

1. (a) The emf of a half-cell measured relative to the standard hydrogen electrode (1)
 all solutions at 1 mol dm^{-3} concentration and gases at 1 atm pressure / 101 kPa
 and at a stated temperature / 298K (1) *Standalone mark*
 ALLOW pressure of 100 kPa 2
- (b) Introducing another metal wire would set up its own p.d. / can
 only measure a potential difference / need source and sink for
 electrons / voltmeter requires two connections 1
- (c) (i) $2\text{Fe}(s) + \text{O}_2(g) + 2\text{H}_2\text{O}(l) \rightarrow 2\text{Fe}^{2+}(\text{aq}) + 4\text{OH}^-(\text{aq})$ or multiples
 OR
 $2\text{Fe}(s) + \text{O}_2(g) + 2\text{H}_2\text{O}(l) \rightarrow 2\text{Fe}(\text{OH})_2(s)$
 Species (1)
 balancing (1)
 Do not allow species mark if electrons still in equation, but allow
 balancing mark if 4e on both sides 2
- (ii) $\Delta E^\ominus_{\text{react}} = (+) 0.84 \text{ (V)}$ (1)
 Greater than zero therefore feasible (1) 2
- QWC (iii) Zn oxidises preferentially to Fe / Zinc acts as sacrificial (anode) (1)
 If Sn used (and damaged), Fe oxidises; preferentially (1)
 Disallow “oxidises more readily”
 $E^\ominus \text{Zn}^{2+} / \text{Zn}$ more negative than for Fe
 OR
 $E^\ominus \text{Zn} / \text{Zn}^{2+}$ more positive than for Fe
 OR
 E^\ominus_{cell} for Zn being oxidised by O_2 is more positive than for Fe
 being oxidised by O_2
 OR
 similar E^\ominus arguments related to preferential oxidation with Sn (1)
 disallow “higher” or “bigger” for more negative or more positive 3
2. (a) $3\text{OCl}^- \rightarrow 2\text{Cl}^- + \text{ClO}_3^-$ (1)
 chlorine (in OCl^-) is (simultaneously) oxidised from +1 to +5 (1)
 and reduced from +1 to -1 (1)
 If only oxidation numbers given max 1 (out of 2)
 If oxidation numbers omitted max 1 (out of 2) 3
- (b) (i) blue / black to colourless 1

[10]

- (ii) no. moles $\text{S}_2\text{O}_3^{2-}$ used = $12.5 \times 0.1 / 1000 = 1.25 \times 10^{-3}$ (1)
 no. moles $\text{I}_2 = 1.25 \times 10^{-3} / 2 = 6.25 \times 10^{-4}$ (1)
 no. moles $\text{ClO}^- = \text{no. moles } \text{I}_2$ (1)
 no. moles ClO^- in original $10 \text{ cm}^3 = 10 \times 6.25 \times 10^{-4}$
 $= 6.25 \times 10^{-3}$ (1)
 no. moles ClO^- in $1 \text{ dm}^3 = 100 \times 6.25 \times 10^{-3}$ (1) = 0.625 5

- (iii) mass $\text{Cl}_2 = 0.625 \times 71$
 $= 44.4 \text{ (g)}$
mark consequentially on (ii)
must be 3s.f. in final answer 1

- (c) Cl_2 is the stronger oxidising agent because Cl_2 oxidises S from (+)2 to (+)6 (1)
 but I_2 oxidises S from (+)2 to (+)2.50 (1) 2

- QWC (d) O_2 oxidises KI / iodide to I_2 , or balanced equation (1)
 I_2 reacts with starch / paper to give blue / black (1) 2

[14]

3. (a) C_{10}H_8
 ALLOW $(\text{C}_5\text{H}_4)_2$
 NOT $(\text{C}_6\text{H}_4)_2$ 1

- (b) (i) -600
 NOT + 600
 NOT 600 1

- (ii) Naphthalene is more/very stable than double bonds suggest (1)
Must be a comparison for the 1st mark
 Therefore the electrons/bonds may be/are delocalised
 (over the ring system)
 OR it is a delocalised system (1)
 No TE from (i)
 Delocalised mark can be given if delocalisation mentioned in (iii) 2

