

Markscheme

May 2016

Chemistry

Higher level

Paper 2

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Subject Details: Chemistry HL Paper 2 Markscheme

Mark Allocation

Candidates are required to answer **ALL** questions. Maximum total = **[95 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	i	$\begin{array}{c} \text{H} - \overset{\ominus}{\text{P}} - \text{H} \\ \\ \text{H} \end{array} \quad \checkmark$	Accept structures using dots and/or crosses to indicate bonds and/or lone pair.	1
1.	a	ii	sp ³ ✓	Do not allow ECF from a (i).	1
1.	a	iii	Lewis base AND has a lone pair of electrons «to donate» ✓		1
1.	a	iv	non-polar AND P and H have the same electronegativity ✓	Accept “similar electronegativities”. Accept “polar” if there is a reference to a small difference in electronegativity and apply ECF in 1 a (v).	1
1.	a	v	PH ₃ has London «dispersion» forces ✓ NH ₃ forms H-bonds ✓ H-bonds are stronger OR London forces are weaker ✓	Accept van der Waals’ forces, dispersion forces and instantaneous dipole – induced dipole forces. Accept “dipole-dipole forces” as molecule is polar. H-bonds in NH ₃ (only) must be mentioned to score [2]. Do not award M2 or M3 if: <ul style="list-style-type: none"> • implies covalent bond is the H-bond • implies covalent bonds break. Accept “dipole-dipole forces are weaker”.	2 max
1.	a	vi	Weak: only partially dissociated/ionized «in dilute aqueous solution» ✓ Brønsted–Lowry base: an acceptor of protons/H ⁺ /hydrogen ions ✓	Accept reaction with water is reversible/an equilibrium. Accept “water is partially dissociated «by the weak base»”. Accept “not fully” for “partially”.	2
1.	b	i	P ₄ is a molecule «comprising 4P atoms» AND 4P is four/separate «P» atoms OR P ₄ represents «4P» atoms bonded together AND 4P represents «4» separate/non-bonded «P» atoms ✓	Accept “4 P is 4 mol of P” for ‘ AND ’ statements.	1

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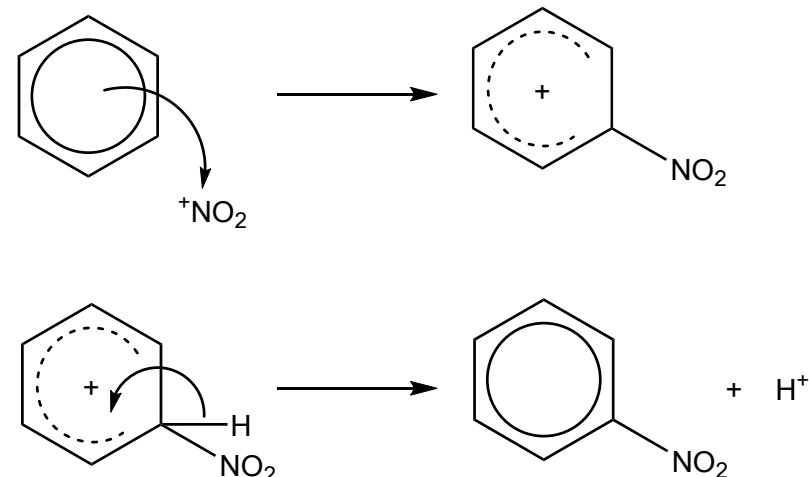
Question			Answers	Notes	Total
1.	b	ii	can act as both a «Brønsted–Lowry» acid and a «Brønsted–Lowry» base OR can accept and/or donate a hydrogen ion/proton/H ⁺ ✓ HPO ₂ ²⁻ AND H ₃ PO ₂ ✓	Accept “reacts with both acids and bases”.	2
1.	b	iii	P ₄ : 0 ✓ H ₂ PO ₂ ⁻ : +1 ✓	Accept Roman numerals notations. Do not accept 1 or 1+ for H ₂ PO ₂ ⁻ .	2
1.	b	iv	oxygen gained, so could be oxidation ✓ hydrogen gained, so could be reduction OR negative charge «on product/H ₂ PO ₂ ⁻ »/gain of electrons, so could be reduction ✓ oxidation number increases so must be oxidation ✓	Award [1 max] for M1 and M2 if candidate displays knowledge of at least two of these definitions but does not apply them to the reaction. Do not award M3 for “oxidation number changes”.	3
1.	c	i	$\left\langle \frac{2.478}{4 \times 30.97} \right\rangle = 0.02000$ «mol» ✓	Accept answers using A _r (P) = 31.	1
1.	c	ii	n(NaOH) = «0.1000 × 5.00 ⇒ 0.500 «mol» AND P ₄ /phosphorus is limiting reagent ✓	Accept $n(\text{H}_2\text{O}) = \frac{100}{18} = 5.50$ AND P ₄ is limiting reagent.	1
1.	c	iii	amount in excess «= 0.500 – (3 × 0.02000)» = 0.440 «mol» ✓		1
1.	c	iv	«22.7 × 1000 × 0.02000» = 454 «cm ³ » ✓	Accept «22.4 × 1000 × 0.02000 ⇒ 448 «cm ³ ». Accept methods employing pV = nRT, with p as either 100 (454 cm ³) or 101.3 kPa (448 cm ³). Do not accept answers in dm ³ .	1
1.	d	i	temperature rise «= $\frac{750 \times 1.00}{0.2000 \times 1.00}$ » = 3750 «°C/K» ✓	Do not accept –3750.	1

