

A-LEVEL CHEMISTRY

CHEM5 Energetics, Redox and Inorganic Chemistry
Mark scheme

2420
June 2015

Version 1: Final

Mark schemes are prepared by the Lead Assessment Writer and considered, together with the relevant questions, by a panel of subject teachers. This mark scheme includes any amendments made at the standardisation events which all associates participate in and is the scheme which was used by them in this examination. The standardisation process ensures that the mark scheme covers the students' responses to questions and that every associate understands and applies it in the same correct way. As preparation for standardisation each associate analyses a number of students' scripts: alternative answers not already covered by the mark scheme are discussed and legislated for. If, after the standardisation process, associates encounter unusual answers which have not been raised they are required to refer these to the Lead Assessment Writer.

It must be stressed that a mark scheme is a working document, in many cases further developed and expanded on the basis of students' reactions to a particular paper. Assumptions about future mark schemes on the basis of one year's document should be avoided; whilst the guiding principles of assessment remain constant, details will change, depending on the content of a particular examination paper.

Further copies of this Mark Scheme are available from aqa.org.uk

1 (b)	<table border="1"> <tr> <td data-bbox="244 304 878 411"> $\text{Mg}^{2+}(\text{g}) + 2\text{e}^{-} + 2\text{Cl}(\text{g})$ (1) (M5) </td> <td data-bbox="878 304 1218 411"></td> </tr> <tr> <td data-bbox="244 411 878 518"> $\text{Mg}^{2+}(\text{g}) + 2\text{e}^{-} + \text{Cl}_2(\text{g})$ (1) (M4) </td> <td data-bbox="878 411 1218 518"></td> </tr> <tr> <td data-bbox="244 518 878 592"></td> <td data-bbox="878 518 1218 592"> $\text{Mg}^{2+}(\text{g}) + 2\text{Cl}^{-}(\text{g})$ (1) (M6) </td> </tr> <tr> <td data-bbox="244 592 878 699"> $\text{Mg}^{+}(\text{g}) + \text{e}^{-} + \text{Cl}_2(\text{g})$ (1) (M3) </td> <td data-bbox="878 592 1218 699"></td> </tr> <tr> <td data-bbox="244 699 878 772"> $\text{Mg}(\text{g}) + \text{Cl}_2(\text{g})$ (1) (M2) </td> <td data-bbox="878 699 1218 772"></td> </tr> <tr> <td data-bbox="244 772 878 845"> $\text{Mg}(\text{s}) + \text{Cl}_2(\text{g})$ (1) (M1) </td> <td data-bbox="878 772 1218 845"></td> </tr> <tr> <td data-bbox="244 845 878 935"> $\text{MgCl}_2(\text{s})$ </td> <td data-bbox="878 845 1218 935"></td> </tr> </table>	$\text{Mg}^{2+}(\text{g}) + 2\text{e}^{-} + 2\text{Cl}(\text{g})$ (1) (M5)		$\text{Mg}^{2+}(\text{g}) + 2\text{e}^{-} + \text{Cl}_2(\text{g})$ (1) (M4)			$\text{Mg}^{2+}(\text{g}) + 2\text{Cl}^{-}(\text{g})$ (1) (M6)	$\text{Mg}^{+}(\text{g}) + \text{e}^{-} + \text{Cl}_2(\text{g})$ (1) (M3)		$\text{Mg}(\text{g}) + \text{Cl}_2(\text{g})$ (1) (M2)		$\text{Mg}(\text{s}) + \text{Cl}_2(\text{g})$ (1) (M1)		$\text{MgCl}_2(\text{s})$		6 Allow e for electrons (i.e no charge) State symbols essential If no electrons allow M5 but not M3,M4 If incorrect 1/2 Cl ₂ used allow M3 and M4 for correct electrons (scores 2/6)
$\text{Mg}^{2+}(\text{g}) + 2\text{e}^{-} + 2\text{Cl}(\text{g})$ (1) (M5)																
$\text{Mg}^{2+}(\text{g}) + 2\text{e}^{-} + \text{Cl}_2(\text{g})$ (1) (M4)																
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$\text{MgCl}_2(\text{s})$																

