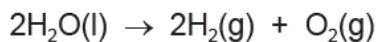


1. Nov/2021/Paper_41/No.1

When dilute sulfuric acid is electrolysed, water is split into hydrogen and oxygen.



A current of $x\text{A}$ is passed through the solution for 14.0 minutes. 462 cm^3 of hydrogen are produced at the cathode, measured under room conditions.

(a) Calculate the number of hydrogen molecules produced during the electrolysis.

number of hydrogen molecules = [2]

(b) Calculate the total number of electrons transferred to produce this number of hydrogen molecules.

total number of electrons = [1]

(c) Calculate the quantity of charge, in coulombs, of the total number of electrons calculated in **(b)**.

quantity of charge = C [1]

(d) Calculate the current, x , passed during this experiment.

x = A [1]

(e) The standard entropies, S° , of three species are given in the table.

species	$S^\circ/\text{JK}^{-1}\text{mol}^{-1}$
$\text{H}_2\text{O}(\text{l})$	+70
$\text{H}_2(\text{g})$	+131
$\text{O}_2(\text{g})$	+205

(i) Calculate ΔS° for the reaction $2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{H}_2(\text{g}) + \text{O}_2(\text{g})$.

$$\Delta S^\circ = \dots\dots\dots \text{JK}^{-1}\text{mol}^{-1} \quad [1]$$

(ii) ΔH° for the reaction $2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{H}_2(\text{g}) + \text{O}_2(\text{g})$ is $+572\text{kJmol}^{-1}$.

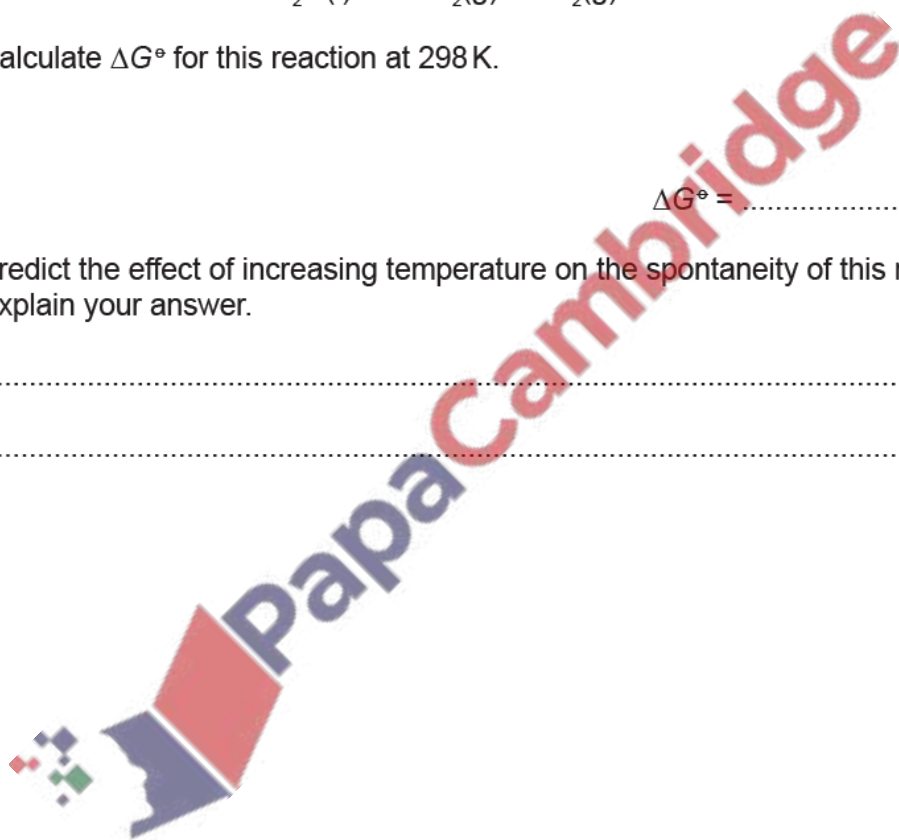
Calculate ΔG° for this reaction at 298 K.

$$\Delta G^\circ = \dots\dots\dots \text{kJmol}^{-1} \quad [2]$$

(iii) Predict the effect of increasing temperature on the spontaneity of this reaction. Explain your answer.

