

---

## A-Level Chemistry - Exam Style Questions

---

**Group A: Multiple Choice Questions**, consisting of 96 marks total

Physical: 15 questions (6 × 1 mark, 5 × 2 marks, 4 × 4 marks), 32 marks total

Organic: 15 questions (6 × 1 mark, 5 × 2 marks, 4 × 4 marks), 32 marks total

Inorganic: 15 questions (6 × 1 mark, 5 × 2 marks, 4 × 4 marks), 32 marks total

Recommended Time: 2 hours 15 minutes.

Approximate Grade Boundaries (marks): A\* > 77, A > 68, B > 58, C > 48, D > 39

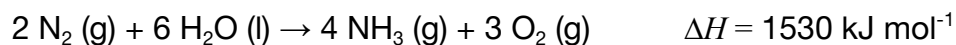
Coverage is based on the AQA Specification.

- A1.** Listed are the electronic configurations for the atoms of different elements. Which one represents the most reactive non-metal?

- ① [He] 2s<sup>1</sup>
- ② [He] 2s<sup>2</sup> 2p<sup>5</sup>
- ③ [Ne] 3s<sup>2</sup> 3p<sup>2</sup>
- ④ [Ne] 3s<sup>2</sup> 3p<sup>5</sup>

[1 mark]

- A2.** Data for the reaction of N<sub>2</sub> (g) with H<sub>2</sub>O (l) at 25 °C and 1 atm is given.



Some molar bond enthalpies are given in the table.

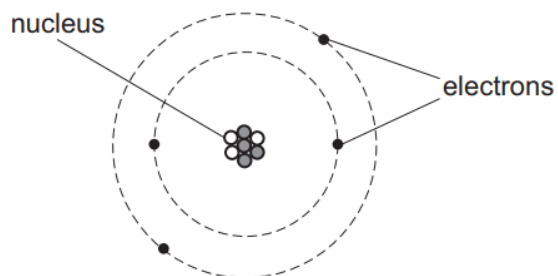
Bond	N $\equiv$ N	H - H	N - H
Enthalpy, kJ mol <sup>-1</sup>	945	435	390

Calculate the standard molar enthalpy of formation of H<sub>2</sub>O (l).

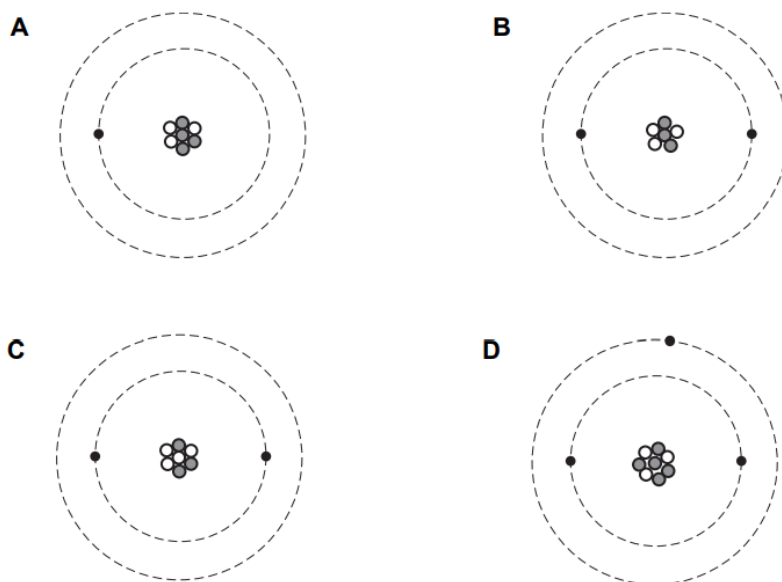
- ① -241 kJ mol<sup>-1</sup>
- ② -264 kJ mol<sup>-1</sup>
- ③ -285 kJ mol<sup>-1</sup>
- ④ -315 kJ mol<sup>-1</sup>

[1 mark]

- A3.** The diagram represents the Bohr model of a charged atom (ion) of one isotope of an element.



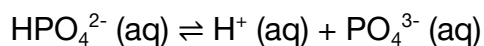
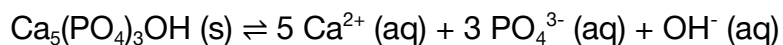
Which diagram(s) represent(s) the structure(s) of an oppositely charged ion of a different isotope of the same element?



- ① **B** only
- ② **A** and **B** only
- ③ **C** and **D** only
- ④ **A**, **B** and **D** only

[1 mark]

- A4.** Hydroxyapatite,  $\text{Ca}_5(\text{PO}_4)_3\text{OH}$ , is the main constituent of tooth enamel. In the presence of saliva, the following equilibria exist:



Which of the following statements help to explain why tooth enamel is dissolved more readily when the saliva is acidic?

- A** Calcium ions react with acids.  
**B** The hydroxide ions are neutralised by the acid.  
**C** The phosphate ion  $\text{PO}_4^{3-} \text{ (aq)}$  accepts  $\text{H}^+ \text{ (aq)}$ .

- ① **A** and **B** only  
② **A** and **C** only  
③ **B** and **C** only  
④ **A**, **B** and **C**

[1 mark]

- A5.** A sample of strontium has a relative atomic mass of 87.7 and consists of three isotopes,  $^{86}\text{Sr}$ ,  $^{87}\text{Sr}$  and  $^{88}\text{Sr}$ . The isotopes  $^{86}\text{Sr}$  :  $^{87}\text{Sr}$  are equally abundant.

What is the percentage abundance of the  $^{86}\text{Sr}$  isotope in this sample?

- ① 10%  
② 20%  
③ 30%  
④ 40%

[1 mark]

- A6.** The acylium ion is an organic cation generated by the reaction of ethanoyl chloride with  $\text{AlCl}_3$ .

The geometry around the carbocation in an acylium ion is

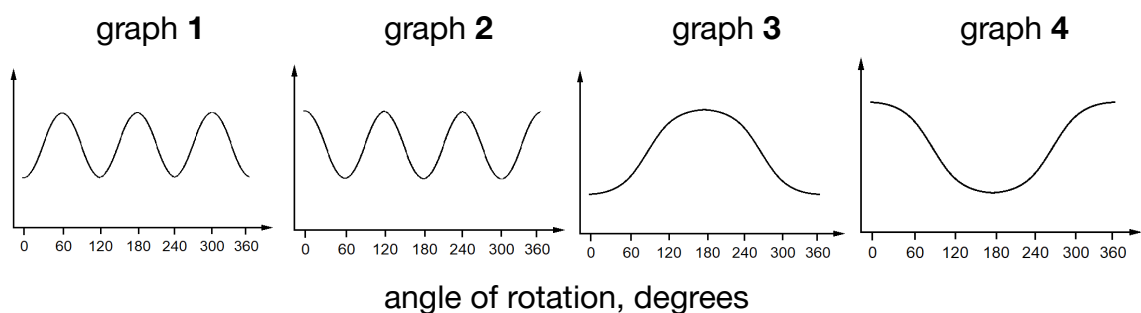
- ① trigonal pyramidal  
② trigonal planar  
③ bent  
④ linear

[1 mark]

- A7.** The two  $\text{CH}_3$  groups in an ethane molecule are free to rotate with respect to each other about the C-C sigma bond.

Which of these graphs shows the correct variation of the relative energy of the ethane molecule as the two  $\text{CH}_3$  groups rotate?

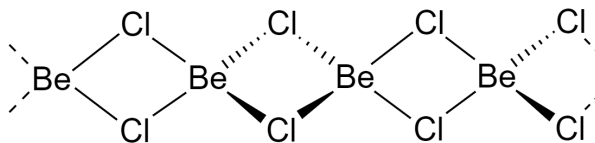
(An angle of  $0^\circ$  indicates that, when viewed along the C-C bond axis, the three C-H bonds on the rear carbon atom are completely in line with the three C-H bonds on the frontal carbon atom.)



- ① graph 1  
② graph 2  
③ graph 3  
④ graph 4

[2 marks]

- A8.** Solid anhydrous beryllium chloride,  $\text{BeCl}_2$ , consists of covalent chains of beryllium and chlorine atoms as shown.



Which statement about the bonding in this structure is true?

- ① every Be-Cl bond is dative covalent, represented as  $\text{Cl} \rightarrow \text{Be}$   
② the difference between the Cl-Be-Cl and Be-Cl-Be bond angles is  $2.5^\circ$   
③ each  $\text{BeCl}_2$  monomer lies in a plane angled at  $120^\circ$  to adjacent monomers  
④ none of the above

[2 marks]

- A9.** The Schrödinger equation mathematically describes the quantum mechanical model of atoms. For a neutral hydrogen atom, the equation states that the wavefunction  $\Psi$  and its derivatives  $\Psi'$  and  $\Psi''$  of the 1s electron varies with distance  $r$  from the nucleus (the proton) such that

$$\Psi'' + \left(\frac{2}{r}\right) \Psi' + \left(\frac{2}{a_0 r}\right) \Psi = \left(-\frac{8\pi^2 m E}{h^2}\right) \Psi$$

where  $a_0$  is the Bohr model orbit radius,  $m$  is the mass of the electron,  $h$  is Planck's constant and  $E$  is the energy of the electron in Joules.