1(c)	$-\Delta H_f(\text{MgCl}_2) + \Delta H_a(\text{Mg}) + 1^{\text{st}} \text{IE}(\text{Mg}) + 2^{\text{nd}} \text{IE}(\text{Mg}) + 2\Delta H_a(\text{Cl})$ $= -2\text{EA}(\text{Cl}) - \text{LE}(\text{MgCl}_2)$ $-2\text{EA}(\text{Cl}) = 642 + 150 + 736 + 1450 + 242 - 2493 = 727$ $\text{EA}(\text{Cl}) = -364 \text{ (kJ mol}^{-1}\text{)}$	1 1 1	<p>Allow Enthalpy of Formation = sum of other enthalpy changes (incl lattice formation)</p> <p>Allow -363 to -364 Allow M1 and M2 for -727 Allow 1 (1 out of 3) for $+364$ or $+363$ but award 2 if due to arithmetic error after correct M2 Also allow 1 for -303 Units not essential but penalise incorrect units Look for a transcription error and mark as AE-1</p>
1(d)(i)	<p>Magnesium (ion) is smaller and more charged (than the sodium ion) OR magnesium (ion) has higher charge to size ratio / charge density</p> <p>(magnesium ion) attracts water more strongly</p>	1 1	<p>Do not allow wrong charge on ion if given Do not allow similar size for M1 Do not allow mass/charge ratio</p> <p>Mark independently Mention of intermolecular forces, (magnesium) atoms or atomic radius CE=0</p>
1(d)(ii)	$\text{Enthalpy change} = -\text{LE}(\text{MgCl}_2) + \Sigma(\Delta H_{\text{hydions}})$ $= 2493 + (-1920 + 2 \times -364)$ $= -155 \text{ (kJ mol}^{-1}\text{)}$	1 1	<p>Units not essential but penalise incorrect units</p>

Question	Marking Guidance	Mark	Comments
2(a)	The enthalpy (change) to break <u>1 mol</u> of H—O / bonds Averaged over a range of compounds / molecules	1 1	Allow heat energy Penalise energy but mark on ignore states CE=0 for ionic bonds
2(b)	$\text{H}_2 + \frac{1}{2}\text{O}_2 \longrightarrow \text{H}_2\text{O}$ $\Delta H = (\text{H-H}) + \frac{1}{2}(\text{O=O}) - 2(\text{H-O}) / \text{sum of (bonds broken)} - \text{sum of (bonds formed)}$ $= 436 + 496/2 - 2 \times 464$ $= -244 \text{ (kJ mol}^{-1}\text{)}$	1 1 1	Allow 1 mark only for +244 and -488 Units not essential but penalise incorrect units
2(c)(i)	same reaction / same equation / same number / same reactants and same products / same number and type of bonds broken and formed	1	Do not allow similar

2(c)(ii)	There must be a slight difference between the actual bond enthalpy (in water) and mean bond enthalpies for the O–H bond (in other molecules)	1	Allow bond enthalpy value for enthalpy of formation may not be under standard conditions. Allow reference to bond energy rather than bond enthalpy Do not allow heat loss or experimental error Do not allow mean bond enthalpies are not accurate
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Question	Marking Guidance	Mark	Comments
3(a)(i)	$\Delta H = \Sigma(\text{enthalpies formation products}) - \Sigma(\text{enthalpies formation reactants})$ $= -111 - (-75 - 242)$ $= (+)206 \text{ (kJ mol}^{-1}\text{)}$	1 1 1	Or correct cycle with enthalpy changes labelled -206 scores 1 only Units not essential if ans in kJ mol^{-1} but penalise incorrect units
3(a)(ii)	$\Delta S = \Sigma(\text{entropies of products}) - \Sigma(\text{entropies reactants})$ $= 198 + 3 \times 131 - (186 + 189)$ $= (+) 216 \text{ (J K}^{-1} \text{ mol}^{-1}\text{)}$ OR $0.216 \text{ kJ K}^{-1} \text{ mol}^{-1}$	1 1	Units not essential but penalise incorrect units

