1 Which of the following gives the oxidation states of manganese in the ions shown?

		MnO_4^{2-}	MnO_3^-
☒	**A**	+7	+6
☒	**B**	+6	+5
☒	**C**	+7	+5
☒	**D**	+6	+6

(Total for Question = 1 mark)

2 Which of the following gives the electrodes and electrolyte that are used in an alkaline hydrogen fuel cell?

		Electrodes	Electrolyte
☒	**A**	graphite	potassium hydroxide solution
☒	**B**	graphite	water with a little salt
☒	**C**	platinum	potassium hydroxide solution
☒	**D**	platinum	water with a little salt

(Total for Question = 1 mark)

3 During a titration between acidified manganate(VII) ions and sulfate(IV) ions, the manganate(VII) ions are reduced to manganese(II) ions and the sulfate(IV) ions are oxidized to sulfate(VI) ions.

The mole ratio of manganate(VII) ions to sulfate(IV) ions in this reaction is

☒ **A** 5:2

☒ **B** 7:4

☒ **C** 2:5

☒ **D** 4:7

(Total for Question = 1 mark)

4 Which of the statements about a standard hydrogen electrode, for which $E^{\ominus} = 0$ V, is correct?

☒ **A** A suitable solution for use in the electrode is hydrochloric acid with a concentration of 0.1 mol dm^{-3}.

☒ **B** The pressure of the hydrogen has no effect on the value of $E^{\ominus}$.

☒ **C** The metal used in the electrode is platinum.

☒ **D** The temperature is 273 K.

(Total for Question = 1 mark)

5 The table below gives the standard electrode potentials of three half cells.

System	$E^{\ominus}$ / V
$H^+(aq) + e^- \rightleftharpoons \frac{1}{2}H_2(g)$	0.00
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$Ag^{2+}(aq) + e^- \rightleftharpoons Ag^+(aq)$	+1.98

From these data it may be deduced that, under standard conditions,

☒ **A** Ag is a stronger reducing agent than H_2.

☒ **B** Ag^{2+} ions are stronger oxidizing agents than H^+ ions.

☒ **C** Ag^+ ions will disproportionate.

☒ **D** Ag^+ ions will react with H^+ ions.

(Total for Question = 1 mark)

6 In a methanol fuel cell, the following half-reaction occurs

$$CH_3OH(l) + H_2O(l) \rightarrow 6H^+(aq) + CO_2(g) + 6e^-$$

The half-reaction occurring in the other half of the fuel cell is

☒ **A** $H_2(g) + O_2(g) + 2e^- \rightarrow 2OH^-(aq)$

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

☒ **C** $2OH^-(aq) \rightarrow H_2(g) + O_2(g) + 2e^-$

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

(Total for Question = 1 mark)

7 Which of the following statements about fuel cells is **not** true?

☒ **A** Reactants must constantly be fed into the cell when it is in use.

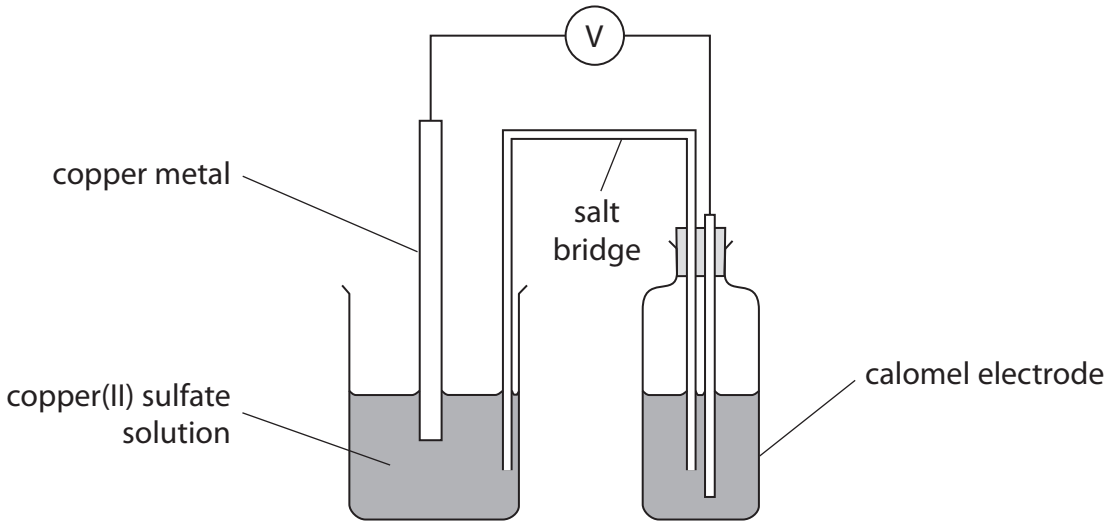
☒ **B** Fuel cells are 100% efficient.

