Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

November 2019

Chemistry

Higher level

Paper 2

18 pages

Subject Details: Chemistry HL 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 underlined 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.

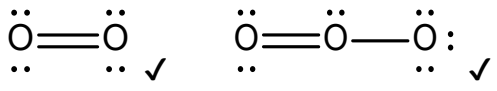
13. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should 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		 ✓ ✓	*Coordinate bond may be represented by an arrow.* *Do **not** accept delocalized structure for ozone.*	**2**
1.	b		resonance **«**structures**»** ***OR*** delocalization of **«**the double/pi bond**»** electrons ✓ 121 **«**pm**»** < length < 148 **«**pm**»** ✓	*Accept any length between these two values.*	**2**
1.	c		any value from 110°–119° ✓		**1**
1.	d		**«**bond**»** in O_2 stronger than in O_3 ✓ ozone absorbs lower frequency/energy **«**radiation than oxygen**»** ***OR*** ozone absorbs longer wavelength **«**radiation than oxygen**»** ✓	*Accept ozone **«**layer**»** absorbs a range of frequencies.*	**2**
1.	e	i	steps 1 ***AND*** 3 ✓		**1**

(continued…)

(Question 1e continued)

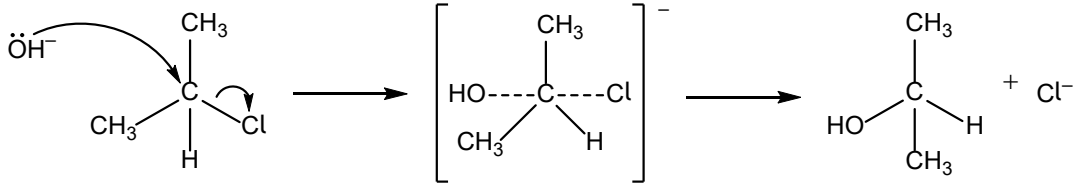
Question			Answers	Notes	Total
1.	e	ii	***ALTERNATIVE 1:*** for oxygen: $E = \text{«}\frac{498\,000\ \text{J mol}^{-1}}{6.02\times10^{23}\ \text{mol}^{-1}}\text{»}\ 8.27\times10^{-19}$ **«J»** ✓ $\lambda = \text{«}\frac{6.63\times10^{-34}\ \text{J s}\times3.00\times10^{8}\ \text{m s}^{-1}}{8.27\times10^{-19}\ \text{J}}\text{»}\ 2.40\times10^{-7}$ **«m»** ✓ ***ALTERNATIVE 2:*** for ozone: similar calculation using 200 < bond enthalpy < 400 for ozone, such as $E = \text{«}\frac{300\,000\ \text{J mol}^{-1}}{6.02\times10^{23}\ \text{mol}^{-1}}\text{»}\ 4.98\times10^{-19}$ **«J»** ✓ $\lambda = \text{«}\frac{6.63\times10^{-34}\ \text{J s}\times3.00\times10^{8}\ \text{m s}^{-1}}{4.98\times10^{-19}\ \text{J}}\text{»}\ 3.99\times10^{-7}$ **«m»** ✓	*Award **[2]** for correct final answer.*	**2**
1.	f		$\bullet NO + O_3 \rightarrow \bullet NO_2 + O_2$ ✓ $\bullet NO_2 + O_3 \rightarrow \bullet NO + 2O_2$ ✓	*Accept $\bullet NO_2 \rightarrow \bullet NO + \bullet O$* ***AND*** *$\bullet O + O_3 \rightarrow 2O_2$ for M2.*	**2**

