Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

May 2022

Chemistry

Higher level

Paper 2

22 pages

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Subject Details: Chemistry higher Paper 2 Markscheme

Candidates are required to answer **ALL** questions. Maximum total = **[90 marks]**.

1. Each row in the "Question" column relates to the smallest subpart of the question.

2. The maximum mark for each question subpart is indicated in the "Total" column.

3. Each marking point in the "Answers" column is shown by means of a tick (✓) at the end of the marking point.

4. A question subpart may have more marking points than the total allows. This will be indicated by "**max**" written after the mark in the "Total" column. The related rubric, if necessary, will be outlined in the "Notes" column.

5. An alternative word is indicated in the "Answers" column by a slash (***/***). Either word can be accepted.

6. An alternative answer is indicated in the "Answers" column by "***OR***". Either answer can be accepted.

7. An alternative markscheme is indicated in the "Answers" column under heading **ALTERNATIVE 1** *etc*. Either alternative can be accepted.

8. Words inside chevrons **« »** in the "Answers" column are not necessary to gain the mark.

9. Words that are <u>underlined</u> are essential for the mark.

10. The order of marking points does not have to be as in the "Answers" column, unless stated otherwise in the "Notes" column.

11. 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 "Answers" column 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) in the "Notes" column.

12. Remember that many candidates are writing in a second language. Effective communication is more important than grammatical accuracy.

13. 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.

14. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the "Notes" column.

15. 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 "Notes" column. Similarly, if the formula is specifically asked for, do not award a mark for a correct name unless directed otherwise in the "Notes" column.

16. 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 "Notes" column.

17. Ignore missing or incorrect state symbols in an equation unless directed otherwise in the "Notes" column.

Question			Answers	Notes	Total
1.	a		$2\ Li\ (s) + 2\ H_2O\ (l) \rightarrow 2\ LiOH\ (aq) + H_2\ (g)$ ✓		1
1.	b	i	n_{Li}«$\frac{0.200\ g}{6.94\ g}$ = »0.0288 «mol» ✓ «$n_{LiOH} = n_{Li}$» [LiOH] «= $\frac{0.0288\ mol}{0.5000\ dm^3}$ = » 0.0576 «$mol\ dm^{-3}$» ✓	*Award **[2]** for correct final answer.*	2
1.	b	ii	«$n_{H_2} = \frac{1}{2} \times 0.0288\ mol = 0.0144\ mol$» «$V = \frac{nRT}{P}$ = »$\left(\frac{0.0144\ mol \times 8.31\ JK^{-1}mol^{-1} \times (22.5+273)K}{103\ kPa}\right)$« $\times 10^3$» ✓ V = 343 «cm^3» ✓	*Award **[2]** for correct final answer.* *Accept answers in the range 334 – 344 cm^3.* *Award **[1 max]** for 0.343 «cm^3/dm^3/m^3».* *Award **[1 max]** for 26.1 cm^3 obtained by using 22.5 K.* *Award **[1 max]** for 687 cm^3 obtained by using 0.0288 mol.*	2
1.	b	iii	lithium was impure/«partially» oxidized ***OR*** gas leaked/ignited ✓	*Accept "gas dissolved".*	1 max
1.	c		H_2O ***AND*** hydrogen gains electrons «to form H_2» ***OR*** H_2O ***AND*** H oxidation state changed from +1 to 0 ✓	*Accept "H_2O **AND** H/H_2O is reduced".*	1

(continued…)

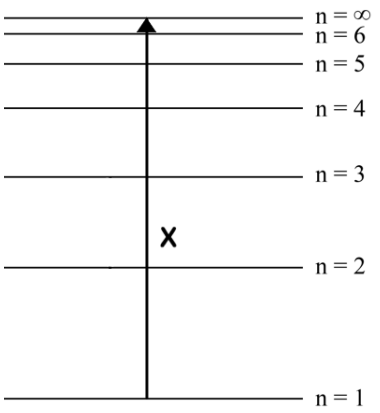
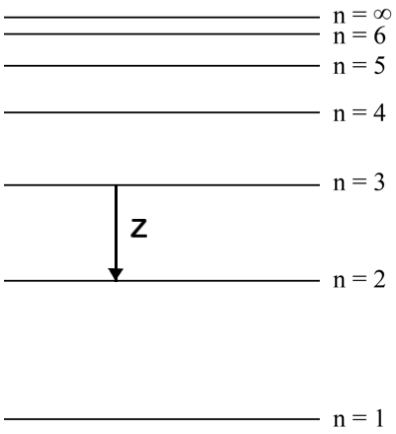
(*Question 1 continued)*

