Diploma Programme
Programme du diplôme
Programa del Diploma

Markscheme

May 2021

Chemistry

Higher level

Paper 2

22 pages

Subject details: Chemistry higher level 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.

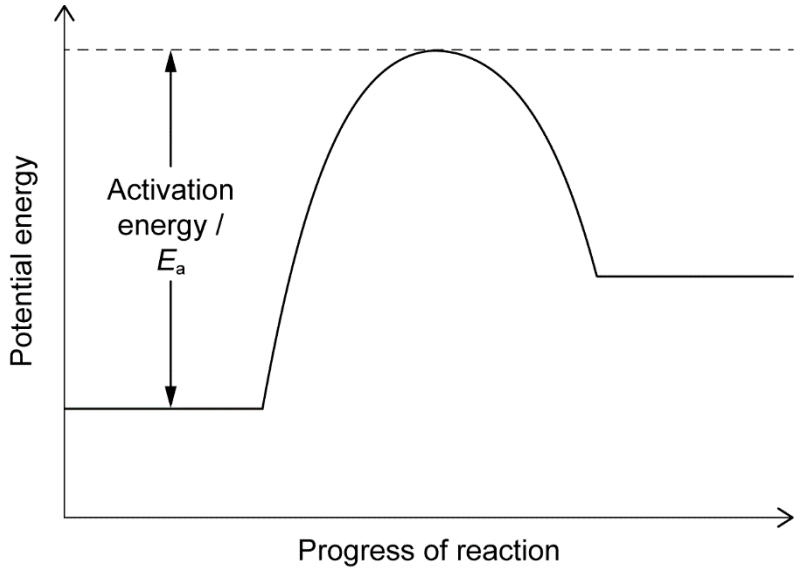
14. Do **not** penalize candidates for errors in units or significant figures, **unless** it is specifically referred to in the "Notes" column.

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		«$n_{CaCO3} = \frac{555\,g}{100.09\,g\,mol^{-1}}$ =» 5.55 «mol» ✓ «$V = 5.55\,mol \times 22.7\,dm^3\,mol^{-1}$ =» 126 «dm^3» ✓	*Award **[2]** for correct final answer.* *Accept method using pV = nRT to obtain the volume with p as either 100 kPa (126 dm^3) or 101.3 kPa (125 dm^3).* *Do not penalize use of 22.4 $dm^3\,mol^{-1}$ to obtain the volume (124 dm^3).*	**2**
1.	b	i	«ΔH =» (–635 «kJ» – 393.5 «kJ») – (–1207 «kJ») ✓ «ΔH = + » 179 «kJ» ✓	*Award **[2]** for correct final answer.* *Award **[1 max]** for –179 kJ.* *Ignore an extra step to determine total enthalpy change in kJ: 179 kJ mol^{-1} x 5.55 mol = 993 kJ.* *Award **[2]** for an answer in the range 990 – 993 « kJ».*	**2**
1.	b	ii	«ΔS = (40 J K^{-1} + 214 J K^{-1}) – (93 J K^{-1}) =» 161 «J K^{-1}» ✓	*Ignore an extra step to determine total entropy change in JK^{-1}: 161 J $mol^{-1}K^{-1}$ x 5.55 mol = 894 «J $mol^{-1}K^{-1}$»* *Award **[1]** for 894 «J $mol^{-1}K^{-1}$».*	**1**

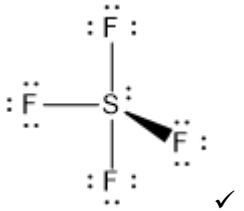
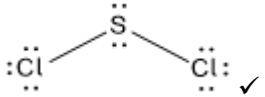
Question			Answers	Notes	Total
1.	b	iii	«spontaneous» if $\Delta G = \Delta H - T\Delta S < 0$ ***OR*** $\Delta H < T\Delta S$ ✓ «$T >$ $\frac{179\,\text{kJ}}{0.161\,\text{kJ}\,\text{K}^{-1}}$ =» 1112 «K» ✓	*Award **[2]** for correct final answer.* *Accept "1056 K" if both of the incorrect values are used to solve the problem.* *Do **not** award M2 for any negative T value.*	**2**
1.	b	iv	endothermic sketch ✓ x-axis labelled "extent of reaction/progress of reaction/reaction coordinate/reaction pathway" ***AND*** y-axis labelled "potential energy/ energy/enthalpy✓ activation energy/E_a ✓  	*Do **not** accept "time" for x-axis.*	**3**

