Diploma Programme
Programme du diplôme
Programa del Diploma

Chemistry
Higher level
Paper 2

9 May 2024

Zone A morning | **Zone B** morning | **Zone C** morning

Candidate session number

2 hours 15 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks].**

2224 – 6202

24 pages

Answer **all** questions. Answers must be written within the answer boxes provided.

1. A powder has the following percentage composition by mass:

30.0 % sucrose, $C_{12}H_{22}O_{11}$

45.0 % citric acid, $C_6H_8O_7$

25.0 % sodium hydrogencarbonate, $NaHCO_3$

In the presence of water, the powder effervesces as the citric acid reacts with the sodium hydrogencarbonate:

$$3NaHCO_3(s) + C_6H_8O_7(aq) \rightarrow Na_3(C_6H_5O_7)(aq) + 3CO_2(g) + 3H_2O(l)$$

(a) (i) Determine the limiting reactant when 1.00 g of this powder reacts. [3]

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(ii) Determine the volume, in dm^3 at SATP, of carbon dioxide released in the reaction in (a)(i). Use sections 1 and 2 of the data booklet. [2]

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(This question continues on the following page)

(Question 1 continued)

(iii) Calculate the percentage yield obtained by a student who collected 0.043 dm^3 of carbon dioxide from 1.00 g of the powder.

If you did not obtain an answer to (a)(ii), use 0.068 dm^3, but this is not the correct value. [1]

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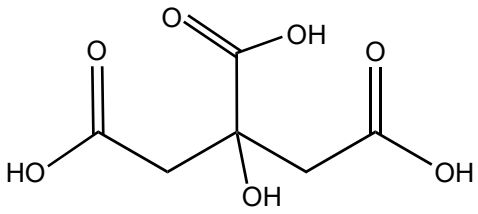
(b) (i) State the number of acidic hydrogens in the citric acid molecule shown. [1]



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(ii) Deduce the structural formula of the conjugate base of citric acid. [1]

(iii) Predict, giving a reason, the strength of citric acid. [1]

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will not be marked.

(Question 1 continued)

(iv) Explain why sodium citrate solutions are basic. [1]

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(c) Calculate the pH of a solution with a hydrogen ion concentration, $[H^+] = 0.0025\,mol\,dm^{-3}$ [1]

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(d) Describe the bonding in solid sodium citrate. [2]

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(e) State, giving a reason, how the lattice and hydration enthalpies would differ if potassium ions were present instead of sodium ions. [2]

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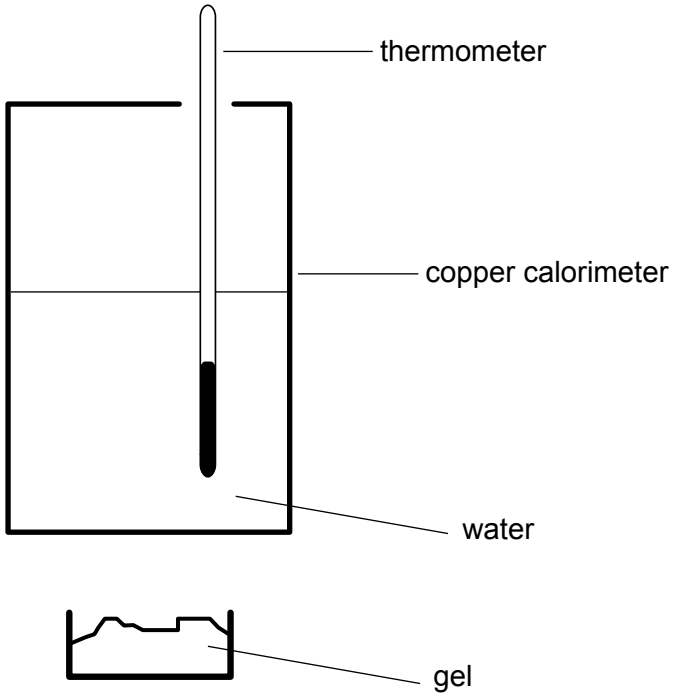
2. A student investigated the use of hand sanitising gel containing propan-1-ol as a camping fuel.