.....
..... [1]

[Total: 9]



(a) Define the term *electron affinity*.

.....
 [2]

(b) Write an equation for the process corresponding to the **second** ionisation energy of calcium. Include state symbols.

..... [1]

Some data relating to calcium and oxygen are listed. Select relevant data from this list for your answers to parts (c), (d) and (e).

process	value / kJ mol ⁻¹
first ionisation energy of oxygen	+1310
second ionisation energy of oxygen	+3390
first electron affinity of oxygen	-142
second electron affinity of oxygen	+844
enthalpy change for $\frac{1}{2}\text{O}_2(\text{g}) + 2\text{e}^- \rightarrow \text{O}^{2-}(\text{g})$	+951
enthalpy change for $\text{Ca}(\text{s}) \rightarrow \text{Ca}^{2+}(\text{g}) + 2\text{e}^-$	+1933
lattice energy of CaO(s)	-3517

(c) Oxygen exists as O₂ molecules.

Use the data in this question to calculate a value for the bond energy of the O=O bond. Show all your working.



bond energy = kJ mol⁻¹ [3]

(d) (i) Suggest why the first electron affinity of oxygen is negative.

.....
..... [1]

(ii) Suggest why the second electron affinity of oxygen is positive.

.....
..... [1]

(e) Calculate the enthalpy of formation of calcium oxide, CaO(s).

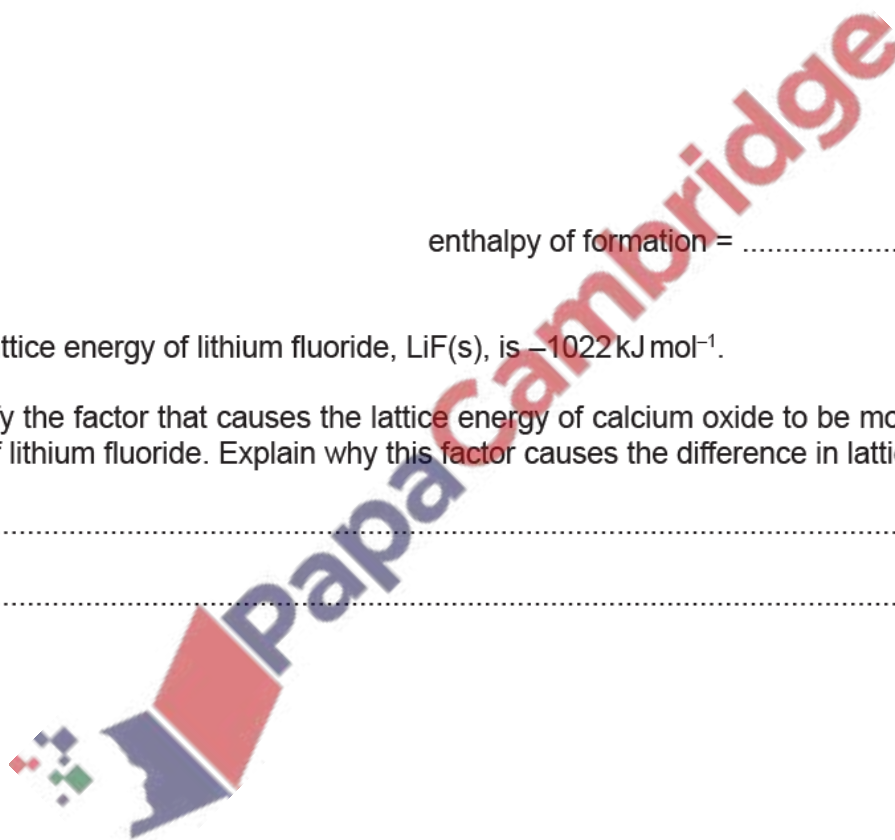
enthalpy of formation = kJ mol⁻¹ [2]

(f) The lattice energy of lithium fluoride, LiF(s), is $-1022 \text{ kJ mol}^{-1}$.