To solve this equation, it is assumed that  $\Psi$  decays exponentially with  $r$ , so that  $\Psi = A \exp(-r/a_0)$ , where  $A$  is a constant factor. For this solution, it is given the wavefunction and its derivatives are related by  $a_0 \Psi' = -\Psi$  and  $a_0^2 \Psi'' = \Psi$ .

By solving the Schrödinger equation for  $E$ , the energy of a single electron, find an expression for  $E$  and hence calculate the ionisation energy of a hydrogen atom.

Given:  $a_0 = 5.292 \times 10^{-11} \text{ m}$ ;  $h = 6.626 \times 10^{-34} \text{ J s}$ ,  $m = \frac{1}{1836} \times \text{mass of proton}$ .

①  $E = -\frac{h^2}{2\sqrt{2}\pi^2 m a_0^2}$ ; ionisation energy = 109.2 kJ mol<sup>-1</sup>

②  $E = -\frac{h^2}{2\sqrt{2}\pi^2 m a_0^2}$ ; ionisation energy = 1321 kJ mol<sup>-1</sup>

③  $E = -\frac{h^2}{8\pi^2 m a_0^2}$ ; ionisation energy = 109.2 kJ mol<sup>-1</sup>

④  $E = -\frac{h^2}{8\pi^2 m a_0^2}$ ; ionisation energy = 1321 kJ mol<sup>-1</sup> [2 marks]

**A10.** The following tests were carried out on separate samples of two monoprotic acids, HCl and HNO<sub>3</sub>, with  $[\text{HCl}] = [\text{HNO}_3] = 1.00 \text{ mol dm}^{-3}$ .

- A** Measure the time taken for a 1 cm strip of magnesium to react completely when added to 25 cm<sup>3</sup> of each acid.
- B** Measure the volume of 1.00 mol dm<sup>-3</sup> sodium hydroxide solution needed to completely neutralise 20 cm<sup>3</sup> of each acid.
- C** Measure the electrical conductance of each acid.

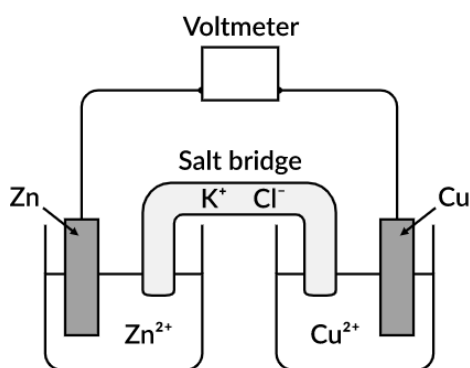
Each test was carried out under the same conditions. Which of the tests, considered independently, would show that HCl was a stronger acid than HNO<sub>3</sub>?

- ① tests **A** and **B** only
- ② tests **A** and **C** only
- ③ tests **B** and **C** only
- ④ tests **A**, **B** and **C**

[2 marks]

- A11.** A galvanic electrochemical cell is shown below. Zinc and copper metal electrodes are suspended in aqueous  $1.0 \text{ mol dm}^{-3}$  solutions of  $\text{ZnSO}_4$  and  $\text{CuSO}_4$  respectively. A salt bridge containing aqueous  $\text{KCl}$  connects the two solutions.

When a conductor is connected between the two electrodes, the cell begins to operate, and electrons flow from the zinc electrode to the copper electrode.



**How many** of the following statements is/are true?

- A** In the salt bridge, viewed as above,  $\text{K}^+$  ions migrate to the left, while  $\text{Cl}^-$  ions migrate to the right.
- B** Increasing the concentration of the electrolyte solution at the anode would increase the e.m.f. of the cell.
- C** Increasing the temperature of both electrolyte solutions by equal amounts would not affect the e.m.f. of the cell.

- ① none of them
- ② one of them
- ③ two of them
- ④ all three of them

[2 marks]



- \*A12.** An organic molecule is known to contain C, H and O only. A sample of mass 0.100 g is carefully burnt in the presence of excess oxygen. The resulting gases are passed over a desiccant (drying agent), and it is observed that the mass of the desiccant increases by 0.0931 g.

After passing through the desiccant the gases are bubbled through 25.0 cm<sup>3</sup> of a solution of 1.00 mol dm<sup>-3</sup> NaOH. The solution is then titrated against 1.00 mol dm<sup>-3</sup> HCl, and the end point is found to be when 14.7 cm<sup>3</sup> of the acid has been added.

The empirical formula of the organic molecule is

- ① C<sub>2</sub>H<sub>3</sub>O<sub>2</sub>
- ② C<sub>2</sub>H<sub>4</sub>O
- ③ C<sub>3</sub>H<sub>6</sub>O
- ④ CH<sub>2</sub>O

[4 marks]

- A13.** A buffer solution is prepared by dissolving 25.0 g of K<sub>2</sub>HPO<sub>4</sub> and 25.0 g of KH<sub>2</sub>PO<sub>4</sub> in 250 ml of water.

10.0 mL of 1.00 mol dm<sup>-3</sup> KOH is then added to the buffer solution.

By how many pH units does the pH of the buffer solution increase?

Given: the dissociation constant  $K_a$  for the H<sub>2</sub>PO<sub>4</sub><sup>-</sup> anion is  $6.31 \times 10^{-8}$  mol dm<sup>-3</sup>; the potassium salts are strong electrolytes.

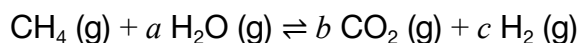
- ① 0.01
- ② 0.05
- ③ 0.10
- ④ 0.20

[4 marks]

- A14.** Steam-methane reforming (SMR) is the main industrial process used to generate hydrogen gas from natural gas in two reaction steps. Data for each reaction, carried out on average at 400 °C, is given below.

Reaction	Equilibrium constant $K_p$ at 400 °C	Standard molar enthalpy change $\Delta H^\ominus$
$\text{CH}_4 + \text{H}_2\text{O} \rightleftharpoons \text{CO} + 3 \text{H}_2$	$5.80 \times 10^{-5} \text{ Pa}^2$	+206 kJ mol <sup>-1</sup>
$\text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{CO}_2 + \text{H}_2$	12.0	-41 kJ mol <sup>-1</sup>

The overall reaction for SMR is therefore of the form



where  $a$ ,  $b$  and  $c$  are stoichiometric coefficients per mole of methane.

You are given that for a homogeneous system at equilibrium, the standard Gibbs free energy change  $\Delta G^\ominus$  is related to the equilibrium constant  $K_p$  by the equation

$$K_p = \exp\left(-\frac{\Delta G^\ominus}{RT}\right)$$

where  $R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$  is the gas constant and  $T$  is temperature in Kelvins.

Assuming that the same conditions are used in each case, which statement(s) about the **overall** reaction is/are true?

- A**  $a = 0$ ,  $b = 1$  and  $c = 4$   
**B**  $K_p = 6.96 \times 10^{-4} \text{ Pa}^2$   
**C**  $\Delta S^\ominus = +305 \text{ J mol}^{-1} \text{ K}^{-1}$

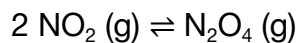
- ① **A** and **C** only  
② **C** only  
③ **B** only  
④ **B** and **C** only

[4 marks]

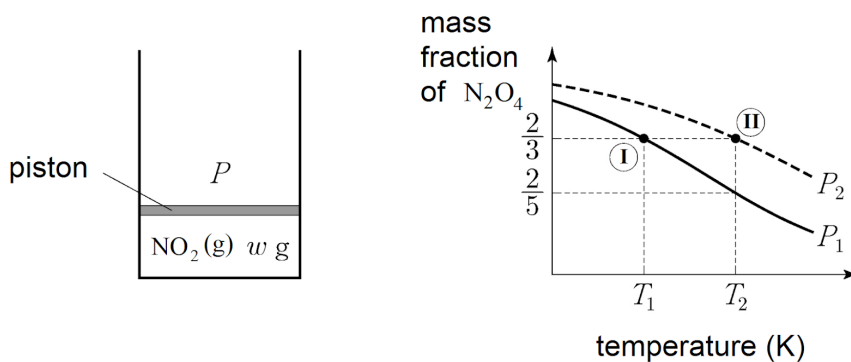
Section A. Multiple Choice Questions

Physical Chemistry

\*A15. Consider the homogeneous equilibrium of nitrogen dioxide and its dimer.



The variation of the equilibrium mass fraction (out of total mass  $w$  grams) of  $\text{N}_2\text{O}_4$  with temperature at two different pressures  $P_1$  and  $P_2$  is shown.



Given that  $\frac{\text{volume of mixture at point I}}{\text{volume of mixture at point II}} = 4$ , what is the value of  $\frac{T_2}{T_1}$ ?

- ①  $\frac{7}{6}$
- ②  $\frac{9}{8}$
- ③  $\frac{6}{5}$
- ④  $\frac{5}{4}$

[4 marks]

- A16.** Glucose can undergo condensation polymerisation to form maltose (a disaccharide), as well as various oligosaccharides from further polymerisation.

A solution of glucose is left to partially polymerise into a mixture of sugars, which are then to be separated by thin-layer chromatography using a polar solvent as the mobile phase.

