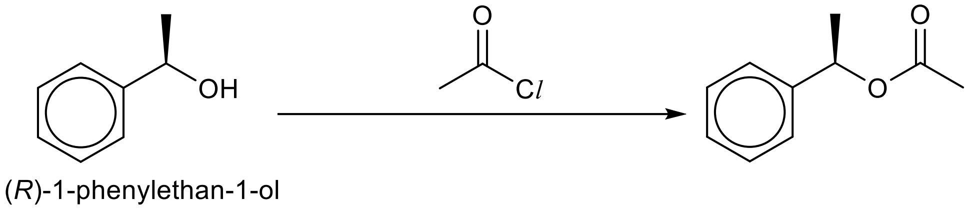
……

……

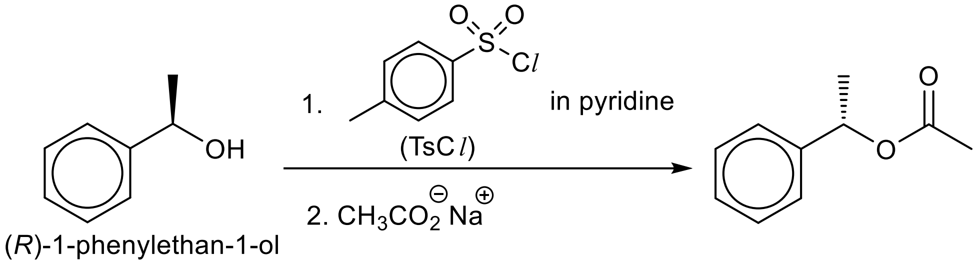
……

……

(c) Optically pure alcohols such as (*R*)-1-phenylethan-1-ol can be converted to enantiomeric esters by two different methods shown below.



Reaction **I**



Reaction **II**

(i) Explain the stereochemistry of the ester produced from reaction **I**. [1]

(ii) Explain why reaction **II** produces an ester of opposite stereochemistry from that of reaction **I**. [2]

(iii) The ester from either reactions above is placed in a mass spectrometer and three fragments, **P**, **Q** and **R** are obtained.

fragment	*m*/z
P	43
Q	122

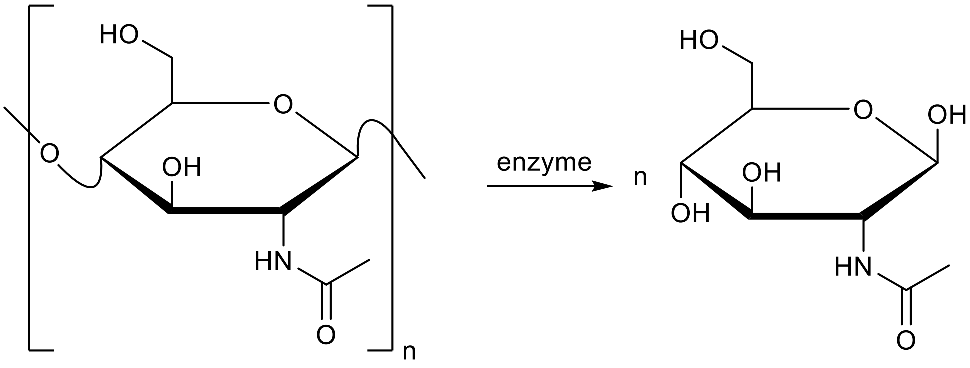
Fragment **Q** is obtained from a rearrangement reaction of the molecular ion, forming a highly reactive gas, **R**. Gas **R** is also formed from the dehydration of ethanoic acid.

Suggest the structures of **P**, **Q** and **R**.

Using appropriate curly arrows, illustrate how **Q** and **R** are formed from the rearrangement reaction. [4]

[Total: 20]

7 **(a)** Chitin is a linear polymer found in a variety of marine animals, insects and fungi. It functions as a protective layer in the skin or shell for these organisms. Upon enzymatic hydrolysis, the monomer of chitin, N-acetylglucosamine, is obtained.



chitin

N-acetylglucosamine
($C_8H_{15}O_6N$)

Use relevant data from the *Data Booklet* together with $\Delta H^{\ominus}_{\text{atomisation}}$ (carbon) = +717 kJ mol^{-1} to estimate the standard enthalpy change of formation of solid N-acetylglucosamine. [2]

(b) Chitosan is a biodegradable polymer with unique biological and physicochemical properties, consisting of glucosamine and N-acetylglucosamine units. It is obtained by treating chitin with hot concentrated NaOH, as shown in Fig. 7.1. During the reaction, some amide groups on chitin is hydrolysed, resulting in a partial deacetylation process.

