IB Diploma Chemistry

Higher Level

Paper 1 Exam Questions

From summer 2008 to 2016 winter
2720 marks in total

Name: ____________________________
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All topics Covered in SL RED area and HL BLUE COLUMNS in IB Chemistry in papers 1, 2 and 3 and IA 
Percentage of all WEIGHTED marks awarded for each topic from exam papers from 1999 through to winter 2016.

PAPER 1 - 
Percentage of all marks awarded for each topic from s2015 to w2016 (red) and P1 s2008 to w2014 (green), all timezones

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All topics Covered in HIGHER Level Chemistry in papers 1, 2 and 3
Percentage of all WEIGHTED marks awarded for each topic from exam papers from 1999 through to winter 2016.

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Higher Level PAPER 2

Percentage of all marks awarded for each topic from summer 2008 to winter 2016 (blue) for Paper 2, weighted for Papers 1, 2 & 3 and all Paper 2s from 1999. From s2016 onwards, all Paper 2 questions are compulsory.
### Number of papers used to calculate topic mark frequencies

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### Papers used for Higher Level P2 Sections A and B

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2. The concentration of a solution of a weak acid, such as ethanedioic acid, can be determined by titration with a standard solution of sodium hydroxide, NaOH(aq).

(c) 5.00g of an impure sample of hydrated ethanedioic acid, \((\text{COOH})_2\cdot 2\text{H}_2\text{O}\), was dissolved in water to make 1.00 dm\(^3\) of solution. 25.0 cm\(^3\) samples of this solution were titrated against a 0.100 mol dm\(^{-3}\) solution of sodium hydroxide using a suitable indicator.

\[(\text{COOH})_2\text{(aq)} + 2\text{NaOH(aq)} \rightarrow (\text{COONa})_2\text{(aq)} + 2\text{H}_2\text{O(l)}\]

The mean value of the titre was 14.0 cm\(^3\).

(ii) Calculate the amount, in mol, of NaOH in 14.0 cm\(^3\) of 0.100 mol dm\(^{-3}\) solution. [1]

(iii) Calculate the amount, in mol, of ethanedioic acid in each 25.0 cm\(^3\) sample. [1]

(iv) Determine the percentage purity of the hydrated ethanedioic acid sample. [3]
Chem 14 Q# 2/IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/Q7

(b) Bute, a painkiller used on horses, has caused widespread concern recently because analytical tests showed that it entered the food chain through horse meat labelled as beef. The drug is suspected of causing cancer.

(i) Analysis of a sample of bute carried out in a food safety laboratory gave the following elemental percentage compositions by mass:

<table>
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<th>Element</th>
<th>Percentage</th>
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<td>C</td>
<td>73.99</td>
</tr>
<tr>
<td>H</td>
<td>6.55</td>
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<tr>
<td>N</td>
<td>9.09</td>
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<tr>
<td>O</td>
<td>Remainder</td>
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</table>

Calculate the empirical formula of bute, showing your working.  

(ii) The molar mass, \( M \), of bute, is 308.37 g mol\(^{-1}\). Calculate the molecular formula.
1. Two IB students carried out a project on the chemistry of bleach.

(a) The bleach contained a solution of sodium hypochlorite, NaClO(aq). The students determined experimentally the concentration of hypochlorite ions, ClO⁻, in the bleach:

**Experimental procedure:**

- The bleach solution was first diluted by adding 25.00 cm³ of the bleach to a 250 cm³ volumetric flask. The solution was filled to the graduation mark with deionized water.

- 25.00 cm³ of this solution was then reacted with excess iodide in acid.

\[
\text{ClO}^- \text{(aq)} + 2\text{I}^- \text{(aq)} + 2\text{H}^+ \text{(aq)} \rightarrow \text{Cl}^- \text{(aq)} + \text{I}_2 \text{(aq)} + \text{H}_2\text{O} \text{(l)}
\]

- The iodine formed was titrated with 0.100 mol dm⁻³ sodium thiosulphate solution, Na₂S₂O₃(aq), using starch indicator.

\[
\text{I}_2 \text{(aq)} + 2\text{S}_2\text{O}_3^{2-} \text{(aq)} \rightarrow 2\text{I}^- \text{(aq)} + \text{S}_4\text{O}_6^{2-} \text{(aq)}
\]

The following data were recorded for the titration:

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<th>Second titre</th>
<th>Third titre</th>
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<td>Initial burette reading of 0.100 mol dm⁻³ Na₂S₂O₃(aq) (in cm³ ± 0.05)</td>
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</table>

(i) Calculate the volume, in cm³, of 0.100 mol dm⁻³ Na₂S₂O₃(aq) required to react with the iodine to reach the end point.  

[1]
(ii) Calculate the amount, in mol, of Na$_2$S$_2$O$_3$(aq) that reacts with the iodine.

\[
\text{.................................................................}
\]

\[
\text{.................................................................}
\]

(iii) Calculate the concentration, in mol dm$^{-3}$, of hypochlorite ions in the diluted bleach solution.

\[
\text{.................................................................}
\]

\[
\text{.................................................................}
\]

(iv) Calculate the concentration, in mol dm$^{-3}$, of hypochlorite ions in the undiluted bleach solution.

\[
\text{.................................................................}
\]

\[
\text{.................................................................}
\]

Chem 19 Q# 4/ IB Chem/2016/S/TZ1/Paper 2 Section A/Higher Level/

1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula PH$_3$.

(b) Phosphine is usually prepared by heating white phosphorus, one of the allotropes of phosphorus, with concentrated aqueous sodium hydroxide. The equation for the reaction is:

\[
P_4(s) + 3OH^-(aq) + 3H_2O(l) \rightarrow PH_3(g) + 3H_2PO_2^-(aq)
\]

(i) The first reagent is written as P$_4$, not 4P. Describe the difference between P$_4$ and 4P.
(c) 2.478 g of white phosphorus was used to make phosphine according to the equation:

\[ P_4(s) + 3OH^-(aq) + 3H_2O(l) \rightarrow PH_3(g) + 3H_2PO_2^-(aq) \]

(i) Calculate the amount, in mol, of white phosphorus used.  

(ii) This phosphorus was reacted with 100.0 cm\(^3\) of 5.00 mol dm\(^{-3}\) aqueous sodium hydroxide. Deduce, showing your working, which was the limiting reagent.

(iii) Determine the excess amount, in mol, of the other reagent.

(iv) Determine the volume of phosphine, measured in cm\(^3\) at standard temperature and pressure, that was produced.

(d) Impurities cause phosphine to ignite spontaneously in air to form an oxide of phosphorus and water.
1 Mole of Phosphine was completely combusted in air.

(ii) The oxide formed in the reaction with air contains 43.6% phosphorus by mass. Determine the empirical formula of the oxide, showing your method. [3]

(iii) The molar mass of the oxide is approximately 285 g mol⁻¹. Determine the molecular formula of the oxide. [1]

1. A student used the technique of titration to determine the concentration of ascorbic acid (C₆H₇O₆) in a sample of orange juice. Excess potassium iodide, KI(aq), was added to acidified orange juice. The resulting solution was titrated with potassium iodate, KIO₃(aq), in the presence of starch as an indicator. The end-point of the titration was shown by a blue-black colour.