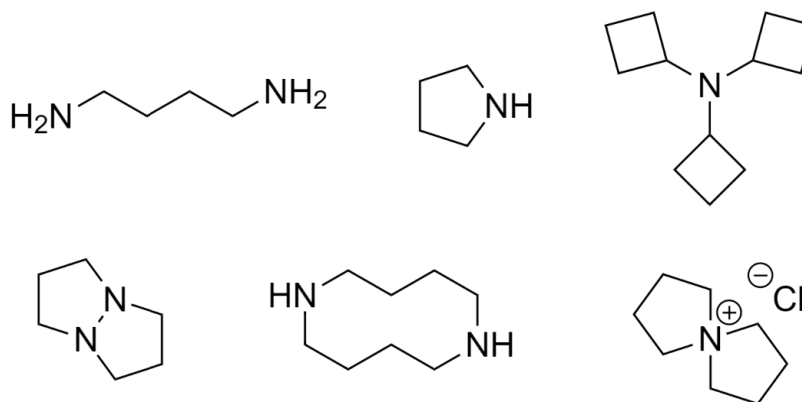
How would you expect the  $R_f$  values of glucose and maltose to compare?

- ① Glucose will have a smaller  $R_f$  value than maltose.
- ② Glucose will have a larger  $R_f$  value than maltose.
- ③ Glucose will have a very similar  $R_f$  value to maltose.
- ④ It cannot be determined without identifying the stationary phase.

[1 mark]

- A17.** A slight excess of 1,4-dichlorobutane is warmed in a sealed tube with ammonia.

**How many** of the following six amines could be formed in the product mixture?



- ① 4
- ② 3
- ③ 2
- ④ 1

[1 mark]

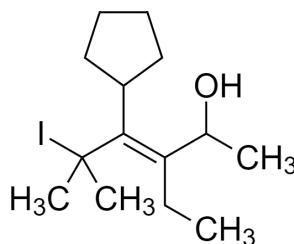
- A18.** The  $^{13}\text{C}$  NMR spectrum of an organic molecule known to contain two carbon atoms and two bromine atoms has two distinct peaks only at  $\delta = 34$  and  $\delta = 39$ , where  $\delta$  is the chemical shift in ppm.

Identify the compound by name.

- ① 1,1-dibromoethane
- ② 1,2-dibromoethane
- ③ 1,1-dibromoethene
- ④ 1,2-dibromoethene

[1 mark]

**A19.**



The IUPAC name of this molecule is

- ① (Z)-3-cyclopentyl-4-ethyl-2-iodo-2-methylhex-3-en-5-ol
- ② (E)-4-cyclopentyl-3-ethyl-5-iodo-5,5-dimethylpent-3-en-2-ol
- ③ (Z)-3-ethyl-5-iodo-5-methyl-4-cyclopentylhex-3-en-2-ol
- ④ (E)-4-cyclopentyl-3-ethyl-5-iodo-5-methylhex-3-en-2-ol

[1 mark]

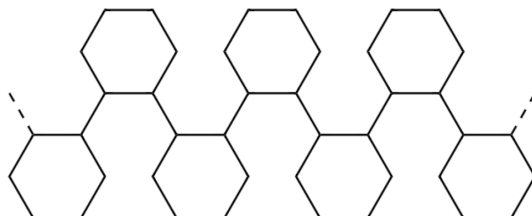
- A20.** Alpha-linolenic acid is a polyunsaturated straight-chain carboxylic acid. 0.001 mol of the acid reacts exactly with 15 ml of  $0.2 \text{ mol dm}^{-3}$  aqueous bromine.

Alpha-linolenic acid contains 18 carbon atoms per molecule. If the chemical formula for the acid is written as  $\text{C}_{17}\text{H}_n\text{COOH}$ , what is the value of  $n$ ?

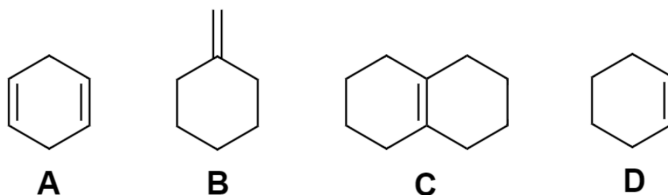
- ① 25
- ② 27
- ③ 29
- ④ 31

[1 mark]

- A21.** The skeletal structure below is part of a chain formed by addition polymerisation.



The monomer used to form this polymer is



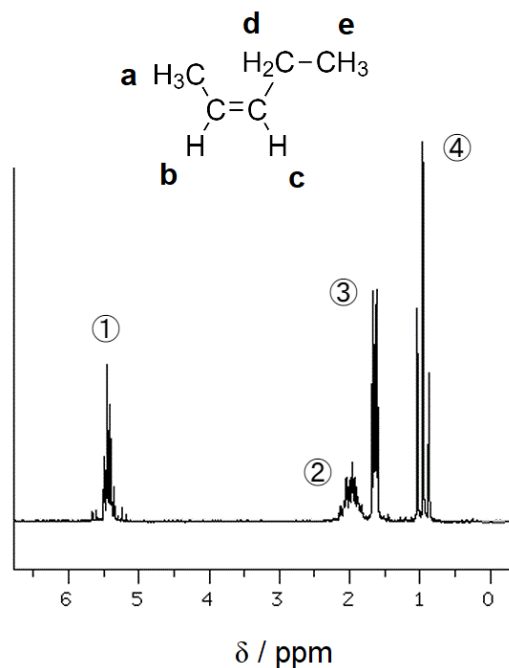
(Assume that the polymer chains are uniform and have negligible cross-linking.)

- ① **A**
- ② **B**
- ③ **C**
- ④ **D**

[1 mark]

- A22.** The proton NMR spectra of (*Z*)-pent-2-ene is shown, carried out in a deuterated solvent.

The standard TMS peak has been removed. The four discernible peaks are labelled ① - ④ and each set of unique proton(s) are labelled **a** - **e**. There are no significant peaks with  $\delta > 6$  ppm.



Which row in the table correctly identifies the source(s) of each peak and its splitting, and its integration ratio (on the basis of number of protons)?

[2 marks]

Peak	Source(s) of peak	Source(s) of splitting (multiplicity type)	Integration ratio(s)
①	<b>b</b> <b>c</b>	<b>a</b> and <b>c</b> (quartet) <b>b</b> and <b>d</b> (quintet)	1 1
②	<b>d</b>	<b>c</b> and <b>e</b> (quintet)	2
③	<b>e</b>	<b>d</b> (doublet)	3
④	<b>a</b>	<b>d</b> (triplet)	3

**A23.** Which of these statements about intermolecular forces in amines is true?

- A** Primary and secondary amines form hydrogen bonds both in the pure state and in aqueous solution
- B** Tertiary amines form hydrogen bonds in aqueous solution but not in the pure state
- C** Quaternary (4°) ammonium salts form ion-dipole attractions in the pure state but only weak Van der Waals dispersion forces in aqueous solution

- ① **A** and **B** only
- ② **B** and **C** only
- ③ **A** and **C** only
- ④ **A, B** and **C**

[2 marks]

**A24.** The structural formulas of the possible dipeptides formed between alanine and cysteine in their aqueous states are

(Neglect differences due to stereoisomerism.)

- A**  $\text{CH}_3\text{CH}(\text{NH}_3^+)\text{CONHCH}(\text{CH}_2\text{SH})\text{COO}^-$
- B**  $\text{CH}_3\text{CH}(\text{NH}_3^+)\text{COOCH}(\text{CH}_2\text{SH})\text{COO}^-$
- C**  $\text{CH}_2(\text{SH})\text{CH}(\text{NH}_3^+)\text{CONHCH}(\text{CH}_3)\text{COO}^-$
- D**  $^-\text{OOCCH}(\text{NH}_3^+)\text{CH}_2\text{SSCH}_2\text{CH}(\text{NH}_3^+)\text{COO}^-$

- ① **A** and **B**
- ② **A** and **C**
- ③ **B** and **D**
- ④ **C** and **D**

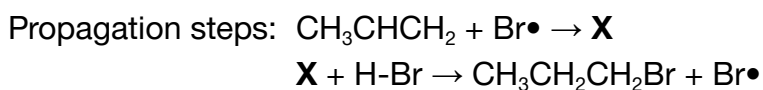
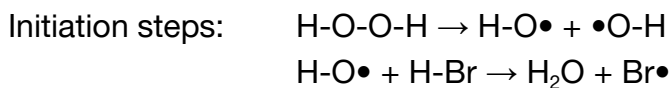
[2 marks]



[2 marks]

- A27.** When aqueous hydrogen bromide reacts with propene in the presence of hydrogen peroxide, the major product is 1-bromopropane, instead of the usual 2-bromopropane which forms when peroxide is not present.

This is due to a different reaction pathway in which free radicals form:



Which of these is true?

- ① In the intermediate species **X**, the unpaired electron lies predominantly on the 2° carbon
- ② 1,3-dibromo-2,3-dimethylbutane could be formed from a termination step
- ③ In the initiation step, the O-O peroxide bond is polarised by the propene
- ④ Hydrogen peroxide disproportionates in the initiation step

[4 marks]

**A28.** Three industrial methods of producing ethene,  $C_2H_4$ , are described below. Different countries use different methods depending on local resource availability and the relative strengths of their industries.

