Diploma Programme
Programme du diplôme
Programa del Diploma

# Markscheme

## May 2016

## Chemistry

## Higher level

## Paper 2

17 pages

# 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 <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.

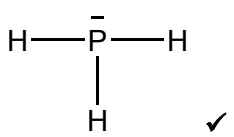
13. Occasionally, a part of a question may require an answer that is required for subsequent marking points. If an error is made in the first marking point then it should be penalized. However, if the incorrect answer is used correctly in subsequent marking points then **follow through** marks should 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 | i |  ✓ | *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".*<br>*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 ✓<br><br>$NH_3$ forms H-bonds ✓<br><br>H-bonds are stronger<br>***OR***<br>London forces are weaker ✓ | *Accept van der Waals' forces, dispersion forces and instantaneous dipole – induced dipole forces.*<br>*Accept "dipole-dipole forces" as molecule is polar.*<br>*H-bonds in $NH_3$ (only) must be mentioned to score **[2]**.*<br>*Do **not** award M2 or M3 if:*<br>• *implies covalent bond is the H-bond*<br>• *implies covalent bonds break.*<br><br>*Accept "dipole-dipole forces are weaker".* | **2 max** |
| 1. | a | vi | *Weak:* only partially dissociated/ionized **«**in dilute aqueous solution**»** ✓<br><br>*Brønsted–Lowry base:* an acceptor of protons/$H^+$/hydrogen ions ✓ | *Accept reaction with water is reversible/an equilibrium.*<br>*Accept "water is partially dissociated **«**by the weak base**»**".* | **2** |
| 1. | b | i | $P_4$ is a molecule **«**comprising 4P atoms**»** ***AND*** 4P is four/separate **«**P**»** atoms<br>***OR***<br>$P_4$ represents **«**4P**»** atoms bonded together ***AND*** 4P represents **«**4**»** separate/non-bonded **«**P**»** atoms ✓ | | **1** |

*(continued)*

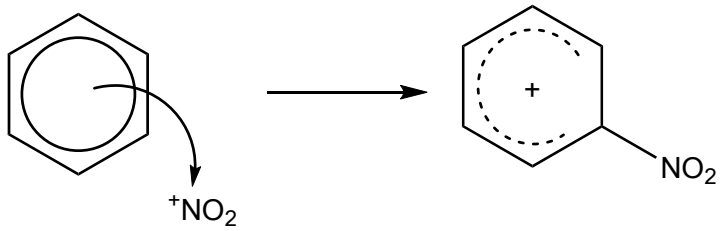
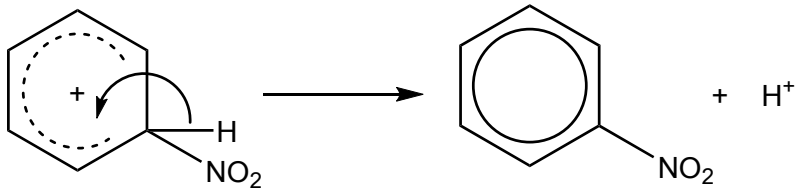
| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 1. | b | ii | can act as both a «Brønsted–Lowry» acid and a «Brønsted–Lowry» base<br>***OR***<br>can accept and/or donate a hydrogen ion/proton/$H^+$ ✓<br><br>$HPO_2^{2-}$ ***AND*** $H_3PO_2$ ✓ | | 2 |
| 1. | b | iii | $P_4$: 0 ✓<br>$H_2PO_2^-$: +1 ✓ | *Do not accept 1 or 1+ for $H_2PO_2^-$.* | 2 |
| 1. | b | iv | oxygen gained, so could be oxidation ✓<br><br>hydrogen gained, so could be reduction<br>***OR***<br>negative charge «on product/$H_2PO_2^-$»/gain of electrons, so could be reduction ✓<br><br>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.*<br><br>*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» ✓ | | 1 |
| 1. | c | ii | $n$(NaOH) = «$0.1000 \times 5.00 =$» 0.500 «mol» ***AND*** $P_4$/phosphorus is limiting reagent ✓ | *Accept $n(H_2O) = \frac{100}{18} = 5.50$ **AND** $P_4$ is limiting reagent.* | 1 |
| 1. | c | iii | amount in excess «$= 0.500 - (3 \times 0.02000)$» $= 0.440$ «mol» ✓ | | 1 |
| 1. | c | iv | «$22.7 \times 1000 \times 0.02000$» $= 454$ «$cm^3$» ✓ | *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 | $n(\text{P})$ «$= \frac{43.6}{30.97}$» $= 1.41$ «mol» ✓<br>$n(\text{O})$ «$= \frac{100 - 43.6}{16.00}$» $= 3.53$ «mol» ✓<br>«$\frac{n(\text{O})}{n(\text{P})} = \frac{3.53}{1.41} = 2.50$ so empirical formula is» $P_2O_5$ ✓ | *Accept other methods where the working is shown.* | **3** |
| 1. | d | iii | «$\frac{285}{141.9} = 2.00$ , so molecular formula $= 2 \times P_2O_5$ =» $P_4O_{10}$ ✓ | | **1** |
| 1. | d | iv | $P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H_3PO_4(aq)$ ✓ | *Accept $P_4O_{10}(s) + 2H_2O(l) \rightarrow 4HPO_3(aq)$ (initial reaction)*<br>*Accept $P_2O_5(s) + 3H_2O(l) \rightarrow 2H_3PO_4(aq)$*<br>*Accept equations for $P_4O_6$/$P_2O_3$ if given in d (iii).*<br>*Accept any ionized form of the acids as the products.* | **1** |
| 1. | d | v | phosphorus not commonly found in fuels<br>***OR***<br>no common pathways for phosphorus oxides to enter the air<br>***OR***<br>amount of phosphorus-containing organic matter undergoing anaerobic decomposition is small ✓ | *Accept "phosphorus oxides are solids so are not easily distributed in the atmosphere".*<br>*Accept "low levels of phosphorus oxide in the air".*<br>*Do not accept "$H_3PO_4$ is a weak acid".* | **1** |
| 1. | d | vi | *Pre-combustion:*<br>remove sulfur/S/sulfur containing compounds ✓<br><br>*Post-combustion:*<br>remove it/$SO_2$ by neutralization/reaction with alkali/base ✓ | <br><br><br>*Accept "lime injection fluidised bed combustion" for either, but not both.* | **2** |

