Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

May 2018

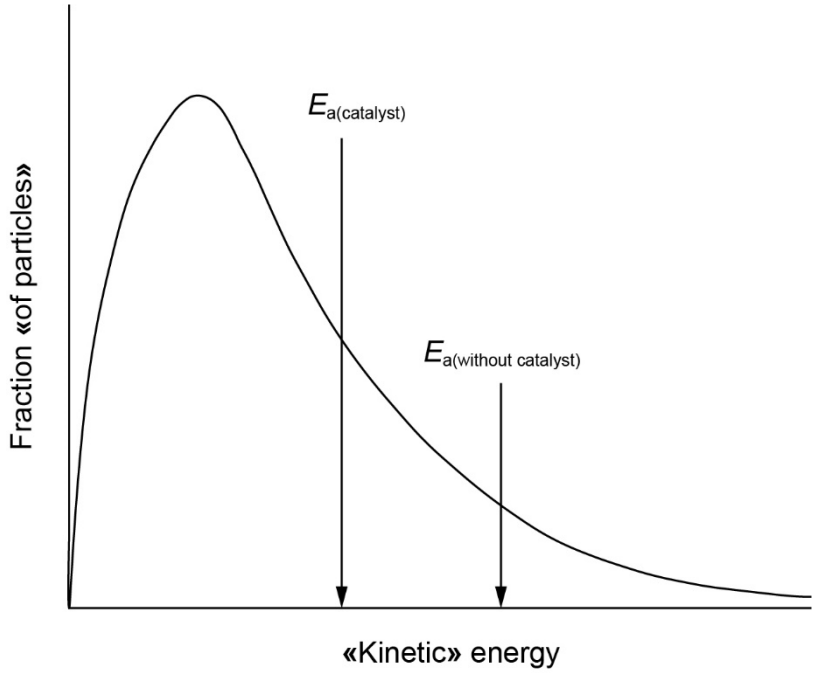
Chemistry

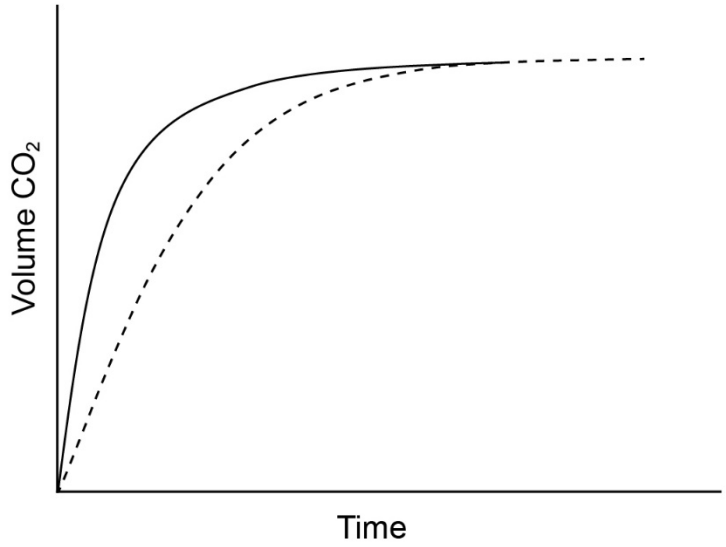
Higher level

Paper 2

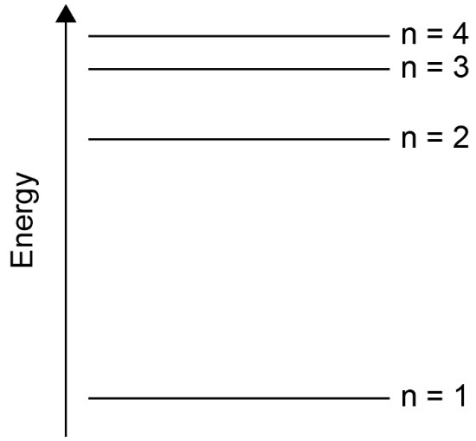
22 pages

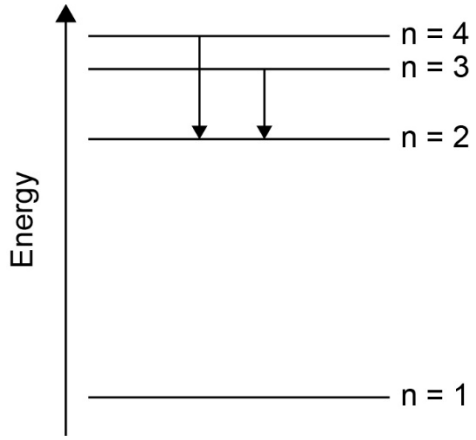
Question			Answers	Notes	Total
1.	a		$n(H_2SO_4)$ «= 0.0500 dm^3 × 0.100 mol dm^{-3}» = 0.00500/5.00 × 10^{-3}«mol» ✓		1
1.	b		$H_2SO_4(aq) + Mg(OH)_2(s) \rightarrow MgSO_4(aq) + 2H_2O(l)$ ✓	*Accept an ionic equation.*	1
1.	c		«$n(H_2SO_4) = \frac{1}{2} \times n(NaOH) = \frac{1}{2}$ (0.02080 dm^3 × 0.1133 mol dm^{-3})» 0.001178/1.178 × 10^{-3} «mol» ✓		1
1.	d		$n(H_2SO_4)$ reacted «= 0.00500 – 0.001178» = 0.00382/3.82 × 10^{-3} «mol» ✓		1
1.	e		$n(Mg(OH)_2)$ «= $n(H_2SO_4)$ =» = 0.00382/3.82 × 10^{-3} «mol» ✓ $m(Mg(OH)_2)$ «= 0.00382 mol × 58.33 g mol^{-1}» = 0.223 «g» ✓	*Award **[2]** for correct final answer.*	2
1.	f		% $Mg(OH)_2$ «= $\frac{0.223\ g}{1.24\ g}$ × 100» = 18.0 «%» ✓	*Answer must show three significant figures.*	1
1.	g		to reduce random errors ***OR*** to increase precision ✓	*Accept "to ensure reliability".*	1

Question			Answers	Notes	Total
2.	a		 both axes correctly labelled ✓ correct shape of curve starting at origin ✓ $E_{a(catalyst)} < E_{a(without\ catalyst)}$ on x-axis ✓	*M1:* *Accept "speed" for x-axis label.* *Accept "number of particles", "N", "frequency" or "probability «density»" for y-axis label.* *Do **not** accept "potential energy" for x-axis label.* *M2:* *Do **not** accept a curve that touches the x-axis at high energy.* *Do **not** award M2 if two curves are drawn.* *M3:* *Ignore any shading under the curve.*	**3**