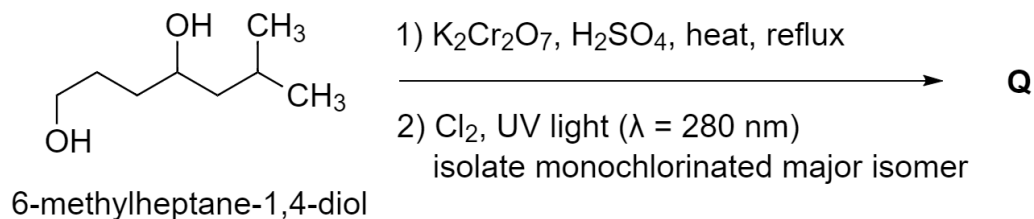
- A** in China, coke (pure carbon) and limestone ( $CaCO_3$ ) are reacted in a blast furnace to form calcium carbide ( $CaC_2$ ), which in turn is reacted with water to form acetylene gas ( $C_2H_2$ ) and calcium hydroxide. The acetylene is hydrogenated over a poisoned palladium catalyst to form ethene.
- B** in Singapore, imported crude oil is refined and passed directly into a highly robust steam cracker to form olefins (alkenes), from which ethene is collected, among many other useful petrochemicals.
- C** in Brazil, glucose from sugar cane is fermented by yeast enzymes to form 'bioethanol', which is then vaporised and dehydrated using phosphoric acid catalyst to form ethene with 95% yield.

Which of these is/are a valid brief assessment of the economic and/or environmental factors surrounding the use of each method?

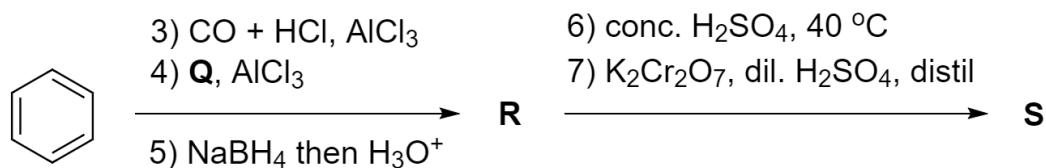
- ① In method **A**, large quantities of toxic carbon monoxide and the greenhouse gas carbon dioxide will be produced in the furnace. The poisoned catalyst poses a significant health risk to humans if the reaction vessel were to break due to excess gas buildup.
- ② As a country with no natural resources, method **B** is more appropriate for Singapore than method **A**. The advanced steam cracker avoids the losses in yield and efficiency caused in other nations in which fractional distillation is used to isolate naphtha from crude oil before cracking.
- ③ Method **C** is a theoretically carbon-neutral method to produce ethanol fuel, but in reality there is a net  $CO_2$  output due to the use of petrol-powered vehicles to transport the sugar cane between facilities. The use of genetically-modified yeast strains in the fermentation process constitutes an imminent biohazard risk to local farm residents.
- ④ All of the above are valid assessments.

[4 marks]

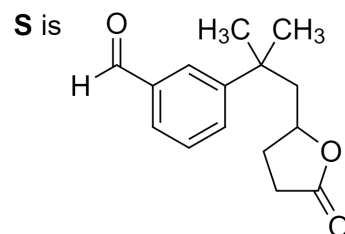
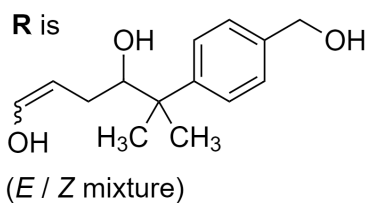
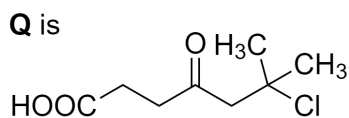
**A29.** A reagent **Q** is prepared from 6-methylheptane-1,4-diol in a two-step synthesis.



**Q** is then used in the following reaction scheme starting with benzene:



The major organic product of each step is isolated and used as the reactant in the next step. Which of the following structures are identified correctly?



- ① **Q** and **R** are correct; **S** is incorrect  
② **Q** and **S** are correct; **R** is incorrect  
③ **Q** is correct; **R** and **S** are incorrect  
④ **S** is correct; **Q** and **R** are incorrect

[4 marks]

**\*A30.** Phenylalanine dehydrogenase (PheDH) is an enzyme found naturally in the bacterial strain *Rhodococcus* sp. M4. PheDH catalyses the reaction shown in Figure (a) via the cofactor  $\text{NAD}^+$ . Using X-ray diffractometry, the structure of the enzyme-substrate complex for this reaction was deduced and shown schematically in Figure (b), in which the substrate makes electrostatic interactions with various amino acid residues in the protein chain active site.

It is required to change the selectivity of the enzyme from carrying out its natural reaction to carrying out the reaction in Figure (c). This will be done by using gene editing on the DNA coding for the enzyme in recombinant *Rhodococcus* sp. M4. The gene edits will change the amino acid sequence expressed in the mutant enzyme at a small number of selected sites in the active site.

Figure (a)

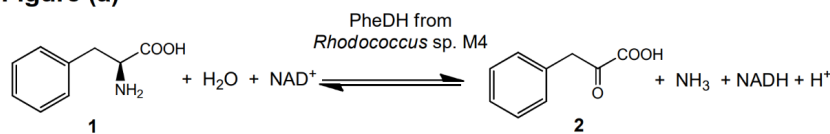


Figure (c)

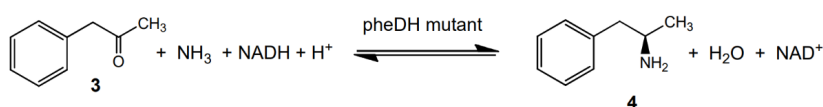
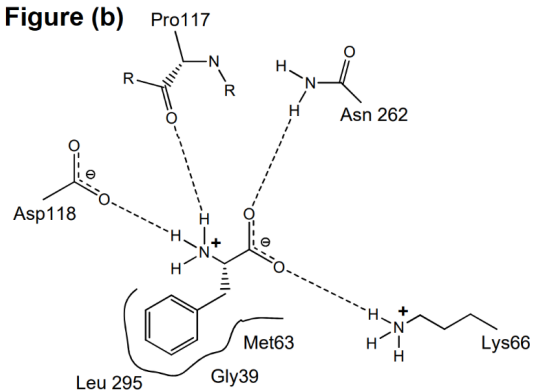


Figure (b)



Which amino acid residues in the enzyme should be changed to give the best chance of creating an enzyme which can carry out the reaction in Figure (c), and why?

- ① Replace Asp118 and Pro117 with more hydrophobic amino acids to decrease the affinity for the amine substrate group.
- ② Replace Leu295, Gly39 and Met63 with more hydrophilic amino acids to increase the affinity for the ketone substrate group.
- ③ Replace Pro117 and Asn262 with amino acids which dissociate into cationic residues at pH 7 to decrease the affinity for the  $\text{NAD}^+$  cofactor.
- ④ Replace Asn262 and Lys66 with more hydrophobic amino acids to increase the Van der Waals' attractions with the substrate's alkyl chain. [4 marks]

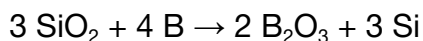
**A31.** Chlorine reacts with cold, dilute aqueous sodium hydroxide.

Which is a complete list of the products?

- ① sodium chloride, sodium chlorate(I) and water
- ② sodium chlorate(I) and water
- ③ sodium chloride, sodium chlorate(V) and water
- ④ sodium chloride and sodium chlorate(I)

[1 mark]

**A32.** Identify the reducing agent in the reaction below.



- ① silicon dioxide
- ② oxygen
- ③ boron
- ④ boron trioxide

[1 mark]

**A33.** Four statements about Group 5 compounds are given, three of which are true.

Which statement is **false**?

- ①  $\text{Bi}_2\text{O}_5$  is a more basic oxide than  $\text{N}_2\text{O}_5$
- ② The N-N  $\sigma$ -bond in  $\text{N}_2\text{H}_4$  is stronger than the P-P  $\sigma$ -bond in  $\text{P}_2\text{H}_4$
- ③  $\text{PH}_3$  boils at a lower temperature than  $\text{NH}_3$
- ④  $\text{NF}_3$  is more covalent than  $\text{BiF}_3$

[1 mark]

**A34.** The oxidation states of the transition metal in the compounds  $\text{CrO}_2\text{F}_2$ ,  $\text{K}_2\text{Mn}_2\text{O}_7$  and  $\text{BaTiO}_3$  respectively, are

- ① +6, +6, +4
- ② +2, +7, +3
- ③ +4, +5, +4
- ④ +6, +4, +3

[1 mark]

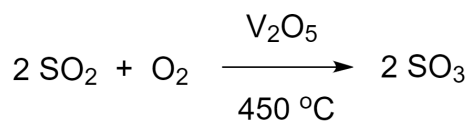
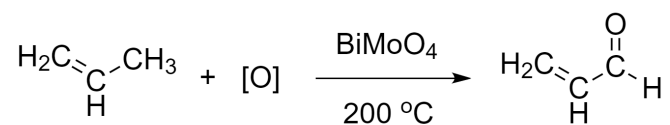
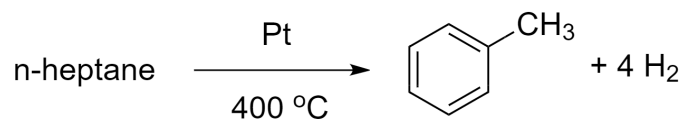
- A35.** When chlorofluorocarbons are exposed to ultraviolet radiation with a wavelength shorter than 290 nm, free radicals are observed to form.

