



# **MARKSCHEME**

**May 2014**

**CHEMISTRY**

**Higher Level**

**Paper 2**

16 pages

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## Subject Details: Chemistry HL Paper 2 Markscheme

### Mark Allocation

Candidates are required to answer **ALL** questions in Section A [**40 marks**] and **TWO** questions in Section B [**2 x 25 marks**]. Maximum total = [**90 marks**].

1. A markscheme often has more marking points than the total allows. This is intentional.
2. Each marking point has a separate line and the end is shown 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 **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. When marking, indicate this by adding **ECF** (error carried forward) on the script.
10. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the markscheme.
11. If a question specifically asks for the name of a substance, do not award a mark for a correct formula unless directed otherwise in the markscheme, similarly, if the formula is specifically asked for, unless directed otherwise in the markscheme do not award a mark for a correct name.
12. 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.
13. Ignore missing or incorrect state symbols in an equation unless directed otherwise in the markscheme.

## SECTION A

1. (a)  $M(\text{CH}_3\text{COOH}) = (4 \times 1.01) + (2 \times 12.01) + (2 \times 16.00) = 60.06 \text{ (g mol}^{-1}\text{)}$ ;  
 Accept 60 (g mol<sup>-1</sup>).  
 mass (CH<sub>3</sub>COOH) = 5.00 × 1.05 = 5.25 (g);  
 $\frac{5.25}{60.06} = 0.0874 \text{ (mol)}$ ; [3]  
 Award [3] for correct final answer.  
 Accept 0.0875 (comes from using Mr = 60 g mol<sup>-1</sup>).
- (b) percentage uncertainty in volume of ethanoic acid =  $100 \times \frac{0.05}{5.00} = 1\%$ ;  
 percentage uncertainty in total volume =  $100 \times \frac{0.62}{50} = 1.24\%$ ;  
 total percentage uncertainty = 1 + 1.24 = 2.24%; [3]  
 Accept rounding down to 2.2/2%.
- (c) (i) ±0.1 / 0.10 (cm<sup>3</sup>); [1]  
 Do **not** accept without ±
- (ii) 26.00 (cm<sup>3</sup>); [1]
- (iii) 26.00 – 3.00 = 23.00 (cm<sup>3</sup>);  
 If other methods used, award **M1** for calculating amount of NaOH reacting with CH<sub>3</sub>COOH.  
 $0.200 \times \frac{23.00}{5.00} = 0.920 \text{ (mol dm}^{-3}\text{)}$ ; [2]  
 Award [2] for correct final answer.  
 If (ii) given as mean titre (26.5 cm<sup>3</sup>) then ECF answer comes to 0.94 (mol dm<sup>-3</sup>).
- (iv)  $(K_c =) \frac{[\text{CH}_3\text{COOC}_2\text{H}_5][\text{H}_2\text{O}]}{[\text{C}_2\text{H}_5\text{OH}][\text{CH}_3\text{COOH}]}$ ; [1]  
 Do not penalize minor errors in formulas.  
 Accept  $(K_c =) \frac{[\text{ester}][\text{water}]}{[\text{ethanol / alcohol}][(\text{ethanoic acid})]}$ .
- (v)  $(K_c =) \frac{0.828 \times 1.80}{0.884 \times 0.920} = 1.83$ ; [1]  
 If assumed [CH<sub>3</sub>COOH] = 0.884 mol dm<sup>-3</sup>, answer is 1.91 – allow this even if an answer was obtained for (iii).  
 If (ii) given as mean titre (26.5 cm<sup>3</sup>) then ECF answer comes to 1.79.
- (d) repeat the titration a day/week later (and result should be the same) / OWTTE; [1]  
 Accept “concentrations/physical properties/macroscopic properties of the system do not change”.

