CAMBRIDGE INTERNATIONAL AS & A LEVEL CHEMISTRY · 9701

# CHEMISTRY



EXAM QUESTION PACK

## 6 ELECTROCHEMISTRY

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# Chapter 6

# Electrochemistry

## 6.1 Redox processes: electron transfer and changes in oxidation number (oxidation state)

281. 9701_m22_qp_12 Q: 10

Two half-equations are shown.

$$MnO_4^- + 2H_2O + 3e^- \rightarrow MnO_2 + 4OH^-$$

$$2OH^- + SO_3^{2-} \rightarrow SO_4^{2-} + H_2O + 2e^-$$

The equation for the reaction between manganate(VII) ions and sulfite ions is shown.

$$uMnO_4^- + vH_2O + wSO_3^{2-} \rightarrow xMnO_2 + ySO_4^{2-} + zOH^-$$

Which statements are correct?

1 $u = x = z$

2 Manganese is reduced to oxidation state +4.

3 Sulfur is oxidised from oxidation state +4 to +6.

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

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282. 9701_m21_qp_12 Q: 8

$VO_2Cl$ reacts with NaI under acidic conditions.

$$2VO_2Cl + 2H_2SO_4 + 2NaI \rightarrow VOCl_2 + VOSO_4 + I_2 + Na_2SO_4 + 2H_2O$$

The oxidation state of $Cl$ is –1 in $VO_2Cl$ and in $VOCl_2$.

Which row about this reaction is correct?

| | vanadium | iodine |
|---|---|---|
| **A** | is oxidised | is oxidised |
| **B** | is oxidised | is reduced |
| **C** | is reduced | is oxidised |
| **D** | is reduced | is reduced |

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283. 9701_s21_qp_11 Q: 9

When hydrogen iodide is reacted with concentrated sulfuric acid, several reactions occur, including:

$$8HI + H_2SO_4 \rightarrow H_2S + 4H_2O + 4I_2$$

Which row gives the change in oxidation number of iodine and of sulfur in this reaction?

| | change in oxidation number of iodine | change in oxidation number of sulfur |
|---|---|---|
| **A** | –1 | +6 |
| **B** | –1 | +8 |
| **C** | +1 | –6 |
| **D** | +1 | –8 |

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284. 9701_s21_qp_12 Q: 9

The equation for a redox reaction is shown.

$$SnCl_2(aq) + 2HgCl_2(aq) \rightarrow SnCl_4(aq) + Hg_2Cl_2(s)$$

Which species is being oxidised in this reaction?

**A** $Sn^{2+}$ **B** $Cl^-$ **C** $Hg^+$ **D** $Hg^{2+}$

---

285. 9701_w21_qp_11 Q: 9

Zinc atoms can be oxidised to $Zn^{2+}$ ions by dichromate(VI) ions in acid solution. Chromium is reduced to $Cr^{3+}$ in this reaction.

Which equation is correct?

**A** $Cr_2O_7^{2-} + Zn + 14H^+ \rightarrow 2Cr^{3+} + Zn^{2+} + 7H_2O$

**B** $Cr_2O_7^{2-} + Zn + 14H^+ \rightarrow 2Cr^{3+} + 3Zn^{2+} + 7H_2O$

**C** $Cr_2O_7^{2-} + 3Zn + 14H^+ \rightarrow 2Cr^{3+} + 3Zn^{2+} + 7H_2O$

**D** $2Cr_2O_7^{2-} + 3Zn + 14H^+ \rightarrow 2Cr^{3+} + 3Zn^{2+} + 7H_2O$

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286. 9701_w21_qp_12 Q: 10

In a catalytic converter in the exhaust system of a car, carbon monoxide is oxidised to carbon dioxide, and nitrogen monoxide is reduced to nitrogen.

What are the changes in oxidation number of carbon and nitrogen in these two processes?

| | carbon | nitrogen |
|---|---|---|
| **A** | –2 | +2 |
| **B** | –1 | +1 |
| **C** | +1 | –1 |
| **D** | +2 | –2 |

---

287. 9701_m20_qp_12 Q: 5

In the redox reaction shown, how do the oxidation states of vanadium and sulfur change?

$$VO_2^+ + SO_2 \rightarrow V^{3+} + SO_4^{2-}$$

| | vanadium | | sulfur | |
|---|---|---|---|---|
| | from | to | from | to |
| **A** | +1 | +3 | 0 | –2 |
| **B** | +1 | +3 | +4 | +6 |
| **C** | +5 | +3 | 0 | –2 |
| **D** | +5 | +3 | +4 | +6 |

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288. 9701_m20_qp_12 Q: 10

When the equation is correctly balanced, what is the value of *c*?

$$aC_2H_4 + bH_2O + cH^+ + 2MnO_4^- \rightarrow dC_2H_6O_2 + eMn^{2+}$$

**A** 3 **B** 4 **C** 5 **D** 6

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289. 9701_s20_qp_11 Q: 2

Cobalt can form the positive ion $Co(NH_3)_4Cl_2^+$.

What is the oxidation number of cobalt in this ion?

**A** +1 **B** +2 **C** +3 **D** +6

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290. 9701_s20_qp_11 Q: 8

In this question you should use changes in oxidation numbers to balance a chemical equation.

Acidified potassium dichromate(VI) solution can oxidise a solution of $V^{2+}$ ions. The equation for this reaction is shown.

$$a\,Cr_2O_7^{2-} + b\,V^{2+} + c\,H^+ \rightarrow d\,Cr^{3+} + e\,VO_3^- + f\,H_2O$$

What is the ratio $a : b$ in the correctly balanced equation?

**A** 1 : 1 **B** 1 : 2 **C** 2 : 1 **D** 4 : 1

---

291. 9701_s20_qp_12 Q: 5

In this question you should use changes in oxidation numbers to balance a chemical equation.

The following reaction occurs when $MnO_2$ is warmed with dilute $H_2SO_4$.

$$a\,MnO_2 + b\,H^+ \rightarrow c\,Mn^{2+} + d\,MnO_4^- + e\,H_2O$$

What is the ratio of $c$ : $d$ in the correctly balanced equation?

**A** 1 : 1 **B** 1 : 2 **C** 2 : 3 **D** 3 : 2

---

292. 9701_s20_qp_12 Q: 10

In which reaction does an element undergo the largest change in oxidation number?

**A** $Cl_2 + 2OH^- \rightarrow OCl^- + Cl^- + H_2O$

**B** $3Cl_2 + 6OH^- \rightarrow ClO_3^- + 5Cl^- + 3H_2O$

**C** $Cr_2O_7^{2-} + 6Fe^{2+} + 14H^+ \rightarrow 2Cr^{3+} + 6Fe^{3+} + 7H_2O$

**D** $3MnO_4^{2-} + 4H^+ \rightarrow MnO_2 + 2MnO_4^- + 2H_2O$

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293. 9701_s20_qp_13 Q: 10

When solid $KClO_3$ is heated in the absence of air, a mixture of two chlorine compounds in the mole ratio of 3 : 1 is formed. Chlorine is the only element whose oxidation number changes in this reaction.

What could be the oxidation numbers of chlorine in the two compounds that are formed?

**A** +3 and –1 **B** +6 and +4 **C** +7 and –1 **D** +7 and +1

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294. 9701_w20_qp_11 Q: 8

In which reaction does the greatest change in the oxidation number of sulfur occur?

**A** $S(s) + O_2(g) \rightarrow SO_2(g)$

**B** $SO_2(g) + \frac{1}{2}O_2(g) \rightleftharpoons SO_3(g)$

**C** $SO_3(g) + H_2SO_4(l) \rightarrow H_2S_2O_7(l)$

**D** $H_2S_2O_7(l) + H_2O(l) \rightarrow 2H_2SO_4(l)$

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295. 9701_w20_qp_11 Q: 9

The first stage in the chloride process for the manufacture of titanium consists of the following reaction.

$$2TiO_2 + 4Cl_2 + 3C \rightarrow 2TiCl_4 + 2CO + CO_2$$

What is reduced in this reaction?

**A** carbon

**B** chlorine

**C** oxygen

**D** titanium

---

296. 9701_w20_qp_12 Q: 1

What is the average oxidation number of sulfur in each compound?

| | $Ca(HSO_3)_2$ | $Na_2S_2O_3$ |
|---|---|---|
| **A** | 4 | 2 |
| **B** | 4 | 4 |
| **C** | 6 | 2 |
| **D** | 6 | 4 |

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297. 9701_w20_qp_12 Q: 9

Chlorine dioxide, $ClO_2$, reacts with sodium hydroxide in the reaction shown.

$$2ClO_2 + 2OH^- \rightarrow ClO_2^- + ClO_3^- + H_2O$$

Which statement correctly describes this redox reaction?

**A** Chlorine atoms are oxidised and oxygen atoms are reduced.

**B** Chlorine atoms are reduced and oxygen atoms are oxidised.

**C** Some chlorine atoms are oxidised and some chlorine atoms are reduced.

**D** Some oxygen atoms are oxidised and some oxygen atoms are reduced.

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298. 9701_m19_qp_12 Q: 10

Acidified potassium manganate(VII) reacts with iron(II) ethanedioate, $FeC_2O_4$.

The reactions taking place are shown.

$$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$$

$$Fe^{2+} \rightarrow Fe^{3+} + e^-$$

$$C_2O_4^{2-} \rightarrow 2CO_2 + 2e^-$$

How many moles of iron(II) ethanedioate react with **one** mole of potassium manganate(VII)?

**A** 0.60 **B** 1.67 **C** 2.50 **D** 5.00

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299. 9701_s19_qp_11 Q: 9

Ethanedioic acid, $HO_2CCO_2H$, can be oxidised by $KMnO_4$ in dilute sulfuric acid. The products of this reaction are carbon dioxide, water, potassium sulfate and manganese(II) sulfate.

In this reaction each ethanedioic acid molecule loses two electrons as it is oxidised. A half-equation for this process is shown.

$$HO_2CCO_2H \rightarrow 2CO_2 + 2H^+ + 2e^-$$

How many water molecules are produced when five ethanedioic acid molecules are oxidised by $KMnO_4$ in dilute sulfuric acid?

**A** 5 **B** 8 **C** 10 **D** 16

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300. 9701_s19_qp_12 Q: 9

X is either chlorine or an oxide of chlorine.

X reacts with water, under suitable conditions, to form the two acids $HCl$ and $HClO_3$ in the mole ratio of 1 ($HCl$) : 5 ($HClO_3$).

What could be X?

**A** $Cl_2$ **B** $Cl_2O$ **C** $ClO_2$ **D** $Cl_2O_7$

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301. 9701_s19_qp_13 Q: 1

Manganese and nitrogen can show a range of different oxidation states.

Calculate the sum of the oxidation states of Mn and N in each row of the table.

In which row is this sum the smallest?

| | manganese-containing species | nitrogen-containing species |
|---|---|---|
| **A** | $MnCl_4$ | $N_2$ |
| **B** | $MnCO_3$ | $NO_2^-$ |
| **C** | $K_2MnO_4$ | $NH_4^+$ |
| **D** | $Mn(OH)_3$ | $NH_2OH$ |

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302. 9701_s19_qp_13 Q: 8

Ethanol can be oxidised to ethanal by dilute acidified dichromate(VI) ions.

The oxidation reaction equation is $C_2H_5OH \rightarrow C_2H_4O + 2H^+ + 2e^-$.

The reduction reaction equation is $Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$.

Which equation is correct?

**A** $Cr_2O_7^{2-} + 8H^+ + 3C_2H_5OH \rightarrow 2Cr^{3+} + 7H_2O + 3C_2H_4O$

**B** $Cr_2O_7^{2-} + 12H^+ + C_2H_5OH \rightarrow 2Cr^{3+} + 7H_2O + C_2H_4O$

**C** $Cr_2O_7^{2-} + 12H^+ + 3C_2H_5OH \rightarrow 2Cr^{3+} + 6H_2O + 3C_2H_4O$

**D** $Cr_2O_7^{2-} + 14H^+ + 3C_2H_5OH \rightarrow 2Cr^{3+} + 6H_2O + 3C_2H_4O$

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303. 9701_w19_qp_11 Q: 6

What is the oxidation number of sulfur in each species?

| | $H_2S$ | $SO_2$ | $H_2SO_3$ |
|---|---|---|---|
| **A** | –2 | +4 | +4 |
| **B** | –2 | +4 | +6 |
| **C** | +2 | –4 | +4 |
| **D** | +2 | –4 | +6 |

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304. 9701_w19_qp_11 Q: 9

In the chemical equation, w, x, y and z are all whole numbers.

$$wClO_3^- + xMnO_4^- + yH^+ \rightarrow wClO_4^- + xMnO_2 + zH_2O$$

When the equation is balanced, what are w, x and y?

| | w | x | y |
|---|---|---|---|
| **A** | 1 | 1 | 2 |
| **B** | 2 | 2 | 2 |
| **C** | 2 | 3 | 8 |
| **D** | 3 | 2 | 2 |

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305. 9701_w19_qp_12 Q: 8

$(NH_4)_2Cr_2O_7$ decomposes when heated.

$$(NH_4)_2Cr_2O_7 \rightarrow N_2 + 4H_2O + Cr_2O_3$$

Which element is oxidised and which element is reduced?

| | oxidised | reduced |
|---|---|---|
| **A** | chromium | nitrogen |
| **B** | hydrogen | chromium |
| **C** | nitrogen | chromium |
| **D** | nitrogen | hydrogen |

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306. 9701_w19_qp_12 Q: 15

Chlorate(V) ions, $ClO_3^-$, are produced in the redox reaction between chlorine and hot aqueous sodium hydroxide. Oxidation numbers can be used to help balance the equation for this reaction.

$$vCl_2(g) + wOH^-(aq) \rightarrow xCl^-(aq) + yClO_3^-(aq) + zH_2O(l)$$

What are the values of v, x and y in the balanced equation?

| | v | x | y |
|---|---|---|---|
| **A** | 2 | 3 | 1 |
| **B** | 3 | 4 | 2 |
| **C** | 3 | 5 | 1 |
| **D** | 7 | 12 | 2 |

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307. 9701_m18_qp_12 Q: 10

Which reaction is **not** a redox reaction?

**A** $Mg + 2HNO_3 \rightarrow Mg(NO_3)_2 + H_2$

**B** $2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$

**C** $SO_2 + NO_2 \rightarrow SO_3 + NO$

**D** $SO_3 + H_2O \rightarrow H_2SO_4$

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308. 9701_m18_qp_12 Q: 11

The reaction between sulfur dioxide and oxygen is reversible.

$$2SO_2 + O_2 \rightleftharpoons 2SO_3 \qquad \Delta H^{\ominus} = -196\,kJ\,mol^{-1}$$

Which conditions of pressure and temperature favour the **reverse** reaction?

| | pressure | temperature |
|---|---|---|
| **A** | high | high |
| **B** | high | low |
| **C** | low | high |
| **D** | low | low |

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309. 9701_m18_qp_12 Q: 12

Which statement about the effect of a catalyst on a reversible reaction is correct?