An estimate for the C-Cl bond enthalpy in these chlorofluorocarbons is

- ① 195 kJ mol<sup>-1</sup>
- ② 284 kJ mol<sup>-1</sup>
- ③ 361 kJ mol<sup>-1</sup>
- ④ 413 kJ mol<sup>-1</sup>

[1 mark]

- A36.** Consider the three reactions shown below.



In **how many** of these reactions is a heterogeneous catalyst used?

- ① 1
- ② 2
- ③ 3
- ④ 0

[1 mark]

## Section A. Multiple Choice Questions

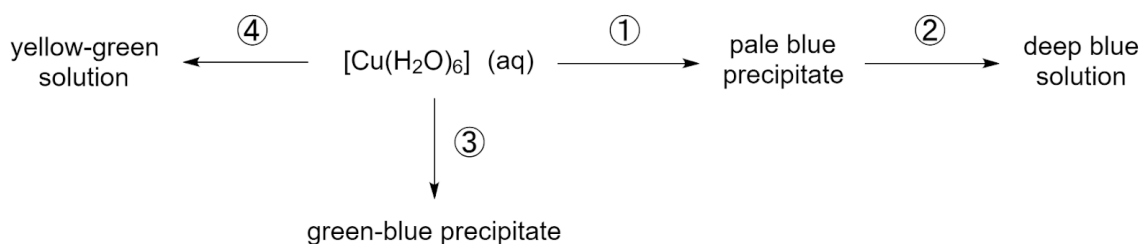
## Inorganic Chemistry

**A37.** Which statement about ligand substitution on coordination compounds is true?

- ① Ligands act as Lewis acids.
- ②  $[\text{CuEDTA}]^{2-}$  is an octahedral complex with coordination number 4.
- ③ The reaction of  $\text{Ni}^{2+}(\text{aq})$  ions with an excess of ethane-1,2-diamine forms an optically active complex.
- ④ The chelate effect is thermodynamically driven by the exothermic nature of coordinate bond formation.

[2 marks]

**A38.** Consider the following reaction scheme, which starts from  $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$  ions.



Which row in the table gives fully correct information about each reaction?

[2 marks]

Reaction number	Formula of metal-containing product formed	Reagent which could have been used	Statement about metal-containing product formed
①	$[\text{Cu}(\text{H}_2\text{O})_2(\text{OH})_4]$	$\text{NH}_3(\text{aq})$ in $\text{NaOH}$	has octahedral geometry
②	$[\text{Cu}(\text{H}_2\text{O})_2(\text{NH}_3)_4]^{2+}$	excess conc. $\text{NH}_3$	does <b>not</b> display <i>cis-trans</i> isomerism
③	$[\text{Cu}(\text{H}_2\text{O})_3(\text{OH})_3]^-$	$\text{Na}_2\text{CO}_3$	forms an ionic compound with $\text{Na}^+$
④	$[\text{CuCl}_4]^{2-}$	excess conc. $\text{HCl}$	has tetrahedral geometry



## Section A. Multiple Choice Questions

## Inorganic Chemistry

**A39.** An aqueous solution of the tetrachloridocuprate(II) anion,  $[\text{CuCl}_4]^{2-}$ , is a different colour to that of only aqueous copper(II) cations. Two possible explanations of this observation are provided.

- A** the energy of the  $\text{Cu} \leftarrow \text{Cl}$  dative bond is different to that of the  $\text{Cu} \leftarrow \text{OH}_2$  dative bond, and the energy difference corresponds to that of the absorbed visible photons
- B** the  $d$ -orbital of  $\text{Cu}^{2+}$  is split into two sets of orbitals by the  $\text{Cl}^-$  ligands, allowing electron transitions between the two energy levels, changing the frequencies at which visible photons are absorbed

Which row in the table gives these colours, and the correct explanation?

[2 marks]

	colour of $\text{Cu}^{2+}$ (aq)	colour of $[\text{CuCl}_4]^{2-}$ (aq)	reason for difference
①	pale blue	yellow-green	explanation <b>A</b>
②	colourless	deep blue	explanation <b>A</b>
③	pale blue	yellow-green	explanation <b>B</b>
④	colourless	deep blue	explanation <b>B</b>

**A40.** The second ionisation energy of calcium is lower than the second ionisation energy of potassium. This is mainly because

- ① the  $\text{Ca}^+$  ion has its valence electron in a higher energy orbital than those of the  $\text{K}^+$  ion.
- ② the  $\text{Ca}^{2+}$  ion has a higher nuclear charge than the  $\text{K}^+$  ion.
- ③ the atomic radius of  $\text{K}^+$  is larger than that of  $\text{Ca}^+$ .
- ④ There is mutual electron repulsion in the  $3p$  sub-orbitals of the  $\text{K}^+$  ion but no such repulsion in the  $4s$  orbital of the  $\text{Ca}^+$  ion.

[2 marks]

- A41.** Platinum acts as a catalyst for the reaction between ammonia and oxygen. It provides an alternative reaction route with a lower activation energy.

Which of these is **not** a stage in this alternative route?

- ① diffusion of  $\text{NH}_3$  and  $\text{O}_2$  molecules to the platinum surface
- ② absorption of  $\text{NH}_3$  and  $\text{O}_2$  molecules into the platinum metal
- ③ weak bond formation between reactants and platinum atoms
- ④ desorption of the products from the platinum surface [2 marks]

- A42.** Both oxygen and carbon monoxide bind reversibly to haemoglobin. Assume that only one molecule of either oxygen or carbon monoxide can bind to haemoglobin at any one time. Within the human body, carbon monoxide is 200 times more effective than oxygen in binding to haemoglobin available in human blood. The binding efficiency is the equilibrium constant for this process and you may assume that the system is at equilibrium.

The effects of carboxy-haemoglobin in humans can typically be observed when it reaches 5% of the concentration of oxy-haemoglobin in their blood. Assume that oxygen and carbon monoxide have the same molar solubility in blood.

What is the minimum proportion of carbon monoxide molecules in dry air, expressed as parts per million (ppm), that will result in a 5% ratio of carboxy-haemoglobin molecules to oxy-haemoglobin molecules in blood?

- ① 10 ppm
- ② 62.5 ppm
- ③ 250 ppm
- ④ 52.5 ppm [4 marks]

**A43.** Aqueous solutions of carboxylate salts can undergo electrolysis. In an experiment, sodium hydroxide solution was added slowly to a flask of aqueous pentanoic acid until complete neutralisation to give an aqueous solution of sodium pentanoate. Inert graphite electrodes were inserted into the solution and a voltage source was connected between them.

When the voltage source was turned on, the following observations were made:

- Effervescence at steady rates was seen from both electrodes. When the gas from the anode was bubbled through a saturated calcium hydroxide solution, a milky white precipitate formed, while the gas from the cathode gave no visible change. When the gas from the cathode was collected and exposed to a lighted splint, a squeaky pop was heard.
- A layer of immiscible, colourless liquid emerged from the anode, which then floated to the top of the solution. This layer had a gasoline-like smell, and when collected, burned easily when touched with a lit splint.
- A pH probe showed that the pH of the solution increased as the reaction continued, with maximum pH occurring at the cathode, diffusing outward.

Which of these correctly identifies the cause of each observation?

- ① the gas at the anode is carbon monoxide
- ② the gas at the cathode is steam
- ③ the liquid layer is butane
- ④ none of the above

[4 marks]

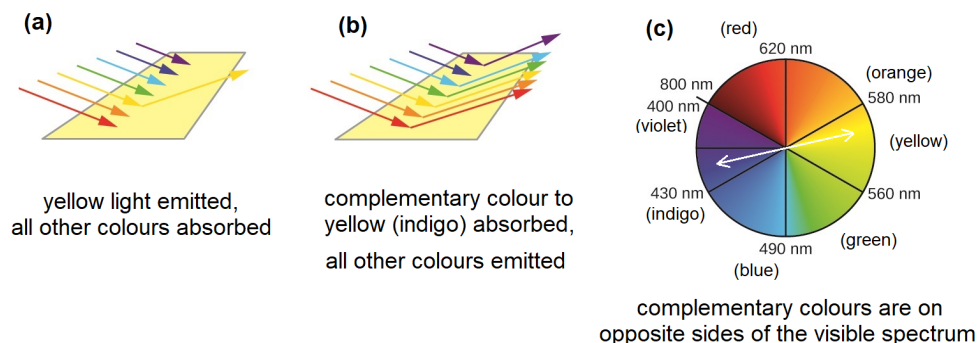
- A44.** Use your knowledge of electrophilic addition mechanisms to predict the major product when a solution of chlorine dissolved in water is added to propene.

Given: O is more electronegative than Cl.

