

## Oxidation and Reduction (HL)

### Markscheme Notes:

1. A markscheme often has more marking points than the total allows. This is intentional. Do not award more than the maximum marks allowed for part of a question.
2. Each marking point has a separate line and the end is signified by means of a semicolon (;).
3. An alternative answer or wording is indicated in the markscheme by a slash (/) – either wording can be accepted.
4. Words in brackets ( ) in the markscheme are not necessary to gain the mark.
5. Words that are underlined are essential for the mark.
6. The order of marking points does not have to be as in the markscheme, unless stated otherwise.
7. If the candidate's answer has the same "meaning" or can be clearly interpreted as being of equivalent significance, detail and validity as that in the markscheme then award the mark. Where this point is considered to be particularly relevant in a question it is emphasized by writing **OWTTE** (or words to that effect).
8. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.
9. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should be awarded. Indicate this with **ECF** (error carried forward).
10. Only consider units at the end of a calculation. Unless directed otherwise in the markscheme, unit errors should only be penalized once in the paper. Indicate this by writing **-1(U)** at the first point it occurs and **U** on the cover page.
11. Significant digits should only be considered in the final answer. Deduct **1 mark in the paper** for an **error of 2 or more digits** unless directed otherwise in the markscheme.

*e.g.* if the answer is 1.63:

2	<i>reject</i>
1.6	accept
1.63	accept
1.631	accept
1.6314	<i>reject</i>

Indicate the mark deduction by writing **-1(SD)** at the first point it occurs and **SD** on the cover sheet.

12. If a question specifically asks for the name of a substance, do not award a mark for a correct formula, similarly, if the formula is specifically asked for, do not award a mark for a correct name.
13. If a question asks for an equation for a reaction, a balanced symbol equation is usually expected, do not award a mark for a word equation or an unbalanced equation unless directed otherwise in the markscheme.
14. Ignore missing or incorrect state symbols in an equation unless directed otherwise in the markscheme.

Answers:

1. A [1]
2. B [1]
3. *Dilute sodium chloride:*  
 $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^- / 4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-;$   
*Concentrated sodium chloride:*  
 $2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-;$  2  
*Accept alternative balanced half-equations with correct number of electrons.*  
*Award [1 max] if equations are given the wrong way round.*  
*Award [2] if correct equations are written in order with dilute sodium chloride first and concentrated sodium chloride second but processes not stated explicitly.*  
*Penalize once only.*  
*Allow e instead of e<sup>-</sup>.*  
*Ignore state symbols.* [2]
4. (i)  $\text{Sn} + \text{Cu}^{2+} \rightarrow \text{Sn}^{2+} + \text{Cu};$  1  
*Ignore state symbols.*  
*Penalize once only.*  
(ii)  $(0.34 - -0.14) = (+) 0.48 \text{ V};$  1  
(iii) 1.0 mol dm<sup>-3</sup> solutions **and** 25 °C/298 K; 1 [3]
5.  $\text{Cd}^{2+}$  is a stronger oxidizing agent than  $\text{H}_2\text{O}$  **and** will be displaced to produce Cd / OWTTE;  
 $\text{Cr}^{2+}$  is a weaker oxidizing agent than  $\text{H}_2\text{O}$  **and**  $\text{H}_2$  will displace in preference to Cr / OWTTE; 2  
*Award [1 max] for stating  $\text{Cd}^{2+}$  stronger oxidizing agent than  $\text{H}_2\text{O}$  **and**  $\text{Cr}^{2+}$  weaker oxidizing agent than  $\text{H}_2\text{O}$  / OWTTE.* [2]
6. (i) Ni;  
only requires 2 mol of e<sup>-</sup> for each mol of Ni / Sn requires 4 mol of e<sup>-</sup> / Cr requires 3 mol of e<sup>-</sup> / Ni<sup>2+</sup> needs least number of e<sup>-</sup> to produce 1 mol of Ni metal;  
*Allow e instead of e<sup>-</sup>.*  
cathode / negative electrode; 3  
*Do not award M3 for "metal deposited at cathode where oxidation occurs".*