3(b)	<p>When $\Delta G = 0$ OR $\Delta H = T\Delta S$</p> <p>$T = \Delta H/\Delta S$</p> <p>$= 206 \times 1000/216$</p> <p>$= 954 \text{ K}$</p>	1 1 1 1	<p>M2 also scores M1</p> <p>Allow error carried forward from (a)(i) and (a)(ii) Ignore unexplained change of sign from – to +</p> <p>Allow 953 – 955, Units of K essential, must be +ve If values from (a)(i) and (a)(ii) lead to negative value in M3 allow M1 to M3 but do not allow negative temperature for M4 If negative value changed to positive for M4, allow M4</p>
3(c)	To speed up the rate of reaction OR wtte	1	<p>Allow so that more molecules have energy greater than the activation energy</p> <p>IF T in 3(b) > 1300 allow answers such as; to reduce energy cost to slow down reaction do NOT allow to increase rate</p>

3(d)(i)	<p>Method 1 $\Delta G = \Delta H - T\Delta S$</p> <p>$\Delta G = -41 - (1300 \times -42/1000)$ (M1)</p> <p>$= +13.6 \text{ kJ mol}^{-1}$</p> <p>$\Delta G$ must be negative for the reaction to be feasible. OR ΔG is positive so reaction is not feasible</p> <p>Method 2 For reaction to be feasible ΔG must be negative or zero T when $\Delta G = 0 = \Delta H / \Delta S = 976K$ ΔS is -ve so ΔG must be +ve at temperatures above 976K / at 1300 K</p>	<p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>If 42 and not 42/1000 used can score M3 only but allow $\Delta G = -41 \times 1000 - (1300 \times -42)$ (M1)</p> <p>$= 13600 \text{ J mol}^{-1}$ (M2) Units essential</p>
3(d)(ii)	<p>If the temperature is lowered (Ignore reference to catalyst and/or pressure) ΔG will become (more) <u>negative</u> because <u>the $-T\Delta S$ term will be less positive/ $T\Delta S > \Delta H$</u></p>	<p>1</p> <p>1</p>	<p>Alternative mark scheme (if T is calculated) Allow T reduced to 976 K or lower M1</p> <p>At this temperature (the reaction becomes feasible because) $\Delta G \leq 0$ M2</p>

Question	Marking Guidance	Mark	Comments
4(a)	$\text{Mg} + \text{H}_2\text{O} \rightarrow \text{MgO} + \text{H}_2$ <p>White solid/powder/ash/smoke</p> <p>(Bright) <u>white</u> light/flame</p>	<p>1</p> <p>1</p> <p>1</p>	<p>ignore state symbols</p> <p>ignore precipitate</p> <p>ignore fumes</p> <p>allow glow</p> <p>penalise effervescence under list principle</p>
4(b)	$2\text{Na} + \frac{1}{2}\text{O}_2 \rightarrow \text{Na}_2\text{O} \quad / \quad 4\text{Na} + \text{O}_2 \rightarrow 2\text{Na}_2\text{O}$ <p>white / yellow solid/ash/smoke</p> <p>orange / yellow flame</p>	<p>1</p> <p>1</p> <p>1</p>	<p>Allow multiples, ignore state symbols</p> <p>Allow $2\text{Na} + \text{O}_2 \rightarrow \text{Na}_2\text{O}_2$</p> <p>ignore precipitate</p> <p>ignore fumes</p>

Question	Marking Guidance	Mark	Comments
5(a)(i)	1500	1	
5(a)(ii)	<p>Ionic lattice / giant ionic</p> <p>Strong <u>attraction</u> between <u>oppositely charged ions</u> / Na⁺ and O²⁻</p> <p>OR lots of energy required to separate/ overcome attraction between oppositely charged ions / Na⁺ and O²⁻</p>	<p>1</p> <p>1</p>	<p>Mention of vdW / covalent bonding / molecules / atoms / metal etc CE=0</p> <p>Do not allow incorrect formulae for ions.</p>
5(a)(iii)	<p>200 (K)</p> <p>SO₂ smaller (molecule) (than P₄O₁₀) (or converse)</p> <p>vdW forces <u>between molecules</u> are weaker / require less energy to separate molecules</p>	<p>1</p> <p>1</p> <p>1</p>	<p>Allow range 10–273 (K)</p> <p>CE = 0 if temperature >573 K, otherwise mark on</p> <p>Allow correct answers in °C but units must be given.</p> <p>also SO₂ has lower M_r/ less surface area/less polarisable / fewer electrons</p> <p>penalise SO₃ and P₂O₅ for M2 only</p> <p>ignore dipole-dipole</p> <p>If covalent bonds broken lose M2 and M3 but can gain M1</p>