☒ **C** Fuel cells convert chemical energy directly into electrical energy.

☒ **D** Fuel cells produce electricity more efficiently than a diesel generator.

(Total for Question = 1 mark)

8 The diagram below shows a cell set up between a copper metal / copper(II) ion electrode and a reference electrode, known as a calomel electrode.



Under standard conditions, the emf of this cell was –0.07 V. The standard electrode potential of the copper metal / copper(II) ion electrode is +0.34 V. Hence the standard electrode potential of the calomel electrode is

☒ **A** –0.41 V

☒ **B** –0.27 V

☒ **C** +0.27 V

☒ **D** +0.41 V

(Total for Question = 1 mark)

9 The standard electrode potentials of two half reactions are shown below.

$$\tfrac{1}{2}Cl_2 + e^- \rightleftharpoons Cl^- \qquad E^{\ominus} = +1.36\ V$$

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

Which of the following processes is thermodynamically favourable? The reaction of

☒ **A** Co^{2+} with Cl_2 to form Cl^-

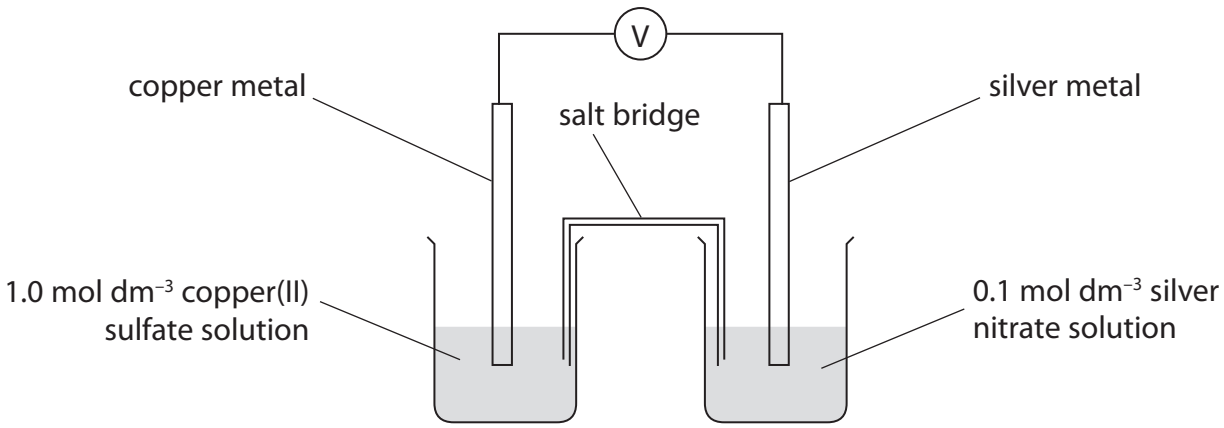
☒ **B** Co^{2+} with Cl^- to form Cl_2

☒ **C** Co^{3+} with Cl_2 to form Cl^-

☒ **D** Co^{3+} with Cl^- to form Cl_2

(Total for Question = 1 mark)

10 The diagram below shows a cell set up between a standard copper metal / copper(II) ion electrode and a silver metal / silver(I) ion electrode in which the silver ion concentration is 0.1 mol dm^{-3}.



At 298 K, the emf of this cell was +0.40 V. The electrode potential of the copper metal / copper(II) ion electrode is +0.34 V. What is the electrode potential of this silver metal / silver(I) ion electrode?