- (e) enthalpy change/ $\Delta H$  for the reaction is (very) small / *OWTTE*; [1]
- (f) decreases (the amount of ethanoic acid converted);  
 Accept “increases amount of ethanoic acid present at equilibrium” / *OWTTE*.  
 (adding product) shifts position of equilibrium towards reactants/LHS / increases the rate of the reverse reaction / *OWTTE*; [2]
- (g) ethyl ethanoate/ $\text{CH}_3\text{COOC}_2\text{H}_5$ /ester;  
 forms only weak hydrogen bonds (to water); [2]  
 Allow “does not hydrogen bond to water” / “hydrocarbon sections too long” / *OWTTE*.  
*M2 can only be given only if M1 correct.*
- (h) (large excess of) water will shift the position of equilibrium (far to the left) / *OWTTE*; [1]  
 Accept any other chemically sound response, such as “dissociation of ethanoic acid would affect equilibrium”.
2. (a)  $63x + 65(100 - x) = 63.55 \times 100$  ; [2]  
 $(x =) 72.50(\%)$ ;  
*Award [2] for correct final answer.*
- (b)  $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1 / 1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^{10}$ ; [1]  
*Do not accept upper case letters or numbers as subscripts.*
- (c) colour is due to movement of electrons (between d orbitals) / *OWTTE*;  
 copper(I) has a full d sub-shell(, hence electrons cannot move) / copper(II) has an incomplete d sub-shell(, hence electrons can move) / *OWTTE*; [2]
- (d) (i)  $(E_{\text{cell}}^{\ominus} = 0.15 - 0.52 =) -0.37(\text{V})$   
 choosing correct  $E_{\text{cell}}^{\ominus}$  values;  
 combining in correct way; [2]  
*Award [2] for correct final answer.*  
*Award [1] for -0.18 (0.34 instead of 0.15) and -0.19 (0.34 instead of 0.52).*
- (ii) not spontaneous **because**  $E^{\ominus}$  negative / *OWTTE*; [1]

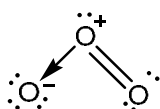
	Product 1	Product 2
<b>Name</b>	propene; <i>Accept prop-1-ene/1-propene.</i>	propan-2-ol; <i>Accept 2-propanol/isopropanol.</i>
<b>Conditions</b>	concentrated alkali; alcoholic solution; high temperature / reflux / hot; <b>[2 max]</b> for conditions to form propene.	dilute alkali; aqueous solution; lower temperature / warm / gentle heat; <b>[2 max]</b> for conditions to form propan-2-ol. <i>Accept room temperature.</i>

[6]

*Accept Product 1 and Product 2 reversed.*

*Do not award marks for conditions if product incorrect.*

4. (a)



[1]

*Accept lines, dots or crosses to represent electron pairs.*

*Formal charges and arrow for dative bond **not** required.*

*If Lewis structure incorrect remember to take into account possible ECF on parts (b)–(d) based on the number of electron domains and bond types in the Lewis diagram in part (a) and do **not** award marks for these if they are inconsistent with the structure given in (a).*

(b) *Shape: non-linear / bent / v-shaped / angular;*

*Bond angle: 117°;*

[2]

*Accept values from 115° to 119° / just/slightly less than 120°.*

(c)  $sp^2$ ;

[1]

(d) one is just one  $\sigma$  **and** one has one  $\sigma$  and one  $\pi$ ;

[1]

*Accept “both bonds comprise one  $\sigma$  and a shared  $\pi$ ” / OWTTE.*

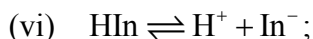
(e) delocalization occurs / delocalized  $\pi$ -bond / (has two) resonance structures / it is a resonance hybrid;

length intermediate between  $H_2O_2$  and  $O_2$  / OWTTE;

[2]

## SECTION B

5. (a) (i) from (pale) green/colourless to yellow/orange/brown; [1]  
*Initial colour must be stated.*  
*Do **not** accept “clear/transparent” instead of “colourless”.*
- (ii) chlorine more reactive/more powerful oxidizing agent (than bromine);  
*Accept opposite statements for bromine.*  
*Accept “chloride ion a weaker reducing agent” / “bromide ion a stronger reducing agent”.*  
*Accept “chlorine more electronegative than bromine”.*
- $\text{Cl}_2(\text{aq}) + 2\text{NaBr}(\text{aq}) \rightarrow \text{Br}_2(\text{aq}) + 2\text{NaCl}(\text{aq}) /$   
 $\text{Cl}_2(\text{aq}) + 2\text{Br}^-(\text{aq}) \rightarrow \text{Br}_2(\text{aq}) + 2\text{Cl}^-(\text{aq});$  [2]  
*Ignore state symbols.*  
*Do **not** accept with equilibrium sign.*
- (b) (i) chloric(I) acid (shown as) a molecule/molecular, but hydrochloric acid (shown as being) split into ions / *OWTTE*; [1]  
*Accept “chloric(I) acid is partially dissociated and hydrochloric acid is fully dissociated”.*  
*Reference needed to both acids for mark.*
- (ii)  $\text{HOCl}(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{ClO}^-(\text{aq}) / \text{HOCl}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{ClO}^-(\text{aq});$  [1]  
*Equilibrium sign required for the mark.*  
*Ignore state symbols.*
- (iii) acid displaces the equilibrium to the left (to form chlorine);  
 chlorine is toxic/poisonous/harmful/lung irritant; [2]  
*Accept answers that refer to the (b) (ii) equilibrium.*
- (iv) chloric(I) acid has -OH group / hydrogen attached to a very electronegative atom;  
*Accept polar molecule.*
- can form hydrogen bonds to water;  
 hydrogen bonding to water increases its solubility;  
 (as a weak acid it is) in equilibrium with ions; [2 max]
- (v)  $K_a = 10^{-7.53} = 2.95 \times 10^{-8} (\text{mol dm}^{-3});$   
 $K_a = \frac{[\text{H}^+][\text{ClO}^-]}{[\text{HOCl}]} = \frac{[\text{H}^+](0.05)}{(0.1)} \approx \frac{[\text{H}^+]}{2} = 2.95 \times 10^{-8} (\text{mol dm}^{-3});$   
 $[\text{H}^+] = 2 \times 2.95 \times 10^{-8} = 5.9 \times 10^{-8} (\text{mol dm}^{-3});$   
 $\text{pH} = -\log(5.9 \times 10^{-8}) = 7.23;$  [4]  
*Accept other methods of carrying out the calculation.*  
*Award [4] for correct final answer.*