Question			Answers	Notes	Total
2.	a	i	4 : 1 ✓		1
2.	a	ii	$n_{S_2O_3^{2-}}$ = «0.0258 dm^3 × 0.010 mol dm^{-3} =» 2.58 × 10^{-4} «mol» ✓ « $\frac{2.58 \times 10^{-4}\ \text{mol}}{4}$ =» 6.45 × 10^{-5} «mol» ✓	*Award **[2]** for correct final answer.*	2
2.	a	iii	«difference in moles per dm^3 = (6.45 × 10^{-5} – 5.03 × 10^{-5}) × $\frac{1000}{300.0}$ =» 4.73 × 10^{-5} «mol dm^{-3}» ✓ «convert to mg per dm^3: 4.73 × 10^{-5} mol dm^{-3} × 32.00 g mol^{-1} × 1000 mg g^{-1} = » 1.51 «ppm/mg dm^{-3}» ✓	*Award **[2]** for correct final answer.*	2
2.	b	i	« $\frac{100 \times 0.1\,\text{cm}^3}{20.1\,\text{cm}^3}$ =» 0.5 «%» ✓		1
2.	b	ii	repetition / take several samples «and average» ✓		1

Question			Answers	Notes	Total
3.	a	i	«electrophilic» addition ✓	*Do **not** accept "nucleophilic addition" or "free radical addition".* *Do **not** accept "halogenation".*	1
3.	a	ii	2-chloropropane ✓		1
3.	a	iii	secondary carbocation/carbonium «ion» is more stable ***OR*** carbocation/carbonium «ion» stabilized by two/more alkyl groups ✓		1
3.	a	iv	$CH_3CHClCH_3\,(l) + OH^-\,(aq) \rightarrow CH_3CH(OH)CH_3\,(aq) + Cl^-\,(aq)$ ***OR*** $CH_3CHClCH_3\,(l) + NaOH\,(aq) \rightarrow CH_3CH(OH)CH_3\,(aq) + NaCl\,(aq)$ ✓		1
3.	b	i	Rate = $k\,[C_3H_7Cl]\,[OH^-]$ ✓ «$[OH^-]$ held constant and» $[C_3H_7Cl]$ triples ***AND*** rate triples «so first order wrt C_3H_7Cl» ✓ $[C_3H_7Cl]$ doubles ***AND*** $[OH^-]$ doubles ***AND*** rate quadruples «so first order wrt OH^-» ✓		3
3.	b	ii	S_N2 ✓	*Accept 'bimolecular nucleophilic substitution.'*	1

(continued…)

(Question 3b continued)

Question			Answers	Notes	Total
3.	**b**	**iii**	 curly arrow going from lone pair on O/negative charge on OH^- to C ✓ curly arrow showing C–Cl bond breaking ✓ representation of transition state showing negative charge, square brackets and partial bonds ✓ formation of $CH_3CH(OH)CH_3$ ***AND*** Cl^- ✓	*Do **not** allow arrow originating on H in OH^-.* *Allow curly arrow going from bond between C and Cl to Cl in either reactant or transition state.* *Do **not** award M3 if OH–C bond is represented.* *Accept formation of NaCl instead of Cl^-.*	**4**
3.	**c**	**i**	$2C_3H_8O\,(l) + 9O_2\,(g) \rightarrow 6CO_2\,(g) + 8H_2O\,(g)$ ***OR*** $C_3H_8O\,(l) + 4.5O_2\,(g) \rightarrow 3CO_2\,(g) + 4H_2O\,(g)$ ✓		**1**

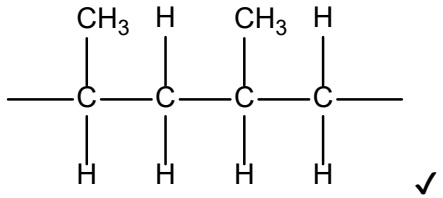
(continued…)

(Question 3c continued)

