# 1 The Periodic Table shows many interesting and recurring trends.

(a) The variation of 1<sup>st</sup> ionisation energies across Period 4 is similar to that of Period 3. Table 1.1 shows the 1<sup>st</sup> ionisation energies of six consecutive elements in Period 4.

l able 1.1						
element	Ga	Ge	As	Se	Br	Kr
1 <sup>st</sup> ionisation energy / kJ mol <sup>-1</sup>	580	760	950	940 <b>[1]</b>	1140	1350
				accept		

(i) Explain why the 1<sup>st</sup> ionisation energies show (760-950) crease from gallium to krypton.

### Across the period.

- the number of protons increases, hence nuclear charge increases.
- the number of electrons increases but they are added to the same outermost shell, hence <u>shielding effect remains relatively constant</u>.
- Effective nuclear charge increases, resulting in <u>stronger electrostatic attraction</u> <u>between the nucleus and the valence electrons.</u>
- Hence, more energy is required to remove the valence electron.

2-3 points - 1m; 4 points -2m

......[2]

- (ii) Using your knowledge of the variations, complete Table 1.1 with a suggested value for the first ionisation of selenium. [1]
- (b) Electrical conductivity is measured in Siemens per meter, S m<sup>-1</sup>, where a higher value represents higher electrical conductivity. Calcium is a Group 2 metal and has an electrical conductivity of 2.9 × 10<sup>7</sup> S m<sup>-1</sup> while copper is a transition metal and electrical conductivity of 5.9 × 10<sup>7</sup> S m<sup>-1</sup>.

(i) State the full electronic configuration of copper.

1s <sup>2</sup> 2s <sup>2</sup> 2p <sup>6</sup> 3s <sup>2</sup> 3p <sup>6</sup> 3d <sup>10</sup> 4s <sup>1</sup> [1]	Marker Comments for (b)(i):	F 4 3
 	• Part (b)(i) was generally well done.	

(ii) Explain the difference in electrical conductivity between calcium and copper.

Copper has a higher electrical conductivity [1] than calcium.

Cu has <u>more mobile electrons</u> (per atom) as there are <u>3d and 4s electrons in</u>
 <u>Cu are available for delocalisation</u>, compared to <u>only 4s electrons</u> in Ca. [1]

Marker Comments for (b)(ii):

• Some students attempted to argue that Cu having 29 electrons makes it a better electrical conductor. But Krypton has 36 electrons and is an electrical insulator, hence we should realise that not all electrons can contribute to conductivity.

(c) Other transition metals such as nickel and platinum are sometimes found in copper ores. To obtain pure copper, the ore was made the anode of an electrolysis cell, with a pure copper cathode and aqueous CuSO<sub>4</sub> as electrolyte.

2

Explain, with reference to relevant  $E^{\circ}$  values from the *Data Booklet* what happens to the platinum impurities during this purification procedure. You should also use the following information:

 $Pt^{2+} + 2e \implies Pt \qquad E^{\ominus} = +1.20 V$ 

The relevant  $E^{\ominus}$  values are:

Pt<sup>2+</sup> + 2e<sup>-</sup>  $\rightleftharpoons$  Pt  $E^{\ominus}$  = +1.20 V Cu<sup>2+</sup> + 2e<sup>-</sup>  $\rightleftharpoons$  Cu  $E^{\ominus}$  = +0.34 V

Since  $\underline{E}^{\Theta}Pt^{2*}/Pt$  is more positive than  $E^{\Theta}cu^{2*}/cu$  [1] with value, <u>Pt does not get oxidised</u> and forms <u>solid deposits</u> below the anode / fall to the base of the cell and form <u>anode</u> <u>sludge</u>. [1]

Marker Comments for (c):

- Many students wasted time describing the chemistry of nickel.
- Some students attempted to calculate E for a reaction between Pt and Cu<sup>2+</sup>, which is irrelevant when electrolysis is driven by the external current.
- Many students wrongly assessed that Pt<sup>2+</sup> was present, either in the ore or electrolyte, and described reduction of Pt<sup>2+</sup>, or worse, reduction of Pt.
- (d) Propene undergoes reaction with Br<sub>2</sub> to form 1,2-dibromopropane. This reaction mechanism features a carbocation intermediate.
  - (i) Draw a labelled diagram to show orbital overlap in the C=C double bond of propene.