Question			Answers	Notes	Total
1.	**d**		*Any two:* temperature of the water increases ✓ lithium melts ✓ pop sound is heard ✓	*Accept "lithium/hydrogen catches fire".* *Do not accept "smoke is observed".*	**2 max**

Question			Answers	Notes	Total
2.	**a**		increasing number of protons/nuclear charge/Z_{eff} ✓ **«**atomic**»** radius/size decreases ***OR*** same number of energy levels ***OR*** similar shielding **«**by inner electrons**»** ✓		**2**
2.	**b**	**i**	*Any two of:* does not represent sub-levels/orbitals ✓ only applies to atoms with one electron/hydrogen ✓ does not explain why only certain energy levels are allowed ✓ the atom is considered to be isolated ✓ does not take into account the interactions between atoms/molecules/external fields ✓ does not consider the number of electrons the energy level can fit ✓ does not consider probability of finding electron at different positions/*OWTTE* ✓	*Do **not** accept "does not represent distance **«**from nucleus**»**".*	**2 max**

(continued…)

(*Question 2 continued)*

Question			Answers	Notes	Total
2.	**b**	**ii**	 upward arrow X ***AND*** starting at n = 1 extending to n = ∞ ✓		**1**
2.	**b**	**iii**	 downward or upward arrow between n = 3 and n = 2 ✓		**1**

Question			Answers	Notes	Total
3.	**a**	**i**	**«**$E^{\ominus}_{cell}$ = 1.09 – 0.77 =**»** 0.32 **«**V**»** ✓		**1**
3.	**a**	**ii**	**«**$2Fe^{2+}(aq) + I_2(s) \rightarrow 2Fe^{3+}(aq) + 2I^-(aq)$ **»** no/non-spontaneous ***AND*** $E^{\ominus}_{cell}$ **«**= 0.54 – 0.77 »= **–**0.23 **«**V**»**/ $E^{\ominus} < 0$ ***OR*** no ***AND*** reduction potential of I_2 lower «than Fe^{3+}»/ 0.54 <0.77 ✓	*Accept "standard electrode potential of I_2 lower /less positive than iron".*	**1**
3.	**b**	**i**	Cathode (negative electrode): $Zn^{2+} + 2e^- \rightarrow Zn(l)$ ✓ Anode (positive electrode): $2Cl^- \rightarrow Cl_2(g) + 2e^-$ ***OR*** $Cl^- \rightarrow ½\ Cl_2(g) + e^-$ ✓		**2**
3.	**b**	**ii**	$ZnCl_2(l) \rightarrow Zn(l) + Cl_2(g)$ balanced equation ✓ correct state symbols ✓	*Accept ionic equation.*	**2**