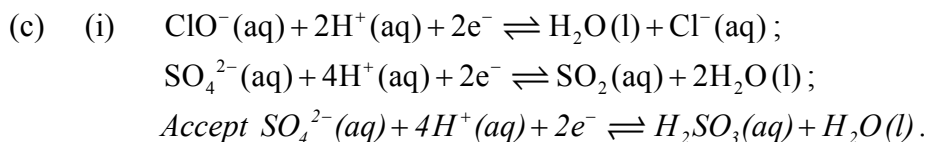


Do **not** accept equation without equilibrium arrow.

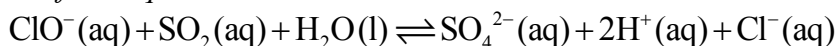
(weak acid in which the) acid/HIn and conjugate base/ $\text{In}^-$  have different colours / *OWTTE*;

excess alkali shifts the equilibrium to the RHS/towards the conjugate base;

[3]



For final equation:



Accept  $\text{ClO}^-(\text{aq}) + \text{H}_2\text{SO}_3(\text{aq}) \rightleftharpoons \text{SO}_4^{2-}(\text{aq}) + 2\text{H}^+(\text{aq}) + \text{Cl}^-(\text{aq})$  .

correct reactants and products;

balancing and cancelling  $\text{e}^-$ ,  $\text{H}^+$  and  $\text{H}_2\text{O}$  ;

[4]

Apply ECF if incorrect half-equations written.

Ignore state symbols and absence of equilibrium arrow for all equations and accept inclusion of  $\text{Na}^+$  in any equation.

(ii) Award [2] for all correct, [1] for 2 or 3 correct.

Element	Initial oxidation number	Final oxidation number
Chlorine	+I / +1;	-I / -1;
Sulfur	+IV / +4;	+VI / +6;

[2]

Remember to apply ECF from final (c) (i) equation.

Penalise incorrect notation (eg, 4 or 4+ rather than +4) once only, so award [1] for a fully correct answer in an incorrect format.

(d) (i) potential (of reduction half-reaction) under standard conditions measured relative to standard hydrogen electrode/SHE / *OWTTE*;  
 Allow "solute concentration of  $1 \text{ mol dm}^{-3}$ " or "1 bar/1 atm (pressure) for gases" instead of "standard conditions".

[1]

(ii) yes / energetically feasible;  
 would have a positive  $E_{\text{cell}}$  / chlorate(V) ion stronger oxidizing agent than dichromate(VI) ion / *OWTTE*;

[2]



6. (a) (i)

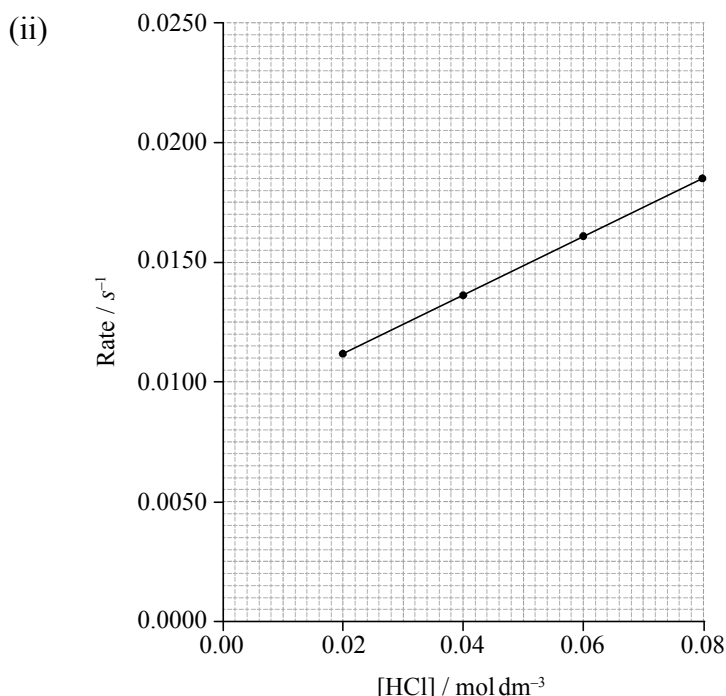
<b>Liquid</b>	0.500 mol dm <sup>-3</sup> HCl	0.0200 mol dm <sup>-3</sup> Na <sub>2</sub> S <sub>2</sub> O <sub>3</sub>	Water
<b>Volume / cm<sup>3</sup></b>	10(.0)	20(.0)	20(.0)