- (iii) No
because it is likely to react like benzene / delocalised structure /
no double bonds
OR bromine not a strong enough electrophile without a catalyst
OR "yes but only if **bromine** [NOT bromine solution] and a catalyst" 1
- (c) (i) Reagent
2-chloropropane (1)
ALLOW 1-chloropropane OR other halogenopropanes
NOT chloropropane
NOT bromo-2-propane

ALLOW formula with or without non-systematic name
ALLOW $\text{ClCH}(\text{CH}_3)_2$ OR $(\text{CH}_3)_2\text{CHCl}$ OR $\text{C}(\text{CH}_3)_2\text{HCl}$ OR $\text{ClC}(\text{CH}_3)_2\text{H}$

Catalyst
aluminium chloride / $\text{AlCl}_3/\text{Al}_2\text{Cl}_6$
OR aluminium bromide / AlBr_3
OR iron(III) chloride/ FeCl_3 (1)
NOT $\text{AlCl}_4^{(-)}$
NOT "iron" on its own

If both correct but wrong way round **1 (out of 2)** 2
- (ii) electrophilic (1)
substitution (1)
Can be given in any order
Mark independently 2

[9]

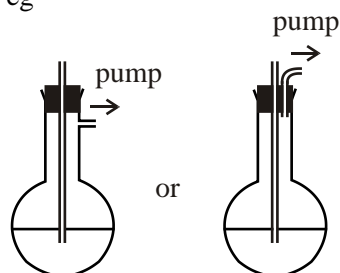
4. (a) (i) **EITHER**
 $\Delta E^\theta = (+) 0.15 \text{ (V)}$ OR $E^\theta (\text{MnO}_4^- / \text{Mn}^{2+})$ more positive or
greater than E^θ
($\text{Cl}_2 / \text{Cl}^-$); accept reverse argument (1)
(so) MnO_4^- reacts with Cl^- OR Cl^- ions form Cl_2
OR KMnO_4 reacts with HCl (1)
OR
 $2\text{MnO}_4^- + 16\text{H}^+ + 10\text{Cl}^- \rightarrow 2\text{Mn}^{2+} + 8\text{H}_2\text{O} + 5\text{Cl}_2$ (1)
 $E^\theta = (+) 0.15 \text{ (V)}$ (1) 2
- (ii) stated colour change of colourless to (pale) pink NOT purple OR
stays (pale) pink
OR pink to colourless
OR first excess of (coloured) manganate((VII))
IGNORE "self-indicating"
IGNORE references to Mn^{2+} 1

- (b) (i) (Multiply iron half-equation by five to) cancel out electrons
OR balance electrons 1
- (ii) Moles $\text{MnO}_4^- = \frac{0.0200 \times 20.10}{1000}$
 $= 0.000402 \text{ mol MnO}_4^-$ (1)
- Moles Fe^{2+} per $25.0 \text{ cm}^3 = 5 \times 0.000402$
 $= 0.00201 \text{ mol Fe}^{2+}$ (1)
- Moles Fe^{2+} per $200 \text{ cm}^3 = 0.00201 \times \frac{200}{25} \text{ mol Fe}^{2+}$
 $= 0.01608 \text{ mol Fe}^{2+}$ (1)
- Mass of $\text{FeSO}_4 \cdot 7\text{H}_2\text{O} = 0.01608 \times 278$
 $= 4.47 \text{ g or via concentrations}$ (1)
- Percentage purity $= \frac{4.47}{6.00} \times 100\%$
 $= 74.5\%$ (1) ALLOW 74.7% / 75%
- Correct answer + working* (5)
 ALLOW 2 or more sig figs
 If start by dividing $\frac{6.00}{278}$, and final answer is **incorrect**, candidate can
 access first three marks only.
 If third step omitted, answer 9.3% OR 9.33% OR 9.4% 5
- (c) (i) $E^\theta = +1.46 - (-0.13) = (+) 1.59 \text{ (V)}$
 Correct answer alone (1) 1
- (ii) PbSO_4 precipitated (1)
 $[\text{H}^+_{(\text{aq})}]$ not 1 mol dm^{-3} (1)
 $[\text{Pb}^{2+}_{(\text{aq})}]$ not 1 mol dm^{-3} (1)
 the conditions (in the car battery) are not standard (1) } any of these
- “temperature non-standard” alone or “not 1 atm pressure”
 alone does not score 1
- [11]**
5. (a) (i) Add silver nitrate (solution) (1) **ACCEPT** correct formula
 (pale) yellow **precipitate**/solid(1)
 OR
 Add chlorine (solution)/bromine (solution) **and** hydrocarbon solvent (1)
 Solvent goes purple/pink/violet (1)
 2nd mark is dependent on 1st 2
- (ii) Iodine / I and sulphur / S identified (1) -NOT I_2 / I^- / iodide
Iodine