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 2. | a | i | «$K_c$ =» $\frac{[COCl_2]}{[CO][Cl_2]}$ ✓ | | 1 |
| 2. | a | ii | $T$ «= 600 + 273» = 873K ✓<br><br>$\Delta G^{\ominus} = -8.31 \times 873 \times \ln(0.200)$<br>***OR***<br>$\Delta G^{\ominus}$ = « + » 11676 «J» ✓<br><br>$\Delta G^{\ominus}$ = « + » 11.7 «kJ» ✓ | *Accept 11.5 to 12.0.*<br>*Award final mark only if correct sig fig.*<br>*Award **[3]** for correct final answer.* | 3 |
| 2. | a | iii | $\Delta H^{\ominus} = -220.1 - (-110.5)$✓<br>$\Delta H^{\ominus} = -109.6$ «kJ» ✓ | *Award **[2]** for correct final answer.*<br>*Award **[1]** for –330.6, or +109.6 «kJ».* | 2 |
| 2. | a | iv | $\Delta G^{\ominus} = -109.6 - (298 \times \Delta S^{\ominus}) = +11.7$ «kJ» ✓<br><br>$\Delta S^{\ominus}$ «= $-\frac{(11.7 + 109.6) \times 10^3}{298}$ » = –407 «J $K^{-1}$» ✓ | *Award **[2]** for correct final answer.*<br>*Award **[2]** for –470 «$JK^{-1}$» (result from given values).*<br>*Do not penalize wrong value for T if already done in (a)(ii).*<br>*Award **[1 max]** for –0.407 «$kJK^{-1}$».*<br>*Award **[1 max]** for –138.9 «$JK^{-1}$».* | 2 |
| 2. | b | i | primary ✓ | | 1 |
| 2. | b | ii | ***ALTERNATIVE 1:***<br>«heat with» tin/Sn ***AND*** hydrochloric acid/HCl ✓<br>aqueous alkali/$OH^-$(aq) ✓<br><br>***ALTERNATIVE 2:***<br>hydrogen/$H_2$ ✓<br>nickel/Ni «catalyst» ✓ | *Accept specific equations having correct reactants.*<br>*Do **not** accept $LiAlH_4$ or $NaBH_4$.*<br>*Accept Pt or Pd catalyst.*<br><br>*Accept equations having correct reactants.* | 2 |