- ①  $\text{CH}_3\text{CH}(\text{OH})\text{CH}_2\text{Cl}$
- ②  $\text{CH}_3\text{CHClCH}_2\text{OH}$
- ③  $\text{CH}_3\text{CHClCH}_2\text{Cl}$
- ④  $\text{CH}_3\text{CH}(\text{OH})\text{CH}_2\text{OH}$

[4 marks]

**\*A45.** The figures below describe the phenomenon of colour, which is relevant to how humans perceive the colours of certain chemical compounds. Figures **(a)** and **(b)** show how two different surfaces can both appear yellow despite having different emission spectra. Figure **(c)** shows the visible spectrum in the form of a colour wheel and the corresponding wavelengths of light.



Two observations about comparisons between colours of compounds are given.

- A** Chlorine gas is green while fluorine gas is yellow.
- B** Haem B is red while chlorophyll is green. Both molecules have an almost identical porphyrin ring system, but in haem the central metal ion is  $\text{Fe}^{2+}$  while in chlorophyll it is  $\text{Mg}^{2+}$ .

Which statement(s), if any, provide valid explanation(s) of these differences?

- ① **A:** The energy gap between the highest occupied orbital and the lowest unoccupied orbitals decreases as an atom gets larger. Fluorine absorbs near-ultraviolet light, corresponding to a pale yellow, while chlorine absorbs in the near-infrared region, corresponding to green.
- ② **B:** The porphyrin ring is a highly conjugated aromatic pi system, which decreases the energy difference between the ground state and the excited state. Additional colour changes in haem B are present due to the field splitting of the  $\text{Fe}^{2+}$  central ion  $d$ -orbital caused by its ligands which do not occur with the  $\text{Mg}^{2+}$  ion  $s$ -orbital.
- ③ Both of the above are valid explanations.
- ④ Neither of the above are valid explanations.

[4 marks]

## Additional Questions

- A16.** Monooxygenase is an enzyme known to hydroxylate N-benzyl pyrrolidine ( $M_r = 162 \text{ g mol}^{-1}$ ) giving the corresponding (S)-3-hydroxy-N-benzylpyrrolidine ( $M_r = 178 \text{ g mol}^{-1}$ ) at close to 100% yield. The enzyme was expressed through plasmid clones with full activity in recombinant *E. coli* to 5% of the total dry protein mass inside the bacteria.

To examine enzyme activity, the biotransformation was performed with 10 mM substrate in aqueous buffer at a cell density of 4 grams of cell dry weight per litre. At 30 min, 200  $\mu\text{L}$  samples were taken from the product mixture; after centrifugation, 100  $\mu\text{L}$  supernatant was treated with 200  $\mu\text{L}$  chloroform to extract the entire product into the organic phase. The organic phase was analysed by gas chromatography to contain 2.5 mM of product.

The enzyme was purified to 50% purity, and then immobilised on a solid support to 10% (wt/wt), which resulted in 50% decrease of the enzyme activity (as measured in amount of product formed per unit time). The solid catalyst was used at 20 g/L in a bioreactor for the transformation.

What is the expected specific yield of this process, in tons per year per cubic metre of bioreactor volume?

(Assume: dry cells are 50% protein by mass)

- ① 12.5 tons per year per  $\text{m}^3$
- ② 62.5 tons per year per  $\text{m}^3$
- ③ 350 tons per year per  $\text{m}^3$
- ④ 875 tons per year per  $\text{m}^3$

[4 marks]

**A17.** How many of the following correctly identifies the compound given by its IUPAC name?

- A**     AcOH is ethanoic acid
- B**     Ac<sub>2</sub>O is ethanoic anhydride
- C**     AcOMe is ethyl methanoate
- D**     (PhCOO)<sub>2</sub> is benzyl benzoate
- E**     PhOPh is 1,1-diphenylmethanal

- ①     1
- ②     2
- ③     3
- ④     4

[1 mark]

**B1.**

- a. Draw **two** alternative 'dot and cross' diagrams to describe the bonding in the linear thiocyanate anion  $\text{SCN}^-$ . In one diagram, place the negative charge on the sulfur, and in the other place the negative charge on the nitrogen. [5 marks]
- b. Breakfast cereals frequently have elemental iron added to them as a dietary supplement. A method for making a quantitative measurement of the amount of iron is to use the reaction between  $\text{Fe}^{3+}(\text{aq})$  and thiocyanate,  $\text{SCN}^-(\text{aq})$ , which gives the deep red complex  $\text{FeSCN}^{2+}(\text{aq})$ :



The depth of the colour can be measured using a spectrophotometer which gives a value for the absorbance proportional to the concentration of the complex:

$$\text{absorbance} = \text{constant} \times [\text{FeSCN}^{2+}]. \quad \textbf{[Equation 1]}$$

The constant can be found by measuring the absorbance of a solution of known concentration.

- i) The absorbance of a solution of the complex with concentration  $2.5 \times 10^{-1}$  millimoles per litre was measured to be 1.85. Determine the value of the constant in **Equation 1**. [2 marks]

100 g of breakfast cereal was mixed with sufficient dilute acid to dissolve all of the iron. The solution was carefully filtered and mixed with sufficient oxidising agent to convert all of the iron to  $\text{Fe}^{3+}$ . The solution was made up to a total volume of  $250 \text{ cm}^3$ .  $10.0 \text{ cm}^3$  of this solution was mixed with  $10.0 \text{ cm}^3$  of a solution of thiocyanate; you may assume that all of the iron is converted to the complex. The absorbance of the resulting solution was measured as 0.519.

- ii) Using the value of the constant found in (i), calculate the concentration of  $\text{Fe}^{3+}$  in the solution for which the absorbance was measured. [2 marks]



iii) Calculate  $[\text{Fe}^{3+}]$  in the solution prepared from the cereal. [2 marks]

iv) Find the mass of iron in 100 g of the breakfast cereal. [4 marks]

**Section B. Physical Chemistry**

***Quantitative Chemistry of Solutions***

---

c. Hydrogen peroxide,  $\text{H}_2\text{O}_2$ , is used as the oxidising agent to convert  $\text{Fe}^{2+}$  to  $\text{Fe}^{3+}$  in the assay described in part b.ii).

i) Determine the oxidation state of oxygen in  $\text{H}_2\text{O}_2$ . [2 marks]

ii) When  $\text{H}_2\text{O}_2$  acts as an oxidising agent in acidic solution, what is the oxygen-containing species that is produced and what is the oxidation state of oxygen in this species?

[4 marks]

iii) Write a balanced chemical equation describing the oxidation of  $\text{Fe}^{2+}(\text{aq})$  to  $\text{Fe}^{3+}(\text{aq})$  by  $\text{H}_2\text{O}_2$  in acidic solution.

[4 marks]

**Section B. Physical Chemistry*****Molecular Structure***

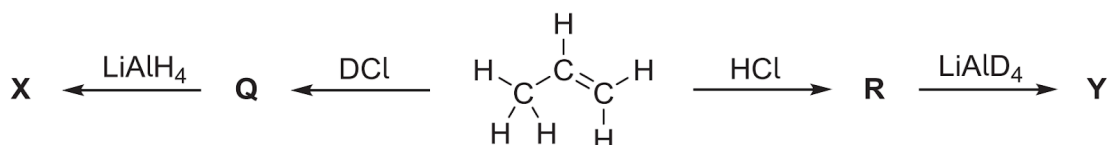
---

- B2.** When lithium metal and hydrogen gas are heated together, a single substance, **A**, is formed as colourless crystals with a melting point of 688 °C. Molten **A** conducts electricity, and electrolysis of the molten substance re-forms the elements.
- a. i) Give an equation for the formation of **A**. [1 mark]
- ii) Classify the structure of **A** as either molecular covalent, giant covalent, or ionic. Briefly justify your answer. [2 marks]
- b. Substance **A** reacts with aluminium chloride to form lithium aluminium hydride ( $\text{LiAlH}_4$ ) and one other by-product.
- i) Give a balanced chemical equation for the formation of lithium aluminium hydride from **A** and aluminium chloride. [2 marks]
- ii) Give a common use of **A** in synthetic chemistry. [1 mark]
- c. When 3.8 g of lithium aluminium hydride is heated to 125 °C, it decomposes to give three substances: 1.8 g of aluminium metal, 2.4 dm<sup>3</sup> of a flammable gas (measured at room temperature and pressure), and substance **B**.
- i) Determine the formula for substance **B**. [5 marks]
- ii) Calculate the density of the flammable gas. [2 marks]

**Section B. Physical Chemistry****Molecular Structure**

- d. Lithium aluminium deuteride can be prepared if deuterium gas is used in place of normal hydrogen. Deuterium, often given the symbol D, is the non-radioactive isotope of hydrogen, i.e.  $D = {}^2\text{H}$ . The formula for lithium aluminium deuteride can be written  $\text{LiAlD}_4$ . Both  $\text{LiAlH}_4$  and  $\text{LiAlD}_4$  are common reducing agents and the latter is useful for preparing deuterium-containing compounds.

Isomers of mono-deuterated propane, **X** and **Y**, may be prepared from propene according to the following scheme which also uses hydrogen chloride,  $\text{HCl}$ , and deuterium chloride,  $\text{DCl}$ . In the scheme, only the carbon-containing compounds are shown; other by-products are not.