Accept other volumes in a 1:2:2 ratio.

(ii) depth of liquid in the beaker must remain constant / *OWTTE*; [1]  
 Accept "same thickness of glass" and any other valid point, such as answers framed around minimizing uncontrolled variables / making it a "fair test".

(iii) 94 (s) / 1 min 34 s; [1]

(b) (i) rate =  $k[S_2O_3^{2-}][H^+]^2$  / rate =  $k[Na_2S_2O_3][HCl]^2$ ; [1]



correct scale and units on y-axis;  
 Accept other suitable scales (such as 1/t) and units (such as ms<sup>-1</sup>).  
 Axes do not have to show origin/start at zero.

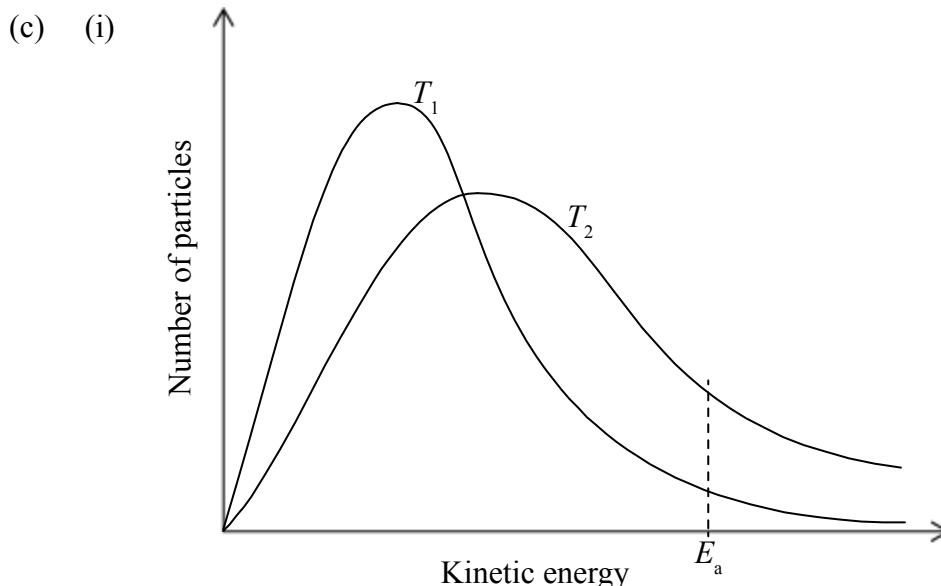
correct calculation of rate in s<sup>-1</sup>;

[HCl] / mol dm <sup>-3</sup>	0.02	0.04	0.06	0.08
Time / s	89.1	72.8	62.4	54.2
Rate / s <sup>-1</sup>	0.0112	0.0137	0.0161	0.0185

If graph correct, assume this has been done on calculator and not written down.

correct plotting of points that the student decides to use **and** a connecting line; [3]  
 Award final mark if 3 or more points are correct, irrespective of what is plotted on y-axis.  
 If line goes through the correct values at given concentrations of HCl, assume that points are marked there.

- (iii) linear dependence on  $[HCl]$  (so not second order in  $[H^+]$ );  
*Accept that doubling of concentration does not result in quadrupling of rate / OWTTE .*  
 does not go through origin;  
*Remember to allow ECF from (b) (i).* [2]



*labelled y-axis: number of particles / probability of particles (with that kinetic energy) and labelled x-axis: (kinetic) energy;*  
*Allow fraction/proportion/amount of particles (with kinetic energy) for y-axis label.*  
*Allow speed/velocity for x-axis label.*

*T<sub>2</sub> curve broader and with maximum lower and to right of T<sub>1</sub> curve;*  
*Do not award this mark if both curves not asymmetric.*  
*Curves must pass through the origin and be asymptotic to x axis.*  
*Do not award this mark if curves not labelled.*