Question			Answers	Notes	Total
2.	b	i	 curve starting from origin with steeper gradient ***AND*** reaching same maximum volume ✓		1
2.	b	ii	rate decreases ***OR*** slower reaction ✓ «ethanoic acid» partially dissociated/ionized «in solution/water» ***OR*** lower $[H^+]$ ✓	*Accept "weak acid" or "higher pH"*.	2

Question			Answers	Notes	Total
2.	c		«pH» converts «wide range of $[H^+]$» into simple «log» scale/numbers ***OR*** «pH» avoids need for exponential/scientific notation ***OR*** «pH» converts small numbers into values «typically» between 0/1 and 14 ***OR*** «pH» allows easy comparison of values of $[H^+]$ ✓	*Accept "uses values between 0/1 and 14".* *Do **not** accept "easier to use".* *Do **not** accept "easier for calculations".*	**1**
2.	d	i	A: CH_3COOH/ethanoic/acetic acid ***AND*** CH_3COO^-/ethanoate/acetate ions ✓ B: CH_3COO^-/ethanoate/acetate ions ✓	*Penalize "sodium ethanoate/acetate" instead of "ethanoate/acetate ions" only once.*	**2**
2.	d	ii	$K_a = 1.74 \times 10^{-5} = \frac{[H^+]^2}{0.10}$ ***OR*** $[H^+] = 1.32 \times 10^{-3}$ «mol dm^{-3}» ✓ «pH =» 2.88 ✓	*Accept **[2]** for correct final answer.*	**2**
2.	d	iii	«forms weak acid and strong base, thus basic» $CH_3COO^-(aq) + H_2O(l) \rightleftharpoons CH_3COOH(aq) + OH^-(aq)$ ✓	*Accept* → *for* ⇌.	**1**
2.	d	iv	less than 7 ✓		**1**