Mass of water / g ± 0.02 g	400.00
Initial temperature of water / °C ± 0.5 °C	19.0
Final temperature of water / °C ± 0.5 °C	40.0
Initial mass of gel / g ± 0.01 g	20.00
Final mass of gel / g ± 0.01 g	18.20

(a) (i) Calculate the heat energy absorbed by the water, in J. Use sections 1 and 2 of the data booklet. [1]

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(ii) Calculate the percentage uncertainty of your answer in (a)(i). [2]

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(This question continues on the following page)

(Question 2 continued)

(iii) Suggest a way to reduce the random uncertainty of the answer. [1]

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(b) (i) Calculate the enthalpy of combustion of propan-1-ol, in $kJ\,mol^{-1}$, stating **one** assumption.

If you did not obtain an answer to (a)(i), use 30 000 J, though this is not the correct value. [3]

Calculation: . . . . . .

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Assumption: . . . . . .

(ii) Calculate the percentage error, using section 13 of the data booklet. [1]

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(iii) Suggest the main source of error, and a way to reduce it. [1]

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(This question continues on the following page)

(Question 2 continued)

(c) The student also investigates a second gel containing ethanol, with the same percentage by mass as the propan-1-ol in the first gel.

Determine whether the second gel would release more or less energy per gram than the first gel. Use section 13 of the data booklet. [3]

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(d) Ethanol and propan-1-ol are members of a homologous series.

(i) State the names of the class of compound and the functional group of this series. [2]

Class: . . . . . .

Functional group: . . . . . .

(ii) State the strongest intermolecular force present in ethanol and propan-1-ol. [1]

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(iii) Predict an intermolecular force which would be stronger in the next member of the homologous series, butan-1-ol. [1]

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(Question 2 continued)

(e) Butan-2-ol is optically active.

(i) Sketch **two** enantiomers of butan-2-ol to show the relationship between them. [2]

(ii) Deduce the organic products when butan-1-ol and butan-2-ol are separately heated under reflux with acidified potassium dichromate(VI). [2]

Butan-1-ol: . . . . . .

Butan-2-ol: . . . . . .

(f) Propan-1-ol can be produced from 1-chloropropane.

(i) Identify a nucleophile which could be used for this reaction. [1]

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(Question 2 continued)

(ii) Sketch the mechanism of the reaction between 1-chloropropane and the nucleophile in (f)(i), using curly arrows. [3]

(g) Ethyl ethanoate can be produced from ethene via a three-step synthetic route.

step 1: $CH_2CH_2 + H_2O \rightarrow CH_3CH_2OH$

step 2: $CH_3CH_2OH + [O] \rightarrow CH_3COOH$

step 3: $CH_3CH_2OH + CH_3COOH \rightarrow CH_3COOCH_2CH_3 +$ ____

(i) State the conditions necessary for the reaction in step 1. [1]

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(ii) Identify the type of reaction occurring in step 3. [1]

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(iii) Identity the second product formed in step 3. [1]

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3. Hydrogen is manufactured from methane by a process called steam reforming:

$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +206\,kJ\,mol^{-1}$

(a) Deduce the equilibrium constant, *K*c, expression for the reaction. [1]

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(b) Predict, with a reason, the effect of increasing the temperature on the position of equilibrium. [1]

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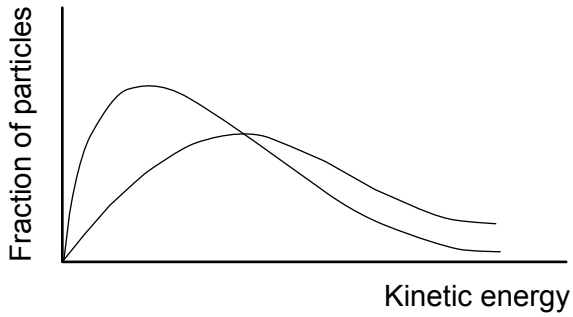
(c) Explain why the reaction rate increases with temperature, adding annotations to the following Maxwell–Boltzmann graph to assist your explanation. [3]



Explanation: . . . . . .