(continued)

Question			Answers	Notes	Total
1.	d	ii	$n(\text{P}) \llcorner = \frac{43.6}{30.97} \llcorner = 1.41 \llcorner \text{mol} \llcorner \checkmark$ $n(\text{O}) \llcorner = \frac{100 - 43.6}{16.00} \llcorner = 3.53 \llcorner \text{mol} \llcorner \checkmark$ $\llcorner \frac{n(\text{O})}{n(\text{P})} = \frac{3.53}{1.41} = 2.50 \llcorner \text{ so empirical formula is} \llcorner \text{P}_2\text{O}_5 \llcorner \checkmark$	<p>Accept other methods where the working is shown.</p> <p>Accept answer using $A_r(\text{P}) = 31$ (which gives the same ratios).</p>	3
1.	d	iii	$\llcorner \frac{285}{141.9} = 2.00 \llcorner \text{ , so molecular formula} = 2 \times \text{P}_2\text{O}_5 \llcorner \Rightarrow \text{P}_4\text{O}_{10} \llcorner \checkmark$	<p>Accept "process" of dividing 285 by empirical mass (answer to d (ii)) even if final formula not possible.</p>	1
1.	d	iv	$\text{P}_4\text{O}_{10}(\text{s}) + 6\text{H}_2\text{O}(\text{l}) \rightarrow 4\text{H}_3\text{PO}_4(\text{aq}) \llcorner \checkmark$	<p>Accept $\text{P}_4\text{O}_{10}(\text{s}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow 4\text{HPO}_3(\text{aq})$ (initial reaction)</p> <p>Accept $\text{P}_2\text{O}_5(\text{s}) + 3\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{H}_3\text{PO}_4(\text{aq})$</p> <p>Accept equations for $\text{P}_4\text{O}_6/\text{P}_2\text{O}_3$ if given in d (iii).</p> <p>Accept any ionized form of the acids as the products.</p> <p>Accept equilibrium sign in equation.</p>	1
1.	d	v	<p>phosphorus not commonly found in fuels OR no common pathways for phosphorus oxides to enter the air OR amount of phosphorus-containing organic matter undergoing anaerobic decomposition is small \checkmark</p>	<p>Accept "phosphorus oxides are solids so are not easily distributed in the atmosphere".</p> <p>Accept "low levels of phosphorus oxide in the air".</p> <p>Do not accept "H_3PO_4 is a weak acid".</p>	1
1.	d	vi	<p><i>Pre-combustion:</i> remove sulfur/S/sulfur containing compounds \checkmark</p> <p><i>Post-combustion:</i> remove it/SO_2 by neutralization/reaction with alkali/base \checkmark</p>	<p>Accept "lime injection fluidised bed combustion" for either, but not both.</p>	2