Step 1 \[ \text{IO}_5^- (aq) + 5\text{I}^- (aq) + 6\text{H}^+ (aq) \rightarrow 3\text{I}_2 (aq) + 3\text{H}_2\text{O} (l) \]

Iodine is only slightly soluble in water; but in the presence of excess iodide ions, \( \text{I}^- (aq) \), it forms the soluble tri-iodide ion, \( \text{I}_3^- (aq) \).

Step 2 \[ \text{I}_2 (aq) + \text{I}^- (aq) \rightarrow \text{I}_3^- (aq) \]

Ascorbic acid reacts with tri-iodide ions as follows.

Step 3 \[ \text{C}_6\text{H}_7\text{O}_6 (aq) + \text{I}_3^- (aq) \rightarrow \text{C}_6\text{H}_5\text{O}_6 (aq) + 2\text{H}^+ (aq) + 3\text{I}^- (aq) \]
(b) Calculate the mass, in g, of potassium iodate, $\text{KIO}_3(s)$, which was required to prepare 0.250 dm$^3$ of a $2.00 \times 10^{-3}$ mol dm$^{-3}$ solution. [2]

(c) The concentration of $\text{KIO}_3$ used in the titration was $2.00 \times 10^{-3}$ mol dm$^{-3}$. The titration produced the following results.

<table>
<thead>
<tr>
<th></th>
<th>Titration 1</th>
<th>Titration 2</th>
<th>Titration 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final volume of $\text{KIO}_3$ (± 0.05 cm$^3$)</td>
<td>7.10</td>
<td>14.40</td>
<td>21.60</td>
</tr>
<tr>
<td>Initial volume of $\text{KIO}_3$ (± 0.05 cm$^3$)</td>
<td>0.00</td>
<td>7.10</td>
<td>14.40</td>
</tr>
<tr>
<td>Volume added of $\text{KIO}_3$ (± 0.10 cm$^3$)</td>
<td>7.10</td>
<td>7.30</td>
<td>7.20</td>
</tr>
<tr>
<td>Mean volume added of $\text{KIO}_3$ (± 0.10 cm$^3$)</td>
<td></td>
<td></td>
<td>7.20</td>
</tr>
</tbody>
</table>

(iii) Determine the amount, in mol, of $\text{KIO}_3(aq)$, in the mean volume. [1]

(d) Determine the amount, in mol, of ascorbic acid, $\text{C}_6\text{H}_6\text{O}_6(aq)$, in the sample of acidified orange juice. [2]

(e) Calculate the mass, in g, of ascorbic acid, $\text{C}_6\text{H}_6\text{O}_6(aq)$, present in the sample of acidified orange juice. [1]
Chem 1 7 Q# 6/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/

1. Ethanedioic acid is a diprotic acid. A student determined the value of \( x \) in the formula of hydrated ethanedioic acid, H\(_2\)OOC—COOH\( \cdot \)\( x \)H\(_2\)O, by titrating a known mass of the acid with a 0.100 mol dm\(^{-3} \) solution of NaOH (aq).

0.795 g of ethanedioic acid was dissolved in distilled water and made up to a total volume of 250 cm\(^3 \) in a volumetric flask.

25 cm\(^3 \) of this ethanedioic acid solution was pipetted into a flask and titrated against aqueous sodium hydroxide using phenolphthalein as an indicator.

The titration was then repeated twice to obtain the results below.

<table>
<thead>
<tr>
<th>Volume of 0.100 mol dm(^{-3} ) NaOH / cm(^3 )</th>
<th>Titration 1</th>
<th>Titration 2</th>
<th>Titration 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final burette reading (± 0.05)</td>
<td>13.00</td>
<td>25.70</td>
<td>38.20</td>
</tr>
<tr>
<td>Initial burette reading (± 0.05)</td>
<td>0.00</td>
<td>13.00</td>
<td>25.70</td>
</tr>
<tr>
<td>Volume added</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a) Calculate the average volume of NaOH added, in cm\(^3 \), in titrations 2 and 3, and then calculate the amount, in mol, of NaOH added. [2]
(b) (i) The equation for the reaction taking place in the titration is:

\[ \text{HOOC–COOH (aq) + 2NaOH (aq) \rightarrow NaOOC–COONa (aq) + 2H}_2\text{O (l)} \]

Determine the amount, in mol, of ethanedioic acid that reacts with the average volume of NaOH (aq).

(ii) Determine the amount, in mol, of ethanedioic acid present in 250 cm\(^3\) of the original solution.

(iii) Determine the molar mass of hydrated ethanedioic acid.

(iv) Determine the value of \(x\) in the formula HOOC–COOH\(\cdot\)\(x\)\(\text{H}_2\text{O}\).
(e) The graph below shows pressure and volume data collected for a sample of carbon dioxide gas at 330 K.

(i) Draw a best-fit curve for the data on the graph.  

(ii) Use the data point labelled X to determine the amount, in mol, of carbon dioxide gas in the sample.
(b) Deduce the empirical formula of D-fructose. [1]

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(c) Calculate the percentage composition by mass of D-fructose. [2]

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Chem 14 Q# 9/ IB Chem/2014/w/TZ0/Paper 2 Section A/Higher Level/
4. Phosphorus(V) oxide, \( \text{P}_4\text{O}_{10} \) \( (M_r = 283.88) \), reacts vigorously with water \( (M_r = 18.02) \), according to the equation below:

\[
\text{P}_4\text{O}_{10}(s) + 6\text{H}_2\text{O}(l) \rightarrow 4\text{H}_3\text{PO}_4(aq)
\]

(a) A student added 5.00 g of \( \text{P}_4\text{O}_{10} \) to 1.50 g of water. Determine the limiting reactant, showing your working. [2]

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(b) Calculate the mass of phosphoric(V) acid, \( \text{H}_3\text{PO}_4 \), formed in the reaction. [2]

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Chem 19 Q# 10/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/Q8

(b) 25.0 cm\(^3\) of 0.200 mol dm\(^{-3}\) ethanoic acid was added to 30.0 cm\(^3\) of a 0.150 mol dm\(^{-3}\) sodium hydrogen carbonate solution, \( \text{NaHCO}_3(aq) \).
The reaction of ethanoic acid and sodium hydrogen carbonate is given below:

\[
\text{CH}_3\text{COOH (aq)} + \text{HCO}_3^- (aq) \rightarrow \text{CH}_3\text{COO}^- (aq) + \text{H}_2\text{O (l)} + \text{CO}_2 (g);
\]

(b) 25.0 cm\(^3\) of 0.200 mol dm\(^{-3}\) ethanoic acid was added to 30.0 cm\(^3\) of a 0.150 mol dm\(^{-3}\) sodium hydrogen carbonate solution, NaHCO\(_3\) (aq).

(i) State an equation for the reaction of ethanoic acid with a solution of sodium hydrogen carbonate. \([1]\]

(ii) Determine which is the limiting reagent. Show your working. \([2]\)
(iii) Calculate the mass, in g, of carbon dioxide gas produced. [2]

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(c) The molar mass of a volatile organic liquid, X, can be determined experimentally by allowing it to vaporize completely at a controlled temperature and pressure. 0.348 g of X was injected into a gas syringe maintained at a temperature of 90 °C and a pressure of 1.01×10^5 Pa. Once it had reached equilibrium, the gas volume was measured as 95.0 cm^3.

(i) Determine the amount, in mol, of X in the gas syringe. [3]

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(ii) Calculate the molar mass of X. [1]

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1. A student decided to determine the molecular mass of a solid monoprotic acid, HA, by titrating a solution of a known mass of the acid.