*E<sub>a</sub> marked on graph;*

[3]

- (ii) kinetic energy of molecules increases;  
*This may be answered implicitly in the final marking point.*

*frequency of collision/number of collisions per unit time increases;*  
*Do not accept "number of collisions increases".*

*greater proportion of molecules have energy greater than/equal to activation energy / rate related to temperature by the Arrhenius equation;*  
*Award [1 max] for statements such as "there will be more successful collisions" if neither of last two marking points awarded.* [3]

- (d) (i)  $[H^+] = 0.5 \times \frac{10}{50} = 0.1 (\text{mol dm}^{-3})$ ;  
 $\text{pH} (= -\log[H^+] = -\log(0.10)) = 1$ ;

[2]

- (ii) 90%;

[1]

(e) (i)  $\text{mol Na}_2\text{S}_2\text{O}_3 = \text{mol SO}_2 = 0.0400 \times 0.0200 = 0.000800$  ;

$$V = \frac{n \times R \times T}{P} = \frac{0.000800 \times 8.31 \times 300}{10^5} ;$$

$$(1.99 \times 10^{-5} \text{ m}^3) = 19.9 (\text{cm}^3) ;$$

*Note that two errors involving a factor of 1000 can also produce the correct answer. If this is the case award [1] not [3].*

*Accept 20.0 cm<sup>3</sup> if R = 8.314 is used.*

*Award [2] for 17.9 cm<sup>3</sup> or 19.2 cm<sup>3</sup> (result from using molar volume at standard temperature and pressure or at room temperature and pressure).*

**OR**

$$\text{mol Na}_2\text{S}_2\text{O}_3 = \text{mol SO}_2 = 0.0400 \times 0.0200 = 0.000800 ;$$

$$V = 0.00080 \times 2.24 \times 10^{-2} \times \left[ \frac{1.00 \times 10^5}{1.01 \times 10^5} \right] \times \frac{300}{273} ;$$

$$(1.95 \times 10^{-5} \text{ m}^3) = 19.5 (\text{cm}^3) ;$$

[3]

*Note that two errors involving a factor of 1000 can also produce the correct answer. If this is the case award [1] not [3].*

*Deduct [1] for answers based on amount of HCl, so correct calculation would score [2 max].*

(ii)  $K_a = \frac{[\text{H}^+][\text{HSO}_3^-]}{[\text{H}_2\text{SO}_3]} = \frac{x^2}{2-x} \approx \frac{x^2}{2} = 1.25 \times 10^{-2} (\text{mol dm}^{-3}) ;$

$$[\text{H}^+] = \sqrt{2.50 \times 10^{-2}} = 0.158 (\text{mol dm}^{-3}) ;$$

$$\text{pH} = -\log(0.158) = 0.80 ;$$

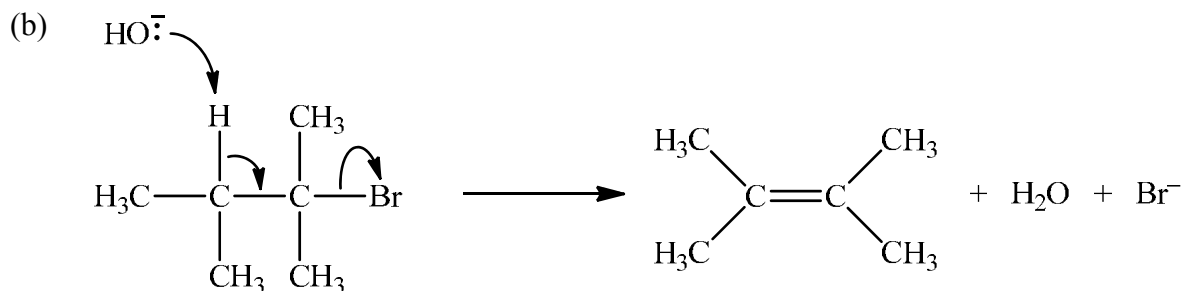
[3]

*Award [3] for correct final answer.*

(iii) dichloroethanoic acid / trichloroethanoic acid / 2,4,6-trinitrophenol;

[1]