Question			Answers	Notes	Total
2.	a	i	$K_c = \frac{[\text{COCl}_2]}{[\text{CO}][\text{Cl}_2]} \checkmark$		1
2.	a	ii	$T = 600 + 273 = 873\text{K} \checkmark$ $\Delta G^\ominus = -8.31 \times 873 \times \ln(0.200)$ OR $\Delta G^\ominus = +11676 \text{ J} \checkmark$ $\Delta G^\ominus = +11.7 \text{ kJ} \checkmark$	Accept 11.5 to 12.0. Award final mark only if correct sig fig. Award [3] for correct final answer.	3
2.	a	iii	$\Delta H^\ominus = -220.1 - (-110.5) \checkmark$ $\Delta H^\ominus = -109.6 \text{ kJ} \checkmark$	Award [2] for correct final answer. Award [1] for -330.6 , or $+109.6 \text{ kJ}$.	2
2.	a	iv	$\Delta G^\ominus = -109.6 - (298 \times \Delta S^\ominus) = +11.7 \text{ kJ} \checkmark$ $\Delta S^\ominus = -\frac{(11.7 + 109.6) \times 10^3}{298} = -407 \text{ J K}^{-1} \checkmark$	Award [2] for correct final answer. Award [2] for -470 J K^{-1} (result from given values). Do not penalize wrong value for T if already done in (a)(ii). Award [1 max] for -0.407 kJ K^{-1} . Award [1 max] for -138.9 J K^{-1} .	2
2.	b	i	primary \checkmark		1
2.	b	ii	ALTERNATIVE 1: «heat with» tin/Sn AND hydrochloric acid/HCl \checkmark aqueous alkali/OH ⁻ (aq) \checkmark ALTERNATIVE 2: hydrogen/H ₂ \checkmark nickel/Ni «catalyst» \checkmark	Accept any reactive metal with any strong non-oxidizing acid. Accept specific equations having correct reactants. Do not accept LiAlH ₄ or NaBH ₄ . Accept Pt or Pd catalyst. Accept equations having correct reactants.	2

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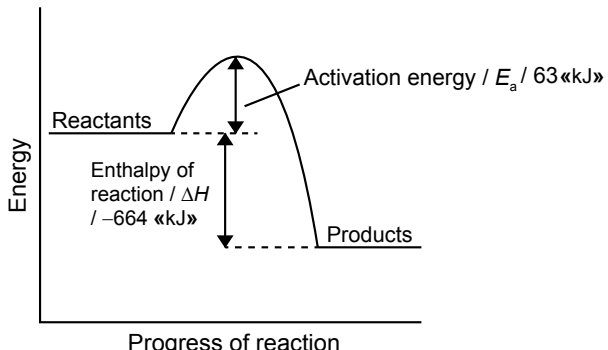
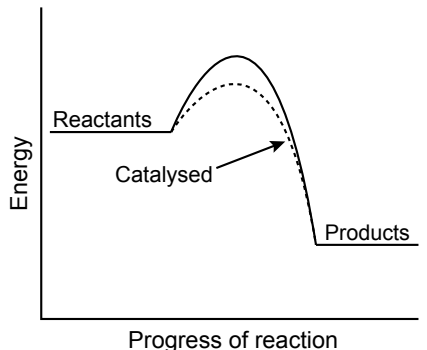
Question			Answers	Notes	Total
2.	b	iii	$\text{HNO}_3 + 2\text{H}_2\text{SO}_4 \rightleftharpoons \text{NO}_2^+ + 2\text{HSO}_4^- + \text{H}_3\text{O}^+ \checkmark$	<p>Accept: $\text{HNO}_3 + \text{H}_2\text{SO}_4 \rightleftharpoons \text{NO}_2^+ + \text{HSO}_4^- + \text{H}_2\text{O}$ Accept $\text{HNO}_3 + \text{H}_2\text{SO}_4 \rightleftharpoons \text{H}_2\text{NO}_3^+ + \text{HSO}_4^-$. Accept a single arrow instead of an equilibrium sign. Accept equivalent two step reactions in which sulfuric acid first behaves as a strong acid and protonates the nitric acid, before behaving as a dehydrating agent removing water from it.</p>	1
2.	b	iv	 <p>curly arrow going from benzene ring to N of $^+\text{NO}_2/\text{NO}_2^+$ \checkmark carbocation with correct formula and positive charge on ring \checkmark curly arrow going from C-H bond to benzene ring of cation \checkmark formation of organic product nitrobenzene AND H^+ \checkmark</p>	<p>Accept mechanism with corresponding Kekulé structures. Do not accept a circle in M2 or M3. Accept first arrow starting either inside the circle or on the circle. M2 may be awarded from correct diagram for M3. M4: Accept $\text{C}_6\text{H}_5\text{NO}_2 + \text{H}_2\text{SO}_4$ if HSO_4^- used in M3.</p>	4