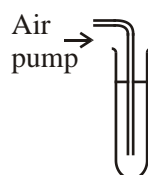
- initial (+)5 final -1 **(1)**
Sulphur
 initial (+)4 final (+)6 **(1)**
ACCEPT as roman numerals
ACCEPT +/- on either side/sub or superscript
ACCEPT as words 3
- (iii) $1 \times -6 = -6$, $3 \times +2 = +6$ *ALLOW TE from (ii)*
OR total change in oxidation number of +6 for S, -6 for I
ACCEPT justification in terms of electrons 1
- (b) (i) pipette
ALLOW burette
NOT measuring cylinder 1
- (ii) Starch (solution) **(1)**
 blue/dark blue/blue-black/black to colourless **(1)**
ALLOW max 1 if candidate states “no indicator needed/self-indicating”
with colour change brown/yellow to colourless
If no indicator given but correct colour change 1 (out of 2) 2
- (iii) $\frac{24.0}{1000} \times 2.4(0) \times 10^{-4}$ *OR* 0.00024 (mol)
The mark is for the answer 1
- (iv) $\frac{2.40 \times 10^{-4}}{2} = 1.2(0) \times 10^{-4}$ (mol) *OR* 0.00012 (mol)
ALLOW TE from (iii)
The mark is for the answer 1
- (v) $1.2 \times 10^{-4} \times 100 = 0.012(0)$ (mol dm⁻³)
ALLOW TE from (iv)
The mark is for the answer 1

[12]

6. (i) (Buchner) flask / boiling tube connected to pump, glass tube through stopper into solution
eg



ACCEPT



But must be a test tube and tube to bottom as shown

1

- (ii) $8\text{H}^+ \quad 4\text{H}_2\text{O}$
ACCEPT multiples

1

- (iii) Number of moles of manganate(VII) ion

$$= \frac{20 \times 0.020}{1000} = 0.0004 \text{ (0) (1)}$$

Number of moles of electrons

$$= 5 \times 0.00040 = 0.002 \text{ (0) (1)}$$

Number of moles of vanadium ions

$$= \frac{10 \times 0.10}{1000} = 0.001 \text{ (1)}$$

(as vanadium(V) is formed by loss of 2 moles of electrons)

Oxidation number of vanadium in aerated solution is +3 (1)

4

- (iv) It is a powerful oxidising agent, $E^\ominus = +1.51 \text{ V}$

OR

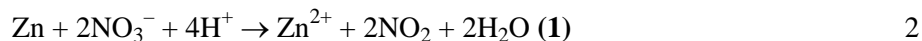
It is self-indicating

1

[7]

7. (a) (i) uses E^\ominus values to find $E_{\text{reaction}} = (+) 1.57 \text{ (V)}$ (1)

Reject - 1.57



Accept equation with equilibrium sign

Rejection equation with Zn on the right

- (ii) E_{reaction} for the production of hydrogen is (+) 0.76 (V) (1)

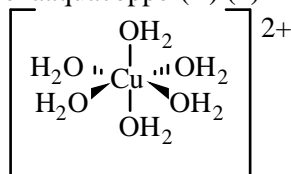
smaller than reaction in (i) so is less likely (1)