The following recordings were made.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of bottle / g ± 0.001 g</td>
<td>1.737</td>
</tr>
<tr>
<td>Mass of bottle + acid HA / g ± 0.001 g</td>
<td>2.412</td>
</tr>
</tbody>
</table>

(a) Calculate the mass of the acid and determine its absolute and percentage uncertainty. [2]

(b) This known mass of acid, HA, was then dissolved in distilled water to form a 100.0 cm³ solution in a volumetric flask. A 25.0 cm³ sample of this solution reacted with 12.1 cm³ of a 0.100 mol dm⁻³ NaOH solution. Calculate the molar mass of the acid. [3]
(c) The percentage composition of HA is 70.56% carbon, 23.50% oxygen and 5.94% hydrogen. Determine its empirical formula.  

(d) Determine the molecular formula of HA.
Chem 1 5 Q# 12/ IB Chem/2012/w/TZ0/Paper 2 Section B/Higher Level/Q7

(b) An ester which gives apples their characteristic smell contains C, H and O. When 3.00 \times 10^{-3} \text{ g} of this ester were completely combusted, 6.93 \times 10^{-3} \text{ g} of CO$_2$ and 2.83 \times 10^{-3} \text{ g} of H$_2$O were produced.

(i) Determine the empirical formula of the ester, showing your working. [4]

(ii) The molar mass of the ester is 116.18 \text{ g mol}^{-1}. Determine its molecular formula. [1]
1. Two groups of students (Group A and Group B) carried out a project on the chemistry of some group 7 elements (the halogens) and their compounds.

(a) In the first part of the project, the two groups had a sample of iodine monochloride (a corrosive brown liquid) prepared for them by their teacher using the following reaction.

\[ I_2(s) + Cl_2(g) \rightarrow 2ICl(l) \]

The following data were recorded.

<table>
<thead>
<tr>
<th>Mass of I$_2$(s)</th>
<th>10.00 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of Cl$_2$(g)</td>
<td>2.24 g</td>
</tr>
<tr>
<td>Mass of ICl(l) obtained</td>
<td>8.60 g</td>
</tr>
</tbody>
</table>

(c) The students reacted ICl(l) with CsBr(s) to form a yellow solid, CsICl$_2$(s), as one of the products. CsICl$_2$(s) has been found to produce very pure CsCl(s) which is used in cancer treatment.

To confirm the composition of the yellow solid, Group A determined the amount of iodine in 0.2015 g of CsICl$_2$(s) by titrating it with 0.0500 mol dm$^{-3}$ Na$_2$S$_2$O$_3$(aq). The following data were recorded for the titration.

<table>
<thead>
<tr>
<th>Mass of CsICl$_2$(s) taken (in g $\pm$ 0.0001)</th>
<th>0.2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial burette reading of 0.0500 mol dm$^{-3}$ Na$_2$S$_2$O$_3$(aq) (in cm$^3$ $\pm$ 0.05)</td>
<td>1.05</td>
</tr>
<tr>
<td>Final burette reading of 0.0500 mol dm$^{-3}$ Na$_2$S$_2$O$_3$(aq) (in cm$^3$ $\pm$ 0.05)</td>
<td>25.25</td>
</tr>
</tbody>
</table>

(i) Calculate the percentage of iodine by mass in CsICl$_2$(s), correct to three significant figures. [1]
(ii) State the volume, in cm$^3$, of 0.0500 mol dm$^{-3}$ Na$_2$S$_2$O$_3$ (aq) used in the titration. [1]

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(iii) Determine the amount, in mol, of 0.0500 mol dm$^{-3}$ Na$_2$S$_2$O$_3$ (aq) added in the titration. [1]

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(iv) The overall reaction taking place during the titration is:

\[ \text{CsICl}_2(s) + 2\text{Na}_2\text{S}_2\text{O}_3(aq) \rightarrow \text{NaCl}(aq) + \text{Na}_2\text{S}_4\text{O}_6(aq) + \text{CsCl}(aq) + \text{NaI}(aq) \]

Calculate the amount, in mol, of iodine atoms, I, present in the sample of CsICl$_2$ (s). [1]

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(v) Calculate the mass of iodine, in g, present in the sample of CsICl$_2$ (s). [1]

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(vi) Determine the percentage by mass of iodine in the sample of CsICl$_2$ (s), correct to three significant figures, using your answer from (v).

(d) Group B heated the yellow solid, CsICl$_2$ (s), which turned white and released a brown gas which condensed into a brown liquid.

Group B identified the white solid as CsCl(s). Suggest the identity of the brown liquid.

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Chem 1 4 Q# 14/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/

1. Two groups of students (Group A and Group B) carried out a project on the chemistry of some group 7 elements (the halogens) and their compounds.

(a) In the first part of the project, the two groups had a sample of iodine monochloride (a corrosive brown liquid) prepared for them by their teacher using the following reaction.

\[ \text{I}_2(\text{s}) + \text{Cl}_2(\text{g}) \rightarrow 2\text{ICl}(\text{l}) \]

The following data were recorded.

<table>
<thead>
<tr>
<th>Mass of I$_2$(s)</th>
<th>10.00 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of Cl$_2$(g)</td>
<td>2.24 g</td>
</tr>
<tr>
<td>Mass of ICl(l) obtained</td>
<td>8.60 g</td>
</tr>
</tbody>
</table>
(ii) The iodine used in the reaction was in excess. Determine the theoretical yield, in g, of ICl(l).

(iii) Calculate the percentage yield of ICl(l).
(c) An important environmental consideration is the appropriate disposal of cleaning solvents. An environmental waste treatment company analysed a cleaning solvent, J, and found it to contain the elements carbon, hydrogen and chlorine only. The chemical composition of J was determined using different analytical chemistry techniques.

*Combustion Reaction:*

Combustion of 1.30 g of J gave 0.872 g CO₂ and 0.089 g H₂O.

*Precipitation Reaction with AgNO₃(aq):*

0.535 g of J gave 1.75 g AgCl precipitate.

(i) Determine the percentage by mass of carbon and hydrogen in J, using the combustion data. [3]

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(c) An important environmental consideration is the appropriate disposal of cleaning solvents. An environmental waste treatment company analysed a cleaning solvent, J, and found it to contain the elements carbon, hydrogen and chlorine only. The chemical composition of J was determined using different analytical chemistry techniques.

\textit{Combustion Reaction:}

Combustion of 1.30 g of J gave 0.872 g CO\textsubscript{2} and 0.089 g H\textsubscript{2}O.

\textit{Precipitation Reaction with AgNO\textsubscript{3}(aq):}

0.535 g of J gave 1.75 g AgCl precipitate.

(i) Determine the percentage by mass of carbon and hydrogen in J, using the combustion data. [3]

(ii) Determine the percentage by mass of chlorine in J, using the precipitation data. [1]
(iii) The molar mass was determined to be 131.38 g mol\(^{-1}\). Deduce the molecular formula of J.

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1. Airbags are an important safety feature in vehicles. Sodium azide, potassium nitrate and silicon dioxide have been used in one design of airbag.

   [Source: www.hilalairbag.net]

Sodium azide, a toxic compound, undergoes the following decomposition reaction under certain conditions.

\[
2\text{NaN}_3(s) \rightarrow 2\text{Na}(s) + 3\text{N}_2(g)
\]

Two students looked at data in a simulated computer-based experiment to determine the volume of nitrogen generated in an airbag.
(b) Using the simulation programme, the students entered the following data into the computer.