(ii) Name and draw the mechanism of the reaction between propene and  $Br_2$  to form 1,2-dibromopropane.

Show all charges and relevant lone pairs and show the movement of electron pairs by using curly arrows.



(iii) Hence, draw the dot-and-cross diagram for the carbocation intermediate in the mechanism drawn in (ii).

State the shape and bond angle at the positively charged carbon in the carbocation intermediate.



[Total: 16]

- 2 Nitrosyl fluoride, NO<sub>2</sub>F, is a colourless gas which is used as a nitrating agent in organic synthesis.
  - NO<sub>2</sub>F is formed from the reaction between nitrogen dioxide and fluorine according to the (a) following reaction.

 $2NO_2(g) + F_2(g) \longrightarrow 2NO_2F(g)$ 

The reaction kinetics for this reaction was studied. The experimental rate equation for this reaction can be expressed as rate =  $k [NO_2]^m [F_2]^n$ , where m and n are non-zero constants.

The concentration of NO<sub>2</sub> gas was determined at regular time intervals as the reaction progressed.

In this experiment, the concentration of NO<sub>2</sub> and  $F_2$  used were at 0.080 mol dm<sup>-3</sup> and 1.20 mol dm<sup>-3</sup> respectively. The results obtained are shown in Fig. 2.1.





(i) Using Fig. 2.1, determine the value of m. Show all your working and any construction lines clearly on your graph.

Construction lines on graph [1]

Since  $t_{\frac{1}{2}} = t_{\frac{1}{2}} = 240$ s, order of reaction wrt NO<sub>2</sub> is **one**[1]

[2]

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Marker Comments for (a)(i):

- Students must indicate the half-life (time) on the graph.
- Must mention in your answer that for reaction to be 1<sup>st</sup> order, the half-life must be constant. If the 2 half-life values are different, you need to take average. татріпез менчал зипіог сопеде

(ii) Hence, sketch on the given axes, a graph to show how the rate of reaction changes with concentration of NO<sub>2</sub>.



(iii) Determine the initial rate using the graph in Fig 2.1.

Initial rate = gradient at t = 0s  

$$= \left| \frac{0.08 - 0.00}{0 - 340} \right|$$
= 0.000235 mol dm<sup>-3</sup> s<sup>-1</sup>  
= 2.35 × 10<sup>-4</sup> mol dm<sup>-3</sup> s<sup>-1</sup> [1 for value] [1]

(iv) Hence, or otherwise, calculate the value of the rate constant and its units, given that the value of n = 1.

rate =  $k [NO_2]^1 [F_2]^1$ , 2.35 × 10<sup>-4</sup> = k (0.080)(1.20)  $k = 2.45 \times 10^{-3}$  [1] mol<sup>-1</sup> dm<sup>3</sup> s<sup>-1</sup> [1] allow e.c.f from (ii) Alternate method rate =  $k' [NO_2]^1$ ,  $k' = k [F_2]^1$   $k' = ln2 / t_{\frac{1}{2}}$   $k' = ln2 / 240 = 2.89 \times 10^{-3}$  $k = 2.89 \times 10^{-3} / [F_2] = 2.41 \times 10^{-3}$  [1] mol<sup>-1</sup> dm<sup>3</sup> s<sup>-1</sup> [1] allow e.c.f from (i) [2]

#### Marker Comments for (a)(iii) (iv):

- Both rate and rate constant should be a positive value in (iii) and (iv).
- Students have to read the question carefully, quite a large number of students did not give units in their answer (this is supposed to be an easy mark).

(v) The experiment was repeated using a larger concentration of 1.80 mol dm<sup>-3</sup> for F<sub>2</sub> instead. Determine the half-life of NO<sub>2</sub> in this experiment.