*(continued)*

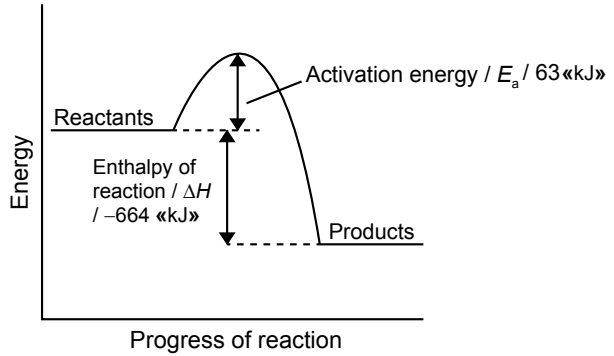
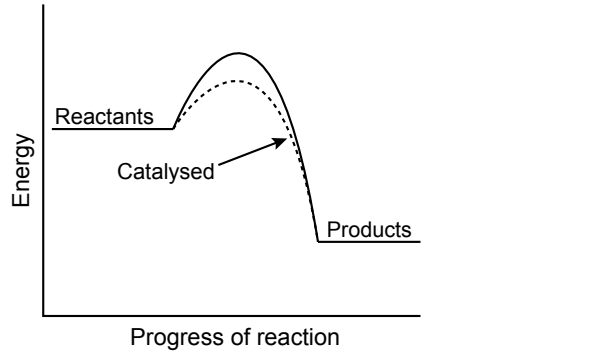
| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 2. | b | iii | $HNO_3 + 2H_2SO_4 \rightleftharpoons NO_2^+ + 2HSO_4^- + H_3O^+$ ✓ | *Accept:* $HNO_3 + H_2SO_4 \rightleftharpoons NO_2^+ + HSO_4^- + H_2O$ *Accept* $HNO_3 + H_2SO_4 \rightleftharpoons H_2NO_3^+ + HSO_4^-$ .<br>*Accept 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.* | 1 |
| 2. | b | iv |  <br><br>  <br><br>curly arrow going from benzene ring to N of $^+NO_2/NO_2^+$ ✓<br>carbocation with correct formula and positive charge on ring ✓<br>curly arrow going from C–H bond to benzene ring of cation ✓<br>formation of organic product nitrobenzene ***AND*** $H^+$ ✓ | *Accept mechanism with corresponding Kekulé structures.*<br>*Do **not** accept a circle in M2 or M3.*<br>*Accept first arrow starting either inside the circle or on the circle.*<br>*M2 may be awarded from correct diagram for M3.*<br>*M4: Accept* $C_6H_5NO_2 + H_2SO_4$ *if* $HSO_4^-$ *used in M3.* | 4 |

*(continued)*

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 2. | c | i | *Name:* ethane-1,2-diol ✓<br>*Class:* alcohol**«**s**»** ✓ | *Accept ethan-1,2-diol / 1,2-ethanediol.*<br>*Do **not** accept "diol" for Class.* | **2** |
| 2. | c | ii | two ***AND*** two hydrogen environments in the molecule<br>***OR***<br>two ***AND*** both $CH_2$ and OH present ✓ | | **1** |
| 2. | c | iii | $^{+}CH_2OH$ ✓ | *Accept $CH_3O^+$.*<br>*Accept $[\bullet CH_2OH]^+$ and $[\bullet CH_3O]^+$.*<br>*Do **not** accept answers in which the charge is missing.* | **1** |
| 2. | c | iv | oxygen-hydrogen **«**bond**»**/O–H **«**in hydroxyl**»** ✓ | | **1** |
| 2. | d | | $K_b \approx \frac{[OH^-]^2}{[C_6H_5NH_2]} = 10^{-9.13}$ / $7.413 \times 10^{-10}$ ✓<br>$[OH^-] = \sqrt{0.0100 \times 10^{-9.13}} = 2.72 \times 10^{-6}$ ✓<br>$[H^+] = \frac{1 \times 10^{-14}}{2.72 \times 10^{-6}} = 3.67 \times 10^{-9}$<br>***OR***<br>pOH = 5.57 ✓<br>pH = –log $[H^+]$ = 8.44 ✓ | *Accept other approaches to the calculation.*<br>*Award **[4]** for correct final answer.*<br>*Accept any answer from 8.4 to 8.5.* | **4** |