Question			Answers	Notes	Total
1.	b	v	ΔH same ***AND*** lower E_a ✓		1
1.	c	i	$Ca(OH)_2\,(aq) + 2HCl\,(aq) \rightarrow 2H_2O\,(l) + CaCl_2\,(aq)$ ✓		1
1.	c	ii	«$n_{HCl} = 0.0350\,dm^3 \times 0.025\,mol\,dm^{-3}$ =» 0.00088 «mol» ***OR*** $n_{Ca(OH)_2} = \frac{1}{2}\ n_{HCl}$/0.00044 «mol» ✓ «$V = \frac{\frac{1}{2} \times 0.00088\,mol}{0.015\,mol\,dm^{-3}}$ =» 0.029 «dm^3» ✓	*Award **[2]** for correct final answer.* *Award **[1 max]** for 0.058 «dm^3».*	2
1.	c	iii	***Alternative 1:*** $[OH^-]$ = « $2 \times 2.33 \times 10^{-2}\,mol\,dm^{-3}$ =» 0.0466 «$mol\,dm^{-3}$» ✓ «$[H^+] = \frac{1.00 \times 10^{-14}}{0.0466} = 2.15 \times 10^{-13}\ mol\,dm^{-3}$» pH = « $-\log(2.15 \times 10^{-13})$ =» 12.668 ✓ ***Alternative 2:*** $[OH^-]$ =« $2 \times 2.33 \times 10^{-2}\,mol\,dm^{-3}$ =» 0.0466 «$mol\,dm^{-3}$» ✓ «pOH = $-\log(0.0466) = 1.332$» pH = «14.000 – pOH = 14.000 – 1.332 =» 12.668 ✓	*Award **[2]** for correct final answer.* *Award **[1 max]** for pH =12.367.*	2

Question			Answers	Notes	Total
1.	d	i	«$n_{Ca(OH)2} = 2.41\,dm^3 \times 2.33 \times 10^{-2}\,mol\,dm^{-3}$ =» 0.0562 «mol» ***AND*** «$n_{CO2} = \frac{0.750\,dm^3}{22.7\,mol\,dm^{-3}}$ =» 0.0330 «mol» ✓ «CO_2 is the limiting reactant» «$m_{CaCO3} = 0.0330\,mol \times 100.09\,g\,mol^{-1}$ =» 3.30 «g» ✓	*Only award ECF for M2 if limiting reagent is used.* *Accept answers in the range 3.30 - 3.35 «g».*	**2**
1.	d	ii	«$\frac{2.85}{3.30} \times 100$ =» 86.4 «%» ✓	*Accept answers in the range 86.1-86.4 «%».* *Accept "71.3 %" for using the incorrect given value of 4.00 g.*	**1**
1.	e		«add» $Ca(OH)_2$/$CaCO_3$/CaO ***AND*** to «acidic» water/river/lake/soil ***OR*** «use» $Ca(OH)_2$/$CaCO_3$/CaO in scrubbers «to prevent release of acidic pollution» ✓	*Accept any correct name for any of the calcium compounds listed.*	**1**

Question			Answers	Notes	Total
2.	**a**	**i**	nuclear charge/number of protons/Z/Z_{eff} increases **«**causing a stronger pull on the outer electrons**»** ✓ same number of shells/**«**outer**»** energy level/shielding ✓		**2**
2.	**a**	**ii**	P has «three» unpaired electrons in 3p sub-level ***AND*** S has one full 3p orbital «and two 3p orbitals with unpaired electrons» ***OR*** P: $[Ne]3s^2 3p_x^1 3p_y^1 3p_z^1$ ***AND*** S: $[Ne]3s^2 3p_x^2 3p_y^1 3p_z^1$ ✓ repulsion between paired electrons in sulfur **«**and therefore easier to remove**»** ✓	*Accept orbital diagrams for 3p sub-level for M1. Ignore other orbitals or sub-levels.* *Accept "removing electron from S gives more stable half-filled sub-level" for M2.*	**2**
2.	**b**	**i**	*Cr:* $[Ar]\ 4s^1 3d^5$ ✓ *Cr^{3+}:* $[Ar]\ 3d^3$ ✓	*Accept "$[Ar]\ 3d^5 4s^1$".* *Accept "$[Ar]\ 3d^3 4s^0$".* *Award **[1 max]** for two correct full electron configurations "$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^5$ **AND** $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3$".* *Award **[1 max]** for $4s^1 3d^5$ **AND** $3d^3$.*	**2**