<table>
<thead>
<tr>
<th>Temperature (T) / °C</th>
<th>Mass of NaN₃(s) (m) / kg</th>
<th>Pressure (p) / atm</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.00</td>
<td>0.0650</td>
<td>1.08</td>
</tr>
</tbody>
</table>

(i) State the number of significant figures for the temperature, mass and pressure data.  [1]

\[ T: \]
\[ m: \]
\[ p: \]

(ii) Calculate the amount, in mol, of sodium azide present.  [1]

\[ \text{..........................................................} \]

(iii) Determine the volume of nitrogen gas, in dm³, produced under these conditions based on this reaction.  [4]

\[ \text{..........................................................} \]

\[ \text{..........................................................} \]

\[ \text{..........................................................} \]

\[ \text{..........................................................} \]
Nitrogen monoxide may be removed from industrial emissions via a reaction with ammonia as shown by the equation below.

\[ 4\text{NH}_3(g) + 6\text{NO}(g) \rightarrow 5\text{N}_2(g) + 6\text{H}_2\text{O}(l) \]

(iii) 30.0 dm\(^3\) of ammonia reacts with 30.0 dm\(^3\) of nitrogen monoxide at 100 °C. Identify which gas is in excess and by how much and calculate the volume of nitrogen produced.

---

1. The data below is from an experiment used to determine the percentage of iron present in a sample of iron ore. This sample was dissolved in acid and all of the iron was converted to \(\text{Fe}^{2+}\). The resulting solution was titrated with a standard solution of potassium manganate(VII), \(\text{KMnO}_4\). This procedure was carried out three times. In acidic solution, \(\text{MnO}_4^-\) reacts with \(\text{Fe}^{3+}\) ions to form \(\text{Mn}^{2+}\) and \(\text{Fe}^{2+}\) and the end point is indicated by a slight pink colour.

<table>
<thead>
<tr>
<th>Titre</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial burette reading / cm(^3)</td>
<td>1.00</td>
<td>23.60</td>
<td>10.00</td>
</tr>
<tr>
<td>Final burette reading / cm(^3)</td>
<td>24.60</td>
<td>46.10</td>
<td>32.50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mass of iron ore / g</th>
<th>(3.682 \times 10^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration of (\text{KMnO}_4) solution / mol dm(^{-3})</td>
<td>(2.152 \times 10^{-2})</td>
</tr>
</tbody>
</table>
(c) Calculate the amount, in moles, of $\text{MnO}_4^-$ used in the titration. [2]

(d) Calculate the amount, in moles, of $\text{Fe}$ present in the $3.682 \times 10^{-1}$ g sample of iron ore. [2]

(e) Determine the percentage by mass of $\text{Fe}$ present in the $3.682 \times 10^{-1}$ g sample of iron ore. [2]
5. Two 1.00 dm$^3$ containers A and B each contain 2.00 g of the gas indicated at 25.0°C.

(a) Calculate the pressure in container B. $[3]$

(b) Deduce without calculation whether the pressure in A is higher or lower than container B and explain your answer. $[2]$
1. The value of $x$ in $\text{Fe(NH}_4\text{)}_2(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$ can be found by determining the amount, in moles, of sulfate in the compound.

A 0.982 g sample was dissolved in water and excess $\text{BaCl}_2(\text{aq})$ was added. The precipitate of $\text{BaSO}_4$ was separated and dried and found to weigh 1.17 g.

(a) Calculate the amount, in moles of $\text{BaSO}_4$ in the 1.17 g precipitate. [2]

(b) Calculate the amount, in moles, of sulfate in the 0.982 g sample of $\text{Fe(NH}_4\text{)}_2(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$. [1]

(c) Calculate the amount, in moles, of iron in the 0.982 g sample of $\text{Fe(NH}_4\text{)}_2(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$. [1]

(d) Determine the mass of the following present in the 0.982 g sample of $\text{Fe(NH}_4\text{)}_2(\text{SO}_4)_2 \cdot x\text{H}_2\text{O}$. [3]

(i) Iron

(ii) Ammonium

(iii) Sulfate
(c) Use your answer from part (d) to determine the amount, in moles, of water present in the 0.982g sample of Fe(NH₄)₂(SO₄)₂·xH₂O.

(ii) Determine the amount, in moles, of Fe(NH₄)₂(SO₄)₂ and hence the value of x.

**Topic 1 Mark Scheme**

**Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. a</td>
<td>Weak acid: partially dissociated/ionized in solution/water AND Strong acid: assumed to be almost completely/100% dissociated/ionized in solution/water</td>
<td>Accept answers relating to pH, conductivity, reactivity if solutions of equal concentrations stated.</td>
<td>1</td>
</tr>
<tr>
<td>2. b</td>
<td>log scale reduces a wide range of numbers to a small range OR simple/easy to use OR converts exponential expressions into a linear scale/simple numbers</td>
<td>Do not accept “easy for calculations”</td>
<td>1</td>
</tr>
<tr>
<td>2. c i</td>
<td>phenolphthalein OR phenol red</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2. c ii</td>
<td>( n(\text{NaOH}) = \left( \frac{14.0}{1000} \right) \text{dm}^3 \times 0.100 \text{mol dm}^{-3} = 1.40 \times 10^{-2} \text{mol} )</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2. c iii</td>
<td>( \frac{1}{2} \times 1.40 \times 10^{-2} \rightarrow 7.00 \times 10^{-3} \text{mol} )</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Question</td>
<td>Answers</td>
<td>Notes</td>
<td>Total</td>
</tr>
<tr>
<td>----------</td>
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</tbody>
</table>
| **2.** | c iv | **ALTERNATIVE 1:**
- Mass of pure hydrated ethanedioic acid in each titration = $7.00 \times 10^{-4} \text{ mol} \times 126.09 \text{ g mol}^{-1} = 0.0883 \text{ g}$
- Mass of sample in each titration = $\frac{25}{1000} \times 5.00 \text{ g} = 0.125 \text{ g}$
- % purity = $\frac{0.0883}{0.125} \times 100 \approx 70.6 \%$
| | **ALTERNATIVE 2:**
- Mol of pure hydrated ethanedioic acid in 1 dm$^3$ solution = $7.00 \times 10^{-4} \times \frac{25}{1000} = 2.80 \times 10^{-5}$ mol
- Mass of pure hydrated ethanedioic acid in sample = $2.80 \times 10^{-5} \text{ mol} \times 126.09 \text{ g mol}^{-1} = 0.353 \text{ g}$
- % purity = $\frac{0.353}{5.00} \times 100 \approx 70.6 \%$
| | **ALTERNATIVE 3:**
- Mol of hydrated ethanedioic acid (assuming sample to be pure) = $\frac{5.00 \text{ g}}{126.09 \text{ g mol}^{-1}} = 0.03936 \text{ mol}$
- Actual amount of hydrated ethanedioic acid = $7.00 \times 10^{-4} \times \frac{1000}{25} = 2.80 \times 10^{-3}$ mol
- % purity = $\frac{2.80 \times 10^{-3}}{0.03936} \times 100 \approx 70.6 \%$
| | Award suitable part marks for alternative methods.
| | Award [3] for correct final answer.
| | Award [2 max] for 50.4% if anhydrous ethanedioic acid assumed.
| **Q# 2**/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/Q7 | b i | $n_1: \frac{73.99}{12.01} = 6.161 \text{ (mol)}$ and $n_2: \frac{6.55}{1.01} = 6.49 \text{ (mol)}$
| | and $n_3: \frac{9.09}{14.01} = 0.649 \text{ (mol)}$ and $n_4: \frac{10.37}{16.00} = 0.6481 \text{ (mol)}$
| | $n_1:n_2:n_3:n_4 = 9.5:10:1:1$
| | Empirical formula: $C_{9n_{12}}H_{2n_{12}}N_{2n_{12}}O_{2n_{12}}$
| | Award [2 max] for correct final answer without working.
| **Q# 3**/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/ | a $\sqrt[3]{(22.05 + 22.15)(0.0) \rightarrow 22.10 \text{ cm}^3}$
| a ii | $\left(\frac{22.10 \times 10^{-3}}{1000}\right) = 2.21 \times 10^{-5}$ mol
| a iii | $\left(\frac{0.6 \times 2.21 \times 10^{-5} \times 1000}{25.00}\right) = 4.42 \times 10^{-3}$ mol dm$^{-3}$
| a iv | $(4.42 \times 10^{-3} \times 10) \rightarrow 4.42 \times 10^{-2}$ mol dm$^{-3}$
| **Q# 4**/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/Q1 | b i | $P_4$ is a molecule comprising 4P atoms and 4P is four separate P atoms.
| | $P_4$ represents 4P atoms bonded together and 4P represents 4P separate/nont-bonded P atoms.
| c i | $\left(\frac{2.478}{4 \times 3.097}\right) = 0.0200 \text{ mol}$
| c ii | $n(\text{NaOH}) = \frac{1000 \times 5.00 \times 0.500 \text{ mol}}{18} = 5.00 \text{ mol}$
| c iii | $n(\text{P}_4\text{O}_3) = (3 \times 0.0200) = 0.440 \text{ mol}$
| c iv | $(22.7 \times 1000 \times 0.0200) = 454 \text{ cm}^3$
| | 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$^3$. |
### Question 5

**IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/**

1. (a) (i) $\text{IO}_3^-$ to $I_2$: $\text{V}/+5$ to 0;
   
   $I^{-}$ to $I_2$: $-1$ to 0;
   
   *Accept change in oxidation number $-5$ and $+1$.*

   *Penalize incorrect notation such as $5+$ or $5$ once only.*

   (ii) **Oxidizing agent:** $\text{IO}_3^-$/iodate and **Reducing agent:** $I^-$/iodide;  
   
   (b) $0.250 \times 2.00 \times 10^{-3} / 5.00 \times 10^{-4}$ (mol of KIO$_3$);
   
   $(5.00 \times 10^{-4} \times 214.00 =) 0.107$ (g);
   
   *Award [2] for the correct final answer.*

   (c) (i) $1.4$ ($\%$);
   
   *Accept 1 ($\%$).*

   (ii) systematic;
   
   dilute the orange juice;
   
   *Accept other valid suggestions, eg. compare with a standard (showing colour at equivalence) / look at mixture through a yellow filter / add more starch (for a sharper colour change) / filter orange juice (through charcoal). Do not accept repeat titrations or alternative indicator.*

   (iii) $1.44 \times 10^{-5}$ (mol);  
   
   (d) $\text{IO}_3^- : 3\text{C}_3\text{H}_2\text{O}_5$ / 1:3 mole ratio;
   
   $(1.44 \times 10^{-5} \times 3 =) 4.32 \times 10^{-5}$ (mol);
   
   *Award [2] for the correct final answer.*

   *Award [1 max] for “$4.80 \times 10^{-5}$ (mol)” obtained from reversed ratio, 3:1.*

   (e) $(4.32 \times 10^{-5} \times 176.14 =) 7.61 \times 10^{-3}$ (g);

   *Accept $M_r = 176$ and mass $= 7.60 \times 10^{-3}$ (g).*
(f) gradient = \( \frac{E_a}{R} \).\( -1233 \, \text{(K)} \):

Accept value from \(-1200\) to \(-1260\) \, (K).

\[
E_a = (1233 \times 8.31 \times 1.02 \times 10^4 \, \text{Jmol}^{-1} / 10.2 \, \text{kJ mol}^{-1}
\]

correct \( E_a \) value;

correct units:

Allow value in range \(9.97 - 10.5\) \, kJ mol\(^{-1}\).

Answer must be given to three significant figures.

Award [3] for correct final answer and units.

Accept J or kJ instead of J mol\(^{-1}\) or kJ mol\(^{-1}\).

Q# 6/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/

1. (a) \( \frac{(12.70 + 12.50)}{2} = 12.60 \, (\text{cm}^3) \):

\(0.01260 \times 0.100 = 1.26 \times 10^{-3} \, \text{(mol)}\);

Award [2] for correct final answer.

(b) \( \frac{1.26 \times 10^{-3}}{2} = 6.30 \times 10^{-4} \, \text{(mol)}\);

(ii) \(6.30 \times 10^{-4} \times 10 = 6.30 \times 10^{-3} \, \text{(mol)}\);

(iii) \(\frac{0.795}{6.30 \times 10^{-3}} = 126 \, (\text{g} \, \text{mol}^{-1})\);

(iv) \(M_r(C_2H_2O_4) = 90.04\) and \(M_r(H_2O) = 18.02\);

\(x = 2\);

Accept integer values for \(M/r\)s of 90 and 18 and any reasonable calculation.

Award [1 max] if no working shown.

Q# 7/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q8

(e) (i) smooth curve through the data;

Do not accept a curve that passes through all of the points or an answer that joins the points using lines.

(ii) \(p = 21 \times 10^5 / 2.1 \times 10^6 \, (\text{Pa}) / 2.1 \times 10^5 \, (\text{kPa})\) and

\(V = 50 \times 10^{-6} / 5.0 \times 10^{-5} \, (\text{m}^3) / 5.0 \times 10^{-3} \, (\text{dm}^3)\);

\[
\left( \frac{n}{RT} \right) = \frac{2.1 \times 10^5 \times 5.0 \times 10^{-5}}{8.31 \times 330}
\]

\(n = 0.038 \, (\text{mol})\);

Award [3] for correct final answer.

For M\(^3\) apply ECF for correct computation of the equation the student has written, unless more than one mistake is made prior this point.
Q# 8/ IB Chem/2014/w/TZ0/Paper 2 Section A/Higher Level/Q6

(b) \( \text{CH}_2\text{O} : \)

(c) \[ \begin{array}{l}
\text{C:} \left( \frac{12.01}{30.03} \times 100 \right) = 39.99/40.0\% \\
\text{H:} \left( \frac{2.02}{30.03} \times 100 \right) = 6.73/6.7\% \\
\text{O:} \left( \frac{16.00}{30.03} \times 100 \right) = 53.28/53.3\% \\
\end{array} \] 

Award [2] if all three are correct, and [1] if two are correct.
Accept if the third value is obtained by subtracting the other two percentages from 100%.
Do not penalize if integer values of relative atomic masses are used.