| | | | | | |
|---|---|---|---|---|---|
| **3.** | **a** | **i** | $2NO(g) + 2H_2(g) \rightarrow N_2(g) + 2H_2O(g)$ ✓ | | **1** |
| **3.** | **a** | **ii** | rate $= k[NO]^2[H_2]$ ✓ | | **1** |
| **3.** | **a** | **iii** | test the effect **«**on the reaction rate**»** of varying each concentration **«**independently**»**<br>***OR***<br>test the effect of varying [NO] **«**on rate**»**, whilst keeping $[H_2]$ constant ***AND***<br>test effect of varying $[H_2]$ **«**on rate**»**, whilst keeping [NO] constant ✓<br><br>rate proportional to $[NO]^2$<br>***OR***<br>doubling [NO] quadruples rate ✓<br><br>rate proportional to $[H_2]$<br>***OR***<br>doubling $[H_2]$ doubles rate ✓ | *Remember to refer back to a (ii) for **ECF**.*<br><br>*If only one species in rate expression, third mark can be awarded for zero order discussion.* | **3** |
| **3.** | **a** | **iv** | no ***AND*** different mechanisms could give the same rate expression<br>***OR***<br>no ***AND*** mechanisms can only be disproved<br>***OR***<br>no ***AND*** just suggest it is consistent with the mechanism given<br>***OR***<br>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<br>***OR***<br>change of volume **«**at constant pressure and temperature**»** with time ✓ | *Accept other methods where rate can be monitored with time.* | **1** |

*(continued)*

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 3. | b | i |  <br>products lower than reactants ***AND*** enthalpy of reaction correctly marked and labelled with name or value ✓<br><br>activation energy correctly marked and labelled with name or value ✓ | *Accept other clear ways of indicating energy/ enthalpy changes.* | **2** |
| 3. | b | ii |  <br>lower dotted curve, between same reactants and products levels, labelled “Catalysed” ✓ | | **1** |

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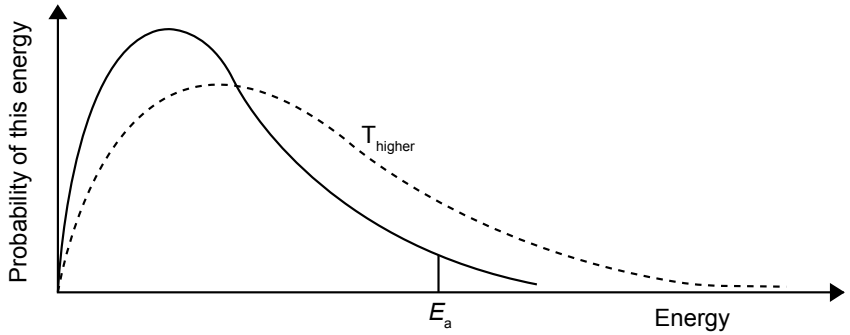
| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 3. | b | iii |  <br>second curve at a higher temperature is correctly drawn (maximum lower and to right of original) ✓ | | 1 |
| 3. | b | iv | greater proportion of molecules have $E \geq E_a$ or $E > E_a$<br>***OR***<br>greater area under curve to the right of the $E_a$ ✓<br><br>greater frequency of collisions «between molecules»<br>***OR***<br>more collisions per unit time/second ✓ | *Do **not** accept just particles have greater kinetic energy.*<br><br>*Do **not** accept just "more collisions".* | 2 |