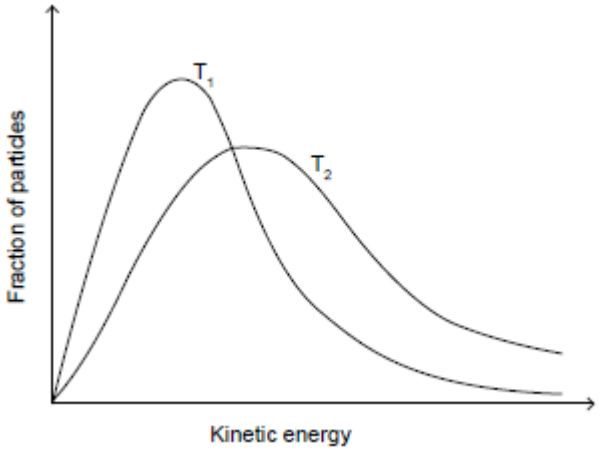
Question			Answers	Notes	Total
4.	a	i	first order ✓		1
4.	a	ii	Rate=k $[H_2]$ $[I_2]$		1
4.	a	iii	k = «$\frac{1.2\times10^{-6}\ \text{mol dm}^{-3}\ \text{s}^{-1}}{2.0\times10^{-3}\ \text{mol dm}^{-3}\times3.0\times10^{-3}\ \text{mol dm}^{-3}}$ =» 0.20 ✓ $\text{mol}^{-1}\,\text{dm}^3\,\text{s}^{-1}$ ✓		2
4.	b		$E \geq E_a$ ***AND*** appropriate «collision» geometry/correct orientation ✓		1
4.	c		$K_c = \frac{[HI]^2}{[H_2]\,[I_2]}$ ✓		1
4.	d	i	«$\Delta S^{\ominus}_{\text{reaction}} = 2\times 206.6 - (130.6 + 116.1)$ =» 166.5 «$\text{J K}^{-1}\,\text{mol}^{-1}$» ✓		1
4.	d	ii	$\Delta S^{\ominus}_{\text{reaction}}$ lower/less positive ***AND*** same number of moles of gas ***OR*** $\Delta S^{\ominus}_{\text{reaction}}$ lower/less positive ***AND*** a solid has less entropy than a gas ✓		1

(continued…)

(*Question 4 continued)*

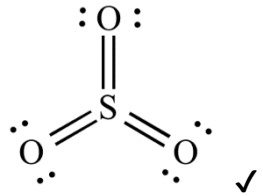
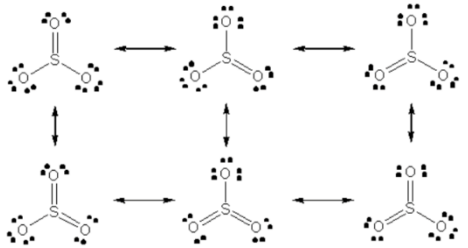
Question			Answers	Notes	Total
4.	**d**	**iii**	**«**$\Delta G^{Ö}$ = 53.0 kJ mol^{-1} – (298 K × 0.1665 kJ K^{-1} mol^{-1}) =**»** 3.4 **«**kJ mol^{-1}**»** ✓		**1**
4.	**d**	**iv**	«ln K_c= - (3.4 × 10^3 J mol^{-1} /8.31 J K^{-1} mol^{-1} × 298 K)» = -1.37 ✓ **«**K_c =**»** 0.25 ✓	*Award **[2]** for "0.45" for the use of 2.0 kJ mol^{-1} for* $\Delta G^{Ö}$*.*	**2**

Question			Answer	Notes	Total
5.	**a**	**i**	$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$ ✓		**1**
5.	**a**	**ii**	*Any two of:* IE_9: electron in lower energy level ***OR*** IE_9: more stable/full electron level ✓ IE_9: electron closer to nucleus ***OR*** IE_9: electron more tightly held by nucleus ✓ IE_9: less shielding by **«**complete**»** inner levels ✓		**2 max**
5.	**b**		–1 ✓	*Accept "– I".*	**1**
5.	**c**		electrostatic attraction/hold between **«**lattice of**»** positive ions/cations ***AND*** delocalized **«**valence**»** electrons ✓		**1**

Question			Answers	Notes	Total
6.	a		increases rate ***AND*** lower E_a ✓ provides alternative pathway **«**with lower E_a**»** ***OR*** more/larger fraction of molecules have the **«**lower**»** E_a ✓	*Accept description of how catalyst lowers E_a for M2 (e.g. "reactants adsorb on surface **«**of catalyst**»**", "reactant bonds weaken **«**when adsorbed**»**", "helps favorable orientation of molecules").*	**2**
6.	b	i	 both axes correctly labelled ✓ peak of T_2 curve lower ***AND*** to the right of T_1 curve ✓ lines begin at origin ***AND*** correct shape of curves ***AND*** T_2 must finish above T_1 ✓	*Accept "probability **«**density**»** / number of particles / N / fraction" on y-axis.* *Accept "kinetic E/KE/E_k" but not just "Energy/E" on x-axis.*	**3**

(continued…)