5(b)	$\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3 / \text{H}^+ + \text{HSO}_3^- / 2\text{H}^+ + \text{SO}_3^{2-}$ 1	1 1	can be equilibrium sign instead of arrow Allow values between 1–3 mark independently
5(c)	Reacts with / neutralises bases / alkalis $\text{SiO}_2 + 2\text{NaOH} \rightarrow \text{Na}_2\text{SiO}_3 + \text{H}_2\text{O}$	1 1	Allow any given base or alkali including OH^- Allow $\text{CaO} + \text{SiO}_2 \rightarrow \text{CaSiO}_3$ or equation with any suitable base M2 can score M1 even if equation unbalanced or incorrect

6(d)	<p>$E_{\text{Au}^+/\text{Au}} > E_{\text{O}_2 / \text{H}_2\text{O}}$ OR e.m.f. / $E_{\text{cell}} = 0.45 \text{ V}$</p> <p><u>Au⁺ (ions) oxidise water</u> OR <u>water reduces Au⁺ (ions)</u></p> <p><u>Gold metal/solid/precipitate</u> OR <u>bubbles</u> / effervescence of (oxygen gas) / gas produced</p> <p>$2\text{Au}^+ + \text{H}_2\text{O} \rightarrow 2\text{Au} + 2\text{H}^+ + \frac{1}{2}\text{O}_2$ OR $4\text{Au}^+ + 2\text{H}_2\text{O} \rightarrow 4\text{Au} + 4\text{H}^+ + \text{O}_2$</p>	<p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>If both species in electrode given, must be in correct order i.e. Au⁺/Au</p> <p>Allow water donates electrons to Au⁺</p> <p>Penalise incorrect observations</p> <p>Allow multiples</p>
6(e)(i)	1.24 (V)	1	Do not allow -1.24
6(e)(ii)	Chloride ions / Cl ⁻ react with / form a precipitate with silver ions/ Ag ⁺ / form AgCl	1	Penalise reaction of chloride ions with iron ions or iron
6(f)	<p>$E_{\text{O}_2 / \text{H}_2\text{O}} > E_{\text{Fe}^{3+} / \text{Fe}^{2+}}$ (or e.m.f / $E_{\text{cell}} = 0.46 \text{ V}$)</p> <p>Therefore the <u>iron(II)</u> ions are oxidised (or converted) into <u>iron(III)</u> ions (by oxygen)</p>	<p>1</p> <p>1</p>	<p>Species in electrode if all given must be in correct order</p> <p>If chloride ions oxidised to chlorine, lose M2</p> <p>M2 can be obtained or lost from equation.</p> <p>Ignore observations.</p>

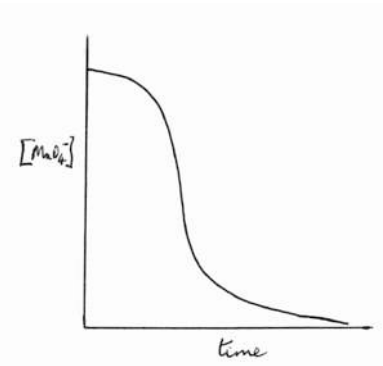
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Question	Marking Guidance	Mark	Comments
7(a)	<p>$\text{Cr(OH)}_3 + 3\text{H}_2\text{O} + 3\text{H}^+ \rightarrow [\text{Cr(H}_2\text{O)}_6]^{3+}$</p> <p>Green / grey-green solid</p> <p>Forms green / purple / ruby / violet <u>solution</u></p> <p>$\text{Cr(OH)}_3 + 2\text{H}_2\text{O} + \text{OH}^- \rightarrow [\text{Cr(H}_2\text{O)}_2(\text{OH})_4]^-$</p> <p>Forms green <u>solution</u></p>	<p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>Can start with $\text{Cr(H}_2\text{O)}_3(\text{OH})_3$ for each equation</p> <p>Ignore any unnecessary preliminary preparation of Cr(OH)_3</p> <p>Mark colours independently from equations</p> <p>Allow green ppt.</p> <p>ignore shades of colours</p> <p>Allow with 5 or 6 OH^- provided complex has co-ordination number of 6</p> <p>Penalise complex ions with incorrect charges overall or or if shown on ligand.</p> <p>Note that for each equation final complex must be 6 co-ordinate</p>