Q# 9/ IB Chem/2014/w/TZ0/Paper 2 Section A/Higher Level/

4. (a) \( \text{P}_2\text{O}_5 : \left( \frac{5.00}{283.88} = \right) 0.0176 \text{(mol)} \) and \( \text{H}_2\text{O} : \left( \frac{1.50}{18.02} = \right) 0.0832 \text{(mol)} \);

\( \text{H}_2\text{O} \) is the limiting reactant and reason related to stoichiometry;

(b) \( \frac{0.0832 \times 4}{6} / 0.0555 \text{(mol)} ; \)

\( (0.0555 \times 98.00 =) 5.44 \text{ g} ; \)

The unit is needed for \( M2 \).
Award [2] for correct final answer.
Do not penalize slight numerical variations due to premature rounding.
Q# 10/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/Q8

(b) (i) \[ \text{CH}_2\text{COOH}^{(aq)} + \text{HCO}_3^{-}(aq) \rightarrow \text{CH}_3\text{COO}^{-}(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g); \]  
Accept NaHCO$_3$(aq) and CH$_3$COONa(aq) instead of ions.  
Ignore state symbols.  

(ii) \[ n(\text{CH}_2\text{COOH}) = 0.00500 \text{(mol)} \]  
and \[ n(\text{NaHCO}_3) = 0.00450 \text{(mol)} ; \]  
NaHCO$_3$ is limiting.  

(iii) \[ n(\text{CO}_2) = n(\text{NaHCO}_3) = 0.00450 \text{(mol)} ; \]  
\[ m(\text{CO}_2) = 0.00450 \times 44.01 = 0.198(\text{g}) ; \]  
Award [2] for correct final answer.

(c) (i) \[ T = 363 \text{ K} \] and \[ V = 9.50 \times 10^{-5} \text{ m}^3 ; \]  
Accept \[ V = 9.5 \times 10^{-2} \text{ dm}^3 \] if \( P \) is used as 101 kPa in calculation.  
\[ \frac{PV}{RT} = \frac{1.01 \times 10^5 \times 9.5 \times 10^{-5}}{8.31 \times 363} ; \]  
\[ = 3.18 \times 10^{-3} \text{(mol)} ; \]  
Award [3] for correct final answer.

(ii) \[ M = \left( \frac{m}{n} = \frac{0.348}{3.18 \times 10^{-3}} \right) 109 \text{(g mol}^{-1} \right) ; \]  

(d) (i)  
\[
\text{H}_3\text{N}^+ \quad \text{C} \quad \text{Br} \\
\text{H} \quad \text{H} \quad \text{H} \quad \text{Br} \\
\text{CH}_3 \quad \text{CH}_3 \\
\text{curly arrow going from lone pair on N in NH}_3 \text{ to C;} \\
\text{curly arrow showing Br leaving;} \\
\text{Accept curly arrow going from bond between C and Br to Br on} \\
\text{1-bromoethane or on the transition state.} \\
\text{representation of transition state showing square brackets, two partial bonds} \\
\text{and curly arrow going from NH bond to NC partial bond/curly arrow going} \\
\text{from NH bond to N;} \\
\text{Do not penalize if NH}_3 \text{ and Br are not at 180° to each other.} \\
\text{Do not award M3 if NH}_3\text{—C bond is represented.} \\
\]

(ii) react CH$_3$I with CN/KCN solution to form ethanenitrile;  
(reduce nitrile by heating with) H$_2$;  
Ni (catalyst);  

[1] [2] [3]
(iii) elimination;
NaOH/KOH dissolved in (hot) ethanol/alcohol;
heat /hot / reflux;  

(e) (i) compounds with same structural formula but different arrangements of atoms in space;  

(ii) \[
\begin{align*}
\text{Cl} & \quad \text{C} & \quad \text{Cl} \\
& \quad \text{C} \quad \text{H} & \quad \text{Cl} \\
\end{align*}
\]
and
\[
\begin{align*}
\text{Cl} & \quad \text{C} & \quad \text{Cl} \\
& \quad \text{C} \quad \text{H} & \quad \text{Cl} \\
\end{align*}
\]  

(iii) restricted rotation around (C=C) double bond;  

(iv) \[
\begin{align*}
\text{Cl} & \quad \text{C} \quad \text{H}_{3} \quad \text{C} & \quad \text{H} \\
& \quad \text{F} & \quad \text{F} \\
\end{align*}
\]

The two structures must be clear 3D representations of mirror images. Tapered (wedge/dash) notation not necessary.  

(v) the two enantiomers rotate the plane of plane-polarized light by equal amounts, but in opposite directions; using a polarimeter;  

Q# 11/ IB Chem/2013/s/TZ1/Paper 2 Section A/Higher Level/  

1. (a) 0.675 (g) ± 0.002 (g);  
Percentage uncertainty: 0.3 %;  
Accept answers correct to one, two or three significant figures for percentage uncertainty.  

(b) In 25.0 cm³: \( n_{\text{H₂A}} = 1.21 \times 10^{-3} \) (mol) ;  
In 100 cm³: \( n_{\text{H₂A}} = 4.84 \times 10^{-3} \) (mol) ;  
\[
M = \frac{0.675}{4.84 \times 10^{-3}} = 139 \text{ (g mol}^{-1}) ;
\]  
Award [3] for correct final answer. Accept suitable alternative methods.  

(c) \( n_{\text{C}}: \frac{70.56}{12.01} = 5.88 \) and \( n_{\text{O}}: \frac{23.50}{16} = 1.47 \) and \( n_{\text{H}}: \frac{5.94}{1.01} = 5.88 \) ;  
\( \text{C}_4\text{H}_4\text{O} \) ;  
Award [2] for correct final answer. Accept answers using integer values of molar mass.  

(d) \( \frac{M}{\text{Mass of C}_4\text{H}_4\text{O}} = \frac{139}{68.08} = 2 ; \)  
\( \text{C}_8\text{H}_8\text{O}_2 \) ;  
Award [2] for correct final answer.
Q# 12/ IB Chem/2012/w/TZ0/Paper 2 Section B/Higher Level/

(b) (i) \[ \text{Mass of C: } \frac{6.93 \times 10^2 \times 12.01}{44.01} = 1.89 \times 10^{-3} / 0.00189 \text{ (g) and} \]

\[ \text{Mass of H: } \frac{2 \times 1.01 \times 2.83 \times 10^3}{18.02} = 3.17 \times 10^{-4} / 0.000317 \text{ (g)}; \]

\[ \text{Mass of O: } 3.00 \times 10^{-3} - 1.89 \times 10^{-3} - 3.17 \times 10^{-4} = 7.93 \times 10^{-4} / 0.000793 \text{ (g)}; \]

\[ n_C: \frac{1.89 \times 10^{-3}}{12.01} = 1.57 \times 10^{-4} / 0.000157 \text{ (mol) and} \]

\[ n_H: \frac{3.17 \times 10^{-4}}{1.01} = 3.14 \times 10^{-4} / 0.000314 \text{ (mol) and} \]

\[ n_O: \frac{7.93 \times 10^{-4}}{16.00} = 4.96 \times 10^{-5} / 0.0000496 \text{ (mol)}; \]

**Empirical formula = C₅H₄O;**

*Allow C₁₉H₃₈O₅.*

*Award [4] for correct final answer if alternative working is used.*

*Award [I max] for C₅H₄O/C₁₉H₃₈O₅ without working.*

(ii) C₅H₁₂O₂;

Q# 13/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/Q1

(c) (i) \[ \left( \frac{126.90}{330.71} \right) \times 100 = 38.4 \%; \]

(ii) \( (25.25 - 1.05) = 24.20 \text{ (cm}^³\text{);} \)