**A** The activation energy of the forward reaction stays the same.

**B** The composition of the equilibrium mixture stays the same.

**C** The rate of the backward reaction stays the same.

**D** The value of the equilibrium constant changes.

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310. 9701_s18_qp_11 Q: 8

Ethanedioate ions, $C_2O_4^{2-}$, react with a suitable reagent to form $CO_2$. A half-equation for this reaction is shown.

$$C_2O_4^{2-} \rightarrow 2CO_2 + 2e^-$$

Which row is correct?

| | oxidation state of carbon in $C_2O_4^{2-}$ | type of reaction |
|---|---|---|
| **A** | +3 | oxidation |
| **B** | +3 | reduction |
| **C** | +5 | oxidation |
| **D** | +5 | reduction |

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311. 9701_s18_qp_11 Q: 9

Oxidation numbers should be used to answer this question.

A redox reaction takes place between hydroxylammonium ions, $[NH_3OH]^+$, and acidified iron(III) ions, $Fe^{3+}$. The products are iron(II) ions, $Fe^{2+}$, $H^+$ ions, water and a compound of nitrogen.

The mole ratio of reacting hydroxylammonium ions to reacting iron(III) ions is 1 : 2.

Which nitrogen-containing compound could be formed in the reaction?

**A** $NH_3$ **B** $N_2O$ **C** NO **D** $NO_2$

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312. 9701_s18_qp_12 Q: 8

Sulfur reacts with concentrated nitric acid in a redox reaction.

$$S + 4HNO_3 \rightarrow SO_2 + 4NO_2 + 2H_2O$$

What are the changes in oxidation number of sulfur and of nitrogen in this reaction?

| | sulfur | nitrogen |
|---|---|---|
| **A** | +2 | –3 |
| **B** | +2 | –1 |
| **C** | +4 | –3 |
| **D** | +4 | –1 |

---

313. 9701_s18_qp_13 Q: 8

Xenon hexafluoride, $XeF_6$, reacts with water.

$$XeF_6 + 3H_2O \rightarrow XeO_3 + 6HF$$

Which statement is correct?

**A** Hydrogen is reduced in this reaction.

**B** Hydrogen is the only element oxidised in this reaction.

**C** The only element oxidised in this reaction is xenon.

**D** This is not a redox reaction.

---

314. 9701_w18_qp_11 Q: 7

Nitric acid is known to take part in the oxidation of atmospheric sulfur dioxide. One possible reaction is shown.

$$SO_2 + HNO_3 \rightarrow NO^+ + HSO_4^-$$

Which row shows the correct changes in oxidation numbers of nitrogen and sulfur?

| | nitrogen | sulfur |
|---|---|---|
| **A** | –3 | +3 |
| **B** | –2 | +2 |
| **C** | –2 | +3 |
| **D** | –1 | +2 |

---

315. 9701_w18_qp_11 Q: 8

A transition metal ion, $M^{2+}$, reacts with acidified dichromate(VI) ions to form $M^{4+}$ ions, $Cr^{3+}$ ions, and $H_2O$.

Which equation correctly represents this reaction?

**A** $Cr_2O_7^{2-} + 14H^+ + M^{2+} \rightarrow 2Cr^{3+} + 7H_2O + M^{4+}$

**B** $Cr_2O_7^{2-} + 14H^+ + 2M^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 2M^{4+}$

**C** $Cr_2O_7^{2-} + 14H^+ + 3M^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 3M^{4+}$

**D** $Cr_2O_7^{2-} + 14H^+ + 6M^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 6M^{4+}$

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316. 9701_w18_qp_12 Q: 8

Ammonium metavanadate, $NH_4VO_3$, can be used to make a solution containing $VO_2Cl$, which contains chloride ions.

What is the **change** in the oxidation number of vanadium in this reaction?

**A** –1 **B** 0 **C** +1 **D** +2

---

317. 9701_m17_qp_12 Q: 8

HOC$l$(aq) is the molecule that kills bacteria when chlorine is added to water.

The following reaction produces this molecule.

$$Cl_2(g) + H_2O(l) \rightleftharpoons HOCl(aq) + H^+(aq) + Cl^-(aq)$$

Which statement about this reaction is correct?

**A** Chlorine is both oxidised and reduced.

**B** Chlorine is oxidised but not reduced.

**C** Hydrogen is both oxidised and reduced.

**D** Hydrogen is oxidised but not reduced.

---

318. 9701_s17_qp_11 Q: 8

Solutions containing chlorate(I) ions are used as household bleaches and disinfectants. These solutions decompose on heating as shown.

$$3ClO^- \rightarrow ClO_3^- + 2Cl^-$$

Which oxidation state is shown by chlorine in each of these three ions?

| | $ClO^-$ | $ClO_3^-$ | $Cl^-$ |
|---|---|---|---|
| **A** | +1 | +3 | –1 |
| **B** | –1 | +3 | +1 |
| **C** | +1 | +5 | –1 |
| **D** | –1 | +5 | +1 |

---

319. 9701_s17_qp_11 Q: 9

When $K_2MnO_4$ is dissolved in water, the following reaction occurs.

$$a\,MnO_4^{2-}(aq) + b\,H_2O(l) \rightarrow c\,MnO_4^-(aq) + d\,MnO_2(s) + e\,OH^-(aq)$$

What are the values of $a$ and $c$ in the balanced chemical equation?

| | $a$ | $c$ |
|---|---|---|
| **A** | 2 | 1 |
| **B** | 3 | 2 |
| **C** | 4 | 3 |
| **D** | 5 | 4 |

---

320. 9701_s17_qp_12 Q: 8

A reaction sequence is shown.

$$SO_2 \xrightarrow{1} SO_3 \xrightarrow{2} H_2SO_4 \xrightarrow{3} H_2S \xrightarrow{4} SO_2$$

In each stage of this sequence the sulfur is oxidised, reduced or neither oxidised nor reduced.

Which row is correct?

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| **A** | neither | oxidised | reduced | reduced |
| **B** | oxidised | neither | reduced | reduced |
| **C** | oxidised | neither | reduced | oxidised |
| **D** | oxidised | oxidised | reduced | oxidised |

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321. 9701_s17_qp_13 Q: 4

Two conversions are shown.

$$NH_4^+ \rightarrow NH_3$$

$$C_2H_4 \rightarrow C_2H_6$$

Which similar feature do these two conversions have?

**A** change in oxidation state of an element

**B** decrease in bond angle

**C** formation of a lone pair of electrons

**D** loss of a $\pi$ bond

---

322. 9701_s17_qp_13 Q: 7

Vanadium reacts with dilute sulfuric acid to form $V_2(SO_4)_3$ and hydrogen gas.

What happens to vanadium atoms in this reaction?

**A** They lose three electrons and are oxidised.

**B** They lose three electrons and are reduced.

**C** They lose two electrons and are oxidised.

**D** They lose two electrons and are reduced.

---

323. 9701_s17_qp_13 Q: 8

$Na_2S_2O_3$ reacts with HC$l$ as shown.

$$Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + SO_2(g) + S(s)$$

When calculating the oxidation number of sulfur in $Na_2S_2O_3$, the **average** oxidation number of the two sulfur atoms should be found.

What is the oxidation number of sulfur in each of $Na_2S_2O_3$, $SO_2$, and S?

| | $Na_2S_2O_3$ | $SO_2$ | S |
|---|---|---|---|
| **A** | +2 | +2 | +1 |
| **B** | +2 | +4 | 0 |
| **C** | +4 | +4 | 0 |
| **D** | +5 | +4 | 0 |

---

324. 9701_w17_qp_11 Q: 6

One of the reactions in a lead / acid cell is shown.

$$Pb(s) + PbO_2(s) + 4H^+(aq) + 2SO_4^{2-}(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$$

Which statement about this reaction is correct?

**A** Lead is both oxidised and reduced.

**B** Lead is neither oxidised nor reduced.

**C** Lead is oxidised only.

**D** Lead is reduced only.

---

325. 9701_w17_qp_12 Q: 8

Which statement is **always** correct for an oxidation reaction?

**A** It involves the gain of oxygen by an element.

**B** For one reactant to be oxidised a different reactant must be reduced.

**C** The element or ion being oxidised will gain electrons.

**D** The oxidation number of the element being oxidised will increase.

---

326. 9701_m16_qp_12 Q: 1

Which compound contains two different elements with identical oxidation states?

**A** HC$l$O **B** $Mg(OH)_2$ **C** $Na_2SO_4$ **D** $NH_4Cl$

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327. 9701_s16_qp_12 Q: 9

In the treatment of domestic water supplies, chlorine is added to the water to form HClO.

$$Cl_2(aq) + H_2O(l) \rightarrow H^+(aq) + Cl^-(aq) + HClO(aq)$$

The HClO reacts further to give $ClO^-$ ions.

$$HClO(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + ClO^-(aq)$$

Both HClO and $ClO^-$ kill bacteria by oxidation.

What is the change in oxidation number of chlorine when forming the $ClO^-$ ion from aqueous chlorine?

**A** –1 **B** 0 **C** +1 **D** +2

---

328. 9701_s16_qp_12 Q: 17

Nitrogen(II) oxide, NO, nitrogen(IV) oxide, $NO_2$, carbon monoxide, CO, and unburnt hydrocarbons are present in the exhaust gases of internal combustion engines. When catalytic converters are used to remove these compounds from the exhaust gases, redox reactions occur.

What happens to each compound in the catalytic converter?

| | NO | $NO_2$ | CO | hydrocarbons |
|---|---|---|---|---|
| **A** | oxidised | oxidised | reduced | oxidised |
| **B** | oxidised | oxidised | oxidised | oxidised |
| **C** | reduced | reduced | oxidised | oxidised |
| **D** | reduced | reduced | reduced | reduced |

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329. 9701_w16_qp_11 Q: 3

The reaction between acidified dichromate(VI) ions, $Cr_2O_7^{2-}$, and aqueous $Fe^{2+}$ ions results in the dichromate(VI) ions being reduced to $Cr^{3+}$ ions.

What is the correct equation for this reaction?

**A** $Cr_2O_7^{2-} + Fe^{2+} + 14H^+ \rightarrow 2Cr^{3+} + Fe^{3+} + 7H_2O$

**B** $Cr_2O_7^{2-} + 2Fe^{2+} + 14H^+ \rightarrow 2Cr^{3+} + 2Fe^{3+} + 7H_2O$

**C** $Cr_2O_7^{2-} + 3Fe^{2+} + 14H^+ \rightarrow 2Cr^{3+} + 3Fe^{3+} + 7H_2O$

**D** $Cr_2O_7^{2-} + 6Fe^{2+} + 14H^+ \rightarrow 2Cr^{3+} + 6Fe^{3+} + 7H_2O$

---

330. 9701_w16_qp_11 Q: 9

Sodium chromate(VI), $Na_2CrO_4$, is manufactured by heating chromite, $FeCr_2O_4$, with sodium carbonate in an oxidising atmosphere. Chromite contains $Cr_2O_4^{2-}$ ions.

$$2FeCr_2O_4 + 4Na_2CO_3 + 3\tfrac{1}{2}O_2 \rightarrow 4Na_2CrO_4 + Fe_2O_3 + 4CO_2$$

What happens in this reaction?

**A** Chromium and iron are the only elements oxidised.

**B** Chromium, iron and carbon are oxidised.

**C** Only chromium is oxidised.

**D** Only iron is oxidised.

---

331. 9701_s15_qp_11 Q: 4

In oxygen difluoride, $OF_2$, fluorine has an oxidation number of –1. $OF_2$ will react with sulfur dioxide according to the following equation.

$$OF_2 + SO_2 \rightarrow SO_3 + F_2$$

What is oxidised and what is reduced in this reaction?

| | fluorine | oxygen in $OF_2$ | sulfur |
|---|---|---|---|
| **A** | oxidised | oxidised | reduced |
| **B** | oxidised | reduced | oxidised |
| **C** | reduced | oxidised | reduced |
| **D** | reduced | reduced | oxidised |

---

332. 9701_s15_qp_12 Q: 10

Photochromic glass, used for sunglasses, darkens when exposed to bright light and becomes more transparent again when the light is less bright. The darkness of the glass is related to the concentration of silver atoms.

The following reactions are involved.

reaction 1 $Ag^+ + Cl^- \rightleftharpoons Ag + Cl$

reaction 2 $Cu^+ + Cl \rightarrow Cu^{2+} + Cl^-$

reaction 3 $Cu^{2+} + Ag \rightarrow Cu^+ + Ag^+$

Which statement about these reactions is correct?

**A** $Cu^+$ and $Cu^{2+}$ ions act as catalysts.

**B** $Cu^+$ ions act as an oxidising agent in reaction 2.

**C** Reaction 3 increases the darkness of the glass.

**D** Silver atoms are reduced in reaction 3.

---

333. 9701_s15_qp_13 Q: 5

In which reaction does an element have the largest change in oxidation number?

**A** $Cr_2O_7^{2-} + 6Fe^{2+} + 14H^+ \rightarrow 2Cr^{3+} + 6Fe^{3+} + 7H_2O$

**B** $3OCl^- \rightarrow ClO_3^- + 2Cl^-$

**C** $5Fe^{2+} + MnO_4^- + 8H^+ \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$

**D** $PbO_2 + Sn^{2+} + 4H^+ \rightarrow Sn^{4+} + Pb^{2+} + 2H_2O$

---

334. 9701_s15_qp_13 Q: 16

Transition elements and their compounds are widely used as catalysts.

What is the identity and what is the oxidation number of the element present in the catalyst used in the Contact process?

| | element | oxidation number |
|---|---|---|
| **A** | iron | 0 |
| **B** | iron | +3 |
| **C** | vanadium | 0 |
| **D** | vanadium | +5 |

---

335. 9701_w15_qp_11 Q: 19

Element X forms a pollutant oxide Y. Y can be further oxidised to Z. Two students made the following statements.

Student P 'The molecule of Y contains lone pairs of electrons.'

Student Q 'The oxidation number of X increases by 1 from Y to Z.'

X could be carbon or nitrogen or sulfur.

Which student(s) made a correct statement?

**A** P only

**B** Q only

**C** both P and Q

**D** neither P nor Q

---

336. 9701_w15_qp_12 Q: 5

Calcium forms an ionic compound with carbon, called calcium carbide. The oxidation number of carbon in calcium carbide is –1.

Calcium carbide is readily hydrolysed by water giving two products only.

What could be the formulae of calcium carbide and the two products of hydrolysis?

| | calcium carbide | products |
|---|---|---|
| **A** | $Ca_2C$ | CaO and $C_2H_4$ |
| **B** | $Ca_2C$ | $Ca(OH)_2$ and $C_2H_2$ |
| **C** | $CaC_2$ | CaO and $C_2H_4$ |
| **D** | $CaC_2$ | $Ca(OH)_2$ and $C_2H_2$ |

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# Chapter 6

# Electrochemistry



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## 6.1 Redox processes: electron transfer and changes in oxidation number

23. 9701_s20_qp_21 Q: 2

**(a)** The equation shown in **(a)(i)** describes the reaction which occurs when aqueous potassium iodide is added to aqueous copper(II) sulfate. A white precipitate of copper(I) iodide forms in a brown solution of iodine and potassium sulfate.

**(i)** Balance the equation and include state symbols.

.....$CuSO_4$(.....) + .....KI(.....) → .....CuI(.....) + .....$I_2$(.....) + .....$K_2SO_4$(.....)

[2]

The table gives the oxidation numbers of iodine in the different species in the equation.

| iodine-containing species | oxidation number of iodine |
|---|---|
| KI | –1 |
| CuI | –1 |
| $I_2$ | 0 |

**(ii)** Deduce the oxidation number of copper in $CuSO_4$ and CuI.

- oxidation number of copper in $CuSO_4$ .....
- oxidation number of copper in CuI .....