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(d) Annotate this Maxwell–Boltzmann distribution graph in (c) to show the effect of a catalyst. [1]

(This question continues on the following page)

(Question 3 continued)

(e) The reactants, CH_4 and H_2O, are passed over nickel metal. The following mechanism is proposed:

$CH_4 + Ni \rightarrow Ni\text{-}CH_2 + H_2$ (slow)

$H_2O + Ni\text{-}CH_2 \rightarrow Ni\text{-}CHOH + H_2$ (fast)

$Ni\text{-}CHOH \rightarrow Ni\text{-}CO + H_2$ (fast)

$Ni\text{-}CO \rightarrow Ni + CO$ (fast)

(i) Deduce, giving a reason, the role of nickel in the reaction. [1]

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(ii) Deduce the rate equation corresponding to the mechanism. [1]

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(Question 3 continued)

(iii) Suggest why experimental confirmation of the rate equation would not prove that the mechanism is correct. [1]

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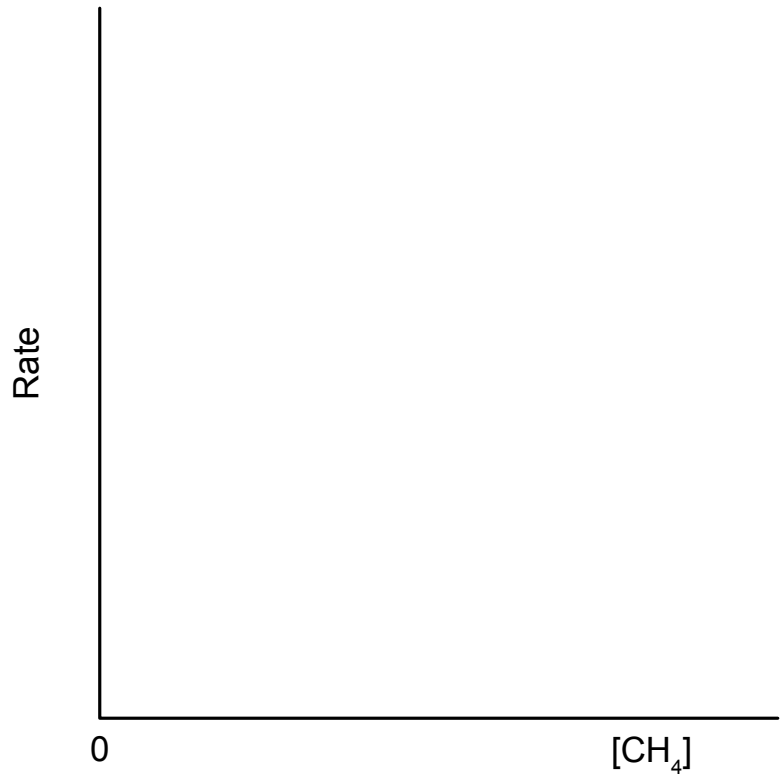
(iv) Sketch a graph of the relationship between the rate of this reaction and the concentration of methane. [1]



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(Question 3 continued)

(f) Calculate the standard entropy change, $\Delta S^{\ominus}$, of the forward reaction, in $J\,K^{-1}$.

$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H = +206\,kJ\,mol^{-1}$

Use section 12 of the data booklet, and the standard entropy of hydrogen:

$S^{\circ}(H_2(g)) = +130.7\,J\,K^{-1}\,mol^{-1}$ [1]

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(g) Calculate the Gibbs Free energy, ΔG, and the equilibrium constant *Kc*, for the forward reaction, at 1500 K. Use sections 1 and 2 of the data booklet.