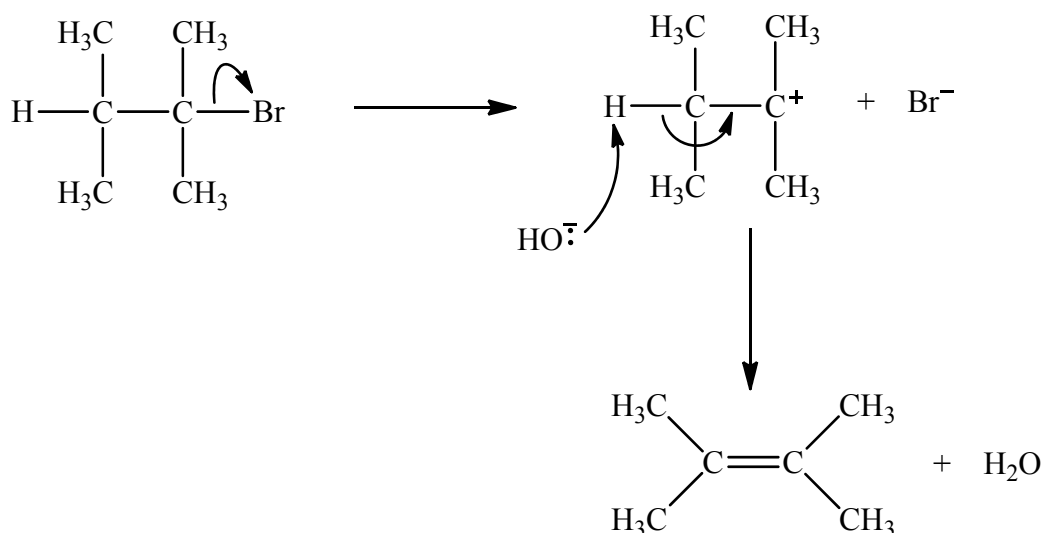
7. (a) hydrogen bromide / hydrobromic acid / HBr; [1]



curly arrow going from lone pair/negative charge on O in  $\text{HO}^-$  to H on  $\beta$ -C;  
 Do not allow curly arrow originating on H in  $\text{HO}^-$ .  
 Accept mechanism with an alkoxide ion rather than  $\text{HO}^-$  acting as the base.

curly arrow going from CH bond to form C=C bond;  
 curly arrow showing Br leaving;  
 formation of organic product **and**  $\text{H}_2\text{O}$  **and**  $\text{Br}^-$ ;

**OR**



curly arrow showing Br leaving;  
 representation of tertiary carbocation;  
 curly arrow going from lone pair on O in  $\text{HO}^-$  to H on C adjacent to  $\text{C}^+$  **and** curly arrow going from CH bond to form C=C bond;  
 formation of organic product **and**  $\text{H}_2\text{O}$  **and**  $\text{Br}^-$ ; [4]  
 Deduct [1] if student gives mechanism for the forward reaction instead of the reverse reaction, so it could score [3 max].

(c) (i) ultraviolet light/sunlight; [1]  
 Accept "very high temperature".

(ii) random/further/multiple substitution (so low probability of desired product) / would give a mixture of many different products / *OWTTE*; [1]

(d) (i) (aqueous) sodium hydroxide/NaOH / potassium hydroxide/KOH; [1]  
 Accept hydroxide ion/ $\text{OH}^-$ .

- (ii)  $\text{rate} = k[\text{B}]$  /  $\text{rate} = k[\text{C}_6\text{H}_{13}\text{Br}]$ ; [1]
- (iii) optical activity requires a chiral/asymmetric centre / *OWTTE*;  
there are no C-atoms that have 4 different groups bonded to them /  
mirror image identical to original molecule / *OWTTE*; [2]
- (iv) (it is a) tertiary/ $3^\circ$  alcohol / carbon of C-OH is not bonded to a hydrogen; [1]  
*Accept "it is not a primary or secondary alcohol".*
- (v)
- $$\begin{array}{c} \text{CH}_3 \\ | \\ \text{H}_3\text{C}-\text{CH}_2-\text{CH}_2-\text{CH}-\text{CH}_2-\text{OH} \end{array} / \begin{array}{c} \text{CH}_3 \\ | \\ \text{H}_3\text{C}-\text{CH}_2-\text{CH}-\text{CH}_2-\text{CH}_2-\text{OH} \end{array}$$
- $$/ \begin{array}{c} \text{CH}_3 \quad \text{CH}_3 \\ | \quad | \\ \text{H}_3\text{C}-\text{CH}-\text{CH}-\text{CH}_2-\text{OH} \end{array}$$
- Accept abbreviated formulas involving  $\text{C}_2\text{H}_5-$  and  $\text{C}_3\text{H}_7-$ .*  
primary alcohol with formula  $\text{C}_6\text{H}_{13}\text{OH}$ ;  
optically active compound with formula  $\text{C}_6\text{H}_{13}\text{OH}$ ; [2]  
*Penalise minor errors in structures (such as missing H-atoms) once only.*
- (e) (i) Ni/Pt/Pd catalyst; [1]
- (ii) conversion of vegetable oil to margarine; [1]  
*Accept "manufacture of margarine" / "saturation of vegetable oils" /*  
*OWTTE.*
- (iii) negative **and** decrease in number of molecules/particles/moles in the gas phase; [1]
- (iv)  $\Delta H = \sum \Delta H_f(\text{products}) - \sum \Delta H_f(\text{reactants}) / -178 - (-68)$ ;  
 $-110(\text{kJ mol}^{-1})$ ; [2]  
*Award [2] for correct final answer.*  
*Award [1] for  $+110(\text{kJ mol}^{-1})$ .*
- (v) reaction is exothermic/ $\Delta H$  is negative **and** involves a decrease in entropy/ $\Delta S$   
is negative;  
reaction will be spontaneous/ $\Delta G$  negative at low temperatures / non-  
spontaneous/ $\Delta G$  positive at high temperatures; [2]  
*Accept correct explanations using  $\Delta G = \Delta H - T\Delta S$ .*  
*Remember to apply ECF from (e) (iii) and (iv) – award both these marks in*  
*accordance with what the candidate has written there.*