Half-life for second experiment = 
$$\frac{2}{3} \times 240 = 160 \text{ s}$$
 [1]

# Marker Comments for (a)(v):

- The half-life of NO<sub>2</sub> will not change regardless of concentration used. However, for this question, the change in concentration is for F<sub>2</sub>. With a higher F<sub>2</sub> concentration, the rate of consumption of NO<sub>2</sub> will be faster and since this is a 1<sup>st</sup> order reaction, the half-life will change proportionally to the change in F<sub>2</sub> conc.
- (b) NO<sub>2</sub> is among the exhaust gases produced by petrol-driven cars. Catalytic converters are fitted in petrol-driven cars to reduce the emission of these harmful NO and NO<sub>2</sub> gases by converting them to less harmful products such as H<sub>2</sub>O and N<sub>2</sub>. Platinum is used as a catalyst inside the catalytic converter.
  - (i) Name the type of catalysis that occurs in the catalytic converter. Outline the mode of action of the platinum catalyst in the reaction.
    - <u>Heterogeneous</u> [1] catalysis.
    - Adsorption: Reactant molecules are adsorbed onto the catalyst surface through the formation of temporary bonds.
    - Activation: This adsorption increases the surface concentration of the reactants and <u>weakens</u> the <u>covalent bonds</u> within the reactant molecules, thereby <u>lowering the activation energy</u>.
    - Reactant molecules are <u>brought closer together</u> and reaction can take place between the reactant molecules more easily.
    - <u>Desorption:</u> Products formed <u>diffuse away</u> from the surface of the catalyst. Any 2 points [1]

Marker Comments for (b)(i):

- Majority of students correctly identified this reaction involved heterogenous catalysis. The mode of action is BOOKWORK, students are expected to score full for this question.
- Students are expected to describe how the different types of catalysis (homogenous, heterogenous, autocatalysis and enzyme) work.
  - (ii) Carbon monoxide is another harmful exhaust gas produced in car exhaust that leads to poisoning for humans because it reduces the capacity of haemoglobin to transport oxygen around the body.

Explain how carbon monoxide prevents oxygen from being transported around the body.

- CO are toxic because the weaker H<sub>2</sub>O ligand in haemoglobin is replaced
   by <u>stronger CO ligands</u> in a ligand exchange reaction to form much
- more stable carboxyhaemoglobin which prevents O<sub>2</sub> ligand from binding to form oxyhaemoglobin. [1]

. . . . .

[1]

- (c) Car airbags is an important safety feature built in cars to minimise injury during collision. When the airbag is being activated, N<sub>2</sub> gas will be produced within milliseconds to inflate the airbag.
  - (i) Calculate the pressure in the airbag of the front passenger with a volume of 70.5 dm<sup>3</sup> when inflated at 25 °C with 135 g of  $N_2$ .



(ii) The plots of pV/RT against p for one mole of an ideal gas and one mole of carbon dioxide at 25 °C are given in Fig. 2.2.





On the axes above, sketch a graph to illustrate the behaviour of one mole of NO<sub>2</sub> at 25 °C. Explain your answer.

NO<sub>2</sub> has <u>stronger permanent dipole-permanent dipole attraction</u> between its molecules compared to the <u>weaker instantaneous dipole-</u> <u>induced dipole interaction</u> between CO<sub>2</sub> molecules. Thus NO<sub>2</sub> has <u>more</u> <u>significant intermolecular attractions</u> and it will tend to deviate more from ideal gas behavior. [1]

### Marker Comments for (c):

• The difference in number of electron is only one (NO<sub>2</sub>=23 & CO<sub>2</sub>=22), thus extent of id-id attraction of NO<sub>2</sub> and CO<sub>2</sub> is comparable. Students should focus their discussion on pd-pd and id-id attractions.

3 (a) The aldol reaction is a useful organic reaction that involves the formation of a C–C bond between the α-carbon of a carbonyl compound with the carbonyl carbon of another carbonyl compound. The product is known as an aldol compound.

For instance, the aldol reaction between ethanal molecules involves 3 steps as shown in Fig. 3.1.



(i) State the type of reaction for steps 2 and 3 given above.