(If you were unable to obtain an answer for part (f) use $227\,J\,K^{-1}$, but this is not the correct value.) [2]

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(h) Determine the temperature, in K, at which the forward reaction becomes spontaneous. Use section 1 of the data booklet. [2]

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4. The water-gas shift reaction is another way to manufacture hydrogen.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \qquad \Delta H = -41\,kJ\,mol^{-1}$$

(a) (i) State the oxidation state of carbon in carbon monoxide and carbon dioxide. [1]

carbon monoxide: . . . . . .

carbon dioxide: . . . . . .

(ii) Identify the oxidising and reducing agents, and the species oxidised and reduced, in the forward reaction. [2]

	CO (g)	**H_2O (g)**
oxidising or reducing agent?		
species oxidised or reduced?		

(b) (i) Draw the Lewis structure of carbon dioxide. [1]

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(ii) Annotate the Lewis structure in (b)(i) to show the polarity of the bonds by adding the symbols $\delta+$ and $\delta-$ as appropriate. [1]

(iii) Explain the molecular geometry and polarity of the carbon dioxide molecule. [2]

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(Question 4 continued)

(iv) State the hybridization of the carbon atom in carbon monoxide and in carbon dioxide. [1]

carbon monoxide: . . . . . .

carbon dioxide: . . . . . .

(v) State the number of σ and π bonds in a carbon monoxide molecule. [1]

σ bonds: . . . . . .

π bonds: . . . . . .

(vi) Determine the bond enthalpy of carbon monoxide, in $kJ\,mol^{-1}$. Use section 11 of the data booklet and the equation:

$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \qquad \Delta H = -41\,kJ\,mol^{-1}$ [2]

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5. Successive ionization energies of an element (E) are shown. E is not the real symbol of the element.

Number of ionization energy	**first**	**second**	**third**	**fourth**	**fifth**	**sixth**	**seventh**
IE / kJ mol^{-1}	1000	2295	3375	4565	6950	8490	27 107

(a) Identify the group of the periodic table in which element E is located, giving a reason. [1]

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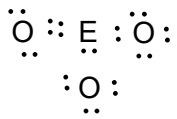
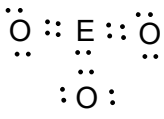
(b) Element E forms an oxide EO_3. Two possible Lewis structures are shown.

(i) Show which structure is most likely, using the concept of formal charge. [3]

Structure 1



Structure 2



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(Question 5 continued)

(ii) Write the balanced equation for the reaction of EO_3 with water. [1]

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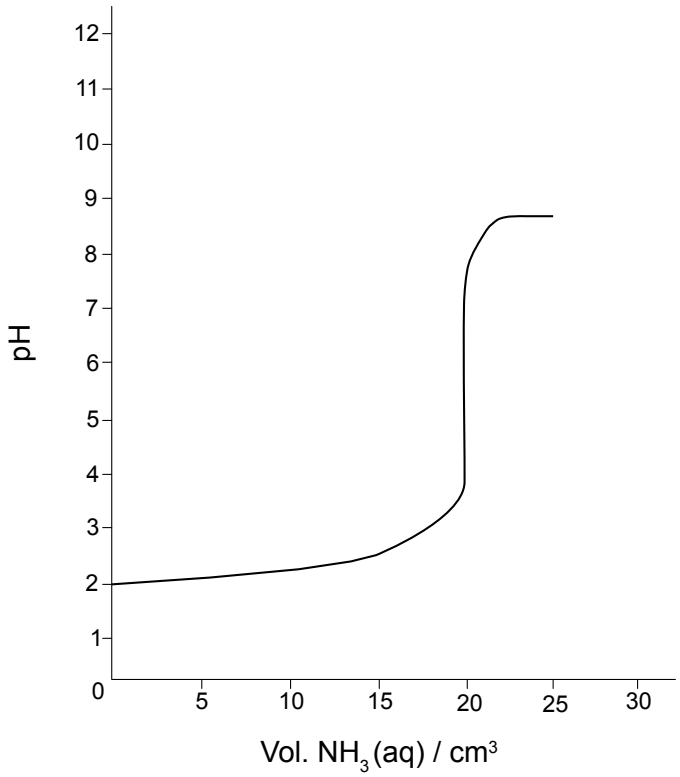
(c) A strong acid was titrated with 0.01 mol dm^{-3} ammonia solution, NH_3(aq). The pH curve for the titration is shown.