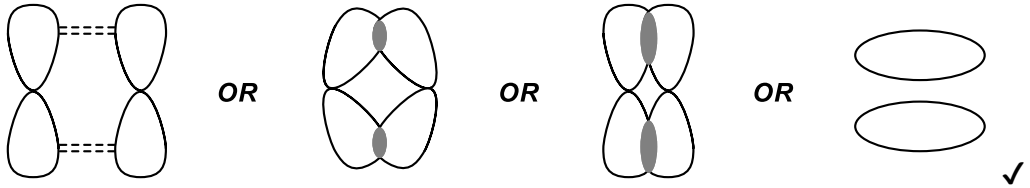
(*Question 6 continued)*

Question			Answers	Notes	Total
6.	**b**	**ii**	decrease ***AND*** equilibrium shifts left / favours reverse reaction ✓ **«**forward reaction is**»** exothermic / ΔH is negative ✓		**2**
6.	**c**	**i**	 ✓	 *Accept any of the above structures as formal charge is not being assessed.*	**1**
6.	**c**	**ii**	three electron domains **«**attached to the central atom**»** ✓ repel/as far away as possible /120° «apart» ✓		**2**
6.	**d**	**i**	sulfuric acid/H_2SO_4 ✓	*Accept "disulfuric acid/$H_2S_2O_7$".*	**1**
6.	**d**	**ii**	fully ionizes/dissociates ✓ proton/H^+ **«**donor **»**✓		**2**

Question			Answers	Notes	Total
7.	a	i	donates «lone/non-bonding» pair of electrons ✓		1
7.	a	ii	$Kb = 10^{-4.75} / 1.78 \times 10^{-5}$ ***OR*** $Kb = \frac{[OH^-]^2}{[NH_3]}$ ✓ $[OH^-]$ = **«**$\sqrt{(1.00 \times 10^{-2} \times 10^{-4.75})}$ =**»** 4.22×10^{-4} **«**(mol dm^{-3})**»** ✓ pOH**«** = $-\log_{10}(4.22 \times 10^{-4})$**»** = 3.37 ***AND*** pH **= «**14 **–** 3.37**»** = 10.6 ***OR*** $[H^+]$**«** = $\frac{1.00 \times 10^{-14}}{4.22 \times 10^{-4}}$ **»** = 2.37×10^{-11} ***AND*** pH**«** = $-\log_{10}$ 2.37×10^{-11}**»** = 10.6 ✓	*Award **[3]** for correct final answer.*	3

(continued…)

(*Question 7 continued*)

Question			Answers	Notes	Total
7.	**a**	**iii**	no ***AND*** is not a weak acid conjugate base system ***OR*** no ***AND*** weak base **«**totally**»** neutralized/ weak base is not in excess ***OR*** no ***AND*** will not neutralize small amount of acid ✓	*Accept "no **AND** contains 0.10 mol NH_4Cl + 0.10 mol HCl".*	**1**
7.	**b**	**i**	*Sigma (σ):*  ***OR*** ***OR*** ✓ *Pi (π):*  ***OR*** ***OR*** ***OR*** ✓	*Accept overlapping p-orbital(s) with both lobes of equal size/shape.* *Shaded areas are not required in either diagram.*	**2**

(continued…)

(*Question 7 continued)*

Question			Answers	Notes	Total
7.	**b**	**ii**	Sigma (σ): 2 ***AND*** Pi (π): 2 ✓		**1**
7.	**b**	**iii**	sp ✓		**1**
7.	**c**		HCN has stronger dipole–dipole attraction ✓	*Do **not** accept reference to H-bonds.*	**1**
7.	**d**		*Any three from:* partially filled d-orbitals ✓ **«**CN- causes**»** d-orbitals **«**to**»** split ✓ light is absorbed as electrons transit to a higher energy level **«**in d–d transitions**»** ***OR*** light is absorbed as electrons are promoted ✓ energy gap corresponds to light in the visible region of the spectrum ✓	*Do **not** accept "colour observed is the complementary colour" for M4.*	**3 max**