☒ **A** −0.74 V

☒ **B** −0.06 V

☒ **C** +0.06 V

☒ **D** +0.74 V

(Total for Question = 1 mark)

11 For the reaction

$$Zn(s) + Cu^{2+}(aq) \rightarrow Cu(s) + Zn^{2+}(aq)$$

$E^{\ominus}_{cell}$ is positive. From this it can be deduced that, for this reaction,

☒ **A** ΔS_{total} and $\ln K$ are positive.

☒ **B** ΔS_{total} and $\ln K$ are negative.

☒ **C** ΔS_{total} is positive and $\ln K$ is negative.

☒ **D** ΔS_{total} is negative and $\ln K$ is positive.

(Total for Question = 1 mark)

12 In a hydrogen-oxygen fuel cell, hydrogen is

☒ **A** oxidized at the anode.

☒ **B** oxidized at the cathode.

☒ **C** reduced at the anode.

☒ **D** reduced at the cathode.

(Total for Question = 1 mark)

13 The following data are provided.

	$E^{\ominus}$ / V
$ClO^-(aq) + H_2O(l) + e^- \rightleftharpoons \frac{1}{2}Cl_2(aq) + 2OH^-(aq)$	+0.40
$Cl_2(aq) + 2e^- \rightleftharpoons 2Cl^-(aq)$	+1.36

What is the value of $E^{\ominus}_{cell}$ in which the following disproportionation reaction occurs?

$$Cl_2(aq) + 2OH^-(aq) \rightarrow ClO^-(aq) + Cl^-(aq) + H_2O(l)$$

☒ **A** $+ \frac{1.36}{2} - 0.40$ V

☒ **B** $+ \frac{1.36}{2} + 0.40$ V

☒ **C** $+ 1.36 - 0.40$ V

☒ **D** $+ 1.36 + 0.40$ V

(Total for Question = 1 mark)

14 Which of the following is always proportional to $E^{\ominus}_{cell}$ for a chemical reaction?

☒ **A** $\Delta H_{reaction}$

☒ **B** ΔS_{system}

☒ **C** $\Delta S_{surroundings}$

☒ **D** ΔS_{total}

(Total for Question = 1 mark)

15 The electrode system based on the half-equation below has the standard electrode potential +1.51 V.

$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$ $\quad E^{\ominus} = +1.51\ V$

Which of the following statements about this electrode system is correct?

☒ **A** Changing the concentration of $Mn^{2+}(aq)$ would cause a change in the electrode potential.

☒ **B** $Mn^{2+}(aq)$ is acting as an oxidizing agent.

☒ **C** The electrode used is made of manganese.

☒ **D** When connected to a standard hydrogen electrode, the resulting cell voltage would be +0.51 V.

(Total for Question = 1 mark)

16 In aqueous solution, manganate(VI) ions disproportionate into manganate(VII) ions and manganese(IV) oxide when carbon dioxide is bubbled through the solution. The ionic equation for the reaction is

$$3MnO_4^{2-}(aq) + 4H^+(aq) \rightarrow 2MnO_4^-(aq) + MnO_2(s) + 2H_2O(l)$$

The role of the carbon dioxide is to

☒ **A** lower the pH of the solution.

☒ **B** raise the pH of the solution.

☒ **C** oxidize the manganate(VI) ions.

☒ **D** reduce the manganate(VI) ions.

(Total for Question = 1 mark)

17 Which of the following will **not** reduce an acidified solution of potassium dichromate(VI)?

☒ **A** $(CH_3)_2C(OH)CH_3$

☒ **B** $FeSO_4$

☒ **C** $CH_3CH_2CH(OH)CH_3$

☒ **D** Zn

(Total for Question = 1 mark)