7(b)	$[\text{Cu}(\text{H}_2\text{O})_6]^{2+} + 4\text{NH}_3 \rightarrow [\text{Cu}(\text{H}_2\text{O})_2(\text{NH}_3)_4]^{2+} + 4\text{H}_2\text{O}$ <p>Blue (solution)</p> <p>Dark/deep/royal blue <u>solution</u></p> $[\text{Co}(\text{H}_2\text{O})_6]^{2+} + 6\text{NH}_3 \rightarrow [\text{Co}(\text{NH}_3)_6]^{2+} + 6\text{H}_2\text{O}$ <p>pink/red (solution)</p> <p>Brown / straw / yellow <u>solution</u></p>	<p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>Allow two correct equations via intermediate hydroxide in both cases even if first equation uses OH⁻ instead of NH₃</p> <p>Mark colours independently from equations</p> <p>ignore darkens in air/with time</p>
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Question	Marking Guidance	Mark	Comments
8(a)	$[\text{Fe}(\text{H}_2\text{O})_6]^{2+} + 2\text{NH}_3 \rightarrow \text{Fe}(\text{H}_2\text{O})_4(\text{OH})_2 + 2\text{NH}_4^+$ <p>Green precipitate</p> $[\text{Fe}(\text{H}_2\text{O})_6]^{2+} + \text{CO}_3^{2-} \rightarrow \text{FeCO}_3 + 6\text{H}_2\text{O}$ <p>Green precipitate</p>	<p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>Allow equation with OH^- provided equation showing formation of OH^- from NH_3 given</p> <p>effervescence incorrect so loses M4</p>
8(b)(i)	<p>Colourless/(pale) green changes to pink/purple (solution)</p> <p>Just after the end-point MnO_4^- is in excess/present</p>	<p>1</p> <p>1</p>	<p>Do not allow pale pink to purple</p>
8(b)(ii)	$\text{MnO}_4^- + 8\text{H}^+ + 5\text{Fe}^{2+} \rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O} + 5\text{Fe}^{3+}$ <p>Moles $\text{KMnO}_4 = 18.7 \times 0.0205/1000 = (3.8335 \times 10^{-4})$</p> <p>Moles $\text{Fe}^{2+} = 5 \times 3.8335 \times 10^{-4} = 1.91675 \times 10^{-3}$</p> <p>Moles Fe^{2+} in $250 \text{ cm}^3 = 10 \times 1.91675 \times 10^{-3} = 0.0191675$ moles in 50 cm^3</p> <p>Original conc $\text{Fe}^{2+} = 0.0191675 \times 1000/50 = 0.383 \text{ mol dm}^{-3}$</p>	<p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>Process mark</p> <p>Mark for M2 x 5</p> <p>Process mark for moles of iron in titration (M3) x10</p> <p>Answer for moles of iron (M4) x 1000/50</p> <p>Answer must be to at least 2 sig. figs. (0.38)</p>

Question	Marking Guidance	Mark	Comments
9(a)	$2\text{MnO}_4^- + 16\text{H}^+ + 5\text{C}_2\text{O}_4^{2-} \rightarrow 2\text{Mn}^{2+} + 8\text{H}_2\text{O} + 10\text{CO}_2$ <p>Mn²⁺ OR Mn³⁺</p> <p>(Possible because) <u>Mn</u> can exist in variable oxidation states</p> <p><i>E</i>_a lowered because oppositely charged ions attract</p> <p>Mn³⁺ (reduced) to Mn²⁺ by C₂O₄²⁻ / equation</p> <p>Mn²⁺ (oxidised (back)) to Mn³⁺ by MnO₄⁻ / equation</p>	<p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>If catalyst incorrect can only score M1 and M3</p> <p>These marks can be gained in any order</p> <p>M5 may appear before M2</p> <p>M5 and M6 can be scored in unbalanced equations or in words showing:</p> $\text{Mn}^{3+} + \text{C}_2\text{O}_4^{2-} \rightarrow \text{Mn}^{2+}$ $\text{Mn}^{2+} + \text{MnO}_4^- \rightarrow \text{Mn}^{3+}$