*(continued)*

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

| | | | | | |
|---|---|---|---|---|---|
| **4.** | **a** | **i** | same charge ***AND*** same/similar ionic radius ✓ | | **1** |
| **4.** | **a** | **ii** | enthalpy of hydration **«**$= -1483 + 2(-359)$**»** $= -2201$ **«**$\text{kJ mol}^{-1}$**»** ✓<br>enthalpy of solution **«**$= 2170 - 2201$**»** $= -31$ **«**$\text{kJ mol}^{-1}$**»** ✓ | *Award **[2]** for correct final answer.*<br>*Award **[1 max]** for $+31$ «$\text{kJ mol}^{-1}$».*<br>*Award **[1 max]** for $\pm 4371$.* | **2** |
| **4.** | **a** | **iii** | hydrochloric acid shifts equilibrium to left<br>***OR***<br>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**»** ✓<br><br>$\Delta G^{\ominus}$ **«**$= -nFE^{\ominus} = -2 \times 96500 \times 0.19$**»** $= -36670$ / $-37000$ **«**J**»** / $-37$ **«**kJ**»** ✓ | *Accept $-18335$ «J» or $-18$ «kJ» as equation not specified.* | **2** |
| **4.** | **b** | **ii** | yes ***AND*** $\Delta G^{\ominus}$ is negative<br>***OR***<br>yes ***AND*** $E^{\ominus}$ for the cell is positive<br>***OR***<br>yes ***AND*** $Sn^{2+}(aq)$ is a stronger reducing agent than $V^{3+}(aq)$<br>***OR***<br>yes ***AND*** $E^{\ominus}$ for $Sn^{4+}(aq)$ is more negative than $E^{\ominus}$ for $VO^{2+}(aq)$<br>***OR***<br>yes ***AND*** $VO^{2+}(aq)$ is a stronger oxidizing agent than $Sn^{4+}(aq)$<br>***OR***<br>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** | | $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3 4s^2$<br>***OR***<br>$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^3$ ✓<br><br>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".*<br>*Accept "by acting as Lewis bases".*<br>*Do not accept "act as ligands".* | **1** |

*(continued)*

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 4. | d | ii | «more chlorido ligands» smaller energy gap between split d-orbitals<br>***OR***<br>$Cl^-$ is lower than $H_2O$ in spectrochemical series<br>***OR***<br>$Cl^-$ is a weaker ligand/has lower charge density ✓<br><br>the absorption will move to longer wavelengths<br>***OR***<br>the absorption wavelength will increase ✓ | *Do not accept answers in terms of change of frequency.* | **2** |
| 4. | e | i | *First*: 4s ***AND*** *Second*: 4s ***AND*** *Third*: 3d ***AND*** *Fourth*: 3d ✓ | *Do **not** apply **ECF** from (c).* | **1** |
| 4. | e | ii | «in the same sub-shell and a» decrease in electron-electron repulsion<br>***OR***<br>«in the same sub-shell and» as more electrons removed, the pull of of the nucleus/positive ions holds the remaining electrons more tightly ✓ | *Do **not** accept "greater nuclear charge/ effective nuclear charge".* | **1** |
| 4. | e | iii | electron 5 is lost from the 3d orbital<br>***OR***<br>electron 5 is lost from the valence shell ✓<br><br>electron 6 is lost from a 3p orbital<br>***OR***<br>electron 6 is lost from a «complete» inner shell ✓<br><br>3p orbital/complete inner shell experiences a much larger effective nuclear charge<br>***OR***<br>3p orbital/complete inner shell is less well shielded<br>***OR***<br>3p orbital/complete inner shell is nearer the nucleus ✓ | *Award **[1 max]** (for M1/M2) (**ECF**) if candidate recognises electrons 5 and 6 are from different levels.* | **3** |
| 4. | e | iv | 28 ✓ | | **1** |

| | | | | | |
|---|---|---|---|---|---|
| **5.** | **a** | **i** | «structural/functional» isomer«s» ✓ | | **1** |
| **5.** | **a** | **ii** | *Test:*<br>«react with» bromine/$Br_2$ «in the dark»<br>***OR***<br>«react with» bromine water/$Br_2$(aq) «in the dark» ✓<br><br>*A*: from yellow/orange/brown to colourless ***AND*** *B*: colour remains/slowly decolourized ✓ | *Accept other correct reagents, such as manganate(VII) or iodine solutions, and descriptions of the corresponding changes observed.*<br><br>*Accept "decolourized" for A and "not decolourized/unchanged" for B.*<br>*Do **not** accept "clear/transparent" instead of "colourless".* | **2** |
| **5.** | **b** | | compound **A** would absorb at 1620–1680 «$cm^{-1}$» ✓ | *Accept any value in range 1620 – 1680 $cm^{-1}$.* | **1** |
| **5.** | **c** | | ***Signal*** **1/2** **2/1**<br>*Chemical shift / ppm* 0.9 – 1.0 ***AND*** 4.5 – 6.0 ✓<br><br>*Splitting pattern* singlet ***AND*** singlet ✓ | *Accept 0.9 to 2.0 for the first signal as the C=C affects the $CH_3$ shift (actually 1.7).*<br><br>*Accept "none/no splitting" for both splitting patterns.*<br><br>*Award **[1 max]** for the correct deduction (both shift and splitting) of signal 1 or 2.* | **2** |