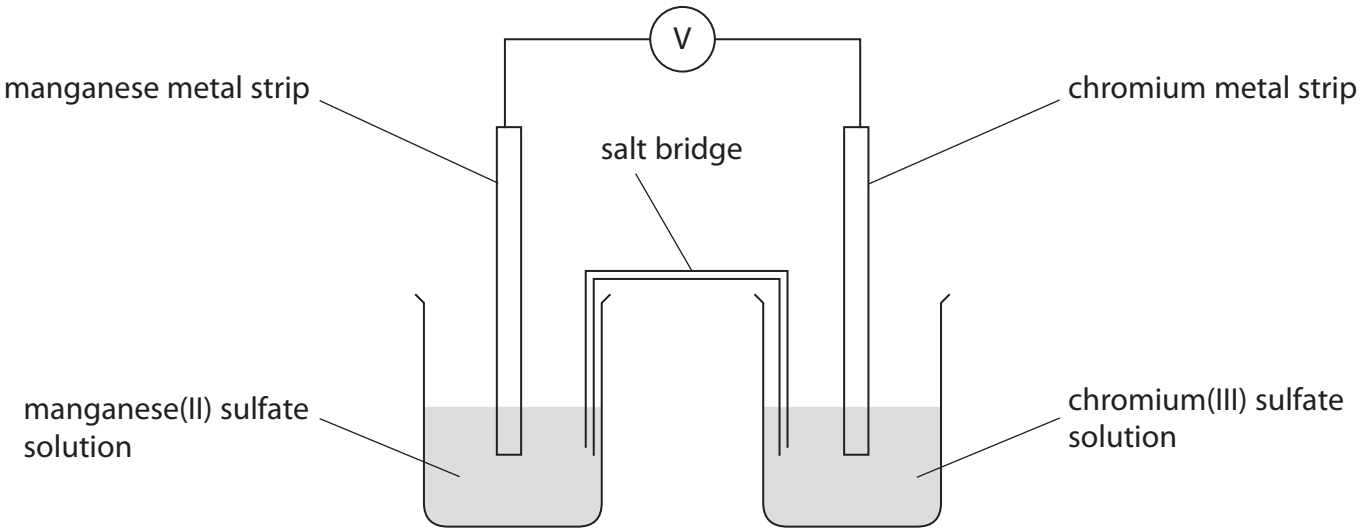
18 What are the components of the half-cell required to measure the standard reduction potential of the following system?

$$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$$

	Ion(s) in the solution	Metal electrode
☒ **A**	Fe^{2+}	iron
☒ **B**	Fe^{3+}	iron
☒ **C**	Fe^{2+} and Fe^{3+}	iron
☒ **D**	Fe^{2+} and Fe^{3+}	platinum

(Total for Question = 1 mark)

19 The following cell is set up:



The standard electrode potential of the chromium(III)/chromium half cell is −0.74 V and that of the manganese(II)/manganese half cell is −1.19 V. Thus the emf of the cell, as shown in the diagram, under standard conditions is

☒ **A** +1.93 V

☒ **B** +0.45 V

☒ **C** −0.45 V

☒ **D** −1.93 V

(Total for Question = 1 mark)

20 Chlorine is prepared in the laboratory by the reaction of potassium manganate(VII) with concentrated hydrochloric acid. The ionic half-equations and their standard electrode potentials are

$$\tfrac{1}{2}Cl_2(g) + e^- \rightleftharpoons Cl^-(aq) \quad E^{\ominus} = +1.36\ V$$

$$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l) \quad E^{\ominus} = +1.51\ V$$

(a) Concentrated hydrochloric acid is preferred to 1 mol dm^{-3} hydrochloric acid because

☒ **A** it lowers the activation energy of the reaction.

☒ **B** the reaction is thermodynamically unfavourable under standard conditions.

☒ **C** it increases the rate of reaction.

☒ **D** it increases the equilibrium constant, K_c, for the overall reaction.

(b) From the half-equations it may be deduced that

☒ **A** 1 mol of manganate(VII) ions reacts with 5 mol of chloride ions.

☒ **B** 5 mol of manganate(VII) ions reacts with 1 mol of chloride ions.

☒ **C** 1 mol of manganate(VII) ions reacts with 2.5 mol of chlorine.

☒ **D** 2.5 mol of manganate(VII) ions reacts with 1 mol of chlorine.

(Total for Question = 2 marks)

21 The acid used in a standard hydrogen electrode to provide a 1 mol dm ^{3} solution of hydrogen ions is

☒ **A** ethanoic acid.

☒ **B** phosphoric(V) acid.

☒ **C** sulfuric acid.

☒ **D** hydrochloric acid.