[1]

**(iii)** Describe the type of reaction shown by the equation in **(a)(i)**. Explain your answer in terms of electron transfer.

.....

.....

..... [2]

**(b)** In the reaction described in **(a)(i)**, a student uses 17.43 g of $CuSO_4$•**y**$H_2O$. By further titration of the reaction products the student concludes that the total amount of $CuSO_4$ in the sample is 0.0982 mol.

Use the *Data Booklet* to complete the table to calculate the value of **y**, where **y** is an integer. Show your working.

| | |
|---|---|
| mass of 0.0982 mol $CuSO_4$ | ..... g |
| amount of $H_2O$ in 17.43 g of $CuSO_4$•**y**$H_2O$ | ..... mol $H_2O$ |
| value of **y** | **y** = ..... |

[4]

[Total: 9]

24. 9701_s19_qp_23 Q: 2

Iodine is an element in Group 17 of the Periodic Table.

**(a) (i)** At room temperature, iodine solid has a lattice structure.

Describe the arrangement of the iodine molecules within the solid.

.....

..... [1]

**(ii)** List **all** of the forces of attraction present in solid iodine and identify which of these are overcome when solid iodine is heated to produce iodine vapour.

force(s) of attraction present

.....

.....

force(s) of attraction overcome

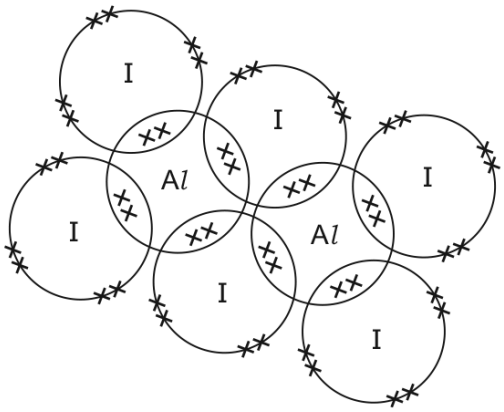
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.....

[2]

Iodine reacts with aluminium to form a white solid, $Al_2I_6$.

**(b)** The diagram shows the arrangement of the outer electrons within a molecule of $Al_2I_6$.




**(i)** How many co-ordinate (dative covalent) bonds are made when a molecule of $Al_2I_6$ is formed from its atoms?

..... [1]

**(ii)** Describe how co-ordinate (dative covalent) bonds form within this molecule.

.....

.....

..... [1]

**(c)** In a reaction between hydrogen iodide and concentrated sulfuric acid, the products are hydrogen sulfide, sulfur, iodine and water.

**(i)** Write an equation for this reaction.

You may wish to use oxidation numbers to help you.

..... [2]

**(ii)** Explain, with reference to oxidation numbers, why this reaction is a redox reaction.

.....

.....

..... [2]

[Total: 9]

25. 9701_s16_qp_22 Q: 3

Acidified potassium dichromate(VI) can oxidise ethanedioic acid, $H_2C_2O_4$.
The relevant half-equations are shown.

$$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$$

$$H_2C_2O_4 \rightarrow 2CO_2 + 2H^+ + 2e^-$$

**(a)** State the overall equation for the reaction between acidified dichromate(VI) ions and ethanedioic acid.

..... [2]

**(b)** In an experiment a 0.242 g sample of hydrated ethanedioic acid, $H_2C_2O_4.\boldsymbol{x}H_2O$, was reacted with a 0.0200 mol $dm^{-3}$ solution of acidified potassium dichromate(VI).

32.0 $cm^3$ of the acidified potassium dichromate(VI) solution was required for complete oxidation of the ethanedioic acid.

**(i)** Calculate the amount, in moles, of dichromate(VI) ions used to react with the sample of ethanedioic acid.

amount = ..... mol [1]

**(ii)** Calculate the amount, in moles, of ethanedioic acid in the sample.

amount = ..... mol [1]

**(iii)** Calculate the relative molecular mass, $M_r$, of the hydrated ethanedioic acid.

$M_r$ = ..... [1]

**(iv)** Calculate the value of $\boldsymbol{x}$ in $H_2C_2O_4.\boldsymbol{x}H_2O$.

$\boldsymbol{x}$ = ..... [1]

[Total: 6]

1.

During electrolysis of brine in a diaphragm cell, chlorine, hydrogen and sodium hydroxide are produced.

What is the molar ratio of these products?

| | *chlorine* | *hydrogen* | *sodium hydroxide* |
|---|---|---|---|
| **A** | 1 | 1 | 1 |
| **B** | 1 | 1 | 2 |
| **C** | 2 | 1 | 1 |
| **D** | 2 | 2 | 1 |

[2002 M/J (16)]

2.

In the industrial electrolysis of brine to manufacture chlorine, the diaphragm used is a porous screen which allows the flow of electrolytes but keeps other chemicals separate.

Which substance needs to be kept separate from the chlorine by the diaphragm?

**A** hydrogen

**B** sodium hydroxide

**C** sodium chloride

**D** water

[2002 O/N (18)]

3.

*Use of the Data Booklet is relevant to this question.*

In the commercial electrolysis of brine, the products are chlorine, hydrogen and sodium hydroxide.

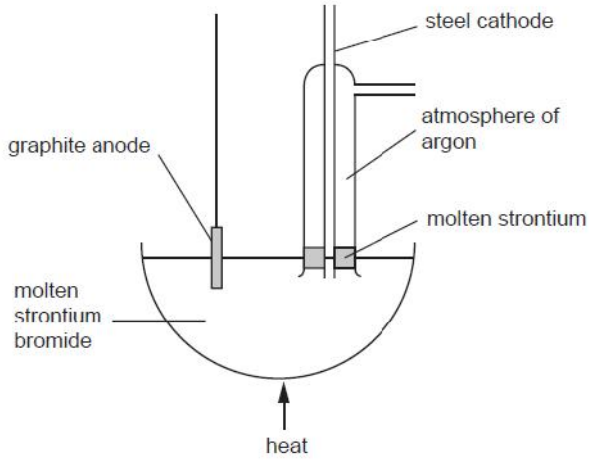
What is the maximum yield of each of these products when 58.5 kg of sodium chloride are electrolysed as brine?

| | yield of chlorine / kg | yield of hydrogen / kg | yield of sodium hydroxide / kg |
|---|---|---|---|
| **A** | 35.5 | 1 | 40 |
| **B** | 35.5 | 2 | 40 |
| **C** | 71 | 1 | 40 |
| **D** | 71 | 2 | 80 |

[2004 M/J (18)]

4.

Strontium metal can be obtained by the electrolysis of molten strontium bromide, $SrBr_2$, using the apparatus shown in the diagram.




Why is an atmosphere of argon used around the cathode?

**A** The argon keeps the strontium molten.

**B** The argon stops the molten strontium rising too high in the tube.

**C** A thin film of a compound of strontium and argon forms on the surface protecting the freshly formed metal.

**D** Without the argon strontium oxide would form in the air.

[2004 O/N (15)]

5.

A weedkiller can be prepared by heating a bleach solution.

$$\underset{\text{bleach}}{3NaClO} \xrightarrow{\text{heat}} \underset{\text{weedkiller}}{2NaCl + NaClO_3}$$

What are the oxidation states of chlorine in these three compounds?

**A** –1 –1 +5

**B** +1 –1 +5

**C** +1 –1 +7

**D** +2 +1 +7

[2004 O/N (16)]



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6.

In the extraction of aluminium by electrolysis, why is it necessary to dissolve aluminium oxide in molten cryolite?

**A** to reduce the very high melting point of the electrolyte

**B** cryolite provides the ions needed to carry the current

**C** cryolite reacts with the aluminium oxide to form ions

**D** molten aluminium oxide alone would not conduct electricity

[2005 M/J (8)]

7.

A cheap carbon monoxide detector for a gas heater consists of a patch containing palladium chloride crystals. When carbon monoxide is present, the crystals turn from orange to black as the following reaction takes place.

$$\underset{\text{orange}}{CO(g) + PdCl_2(s)} + H_2O(l) \rightarrow CO_2(g) + \underset{\text{black}}{Pd(s)} + 2HCl(aq)$$

Which is the element whose oxidation number **decreases** in this reaction?

**A** carbon

**B** chlorine

**C** hydrogen

**D** palladium

[2005 M/J (9)]

8.

During the electrolysis of brine using a diaphragm cell, which reaction occurs at the cathode?

**A** $2Cl^-(aq) \rightarrow Cl_2(g) + 2e$

**B** $4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e$

**C** $2H_2O(l) + 2e \rightarrow H_2(g) + 2OH^-(aq)$

**D** $Na^+(aq) + e \rightarrow Na(s)$

[2005 O/N (8)]

9.

The nickel-cadmium rechargeable battery is based upon the following overall reaction.

$$Cd + 2NiOOH + 4H_2O \rightarrow Cd(OH)_2 + 2Ni(OH)_2.H_2O$$

What is the oxidation number of nickel at the beginning and at the end of the reaction?

| | beginning | end |
|---|---|---|
| **A** | +1.5 | +2 |
| **B** | +2 | +3 |
| **C** | +3 | +2 |
| **D** | +3 | +4 |

[2006 M/J (9)]

10.

When copper is extracted from its ores, the metal is not pure enough for electrical uses. The impure copper, which contains small amounts of silver and gold, is purified by electrolysis. During this process a 'sludge' forms beneath the anode which is found to contain silver and traces of gold.

Why is silver found in this sludge?

**A** Silver is less electropositive than copper.

**B** Silver is more dense than copper and falls off the cathode.

**C** Silver reacts with the electrolyte to form an insoluble chloride salt.

**D** Silver reacts with the electrolyte to form an insoluble sulfate salt.

[2009 M/J (9)]

11.

Which conversion involves a reduction of chromium?

**A** $CrO_4^{2-} \rightarrow CrO_3$

**B** $CrO_4^{2-} \rightarrow Cr_2O_7^{2-}$

**C** $CrO_2Cl_2 \rightarrow CrO_4^{2-}$

**D** $CrO_2Cl_2 \rightarrow Cr_2O_3$

[2009 O/N-11 (7)]



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12.

Photochromic glass, used for sunglasses, darkens when exposed to bright light and becomes more transparent again when the light is less bright. The depth of colour of the glass is related to the concentration of silver atoms.

The following reactions are involved.

reaction 1 $Ag^+ + Cl^- \rightleftharpoons Ag + Cl$

reaction 2 $Cu^+ + Cl \rightarrow Cu^{2+} + Cl^-$

reaction 3 $Cu^{2+} + Ag \rightarrow Cu^+ + Ag^+$

Which statement about these reactions is correct?

**A** $Cu^+$ and $Cu^{2+}$ ions act as catalysts.

**B** $Cu^+$ ions act as an oxidising agent in reaction 2.

**C** Reaction 2 is the one in which light is absorbed.

**D** $Ag^+$ ions are oxidised in reaction 1.

[2009 O/N-11 (11)]

13.

How does concentrated sulfuric acid behave when it reacts with sodium chloride?

**A** as an acid only

**B** as an acid and oxidising agent

**C** as an oxidising agent only

**D** as a reducing agent only

[2010 M/J-11 (13)]

14.

What happens when chlorine is bubbled through aqueous potassium iodide?

**A** Chlorine is oxidised to chlorate(V) ions.

**B** Chlorine is oxidised to chloride ions.

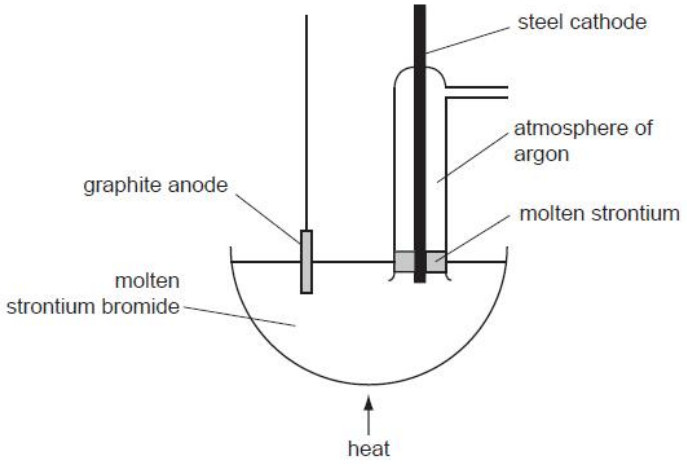
**C** Iodide ions are oxidised to iodine.

**D** There is no observable reaction.

[2010 O/N-12 (16)]

15.

Strontium metal can be obtained by the electrolysis of molten strontium bromide, $SrBr_2$, using the apparatus shown in the diagram.




Why is an atmosphere of argon used around the cathode?

**A** A thin film of a compound of strontium and argon forms on the surface protecting the freshly formed metal.

**B** The argon keeps the strontium molten.

**C** The argon stops the molten strontium rising too high in the tube.

**D** Without the argon, strontium oxide would form in the air.

[2010 O/N-12 (17)]

16.

In the extraction of aluminium by the electrolysis of molten aluminium oxide, why is cryolite added to the aluminium oxide?

**A** to ensure the aluminium is not oxidised

**B** to ensure the anode is not oxidised

**C** to lower the melting point of the aluminium oxide

**D** to prevent corrosion of the cathode

[2011 M/J-11 (3)]



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17.

Aluminium is the most abundant metal in the Earth's crust. The extraction of aluminium is carried out by the electrolysis of aluminium oxide dissolved in molten cryolite.

Which material is used for each of the electrodes in this electrolysis?

| | anode | cathode |
|---|---|---|
| **A** | aluminium | carbon |
| **B** | carbon | carbon |
| **C** | carbon | steel |
| **D** | steel | aluminium |

[2011 M/J-12 (3)]

18.

When chlorine and aqueous sodium hydroxide are heated together the following overall reaction occurs.

$$3Cl_2(aq) + 6NaOH(aq) \rightarrow 5NaCl(aq) + NaClO_3(aq) + 3H_2O(l)$$

What are the oxidation numbers for chlorine in each of the following species?

| | $Cl_2$ | $NaCl$ | $NaClO_3$ |
|---|---|---|---|
| **A** | 0 | +1 | –5 |
| **B** | +2 | –1 | +3 |
| **C** | 0 | –1 | +5 |
| **D** | –2 | +1 | –3 |

[2011 O/N-11 (7)]

19.

The amount of titanium dioxide in an ore can be determined by using the following reaction.

$$3TiO_2 + 4BrF_3 \rightarrow 3TiF_4 + 2Br_2 + 3O_2$$

Which element increases in oxidation number in this reaction?

**A** bromine

**B** fluorine

**C** oxygen

**D** titanium

[2011 O/N-12 (11)]

20.

Chlorine can be manufactured from brine in a diaphragm cell.

Which row represents the correct electrodes?

| | nature of anode | nature of cathode |
|---|---|---|
| **A** | graphite | titanium |
| **B** | steel | titanium |
| **C** | titanium | graphite |
| **D** | titanium | steel |

[2011 O/N-12 (15)]

21.

Sodium iodide reacts with concentrated sulfuric acid. The equation which represents one of the reactions that takes place is shown.

$$8NaI + 9H_2SO_4 \rightarrow 8NaHSO_4 + 4I_2 + H_2S + 4H_2O$$

Which species has been oxidised in this reaction?