Question			Answers	Notes	Total
8.	**a**	**i**	Any **two** of: C_{60} fullerene: bonded to 3 C ***AND*** diamond: bonded to 4 C ✓ C_{60} fullerene: delocalized/resonance ***AND*** diamond: not delocalized / no resonance ✓ C60 fullerene: sp^2 ***AND*** diamond: sp^3✓ C_{60} fullerene: bond angles between 109–120° ***AND*** diamond: 109° ✓	*Accept "bonds in fullerene are shorter/stronger/have higher bond order **OR** bonds in diamond longer/weaker/have lower bond order".*	**2 max**
8.	**a**	**ii**	diamond giant/network covalent ***AND*** sublimes at higher temperature ✓ C_{60} molecular/London/dispersion/intermolecular **«**forces**»** ✓	*.* *Accept "diamond has strong covalent bonds **AND** require more energy to break **«**than intermolecular forces**»**" for M1.*	**2**
8.	**b**	**i**	same general formula / C_nH_{2n+2} ✓ differ by CH_2/common structural unit ✓	*Accept "similar chemical properties".* *Accept "gradation/gradual change in physical properties".*	**2**
8.	**b**	**ii**	**R**: $^+C_3H_7$ ✓		**1**

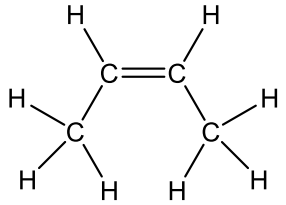
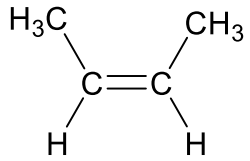
(continued…)

(*Question 8 continued)*

Question			Answers	Notes	Total
8.	**c**		**ALTERNATIVE 1:** *Test:* add bromine **«**water**»**/Br_2 (aq) ✓ *Result:* **«**orange/brown/yellow**»** to colourless/decolourised ✓ **ALTERNATIVE 2:** *Test:* add **«**acidified**»** $KMnO_4$ ✓ *Result:* **«**purple**»** to colourless/decolourised/brown ✓ **ALTERNATIVE 3:** *Test:* add iodine /I_2 ✓ *Result:* **«**brown**»** to colourless/decolourised ✓	*Do **not** accept "clear" for M2.* *Accept "colour change" for M2.*	**2**

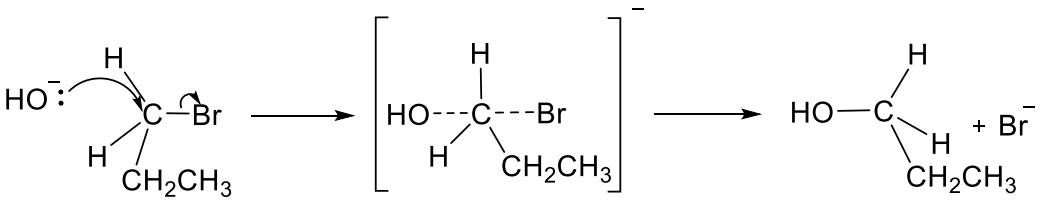
(continued…)

(*Question 8 continued)*

Question			Answers	Notes	Total
8.	**d**	**i**		*Accept* 	**1**
8.	**d**	**ii**	$CH_3CH{=}CHCH_3 + HBr \rightarrow CH_3CH_2CHBrCH_3$ Correct reactants ✓ Correct products ✓	*Accept molecular formulas for both reactants and product*	**2**
8.	**d**	**iii**	**«**electrophilic**»** addition/E_A ✓	*Do **not** accept nucleophilic or free radical addition.*	**1**
8.	**d**	**iv**	***ALTERNATIVE 1:*** *Any two of:* but-2-ene: 2 signals ***AND*** product: 4 signals ✓ but-2-ene: «area ratio» 3:1/6:2 ***AND*** product: «area ratio» 3:3:2:1 ✓ product: «has signal at» 3.5-4.4 ppm «and but-2-ene: does not» ✓ but-2-ene: «has signal at» 4.5-6.0 ppm «and product: does not» ✓ ***ALTERNATIVE 2:*** but-2-ene: doublet ***AND*** quartet/multiplet/4 ✓ product: doublet ***AND*** triplet ***AND*** quintet/5/multiplet ***AND*** sextet/6/multiplet ✓	*Accept "product **«**has signal at**»** 1.3–1.4 ppm **«**and but-2-ene: does not**»**".*	**2 max**