Question			Answers	Notes	Total
2.	b	ii	electrostatic attraction ✓ between **«**a lattice of**»** cations/positive «metal» ions ***AND*** **«**a sea of**»** delocalized electrons ✓ mobile electrons responsible for conductivity ***OR*** electrons move when a voltage/potential difference/electric field is applied ✓	*Do **not** accept "nuclei" for "cations/positive ions" in M2.* *Accept "mobile/free" for "delocalized" electrons in M2.* *Accept "electrons move when connected to a cell/battery/power supply" **OR** "electrons move when connected in a circuit" for M3.*	**3**
2.	b	iii	$[Cr(CN)_6]^{3-}$ ***AND*** CN^-/ligand causes larger splitting **«**in d-orbitals compared to OH^-**»** ***OR*** $[Cr(CN)_6]^{3-}$ ***AND*** CN^-/ligand associated with a higher Δ/«crystal field» splitting energy/energy difference «in the spectrochemical series compared to OH^- » ✓	*Accept "$[Cr(CN)_6]^{3-}$ **AND** «CN^-» strong field ligand".*	**1**
2.	b	iv	any value or range between 647 and 700 nm ✓		**1**

<table>
<tr><th colspan="3">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>2.</td><td>c</td><td></td><td>
<table>
<tr><th>Species</th><th>SF_4</th><th>SCl_2</th></tr>
<tr><td>Lewis structure</td><td>  ✓</td><td>  ✓</td></tr>
<tr><td>Molecular geometry</td><td>saw horse/
see saw ✓</td><td>bent/V
shaped/angular ✓</td></tr>
</table>
</td><td>SF_4/SCl_2 structure does not have to be 3-D for mark.

Penalize missing lone pairs of electrons on halogens once only.

Accept any combination of dots, lines or crosses for bonds/lone pairs.

Accept “non-linear” for SCl_2 molecular geometry.

Award [1] for two correct electron domain geometries, e.g. trigonal bipyramidal for SF_4 and tetrahedral for SCl_2.</td><td>4</td></tr>
<tr><td>2.</td><td>d</td><td></td><td>H_2O forms hydrogen bonding «while SCl_2 does not» ✓

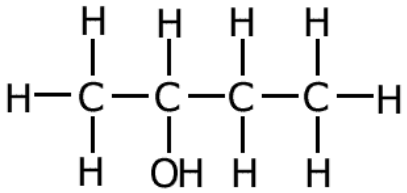
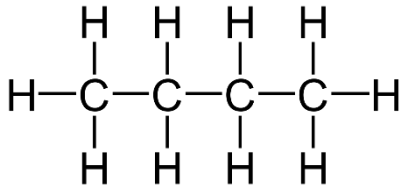
SCl_2 «much» stronger London/dispersion/«instantaneous» induced dipole-induced dipole forces ✓

Alternative 1:
H_2O less volatile AND hydrogen bonding stronger «than dipole–dipole and dispersion forces» ✓

Alternative 2:
SCl_2 less volatile AND effect of dispersion forces «could be» greater than hydrogen bonding ✓</td><td>Ignore reference to Van der Waals.