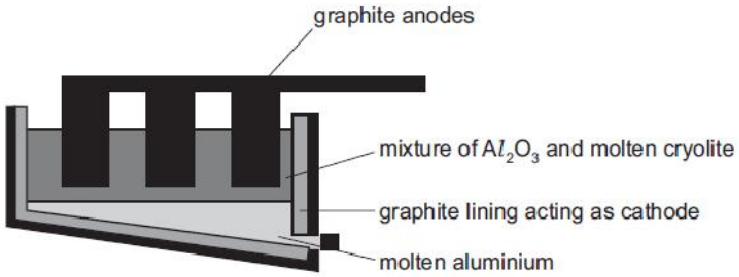
**A** $H^+$ **B** $I^-$ **C** $Na^+$ **D** $SO_4^{2-}$

[2011 O/N-12 (16)]



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22.
The diagram shows a cell for the manufacture of aluminium.




Which statement is **incorrect**?

**A** Aluminium ions are oxidised in this process.

**B** Aluminium is liberated at the cathode by the reaction $Al^{3+} + 3e^- \rightarrow Al$.

**C** The cryolite acts as a solvent.

**D** The graphite anode burns away.

[2012 M/J-11 (11)]

23.
Aluminium is extracted by the electrolysis of a molten mixture containing aluminium oxide. By a similar method, magnesium is extracted by the electrolysis of a molten mixture containing magnesium chloride.

Which statement about the extraction of magnesium is correct?

**A** Magnesium ions travel to the anode and are oxidised to magnesium metal.

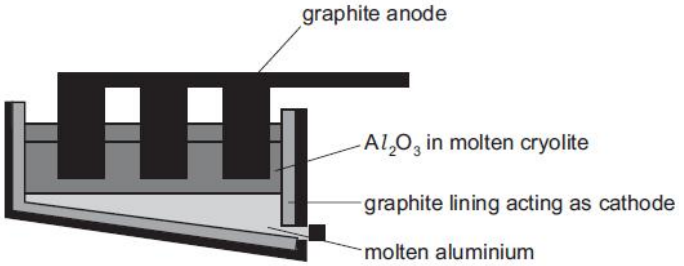
**B** Magnesium ions travel to the anode and are reduced to magnesium metal.

**C** Magnesium ions travel to the cathode and are oxidised to magnesium metal.

**D** Magnesium ions travel to the cathode and are reduced to magnesium metal.

[2012 O/N-11 (7)]

24.
The diagram shows an electrolytic cell for the extraction of aluminium.




Which statement is correct?

**A** Aluminium ions are oxidised in this process.

**B** Aluminium is liberated at the anode by the reaction $Al^{3+} + 3e^- \rightarrow Al$.

**C** Cryolite is purified aluminium oxide.

**D** The graphite anode burns away.

[2013 M/J-11 (3)]

25.
During the electrolysis of molten aluminium oxide to produce aluminium, using carbon electrodes, two consecutive reactions occur at the anode, each producing a different gas.

How does the oxidation number of oxygen change in these reactions?

**A** decreases by 2, then increases by 2

**B** increases by 2, then decreases by 2

**C** increases by 2, then decreases by 4

**D** no change, then decreases by 2

[2013 M/J-12 (1)]



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26.

In the redox reaction shown, how do the oxidation states of vanadium and sulfur change?

$$VO_2^+ + SO_2 \rightarrow V^{3+} + SO_4^{2-}$$

| | vanadium | | sulfur | |
|---|---|---|---|---|
| | from | to | from | to |
| **A** | +1 | +3 | 0 | –2 |
| **B** | +1 | +3 | +4 | +6 |
| **C** | +5 | +3 | 0 | –2 |
| **D** | +5 | +3 | +4 | +6 |

[2013 M/J-13 (1)]

27.

A space shuttle's upward thrust came from the following reaction between aluminium and ammonium perchlorate.

$$10Al + 6NH_4ClO_4 \rightarrow 4Al_2O_3 + 2AlCl_3 + 12H_2O + 3N_2$$

Which statements about this reaction are correct?

1 Aluminium is oxidised.

2 Chlorine is reduced.

3 Nitrogen is oxidised.

[2013 M/J-13 (31)]

28.

At the age of 17, in a woodshed in Ohio, Charles Martin Hall discovered the commercial process for the production of aluminium metal by the electrolysis of a mixture of bauxite, $Al_2O_3$, and cryolite, $Na_3AlF_6$.

What is the main purpose of the cryolite?

**A** $Al_2O_3$ is covalent, and $AlF_6^{3-}$ ions interact with it to produce $Al^{3+}$ ions which can be discharged at the cathode.

**B** Cryolite is a base, forming $NaAlO_2$ with bauxite, enabling aluminium to be discharged at the anode.

**C** Cryolite minimises the release of $O^{2-}$ ions at the graphite anodes, which are otherwise burnt away to CO.

**D** Cryolite reduces the melting point of the bauxite.

[2013 O/N-11 (1)]

29.

In which reaction does a single nitrogen atom have the greatest change in oxidation number?

**A** $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$

**B** $3NO_2 + H_2O \rightarrow 2HNO_3 + NO$

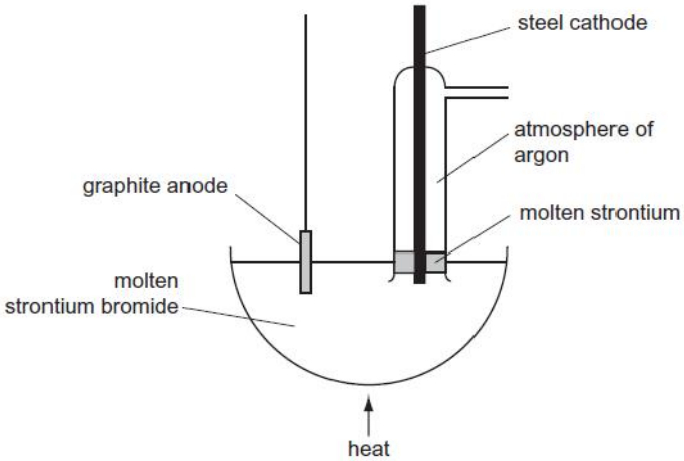
**C** $2NO + O_2 \rightarrow 2NO_2$

**D** $4NH_3 + 6NO \rightarrow 5N_2 + 6H_2O$

[2013 O/N-11 (2)]

30.

Strontium metal can be obtained by the electrolysis of molten strontium bromide, $SrBr_2$, using the apparatus shown in the diagram.




Why is an atmosphere of argon used around the cathode?

**A** A thin film of a compound of strontium and argon forms on the surface protecting the freshly formed metal.

**B** The argon keeps the strontium molten.

**C** The argon stops the molten strontium rising too high in the tube.

**D** Without the argon, strontium oxide would form in the air.

[2013 O/N-11 (12)]



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31.

Ammonium nitrate, $NH_4NO_3$, can decompose explosively when heated.

$$NH_4NO_3 \rightarrow N_2O + 2H_2O$$

What are the changes in the oxidation numbers of the two nitrogen atoms in $NH_4NO_3$ when this reaction proceeds?

**A** –2, –4 **B** +2, +6 **C** +4, –6 **D** +4, –4

[2013 O/N-13 (1)]

32.

In the extraction of aluminium by electrolysis, why is it necessary to dissolve aluminium oxide in molten cryolite?

**A** to reduce the very high melting point of the electrolyte

**B** cryolite is a base; aluminium oxide is amphoteric

**C** cryolite reacts with the aluminium oxide to form ions

**D** molten aluminium oxide alone would not conduct electricity

[2013 O/N-13 (2)]

33.

The electrolysis of brine using the diaphragm cell is an important industrial process.

What happens at the anode?

**A** Chloride ions are oxidised.

**B** Hydrogen gas is produced.

**C** Hydroxide ions are formed.

**D** The electrode reaction is $2Cl^-(aq) + 2e^- \rightarrow Cl_2(g)$.

[2014 M/J-13 (5)]

34.

Many crude oils contain $H_2S$. During refining, by the Claus process, the $H_2S$ is converted into solid sulfur, which is then removed.

reaction I $2H_2S(g) + 3O_2(g) \rightarrow 2H_2O(l) + 2SO_2(g)$

reaction II $2H_2S(g) + SO_2(g) \rightarrow 2H_2O(l) + 3S(s)$

Which statements about the Claus process are correct?

**1** $H_2S$ is oxidised in reaction I.

**2** $SO_2$ oxidises $H_2S$ in reaction II.

**3** Hydrogen is oxidised in reaction II.

[2014 M/J-13 (33)]

35.

In which reaction does hydrogen behave as an oxidising agent?

**A** $H_2 + Cl_2 \rightarrow 2HCl$

**B** $C_2H_4 + H_2 \rightarrow C_2H_6$

**C** $N_2 + 3H_2 \rightarrow 2NH_3$

**D** $2Na + H_2 \rightarrow 2NaH$

[2014 O/N-12 (2)]

36.

Impure copper is purified by electrolysis. The electrolyte used in this process is aqueous copper(II) sulfate.

Which reaction takes place at the anode?

**A** $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$

**B** $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

**C** $2OH^-(aq) \rightarrow \frac{1}{2}O_2(g) + H_2O(l) + 2e^-$

**D** $2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

[2014 O/N-13 (4)]



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37.

In a solution that contains both $Br_2$ and $Cl_2$, a process takes place that produces $BrO_3^-$ ions.

The process is represented by the following equations.

equation 1 $Br_2 + H_2O \rightarrow HBr + HBrO$

equation 2 $3HBrO + Cl_2 \rightarrow 2Cl^- + BrO_3^- + Br_2 + 3H^+$

Which statements about these reactions are correct?

1 Chlorine is reduced in equation 2.

2 Bromine is oxidised in both equation 1 and equation 2.

3 Bromine is reduced in both equation 1 and equation 2.

[2014 O/N-13 (31)]



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# Electrochemistry - 2021

**1.** Nov/2020/Paper_41/No.3

**(a)** Identify the substances liberated at the anode and at the cathode during the electrolysis of aqueous sodium sulfate, $Na_2SO_4(aq)$.

anode .....

cathode .....

[1]

**(b)** When molten sodium chloride is electrolysed, chlorine is liberated at the anode and sodium is liberated at the cathode.

A sample of molten sodium chloride is electrolysed for 1.50 hours using a current of 4.50 A.

Calculate the volume of chlorine and the mass of sodium that are liberated under room conditions.

volume of chlorine = ..... $dm^3$

mass of sodium = ..... g

[4]



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**(c)** The equation representing the standard electrode potential, $E^{\ominus}$, for the reduction of $MnO_4^-(aq)$ to $Mn^{2+}(aq)$ in acid solution is given.

$$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l) \qquad E^{\ominus} = +1.52\,V$$

**(i)** Draw a diagram of the apparatus that would be used to measure the $E^{\ominus}$ value of this half-cell. Your diagram should be fully labelled to identify all apparatus, substances and conditions.

[4]

**(ii)** Use the *Data Booklet* to identify a substance that could be used to oxidise $Mn^{2+}$ ions to $MnO_4^-$ ions under standard conditions.

Write an equation for the reaction.

.....

.....

..... [2]

[Total: 11]



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**2.** Nov/2020/Paper_42/No.4

**(a)** Identify the substances liberated at the anode and at the cathode during the electrolysis of saturated KC$l$(aq).

at the anode .....

at the cathode .....

[1]

**(b)** When dilute sulfuric acid is electrolysed, oxygen is liberated at the anode.

Dilute sulfuric acid is electrolysed for 15.0 minutes using a current of 0.750A.

Calculate the volume of oxygen that is liberated under room conditions.

volume of oxygen = ..... $cm^3$ [3]

**(c)** The halogens chlorine, bromine and iodine differ in their strengths as oxidising agents. These strengths are indicated by the $E^{\ominus}$ values for these halogens.

**(i)** Give the $E^{\ominus}$ values for chlorine, bromine and iodine acting as oxidising agents.

..... [1]

**(ii)** Deduce which of chlorine, bromine and iodine will react with a solution of $Sn^{2+}$(aq) under standard conditions.

Explain your answer. Include a relevant equation in your explanation.

.....

.....

..... [3]



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**(iii)** An excess of chlorine is added to a solution of acidified $Mn^{2+}(aq)$ under standard conditions.

Give the formula of the product of this reaction that contains manganese.

..... [1]

**(d)** An electrochemical cell can be made by connecting an $Fe^{3+}/Fe^{2+}$ half-cell to an $S_2O_8^{2-}/SO_4^{2-}$ half-cell under standard conditions.

**(i)** Calculate the standard cell potential of this electrochemical cell.

$E^{\ominus}_{cell}$ = ..... V [1]

**(ii)** State the material that should be used as the electrode in each half-cell.

in the $Fe^{3+}/Fe^{2+}$ half-cell .....

in the $S_2O_8^{2-}/SO_4^{2-}$ half-cell .....
[1]

**(iii)** Describe **one** change to each half-cell that would **increase** the value of the cell potential. The temperature should remain at 298 K.

$Fe^{3+}/Fe^{2+}$ half-cell .....

.....

$S_2O_8^{2-}/SO_4^{2-}$ half-cell .....

.....
[1]

[Total: 12]



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**3.** March/2020/Paper_42/No.3

Gold is an unreactive metal that can only be oxidised under specific conditions.

**(a)** The standard electrode potential, $E^{\ominus}$, of $Au^{3+}(aq)/Au(s)$ is +1.50 V.

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

.....

.....

..... [2]

**(ii)** Draw a fully labelled diagram of the apparatus that should be used to measure the standard cell potential, $E^{\ominus}_{cell}$, of $Au^{3+}(aq)/Au(s)$ and $HNO_3(aq)/NO(g)$.

Include all necessary chemicals.

[4]



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Some relevant half-equations and their standard electrode potentials are given.

| | half-equation | $E^{\ominus}$/V |
|---|---|---|
| 1 | $Au^{3+}(aq) + 3e^- \rightleftharpoons Au(s)$ | +1.50 |
| 2 | $[AuCl_4]^-(aq) + 3e^- \rightleftharpoons Au(s) + 4Cl^-(aq)$ | +1.00 |
| 3 | $NO_3^-(aq) + 4H^+(aq) + 3e^- \rightleftharpoons NO(g) + 2H_2O(l)$ | +0.96 |

**(iii)** Write an ionic equation to show the spontaneous reaction that occurs when an electric current is drawn from the cell in **(a)(ii)**.

..... [1]

**(iv)** Calculate the $E^{\ominus}_{cell}$ of the reaction in **(a)(iii)**.

$E^{\ominus}_{cell}$ = ..... V [1]

**(v)** Gold can be oxidised by a mixture of concentrated hydrochloric acid and concentrated nitric acid, known as *aqua regia*. Concentrated hydrochloric acid is 12 mol dm$^{-3}$. Concentrated nitric acid is 16 mol dm$^{-3}$.

Explain why *aqua regia* is able to dissolve gold.

In your answer, state and explain what effect the use of concentrated hydrochloric acid and concentrated nitric acid have on the *E* values of half-equations 2 and 3.

.....

.....

.....

.....

.....

..... [3]



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**(b)** Aqueous gold(III) chloride, $AuCl_3$, reacts with aqueous hydrogen peroxide, $H_2O_2$, under certain conditions, forming Au, $O_2$ and $HCl$.

A student carries out separate experiments using different initial concentrations of $AuCl_3$ and $H_2O_2$. The initial rate of each reaction is measured.