Question			Answers	Notes	Total
2.	e	i	$2NO_2\,(g) + H_2O\,(l) \rightarrow HNO_2\,(aq) + HNO_3\,(aq)$ ✓		1
2.	e	ii	$2HNO_2\,(aq) + CaCO_3\,(s) \rightarrow Ca(NO_2)_2\,(aq) + CO_2\,(g) + H_2O\,(l)$ ***OR*** $2HNO_3\,(aq) + CaCO_3\,(s) \rightarrow Ca(NO_3)_2\,(aq) + CO_2\,(g) + H_2O\,(l)$ ✓		1
3.	a	i	 4 levels showing convergence at higher energy ✓		1

Question			Answers	Notes	Total
3.	a	ii	 arrows (pointing down) from n = 3 to n = 2 ***AND*** n = 4 to n = 2 ✓		**1**

(continued…)

(Question 3a continued)

Question			Answers	Notes	Total
3.	a	iii	IE «$= \Delta E = h\nu = 6.63 \times 10^{-34}$ J s $\times 3.28 \times 10^{15}$ s^{-1}» $= 2.17 \times 10^{-18}$ «J» ✓		1
3.	a	iv	«$\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^{8}\ ms^{-1}}{3.28 \times 10^{15}\ s^{-1}}$ =» 9.15×10^{-8} «m» ✓		1
3.	b	i	same number of shells/«outer» energy level/shielding ***AND*** nuclear charge/number of protons/Z_{eff} increases «causing a stronger pull on the outer electrons» ✓		1
3.	b	ii	K^+ 19 protons ***AND*** Cl^- 17 protons ***OR*** K^+ has «two» more protons ✓ same number of electrons/isoelectronic «thus pulled closer together» ✓		2
3.	c	i			1
3.	c	ii	*Anode (positive electrode):* $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$ ✓ *Cathode (negative electrode):* $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ ✓	*Accept* $Cu(s) - 2e^- \rightarrow Cu^{2+}(aq)$. *Accept* $\rightleftharpoons$ *for* $\rightarrow$. *Award* ***[1 max]*** *if the equations are at the wrong electrodes.*	2

(continued…)

(Question 3c continued)

Question			Answers	Notes	Total
3.	**c**	**iii**	«external» circuit/wire ***AND*** from positive/anode to negative/cathode electrode ✓	*Accept "through power supply/battery" instead of "circuit".*	**1**
3.	**c**	**iv**	no change «in colour» ✓	*Do **not** accept "solution around cathode will become paler and solution around the anode will become darker".*	**1**
3.	**c**	**v**	oxygen/O_2 ✓	*Accept "carbon dioxide/CO_2".*	**1**
3.	**d**		*Transition metals*: «contain» d and s orbitals «which are close in energy» ***OR*** «successive» ionization energies increase gradually ✓ *Alkali metals*: second electron removed from «much» lower energy level ***OR*** removal of second electron requires large increase in ionization energy ✓		**2**

Question			Answers	Notes	Total
4.	a		$BrO_3^-(aq) + 6H^+(aq) + 6I^-(aq) \rightleftharpoons Br^-(aq) + 3I_2(s) + 3H_2O(l)$ ✓	*Accept* $\rightarrow$ *for* $\rightleftharpoons$.	1
4.	b		n = 6 ✓ «$\Delta G^\ominus = -nFE^\ominus$» «$E^\ominus = -\frac{\Delta G^\ominus}{nF} = \frac{514 \times 10^3\ J\ mol^{-1}}{6 \times 9.65 \times 10^4\ C\ mol^{-1}}$ =» 0.888 «V» ✓		2
4.	c		«$E^\ominus = E^\ominus (BrO_3^-/Br^-) - E^\ominus (I_2/I^-)$» «$E^\ominus (BrO_3^-/Br^-) = E^\ominus + E^\ominus (I_2/I^-) = 0.888 + 0.54$ =» «+» 1.43 «V» ✓		1

Question			Answers	Notes	Total
5.	a		*bonds broken:* 4(C–H) + 2(H–O) / 4(414) + 2(463) / 2582 «kJ» ✓ *bonds made:* 3(H–H) + C≡O / 3(436) + 1077 / 2385 «kJ» ✓ ΔH «= $\sum BE_{(\text{bonds broken})} - \sum BE_{(\text{bonds made})} = 2582 - 2385$» = «+» 197 «kJ» ✓	*Award **[3]** for correct final answer.* *Award **[2 max]** for –197 «kJ».*	3
5.	b	i	$\Delta H_f^\ominus$ for any element = 0 «by definition» ***OR*** no energy required to form an element «in its stable form» from itself ✓		1
5.	b	ii	$\Delta H^\ominus$ « $= \sum \Delta H_{f\,(\text{products})}^\ominus - \sum \Delta H_{f\,(\text{reactants})}^\ominus = -111 + 0 - [-74.0 + (-242)]$» = «+» 205 «kJ» ✓		1
5.	b	iii	«bond enthalpies» averaged values «over similar compounds» ***OR*** «bond enthalpies» are not specific to these compounds ✓		1
5.	c		«$\Delta S^\ominus = \sum S^\ominus_{\text{products}} - \sum S^\ominus_{\text{reactants}} = 198 + 3 \times 131 - (186 + 189) =$» «+» 216 «J K^{-1}» ✓		1
5.	d		«$\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus = 205\text{ kJ} - 298\text{ K} \times \frac{216}{1000}\text{ kJ K}^{-1}$ =» «+» 141 «kJ» ✓		1