- (vi) energy required to heat water ( $= m \times s \times \Delta T = 1 \times 4.18 \times (100 - 20) = 334.4 \text{ (kJ)}$ );  
*Ignore sign of energy change.*

$$\text{amount required} = \frac{334.4}{4000} = 0.0836 \text{ (mol)}; \quad [2]$$

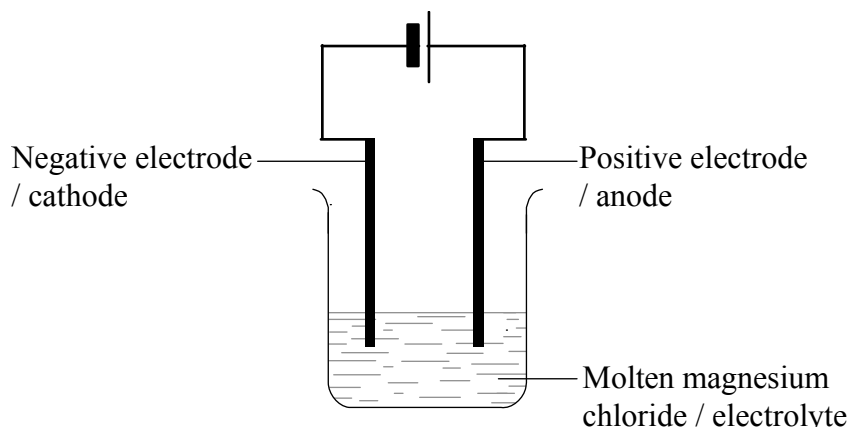
*Award [2] for correct final answer.*

- (vii) D lower/hexane higher **and** van der Waals'/London/dispersion forces  
between molecules weaker in D/stronger in hexane;  
*Accept "intermolecular forces" instead of dispersion forces.*

D is more branched / D has a lower surface area / D has a more  
spherical shape / does not pack as closely; [2]  
*Accept opposite statements for hexane.*

8. (a) minimum energy required to remove one electron / energy required to remove most loosely bound/outermost electron;  
from gaseous/isolated atom; [2]  
*Accept "gaseous state".*  
*More extensive definitions involving one mole may be given.*
- (b) (i) electrons lost in same orbital/valence shell;  
(second) electron/electron (being lost from  $\text{Mg}^+$  is) closer to the nucleus;  
(second) electron/electron (being lost from  $\text{Mg}^+$ ) not subject to e-e repulsion from others in same level; [2 max]  
*Apply OWTTE for all marking points.*  
*Do **not** accept "less electrons to share the charge" or answers employing this concept.*
- (ii) electron in lower energy level / more stable electron shell;  
electron closer to nucleus;  
less shielding by complete inner shells / increase in effective nuclear charge; [2 max]  
*Apply OWTTE for all marking points.*
- (c)  $\Delta H_{\text{at}}(\text{Cl}) = \frac{1}{2} \times 243 (\text{kJ mol}^{-1})$ ;  
*Correct calculation of atomization enthalpy of Cl.*
- $\Delta H_{\text{f}} = +146 + \frac{1}{2} 243 + 738 + (-349) + (-790)$ ;  
*Correct sign and magnitude of all terms.*
- $= -134 (\text{kJ mol}^{-1})$ ; [3]  
*Award [3] for correct final answer.*  
*Final mark involves correct computation of equation the student has produced.*  
*Award [2] for -12 (bond enthalpy of Cl not halved) or +134 (signs wrong).*  
*Award [1] for +12 (bond enthalpy of Cl not halved and signs wrong).*
- (d)  $\text{MgF}_2 - \text{MgCl}_2 - \text{CaCl}_2$ ;  
 $\text{F}^-$  smaller (ionic radius) than  $\text{Cl}^-$  /  $\text{Cl}^-$  larger (ionic radius) than  $\text{F}^-$ ;  
 $\text{Mg}^{2+}$  smaller (ionic radius) than  $\text{Ca}^{2+}$  /  $\text{Ca}^{2+}$  larger (ionic radius) than  $\text{Mg}^{2+}$ ; [3]  
*Accept use of atomic radius rather than ionic radius.*
- (e) more soluble at low pH / less soluble at high pH;  
higher pH /  $\text{OH}^-$  will shift the equilibrium to the left / lower pH /  $\text{H}^+$  will (react with  $\text{OH}^-$  and) shift the equilibrium to the right; [2]
- (f) (i) lattice/layers/framework of cations/magnesium ions/ $\text{Mg}^{2+}$ ;  
surrounded by delocalized electrons / in a sea/flux of delocalized electrons; [2]  
*Accept "mobile" instead of "delocalized".*
- (ii) Mg has more delocalized electrons (than Na); [1]  
*Accept "Mg has more valence electrons than Na" / "Mg is  $\text{Mg}^{2+}$  but Na is only  $\text{Na}^+$ ".*
- (iii) layers of ions/atoms/particles cannot slide over each other so easily (as different sized ions/atoms/particles) / OWTTE; [1]