OR

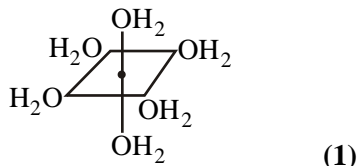
NO_3^- being the oxidised form of a redox couple with a more positive E^\ominus than $E^\ominus \text{H}^+ / \frac{1}{2} \text{H}_2$ (1)

is a stronger oxidising agent than H^+ (1) 2

- (iii) hexaaquacopper(II) (1)



OR



Both marks stand alone

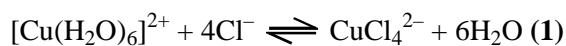
[IGNORE charge]

[IGNORE how H_2O ligand is bonded to central cation] 2

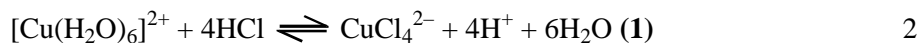
Accept hexaquacopper(II)

Reject formula

- (iv) **ligand** exchange/replacement/substitution (1)



OR



ALLOW →

Accept $\text{H}_2\text{CuCl}_4 + 2\text{H}^+$ for $\text{CuCl}_4^{2-} + 4\text{H}^+$

- (b) (i) E^\ominus for the reaction is -0.39 (V) (so not feasible) [value is required]. 1
Accept Cu^{2+} being the oxidised form of the redox couple with the more negative E^\ominus , will not oxidise I^-
- (ii) CuI is a solid (so conditions are not standard) (1)
 Equilibrium is pulled over/moves to favour the r.h.s. (1) 2
Reject just 'conditions not standard'
- (iii) $[\text{Cu}(\text{NH}_3)_4]^+$
 OR $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^+$ 1
Accept $[\text{Cu}(\text{NH}_3)_2]^+$
Reject $[\text{Cu}(\text{NH}_3)_6]^+$
Reject any 2+ complex
- (iv) (atmospheric) oxygen (1)
 oxidises Cu^+ to Cu^{2+} (1) 2
Reject air for oxygen
- (c) (i) starch (1)
 blue-black/blue/black to colourless (1) 2
Reject clear for colourless
- (ii) (If added too early) insoluble complex/black solid formed, making titre too low
 OR (If added too early) insoluble complex/black solid formed, removes iodine from solution
 OR (If added too early) insoluble complex/black solid formed, causes inaccurate titre.
 OR (If added too early) insoluble complex/black solid formed, not all the iodine is titrated. 1

- (iii) Amount thiosulphate = $0.01655 \text{ dm}^3 \times 0.1 \text{ mol dm}^{-3}$ (1)
 = amount Cu^{2+} in $25.0 \text{ cm}^3 = 1.655 \times 10^{-3} \text{ mol}$ (1)
 amount of Cu^{2+} in $250 \text{ cm}^3 = 1.655 \times 10^{-3} \times 10$ (1)
 mass of Cu (in sample) = $1.655 \times 10^{-2} \times 63.5$ (1) = 1.051 g
 % Cu in brass = $1.051 \times 100/1.5 = 70 \%$ (1)
 [IGNORE sf]
 [mass of 1.051g with working scores (4);
 correct answer with no working scores (3).]
 Mark consequentially

5

[22]

8. (a) $3d^{10}4s^1$ and $3d^{10}$ 1

Accept $4s^1 3d^{10}$

- (b) (i) QWC*

the (3)d sub-shell is full (1)

Accept orbitals (it must be plural) for sub-shell

Reject comments on partially filled sub-shell

so no d-d transitions are possible

OR no transitions in the right energy range are possible (1)

(and no light is absorbed)

Any mention of light emission loses 2nd mark

2

- (ii) combine the half-reactions to get $2\text{Cu}^+ \rightarrow \text{Cu}^{2+} + \text{Cu}$ (1)
 IGNORE state symbols

and show that E^\ominus for this is (+) 0.37 (V) (and as it is positive it is feasible) (1)

conditional on correct reaction

2

Reject just '> 0.3 (V)'