Accept “SCl_2 has «much» larger molar mass/electron density” for M2.</td><td>3</td></tr>
</table>

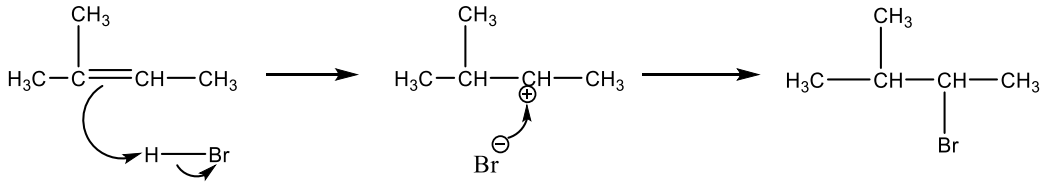
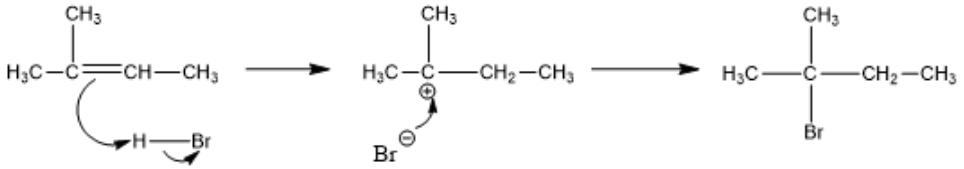
Question			Answers	Notes	Total
3.	**a**		Al / aluminium **«**electrode**»** ***AND*** aluminium nitrate/$Al(NO_3)_3$/Al^{3+} on left ✓ Sn/tin **«**electrode**»** ***AND*** tin**«**(II)**»** nitrate/$Sn(NO_3)_2$/Sn^{2+} on right ✓ salt bridge ***AND*** voltmeter/V/lightbulb ✓	*Award **[1]** if M1 and M2 are reversed.* *Award **[1]** for two correctly labelled solutions **OR** two correctly labelled electrodes for M1 and M2.* *Accept a specific salt for "salt bridge".* *Accept other circuit components such as ammeter/A, fan, buzzer, resistor/heating element/R/Ω.*	**3**
3.	**b**		$3Sn^{2+}(aq) + 2Al(s) \rightarrow 3Sn(s) + 2Al^{3+}(aq)$ ***OR*** $3Sn(NO_3)_2(aq) + 2Al(s) \rightarrow 3Sn(s) + 2Al(NO_3)_3(aq)$ ✓	*If half-cells are reversed in (a) then the equation must be reversed to award the mark.* *Do **not** penalize equilibrium arrows.*	**1**
3.	**c**		**«**1.66 + (−0.14) = +**»**1.52 **«**V**»** ✓	*Calculation must be consistent with equation given in 3 b.*	**1**
3.	**d**		**«**$\Delta G^{\ominus} = -nFE^{\ominus} = -6 \times 9.65 \times 10^4 \times 1.52 =$**»** −880080 **«**J mol^{-1}**»** ***OR*** 6 **«**electrons**»** ✓ **«** $\frac{-880080}{1000}$ **=»** −880 **«**kJ**»** ✓	*Award **[1]** for "**«+»**880".* *Award **[2]** for correct final answer.*	**2**

Question			Answers	Notes	Total
4.	**a**		 ✓  ✓	*Penalize missing hydrogens in displayed structural formulas once only.* *Accept condensed structural formulas: $CH_3CH(OH)CH_2CH_3$ /$CH_3CH_2CH_2CH_3$ or skeletal structures.*	**2**
4.	**b**		*Bonds broken:* 2(C–C) + 1(C=C) + 8(C–H) + 6O=O / 2(346) + 1(614) + 8(414) + 6(498) / 7606 **«**kJ**»** ✓ *Bonds formed:* 8(C=O) + 8(O–H) / 8(804) + 8(463) / 10 136 **«**kJ**»** ✓ *Enthalpy change:* **«**Bonds broken – Bonds formed = 7606 kJ – 10 136 kJ =**»** –2530 **«**kJ**»** ✓	*Award **[3]** for correct final answer.* *Award **[2 max]** for **«**+**»** 2530 **«**kJ**»**.*	**3**