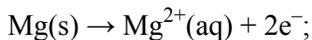
	(ii)	temperature of solution; [Sn <sup>4+</sup> ]; surface area/size of electrode; material of electrodes; <i>Do not allow nature of electrodes.</i>	2 max	<b>[5]</b>
7.	D			<b>[1]</b>
8.	B			<b>[1]</b>
9.	(i)	the potential difference/voltage obtained when a half-cell is connected to a standard hydrogen electrode; under standard conditions / 1.00 mol dm <sup>-3</sup> solutions, 298 K;	2	
	(ii)	the electrons flow from the half-cell to the standard hydrogen electrode / the half-cell forms the negative electrode when connected to the standard half-cell / Fe is a better reducing agent than H <sub>2</sub> / Fe is above H <sub>2</sub> in electrochemical series; <i>Accept "the half reaction is not spontaneous".</i>	1	<b>[3]</b>
10.	(i)	bromine/Br <sub>2</sub> ;	1	
	(ii)	hydrogen/H <sub>2</sub> ;	1	
	(iii)	iron/Fe; <i>Ignore coefficients for Br<sub>2</sub>, H<sub>2</sub> or Fe.</i>	1	<b>[3]</b>
11.	(i)	sodium is a very powerful reducing agent/high in electrochemical series; any chemical reducing agent would need to be even higher in ECS to reduce Na <sup>+</sup> / <i>OWTTE</i> ;	2 max	
	(ii)	H <sup>+</sup> ions gain electrons more readily than Na <sup>+</sup> / hydrogen is evolved instead; hydrogen is below Na in ECS; if sodium were to be formed it would react with the water in the solution / <i>OWTTE</i> ;	2 max	<b>[4]</b>
12.	D			<b>[1]</b>
13.	C			<b>[1]</b>

14. (a) (i)

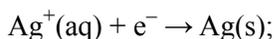
correctly labelled electrodes and solutions;  
labelled salt bridge;  
voltmeter;  
*Allow bulb or ammeter.*

direction of electron flow; 4

(ii) *Oxidation:*



*Reduction:*



*Ignore state symbols.*

*Award [1 max] if equations not labelled reduction or oxidation or labelled the wrong way round.*

*Allow e instead of e<sup>-</sup>.*

*Penalize equilibrium sign or reversible arrows once only.* 2

(iii)  $+0.80 - (-2.37) = 3.17 \text{ V}$

correct data;

answer with unit;

*Award [1] for  $-3.17 \text{ V}$  or correct working of wrong values.* 2

(b) (i) Cd/Cd(s);

*Do not allow Cd<sup>2+</sup>.* 1

(ii)  $5\text{Cd(s)} + 2\text{MnO}_4^{-}(\text{aq}) + 16\text{H}^{+}(\text{aq}) \rightarrow 5\text{Cd}^{2+}(\text{aq}) + 2\text{Mn}^{2+}(\text{aq}) + 8\text{H}_2\text{O(l)}$

correct reactants and products;

correct balancing of this equation;

*Ignore state symbols.* 2

(c) *Accept suitable diagram with the following indicated:*

Pt electrode;

$[\text{H}^{+}(\text{aq})] = 1 \text{ mol dm}^{-3} / 0.5 \text{ mol dm}^{-3} \text{ H}_2\text{SO}_4$ ;

H<sub>2</sub> gas;

at 1 atm /  $1.01 \times 10^5 \text{ Pa}$ ;

*Do not award mark for pressure if no hydrogen gas given.*

298 K / 25 °C;

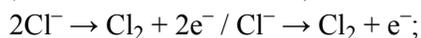
4 max

[15]

15. (i) sodium chloride crystals consist of ions in a (rigid) lattice / ions cannot move (to electrodes) / *OWTTE*; when melted ions free to move / ions move when potential difference/voltage applied; 2

(ii) positive sodium ions/ $\text{Na}^+$  move to the negative electrode/cathode **and** negative chloride ions/ $\text{Cl}^-$  move to the positive electrode/anode; electrons are released to positive electrode/anode by negative ions and accepted from negative electrode/cathode by positive ions / reduction occurs at the negative electrode/cathode **and** oxidation occurs at the positive electrode/anode /  $\text{Na}^+$  ions are reduced **and**  $\text{Cl}^-$  ions are oxidized;