### Marker Comments for (a)(i):

- Step 2 was generally well-attempted as majority of the students could identify the carbanion, as the nucleophile, attacking the electron-deficient carbonyl carbon of ethanal.
- For Step 3, water serves as an acid donating H<sup>+</sup> to the intermediate compound.
- (ii) Heptanedial undergoes aldol reaction to form a compound with the same number of carbon atoms.



Suggest the structure of the product formed.



[1]

### Marker Comments for (a)(ii):

- Some students failed to identify this reaction as a self-aldol reaction, since the molecule contains 2 carbonyl groups. Students were also hinted that the number of carbon atoms remained unchanged.
- Such ring formation questions are particularly relevant in A-level. Students are strongly advised to be equipped with the right set of skills for organic compound questions.
- (iii) Hydrogen atoms in alkyl groups do not deprotonate easily. However, in step 1, the α-carbon in the carbonyl compound is deprotonated. Suggest a reason to explain why this deprotonation occurs. Use the concepts of electronic effects or delocalisation in your answers.



- Some students are still confused about the concept on delocalisation as they mentioned the delocalisation of the lone pair of electron on oxygen which is incorrect and irrelevant.
- (b) Succinic anhydrides are primarily used in the production of various polymers and resins.

Fig. 3.2 shows a possible reaction scheme to form succinic anhydrides.



Fig. 3.2



[Turn over 2023 JC2 Preliminary Examination H2 Chemistry (i) State the reagents and conditions for step 2 and 3.

step 2: ethanolic NaCN, heat [1] step 3: I <u>2 (aq), NaOH, heat [1]</u>	[2]
Marker Comments for (b)(i):	
• Generally well-attempted question for students who have put in cons to revise on the reagents and conditions from organic chemistry.	cientious effort

(ii) Draw the structures for compound **A** and **B**.



- Students are reminded about the idea of concurrent reactions occurring in Step 3. The nitrile • group (-CN) undergoes basic hydrolysis to form a carboxylate anion (-COO<sup>-</sup>) with NaOH, heat.
  - (iii) Suggest the type of reaction occurring in step 5.

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Condensation or nucleophilic (acyl) substitution [1]
                                                         .....[1]
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(iv) Propose a chemical test used to confirm that succinic acid has been completely reacted in step 5. State your expected observation.



Succinic anhydride reacts with water in a 1:1 ratio as shown. (v)



succinic anhydride

succinic acid

With reference to the above reaction, suggest the structure of the product when succinic anhydride reacts with ethanol in a 1:1 ratio.



(vi) Maleic acid and fumaric acid are unsaturated forms of succinic acid. The boiling points of both compounds are given below.

compound	boiling point / °C
HOOC COOH maleic acid	135
HOOC COOH fumaric acid	280

Account for the difference in boiling points of the two compounds.



### Marker Comments for (b)(vi):

- This question is poorly attempted by students. Students failed to identify the correct factor to account for the difference in boiling point. The main intermolecular forces of attraction is hydrogen bonding. Students must explore the use of extent of hydrogen bonding to justify the difference in boiling point, which in this case would be inter vs intra molecular hydrogen bonding.
- Students who explained using surface area of contact or packing are deemed as incorrect.

(c) Other than succinic anhydrides, alcohols and acids are commonly used as industrial solvents in cleaning products and disinfectants. Explain why ethanoic acid is a stronger acid compared to ethanol.

In the ethanoate ion, the <u>negative charge is dispersed due to delocalisation over</u>	]
In the ethoxide ion, the negative charge is intensified due to the electron- donating alkyl group.	
Hence, the <b>ethanoate anion is more stable than the ethoxide ion</b> .	
There is a greater tendency for ethanoic acid to ionise compared to ethanol.	
4 pts: <b>[2]</b> , 2-3 pts: <b>[1]</b>	[2]
[Total: 1	[6]

Marker Comments for (b)(vi):

• This is a basic recall question found in the lecture notes yet majority of students did not manage to score full marks. This is evident that they did not do their bookwork thoroughly.



(i) Explain the differences in the behaviour of the electrons and protons in the electric field. Account for both direction and magnitude of deflection.