The table shows the results that are obtained.

| experiment | $[AuCl_3]$ / mol dm$^{-3}$ | $[H_2O_2]$ / mol dm$^{-3}$ | rate of production of $O_2(g)$ / dm$^3$ minute$^{-1}$ |
|---|---|---|---|
| 1 | 0.05 | 0.50 | $7.66 \times 10^{-2}$ |
| 2 | 0.10 | 0.50 | $1.53 \times 10^{-1}$ |
| 3 | 0.15 | 1.00 | $4.60 \times 10^{-1}$ |

**(i)** Write an equation for the reaction of $AuCl_3$ with $H_2O_2$.

..... [1]

**(ii)** Determine the rate equation of the reaction.

Show your reasoning, quoting data from the table.

.....

.....

.....

.....

..... [3]

**(iii)** Use the results of experiment 2 to calculate the value of the rate constant, *k*, for this reaction.

Include the units of *k*.

rate constant, *k* = .....

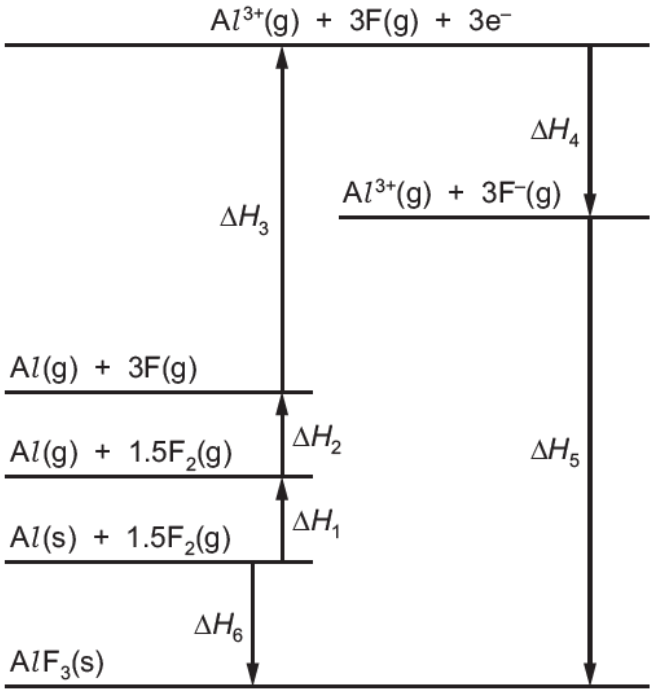
units = .....
[2]



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**(c)** $Al F_3$ is an ionic compound.

The Born–Haber cycle for the formation of $Al F_3$ is shown.




**(i)** Name the enthalpy changes labelled $\Delta H_4$ and $\Delta H_6$.

$\Delta H_4$ = .....

$\Delta H_6$ = .....

[2]

**(ii)** Use the data in the table and data from the *Data Booklet* to calculate the lattice energy of $Al F_3$.

| process | enthalpy change / kJ mol$^{-1}$ |
|---|---|
| $Al(s) \rightarrow Al(g)$ | +326 |
| $Al(g) \rightarrow Al^{3+}(g)$ | +5137 |
| $F(g) \rightarrow F^-(g)$ | –328 |
| $Al(s) + 1.5F_2(g) \rightarrow AlF_3(s)$ | –1504 |

lattice energy of $Al F_3$ = ..... kJ mol$^{-1}$ [2]



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**(iii)** Scandium fluoride, $ScF_3$, is an ionic compound.

Use data from the *Data Booklet* to suggest how the lattice energy of $AlF_3$ compares with the lattice energy of $ScF_3$.

Explain your answer.

.....

.....

..... [2]

**(d)** $AlF_3$ is sparingly soluble in water. The concentration of its saturated solution at 298 K is $6.5 \times 10^{-2}$ mol dm$^{-3}$.

**(i)** Write an expression for the solubility product, $K_{sp}$, of $AlF_3$.

$K_{sp}$ = ..... [1]

**(ii)** Calculate the numerical value of $K_{sp}$ for $AlF_3$ at 298 K.

$K_{sp}$ = .....
[1]

[Total: 25]



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**4.** June/2020/Paper_41/No.3

The overall reaction for photosynthesis is shown.

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

Water is oxidised in this process according to the following half-equation.

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^- \qquad \text{half-equation 1}$$

**(a) (i)** Use these equations to deduce the half-equation for the reduction of carbon dioxide in this process.

[2]

**(ii)** Draw a fully labelled diagram of the apparatus that should be used to measure the standard electrode potential, $E^\ominus$, of $O_2(g)$ in half-equation 1 under standard conditions. Include all necessary chemicals.

[4]

**(iii)** For the cell drawn in **(a)(ii)**, use the *Data Booklet* to calculate the $E^\ominus_{cell}$ and deduce which electrode is positive.

$E^\ominus_{cell}$ = ..... V

identity of the positive electrode = .....

[1]



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5. June/2020/Paper_41/No.7a

**(a)** Silver carbonate, $Ag_2CO_3$, is sparingly soluble in water. The numerical value of the solubility product, $K_{sp}$, for silver carbonate is $6.3 \times 10^{-12}$ at 25 °C.

**(i)** Write an expression for the solubility product, $K_{sp}$, of $Ag_2CO_3$, and state its units.

$K_{sp}$ =

units = .....
[2]

**(ii)** Calculate the equilibrium concentration of $Ag^+$ in a saturated solution of $Ag_2CO_3$ at 25 °C.

$[Ag^+]$ = ..... $mol\,dm^{-3}$ [1]

**(iii)** Solid $Ag_2CO_3$ is stirred at 25 °C with 0.050 $mol\,dm^{-3}$ $AgNO_3$ until no more $Ag_2CO_3$ dissolves.

Calculate the concentration of carbonate ions, $[CO_3^{2-}]$, in this solution.

$[CO_3^{2-}]$ = ..... $mol\,dm^{-3}$ [1]

**(iv)** An electrochemical cell is set up to measure the electrode potential, $E$, for the $Ag^+/Ag$ half-cell using the saturated $Ag_2CO_3(aq)$ with a standard hydrogen electrode.

Use the *Data Booklet*, your answer to **(a)(ii)**, and the Nernst equation to calculate the electrode potential, $E$, for this $Ag^+/Ag$ half-cell.

$E$ for $Ag^+/Ag$ half-cell = ..... V [2]



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**6.** June/2020/Paper_41/No.9

**(a)** Manganese(IV) oxide, $MnO_2$, catalyses the decomposition of hydrogen peroxide, $H_2O_2$, as shown.

$$2H_2O_2(aq) \xrightarrow{MnO_2} 2H_2O(l) + O_2(g)$$

The mechanism involves the formation of the intermediate species, $Mn^{2+}$, in the first step which is subsequently used up in the second step.

State and use relevant electrode potentials, $E^{\ominus}$, to construct **two** equations to show how $MnO_2$ can catalyse this reaction.

.....

.....

.....

.....

.....

equation 1 .....

equation 2 .....

[3]

**(b)** The equation for the decomposition of hydrogen peroxide without a catalyst is shown.

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

Under certain conditions this reaction is found to be first order with respect to hydrogen peroxide, with a rate constant, $k$, of $2.0 \times 10^{-6}\,s^{-1}$ at 298 K.

Calculate the initial rate of decomposition of a $0.75\,mol\,dm^{-3}$ hydrogen peroxide solution at 298 K.

initial rate = ..... $mol\,dm^{-3}\,s^{-1}$ [1]



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**(c)** A four-step mechanism is suggested for the reaction between hydrogen peroxide and iodide ions in an acidic solution.

step 1 $H_2O_2 + I^- \rightarrow IO^- + H_2O$

step 2 $H^+ + IO^- \rightarrow HIO$

step 3 $HIO + I^- \rightarrow I_2 + OH^-$

step 4 $OH^- + H^+ \rightarrow H_2O$

Step 1 is the rate-determining step.

**(i)** State what is meant by the term *rate-determining step*.

.....

..... [1]

**(ii)** Use this mechanism to construct a balanced equation for this reaction.

..... [1]

**(iii)** Deduce the order of reaction with respect to each of the following.

$H_2O_2$ = ..... $I^-$ = ..... $H^+$ = ..... [1]

[Total: 7]



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**7.** June/2020/Paper_42/No.7a

**(a) (i)** Define the term *electron affinity*.

.....

.....

..... [2]

**(ii)** Define the term *lattice energy*.

.....

.....

..... [2]



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# Electrochemistry - 2021

**1.** Nov/2021/Paper_41/No.1

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

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$$

A current of **x** 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]



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**(e)** The standard entropies, $S^{\ominus}$, of three species are given in the table.

| species | $S^{\ominus}$ / $JK^{-1}mol^{-1}$ |
|---|---|
| $H_2O(l)$ | +70 |
| $H_2(g)$ | +131 |
| $O_2(g)$ | +205 |

**(i)** Calculate $\Delta S^{\ominus}$ for the reaction $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$.

$\Delta S^{\ominus}$ = ..... $JK^{-1}mol^{-1}$ [1]

**(ii)** $\Delta H^{\ominus}$ for the reaction $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$ is $+572\,kJ\,mol^{-1}$.

Calculate $\Delta G^{\ominus}$ for this reaction at 298 K.

$\Delta G^{\ominus}$ = ..... $kJ\,mol^{-1}$ [2]

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

.....

..... [1]

[Total: 9]



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**2.** Nov/2021/Paper_41/No.3

**(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 $\frac{1}{2}O_2(g) + 2e^- \rightarrow O^{2-}(g)$ | +951 |
| enthalpy change for $Ca(s) \rightarrow Ca^{2+}(g) + 2e^-$ | +1933 |
| lattice energy of CaO(s) | –3517 |

**(c)** Oxygen exists as $O_2$ 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]



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**(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 $-1022\,kJ\,mol^{-1}$.

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]



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**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 $E^{\ominus}$ 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, $[Cu^{+}]$ 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]



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**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.

$$HCl(g) + aq \rightarrow H^+(aq) + Cl^-(aq)$$

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

$$2HCl(g) \rightarrow H_2(g) + Cl_2(g)$$

When a current of 3.10A is passed through the solution for *Y* minutes, 351 $cm^3$ 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]



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**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*, $E^{\ominus}_{cell}$.

.....

.....

..... [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.



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**(c)** The reaction between $S_2O_8^{2-}(aq)$ and $I^-(aq)$ is catalysed by adding a few drops of $Fe^{3+}(aq)$.

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

[2]

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

Use $E^{\ominus}$ values to explain these observations.

.....

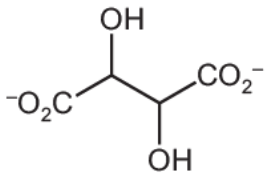
.....

.....

..... [2]

**(d)** When aqueous solutions of $S_2O_8^{2-}$ and tartrate ions are mixed the reaction proceeds very slowly. However, this reaction proceeds quickly in the presence of an $Fe^{3+}(aq)$ catalyst.
The overall equation for this reaction is shown.

tartrate ions



$$+ 3S_2O_8^{2-} + 2H_2O \rightarrow 2CO_2 + 2HCO_2^- + 6H^+ + 6SO_4^{2-}$$

**(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, $C_4H_4O_6^{2-}$, to carbon dioxide, $CO_2$, and methanoate ions, $HCO_2^-$.

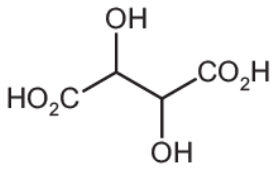
$C_4H_4O_6^{2-}$ + ..... $\rightleftharpoons$ ..... [1]



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**(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, $C_6H_5CH(NH_2)CH_3$, to form an ionic salt.

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

[1]

[Total: 17]



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**6.** June/2021/Paper_41/No.4

**(a)** Samples of $[Cu(H_2O)_6]^{2+}$ 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: $[Cu(H_2O)_6]^{2+}$ with an excess of aqueous of sodium hydroxide

colour and state of the copper-containing species .....

ionic equation .....

type of reaction .....

[3]

**(ii)** reaction 2: $[Cu(H_2O)_6]^{2+}$ 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]



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**7.** June/2021/Paper_42/No.3

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

.....

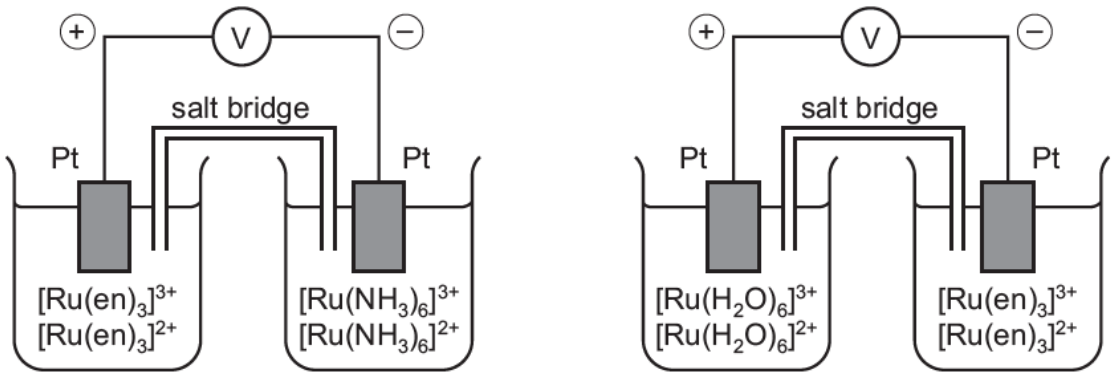
.....

..... [2]

Three redox systems, **A**, **B** and **C**, are shown. The ligand 1,2-diaminoethane, $H_2NCH_2CH_2NH_2$, is represented by en.

| | |
|---|---|
| **A** | $[Ru(H_2O)_6]^{3+} + e^- \rightleftharpoons [Ru(H_2O)_6]^{2+}$ |
| **B** | $[Ru(NH_3)_6]^{3+} + e^- \rightleftharpoons [Ru(NH_3)_6]^{2+}$ |
| **C** | $[Ru(en)_3]^{3+} + e^- \rightleftharpoons [Ru(en)_3]^{2+}$ |

Two electrochemical cells are set up to compare the standard electrode potentials, $E^\ominus$, 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 $E^\ominus$ for the three half-cells.

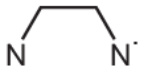
| $E^\ominus$ | redox system |
|---|---|
| most negative | |
| ↑ | |
| least negative | |

[1]



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

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

.

Name the type of stereoisomerism.

isomer 1

Ru

isomer 2

Ru

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 $E^{\ominus}_{cell}$. Deduce the direction of electron flow in the wire through the voltmeter between these two half-cells.

$E^{\ominus}_{cell}$ = ..... 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 (✓) in the appropriate box.

| less positive | no change | more positive |
|---|---|---|
| | | |

Explain your answer.

.....

.....

..... [2]



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**(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.

equilibrium 1 $AgBr(s) + 2S_2O_3^{2-}(aq) \rightleftharpoons [Ag(S_2O_3)_2]^{3-}(aq) + Br^-(aq)$

**(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 | $5.4 \times 10^{-13}$ |
| stability constant, $K_{stab}$, of $[Ag(S_2O_3)_2]^{3-}$ | $2.9 \times 10^{13}$ |

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 $K_{stab}$ |
|---|---|
| $[Ag(CN)_2]^-$ | $5.3 \times 10^{18}$ |
| $[Ag(NH_3)_2]^+$ | $1.6 \times 10^7$ |

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]



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**1.** June/2022/Paper_41/No.2(d, e)

**(d)** Manganese(VII) oxide, $Mn_2O_7$, can be made by treatment of $KMnO_4$ with concentrated sulfuric acid (reaction 1).