*Accept 24.2 (cm}^³\text{ but not 24 (cm}^³\text{).}*

(iii) \[ \left( \frac{24.20 \times 5.00 \times 10^{-2}}{1000} \right) = 1.21 \times 10^{-4} / 0.00121 \text{ (mol)}; \]

(iv) \( (0.5 \times 1.21 \times 10^{-3}) - 6.05 \times 10^{-4} / 0.000605 \text{ (mol)}; \)

*Accept alternate method e.g. \( (0.384/126.9 \times 0.2015) = 6.10 \times 10^{-4} / 0.000610 \text{ (mol).} \)

(v) \( (126.90 \times 6.05 \times 10^{-4}) = 7.68 \times 10^{-2} / 0.0768 \text{ (g)}; \)

*Accept alternate method e.g. \( (6.10 \times 10^{-4} \times 126.9) \text{ or } (0.2015 \times 0.384) = 7.74 \times 10^{-2} / 0.00774 \text{ (g).} \)

(vi) \[ \left( \frac{7.68 \times 10^{-2}}{0.2015} \right) \times 100 = 38.1 \%; \]

*Answer must be given to three significant figures.*

(d) ICl / iodine monochloride;

*Do not accept iodine or bromine.*
Q# 14/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/

1. (a) (i) \( I_2(s) \): four/4 and \( ICl(l) \): three/3; 

(ii) \( n(Cl_2) = \left( \frac{2.24}{2 \times 35.45} \right) \times 0.0316 / 3.16 \times 10^{-2} \) (mol); 
Allow answers such as \( 3.2 \times 10^{-2} / 0.032/3.15 \times 10^{-2} / 0.0315 \) (mol). 

\( n(ICl) = 2 \times 0.0316 / 0.0632 / 6.32 \times 10^{-2} \) (mol); 
Allow answers such as \( 6.4 \times 10^{-2} / 0.064 / 6.3 \times 10^{-2} / 0.063 \) (mol). 

\( m(ICl) = (0.0632 \times 162.35 - 10.3) \) (g); 
Allow answers in range 10.2 to 10.4 (g). 
Award [3] for correct final answer. 

(iii) \( \left( \frac{8.60}{10.3} \right) \times 100 = 83.5\% \); 
Allow answers in the range of 82.5 to 84.5\%. 

Q# 15/ IB Chem/2011/w/TZ0/Paper 2 Section B/Higher Level/Q9

(c) (i) \( \left( \frac{2 \times 1.01}{18.02} \right) (0.089) = 1.0 \times 10^{-2} \) g H and \( \left( \frac{12.01}{44.01} \right) (0.872) = 2.38 \times 10^{-1} \) g C; 

\( \left( \frac{0.238}{1.30} \right) (100) = 18.3\% \) C; 

\( \left( \frac{1.0 \times 10^{-2}}{1.30} \right) (100) = 0.77\% \) H; 
Award [3] for correct final answer of 18.3% C and 0.77% H without working. 
Allow whole numbers for molar masses. 

(ii) \( \left( \frac{1.75}{35.45} \right) \left( \frac{35.45}{143.32} \right) = 0.433 \) g (Cl) and \( \left( \frac{0.433}{0.535} \right) (100) = 80.9\% \) (Cl); 
Allow whole numbers for molar masses. 

(iii) \( \left( \frac{18.3}{12.01} \right) = 1.52 \) mol C and \( \left( \frac{0.77}{1.01} \right) = 0.76 \) mol H and \( \left( \frac{80.9}{35.45} \right) = 2.28 \) mol Cl; 
Allow whole numbers for atomic masses. 

Empirical formula = \( C_2HCl_3 \); 
Award [2] for correct empirical formula without working. 

\( M_r = (24.02 + 1.01 + 106.35) = 131.38 \) , so molecular formula is \( C_2HCl_3 \); 
Award [3] for correct final answer without working. 
Allow whole numbers for atomic masses.
Q# 16/ IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/Q1

(b) (i) \( T: 4 \text{ and } m: 3 \text{ and } p: 3 \);  

(ii) \( n = \frac{65.0}{65.02} = 1.00 \text{ (mol)} \);  
No penalty for using whole number atomic masses.

(iii) \( n(N_2) = \left(\frac{3}{2} \times 1.00\right) = 1.50 \text{ (mol)} \);  
\( T = \frac{(25.00 + 273.15)}{(25.00 + 273)} = 298.15 \text{ K} \);  
\( p = 1.08 \times 1.01 \times 10^5 \text{ Pa} / 1.08 \times 1.01 \times 10^5 \text{ kPa} / 1.09 \times 10^5 \text{ Pa} / 1.09 \times 10^3 \text{ kPa} \);  
\( V = \frac{nRT}{p} = \frac{(10^3)(1.50)(8.31)(298.15 / 298)}{(1.08 \times 1.01 \times 10^5)} = 34.1 \text{ (dm}^3) \);  
Award [4] for correct final answer.
Award [3 max] for 0.0341 (dm\(^3\)) or 22.7 (dm\(^3\)).
Award [3 max] for 34.4 (dm\(^3\)).
Award [2 max] for 22.9 (dm\(^3\)).
Award [2 max] for 0.0227 (dm\(^3\)).
Award [2 max] for 0.034 (dm\(^3\)).

Q# 17/ IB Chem/2011/s/TZ1/Paper 2 Section B/Higher Level/Q9e

(iii) \( \text{NH}_3/\text{ammonia (in excess by) and 10 (dm}^3\)) \);  
25.0 (dm\(^3\));  

Q# 18/ IB Chem/2009/w/TZ0/Paper 2 Section A/Higher Level/Q1

(c) \( n = 2.152 \times 10^{-2} \times 2.250 \times 10^{-2} \);  
4.842 \times 10^{-4} \text{ (mol)};
Award [1] for correct volume
Award [1] for correct calculation.

(d) 1 mol of \( \text{MnO}_4^- \) reacts with 5 mol of \( \text{Fe}^{2+} \);  
5 \times 4.842 \times 10^{-4} = 2.421 \times 10^{-3} \text{ (mol)};  
(same number of moles of Fe in the iron ore)
Allow ECF from part (a) and (c) provided some mention of mole ratio is stated.

(e) \( 2.421 \times 10^{-3} \times 55.85 = 0.1352 \text{ (g)} \);
\( 0.1352 \times 100 = 36.72\% \);  
0.3682  
Allow ECF from part (d)
Q# 19/ IB Chem/2008/s/TZ1/Paper 2 Section A/Higher Level/

5. (a) \[ PV = \frac{nRT}{V} \]
\[ P = \frac{2.00 \times 8.31 \times 298}{1.00 \times 32.0} \times \frac{0.0625 \times 8.31 \times 298}{1.00} \times \frac{0.0625 \times 0.0821 \times 298}{1.00} \]
\[ P = 155 \text{ kPa} / 1.53 \text{ atm}; \]
Apply \( \frac{P}{T} \) rule
Award [3] for final answer.