Identify the factor that causes the lattice energy of calcium oxide to be more exothermic than that of lithium fluoride. Explain why this factor causes the difference in lattice energies.

.....
..... [2]

[Total: 12]



3. Nov/2021/Paper_41/No.6

An excess of sodium iodide is added to a solution of copper(II) sulfate. Iodine and a white precipitate of copper(I) iodide are formed.

(a) Write an equation for the reaction that occurs.

..... [1]

(b) (i) Explain why the copper(II) sulfate solution is coloured.

.....
.....
.....
.....
..... [4]

(ii) Suggest why the precipitate of copper(I) iodide is white.

.....
..... [1]

(c) Use suitable E° values from the *Data Booklet* to predict whether iodide ions can reduce Cu^{2+} to Cu^+ under standard conditions. Explain your answer.

.....
.....
..... [2]

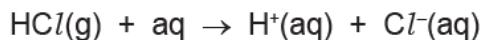
(d) An excess of sodium iodide is added to copper(II) sulfate solution. Copper(I) iodide forms as a precipitate. After precipitation, $[\text{Cu}^+]$ is much lower than 1.0 mol dm^{-3} .

Use this information and your answer to (c) to explain how the relevant electrode potentials change and hence why I^- ions can reduce Cu^{2+} ions.

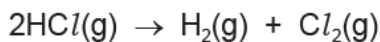
.....
.....
.....
..... [2]

4. Nov/2021/Paper_42/No.3a-d

Pure water is a very poor conductor of electricity. However, when hydrogen chloride gas is dissolved in water, ions are formed and a current flows during electrolysis.



The overall change after electrolysis is that hydrogen chloride gas is converted into hydrogen and chlorine.



When a current of 3.10A is passed through the solution for Y minutes, 351 cm³ of chlorine are produced at the anode, measured under room conditions.

(a) Calculate the number of chlorine molecules produced during the electrolysis.

number of chlorine molecules = [2]

(b) Calculate the total number of electrons transferred to produce this number of chlorine molecules.

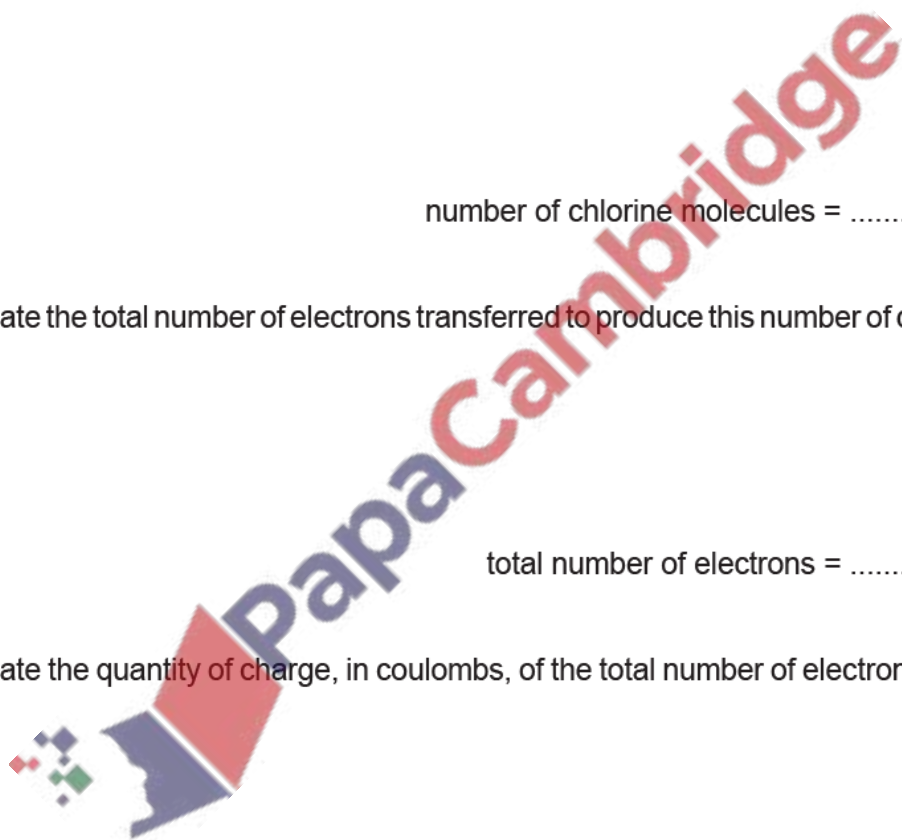
total number of electrons = [1]

(c) Calculate the quantity of charge, in coulombs, of the total number of electrons calculated in (b).

quantity of charge = C [1]

(d) Calculate the time, Y, in minutes, for which the current flows.