(Total for Question 1 mark)

22 To measure the standard electrode potential for the $Ag^{+}(aq)|Ag(s)$ electrode, the most suitable chemical for the solution in a salt bridge to connect the two half cells is

☒ **A** potassium chloride.

☒ **B** potassium iodide.

☒ **C** potassium nitrate.

☒ **D** potassium sulfate.

(Total for Question 1 mark)

23 For any reversible reaction, ln K is proportional to

☒ **A** both ΔS_{total} and E_{cell}.

☒ **B** ΔS_{total} but not E_{cell}.

☒ **C** E_{cell} but not ΔS_{total}.

☒ **D** neither E_{cell} nor ΔS_{total}.

(Total for Question 1 mark)

24 Some fuel cells are used to produce energy from the combination of hydrogen and oxygen. The half-equations for a hydrogen-oxygen fuel cell in alkaline solution are

$$2H_2O(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq) \qquad E^{\ominus} \quad 0.83\ V$$

$$\tfrac{1}{2}O_2(g) + H_2O(l) + 2e^- \rightleftharpoons 2OH\ (aq) \qquad E^{\ominus} \quad +0.40\ V$$

(a) The equation for the cell reaction is

(1)

☒ **A** $3H_2O(l) + \tfrac{1}{2}O_2(g) \rightarrow H_2(g) + 4OH\ (aq)$

☒ **B** $H_2(g) + 4OH\ (aq) \rightarrow 3H_2O(l) + \tfrac{1}{2}O_2(g)$

☒ **C** $H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(l)$

☒ **D** $H_2O(l) \rightarrow H_2(g) + \tfrac{1}{2}O_2(g)$

(b) From the data above, E_{cell} for the reaction in the hydrogen-oxygen fuel cell is

(1)

☒ **A** 0.43 V

☒ **B** +0.43 V

☒ **C** 1.23 V

☒ **D** +1.23 V

(c) An advantage of operating a hydrogen fuel cell over a conventional jet engine for powering an aeroplane is

(1)

☒ **A** it is 100% efficient.

☒ **B** it does not produce greenhouse gas emissions.

☒ **C** it does not produce emissions which damage the ozone layer.

☒ **D** hydrogen is easier to transport.

(Total for Question 3 marks)

25 Which of these statements about a standard hydrogen electrode, for which $E^{\ominus}$ 0 V, is **not** correct?

☒ **A** The hydrogen gas is at a pressure of 1 atm.

☒ **B** A solution containing 1 mol dm^{-3} of $H^{+}(aq)$ ions is used.

☒ **C** A platinum electrode is used.

☒ **D** The temperature is kept at 20 °C.

(Total for Question 1 mark)

26 In the titration of iodine with standard sodium thiosulfate solution, starch is often used as an indicator. The starch should **not** be added until nearly all the iodine has reacted because

☒ **A** it is decomposed by high concentrations of iodine.

☒ **B** the blue complex formed is bleached by high concentrations of iodine.

☒ **C** the blue complex formed with high concentrations of iodine is insoluble and does not re-dissolve as more thiosulfate is added.

☒ **D** the starch reacts with the thiosulfate ions being added.

(Total for Question = 1 mark)

27 The conditions needed for the $E^{\ominus}$ value of the standard hydrogen electrode to be exactly 0 V are

☒ **A** 1 mol dm^{-3} solution of hydrogen ions, 1 atm pressure of hydrogen, 25 °C.

☒ **B** 1 mol dm^{-3} solution of hydrogen ions, 1 atm pressure of hydrogen, room temperature.

☒ **C** 1 mol dm^{-3} solution of hydrogen ions, laboratory pressure of hydrogen, 25 °C.

☒ **D** 0.1 mol dm^{-3} solution of hydrogen ions, 1 atm pressure of hydrogen, 25 °C.

(Total for Question = 1 mark)

28 The electrode potential for a cell can be used to calculate the equilibrium constant for the cell reaction. This is because

☒ **A** $E^{\ominus}_{cell}$ is proportional to $\ln K$.

☒ **B** $E^{\ominus}_{cell}$ is proportional to K.

☒ **C** $\ln E^{\ominus}_{cell}$ is proportional to $\ln K$.

☒ **D** $\ln E^{\ominus}_{cell}$ is proportional to K.