Question			Answers	Notes	Total
5.	**e**		«$\Delta H^{\ominus} = T\Delta S^{\ominus}$» «$T = \frac{\Delta H^{\ominus}}{\Delta S^{\ominus}} = \frac{205000\ J}{216\ J\ K^{-1}}$» «T =» 949 «K» ✓	*Do **not** award a mark for negative value of T.*	**1**

Question			Answers	Notes	Total
6.	a		*Q*: non-equilibrium concentrations ***AND*** K_c: equilibrium concentrations ***OR*** *Q*: **«**measured**»** at any time ***AND*** K_c: **«**measured**»** at equilibrium ✓		1
6.	b		**«**$Q = \frac{[SO_3]^2}{[SO_2]^2[O_2]} = \frac{1.00^2}{1.00^2 \times 2.00}$**»** = 0.500 ✓ reverse reaction favoured/reaction proceeds to the left ***AND*** $Q > K_c/0.500 > 0.282$ ✓	*Do **not** award M2 without M1.*	2
6.	c	i	$[N_2O_2]$ decreases ***AND*** exothermic **«**thus reverse reaction favoured**»** ✓	*Accept "product" for $[N_2O_2]$.* *Do **not** accept just "reverse reaction favoured/shift to left" for "$[N_2O_2]$ decreases".*	1

(continued…)

(Question 6c continued)

Question			Answers	Notes	Total
6.	**c**	**ii**	***ALTERNATIVE 1:*** **«**from equilibrium, step 1**»** $K_c = \frac{[N_2O_2]}{[NO]^2}$ ***OR*** $[N_2O_2] = K_c [NO]^2$ ✓ **«**from step 2, rate **«**$= k_1 [N_2O_2][O_2] = k_2 K [NO]^2[O_2]$**»** rate $= k [NO]^2[O_2]$ ✓ ***ALTERNATIVE 2:*** **«**from step 2**»** rate $= k_2 [N_2O_2] [O_2]$ ✓ **«**from step 1, $\text{rate}_{(1)} = k_1 [NO]^2 = k_{-1} [N_2O_2]$, $[N_2O_2] = \frac{k_1}{k_{-1}} [NO]^2$**»** **«**rate $= \frac{k_1}{k_{-1}} k_2 [NO]^2 [O_2]$**»** rate $= k [NO]^2 [O_2]$ ✓	*Award **[2]** for correct rate expression.*	**2**
6.	**d**		**«**$\ln \frac{k_1}{k_2} = \frac{E_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$**»** T_2 = **«**273 + 35 =**»** 308 K ***AND*** T_1 = **«**273 + 25 =**»** 298 K ✓ $E_a = 52.9$ **«**kJ mol^{-1}**»** ✓	*Award **[2]** for correct final answer.*	**2**

Question			Answers	Notes	Total
7.	a	i	polar bonds **«**between H and group 16 element**»** ***OR*** difference in electronegativities «between H and group 16 element» ✓ uneven distribution of charge/electron cloud ***OR*** non-linear/bent/V-shaped/angular shape «due to lone pairs» ***OR*** polar bonds/dipoles do not cancel out ✓	*M2:* *Do **not** accept "net/overall dipole moment" without further explanation.* *Accept "non-symmetrical **«**shape/distribution of charge**»**".*	**2**
7.	a	ii	number of electrons increases ✓ London/dispersion/instantaneous induced dipole-induced dipole forces increase ✓	*M1: Accept "M_r/A_r increases" or "molecules become larger in size/mass/surface area".*	**2**
7.	b		*Electron domain geometry:* tetrahedral ✓ *Molecular geometry:* bent/V-shaped/angular ✓	*Both marks can be awarded for clear diagrams. Electron domain geometry requires a 3-D diagram showing the tetrahedral arrangement.*	**2**