Y = minutes [1]



5. June/2021/Paper_41/No.3

(a) (i) Define the term *transition element*.

.....
..... [1]

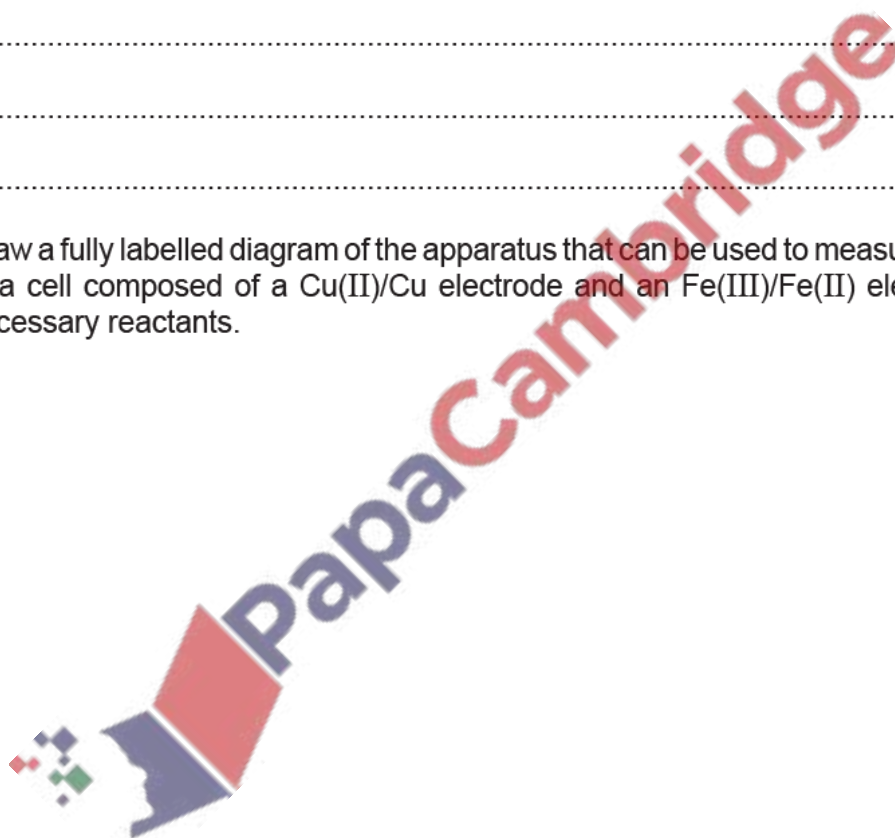
(ii) State how the melting point and density of iron compare to those of calcium.

.....
..... [1]

(b) (i) Define the term *standard cell potential*, E_{cell}° .

.....
..... [2]

(ii) Draw a fully labelled diagram of the apparatus that can be used to measure the cell potential of a cell composed of a Cu(II)/Cu electrode and an Fe(III)/Fe(II) electrode. Include all necessary reactants.



(c) The reaction between $\text{S}_2\text{O}_8^{2-}(\text{aq})$ and $\text{I}^-(\text{aq})$ is catalysed by adding a few drops of $\text{Fe}^{3+}(\text{aq})$.

(i) Use equations to show the catalytic role of Fe^{3+} in this reaction.

[2]

(ii) $\text{Fe}^{3+}(\text{aq})$ can oxidise $\text{I}^-(\text{aq})$, whereas $[\text{Fe}(\text{CN})_6]^{3-}(\text{aq})$ cannot oxidise $\text{I}^-(\text{aq})$.

Use E^\ominus values to explain these observations.

.....