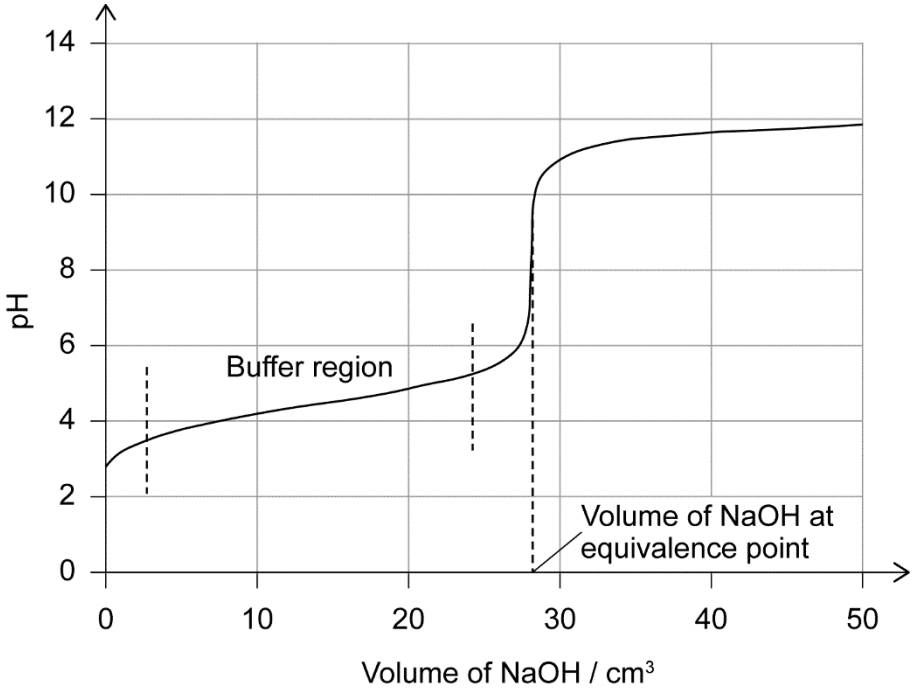
Question			Answers	Notes	Total
3.	**c**	**ii**	*bonds broken:* 7(C–H) + C–O + O–H + 2(C–C) + 4.5(O=O) ***OR*** 7(414 **«**kJ mol^{-1}**»**) + 358 **«**kJ mol^{-1}**»** + 463 **«**kJ mol^{-1}**»** + 2(346 **«**kJ mol^{-1}**»**) + 4.5(498 **«**kJ mol^{-1}**»**) / 6652 **«**kJ**»** ✓ *bonds formed:* 6(C=O) + 8(O–H) ***OR*** 6(804 **«**kJ mol^{-1}**»**) + 8(463 **«**kJ mol^{-1}**»**) / 8528 **«**kJ**»** ✓ **«**ΔH = bonds broken − bonds formed = 6652 – 8528 =**»** −1876 **«**kJ mol^{-1}**»** ✓	*Award **[3]** for correct final answer.*	**3**
3.	**d**	**i**	$K_2Cr_2O_7$/$Cr_2O_7^{2-}$/**«**potassium**»** dichromate **«**(VI)**»** ***AND*** acidified/H^+ ***OR*** **«**acidified potassium**»** manganate(VII) / **«**H^+ and**»** $KMnO_4$ / **«**H^+ and**»** MnO_4^- ✓	*Accept "H_2SO_4" or "H_3PO_4" for "H^+".* *Do **not** accept HCl.* *Accept "permanganate" for "manganate(VII)".*	**1**

(continued…)

(Question 3d continued)

Question			Answers	Notes	Total
3.	**d**	**ii**	C_3H_8O/propan-2-ol: hydrogen-bonding ***AND*** C_3H_6O/propanone: no hydrogen bonding/**«**only**»** dipole–dipole/dispersion forces ✓ hydrogen bonding stronger **«**than dipole–dipole**»** ✓		**2**
3.	**d**	**iii**	only one hydrogen environment ***OR*** methyl groups symmetrical **«**around carbonyl group**»** ✓	*Accept "all hydrogens belong to methyl groups **«**which are in identical positions**»**".*	**1**
3.	**e**		 ✓	*Continuation bonds must be shown.* *Methyl groups may be drawn on opposite sides of the chain or head to tail.* *Ignore square brackets and "n".*	**1**