Electrons have a larger charge/mass ratio (or smaller mass) and are therefore deflected to a greater extent. [1] Electrons are negatively charged and therefore attracted to the positive potential. Protons are positively charged and therefore attracted to the megative potential. [1]

Marker Comments for (a)(i):

 Candidates are advised to answer questions with specificity and clarity without the examiners having to "interpret" what the vague answer means. Example of a vague and unclear answer: "Electrons and protons are oppositely charged and hence are deflected in opposite directions." Answers that were awarded credit compared the charge of the particle to the charge of the potential (as opposed to the vague answer of just comparing the charges of the particles).
 Candidates are reminded that the correct factor to consider should be charge to mass ratio (<sup>q</sup>/<sub>m</sub>). Any reference to charge density (<sup>q</sup>/<sub>r</sub>) as the factor affecting the angle of

deflection is INCORRECT. Charge over mass ratio is NOT charge density.

(ii) If the protons are deflected by an angle of +24.0°, predict the angle of deflection of a beam containing <sup>32</sup>S<sup>2-</sup> ions travelling at the same speed in the same electric field. Show your working clearly.



# Marker Comments for (a)(ii):

- The sign needs to be included for the angle of deflection as it indicates the direction in which the particle is deflected towards.
- Some candidates were unable to obtain the correct charge to mass ratio of <sup>32</sup>S<sup>2-</sup> due to errors such as using the proton number as the mass, or adding the number of electrons to the mass number.

ver

[1]

<sup>'</sup> [1]

- (b) Sulfur forms compounds that can behave as either Lewis acids or bases.
  - (i) Explain what is meant by a Lewis acid.

Marker Comments for (b)(i):

- Some candidates did not do their bookwork thoroughly and gave the definition of a Bronsted acid instead.
- Do take note that the term "pair" is crucial. "Electron acceptor" is not accepted.
  - (ii) Deduce whether the sulfur containing compound in the following reaction behaves as a Lewis acid or base.

$$H_3C \xrightarrow{S} CH_3 + CH_3I \rightarrow S(CH_3)_3^+ + I^-$$

The sulfur-containing compound behaves as a <u>Lewis base as sulfur</u>.
 <u>donates a lone pair of electrons to (C atom of) CH<sub>3</sub>I.</u> [1] for BOTH
 answer and explanation.

Marker Comments for (b)(ii):

- Once again, it is important to answer with specificity and clarity by including which atom is the lone pair donor and which atom is the lone pair acceptor.
- CH<sub>3</sub><sup>+</sup> is not accepted as the lone pair acceptor as it is unlikely for a primary halogenoalkane like CH<sub>3</sub>I to undergo S<sub>N</sub>1 to form a carbocation. Neither is CH<sub>3</sub>I ionic to begin with.
- (c) When mixed with water at 25 °C, hydrogen sulfide (H<sub>2</sub>S) dissociates in two steps:

equation 1	$H_2S + H_2O \Longrightarrow HS^- + H_3O^+$	$K_{a_1} = 8.9 \times 10^{-8} \text{ mol dm}^{-3}$
equation 2	$HS^- + H_2O \implies S^{2-} + H_3O^+$	$K_{a_2} = 1.0 \times 10^{-15} \text{ mol dm}^{-3}$

(i) Explain why the value of  $K_{a_2}$  is much smaller than  $K_{a_1}$ .

It is more difficult to lose a proton from the negatively charged HS<sup>-</sup> .... than the neutral H<sub>2</sub>S molecule. [1]

Marker Comments for (c)(i):

- It was surprising that a sizeable number of candidates were unable to answer this basic bookwork question. Please refer to pg 39 of Acid-Base Equilibria Lecture Notes.
- Some candidates used the term "ion" loosely and described H<sub>2</sub>S as a neutral ion which does not make any sense. Ions are charged species.
  - (ii) Write the expression for the acid dissociation constant,  $K_{a_1}$ .

[HS <sup>-</sup> ][H₂O <sup>+</sup> ]	Marker Comments for (c)(ii):
$K_{a_1} = \frac{[H_2S]}{[H_2S]}$ [1]	<ul> <li>As equation 1 was given, K<sub>a1</sub> should be written based on the species present in equation 1. Hence, answers which used H<sup>+</sup> instead of H<sub>3</sub>O<sup>+</sup> were rejected.</li> </ul>
	• Even though the state symbols were not given in the equation, candidates should be aware that this is a heterogenous equilibrium with water in the liquid state and the other species in the aqueous state. Hence, water should not have been
npines Meridian Junior College	included in the $K_{a_1}$ expression.