$Mn_2O_7$ readily decomposes at room temperature to form manganese(IV) oxide and a colourless diatomic gas (reaction 2).

Construct equations for **both** the reactions described.

reaction 1 .....

reaction 2 .....

[2]



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**(e)** Aqueous manganese(II) ions show similar chemical properties to aqueous copper(II) ions when reacted separately with NaOH(aq) and with concentrated HC*l*.

**(i)** Write the ionic equation, and state the type of reaction, for the reaction of $[Mn(H_2O)_6]^{2+}$ with NaOH(aq).

ionic equation .....

type of reaction .....

[2]

**(ii)** Write the ionic equation, and state the type of reaction, for the reaction of $[Mn(H_2O)_6]^{2+}$ with concentrated HC*l*.

ionic equation .....

type of reaction .....

[2]

**(iii)** Table 2.1 lists relevant electrode potentials for some electrode reactions.

**Table 2.1**

| electrode reaction | $E^{\ominus}$/V |
|---|---|
| $Mn^{2+} + 2e^- \rightleftharpoons Mn$ | –1.18 |
| $Cl_2 + 2e^- \rightleftharpoons 2Cl^-$ | +1.36 |
| $2HOCl + 2H^+ + 2e^- \rightleftharpoons Cl_2 + 2H_2O$ | +1.64 |
| $MnO_2 + 4H^+ + 2e^- \rightleftharpoons Mn^{2+} + 2H_2O$ | +1.23 |
| $MnO_4^- + 4H^+ + 3e^- \rightleftharpoons MnO_2 + 2H_2O$ | +1.67 |

Suggest the formula of the manganese species formed when $Mn^{2+}(aq)$ reacts with $Cl_2$.

State the type of reaction.

formula of manganese species formed .....

type of reaction .....

[1]



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**2.** June/2022/Paper_41/No.3(c, d)

**(c) (i)** Define standard electrode potential, $E^{\ominus}$.

.....

.....

..... [1]

**(ii)** A salt bridge is used in an electrochemical cell.

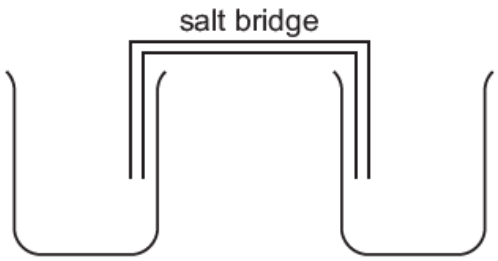
State the function of the salt bridge. Explain your answer.

.....

..... [1]

**(iii)** Complete the diagram of the apparatus that can be used to measure the $E^{\ominus}$ of the $Cr_2O_7^{2-}(aq)$, $H^+(aq)/Cr^{3+}(aq)$ electrode against the standard hydrogen electrode.

Your diagram should be fully labelled to identify all apparatus, substances and conditions.




[3]

**(iv)** The $E^{\ominus}$ of the $Cr_2O_7^{2-}(aq)$, $H^+(aq)/Cr^{3+}(aq)$ electrode is +1.33 V.

Label the negative electrode and the direction of electron flow in the external circuit when the current flows in your diagram in **(c)(iii)**. [1]



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**(d)** Table 3.1 lists relevant electrode potentials for some electrode reactions for use in **(d)(i)** and **(d)(ii)**.

**Table 3.1**

| electrode reaction | $E^{\ominus}$/V |
|---|---|
| $Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$ | +1.33 |
| $CH_3CHO + 2H^+ + 2e^- \rightleftharpoons CH_3CH_2OH$ | –0.61 |
| $CH_3COOH + 2H^+ + 2e^- \rightleftharpoons CH_3CHO + H_2O$ | –0.94 |
| $O_2 + 4H^+ + 4e^- \rightleftharpoons 2H_2O$ | +1.23 |

**(i)** Ethanal is oxidised to ethanoic acid in the presence of $Cr_2O_7^{2-}$ ions.

Construct the ionic equation for the oxidation of ethanal to ethanoic acid using dichromate(VI) in acid conditions. Calculate the $E^{\ominus}_{cell}$ for this reaction.

ionic equation .....

$E^{\ominus}_{cell}$ = ..... V
[2]

**(ii)** In an ethanol-oxygen fuel cell, $CH_3CH_2OH(l)$ and $O_2(g)$ are in contact with two inert electrodes immersed in an acidic solution.

The cell reaction for the oxidation of ethanol by oxygen is shown.

$$CH_3CH_2OH + O_2 \rightarrow CH_3COOH + H_2O \qquad E^{\ominus}_{cell} = +2.01\,V$$

Calculate $\Delta G^{\ominus}$, in kJ mol$^{-1}$, for the oxidation of ethanol by oxygen.

$\Delta G^{\ominus}$ = ..... kJ mol$^{-1}$ [2]



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**3.** June/2022/Paper_42/No.5

**(a)** Complete Table 5.1 to predict the substance liberated at each electrode during electrolysis of the indicated electrolyte with inert electrodes.

**Table 5.1**

| electrolyte | substance liberated at the anode | substance liberated at the cathode |
|---|---|---|
| $PbBr_2(l)$ | | |
| concentrated $NaCl(aq)$ | | |
| $Cu(NO_3)_2(aq)$ | | |

[3]

**(b)** An electrolytic cell is set up to determine a value for the Avogadro constant, *L*. The electrolyte is dilute sulfuric acid and both electrodes are copper.

When a current of 0.600A is passed through the acid for 30.0 minutes, the anode decreases in mass by 0.350g.

**(i)** State the relationship between the Faraday constant, *F*, and the Avogadro constant, *L*.

..... [1]

**(ii)** Use the experimental information in **(b)** and data from the table on page 23 to calculate a value for the Avogadro constant, *L*.

Show all working.

Avogadro constant, *L* = ..... [4]

[Total: 8]



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**1.** Nov/2022/Paper_41/No.3

Data should be selected from Table 3.1 in order to answer some parts of this question.

**Table 3.1**

| electrode reaction | $E^{\ominus}$ / V |
|---|---|
| $Cl_2 + 2e^- \rightleftharpoons 2Cl^-$ | +1.36 |
| $2HOCl + 2H^+ + 2e^- \rightleftharpoons Cl_2 + 2H_2O$ | +1.64 |
| $ClO^- + H_2O + 2e^- \rightleftharpoons Cl^- + 2OH^-$ | +0.89 |
| $Sn^{4+} + 2e^- \rightleftharpoons Sn^{2+}$ | +0.15 |
| $Sn^{2+} + 2e^- \rightleftharpoons Sn$ | –0.14 |
| $V^{2+} + 2e^- \rightleftharpoons V$ | –1.20 |
| $V^{3+} + e^- \rightleftharpoons V^{2+}$ | –0.26 |
| $VO^{2+} + 2H^+ + e^- \rightleftharpoons V^{3+} + H_2O$ | +0.34 |
| $VO_2^+ + 2H^+ + e^- \rightleftharpoons VO^{2+} + H_2O$ | +1.00 |

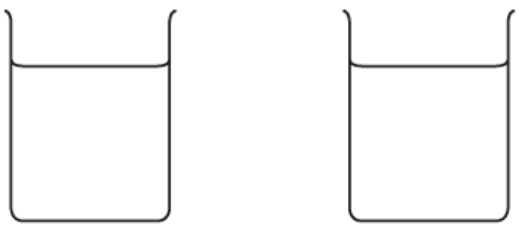
**(a)** Standard electrode potentials are measured under standard conditions.

**(i)** Describe the standard conditions used in the $Sn^{4+}/Sn^{2+}$ half-cell.

.....

..... [1]

**(ii)** Complete the diagram below to show how $E^{\ominus}$ ($Sn^{4+}/Sn^{2+}$) can be measured experimentally. Your diagram should be fully labelled to identify all apparatus and substances.



[3]



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**(iii)** Equal volumes of 1.0 mol dm$^{-3}$ $Sn^{2+}$(aq) and 1.0 mol dm$^{-3}$ $Cl^{-}$(aq) are mixed.

Use relevant $E^{\ominus}$ values to explain whether a reaction occurs between these two ions.

.....

.....

.....

..... [2]

**(iv)** Equal volumes of 1.0 mol dm$^{-3}$ of $Sn^{2+}$(aq) and acidified 1.0 mol dm$^{-3}$ $VO^{2+}$(aq) are mixed.

Write an equation for the reaction that takes place in the resulting mixture.

..... [2]

**(b)** A solution of $SnCl_2$(aq) is electrolysed for a measured time using a steady current.

A mass of 2.95 g of tin metal is produced at the cathode.

$Al_2O_3$(l) is electrolysed for the same time by the same current.

Calculate the mass of aluminium metal produced at the cathode. Give your answer to **three** significant figures. Show your working.

mass of aluminium metal = ..... g [2]

[Total: 10]



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**2.** Nov/2022/Paper_42/No.3

Data should be selected from Table 3.1 in order to answer some parts of this question.

**Table 3.1**

| electrode reaction | $E^{\ominus}$/V |
|---|---|
| $Mg^{2+} + 2e^- \rightleftharpoons Mg$ | –2.38 |
| $Mn^{2+} + 2e^- \rightleftharpoons Mn$ | –1.18 |
| $Mn^{3+} + e^- \rightleftharpoons Mn^{2+}$ | +1.49 |
| $MnO_2 + 4H^+ + 2e^- \rightleftharpoons Mn^{2+} + 2H_2O$ | +1.23 |
| $MnO_4^- + e^- \rightleftharpoons MnO_4^{2-}$ | +0.56 |
| $MnO_4^- + 4H^+ + 3e^- \rightleftharpoons MnO_2 + 2H_2O$ | +1.67 |
| $MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O$ | +1.52 |

**(a)** An electrochemical cell can be constructed from a $Mg^{2+}/Mg$ half-cell and a $MnO_4^-/Mn^{2+}$ half-cell. The standard cell potential of this cell can be calculated using the standard electrode potentials of the two half-cells.

**(i)** Define standard electrode potential. Include details of the standard conditions used.

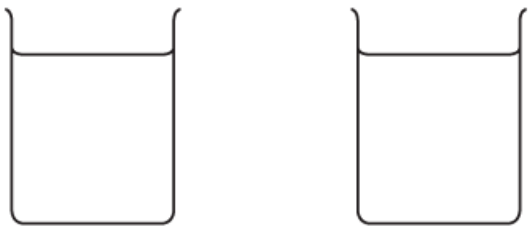
.....

.....

.....

..... [2]

**(ii)** Complete the diagram below to show an electrochemical cell constructed from a $Mg^{2+}/Mg$ half-cell and a $MnO_4^-/Mn^{2+}$ half-cell.
Label your diagram.



[3]

**(iii)** Use a positive (+) sign and a negative (–) sign to identify the polarity of each of the two electrodes in your diagram.
Use an arrow and the symbol 'e' to show the direction of electron flow in the external circuit. [1]



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**(iv)** Calculate the standard cell potential, $E^{\ominus}_{cell}$, of this cell.

$E^{\ominus}_{cell}$ = ..... V [1]

**(v)** Construct an equation for the cell reaction.

..... [1]

**(vi)** Predict how the cell reaction will change, if at all, when the solution in the $Mg^{2+}$ / Mg half-cell is diluted by the addition of a large volume of water. Explain your answer.

.....

.....

..... [1]

**(b)** A molten magnesium salt is electrolysed for 15.0 minutes by a constant current.

$4.75 \times 10^{22}$ magnesium atoms are produced at the cathode.

Calculate the value of the current used.

current = ..... A [2]

[Total: 11]



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**1.** Nov/2023/Paper_9701/41/No.3(e, f)

**(e)** The $E^{\ominus}$ values for two electrode reactions are given.

$$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O \qquad E^{\ominus} = +1.77\,V$$

$$Cr^{3+} + e^- \rightleftharpoons Cr^{2+} \qquad E^{\ominus} = -0.41\,V$$

**(i)** An electrochemical cell is constructed with the following half-cells (electrodes):

- an acidified solution of $H_2O_2$, a platinum wire
- $Cr^{2+}$ mixed with $Cr^{3+}$, a platinum wire.

Identify the positive half-cell and calculate the standard cell potential, $E^{\ominus}_{cell}$.

positive half-cell ..... $E^{\ominus}_{cell}$ = ..... V [1]

**(ii)** Calculate the value of $\Delta G^{\ominus}$ for the cell reaction that occurs, per mole of $H_2O_2$.

$\Delta G^{\ominus}$ = ..... $kJ\,mol^{-1}$ [2]



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**(f)** The $E^{\ominus}$ values for two electrode reactions are given.

$$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O \qquad E^{\ominus} = +1.77\,V$$

$$Co^{3+} + e^- \rightleftharpoons Co^{2+} \qquad E^{\ominus} = +1.82\,V$$

An electrochemical cell is constructed with the following half-cells.

half-cell 1 an acidified solution of $H_2O_2$ under standard conditions, a platinum wire

half-cell 2 a solution containing $0.020\,mol\,dm^{-3}$ $Co^{3+}$ and $2.0\,mol\,dm^{-3}$ $Co^{2+}$, a platinum wire

**(i)** Use the Nernst equation to calculate the value of $E$, the electrode potential of half-cell 2 under these conditions.

$E$ = ..... V [2]

**(ii)** Write an equation for the cell reaction that occurs in this cell under these conditions.

..... [1]



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**2.** Nov/2023/Paper_9701/42/No.3

Some electrode potentials are shown in Table 3.1.

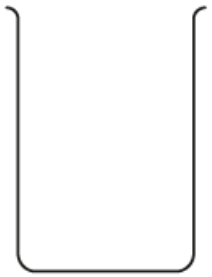
**Table 3.1**

| electrode reaction | $E^{\ominus}$/V |
|---|---|
| $V^{2+} + 2e^- \rightleftharpoons V$ | –1.20 |
| $V^{3+} + e^- \rightleftharpoons V^{2+}$ | –0.26 |
| $VO^{2+} + 2H^+ + e^- \rightleftharpoons V^{3+} + H_2O$ | +0.34 |
| $VO_2^+ + 2H^+ + e^- \rightleftharpoons VO^{2+} + H_2O$ | +1.00 |
| $Fe^{2+} + 2e^- \rightleftharpoons Fe$ | –0.44 |
| $Fe^{3+} + 3e^- \rightleftharpoons Fe$ | –0.04 |
| $Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$ | +0.77 |
| $2H^+ + 2e^- \rightleftharpoons H_2$ | 0.00 |
| $ClO^- + H_2O + 2e^- \rightleftharpoons Cl^- + 2OH^-$ | +0.89 |



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**(a) (i)** Complete the diagram to show a standard hydrogen electrode.
Label your diagram. Identify all substances. You do **not** need to state standard conditions.



[1]

**(ii)** An electrochemical cell is set up using an $Fe^{3+}/Fe^{2+}$ electrode and a standard hydrogen electrode.

Identify the positive electrode in the electrochemical cell and the direction of electron flow in the external circuit.

positive electrode .....

Electrons flow from the ..... electrode to the ..... electrode.
[1]



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**(b)** The vanadium-containing species in the electrode reactions given in Table 3.1 are V, $V^{2+}$, $V^{3+}$, $VO^{2+}$ and $VO_2^{+}$.

**(i)** Identify **one** vanadium-containing species that does **not** react with $Fe^{2+}$ ions under standard conditions.

Use data from Table 3.1 to explain your answer.

.....