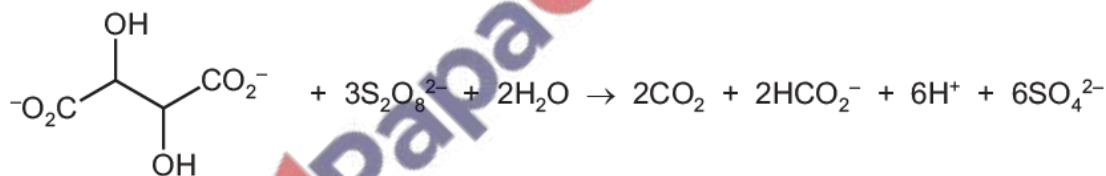
.....

.....

..... [2]

(d) When aqueous solutions of $\text{S}_2\text{O}_8^{2-}$ and tartrate ions are mixed the reaction proceeds very slowly. However, this reaction proceeds quickly in the presence of an $\text{Fe}^{3+}(\text{aq})$ catalyst. The overall equation for this reaction is shown.

tartrate ions



(i) Suggest why this reaction is slow without the Fe^{3+} catalyst.

.....

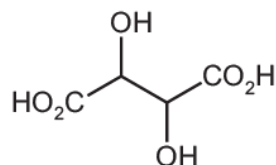
..... [1]

(ii) Use the overall equation to deduce the half-equation for the oxidation of tartrate ions, $\text{C}_4\text{H}_4\text{O}_6^{2-}$, to carbon dioxide, CO_2 , and methanoate ions, HCO_2^- .



- (e) (i) Complete the following table to show the structures of the organic products formed when tartaric acid reacts separately with each reagent. Identify each type of reaction.

tartaric acid



reagent	structure of organic product	type of reaction
an excess of LiAlH_4		
an excess of CH_3COCl		

[3]

- (ii) Tartaric acid reacts with the amine 1-phenylethylamine, $\text{C}_6\text{H}_5\text{CH}(\text{NH}_2)\text{CH}_3$, to form an ionic salt.

Draw the structure of the salt formed in this reaction. Include the charges on the ions.

[1]

[Total: 17]

6. June/2021/Paper_41/No.4

(a) Samples of $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ are reacted separately with an excess of aqueous sodium hydroxide or with an excess of aqueous ammonia.

Give the following information about these reactions.

(i) reaction 1: $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ with an excess of aqueous sodium hydroxide

colour and state of the copper-containing species

ionic equation

type of reaction

[3]

(ii) reaction 2: $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ with an excess of aqueous ammonia

colour and state of the copper-containing species

ionic equation

type of reaction

[3]

(b) Copper(I) oxide is added to hot dilute sulfuric acid. A blue solution, X, and a red-brown solid, Y, form.

Suggest the identities of X and Y. Name the type of reaction.

X

Y

type of reaction

[2]

[Total: 8]



(a) (i) Define the term *standard electrode potential*.

.....

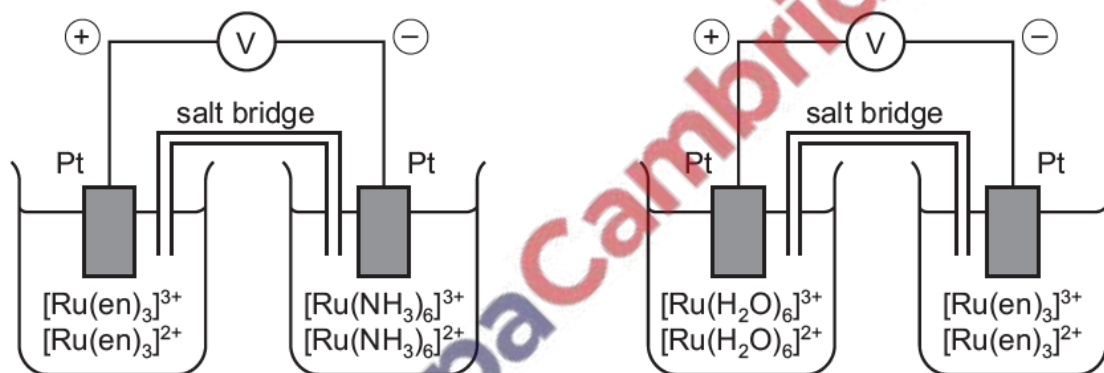
.....