(iii) Hence show, by calculating the  $[HS^{-}]/[H_2S]$  ratio, that an aqueous H<sub>2</sub>S solution which has pH 3.16 contains H<sub>2</sub>S as the predominant sulfur-containing species.

[You may disregard the effect of  $K_{a_2}$ .]  $K_{a_1} = \frac{[HS^-][H_3O^+]}{[H_2S]}$  $8.9 \times 10^{-8} = \frac{[HS^-](10^{-3.16})}{[H_2S]}$  [1]  $\Rightarrow \frac{[HS^-]}{[H_2S]} = 1.29 \times 10^{-4}$  [1] Since  $\frac{[HS^-]}{[H_2S]} \ll 1$ , H<sub>2</sub>S is the predominant species.

#### Marker Comments for (c)(iii):

- For candidates who knew how to approach this question, it was generally well-attempted. [2]
- However, some candidates did not realise that they should make use of the expression in (ii) and hence used irrelevant methods such as  $[H^+] = \sqrt{c \times K_a}$  to find the concentration of H<sub>2</sub>S before substituting the [HS<sup>-</sup>] and [H<sub>2</sub>S] to find the ratio.
- Candidates are reminded to make a conclusion about the ratio they have calculated and use it to prove that H<sub>2</sub>S is the predominant sulfur-containing species.
  - (iv) A solution containing H<sub>2</sub>S(aq) and HS<sup>-</sup>(aq) can act as a buffer solution, resisting changes in pH when small amounts of acid or alkali are added.

Write two equations to show how this mixture acts as a buffer.

Marker Comments for (c)(iv):

- Majority of the cohort obtained full credit for this part.
- A reminder that a single arrow  $(\longrightarrow)$  should be used to show that the acid or base added has been removed.
- A 1.0 dm<sup>3</sup> solution containing 0.50 mol each of H<sub>2</sub>S(aq) and HS<sup>-</sup>(aq) was prepared. (v) Calculate the increase in pH when 0.020 mol of solid sodium hydroxide was added (assume no change in volume).

Initial pH = pK<sub>a1</sub> [max. buffer]  
After addition of NaOH, pH = pK<sub>a1</sub> + lg
$$\frac{[HS^-]}{[H_2S]}$$
  
 $\Rightarrow$  [HS<sup>-</sup>] increases and [H<sub>2</sub>S] decreases.  
 $\Rightarrow$  increase in pH = lg $\left(\frac{0.50 + 0.020}{0.50 - 0.020}\right) = 0.0348$  [1]  
Marker Comments for (c)(v):  
• This was the most challenging part for Q4. For the candidates who managed to obtain the correct answer, they often used a longer method of finding the initial and final pH, without realising that the increase in pH was simply lg $\frac{[HS^-]}{[H_2S]}$  as the solution [Total: 12]

started out at maximum buffer capacity (equal concentration of the weak acid and conjugate base).

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5 (a) Green hydrogen fuel is a promising renewable energy source and is produced through the process of electrolysis, using renewable electricity to split water into hydrogen and oxygen. The cell used is known as the Solid Oxide Electrolysis Cell (SOEC) and it offers high efficiency and scalability.

$$2H_2O(g) \longrightarrow O_2(g) + 2H_2(g)$$
  $\Delta H = +241.8 \text{ kJ mol}^{-1}$ 

SOEC, as shown in Fig. 5.1 below, utilises a solid oxide electrolyte such as cerium oxide  $(CeO_2)$  and nickel-based electrodes as key components in the electrolysis process. Steam goes into the cathode and produces hydrogen gas, H<sub>2</sub>, and oxide ions, O<sup>2-</sup>. The oxide ions migrate through the electrolyte to the anode, where they release electrons to become oxygen gas. Typically, the operating temperatures for SOECs are from 800 to 1,000 °C and current at 1.5 A cm<sup>-2</sup> of cross section area.