(Total for Question = 1 mark)

29 The reaction between iron and nickel(II) sulfate may be represented by the ionic equation

$$Ni^{2+}(aq) + Fe(s) \rightarrow Ni(s) + Fe^{2+}(aq)$$

(a) This reaction is classified as a redox reaction because

(1)

☒ **A** the nickel(II) ions are oxidized and iron acts as an oxidizing agent.

☒ **B** the nickel(II) ions are oxidized and iron acts as a reducing agent.

☒ **C** the nickel(II) ions are reduced and iron acts as a reducing agent.

☒ **D** the nickel(II) ions are reduced and iron acts as an oxidizing agent.

(b) This reaction proceeds spontaneously, therefore

(1)

☒ **A** E_{cell} and ΔS_{total} for this reaction must both be positive.

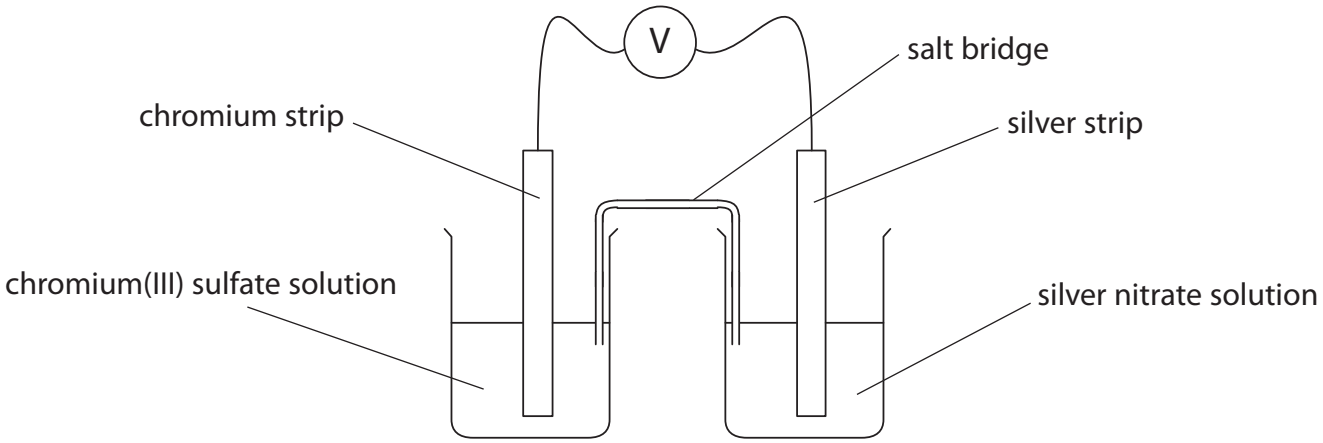
☒ **B** E_{cell} and ΔS_{total} for this reaction must both be negative.

☒ **C** E_{cell} for this reaction must be positive and ΔS_{total} negative.

☒ **D** E_{cell} for this reaction must be negative and ΔS_{total} positive.

(Total for Question = 2 marks)

30 The diagram below shows an electrochemical cell.



(a) The salt bridge in this cell is **best** prepared by soaking filter paper in a

(1)

☒ **A** 1 mol dm^{-3} solution of potassium bromide.

☒ **B** 1 mol dm^{-3} solution of potassium chloride.

☒ **C** saturated solution of potassium nitrate.

☒ **D** saturated solution of potassium iodide.

(b) The relevant standard electrode potentials for this cell are shown below.

$$Cr^{3+}(aq) + 3e^- \rightleftharpoons Cr(s) \quad E^{\ominus} = -0.74\ V$$

$$Ag^{+}(aq) + e^- \rightleftharpoons Ag(s) \quad E^{\ominus} = +0.80\ V$$

The emf of the cell shown in the diagram is

(1)

☒ **A** +1.54 V

☒ **B** −1.54 V

☒ **C** +0.06 V

☒ **D** −0.06 V

(c) The mass of 1 mol of chromium(III) sulfate ($Cr_2(SO_4)_3$) is 392 g. Hence, for the cell in the diagram to measure the **standard** electrode potential, 1 dm^3 of the chromium(III) sulfate solution used must contain

(1)

☒ **A** 104 g of chromium(III) sulfate.