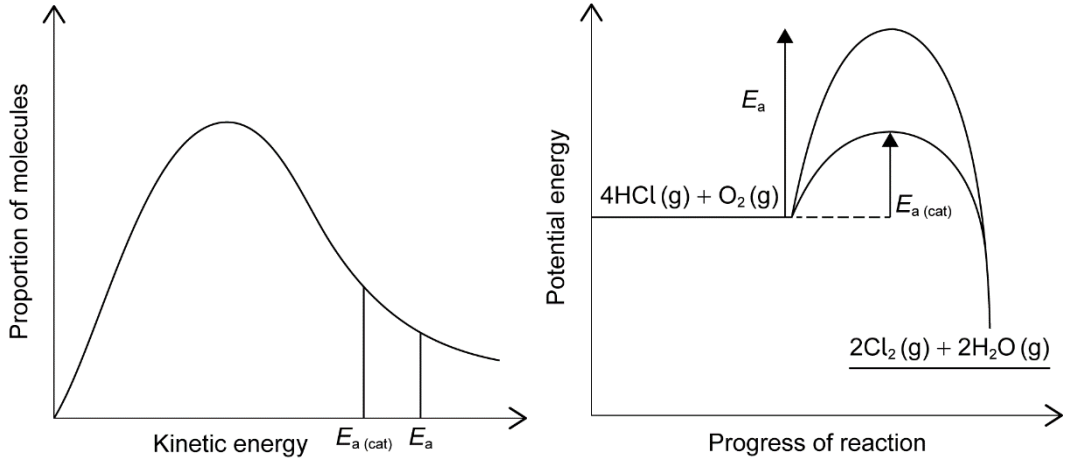
<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>4.</td><td>a</td><td>i</td><td>$C_6H_8O_7$ AND $C_6H_7O_7^-$
OR
H_2O AND H_3O^+ ✓</td><td></td><td>1</td></tr>
<tr><td>4.</td><td>a</td><td>ii</td><td>weak acid AND partially dissociated
OR
weak acid AND equilibrium lies to left
OR
weak acid AND $K_a < 1$ ✓</td><td></td><td>1</td></tr>
<tr><td>4.</td><td>a</td><td>iii</td><td><table><tr><th>Effect on $[H^+]$</th><th>Effect on K_a^+</th></tr><tr><td>increases ✓</td><td>increases ✓</td></tr></table></td><td></td><td>2</td></tr>
<tr><td>4.</td><td>a</td><td>iv</td><td>«$\Delta G^\ominus = -RT\ln K = -8.31\,\text{J K}^{-1}\,\text{mol}^{-1} \times 298\,\text{K} \times \ln(5.01 \times 10^{-4}) \div 1000 =$» 18.8
«kJ mol^{-1}» ✓</td><td></td><td>1</td></tr>
<tr><td>4.</td><td>a</td><td>v</td><td>non-spontaneous AND $\Delta G^\ominus$ positive ✓</td><td></td><td>1</td></tr>
<tr><td>4.</td><td>b</td><td></td><td>Any two of:
«electrical» conductivity AND HCl greater ✓
pH AND citric acid higher ✓
titrate with strong base AND pH at equivalence higher for citric acid ✓
add reactive metal/carbonate/hydrogen carbonate AND stronger effervescence/faster reaction with HCl ✓
titration AND volume of alkali for complete neutralisation greater for citric acid ✓</td><td>Accept “add universal indicator AND HCl more red/pink” for M2.
Accept any acid reaction AND HCl greater rise in temperature.
Accept specific examples throughout.
Do not accept “smell” or “taste”.</td><td>2 max</td></tr>
</table>

			titrate with strong base ***AND*** more than one equivalence point for complete neutralisation of citric acid ✓ titrate with strong base ***AND*** buffer zone with citric acid ✓		
Question			**Answers**	**Notes**	**Total**
5.	**a**		 buffer region on graph ✓ equivalence point/V_{eq} on graph ✓	*Construction lines not required.*	**2**
5.	**b**	**i**	phenolphthalein ✓	*Accept phenol red.*	**1**