Modified from: https://www.researchgate.net/figure/Alkaline-Electrolyser-Cell-AEC-working-principle-Reprinted-from-ref-9-with\_fig1\_354214398



(i) Write the equation for the reaction that occurs at the cathode and the anode respectively.

cathode:	$2H_2O + 4e^- \rightarrow 2H_2 + 2O^{2-}$ [1]	
anode:	$20^{2-} \rightarrow 0_2 + 4e^{-}$ [1]	[2]

### Marker Comments for (a)(i):

Students should carefully analyze the context to identify the reactants and products at each electrode. Many students tend to rely solely on the half-equations provided in the Data Booklet, which include  $H_2O$  as a reactant or product.

It's crucial for students to note that equations must employ a single arrow, not a double arrow, as these represent the reactions occurring at each electrode. Balancing the anode half-equation can be challenging to some students; to generate one mole of  $O_2$ , you require 2 moles of  $O^{2-}$  ions and 4 moles of electrons being released.



(ii) Given that the total cross section area of the anode is 1500 cm<sup>2</sup>, calculate the mass of H<sub>2</sub>, in kg, generated in one day of operation.

Total charge per day = It =  $1500 \times 1.5 \times 60 \times 60 \times 24 = 1.944 \times 10^8$  C [1] No of mole of H<sub>2</sub> =  $\frac{1.944 \times 10^8}{2 \times 96500}$  = 1007 mol or 1010 mol Mass of H<sub>2</sub> = 2015 g or 2020 g = 2.02 kg [1]

### Marker Comments for (a)(ii):

This question saw numerous errors stemming from fundamental misconceptions:

1. Some students failed to consider the cross-sectional area, while others incorrectly divided the current by the cross-section.

2. Many students were unaware of the significance of the 'n' term in the equation, representing the moles of electrons needed to produce one mole of hydrogen gas – in this case, it's 2.

3. Some mistakenly believed that hydrogen referred to H atoms and, as a result, omitted multiplying by 2 to calculate the mass.

(iii) Propose an explanation, in terms of thermodynamics, why high temperature is necessary in this reaction.

Since  $\Delta H = +$  ve and  $\Delta S = +$  ve When  $\Delta H > 0$  and  $\Delta S > 0$  then  $-T\Delta S < 0$ , <u>At high T</u>,  $|T\Delta S| > |\Delta H|$  [1] Hence,  $\Delta G < 0$  at high temperatures thus reaction is <u>spontaneous at high temperature</u>. [1]

......[2]

(iv) Suggest a physical property of cerium oxide that makes it suitable to be used as the solid electrolyte in SOEC.

Cerium oxide has very high melting point to withstand the high temperature condition. [1]

.....[1]

### Marker Comments for (a) (iii) & (iv):

Several students attempted to address this question using kinetic or LCP explanations, even though the question explicitly called for the use of the thermodynamic factor. Therefore, it's essential to use  $\Delta G = \Delta H - T\Delta S$  for the explanation. Students often provided disorganized explanations that included unnecessary details, leading to time wastage.

The key to answering this question lies in the context – SOECs must operate at very high temperatures. In this case, the only acceptable answer is a high melting point. Answers such as boiling point (cerium oxide is a solid), thermal stability (cerium oxide cannot decompose into simpler compounds), porous (too general), and good electrical conductivity (electrons don't flow through solid electrolytes) are not acceptable.





(b) Fig 5.2 shows the reactions of nickel and its compounds.



compound E:	H <sub>2</sub> [1]	
compound G:	Ni(OH) <sub>2</sub> [1]	

(ii) Write an ionic equation for the formation of **F** from  $[Ni(H_2O)_6]^{2+}$ .

 $[Ni(H_2O)_6]^{2+} + EDTA^{4-} \rightarrow [Ni(EDTA)]^{2-} + 6H_2O$ [1]	[1	]

(iii) State the type of reaction that occurred in steps 1 and 6.

step 1: .	redox reaction [1]	
step 6: .	ligand exchange [1]	[2]

### Marker Comments for (b)(i) to (iii):

The question already mentions that E is a neutral gas, and it involves an acid-metal displacement reaction resulting in the release of hydrogen gas. Students should have recognized that G is a precipitate, resulting in the overall charge of the suggested compound being zero. Drawing from their knowledge of copper chemistry would have been beneficial here.