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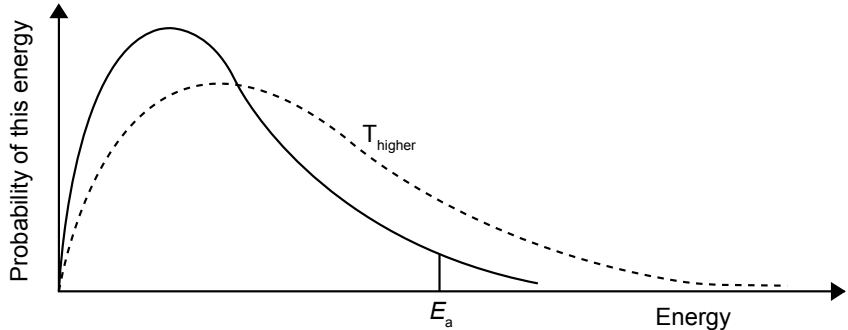
Question			Answers	Notes	Total
2.	c	i	Name: ethane-1,2-diol ✓ Class: alcohol«s» ✓	Accept ethan-1,2-diol / 1,2-ethanediol. Do not penalize minor errors with hyphens and commas. Accept "dialcohols". Do not accept "diol" for Class.	2
2.	c	ii	two AND two hydrogen environments in the molecule OR two AND both CH ₂ and OH present ✓		1
2.	c	iii	⁺ CH ₂ OH ✓	Accept CH ₃ O ⁺ . Accept [⁺ CH ₂ OH] and [⁺ CH ₃ O]. Do not accept answers in which the charge is missing.	1
2.	c	iv	oxygen-hydrogen «bond»/O–H «in hydroxyl» ✓	Accept –OH.	1
2.	d		$K_b \approx \frac{[\text{OH}^-]^2}{[\text{C}_6\text{H}_5\text{NH}_2]} = 10^{-9.13} / 7.413 \times 10^{-10} \checkmark$ $[\text{OH}^-] = \sqrt{0.0100 \times 10^{-9.13}} = 2.72 \times 10^{-6} \checkmark$ $[\text{H}^+] = \frac{1 \times 10^{-14}}{2.72 \times 10^{-6}} = 3.67 \times 10^{-9}$ OR pOH = 5.57 ✓ pH = -log [H ⁺] = 8.44 ✓	Accept other approaches to the calculation. Award [4] for correct final answer. Accept any answer from 8.4 to 8.5.	4

3.	a	i	$2\text{NO}(\text{g}) + 2\text{H}_2(\text{g}) \rightarrow \text{N}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g}) \checkmark$	<i>Accept equilibrium sign.</i>	1
3.	a	ii	rate = $k[\text{NO}]^2[\text{H}_2] \checkmark$		1
3.	a	iii	test the effect «on the reaction rate» of varying each concentration «independently» OR test the effect of varying [NO] «on rate», whilst keeping [H ₂] constant AND test effect of varying [H ₂] «on rate», whilst keeping [NO] constant ✓ rate proportional to [NO] ² OR doubling [NO] quadruples rate ✓ rate proportional to [H ₂] OR doubling [H ₂] doubles rate ✓	<i>Remember to refer back to a (ii) for ECF.</i> <i>If only one species in rate expression, third mark can be awarded for zero order discussion.</i>	3
3.	a	iv	no AND different mechanisms could give the same rate expression OR no AND mechanisms can only be disproved OR no AND just suggest it is consistent with the mechanism given OR no AND does not give information about what occurs after RDS ✓		1
3.	a	v	change of pressure «at constant volume and temperature» with time OR change of volume «at constant pressure and temperature» with time ✓	<i>Accept other methods where rate can be monitored with time.</i>	1

(continued)