- (iii) activation energy (for the disproportionation) is high
 OR

Cu^+ is kinetically stable

1

Reject activation energy for one of the half-equations is too high

- (c) (i) divides each by atomic mass (1)
divides by smallest to obtain $\text{Cu}_2\text{SO}_6\text{H}_2$ (1) 2
Division by atomic number scores zero
- (ii) $\text{CuSO}_4 \cdot \text{Cu}(\text{OH})_2$ (2)
If formula wrong but sulphate/ SO_4 is present scores 1 (out of 2) 2
Accept $\text{Cu}_2\text{SO}_4(\text{OH})_2$
Accept $\text{Cu}_2(\text{OH})_2\text{SO}_4$
Accept $(\text{CuOH})_2\text{SO}_4$
Reject HSO_4 instead of SO_4
- (iii) $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ 1
Accept $[\text{Cu}(\text{NH}_3)_4]^{2+}$
Reject $[\text{Cu}(\text{NH}_3)_6]^{2+}$
- (iv) ligand exchange / ligand substitution 1
- (d) (i) QWC
(add aldehyde to 2,4-DNP) to obtain precipitate/ppt/solid/crystals (1)
recrystallise derivative (1)
determine melting temperature of derivative (1)
compare with data tables (1) 4th mark conditional on melting
temperature of a derivative being measured 4
*Reject any identification method based on IR, NMR or mass for
last 2 marks*
- (ii) the aldehyde is distilled off as it is formed 1
Reject any mention of reflux
Reject just 'the aldehyde is distilled off'
- (iii) propanoic acid OR $\text{CH}_3\text{CH}_2\text{COOH}$ OR $\text{CH}_3\text{CH}_2\text{CO}_2\text{H}$ 1
Accept C_2H_5 for CH_3CH_2

- (iv) No (extra) oxygen present
 OR catalyst specific to formation of aldehyde / only lowers E_a of first oxidation
 OR presence of hydrogen gives reducing conditions
 OR copper is not an oxidising agent
 OR aldehydes rapidly leave catalyst surface 1
- (v) (At high pressure) all active sites are occupied/full
 OR
 (At higher pressures) rate controlled by availability of sites. 1
Accept reverse argument for low pressure

[20]

9. (a) (i) Cr: $[\text{Ar}] 3d^5 4s^1$
 Cu: $[\text{Ar}] 3d^{10} 4s^1$
Both needed for the mark 1
Accept $4s^1 3d^5$
Accept $4s^1 3d^{10}$
Accept [Ar] written in full
- (ii) all the others are $4s^2$ / have full 4s orbital (1)
Accept Cr and Cu/they do not have a full 4s orbital
Reject just 'only have one electron in 4s'
 OR
Have incomplete 4s orbital
- The d subshell is more stable when either half or fully filled
 OR
 A specific example of chromium having half-filled or copper having filled d sub-shell/set of d orbitals which is more stable (1) 2
Accept sub-energy levels d shell
Reject half-filled or filled d orbital(s)
- (b) (i) Octahedral drawn must be 3-D
 IGNORE any or no charge 1
Accept $-\text{H}_2\text{O}$ (bond to H) except on water molecules on left of Cr

- (ii) Dative bond formed from electron pair/lone pair on oxygen
(of the water molecule) to the ion
This could be shown on a diagram 1
Accept a clear description of the dative bond
Reject 'dative' alone or from water
Reject just "dative bond formed from oxygen"
- (iii) $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + \text{OH}^- \rightarrow [\text{Cr}(\text{H}_2\text{O})_5\text{OH}]^{2+} + \text{H}_2\text{O}$
OR
 $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 2\text{OH}^- \rightarrow [\text{Cr}(\text{H}_2\text{O})_4(\text{OH})_2]^+ + 2\text{H}_2\text{O}$
OR
 $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{OH}^- \rightarrow \text{Cr}(\text{OH})_3 + 6\text{H}_2\text{O}$
OR
 $[\text{Cr}(\text{H}_2\text{O})_6]^{3+} + 3\text{OH}^- \rightarrow [\text{Cr}(\text{H}_2\text{O})_3(\text{OH})_3] + 3\text{H}_2\text{O}$
First mark is for the correct Cr product
Second mark is conditional on the first and is for the rest
of the equation correct and balanced 2
- (iv) Forms a green precipitate (**1**)
IGNORE initial colour of solution
(which reacts or dissolves or changes to)
a **green solution** (with excess reagent) (**1**)
Accept any shade of green
2nd mark is conditional on an initial ppt 2
- (v) acid / acidic 1
Accept amphoteric/able to be deprotonated
*Reject coloured ions/ligand exchange/ deprotonation /partially
filled d orbitals*