(i) Identify the best indicator for this titration, using section 22 of the data booklet. [1]

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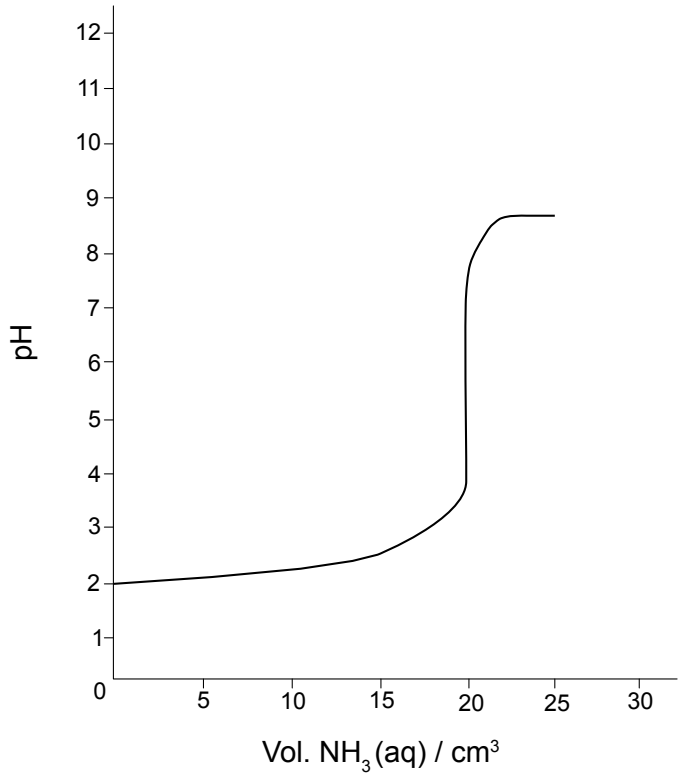
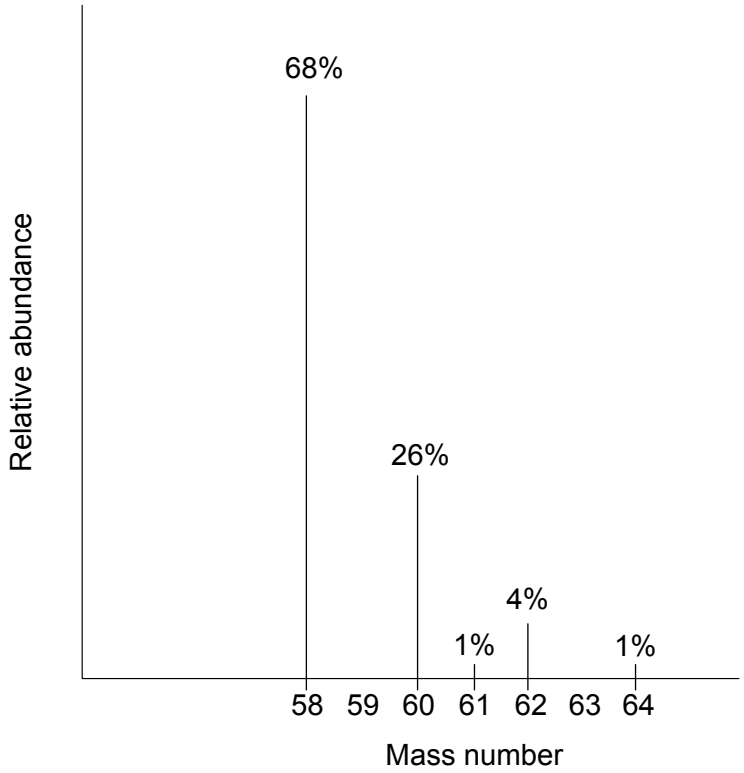
(Question 5 continued)