<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>7.</td><td>c</td><td>i</td><td>
<table>
<tr><th>Structure:</th><th>I</th><th>II</th></tr>
<tr><td>O atom labelled (1)</td><td>0</td><td>«+»1</td></tr>
<tr><td>O atom labelled (2)</td><td>0</td><td>–1</td></tr>
</table>
✓
✓</td><td>Award [1] for any two correctly filled cells.</td><td>2</td></tr>
<tr><td>7.</td><td>c</td><td>ii</td><td>structure I AND no formal charges
OR
structure I AND no charge transfer «between atoms» ✓</td><td></td><td>1</td></tr>
<tr><td>7.</td><td>d</td><td></td><td>O_3 has bond between single and double bond AND O_2 has double bond
OR
O_3 has bond order of 1.5 AND O_2 has bond order of 2
OR
bond in O_3 is weaker/longer than in O_2 ✓

O_3 requires longer wavelength ✓</td><td>M1: Do not accept “ozone has one single and one double bond”.</td><td>2</td></tr>
<tr><td>7.</td><td>e</td><td></td><td>CO_2 «non-polar» «weak» London/dispersion forces/instantaneous induced dipole-induced dipole forces between molecules ✓

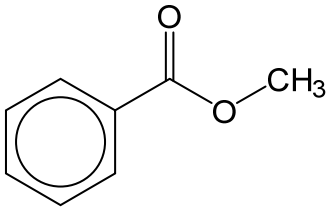
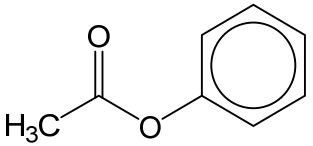
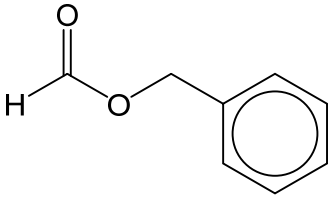
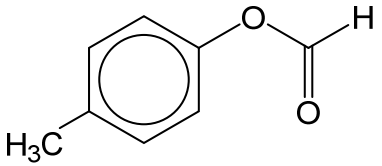
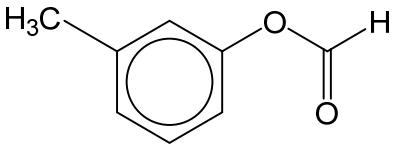
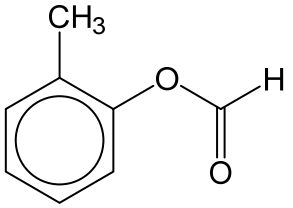
SiO_2 network/lattice/3D/giant «covalent» structure ✓</td><td>M1: The concept of “between” is essential.</td><td>2</td></tr>
</table>

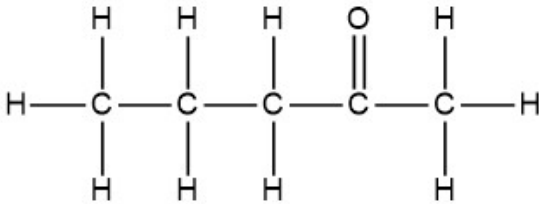
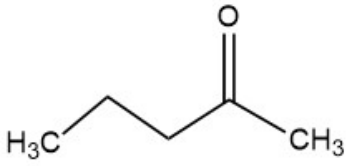
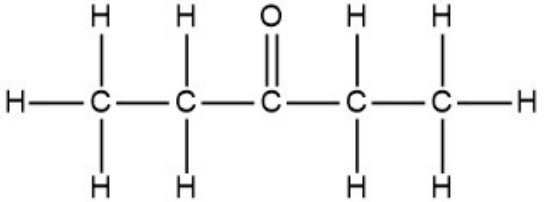
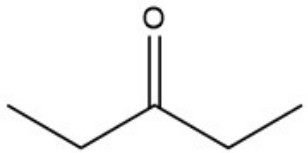
Question			Answers	Notes	Total
8.	a		*Physical evidence:* equal C–C bond «lengths/strengths» ***OR*** regular hexagon ***OR*** **«**all**»** C–C have bond order of 1.5 ***OR*** «all» C–C intermediate between single and double bonds ✓ *Chemical evidence:* undergoes substitution reaction **«**more readily than addition**»** ***OR*** does not discolour/react with bromine water ***OR*** substitution forms only one isomer for 1,2-disubstitution **«**presence of alternate double bonds would form two isomers**»** ***OR*** more stable than expected **«**compared to hypothetical molecule cyclohexa-1,3,5-triene**»** ***OR*** enthalpy change of hydrogenation/combustion is less exothermic than predicted **«**for cyclohexa-1,3,5-triene**»** ✓	*M1:* *Accept "all C–C–C bond angles are equal".*	**2**