☒ **B** 196 g of chromium(III) sulfate.

☒ **C** 392 g of chromium(III) sulfate.

☒ **D** 784 g of chromium(III) sulfate.

(Total for Question = 3 marks)

31 The reaction betwee brium.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

(a) Which of these statements about a dynamic equilibrium is **not** true?

(1)

☒ **A** The forward rate of reaction is equal to the backward rate of reaction.

☒ **B** The concentrations of the products and reactants do not change.

☒ **C** The concentrations of the products and reactants are equal.

☒ **D** The equilibrium can be approached from either direction.

(b) The K_c expression for the above reaction is

(1)

☒ **A** $K_c = \dfrac{[CH_3OH]}{[CO] \times [H_2]^2}$

☒ **B** $K_c = \dfrac{[CO] \times 2[H_2]}{[CH_3OH]}$

☒ **C** $K_c = \dfrac{[CO] \times [H_2]^2}{[CH_3OH]}$

☒ **D** $K_c = \dfrac{[CH_3OH]}{[CO] \times 2[H_2]}$

(Total for Question 2 marks)

32 Hydrogen and iodine, both with an initial concentration of 0.010 mol dm^{-3}, were allowed to react. At equilibrium, the concentration of hydrogen iodide was 0.0030 mol dm^{-3}.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

K_c is calculated using the values

		$H_2(g)$ / mol dm^{-3}	$I_2(g)$ / mol dm^{-3}	$HI(g)$ / mol dm^{-3}
☒	**A**	0.0070	0.0070	0.0030
☒	**B**	0.0040	0.0040	0.0030
☒	**C**	0.0040	0.0040	0.0060
☒	**D**	0.0085	0.0085	0.0030

(Total for Question 1 mark)

33 The reaction below reached a dynamic equilibrium from an initial mixture of all four substances P, Q, R and S in aqueous solution.

$$P + Q \rightleftharpoons R + S$$

The following data were obtained.

Substance	Concentration at equilibrium / mol dm ^{3}
P	0.050
Q	0.040
R	0.020
S	0.010

K_c for the equilibrium is

☒ **A** 0.10

☒ **B** 0.33

☒ **C** 3.00

☒ **D** 10.0

(Total for Question 1 mark)

34 The Haber process is used to make ammonia from nitrogen and hydrogen at 450 °C.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H \quad 92.0 \text{ kJ mol}^{-1}$$

(a) If the partial pressures of these gases were measured in atm, the units of the equilibrium constant K_p will be

(1)

☒ **A** atm

☒ **B** atm^2

☒ **C** atm^{-2}

☒ **D** atm^{-1}

(b) When the temperature of the system is increased

(1)

☒ **A** K_p decreases.

☒ **B** K_p increases.

☒ **C** K_p stays the same.

☒ **D** K_p first decreases and then increases.

(Total for Question 2 marks)

35 An electrochemical cell consists of a standard hydrogen electrode and a $Cu^{2+}(aq)|Cu(s)$ electrode which uses copper(II) sulfate solution. Which one of the following does **not** affect the e.m.f. of the cell?

☒ **A** The volume of the copper(II) sulfate solution.

☒ **B** The temperature.

☒ **C** The pressure of the hydrogen.

☒ **D** The concentration of the copper(II) sulfate solution.

(Total for Question 1 mark)

36 Which answer corresponds to the correct value of $E^{\ominus}_{cell}$ for the oxidation of hydrogen peroxide by manganate(VII) ions? The half-reactions are

$$2H^+ + O_2 + 2e \rightleftharpoons H_2O_2 \qquad E^{\ominus} \quad + 0.68 \text{ V}$$

$$MnO_4^- + 8H^+ + 5e \rightleftharpoons Mn^{2+} + 4H_2O \qquad E^{\ominus} \quad + 1.51 \text{ V}$$

The overall equation is

$$2MnO_4^- + 6H^+ + 5H_2O_2 \rightleftharpoons 2Mn^{2+} + 8H_2O + 5O_2$$

☒ **A** $E^{\ominus}_{cell}$ + 2.19 V

☒ **B** $E^{\ominus}_{cell}$ 0.83 V

☒ **C** $E^{\ominus}_{cell}$ 0.38 V

☒ **D** $E^{\ominus}_{cell}$ + 0.83 V

(Total for Question 1 mark)

37 Hydrogen peroxide, H_2O_2, can be analysed by titration. The hydrogen peroxide solution is treated with acidified potassium iodide solution, and the liberated iodine is titrated with a standard solution of sodium thiosulfate, $Na_2S_2O_3$. The products are iodide ions and tetrathionate ions, $S_4O_6^{2-}$.