Question			Answers	Notes	Total
3.	b	i	 <p>products lower than reactants AND enthalpy of reaction correctly marked and labelled with name or value ✓</p> <p>activation energy correctly marked and labelled with name or value ✓</p>	<p>Accept other clear ways of indicating energy/enthalpy changes. Reactant/product lines do not need to be labelled.</p>	2
3.	b	ii	 <p>lower dotted curve, between same reactants and products levels, labelled "Catalysed" ✓</p>	<p>Accept curve that is not labelled if it can be differentiated from the initial curve.</p>	1

(continued)

Question			Answers	Notes	Total
3.	b	iii	 <p>second curve at a higher temperature is correctly drawn (maximum lower and to right of original) ✓</p>	<p><i>Accept curve that is not labelled.</i></p> <p><i>Do not penalize if curve doesn't appear to go through origin or crosses x-axis.</i></p>	1
3.	b	iv	<p>greater proportion of molecules have $E \geq E_a$ or $E > E_a$ OR greater area under curve to the right of the E_a ✓</p> <p>greater frequency of collisions «between molecules» OR more collisions per unit time/second ✓</p>	<p><i>Accept more molecules have energy greater than E_a.</i></p> <p><i>Do not accept just particles have greater kinetic energy.</i> <i>Accept "chance/probability/likelihood" instead of "frequency".</i> <i>Do not accept just "more collisions".</i></p>	2

(continued)

Question			Answers	Notes	Total
3.	c	i	<p>ALTERNATIVE 1: σ-bond from N to N AND from N to O ✓</p> <p>π-bond from N to N ✓</p> <p><u>delocalized</u> π-bond/π-electrons «extending over the oxygen and both nitrogens» ✓</p> <p>ALTERNATIVE 2: both have 2 σ-bonds «from N to N and from N to O» AND π-bond from N to N ✓</p> <p>one structure has second π-bond from N to N and the other has π-bond from N to O ✓</p> <p>delocalized π-bond/π-electrons ✓</p>	<p><i>Award [1 max] if candidate has identified both/either structure having 2 σ-bonds and 2 π-bonds.</i></p>	3
3.	c	ii	<p>more than one possible position for a multiple/π-/π-bond ✓</p>	<p><i>Accept "more than one possible Lewis structure".</i></p> <p><i>Accept reference to delocalisation if M3 not awarded in c (i).</i></p> <p><i>Accept reference to fractional bond orders.</i></p>	1

4.	a	i	same charge AND same/similar ionic radius ✓		1
4.	a	ii	enthalpy of hydration «= -1483 + 2(-359)» = -2201 «kJ mol ⁻¹ » ✓ enthalpy of solution «= 2170 - 2201» = -31 «kJ mol ⁻¹ » ✓	Award [2] for correct final answer. Award [1 max] for +31 «kJ mol ⁻¹ ». Award [1 max] for ±4371.	2
4.	a	iii	hydrochloric acid shifts equilibrium to left OR hydrochloric acid prevents the basic chloride forming/precipitating ✓	Accept "hydrochloric acid reacts with «basic» chloride" OR "hydrochloric acid suppresses salt hydrolysis".	1
4.	b	i	E^\ominus «= 0.34 - 0.15» = 0.19 «V» ✓ ΔG^\ominus «= -nFE [⊖] = -2 × 96500 × 0.19» = -36670 / -37000 «J» / -37 «kJ» ✓	Accept -18335 «J» or -18 «kJ» as equation not specified.	2
4.	b	ii	yes AND ΔG^\ominus is negative OR yes AND E^\ominus for the cell is positive OR yes AND Sn ²⁺ (aq) is a stronger reducing agent than V ³⁺ (aq) OR yes AND E^\ominus for Sn ⁴⁺ (aq) is more negative than E^\ominus for VO ²⁺ (aq) OR yes AND VO ²⁺ (aq) is a stronger oxidizing agent than Sn ⁴⁺ (aq) OR yes AND E^\ominus for VO ²⁺ (aq) is more positive than E^\ominus for Sn ⁴⁺ (aq) ✓	Do not accept reference to anti-clockwise rule.	1
4.	c		1s ² 2s ² 2p ⁶ 3s ² 3p ⁶ 3d ³ 4s ² OR 1s ² 2s ² 2p ⁶ 3s ² 3p ⁶ 4s ² 3d ³ ✓ incomplete d «sub-» level/orbital/shell «in its compounds/ions» ✓		2
4.	d	i	give/donate a lone/non-bonding electron pair ✓	Accept "through the formation of a dative/coordinate bond". Accept "by acting as Lewis bases". Do not accept "act as ligands".	1