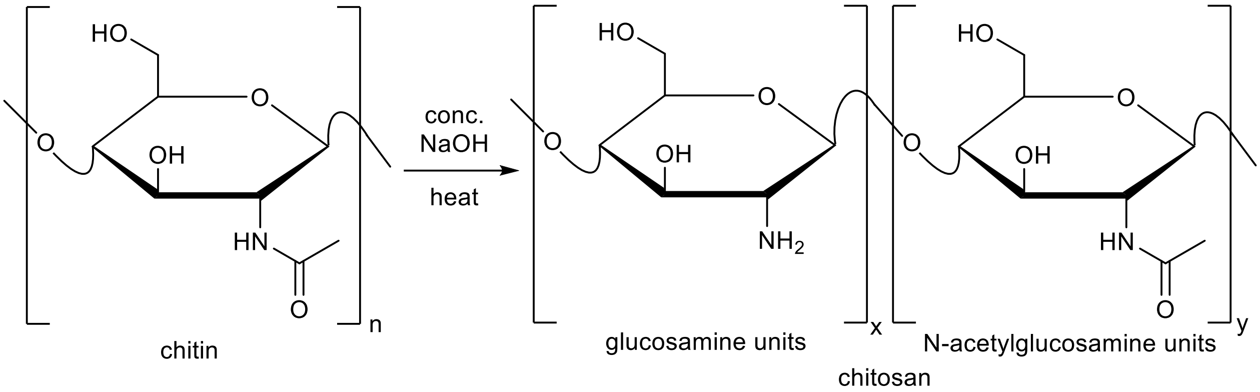


Fig. 7.1

(i) By drawing a suitable diagram, suggest why the IR absorption frequency of the carbonyl group in N-acetylglucosamine is less than the IR absorption frequency of the carbonyl group in propanone. [2]

(ii) Describe how the IR and ^{1}H NMR spectra of chitin changes as the conversion of chitin to chitosan progresses. You should include two differences in each spectrum, and the details of the signals clearly in your answer. [4]

....

....

....

....

....

....

....

....

....

....

....

....

....

....

....

(c) The process of deacetylation of chitin to produce chitosan depends on the reaction conditions used, and the complete deacetylation of chitin is difficult to achieve.

The degree of deacetylation, DD, is defined as the molar percentage of the deacetylated glucosamine units in the products. The value of DD, which varies from 0 (chitin) to 100 (fully deacetylated chitin), can be calculated using equation 7.1.

$$\text{equation 7.1} \quad \text{DD} = \frac{\text{number of moles of glucosamine units}}{\text{total number of moles of glucosamine and N-acetylglucosamine units}} \times 100\%$$

To determine DD, the following experimental procedure is carried out on a sample of chitosan:

1. 0.20 g of chitosan is first dissolved in excess $HCl(aq)$ and deionised water.
2. The solution is then titrated with 0.10 mol dm^{-3} $NaOH(aq)$. The conductivity of the solution is simultaneously measured.
3. A graph of conductivity vs volume of $NaOH(aq)$ added is plotted, as shown in Fig. 7.2.