*(Positive electrode/anode):*



*(Negative electrode/cathode)*



*Award [1 max] if equations not labelled or labelled wrong way round.*

*Allow e instead of  $\text{e}^-$ .*

*Penalize equilibrium sign or reversible arrows once only.* 4

(iii) *Products:*  
oxygen at positive electrode **and** hydrogen at negative electrode;  
moles of Mg = 0.5 / mole ratio of  $\text{O}_2:\text{H}_2$  is 1:2;  
*Can be implied by calculation.*

mass oxygen = 8.00 g;

mass hydrogen = 1.01 g;

*Do not apply SD rule here.* 4

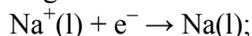
[10]

16. D

[1]

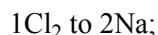
17. (i) Positive/+/anode  
 $2\text{Cl}^-(\text{l}) \rightarrow \text{Cl}_2(\text{g}) + 2\text{e}^-;$   
*Allow e instead of  $\text{e}^-$ .*

Negative/-/cathode



*Penalize missing or incorrect states such as (aq) or (s) once only.*

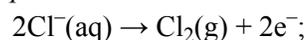
*Award only [1] if electrodes not specified or if equations switched.*



3

- (ii) (choice of  $\text{Cl}^-$  or  $\text{H}_2\text{O}/\text{OH}^-$  to be oxidized),  $\text{Cl}^-$  oxidized because of concentrated solution/higher concentration / *OWTTE*;  
 (choice of  $\text{Na}^+$  or  $\text{H}_2\text{O}/\text{H}^+$  to be reduced),  $\text{H}_2\text{O}/\text{H}^+$  reduced because  $\text{Na}^+$  is a (much) weaker oxidizing agent /  $\text{Na}^+$  not reduced to Na in water /  $\text{H}^+$  easier to reduce than  $\text{Na}^+$  / *OWTTE*;

*positive/+ / anode*



*negative/- / cathode*



*Penalize missing or incorrect states once only.*

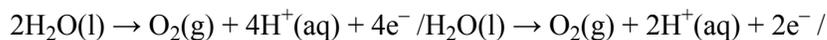
*Award only [1] out of the last two marks if electrodes not specified or if equations switched.*

*Allow e instead of  $\text{e}^-$ .*

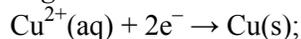
4

[7]

18. *Positive/+ / anode*



*Negative/- / cathode*



*Ignore state symbols.*

*Award only [1] if electrodes not specified or if equations switched.*

*Allow e instead of  $\text{e}^-$ .*

*Observations: [2 max]*

blue colour of  $\text{Cu}^{2+}(\text{aq})$   fades;

Cu/metal deposited on negative/- / cathode/tin (jewelry);

gas produced/bubbles formed (at positive/+ / anode);

pH of solution decreases/acidity increases (observed with indicator/pH paper);

4 max

[4]

19. B

[1]

20. A

[1]

21. C

[1]

22. (i) contains ions which are free to move (only) in molten state;  
 $\text{Mg}^{2+}$  move to cathode/negative electrode and  $\text{Cl}^-$  move to anode/positive electrode / *OWTTE*; 2
- (ii) anode/positive electrode;  
 $2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^- / \text{Cl}^- \rightarrow \text{Cl}_2 + \text{e}^-$ ;  
*Accept e instead of  $\text{e}^-$ .*  
*Do not accept  $\text{Cl}^- \rightarrow \text{Cl} + \text{e}^-$ .*  
*Ignore state symbols.* 2
- (iii) magnesium has large negative electrode potential /  $E^\ominus$ ;  
reduction of  $\text{H}_2\text{O}/\text{H}^+$  to  $\text{H}_2$  has less negative electrode potential;  
 $\text{Mg}^{2+}$  not readily reduced (in comparison to  $\text{H}_2\text{O}$ );  
if formed, magnesium would (immediately) react with water to form  $\text{Mg}^{2+}$ ;  
magnesium more reactive than hydrogen;  
*Do not accept Mg too reactive.* 1 max [5]
23. B [1]
24. B [1]
25. (i) the voltage obtained when the half-cell is connected to the standard hydrogen electrode;  
under standard conditions of 298 K **and** 1 mol dm<sup>-3</sup> solutions;  
electrons flow (in the external circuit) from the half-cell to the hydrogen electrode / the metal in the half-cell is above hydrogen in the ECS / Fe is a better reducing agent than  $\text{H}_2$  / Fe is oxidized more readily than  $\text{H}_2$ ; 3
- (ii) -0.28 V; 1
- (iii)  $\text{Co}^{2+}$ /cobalt(II) ion; 1
- (iv)  $2\text{Al} + 3\text{Fe}^{2+} \rightarrow 3\text{Fe} + 2\text{Al}^{3+}$ ;  
*Award [1] for correct reactants and products and [1] for correctly balanced, ignore states.*  
*Do not accept* 2
- (v) to complete the electrical circuit / *OWTTE*;  
by allowing the movement of ions; 2
- [9]