(continued)

Question			Answers	Notes	Total
4.	d	ii	<p>«more chlorido ligands» smaller energy gap between split d-orbitals OR Cl⁻ is lower than H₂O in spectrochemical series OR Cl⁻ is a weaker ligand/has lower charge density ✓</p> <p>the absorption will move to longer wavelengths OR the absorption wavelength will increase ✓</p>	<p>Accept “chloride ions/chlorides” for “chlorido ligands”.</p> <p>Do not accept answers in terms of change of frequency.</p>	2
4.	e	i	<p>First: 4s AND Second: 4s AND Third: 3d AND Fourth: 3d ✓</p>	<p>Do not apply ECF from (c).</p>	1
4.	e	ii	<p>«in the same sub-shell and a» decrease in electron-electron repulsion OR «in the same sub-shell and» as more electrons removed, the pull of of the nucleus/positive ions holds the remaining electrons more tightly ✓</p>	<p>Do not accept “greater nuclear charge/effective nuclear charge”.</p> <p>Accept “removing electron from ion with increasing charge”.</p> <p>Accept “increase in attraction between nucleus and outer electrons «as e⁻ removed»”.</p>	1
4.	e	iii	<p>electron 5 is lost from the 3d orbital OR electron 5 is lost from the valence shell ✓</p> <p>electron 6 is lost from a 3p orbital OR electron 6 is lost from a «complete» inner shell ✓</p> <p>3p orbital/complete inner shell experiences a much larger effective nuclear charge OR 3p orbital/complete inner shell is less well shielded OR 3p orbital/complete inner shell is nearer the nucleus ✓</p>	<p>Award [1 max] (for M1/M2) (ECF) if candidate recognises electrons 5 and 6 are from different levels.</p>	3
4.	e	iv	<p>28 ✓</p>		1

5.	a	i	«structural/functional» isomer«s» ✓		1															
5.	a	ii	<p><i>Test:</i> «react with» bromine/Br₂ «in the dark» OR «react with» bromine water/Br₂(aq) «in the dark» ✓</p> <p>A: from yellow/orange/brown to colourless AND B: colour remains/slowly decolourized ✓</p>	<p>Accept other correct reagents, such as manganate(VII) or iodine solutions, and descriptions of the corresponding changes observed.</p> <p>Accept “decolourized” for A and “not decolourized/unchanged” for B. Do not accept “clear/transparent” instead of “colourless”.</p>	2															
5.	b		compound A would absorb at 1620–1680 «cm ⁻¹ » ✓	Accept any value in range 1620 – 1680 cm ⁻¹ .	1															
5.	c		<table style="width: 100%; border-collapse: collapse;"> <tr> <td style="text-align: center;">Signal</td> <td style="text-align: center;">1/2</td> <td style="text-align: center;">AND</td> <td style="text-align: center;">2/1</td> <td></td> </tr> <tr> <td style="text-align: center;"><i>Chemical shift / ppm</i></td> <td style="text-align: center;">0.9 – 1.0</td> <td style="text-align: center;">AND</td> <td style="text-align: center;">4.5 – 6.0</td> <td style="text-align: center;">✓</td> </tr> <tr> <td style="text-align: center;"><i>Splitting pattern</i></td> <td style="text-align: center;">singlet</td> <td style="text-align: center;">AND</td> <td style="text-align: center;">singlet</td> <td style="text-align: center;">✓</td> </tr> </table>	Signal	1/2	AND	2/1		<i>Chemical shift / ppm</i>	0.9 – 1.0	AND	4.5 – 6.0	✓	<i>Splitting pattern</i>	singlet	AND	singlet	✓	<p>Accept 0.9 to 2.0 for the first signal as the C=C affects the CH₃ shift (actually 1.7).</p> <p>Accept “none/no splitting” for both splitting patterns.</p> <p>Award [1 max] for the correct deduction (both shift and splitting) of signal 1 or 2.</p>	2
Signal	1/2	AND	2/1																	
<i>Chemical shift / ppm</i>	0.9 – 1.0	AND	4.5 – 6.0	✓																
<i>Splitting pattern</i>	singlet	AND	singlet	✓																