Give the structures of

- the intermediates **Q** and **R** formed during the syntheses [2 marks]
  - the products **X** and **Y**. [2 marks]
- e. 2,2-dideuterated propane may be prepared easily in two steps, from a mono-deuterated propene, **Z**. The formula for **Z** is  $\text{C}_3\text{H}_5\text{D}$ .
- Draw the structures of all the alkenes with formula  $\text{C}_3\text{H}_5\text{D}$ . [2 marks]
  - Give a synthesis of 2,2-dideuterated propane starting from **Z** showing reagents and intermediates in each step, making sure to give the

displayed formula for **Z**.

[3 marks]

**Section B. Physical Chemistry**

***Kinetics of Free-Radicals***

---

**B3.** Free radicals are highly reactive species, relevant in several types of chemical reaction. They are typically formed when external energy sources are present in a reaction.

a. Identify the energy source and the free radical species formed in each of the following processes:

- i) the thermal cracking of long-chained aliphatic hydrocarbons; [2 marks]
- ii) the action of CFCs on ozone in the upper atmosphere; [2 marks]

b. The extent to which concentration affects its rate is indicated by the order of reaction. For most reactions, the order is a whole number such as 0, 1 or 2. Some reactions can have fractional (non-integer) orders. A fractional order often indicates a chain reaction mechanism such as those involving free radicals.

Consider the thermal decomposition of ethanal at 500 °C in an inert atmosphere into methane and carbon monoxide.

- i) Write down the symbol equation for this reaction. [1 mark]
- ii) Write down the form of the rate equation for this reaction. [1 mark]

The initiation step for the decomposition is the homolytic fission of the C-C bond in ethanal, symbolised as:  $\text{CH}_3\text{CHO} \rightarrow \bullet\text{CH}_3 + \bullet\text{CHO}$ .

- iii) Draw dot-and-cross structures for the two free radicals formed from the initiation step. [4 marks]
- iv) The first propagation step involves the methyl radical and generates methane as a stable gaseous product.

Write down the equation for this step, and draw the dot-and-cross structure for the other product, showing any unpaired electrons.

[3 marks]

- v) Suggest an equation for the second propagation step. [2 marks]

**Section B. Physical Chemistry**

***Kinetics of Free-Radicals***

- c. The kinetics of the thermal decomposition described in part b) can be analysed by making the following assumptions:

- (1) the rates of formation and destruction of methyl radicals are equal
- (2) any reaction of the  $\bullet\text{CHO}$  radical is ignored
- (3) the only major termination step forms ethene:  $2 \bullet\text{CH}_3 \rightarrow \text{C}_2\text{H}_6$

It is also assumed that, for each step of the reaction, the reaction occurs in a single step, with no further intermediates. This allows us to assume that the order of reaction with respect to a particular species is **equal** to its stoichiometric coefficient.

- i) Using assumption (1), show that

$$k_i [\text{CH}_3\text{CHO}] - k_t [\bullet\text{CH}_3]^2 = 0,$$

where  $k_i$  and  $k_t$  are the rate constants for the initiation and termination steps respectively.

[4 marks]

- ii) Show that this implies that  $[\bullet\text{CH}_3]$  is proportional to  $[\text{CH}_3\text{CHO}]^{1/2}$ . [2 marks]

- iii) By considering the rate of formation of methane, show that the overall order of the reaction is  $\frac{3}{2}$ . [4 marks]

## Section B. Physical Chemistry

---

- B4.** Aqueous solutions of carboxylate salts can undergo electrolysis. In an experiment, sodium hydroxide solution was added slowly to a flask of aqueous pentanoic acid until complete neutralisation to give an aqueous solution of sodium pentanoate. Inert graphite electrodes were inserted into the solution and a voltage source was connected between them.
- a. When the voltage source was turned on, the following observations were made:
- Effervescence at steady rates was seen from both electrodes. When the gas from the anode was bubbled through a saturated calcium hydroxide solution, a white precipitate formed, while the gas from the cathode gave no visible change. When the gas from the cathode was collected and exposed to a lighted splint, a squeaky pop was heard.
  - A layer of immiscible, colourless liquid emerged from the anode, which then floated to the top of the solution. This layer had a gasoline-like smell, and when collected, burned easily when touched with a lit splint.
  - A pH probe showed that the pH of the solution increased as the reaction continued, with maximum pH occurring at the cathode, diffusing outward.
- i) Identify all products formed during the reaction, giving half-equations for each electrode, and the overall balanced equation. [7 marks]
- ii) Suggest and outline how free radicals are involved in the mechanism of the anode reaction. [4 marks]
- b. 7.6 ml of  $0.1 \text{ mol dm}^{-3}$  NaOH was added to the flask for neutralisation, and the 50 ml of pentanoic acid used had a concentration of  $2.5 \text{ mol dm}^{-3}$ , with a dissociation constant  $K_a = 1.51 \times 10^{-5} \text{ mol dm}^{-3}$ .
- i) Calculate the concentration of the sodium pentanoate. [4 marks]

A steady electric current of 1.2 A was registered on an ammeter connected in series between the electrodes. The charge of a single electron is  $1.61 \times 10^{-19}$  C.

- ii) Calculate the rate of formation (in millilitres per second) of the immiscible liquid layer at the anode, given that its density is  $703 \text{ kg m}^{-3}$ . [5 marks]

### Section C. Organic Chemistry

---

**C1.** There are six isomers with the formula  $\text{C}_5\text{H}_{10}$  that are alkenes. The alkenes all have different enthalpies of formation, all of which are negative.

a. Using skeletal formulae, draw the structures of the six alkenes. [6 marks]

b. Samples of the six alkenes, in a random order, are labelled **P**, **Q**, **R**, **S**, **T**, and **U**.

Alkenes **P**, **Q**, and **R** react with hydrogen gas and a metal catalyst to give the same alkane **A**; alkenes **S**, **T**, and **U** react under the same conditions to give a different alkane **B**. Both alkanes **A** and **B** react with chlorine gas under UV light to form chloroalkanes with the formula  $\text{C}_5\text{H}_{11}\text{Cl}$ . Under such conditions, alkane **A** forms four different structural isomers, whereas **B** gives three.

i) Draw the skeletal structures of alkanes **A** and **B**. [2 marks]

ii) Draw the skeletal structures of the four isomers arising from the chlorination of **A**, and the three isomers arising from the chlorination of **B**. [4 marks]

c. The alkenes react with  $\text{HBr}$  to form bromoalkanes with the formula  $\text{C}_5\text{H}_{11}\text{Br}$ ; the reaction proceeds via a carbocation intermediate. Alkenes **S** and **T** give a mix of two structural isomers, whereas alkene **U** gives only one.

Give the displayed formula of alkene **U**. [4 marks]

\*d. Out of **P**, **Q** and **R**, **R** has the most negative (most exothermic) enthalpy of formation.

i) Give the displayed formula of **R**. [1 mark]

ii) Some standard enthalpy change data are given as follows.

Hydrogenation of **P** =  $-113 \text{ kJ mol}^{-1}$ ; Hydrogenation of **Q** =  $-119 \text{ kJ mol}^{-1}$ ;  
Combustion of **A** =  $-3528 \text{ kJ mol}^{-1}$ ; Formation of  $\text{H}_2\text{O (l)}$  =  $-286 \text{ kJ mol}^{-1}$ .

Use the data to deduce the structures of alkenes **P** and **Q**. [4 marks]

- iii) Calculate the standard enthalpy of combustion of alkene **P**. [4 marks]

**Section C. Organic Chemistry**

***Haloalkanes***

---

**C2.** Tetrachloromethane ( $\text{CCl}_4$ ) is an effective fire extinguisher but it is no longer used because of its toxicity and its role in the depletion of the ozone layer. In the upper atmosphere, a bond in  $\text{CCl}_4$  breaks and reactive species are formed.

- a. Identify the condition that causes a bond in  $\text{CCl}_4$  to break in the upper atmosphere and deduce an equation for the formation of the reactive species. [2 marks]

- b. One of the reactive species formed from  $\text{CCl}_4$  acts as a catalyst in the decomposition of ozone.

- i) Write two equations to show how this species acts as a catalyst. [2 marks]

- ii) Write down the overall equation for the decomposition of ozone. [1 mark]

- c. A small amount of the freon  $\text{CF}_3\text{Cl}$  with a mass of  $1.78 \times 10^{-4} \text{ kg}$  escaped from a refrigerator, into a room of volume  $100 \text{ m}^3$ . Assuming that the freon is evenly distributed throughout the air in the room, calculate the number of freon molecules in a volume of  $500 \text{ cm}^3$ . [4 marks]

- d. The refrigerant R410A, used in air conditioners, is a mixture of two fluoroalkanes, pentafluoroethane and difluoromethane. The mechanism for the reaction of fluorine with either an alkane or a fluoroalkane is similar to that for the reaction of chlorine with methane.

- i) Name the type of mechanism for the reaction of chlorine with methane. [1 mark]

- ii) Write equations for the initiation, propagation and termination steps in the



mechanism for the reaction of fluorine with fluoromethane to form difluoromethane. In the termination step, form 1,2-difluoroethane.

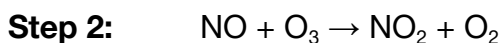
[4 marks]

- iii) Write an overall equation for the reaction of fluorine with ethane to form pentafluoroethane by this mechanism. [1 mark]

**Section C. Organic Chemistry**

***Haloalkanes***

- e. Nitrogen monoxide (NO) also catalyses the decomposition of ozone into oxygen. The sequence of reactions that occur when nitrogen monoxide catalyses the decomposition of ozone is shown.