..... [1]

**(ii)** Identify **all** the vanadium-containing species that will react with $Fe^{2+}$ ions under standard conditions.

..... [1]

**(iii)** Write an equation for **one** of the possible reactions identified in **(ii)**.

..... [1]

**(c)** Another electrochemical cell is set up using an $Fe^{3+}/Fe^{2+}$ electrode and an alkaline $ClO^-/Cl^-$ electrode.

The concentration of $Fe^{3+}$ is 1000 times greater than the concentration of $Fe^{2+}$ in the $Fe^{3+}/Fe^{2+}$ electrode. All other conditions are standard.

**(i)** Use the Nernst equation to calculate the $E$ value of the $Fe^{3+}/Fe^{2+}$ electrode.

Show your working.

$E$ = ..... V [2]

**(ii)** Write an equation for the reaction that occurs in the cell, under these conditions.

..... [1]

**(d)** Another electrochemical cell is set up using an $Fe^{2+}/Fe$ electrode and an alkaline $ClO^-/Cl^-$ electrode under standard conditions.

Calculate the value of $\Delta G^{\ominus}$ for the cell.

$\Delta G^{\ominus}$ = ..... $kJ\,mol^{-1}$ [3]



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**(e)** A solution of iron(II) sulfate, $FeSO_4(aq)$ is electrolysed with iron electrodes. Under the conditions used, no gas is evolved at the cathode.

A current of 0.640 A is passed for 17.0 minutes. The mass of the cathode increases by 0.185 g.

Use these results to calculate an experimental value for the Avogadro constant, *L*.

Show your working.

*L* = ..... $mol^{-1}$ [3]

**(f)** Iron(II) chloride, $FeCl_2$, is oxidised by chlorine to form iron(III) chloride, $FeCl_3$, under standard conditions.

$$2FeCl_2(s) + Cl_2(g) \rightarrow 2FeCl_3(s) \qquad \Delta H^{\ominus} = -128\,kJ\,mol^{-1}$$

**Table 3.2**

| species | $S^{\ominus}/J\,K^{-1}\,mol^{-1}$ |
|---|---|
| $Cl_2(g)$ | 223 |
| $FeCl_2(s)$ | 120 |
| $FeCl_3(s)$ | 142 |

**(i)** Use Table 3.2 and other data to calculate the Gibbs free energy change, $\Delta G^{\ominus}$, for this reaction.

Show your working.

$\Delta G^{\ominus}$ = ..... kJ $mol^{-1}$ [3]



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**(ii)** Predict whether this reaction becomes more or less feasible at a higher temperature.

Explain your answer.

The reaction becomes ..... feasible.

explanation .....

.....

[1]

[Total: 18]



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**3.** June/2023/Paper_9701/42/No.1(c _ d)

**(c)** Potassium sulfite, $K_2SO_3$, is used as a food additive.

The concentration of sulfite ions, $SO_3^{2-}$, can be determined by titration using aqueous acidified manganate(VII) ions, $MnO_4^-$.

- A 250 $cm^3$ solution contains 3.40 g of impure $K_2SO_3$.
- 25.0 $cm^3$ of this solution requires 22.40 $cm^3$ of 0.0250 mol $dm^{-3}$ acidified $MnO_4^-$ to reach the end-point. All the $SO_3^{2-}$ ions are oxidised. None of the other species in the impure $K_2SO_3$ are oxidised.

The reaction occurs as shown by the two half-equations.

$$H_2O + SO_3^{2-} \rightarrow SO_4^{2-} + 2H^+ + 2e^-$$

$$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$$

**(i)** Give the ionic equation for the reaction between $SO_3^{2-}$ and acidified $MnO_4^-$.

..... [1]

**(ii)** Calculate the percentage purity of the sample of $K_2SO_3$.
Show your working.

percentage purity of $K_2SO_3$ = ..... [3]

**(d)** Potassium disulfite, $K_2S_2O_5$, is another food additive. The disulfite ion, $S_2O_5^{2-}$, has the displayed formula shown in Fig. 1.2.

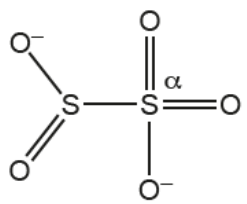



**Fig. 1.2**

Deduce the geometry (shape) around the S(α) atom in $S_2O_5^{2-}$.

geometry around S(α) ..... [1]

**4.** June/2023/Paper_9701/42/No.9



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**(a)** Define standard cell potential, $E^{\ominus}_{cell}$.

.....

..... [1]

**(b)** An electrochemical cell is set up to measure $E^{\ominus}_{cell}$ of a cell consisting of an $Fe^{3+}/Fe^{2+}$ half-cell and a $Cl_2/Cl^-$ half-cell.

Draw a labelled diagram of this electrochemical cell.

Include all necessary substances. It is **not** necessary to state conditions used.

[3]

**(c)** The cell reaction for the electrochemical cell in **(b)** is shown.

$$Cl_2 + 2Fe^{2+} \rightarrow 2Fe^{3+} + 2Cl^- \qquad E^{\ominus}_{cell} = +0.59\,V$$

Calculate $\Delta G^{\ominus}$, in $kJ\,mol^{-1}$, for this cell reaction.

$\Delta G^{\ominus}$ = ..... $kJ\,mol^{-1}$ [2]



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**(d)** Another experiment is set up using the same electrochemical cell.

In this experiment the $Fe^{2+}$ concentration is $0.15\,mol\,dm^{-3}$. All other concentrations remain at their standard values.

The Nernst equation is shown.

$$E = E^{\ominus} + (0.059/z) \log \frac{[\text{oxidised species}]}{[\text{reduced species}]}$$

**(i)** Use the Nernst equation to calculate the electrode potential, $E$, for the $Fe^{3+}/Fe^{2+}$ half-cell in this experiment.

[$E^{\ominus}$: $Fe^{3+}/Fe^{2+}$ = +0.77 V]

$E$ = ..... V [1]

**(ii)** Use your answer to **(d)(i)** to calculate $E_{cell}$ for this electrochemical cell.

$E_{cell}$ = ..... V [1]

[Total: 8]



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**5.** March/2023/Paper_9701/42/No.2(a, b)

Hypophosphorous acid is an inorganic acid.

The conjugate base of hypophosphorous acid is $H_2PO_2^-$.

**(a)** Give the formula of hypophosphorous acid.

..... [1]

**(b)** $H_2PO_2^-$ is a strong reducing agent. It can be used to reduce metal cations without the need for electrolysis.

equation 1 $\quad HPO_3^{2-} + 2H_2O + 2e^- \rightleftharpoons H_2PO_2^- + 3OH^- \quad E^\ominus = -1.57\,V$

**(i)** In an experiment, an alkaline $HPO_3^{2-}/H_2PO_2^-$ half-cell is constructed with $[H_2PO_2^-] = 0.050\,mol\,dm^{-3}$.

All other ions are at their standard concentration.

Predict how the value of $E$ of this half-cell differs from its $E^\ominus$ value.

Explain your answer.

.....

.....

.....

..... [2]

**(ii)** The $Cr^{3+}/Cr$ half-cell has a standard electrode potential of –0.74 V.

An electrochemical cell consists of an alkaline $HPO_3^{2-}/H_2PO_2^-$ half-cell and a $Cr^{3+}/Cr$ half-cell.

Calculate the standard cell potential, $E^\ominus_{cell}$.

$E^\ominus_{cell}$ = ..... V [1]



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**(iii)** Complete the diagram in Fig. 2.1 to show how the standard electrode potential of the $Cr^{3+}/Cr$ half-cell can be measured relative to that of the standard hydrogen electrode.

Identify the chemicals, conditions and relevant pieces of apparatus.

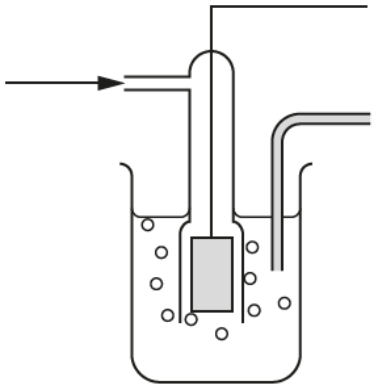


**Fig. 2.1**

[3]

**(iv)** Label Fig. 2.1 to show:

- which is the positive electrode
- the direction of electron flow in the external circuit.

[1]

**(v)** $H_2PO_2^-$ reduces $Ni^{2+}$ to Ni in alkaline conditions.

Use equation 1 to construct the ionic equation for this reaction.

equation 1 $\quad HPO_3^{2-} + 2H_2O + 2e^- \rightleftharpoons H_2PO_2^- + 3OH^-$

..... [1]



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# Electrochemistry – 2021 AS

**1.** Nov/2021/Paper_12/No.32

Four solutions, each of concentration 0.1 mol $dm^{-3}$, were tested with a pH meter. The results are shown.

| solution | formula of acid or base | pH |
|---|---|---|
| acid 1 | $CH_3CO_2H$ | 4 |
| acid 2 | $HNO_3$ | 1 |
| base 1 | $CH_3NH_2$ | 11 |
| base 2 | NaOH | 14 |

Which statements explain these results?

**1** Acid 2 has a lower pH than acid 1 because it is more soluble.

**2** Base 2 has a higher concentration of hydroxide ions in solution than base 1.

**3** Acid 1 dissociates less than acid 2.

**2.** Nov/2021/Paper_13/No.9

Zinc atoms can be oxidised to $Zn^{2+}$ ions by dichromate(VI) ions in acid solution. Chromium is reduced to $Cr^{3+}$ in this reaction.

Which equation is correct?

**A** $Cr_2O_7^{2-} + Zn + 14H^+ \rightarrow 2Cr^{3+} + Zn^{2+} + 7H_2O$

**B** $Cr_2O_7^{2-} + Zn + 14H^+ \rightarrow 2Cr^{3+} + 3Zn^{2+} + 7H_2O$

**C** $Cr_2O_7^{2-} + 3Zn + 14H^+ \rightarrow 2Cr^{3+} + 3Zn^{2+} + 7H_2O$

**D** $2Cr_2O_7^{2-} + 3Zn + 14H^+ \rightarrow 2Cr^{3+} + 3Zn^{2+} + 7H_2O$

**3.** Nov/2021/Paper_13/No.17

Z is a compound of sodium, chlorine and oxygen.

It contains 45.1% by mass of oxygen.

Z is prepared by reacting sodium hydroxide with chlorine.

Which row shows the conditions used for the reaction and the oxidation state of chlorine in Z?

| | reaction conditions | oxidation state of Cl in Z |
|---|---|---|
| **A** | cold dilute NaOH | +1 |
| **B** | cold dilute NaOH | +5 |
| **C** | hot concentrated NaOH | +1 |
| **D** | hot concentrated NaOH | +5 |

**4.** Nov/2021/Paper_21/No.1(c)

**(c)** Hydrogen sulfide gas, $H_2S(g)$, is slightly soluble in water. It acts as a weak acid in aqueous solution.

**(i)** State the meaning of *weak acid*.

.....

..... [1]

**(ii)** Give the formula of the conjugate base of $H_2S$.

..... [1]

**(iii)** $H_2S(aq)$ reacts slowly with oxygen dissolved in water. The reaction is represented by the following equation.

$$H_2S(aq) + \tfrac{1}{2}O_2(aq) \rightarrow H_2O(l) + S(s)$$

Explain, with reference to oxidation numbers, why this reaction is a redox reaction.

.....

.....

.....

..... [2]



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**5.** Nov/2021/Paper_21/No.3

Phosphorus is a reactive Period 3 element.

**(a)** Phosphorus has several allotropes. Details of two allotropes are given.

| allotrope of phosphorus | formula | melting point / °C |
|---|---|---|
| white | $P_4$ | 44 |
| red | P | 590 |

**(i)** White phosphorus and red phosphorus both have covalent bonding.

Suggest the types of structure shown by white phosphorus ($P_4$) and red phosphorus (P).

Explain why red phosphorus (P) has a higher melting point than white phosphorus ($P_4$).

structure of $P_4$ .....

structure of P .....

explanation .....

.....

.....

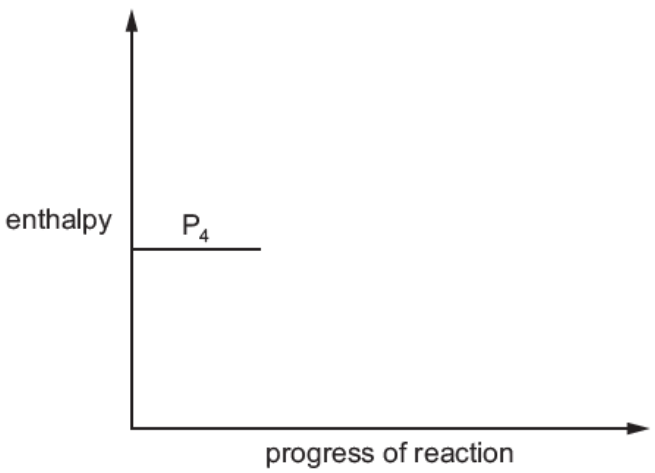
[3]

**(ii)** Red phosphorus (P) forms when white phosphorus ($P_4$) is exposed to sunlight.

$$\tfrac{1}{4}P_4(s) \rightarrow P(s) \qquad \Delta H = -17.6\,kJ\,mol^{-1}$$

white red

Use this information to draw a reaction pathway diagram to show the formation of red phosphorus (P) from white phosphorus ($P_4$).

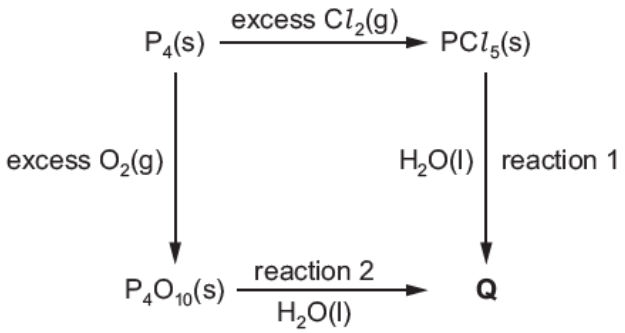



[1]



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**(b)** Some reactions of $P_4(s)$ are shown in the reaction scheme.




**(i)** State the oxidation number of phosphorus in $P_4O_{10}$.

..... [1]

**(ii)** Deduce the identity of **Q** and hence construct chemical equations for reactions 1 and 2.

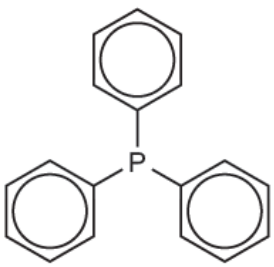
reaction 1 $PCl_5$ + .....$H_2O$ → .....

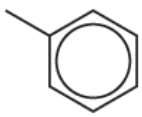
reaction 2 $P_4O_{10}$ + .....$H_2O$ → .....

[2]

**(c)** Triphenylphosphine is used in a type of reaction known as a *Wittig reaction*.

triphenylphosphine




where  = $-C_6H_5$

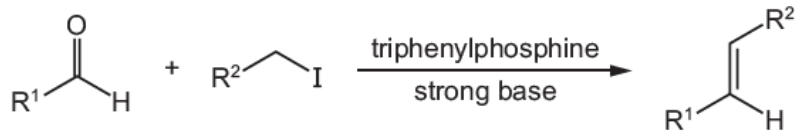
**(i)** Give the empirical formula of triphenylphosphine.