EDTA carries a charge of -4 with a coordination of 6, meaning the new complex formed should have a charge of -2, and all water molecules are displaced. Since the question requests an ionic equation, spectator ions like Na<sup>+</sup> should not be included.

Nickel and bromine gas undergo a redox reaction to form nickel bromide (the yellow-brown solid). "Reduction" or "oxidation" is not acceptable since the question pertains to the overall equation. The term "precipitation" is also not appropriate as it doesn't involve the formation of a solid from a solution. Students should not assume that solid formation equates to a precipitation reaction. Common reactions involving transition metals include redox, ligand exchange, and precipitation.

(iv) The "en" refers to ethylenediamine, which is a bidentate ligand as it has two nitrogen atoms that can form coordination bonds with a metal ion.



 $[Ni(H_2O)_6]^{2+}$  reacts with excess ethylenediamine to form a purple-blue solution of  $[Ni(H_2O)_2(en)_2]^2$ .

 $[Ni(H_2O)_2(en)_2]^{2+}$  can exist in both cis and trans isomeric forms due to the placement of the ligands around nickel cation. Given that the cis form is non-symmetrical, suggest a 3-dimensional structure of cis- $[Ni(H_2O)_2(en)_2]^{2+}$ .



- (v) Ni<sup>2+</sup> undergoes a reaction with an excess of chloride ions to yield  $[NiCl_4]^{2-}$  instead of  $[NiCl_6]^{4-}$ . Suggest a reason.
  - Steric hinderance due to the large size of chloride or small size of nickel ion
  - As chloride ion and [NiCl<sub>4</sub>]<sup>2-</sup> are both negatively charge, there is charge repulsion between the complex [NiCl<sub>4</sub>]<sup>2-</sup> and incoming Cl<sup>-</sup> ligand. [either answer 1]

### Marker Comments for (b)(iv) and (v):

The placement of  $H_2O$  in the octahedral complex determines whether it is in a trans (180° apart) or cis (90° apart) configuration. No lone pairs should be drawn, and students should use the correct atoms (O from  $H_2O$  and N from en) to bind with the central atom.

Merely stating that  $[NiCl_6]^{4-}$  is not stable and  $[NiCl_4]^{2-}$  is not enough; a more detailed answer is required. To earn marks, students must elaborate on the property and explain how it affects the formation. They should not explain from the angle of inaccessible d orbitals or no electrons, as Ni<sup>2+</sup> can form  $[Ni(H_2O)_6]^{2+}$  but not NiCl<sub>6</sub><sup>4-</sup>.

(vi) Ethylenediamine is a versatile organic compound used as a starting material in organic synthesis due to its ability to form stable complexes and its amine properties.

Fig. 5.3 illustrates a synthesis pathway that utilises ethylenediamine as a starting material to produce compound Z through a series of chemical transformations.





Draw the structure of the compounds **X**, **Y** and **Z** in the spaces provided.









There are two different chlorides involved – acyl chloride and chloroalkane. Based on the conditions, acyl chloride will undergo condensation with an amine in step 1 and electrophilic substitution with a benzene ring in step 2. While many students performed well on this question, earning 1 to 2 out of 3 marks, some common mistakes persisted:

- 1.Omitting the hydrogen bonded to the nitrogen atom in skeletal formulae, only the hydrogen atoms bonded to carbon atoms need not be shown.
- 2.Forgetting to include a carbon atom after electrophilic substitution. Students should count the number of carbon atoms in their drawing.
- 3.Reacting with the wrong chloride. Students should pay attention to the conditions stated for step one (room temperature and pressure), and only acyl chloride can react with an amine to form an amide.
- 4. Misidentifying the reduction of the amide some students thought it was a ketone and assumed it underwent reduction to form an alcohol. Students should refer to the given chemical formula, which lacks an oxygen atom. The reaction involves the reduction of an amide to an amine, the last organic reaction covered in the curriculum.