(ii) Sketch on the following graph the curve expected if 0.01 mol dm^{-3} NaOH (aq) is used instead of the 0.01 mol dm^{-3} NH_3 (aq). [2]



6. (a) Determine the relative atomic mass of nickel from the mass spectrum shown. [1]



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(b) (i) Deduce the nuclear symbol, ${}^{A}_{Z}X$, for an ion of nickel-58 with 26 electrons. [1]

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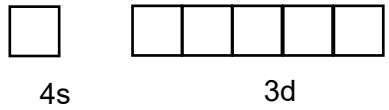
(Question 6 continued)

(ii) Draw arrows to represent electrons in the orbital diagram for this ion. [1]



(iii) Predict, giving a reason, whether Ni^{2+} is para- or diamagnetic. [1]

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(c) Nickel forms the green complex ion $[Ni(H_2O)_6]^{2+}$

(i) Explain why $[Ni(NH_3)_6]^{2+}$ is blue-violet. Use sections 15 and 17 of the data booklet. [2]

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(ii) Identify, with a reason, whether ammonia acts as a Lewis acid or Lewis base in the complex ion, $[Ni(NH_3)_6]^{2+}$. [1]

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(iii) Describe whether ammonia acts as a Brønsted–Lowry acid or base in its reaction with water. Include an equation in your answer. [2]

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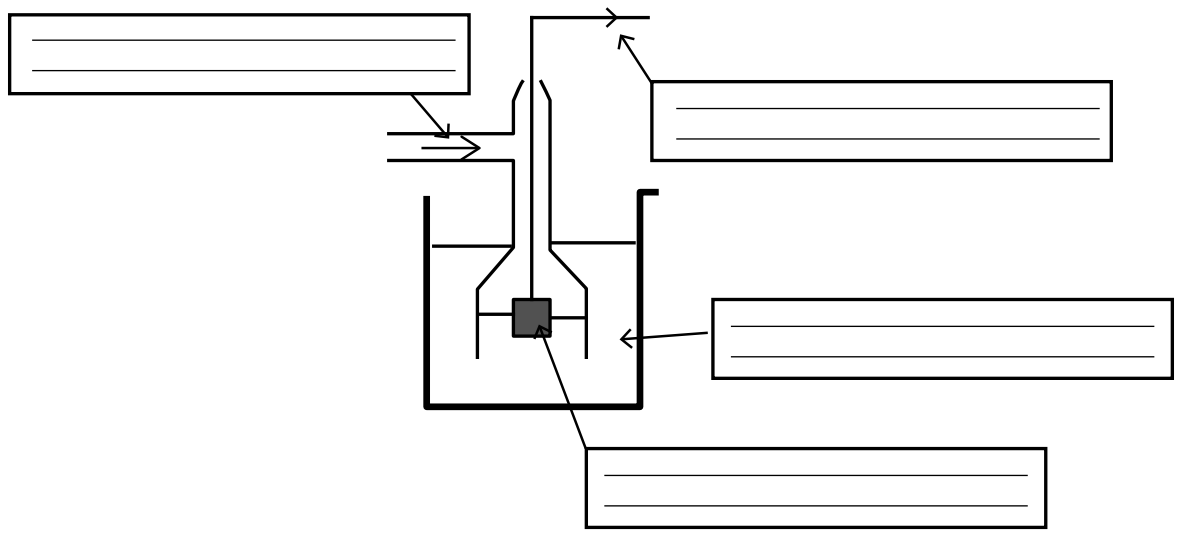
7. (a) Label the figure with the essential features of the standard hydrogen electrode, by writing in the boxes. [2]



(b) A standard hydrogen electrode is connected to a copper-copper (II) nitrate half-cell.

(i) Formulate a cell diagram for the spontaneous reaction, representing phase boundaries with "|" and the salt bridge with "||". Use section 24 of the data booklet. [1]

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(ii) Calculate the standard Gibbs free energy of the cell, in $kJ\,mol^{-1}$. Use sections 1, 2 and 24 of the data booklet. [2]

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