9(b)	<p>Graph marks</p>  <p>S-shaped curve must not rise significantly and must not fall rapidly initially.</p> <p>Starts on concentration axis and is levelling out (can level out on time axis or above but parallel to time axis)</p> <p>Explanation marks</p> <p><u>Slope</u> / rate increases as catalyst (concentration) forms</p> <p>Slope / rate decreases as (concentration) of MnO_4^- ions /reactant(s) decreases (OR reactants are being used up)</p>	<p>1</p> <p>1</p> <p>1</p> <p>1</p>	<p>Cannot score graph marks (M1 and M2) if no axes and/or no labels</p> <p>Explanation marks can be awarded independent of graph.</p>

CHEM5 Mark scheme instructions to examiners

1. General

The mark scheme for each question shows:

- the marks available for each part of the question
- the total marks available for the question
- the typical answer or answers which are expected
- extra information to help the Examiner make his or her judgement and help to delineate what is acceptable or not worthy of credit or, in discursive answers, to give an overview of the area in which a mark or marks may be awarded.

The extra information is aligned to the appropriate answer in the left-hand part of the mark scheme and should only be applied to that item in the mark scheme.

At the beginning of a part of a question a reminder may be given, for example: where consequential marking needs to be considered in a calculation; or the answer may be on the diagram or at a different place on the script.

In general the right-hand side of the mark scheme is there to provide those extra details which confuse the main part of the mark scheme yet may be helpful in ensuring that marking is straightforward and consistent.

2. **Emboldening**

- 2.1** In a list of acceptable answers where more than one mark is available ‘any **two** from’ is used, with the number of marks emboldened. Each of the following bullet points is a potential mark.
- 2.2** A bold **and** is used to indicate that both parts of the answer are required to award the mark.
- 2.3** Alternative answers acceptable for a mark are indicated by the use of **or**. Different terms in the mark scheme are shown by a / ; eg allow smooth / free movement.

3. **Marking points**

3.1 **Marking of lists**

This applies to questions requiring a set number of responses, but for which candidates have provided extra responses. The general principle to be followed in such a situation is that ‘right + wrong = wrong’.

Each error / contradiction negates each correct response. So, if the number of error / contradictions equals or exceeds the number of marks available for the question, no marks can be awarded.

However, responses considered to be neutral (often prefaced by ‘ignore’ in the mark scheme) are not penalised.

3.2 **Marking procedure for calculations**

Full marks can be given for a correct numerical answer, without any working shown unless the question states ‘Show your working’.

However, if the answer is incorrect, mark(s) can usually be gained by correct substitution / working and this is shown in the ‘extra information’ column or by each stage of a longer calculation.

3.3 **Interpretation of ‘it’**

Answers using the word ‘it’ should be given credit only if it is clear that the ‘it’ refers to the correct subject.

3.4 Errors carried forward, consequential marking and arithmetic errors

Allowances for errors carried forward are most likely to be restricted to calculation questions and should be shown by the abbreviation e.c.f. or conseq in the marking scheme.

An arithmetic error should be penalised for one mark only unless otherwise amplified in the marking scheme. Arithmetic errors may arise from a slip in a calculation or from an incorrect transfer of a numerical value from data given in a question.

3.5 Phonetic spelling

The phonetic spelling of correct scientific terminology should be credited **unless** there is a possible confusion with another technical term.

3.6 Brackets

(.....) are used to indicate information which is not essential for the mark to be awarded but is included to help the examiner identify the sense of the answer required.

3.7 Ignore / Insufficient / Do not allow

Ignore or insufficient is used when the information given is irrelevant to the question or not enough to gain the marking point. Any further correct amplification could gain the marking point.

Do **not** allow means that this is a wrong answer which, even if the correct answer is given, will still mean that the mark is not awarded.