26. (a) (i) diagram to show:  
 battery/source of electricity connected to two electrodes in the solution with positive and negative electrodes correctly labelled;  
 electrons/current flowing from the cell to the negative electrode;  
 labelled solution of sodium chloride;  
*If the connecting wires to electrodes are immersed in the solution [1 max].* 3
- (ii)  $\text{Na}^+$ ,  $\text{H}^+/\text{H}_3\text{O}^+$ ,  $\text{Cl}^-$ ,  $\text{OH}^-$   
*All four correct [2], any three correct [1].* 2 max
- (iii) hydrogen at (-)/cathode **and** oxygen at (+)/anode;  
 $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$  /  $2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$ ;  
 $4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$  /  $2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4\text{e}^-$ ;  
*Accept e instead of e<sup>-</sup>*  
*If electrodes omitted or wrong way round [2 max].* 3
- (iv) Ratio of  $\text{H}_2:\text{O}_2$  is 2:1; 1
- (b) (i) (-)/(cathode)  $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$  /  $2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$ ;  
 (+)/(anode)  $2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-$ ;  
*Accept e instead of e<sup>-</sup>.*  
*If electrodes omitted or wrong way round [1 max]* 2
- (ii) (-)/(cathode)  $\text{Na}^+ + \text{e}^- \rightarrow \text{Na}$ ;  
 (+)/(anode)  $2\text{Br}^- \rightarrow \text{Br}_2 + 2\text{e}^-$ ;  
*Accept e instead of e<sup>-</sup>.*  
*If electrodes omitted or wrong way round [1 max].* 2
- [13]
27. C [1]
28. A [1]
29. B [1]
30. (i)  $2\text{Al}(\text{s}) + 3\text{Ni}^{2+}(\text{aq}) \rightarrow 2\text{Al}^{3+}(\text{aq}) + 3\text{Ni}(\text{s})$ ;  
*Correct reactants and products, award [1]*  
*Balancing award [1].*  
*Ignore state symbols and equilibrium sign.* 2

	(ii)	(+) 1.40 (V) $\text{Ni} \text{Ni}^{2+}$ ;	1	
	(iii)	aluminium anode/negative electrode; nickel cathode/positive electrode; electron movement from Al to Ni; correct movement of cations and anions through salt bridge; <i>If electron movement shown correctly but not labelled, award the mark</i>	4	[7]
31.	C			[1]
32.	A			[1]
33.	(a)	Pt electrode; $1 \text{ mol dm}^{-3} [\text{H}^+(\text{aq})]$ ; $\text{H}_2$ gas; at 1 atm/ $1.01 \times 10^5$ Pa; 298 K/25°C;	5	
		<i>Accept suitable labelled diagram with the above.</i>		
	(b)	electron acceptor; $\text{F}_2$ /fluorine;	2	
	(c)	(i) (+)0.48 (V);	1	
		(ii) $\text{Cu}^{2+}(\text{aq}) + \text{Sn}(\text{s}) \rightarrow \text{Sn}^{2+}(\text{aq}) + \text{Cu}(\text{s})$	2	
		<i>Award [1] for correct reactants and products from (c)(i), and [1] for state symbols.</i>		
				[10]