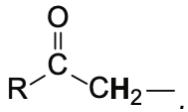
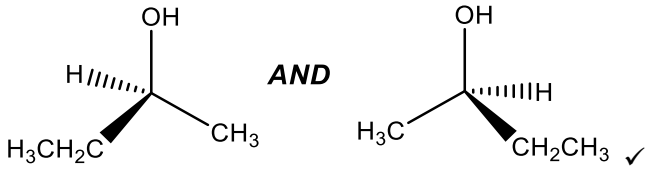
<table>
<tr><th colspan="2">Question</th><th>Answers</th><th>Notes</th><th>Total</th></tr>
<tr><td>4.</td><td>c</td><td>
<table>
<tr><td>Carbon</td><td>I</td><td rowspan="2">AND</td><td>II</td></tr>
<tr><td>Hybridization</td><td>sp^3</td><td>sp^2 ✓</td></tr>
</table>
</td><td></td><td>1</td></tr>
<tr><td>4.</td><td>d</td><td>Sigma (σ):
  ✓

Pi (π):
  ✓</td><td>Accept any diagram showing end to end/direct overlap of atomic/hybridized orbitals and electron density concentrated between nuclei.

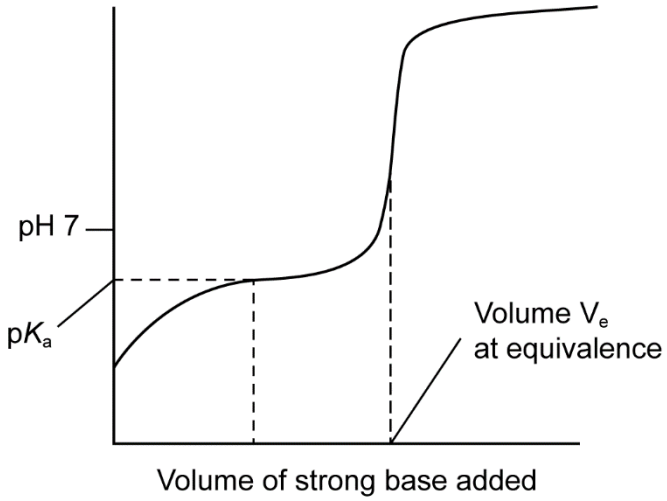
Accept any diagram showing sideways overlap of unhybridized p/atomic orbitals and electron density above and below plane of bond axis.</td><td>2</td></tr>
</table>

Question			Answers	Notes	Total
4.	e		***Alternative 1***  ***Alternative 2***  curly arrow going from C=C to H of HBr ***AND*** curly arrow showing Br leaving ✓ representation of carbocation ✓ curly arrow going from lone pair/negative charge on Br^- to C^+ ✓	*Penalize incorrect bond e.g., -CH-H_3C or –CH_3C only once in the paper.*	**3**

Question			Answers	Notes	Total
4.	**f**		**«**2-bromo-2-methylbutane involves**»** formation of more stable **«**tertiary**»** carbocation/intermediate ***OR*** «2-bromo-3-methylbutane involves» formation of less stable **«**secondary**»** carbocation/intermediate ✓ «intermediate» more stable due to «increased positive» inductive/electron-releasing effect of extra –R/alkyl group/–CH_3/methyl ✓	*Do **not** award marks for quoting Markovnikov's rule without any explanation.*	**2**
4.	**g**	**i**	*m/z 58:* molar/**«**relative**»** molecular mass/weight/M_r **«**is 58 g mol^{-1}/58**»** ✓ *m/z 43:* **«**loses**»** methyl/CH_3 **«**fragment**»** ***OR*** $COCH_3^+$ **«**fragment**»** ✓	*Do **not** penalize missing charge on the fragments.* *Accept molecular ion **«**peak**»**/ $CH_3COCH_3^+/C_3H_6O^+$.* *Accept any $C_2H_3O^+$ fragment/ $CH_3CH_2CH_2^+/C_3H_7^+$.*	**2**
4.	**g**	**ii**	C=O ✓	*Accept "carbonyl/C=C".*	**1**

Question			Answers	Notes	Total
4.	**g**	**iii**	*Information deduced from ^{1}H NMR:* **«**one signal indicates**»** one hydrogen environment/symmetrical structure ***OR*** **«**chemical shift of 2.2 indicates**»** H on C next to carbonyl ✓ *Compound:* propanone/CH_3COCH_3 ✓	*Accept "one type of hydrogen".* *Accept*  .	**2**
4.	**h**	**i**	 ✓		**1**
4.	**h**	**ii**	enantiomers rotate «plane of» plane-polarized light ✓ equal degrees/angles/amounts ***AND*** opposite directions/rotation ✓	*Accept "optical isomers" for "enantiomers".*	**2**