(continued…)

(Question 5b continued)

Question			Answers	Notes	Total
5.	**b**	**ii**	***ALTERNATIVE 1:*** $H^+(aq) + CH_3COO^-(aq) \rightarrow CH_3COOH(aq)$ ✓ added acid neutralised by ethanoate ions ***OR*** **«**weak**»** $CH_3COOH(aq)$/ethanoic acid replaces $H^+(aq)$ ***OR*** CH_3COOH/CH_3COO^- ratio virtually/mostly unchanged ✓ ***ALTERNATIVE 2:*** $CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)$ ✓ equilibrium shifts to the ethanoic acid side ***OR*** CH_3COOH/CH_3COO^- ratio virtually/mostly unchanged ✓		**2**

Question			Answers	Notes	Total
6.	a	i	[Ar] $3d^{10}$ ***OR*** $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}$ ✓		1
6.	a	ii	$\Delta H^{\ominus} = \sum \Delta H^{\ominus}_f$ (products) $- \sum \Delta H^{\ominus}_f$ (reactants) ✓ $\Delta H^{\ominus} = 2(-241.8$ «kJ mol^{-1}») $- 4(-92.3$ «kJ mol^{-1}») $= -114.4$ «kJ» ✓	*Award **[2]** for correct final answer.*	2
6.	a	iii	 $E_{a\ (cat)}$ to the left of E_a ✓ peak lower ***AND*** $E_{a\ (cat)}$ smaller ✓		2
6.	a	iv	«catalyst provides an» alternative pathway ✓ «with» lower E_a *OR* higher proportion of/more particles with «kinetic» $E \geq E_{a(cat)}$ «than E_a» ✓		2

Question			Answers	Notes	Total
6.	**b**		mass of H_2O = **«**18.360 g – 17.917 g =**»** 0.443 **«**g**»** ***AND*** mass of $CuCl_2$ = **«**17.917 g – 16.221 g =**»** 1.696 **«**g**»** ✓ moles of $H_2O = \text{«}\frac{0.443\text{ g}}{18.02\text{ g mol}^{-1}}\text{=»}$ 0.0246 **«**mol**»** ***OR*** moles of $CuCl_2 = \text{«}\frac{1.696\text{ g}}{134.45\text{ g mol}^{-1}}\text{= »}$ 0.0126 **«**mol**»** ✓ **«**water : copper(II) chloride = 1.95 : 1**»** **«**x =**»** 2 ✓	*Award **[3]** for correct final answer.* *Accept **«**x =**»** 1.95.*	**3**
6.	**c**	**i**	*Wires:* **«**delocalized**»** electrons **«**flow**»** ✓ *Electrolyte:* **«**mobile**»** ions **«**flow**»** ✓		**2**
6.	**c**	**ii**	$2Cl^- \rightarrow Cl_2\,(g) + 2e^-$ ***OR*** $Cl^- \rightarrow \frac{1}{2}Cl_2\,(g) + e^-$ ✓	*Accept e for* e^-.	**1**
6.	**c**	**iii**	**«**electrode**»** 3 ***AND*** oxygen/O_2 ✓	*Accept chlorine/Cl_2.*	**1**
6.	**c**	**iv**	$2H_2O\,(l) \rightarrow 4H^+\,(aq) + O_2\,(g) + 4e^-$ ✓	*Accept $2Cl^-\,(aq) \rightarrow Cl_2\,(g) + 2e^-$.* *Accept $4OH^- \rightarrow 2H_2O + O_2 + 4e^-$*	**1**