**Step 3:**

Complete **Step 3** in the above mechanism.

[1 mark]

- f. Bromine atoms have a similar role to chlorine atoms in the decomposition of ozone. Suggest and explain which of  $\text{CClF}_3$  or  $\text{CBrF}_3$ , if released into the upper atmosphere, would form free halogen atoms more readily.

[2 marks]

## Section C. Organic Chemistry

---

C3.

**C4.** Some alkenes can undergo dimerisation reactions at room temperature.

a. State what is meant by the term *dimerisation*. [2 marks]

b. 2-methylpropene dimerises in the presence of concentrated sulfuric acid catalyst to form two products, one of which is **X**, named 2,4,4-trimethylpent-1-ene.

i) Name the mechanism for the reaction of 2-methylpropene with concentrated sulfuric acid. [1 mark]

ii) Suggest and outline a mechanism for this dimerisation to form this particular product **X**.

In each step, explain your reasoning to justify why each step might occur. [8 marks]

iii) Name the other dimer **Y** that could form as a product of this reaction. [1 mark]

iv) State the type of isomerism exhibited by **X** and **Y**. [1 mark]

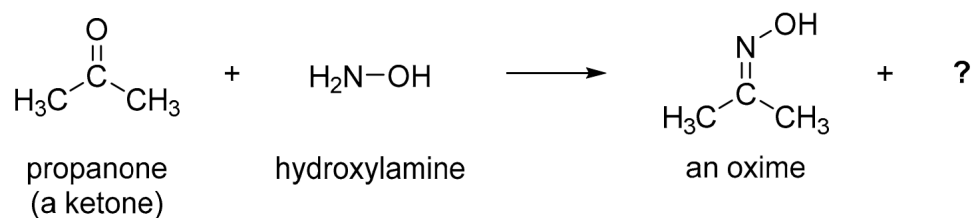
v) When **X** and **Y** are hydrogenated in the presence of a nickel catalyst at 150 °C, the same product **Z** is formed in each case.

Draw the skeletal formula of **Z** and give a common use of this compound. [2 marks]

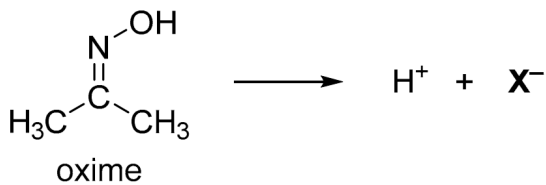
## Section C. Organic Chemistry

---

**C5.** Ketones react with hydroxylamine,  $\text{NH}_2\text{OH}$ , to give oximes. An example of such a reaction involving the ketone propanone is shown below:



- a. i) In addition to the oxime, this reaction produces a second product. Suggest what this molecule might be. [1 mark]
- ii) Draw the structure of the oxime that you would expect to be formed from the reaction of cyclohexanone with hydroxylamine. [2 marks]
- iii) Oximes are weakly acidic. For the oxime below, explain which hydrogen atom will be the most acidic and draw the structure of the resulting anion  $\text{X}^-$ .

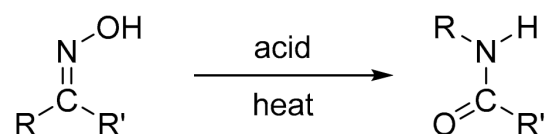


[3 marks]

**Section C. Organic Chemistry**

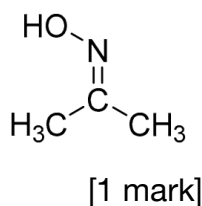
**Carbonyl Compounds**

- b. Under acidic conditions, oximes undergo the following rearrangement reaction (note carefully that there are two different groups R and R').

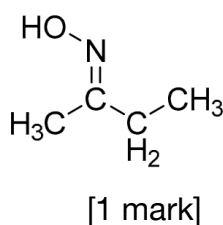


Give the analogous structures into which each of the following oximes rearrange under the same conditions.

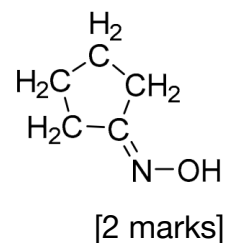
i)



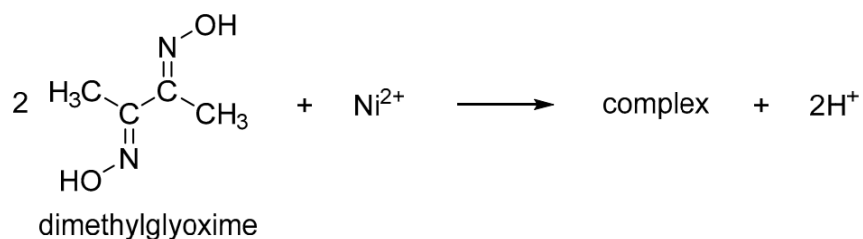
ii)



iii)



- c. Dimethylglyoxime reacts with  $\text{Ni}^{2+}$  ions in aqueous solution under mildly basic conditions to give a complex which is an insoluble red precipitate. The reaction involves two molecules of dimethylglyoxime and also results in the production of two  $\text{H}^+$  ions, as shown in the balanced equation below.



Determine the **molecular formula** of the complex and state its relative molecular mass. [4 marks]

**Section C. Organic Chemistry**

***Carbonyl Compounds***

---

- d. The reaction between dimethylglyoxime and  $\text{Ni}^{2+}$  ions can be used to determine the nickel content of alloys by weighing the amount of the red precipitate produced from a known mass of a sample of an alloy.

A sample of mass 1.50 g of an alloy was dissolved in dilute acid and an excess of dimethylglyoxime was then added to the resulting solution. The pH was then adjusted to make the solution mildly alkaline, and this resulted in the formation of a red precipitate. The precipitate was carefully filtered off, dried and then weighed. The mass of the dry precipitate was 0.368 g.

Determine the nickel content of the alloy, expressed as a percentage by mass.

[4 marks]

- e. Other metal ions, such as  $\text{Pd}^{2+}$  or  $\text{Pt}^{2+}$ , also react with dimethylglyoxime to give insoluble precipitates.

What effect would the presence of palladium in the alloy have on the value of the nickel content determined using the method in part d)?

[2 marks]

## Section D. Inorganic Chemistry

---

**D1.** This question concerns the chemistry of tellurium, an element in Group 6 of the Periodic Table.

- a.
- i) Predict the maximum and minimum oxidation states of tellurium. Briefly explain your answer. [3 marks]
  - ii) How do the electronegativities of the elements vary on descending Group 6? [1 mark]
  - iii) Which hydride,  $\text{H}_2\text{O}$  or  $\text{H}_2\text{Te}$ , has the higher boiling point? Briefly explain your answer. [2 marks]
- b. Tellurium reacts directly with fluorine gas to form a dense gas, **A**, in which each molecule contains a single tellurium atom bonded to several fluorine atoms. In an experiment,  $50\text{ cm}^3$  of gas **A** is formed from  $150\text{ cm}^3$  of fluorine and a certain mass of tellurium, measured at room temperature and pressure (rtp).
- i) Calculate the formula of the gas **A**. [2 marks]
  - ii) Predict the value(s) of the F–Te–F bond angles in **A**. [1 mark]
  - iii) Calculate the minimum mass of tellurium needed to produce  $50\text{ cm}^3$  of **A**. [2 marks]
  - iv) Calculate the density of gas **A** in  $\text{g cm}^{-3}$  at rtp. [2 marks]
  - v) Calculate how many times denser gas **A** is than oxygen gas at rtp. [1 mark]

## Section D. Inorganic Chemistry

---

- c. In another experiment, 5.0 g of tellurium is oxidised and dissolved in water to form 9.0 g of an acid with general formula  $\text{H}_m\text{TeO}_n$ . On neutralisation with aqueous KOH, 18 g of a salt is formed with the general formula  $\text{K}_m\text{TeO}_n$ .
- i) Give an expression, in terms of  $m$  and  $n$ , for the oxidation state of the tellurium in the acid  $\text{H}_m\text{TeO}_n$ . [1 mark]
  - ii) Calculate the relative molecular mass of the acid  $\text{H}_m\text{TeO}_n$ . [1 mark]
  - iii) Calculate the values of  $m$  and  $n$ , and hence the formulae of the acid  $\text{H}_m\text{TeO}_n$  and the salt formed on neutralisation. [2 marks]
  - iv) Calculate the volume of a  $2.0 \text{ mol dm}^{-3}$  aqueous solution of KOH that would be needed to neutralise the 9.0 g of acid formed from 5.0 g of tellurium. [2 marks]



## Question Sources

All questions sampled from past AQA / OCR A-Level Chemistry exams, **except:**

**A1.** NSAA Specimen 2016 Section 1 Question 47

**A2.** 수능 Chemistry 2021 Paper 2 Question 15

**A3.** NSAA 2020 Section 1 Question 21

**A12.** NSAA 2018 Section 2 Question C2b

**A15.** 수능 Chemistry 2021 Paper 2 Question 20

**A33.** IIT JEE Chemistry 2018 Paper 1 Question 30

수능: Suneung (Korean SAT)

NSAA: Cambridge Natural Sciences Entrance Exam

IIT JEE: Indian College Entrance Exam