- (c) (i) **Check working – correct answer can be obtained by not dividing by 2 for 2nd mark and not multiplying by 2 for 4th mark**

$$\begin{aligned} \text{amount thiosulphate in titre} &= 0.0372 \text{ dm}^3 \times 0.100 \text{ mol dm}^{-3} \\ &= 3.72 \times 10^{-3} \text{ mol (1)} \end{aligned}$$

$$\text{amount I}_2 = \frac{3.72 \times 10^{-3}}{2} \text{ (1)} = 1.86 \times 10^{-3} \text{ mol}$$

2nd mark cq on amount thiosulphate

$$\begin{aligned} \text{amount dichromate in } 25 \text{ cm}^3 \\ = \frac{1.86 \times 10^{-3}}{3} \text{ (1)} = 6.2 \times 10^{-4} \text{ mol} \end{aligned}$$

3rd mark cq on amount I₂

$$\begin{aligned} \text{Total mass Cr} &= 6.2 \times 10^{-4} \text{ mol} \times 2 \times 10 \times 52 \text{ g mol}^{-1} \text{ (1)} \\ &= 0.645 \text{ g} \end{aligned}$$

4th mark cq on amount dichromate

$$\% \text{ of Cr} = 64.5 \% \text{ (1)}$$

IGNORE SF unless rounded to 1 SF cq on mass Cr, provided less than 1 g

Accept 64.48 %

OR

$$\begin{aligned} \text{amount thiosulphate for whole sample} \\ &= 0.0372 \text{ dm}^3 \times 0.100 \text{ mol dm}^{-3} \times 10 \\ &= 3.72 \times 10^{-2} \text{ mol (1)} \end{aligned}$$

$$\text{amount I}_2 = 1.86 \times 10^{-2} \text{ mol (1)}$$

$$\text{amount dichromate} = 6.2 \times 10^{-3} \text{ mol (1)}$$

$$\begin{aligned} \text{mass Cr} &= 6.2 \times 10^{-3} \text{ mol} \times 2 \times 52 \text{ g mol}^{-1} \text{ (1)} \\ &= 0.645 \text{ g} \end{aligned}$$

$$\% \text{ of Cr} = 64.5\% \text{ (1)}$$

IGNORE SF unless rounded to 1sf Mark consequentially, as above

Note:

Correct answer with no working (3)

5

- (ii) Colour at the end point would be green which would prevent the loss of iodine colour being seen

OR

colour change at end point would be disguised by the colour of Cr³⁺

1

Accept chromium instead of Cr³⁺

Reject end point disguised by colour of Cr₂O₇²⁻/orange

[16]

10. (a) MnO_4^- needs acid to be reduced to Mn^{2+} 1
- (b) 5 1
- (c) (i) 1.79×10^{-4} 1
- (ii) 1.79×10^{-4} mols of Fe^{2+} in one tablet
 \therefore mols of $\text{MnO}_4^- = \frac{1}{5} \times 1.79 \times 10^{-4}$ (1)
 0.01 mol in 1000 cm^3
 $\therefore \frac{1}{5} \times 1.79 \times 10^{-4}$ in $\frac{1000}{0.01} \times \frac{1.79 \times 10^{-4}}{5}$
 $= 3.58$
 $= 3.6 \text{ cm}^3$ (1) 2
- (iii) No, titration value too low
 Either: use more tablets
 Or: use more dilute solution of KMnO_4 1
- (d) QWC
 (It is acceptable because) well below the maximum safe limit (1)
 Not significantly different from recommended daily dose
 OR Variation in body mass means that different doses are acceptable
 OR only if max 1 tablet per day is written on the bottle (1) 2

[8]