(continued…)

(*Question 8 continued)*

Question			Answers	Notes	Total
8.	**d**	**v**	$CH_3CH_2CH(OH)CH_3$ ✓ «secondary» carbocation/$CH_3CH_2CH^+CH_3$ more stable ✓	*Do **not** accept "Markovnikov's rule" without reference to carbocation stability.*	**2**
8.	**e**	**i**	 curly arrow going from lone pair/negative charge on O in HO^- to C ✓ curly arrow showing Br breaking ✓ representation of transition state showing negative charge, square brackets and partial bonds ✓ formation of organic product $CH_3CH_2CH_2OH$ ***AND*** Br^- ✓	*Do **not** allow curly arrow originating on H in HO^-.* *Accept curly arrow either going from bond between C and Br to Br in 1-bromopropane or in the transition state.* *Do **not** penalize if HO and Br are not at 180° to each other.* *Award **[3 max]** for S_N1 mechanism.*	**4**
8.	**e**	**ii**	triplet/3 ***AND*** multiplet/6 ***AND*** triplet/3 ✓		**1**

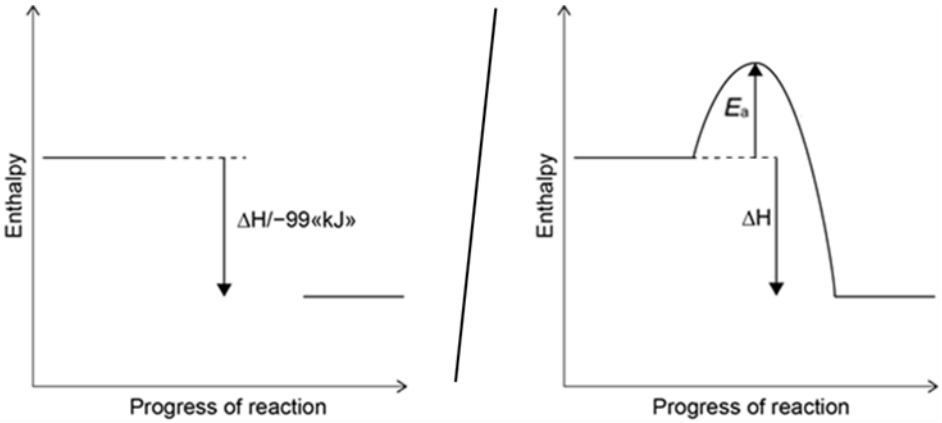
(continued…)

(*Question 8 continued)*

Question			Answers	Notes	Total
8.	**f**	**i**	bond breaking: C–H + Cl–Cl / 414 **«**kJ mol^{-1}**»** + 242 **«**kJ mol^{-1}**»**/656 **«**kJ**»** ***OR*** bond breaking: 4C–H + Cl–Cl / 4 × 414 **«**kJ mol^{-1}**»** + 242 **«**kJ mol^{-1}**»** / 1898 **«**kJ**»** ✓ bond forming: **«**C–Cl + H–Cl / 324 kJ mol^{-1} + 431 kJ mol^{-1}**»** / 755 **«**kJ**»** ***OR*** bond forming: **«**3C–H + C–Cl + H–Cl / 3 × 414 **«**kJ mol^{-1}**»** + 324 **«**kJ mol^{-1}**»** + 431 kJ mol^{-1}**»** / 1997 **«**kJ**»** ✓ **«**ΔH = bond breaking – bond forming = 656 kJ – 755 kJ**»** = –99 **«**kJ**»** ✓	*Award **[3]** for correct final answer.* *Award **[2 max]** for 99 «kJ».*	**3**

(continued…)

(*Question 8 continued)*

Question			Answers	Notes	Total
8.	**f**	**ii**	 reactants at higher enthalpy than products ✓ ΔH/-99 **«**kJ**»** labelled on arrow from reactants to products ***OR*** activation energy/E_a labelled on arrow from reactant to top of energy profile ✓	*Accept a double headed arrow between reactants and products labelled as ΔH for M2.*	**2**