..... [1]



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In a Wittig reaction, an aldehyde reacts with a halogenoalkane to form an alkene. The conversion is shown in the following unbalanced equation.




Compound **H** can be made from propanal, $C_2H_5CHO$. Stage 3 in the reaction scheme is a Wittig reaction.

stage 1 $C_2H_5CHO \xrightarrow{NaBH_4}$ **G**

stage 2 **G** $\xrightarrow{\text{red phosphorus and } I_2}$ $C_2H_5CH_2I$

stage 3 (Wittig reaction) $C_2H_5CH_2I + C_2H_5CHO \xrightarrow[\text{strong base}]{\text{triphenylphosphine}}$ **H**

**(ii)** State the types of reaction that occur in stages 1 and 2.

stage 1 .....

stage 2 .....

[2]

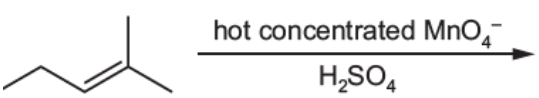
**(iii)** Draw the structures of **G** and **H** in the boxes provided.

| **G** | **H** |
|---|---|
| | |

[2]

**(d)** Identify the organic products formed when compound **J**, shown below, is heated with hot concentrated acidified manganate(VII) ions.

**J**




[2]

[Total: 14]



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**6.** March/2021/Paper_12/No.8

$VO_2Cl$ reacts with NaI under acidic conditions.

$$2VO_2Cl + 2H_2SO_4 + 2NaI \rightarrow VOCl_2 + VOSO_4 + I_2 + Na_2SO_4 + 2H_2O$$

The oxidation state of $Cl$ is –1 in $VO_2Cl$ and in $VOCl_2$.

Which row about this reaction is correct?

| | vanadium | iodine |
|---|---|---|
| **A** | is oxidised | is oxidised |
| **B** | is oxidised | is reduced |
| **C** | is reduced | is oxidised |
| **D** | is reduced | is reduced |

**7.** June/2021/Paper_11/No.9

When hydrogen iodide is reacted with concentrated sulfuric acid, several reactions occur, including:

$$8HI + H_2SO_4 \rightarrow H_2S + 4H_2O + 4I_2$$

Which row gives the change in oxidation number of iodine and of sulfur in this reaction?

| | change in oxidation number of iodine | change in oxidation number of sulfur |
|---|---|---|
| **A** | –1 | +6 |
| **B** | –1 | +8 |
| **C** | +1 | –6 |
| **D** | +1 | –8 |



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**8.** June/2021/Paper_11/No.25

When an organic compound is oxidised, any oxygen atom gained by the organic molecule is considered to be from a water molecule also producing $2H^+ + 2e^-$. Any hydrogen atom lost may be considered to be lost as $H^+ + e^-$.

These changes can be represented by the following two equations.

$$H_2O \rightarrow [O] + 2H^+ + 2e^-$$

$$[H] \rightarrow H^+ + e^-$$

Compound X is oxidised by heating under reflux with hot, acidified potassium dichromate(VI) for one hour. The half-equation for the reduction reaction is shown.

$$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$$

Under these conditions, one mole of potassium dichromate(VI) oxidises three moles of X.

What could X be?

**A** propanal

**B** propan-1-ol

**C** propan-1,2-diol

**D** propan-1,3-diol

**9.** June/2021/Paper_12/No.9

The equation for a redox reaction is shown.

$$SnCl_2(aq) + 2HgCl_2(aq) \rightarrow SnCl_4(aq) + Hg_2Cl_2(s)$$

Which species is being oxidised in this reaction?

**A** $Sn^{2+}$ **B** $Cl^-$ **C** $Hg^+$ **D** $Hg^{2+}$

**10.** June/2021/Paper_13/No.32

The equation shows the decomposition of three moles of an ion containing chromium in an acid solution.

$$3CrO_4^{3-}(aq) + 8H^+(aq) \rightarrow 2CrO_4^{2-}(aq) + Cr^{3+}(aq) + 4H_2O(l)$$

Which statements are correct?

**1** One mole of $CrO_4^{3-}$ is reduced.

**2** Two moles of $CrO_4^{3-}$ are oxidised.

**3** Three moles of electrons are transferred.



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**11.** June/2021/Paper_13/No.35

Which reagents produce a solution of sodium chlorate(V)?

1 chlorine and hot concentrated sodium hydroxide solution

2 chlorine and cold dilute sodium hydroxide solution

3 chlorine dissolved in water at room temperature

**12.** June/2021/Paper_23/No.1(f)

**(f)** Sodium chlorate(I), NaC*l*O, oxidises dilute hydrochloric acid to form three products. The products which contain chlorine have chlorine species with oxidation number –1 or 0.

No other species changes its oxidation number during the reaction.

Use this information to complete the ionic equation.

.....C*l*O$^-$ + .....HC*l* → ..... + ..... + ..... [2]



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# Electrochemistry – 2022 June AS Chemistry 9701

**1.** June/2022/Paper_11/No.17

Solid sodium iodide reacts with concentrated sulfuric acid to form more than one product that contains sulfur.

What is the lowest oxidation number of sulfur in these products?

**A** –2 **B** 0 **C** +4 **D** +6

**2.** June/2022/Paper_12/No.11

$NCl_3$ reacts with $H_2O$.

$$NCl_3 + 3H_2O \rightarrow NH_3 + 3HClO$$

The oxidation state of nitrogen does not change in this reaction.

Which statement is correct?

**A** Chlorine is reduced.

**B** Chlorine is oxidised.

**C** Hydrogen is both oxidised and reduced.

**D** This is not a redox reaction.

**3.** June/2022/Paper_12/No.12

In which row do the oxidation numbers of vanadium increase?

| | smallest | ⟶ | largest |
|---|---|---|---|
| **A** | $VO_4^{3-}$ | $VO_3^-$ | $VO_2^+$ |
| **B** | $VO^{2+}$ | $V_2O_3$ | $VO_4^{3-}$ |
| **C** | $V_2O_3$ | $VO^{2+}$ | $VO_3^-$ |
| **D** | $VO_4^{3-}$ | $VO_2^+$ | $VO^{2+}$ |



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**4.** June/2022/Paper_13/No.11

$NH_4NO_3$ decomposes into $N_2O$ and $H_2O$ on heating.

Which statements are correct?

1 The ammonium ion is behaving as a reducing agent.

2 The nitrate(V) ion is behaving as an oxidising agent.

3 It is a redox reaction.

4 It is a disproportionation reaction.

**A** 1, 2, 3 and 4

**B** 1, 2 and 3 only

**C** 3 and 4 only

**D** 3 only

**5.** June/2022/Paper_13/No.12

A student adds 3 mol of acidified $K_2Cr_2O_7$ to an excess of $I^-$ ions.

The chromium is all reduced to $Cr^{3+}$ and $I^-$ ions are oxidised to $I_2$.

The $I_2$ released is reduced back to $I^-$ ions by X mol of $S_2O_3^{2-}$ ions.

1 mol of $I_2$ is reduced by 2 mol of $S_2O_3^{2-}$ ions.

What is the value of X?

**A** 3 **B** 6 **C** 9 **D** 18



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# Electrochemistry – 2022 Nov AS Chemistry 9701

**1.** Nov/2022/Paper_11/No.11

Ammonium ions are converted into nitrate ions by bacteria.

What is the change in the oxidation number of nitrogen?

**A** –6 **B** +6 **C** +8 **D** +9

**2.** Nov/2022/Paper_11/No.12

Sodium dichromate(VI), $Na_2Cr_2O_7$, reacts with hydrogen peroxide, $H_2O_2$, producing $Cr^{3+}$ ions, water and oxygen.

What is the correctly balanced ionic equation for this reaction?

**A** $Cr_2O_7^{2-} + 2H^+ + H_2O_2 \rightarrow 2Cr^{3+} + 2H_2O + 4O_2$

**B** $Cr_2O_7^{2-} + 8H^+ + 3H_2O_2 \rightarrow 2Cr^{3+} + 7H_2O + 3O_2$

**C** $Cr_2O_7^{2-} + 8H^+ + 6H_2O_2 \rightarrow 2Cr^{3+} + 10H_2O + 6O_2$

**D** $Cr_2O_7^{2-} + 14H^+ + 3H_2O_2 \rightarrow 2Cr^{3+} + 7H_2O + 3O_2$

**3.** Nov/2022/Paper_12/No.5

Two moles of $VO_2^+$ ions react with one mole of zinc atoms in the presence of dilute acid. The products include $Zn^{2+}$ ions and an ion, Y. Ion Y contains vanadium. Only zinc and vanadium change oxidation state in the reaction.

What is ion Y?

**A** $VO_3^-$ **B** $VO^+$ **C** $VO^{2+}$ **D** $VO_2^{2+}$



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**4.** Nov/2022/Paper_22/No.1(b)

**(b)** Complete Table 1.1 to show the total numbers of protons and electrons in the molecular ions $NH_4^+$, $CO_3^{2-}$ and $PO_4^{3-}$.

**Table 1.1**

| molecular ion | total number of protons | total number of electrons |
|---|---|---|
| $NH_4^+$ | | |
| $CO_3^{2-}$ | | |
| $PO_4^{3-}$ | | |

[3]



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# Electrochemistry – 2023 AS Chemistry 9701

**1.** Nov/2023/Paper_ 9701/11/No.11

HOCl(aq) is the molecule that kills bacteria when chlorine is added to water.

The following reaction produces this molecule.

$$Cl_2(g) + H_2O(l) \rightleftharpoons HOCl(aq) + H^+(aq) + Cl^-(aq)$$

Which statement about this reaction is correct?

**A** Chlorine is both oxidised and reduced.

**B** Chlorine is oxidised but **not** reduced.

**C** Hydrogen is both oxidised and reduced.

**D** Hydrogen is oxidised but **not** reduced.

**2.** Nov/2023/Paper_ 9701/12/No.12

Chlorine reacts with sodium bromide.

$$\tfrac{1}{2}Cl_2 + NaBr \rightarrow NaCl + \tfrac{1}{2}Br_2$$

Which words correctly describe this reaction?

1 redox

2 displacement

3 disproportionation

**A** 1, 2 and 3

**B** 1 and 2 only

**C** 1 only

**D** 2 only

**3.** Nov/2023/Paper_ 9701/12/No.13

The equation for the reaction between aqueous copper ions and aqueous iodide ions is as follows.

$$2Cu^{2+}(aq) + 4I^-(aq) \rightarrow 2CuI(s) + I_2(aq)$$

What is the change in oxidation state of copper?

**A** +2 to –1 **B** +2 to 0 **C** +2 to +1 **D** +4 to +2

**4.** Nov/2023/Paper_ 9701/21/No.3(a)

Potassium chlorate, $KClO_3$, is widely used as an oxidising agent and to make $O_2(g)$.

**(a)** Define oxidising agent.

.....

..... [1]

**5.** June/2023/Paper_9701/12/No.11

$LiAlH_4$ contains $AlH_4^-$ ions in which aluminium has an oxidation state of +3.

$LiAlH_4$ reacts with water, as shown.

$$LiAlH_4 + 4H_2O \rightarrow 4H_2 + LiOH + Al(OH)_3$$

In this reaction, each of the four water molecules produces one hydroxide ion. It does this by losing one $H^+$ ion, which reacts with the $LiAlH_4$.

Which changes in oxidation number occur in this reaction?

**A** Al increases by 1 and H decreases by 1.

**B** H decreases by 2 and also increases by 1.

**C** H increases by 1 and also decreases by 1.

**D** O decreases by 1 and H increases by 1.

**6.** June/2023/Paper_9701/12/No.12

The vanadium salt, $VOSO_4$, is soluble in water and reacts readily with powdered manganese in dilute sulfuric acid.

The equation for the reaction is shown.

$$Mn(s) + 2VOSO_4(aq) + 2H_2SO_4(aq) \rightarrow V_2(SO_4)_3(aq) + MnSO_4(aq) + 2H_2O(l)$$

Which statement about this reaction is correct?

**A** Hydrogen is oxidised in the reaction.

**B** Manganese is the reducing agent in this reaction.

**C** Sulfuric acid is the oxidising agent in this reaction.

**D** The oxidation state of the vanadium changes from +5 to +3.



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**7.** June/2023/Paper_9701/13/No.2

The ionic equation shows iodide ions reacting with manganate(VII) ions in acidic solution.

$$u\mathrm{MnO_4^-} + v\mathrm{H^+} + w\mathrm{I^-} \rightarrow x\mathrm{Mn^{2+}} + y\mathrm{H_2O} + z\mathrm{I_2}$$

The letters *u*, *v*, *w*, *x*, *y* and *z* all represent whole numbers. Two or more of *u*, *v*, *w*, *x*, *y* and *z* are the same as each other.

What is the lowest possible value of *v*?

**A** 2 **B** 8 **C** 10 **D** 16

**8.** June/2023/Paper_9701/13/No.6

Electronegativity differences can be used to help determine the oxidation number of an atom in different species. A number of rules are used which include:

- The more electronegative atom is given a negative oxidation number.
- Hydrogen is more electronegative than Group 1 metals.
- Oxygen is more electronegative than hydrogen.

Which row is correct?

| | equation of reaction | redox reaction | disproportionation reaction |
|---|---|---|---|
| **A** | $2\mathrm{CrO_4^{2-}} + 2\mathrm{H^+} \rightarrow \mathrm{Cr_2O_7^{2-}} + \mathrm{H_2O}$ | ✓ | ✗ |
| **B** | $\mathrm{NaH} + \mathrm{H_2O} \rightarrow \mathrm{NaOH} + \mathrm{H_2}$ | ✓ | ✓ |
| **C** | $3\mathrm{MnO_4^{2-}} + 4\mathrm{H^+} \rightarrow \mathrm{MnO_2} + 2\mathrm{MnO_4^-}$ | ✓ | ✓ |
| **D** | $\mathrm{VO_3^-} + 2\mathrm{H^+} \rightarrow \mathrm{VO_2^+} + \mathrm{H_2O}$ | ✓ | ✗ |

**9.** June/2023/Paper_9701/13/No.14

Which particle contains nitrogen in the same oxidation state as in the ion $\mathrm{N_2O_2^{2-}}$?

**A** $\mathrm{NH_2F}$ **B** $\mathrm{N_2O_4}$ **C** $\mathrm{NO_3^-}$ **D** $\mathrm{HNF_2}$



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**10.** March/2023/Paper_9701/12/No.6

The ore psilomelane may be considered to have the general formula $Ba(Mn^{x+})(Mn^{y+})_8O_{16}(OH)_4$.

In this general formula, *x*+ and *y*+ are the two different oxidation states of manganese in psilomelane.

What could be the values of *x* and *y*?

| | *x* | *y* |
|---|---|---|
| **A** | 2 | 4 |
| **B** | 6 | 4 |
| **C** | 6 | 3 |
| **D** | 7 | 3 |

**11.** March/2023/Paper_9701/12/No.7

Silicon reacts with a mixture of calcium oxide and magnesium oxide at 1200 °C.

$$2MgO + 2CaO + Si \rightarrow 2Mg + Ca_2SiO_4$$

Which statement about this reaction is correct?

**A** Calcium is reduced and silicon is neither oxidised nor reduced.

**B** Magnesium is reduced and calcium is neither oxidised nor reduced.

**C** Magnesium is reduced and silicon is neither oxidised nor reduced.

**D** Silicon is reduced and calcium is neither oxidised nor reduced.