..... [2]

Three redox systems, **A**, **B** and **C**, are shown. The ligand 1,2-diaminoethane, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$, is represented by en.

A	$[\text{Ru}(\text{H}_2\text{O})_6]^{3+} + \text{e}^- \rightleftharpoons [\text{Ru}(\text{H}_2\text{O})_6]^{2+}$
B	$[\text{Ru}(\text{NH}_3)_6]^{3+} + \text{e}^- \rightleftharpoons [\text{Ru}(\text{NH}_3)_6]^{2+}$
C	$[\text{Ru}(\text{en})_3]^{3+} + \text{e}^- \rightleftharpoons [\text{Ru}(\text{en})_3]^{2+}$

Two electrochemical cells are set up to compare the standard electrode potentials, E° , of three half-cells. The diagrams show the relative potential of each electrode.



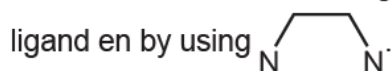
(ii) Use this information to complete the table by adding the labels **A**, **B** and **C** to deduce the order of E° for the three half-cells.

E°	redox system
most negative	
↑	
least negative	

[1]

(iii) The complex $[\text{Ru}(\text{en})_3]^{3+}$ shows stereoisomerism. The ligand en is bidentate.

Draw three-dimensional diagrams to show the two isomers of $[\text{Ru}(\text{en})_3]^{3+}$. Represent the



Name the type of stereoisomerism.



type of stereoisomerism [3]

(b) (i) An electrochemical cell consists of a Br_2/Br^- half-cell and a Ag^+/Ag half-cell, under standard conditions.

Use the *Data Booklet* to calculate the E_{cell}^\ominus . Deduce the direction of electron flow in the wire through the voltmeter between these two half-cells.

$E_{\text{cell}}^\ominus = \dots \text{ V}$

direction of electron flow from to [1]

(ii) Water is added to the Ag^+/Ag half-cell in (b)(i).

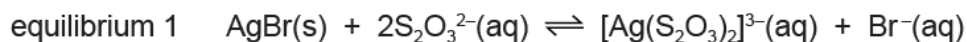
Suggest the effect of this addition on the E_{cell} . Place a tick (\checkmark) in the appropriate box.

less positive	no change	more positive

Explain your answer.

.....

- (c) Silver bromide, AgBr, dissolves in an aqueous solution of $S_2O_3^{2-}$ ions to form the complex ion $[Ag(S_2O_3)_2]^{3-}$. The $S_2O_3^{2-}$ ions act as monodentate ligands.



- (i) Define the term *ligand*.

.....
 [1]

- (ii) Write an expression for the equilibrium constant, K_c , for equilibrium 1.

$K_c =$ [1]

- (iii) Some additional data are given about the dissolution of AgBr in $S_2O_3^{2-}(aq)$.

equilibrium constant	numerical value
solubility product, K_{sp} , of AgBr	5.4×10^{-13}
stability constant, K_{stab} , of $[Ag(S_2O_3)_2]^{3-}$	2.9×10^{13}

Use your answer to (c)(ii) and these data to calculate K_c for equilibrium 1. Include the units for K_c .

$K_c =$ units [2]

- (d) The numerical values for the stability constants, K_{stab} , of two other silver(I) complexes are given.

silver(I) complex	numerical value of K_{stab}
$[Ag(CN)_2]^-$	5.3×10^{18}
$[Ag(NH_3)_2]^+$	1.6×10^7

An aqueous solution containing Ag^+ is added to a solution containing equal concentrations of $CN^-(aq)$, $NH_3(aq)$ and $S_2O_3^{2-}(aq)$. The mixture is left to reach equilibrium.

Deduce the relative concentrations of $[Ag(CN)_2]^-$, $[Ag(NH_3)_2]^+$ and $[Ag(S_2O_3)_2]^{3-}$ present in the resulting mixture. Explain your answer.

..... > >
 highest concentration lowest concentration

.....
 [2]

[Total: 15]