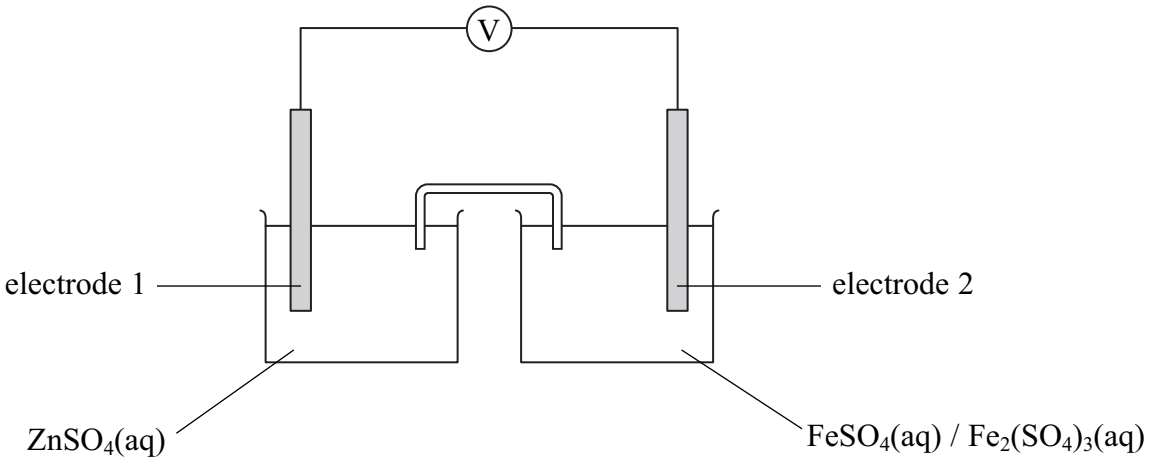
Which of the following applies to this reaction?

		Action of H_2O_2	Action of $S_2O_3^{2-}$
☒	**A**	oxidizing agent	oxidizing agent
☒	**B**	oxidizing agent	reducing agent
☒	**C**	reducing agent	oxidizing agent
☒	**D**	reducing agent	reducing agent

(Total for Question 1 mark)

38 The apparatus below can be used to measure the value of E_{cell} for the reaction

$$2Fe^{3+}(aq) + Zn(s) \rightarrow 2Fe^{2+}(aq) + Zn^{2+}(aq)$$



The electrodes are:

		electrode 1	electrode 2
☒	**A**	zinc	iron
☒	**B**	iron	zinc
☒	**C**	zinc	plat
☒	**D**	platinum	platinum

(Total for Question 1 mark)

39 Copper reacts with silver ions according to the reaction below.

$$Cu(s) + 2Ag^{+}(aq) \rightarrow Cu^{2+}(aq) + 2Ag(s)$$

$E^{\ominus}_{cell}$ for this reaction is

☒ **A** +0.46 V

☒ **B** +1.14 V

☒ **C** +1.26 V

☒ **D** +1.94 V

(Total for Question 1 mark)

40 $E^{\ominus}_{cell}$ for four reactions are shown in the table below.

	$E^{\ominus}_{cell}$ / V
Reaction 1	+1.10
Reaction 2	+0.65
Reaction 3	+0.10
Reaction 4	1.30

Which reaction

(a) is thermodynamically not feasible?

(1)

☒ **A** Reaction 1

☒ **B** Reaction 2

☒ **C** Reaction 3

☒ **D** Reaction 4

(b) has the largest value for ln *K*?

(1)

☒ **A** Reaction 1

☒ **B** Reaction 2

☒ **C** Reaction 3

☒ **D** Reaction 4

(Total for Question 2 marks)