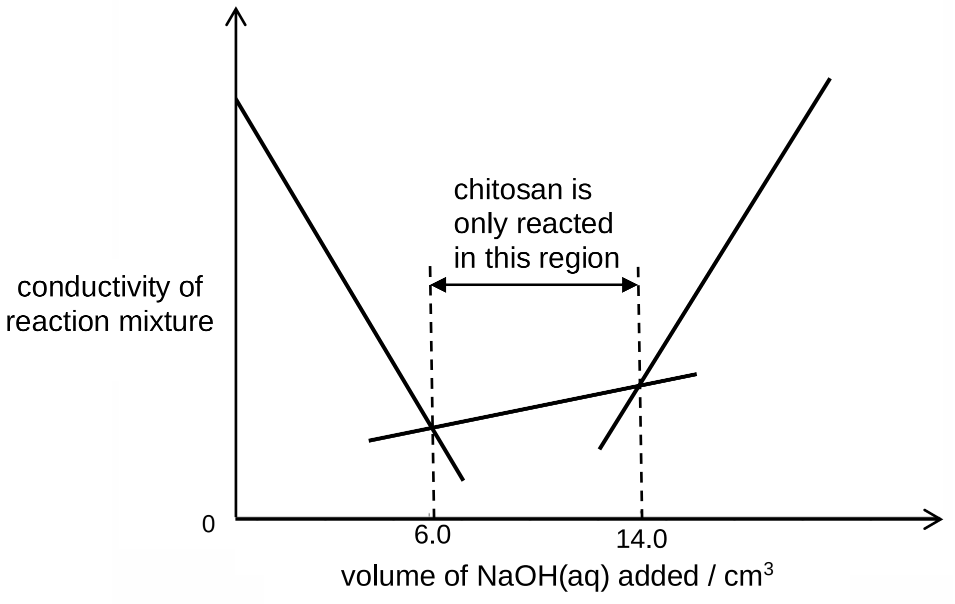


Fig. 7.2

(i) Using the diagram shown in Fig. 7.1, draw a unit of chitosan that exists in the solution after step 1, before titration is carried out.

Hence, explain why chitosan is not soluble in pure water, but soluble in an acidic solution. [3]

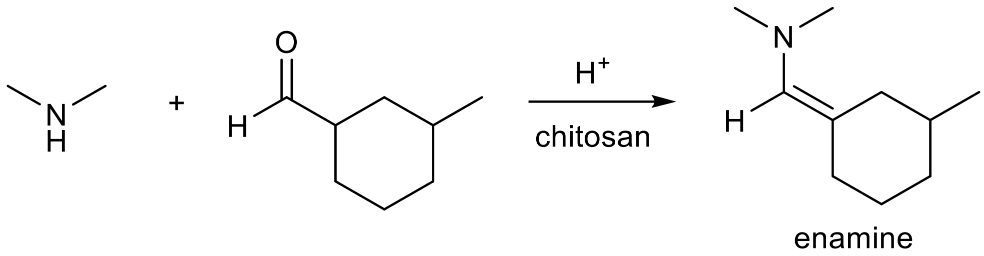
(ii) The conductivity of a reaction mixture depends on both the charge and mass of the ions present in the solution.

With reference to the graph in Fig. 7.2, describe and explain how the conductivity of the reaction mixture changes with the addition of $NaOH(aq)$. [3]

(iii) The relative molecular mass of an N-acetylglucosamine unit and a glucosamine unit is 203 and 161 respectively.

Calculate the DD of the sample of chitosan in this experiment. [2]

(d) Chitosan can be used as a catalyst to synthesise enamines and the reaction is carried out in a mildly acidic medium.



(i) Draw the mechanism for the reaction above. [2]

(ii) Assign the configuration of the enamine product using the *E*/*Z* convention. Explain your answer using the priority assignments as defined by the Cahn-Ingold-Prelog rules. [2]

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

………

[Total: 20]

Additional page

If you use the following pages to complete the answer to any question, the question number must be clearly shown.

Copyright Acknowledgements:

Question 1	© Horn, J. H., Rosen, B. R., Chen, Y., Tang, J., Chen, K., Eastgate, M. D. & Baran, P. S. Scalable and sustainable electrochemical allylic C–H oxidation. *Nature*, **533**, 77–81. (2016)
Question 1	© Peters, B. K., Rodriguez, K. X., Reisberg, S. H., Beil, S. B., Hickey, D. P., Kawamata, Y., Collins, M., Starr, J., Chen, L., Udyavara, S., Klunder, K., Gorey, T. J., Anderson, S. L., Neurock, M., Minteer, S. D. & Baran, P. S. Scalable and safe synthetic organic electroreduction inspired by Li-ion battery chemistry. *Science*, **363**, 838–845. (2019)
Question 2b	© Mills, A.; Hazafy, D.; Parkinson, J.; Tuttle, T. & Hutchings, M. G. Effects of alkali on methylene blue (C.I. Basic Blue 9) and other thiazine dyes. *Dyes Pigm*., **88**, 149 – 155. (2011)