(g) (i)



*Diagram:*

two electrodes connected to a power pack/battery and immersed in an electrolyte;

*Do **not** award mark if salt bridge included in diagram.*

*Labelling:*

anode/positive electrode, cathode/negative electrode, molten magnesium chloride/MgCl<sub>2</sub> (l)/electrolyte correctly labelled;

[2]

*Check candidates know which end of a battery symbol is which charge.*

(ii) *Negative electrode (cathode):*  $\text{Mg}^{2+}(\text{l}) + 2\text{e}^{-} \rightarrow \text{Mg}(\text{s})$  ;

*Positive electrode (anode):*  $2\text{Cl}^{-}(\text{l}) \rightarrow \text{Cl}_2(\text{g}) + 2\text{e}^{-}$  ;

[2]

*Accept*  $\text{Cl}^{-}(\text{l}) \rightarrow \frac{1}{2}\text{Cl}_2(\text{g}) + \text{e}^{-}$  .

*Ignore state symbols.*

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

*If both correct equations are given for the wrong electrodes award [1 max].*

(iii) *Negative electrode (cathode):*

$2\text{H}_2\text{O}(\text{l}) + 2\text{e}^{-} \rightarrow \text{H}_2(\text{g}) + 2\text{OH}^{-}(\text{aq})$  /  $2\text{H}^{+}(\text{aq}) + 2\text{e}^{-} \rightarrow \text{H}_2(\text{g})$  ;

*Accept*  $4\text{H}_2\text{O}(\text{l}) + 4\text{e}^{-} \rightarrow 2\text{H}_2(\text{g}) + 4\text{OH}^{-}(\text{aq})$  /  $4\text{H}^{+}(\text{aq}) + 4\text{e}^{-} \rightarrow 2\text{H}_2(\text{g})$  /

$\text{H}_2\text{O}(\text{l}) + \text{e}^{-} \rightarrow \frac{1}{2}\text{H}_2(\text{g}) + \text{OH}^{-}(\text{aq})$  /  $\text{H}^{+}(\text{aq}) + \text{e}^{-} \rightarrow \frac{1}{2}\text{H}_2(\text{g})$  .

*Positive electrode (anode):*

$2\text{H}_2\text{O}(\text{l}) \rightarrow \text{O}_2(\text{g}) + 4\text{H}^{+}(\text{aq}) + 4\text{e}^{-}$  /  $4\text{OH}^{-}(\text{aq}) \rightarrow \text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^{-}$  ;

[2]

*Accept*  $\text{H}_2\text{O}(\text{l}) \rightarrow \frac{1}{2}\text{O}_2(\text{g}) + 2\text{H}^{+}(\text{aq}) + 2\text{e}^{-}$  /  $2\text{OH}^{-}(\text{aq}) \rightarrow \frac{1}{2}\text{O}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) + 2\text{e}^{-}$  .

*State symbols not required.*

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

*If both correct equations are given for the wrong electrodes award [1 max].*

(iv) water/hydrogen ions more easily reduced/better oxidizing agents/have a more positive  $E^{\ominus}$  (than magnesium ions);

[1]

*Accept converse statements for magnesium ions.*

*Accept "magnesium is very reactive/high in reactivity series" / OWTTE.*