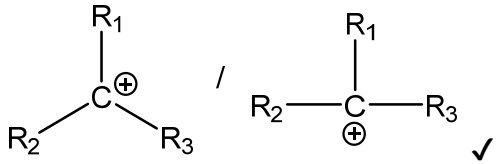
Question			Answers	Notes	Total
8.	**b**	**i**	$3CH_3CH_2CH_2OH\,(l) + Cr_2O_7^{2-}\,(aq) + 8H^+\,(aq) \rightarrow 3CH_3CH_2CHO\,(aq) + 2Cr^{3+}\,(aq) + 7H_2O\,(l)$ correct reactants and products ✓ balanced equation ✓		**2**
8	**b**	**ii**	*Aldehyde:* by distillation **«**removed from reaction mixture as soon as formed**»** ✓ *Carboxylic acid:* **«**heat mixture under**»** reflux **«**to achieve complete oxidation to –COOH**»** ✓	*Accept clear diagrams or descriptions of the processes.*	**2**
8.	**c**	**i**	**«** $\frac{136}{48 + 4 + 16} = 2$ **»** $C_8H_8O_2$ ✓		**1**
8.	**c**	**ii**	A: C–H **«**in alkanes, alkenes, arenes**»** ***AND*** B: C=O **«**in aldehydes, ketones, carboxylic acids and esters**»** ✓		**1**

(continued…)

(Question 8c continued)

Question			Answers	Notes	Total
8.	**c**	**iii**	*Any two of:*  ***OR*** $C_6H_5COOCH_3$ ✓  ***OR*** $CH_3COOC_6H_5$ ✓  ***OR*** $HCOOCH_2C_6H_5$ ✓	*Do **not** penalize use of Kekule structures for the phenyl group.* *Accept the following structures:*    *Award **[1 max]** for two correct aliphatic/linear esters with the molecular formula $C_8H_8O_2$.*	**2**
8.	**c**	**iv**	$C_6H_5COOCH_3$ **«**signal at 4 ppm (3.7–4.8 range in data table) due to alkyl group on ester**»** ✓		**1**

Question			Answers	Notes	Total
9.	a	i	 /  ✓  /  ✓	*Accept condensed formulas.*	**2**
9.	a	ii	***A:*** $CH_3CH_2COCH_2CH_3$ ***AND*** **«**peak at**»** 29 due to $(CH_3CH_2)^+/(C_2H_5)^+/(M - CH_3CH_2CO)^+$ ***OR*** $CH_3CH_2COCH_2CH_3$ ***AND*** **«**peak at**»** 57 due to $(CH_3CH_2CO)^+/(M - CH_3CH_2)^+/(M - C_2H_5)^+$ ✓ ***B:*** $CH_3COCH_2CH_2CH_3$ ***AND*** **«**peak at**»** 43 due to $(CH_3CH_2CH_2)^+/(CH_3CO)^+/(C_2H_3O)^+/ (M - CH_3CO)^+$ ✓	*Penalize missing "+" sign once only.* *Accept "$CH_3COCH_2CH_2CH_3$ by elimination since fragment CH_3CO is not listed" for M2.*	**2**

Question			Answers	Notes	Total
9.	b	i	heterolytic/heterolysis ✓		1
9.	b	ii	polar protic ✓		1
9.	b	iii	 ✓ *Shape:* triangular/trigonal planar ✓		2
9.	b	iv	«around» 50 % «each» ***OR*** similar/equal percentages ✓ nucleophile can attack from either side «of the planar carbocation» ✓	*Accept "racemic mixture/racemate" for M1.*	2
9.	c		*Stage one:* $C_6H_5NO_2\,(l) + 3Sn\,(s) + 7H^+\,(aq) \rightarrow C_6H_5NH_3^+\,(aq) + 3Sn^{2+}\,(aq) + 2H_2O\,(l)$ ✓ *Stage two:* $C_6H_5NH_3^+\,(aq) + OH^-\,(aq) \rightarrow C_6H_5NH_2\,(l) + H_2O\,(l)$ ✓		2