Question			Answers	Notes	Total
5.	**a**	**i**	$CH_3CH_2OH\,(l) + 3O_2\,(g) \rightarrow 2CO_2\,(g) + 3H_2O\,(g)$ ✓		**1**
5.	**a**	**ii**	**«**$n = \frac{56.00\,g}{46.08\,g\,mol^{-1}}$ **=»** 1.215 **«**mol**»** ✓ **«**1.215 mol × (−1367 kJ mol^{-1}) **=»** −1661 **«**kJ**»** ✓	*Award **[2]** for correct final answer.* *Award **[1 max]** for "**«+»**1661 **«**kJ**»**".*	**2**
5.	**b**		ethanal ***AND*** distillation ✓ ethanoic acid ***AND*** reflux **«**followed by distillation**»** ✓	*Award **[1]** for both products **OR** both methods.*	**2**
5.	**c**		*Equation:* $CH_3CH_2OH + HCOOH \rightleftharpoons HCOOCH_2CH_3 + H_2O$ ✓ *Product name:* ethyl methanoate ✓	*Accept equation without equilibrium arrows.* *Accept equation with molecular formulas ($C_2H_6O + CH_2O_2 \rightleftharpoons C_3H_6O_2 + H_2O$) only if product name is correct.*	**2**

Question			Answers	Notes	Total
5.	**d**	**i**	 increasing S-shape pH curve ✓ p*K*a: pH at half neutralization/equivalence ✓	*M1: Titration curve must show buffer region at pH <7 and equivalence at pH >7.* *Ignore other parts of the curve, i.e., before buffer region, etc.* *Accept curve starting from where two axes meet as pH scale is not specified.*	**2**
5.	**d**	**ii**	phenolphthalein ***OR*** phenol red ✓		**1**

Question			Answers	Notes	Total
5.	**e**		***Alternative 1:*** $K_a = \frac{[H^+][HCOO^-]}{[HCOOH]}$ ***OR*** $[HCOOH] = \frac{(10^{-4.12})^2}{10^{-3.75}}$ ✓ **«**[HCOOH] =**»** 3.24×10^{-5} **«**mol dm^{-3}**»** ✓ ***Alternative 2:*** **«**$pH = pK_a + \log\frac{[HCOO^-]}{[HCOOH]}$**»** $4.12 = 3.75 + \log\frac{10^{-4.12}}{[HCOOH]}$ ✓ **«**[HCOOH] =**»** 3.24×10^{-5} **«**mol dm^{-3}**»** ✓	*Award **[2]** for correct final answer.*	**2**
5.	**f**		*Sodium methanoate:* basic *Ammonium chloride:* acidic *Sodium nitrate:* neutral ✓ ✓	*Award **[2]** for three correct.* *Award **[1]** for two correct.*	**2**

Question			Answers	Notes	Total
6.	**a**		*BrO_3^-:* 1/first ***AND*** *Br^-:* 1/first ***AND*** *H^+:* 2/second ✓ **«**Rate =**»** $k[BrO_3^-][Br^-][H^+]^2$ ✓	*M2: Square brackets required for the mark.*	**2**
6.	**b**		**«***k* = $\frac{8.0 \times 10^{-4}}{0.10 \times 0.10 \times (0.10)^2}$ **=»** 8.0 ✓ $mol^{-3}\,dm^9\,s^{-1}$ ✓		**2**

Question			Answers	Notes	Total
7.	**a**		«K_c =» $\frac{[SO_3]^2}{[SO_2]^2[O_2]}$ ✓	*Square brackets required for the mark.*	**1**
7.	**b**		pressure decrease «due to larger volume» ✓ reaction shifts to side with more moles/molecules «of gas» ✓ reaction shifts left/towards reactants ✓	*Award M3 only if M1* ***OR*** *M2 awarded.*	**3**
7.	**c**		$[O_2] = 1.25$ «mol dm^{-3}» ***AND*** $[SO_3] = 3.50$ «mol dm^{-3}» ✓ «$K_c = \frac{[3.50]^2}{[1.50]^2[1.25]}$ =» 4.36 ✓	*Award* ***[2]*** *for correct final answer*	**2**