Question			Answers	Notes	Total
6.	d		enthalpy of solution = lattice enthalpy + enthalpies of hydration «of Cu^{2+} and Cl^-» ✓ «+2824 kJ mol^{-1} − 2161 kJ mol^{-1} − 2(359 kJ mol^{-1}) =» −55 «kJ mol^{-1}» ✓	*Accept enthalpy cycle.* *Award **[2]** for correct final answer.*	**2**
6.	e	i	$E^{\ominus}$ = «+0.52 – 0.15 = +» 0.37 «V» ✓		**1**
6.	e	ii	spontaneous ***AND*** $E^{\ominus}$ positive ✓		**1**
6.	e	iii	$\Delta G^{\ominus}$ = «$-nFE$ = −1 mol × 96 500 C Mol^{-1} × 0.37 V=» −36 000 J/−36 kJ ✓	*Accept "−18 kJ mol^{-1} «per mole of Cu^+»".* *Do **not** accept values of n other than 1.* *Apply SF in this question.* *Accept J/kJ or J mol^{-1}/kJ mol^{-1} for units.*	**1**
6.	e	iv	2 mol (aq) → 1 mol (aq) ***AND*** decreases ✓	*Accept "solid formed from aqueous solution **AND** decreases".* *Do **not** accept 2 mol → 1 mol without (aq).*	**1**
6.	e	v	$\Delta G^{\ominus} < 0$ ***AND*** $\Delta S^{\ominus} < 0$ ***AND*** $\Delta H^{\ominus} < 0$ ***OR*** $\Delta G^{\ominus} + T\Delta S^{\ominus} < 0$ ***AND*** $\Delta H^{\ominus} < 0$ ✓		**1**

(continued…)

(Question 6e continued)

Question			Answers	Notes	Total
6.	**e**	**vi**	$T\Delta S$ more negative **«**reducing spontaneity**»** ***AND*** stability increases ✓	*Accept calculation showing non-spontaneity at 433 K.*	**1**
6.	**f**	**i**	**«**ligands cause**»** d-orbitals **«**to**»** split ✓ light absorbed as electrons transit to higher energy level **«**in d–d transitions**»** ***OR*** light absorbed as electrons promoted ✓ energy gap corresponds to **«**orange**»** light in visible region of spectrum ✓ colour observed is complementary ✓		**3 max**
6.	**f**	**ii**	full **«**3**»**d sub-level/orbitals ***OR*** no d–d transition possible **«**and therefore no colour**»** ✓		**1**
6.	**f**	**iii**	octahedral ***AND*** 90° **«**180° for axial**»** ✓	*Accept square-based bi-pyramid.*	**1**
6.	**f**	**iv**	*Any **two** of:* ligand/chloride ion Lewis base ***AND*** donates e-pair ✓ not Brønsted–Lowry base ***AND*** does not accept proton/H^+ ✓ Lewis definition extends/broader than Brønsted–Lowry definition ✓		**2 max**

Question			Answers	Notes	Total
7.	a	i	$C(NH_2)_3NO_3\,(s) \rightarrow 2N_2\,(g) + 3H_2O\,(g) + C\,(s)$ ✓		1
7.	a	ii	moles of gas = «$5 \times \frac{10.0\,g}{122.11\,g\,mol^{-1}}$ =» 0.409 «mol» ✓		1
7.	a	iii	«$p = \frac{0.409\,mol \times 8.31\,J\,K^{-1}\,mol^{-1} \times (127 + 273)\,K}{10.0\,dm^3}$ » = 136 «kPa» ✓		1
7.	a	iv	*Any **two** of:* nitrogen non-polar/London/dispersion forces ***AND*** water polar/H-bonding ✓ water has «much» stronger intermolecular forces ✓ water molecules attract/condense/occupy smaller volume «and therefore deviate from ideal behaviour» ✓		2 max
7.	b		$2Na\,(s) + 2H_2O\,(l) \rightarrow 2NaOH\,(aq) + H_2\,(g)$ ✓ hydrogen explosive ***OR*** highly exothermic reaction ***OR*** sodium reacts violently with water ***OR*** forms strong alkali ✓	*Accept the equation of combustion of hydrogen.* *Do **not** accept just "sodium is reactive/dangerous".*	2