(b) higher (because \( M \) is lower);
number of moles/particles/molecules is higher / more frequent collisions with
the wall of the container;

Q# 20/ IB Chem/2008/s/TZ0/Paper 2 Section A/Higher Level/

1. (a) \[ 1.17/233.4; \]
\[ 5.01 \times 10^{-3} / \frac{5.02 \times 10^{-3}}{\text{mol}}; \]
Award [2]

(b) \[ 5.01 \times 10^{-3} / \frac{5.02 \times 10^{-3}}{\text{mol}}; \]
Award [1]

(c) \[ 2.50 \times 10^{-3} / \frac{2.51 \times 10^{-3}}{\text{mol}}; \]
Award [1]

(d) (i) Iron \[ 55.85 \times 2.50 \times 10^{-3} = 0.140 \text{ g}; \]
(ii) Ammonium \[ 18.05 \times 5.01 \times 10^{-3} = 0.0904 \text{ g}; \]
(iii) Sulfate \[ 96.06 \times 5.01 \times 10^{-3} = 0.481 \text{ g}; \]
Award [3]

(e) \[ 0.982 \text{ g} - 0.711 \text{ g} = 0.271 \text{ g H}_2\text{O}; \]
\[ \frac{0.271}{18.02} = 1.50 \times 10^{-2} \text{ (mol)}; \]
Award [2]

(f) \[ \frac{0.711}{284.07} = 2.50 \times 10^{-3} \text{ (mol)}; \]
\[ \frac{1.50 \times 10^{-2}}{2.50 \times 10^{-3}} = 6 \text{ (mol)}; \]
Award [2] for the correct final answer.
Allow ECF throughout question one.
Topic 2
Chem 26 Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

4. Magnesium is a group 2 metal which exists as a number of isotopes and forms many compounds.

(a) State the nuclear symbol notation, $^A_2X$, for magnesium-26. [1]

(b) Mass spectroscopic analysis of a sample of magnesium gave the following results:

<table>
<thead>
<tr>
<th>Isotope</th>
<th>% Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg-24</td>
<td>78.60</td>
</tr>
<tr>
<td>Mg-25</td>
<td>10.11</td>
</tr>
<tr>
<td>Mg-26</td>
<td>11.29</td>
</tr>
</tbody>
</table>

Calculate the relative atomic mass, $A_r$, of this sample of magnesium to two decimal places. [2]

(c) Magnesium ions produce no emission or absorption lines in the visible region of the electromagnetic spectrum. Suggest why most magnesium compounds tested in a school laboratory show traces of yellow in the flame. [1]
(d) (i) Explain the convergence of lines in a hydrogen emission spectrum. [1]

(ii) State what can be determined from the frequency of the convergence limit. [1]

Chem 2 Q# 2/ IB Chem/2016/s/TZ0SP/Paper 2 Section A/Higher Level/
2. One of the main constituents of acid deposition is sulfuric acid, H₂SO₄. This acid is formed from the sulfur dioxide pollutant, SO₂.

(e) With reference to section 9 of the data booklet, explain the difference between the atomic radius and the ionic radius of nitrogen. [1]

Chem 2 Q# 3/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/Q4
(e) Eight successive ionisation energies of vanadium are shown in the graph below:
(i) State the sub-levels from which each of the first four electrons are lost. [1]


(ii) Outline why there is an increase in ionization energy from electron 3 to electron 5. [1]

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(iii) Explain why there is a large increase in the ionization energy between electrons 5 and 6. [3]

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(iv) Vanadium is comprised almost entirely of $^{51}$V. State the number of neutrons an atom of $^{51}$V has in its nucleus. [1]

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Table 5 refers to the periodic table.

(g) The two most abundant isotopes of bromine have the mass numbers 79 and 81. Calculate the relative abundance of $^{79}\text{Br}$ using table 5 of the data booklet, assuming the abundance of the other isotopes is negligible. [2]

(a) (i) Calculate the relative atomic mass of this sample of magnesium correct to two decimal places. [2]

(ii) Predict the relative atomic radii of the three magnesium isotopes, giving your reasons. [2]
(b) A graph of the successive ionization energies of magnesium is shown below.

(i) Explain the increase in ionization energy values from the 3rd to the 8th electrons.  

(ii) Explain the sharp increase in ionization energy values between the 10th and 11th electrons.
8. Magnesium, a reactive metal found in many common minerals, is also an essential nutrient for both plants and animals.

(a) Define the term first ionization energy. [2]

(b) Successive ionization energies of magnesium are given in the table below.

<table>
<thead>
<tr>
<th>Energy required / kJ mol⁻¹</th>
<th>First</th>
<th>Second</th>
<th>Third</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>738</td>
<td>1450</td>
<td>7730</td>
</tr>
</tbody>
</table>

(i) Explain why the second ionization energy is greater than the first ionization energy. [2]

(ii) Explain why the third ionization energy is much greater than the second ionization energy. [2]
2. There are only two isotopes, $^{63}\text{Cu}$ and $^{65}\text{Cu}$, in naturally occurring copper.

(a) The relative atomic mass of copper is 63.55. Calculate the percentage of $^{63}\text{Cu}$ in the naturally occurring element. [2]


Chem 2 2 Q# 8/ IB Chem/2014/s/TZ1/Paper 2 Section A/Higher Level/

3. Magnesium has three stable isotopes, $^{24}\text{Mg}$, $^{25}\text{Mg}$ and $^{26}\text{Mg}$. The relative abundance of each isotope is 78.99%, 10.00% and 11.01%, respectively, and can be determined using a mass spectrometer.

(b) Calculate, showing your working, the relative atomic mass, $A_r$, of magnesium, giving your answer to two decimal places. [2]
6. The element boron has two naturally occurring isotopes, $^{10}$B and $^{11}$B.

(a) (i) Define the term *isotopes of an element*. [1]

(ii) Calculate the percentage abundance of *each* isotope, given that the relative atomic mass of B is 10.81. [2]

(b) (iii) Identify the species that is used as the scale for the mass of the isotopes. [1]

(c) Phosphorus forms two chlorides, PCl$_3$ and PCl$_5$.

(i) Apply the Aufbau principle to state the *full* electron configuration for an atom of phosphorus. [1]
(ii) Lithium exists as two isotopes with mass numbers of 6 and 7. Deduce the number of protons, electrons and neutrons for each isotope.

<table>
<thead>
<tr>
<th>Mass number (A)</th>
<th>Number of protons</th>
<th>Number of electrons</th>
<th>Number of neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(iii) The electron configuration of boron is 1s\(^2\)2s\(^2\)2p\(^1\). Draw the shape of an s orbital and a \(p_x\) orbital on the axes below.
8. The element titanium is present in meteorites.

(a) A meteorite was analysed using mass spectrometry (MS). The mass spectrum below shows the relative abundances of the different titanium isotopes.

(ii) Define the term relative atomic mass \( A_r \).

(iii) Calculate the relative atomic mass of this sample of titanium, giving your answer to one decimal place.
(b) The successive ionization energies of titanium are shown below.

![Graph showing ionization energy vs. electron removed]

(i) State the **full** electron configuration of an atom of titanium and identify the sub-level from which the electron is removed when the 1st ionization energy is measured. [2]

(ii) Explain why there are relatively large differences between the 4th and 5th, and between the 10th and 11th ionization energies. [3]
(c) Successive ionization energy data provides evidence for the existence of energy levels in atoms. Other evidence is provided by the hydrogen emission spectrum.

(i) Describe the appearance of the visible emission spectrum of hydrogen. [2]

(ii) Explain how this spectrum is related to the electron energy levels in a hydrogen atom. [3]

2. Isotopes are atoms of the same element with different mass numbers. Two isotopes of cobalt are Co-59 and Co-60.

(a) Deduce the missing information and complete the following table. [2]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>(^{59}\text{Co}^{2+})</th>
<th>(^{60}\text{Co})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of protons</td>
<td>27</td>
<td>53</td>
</tr>
<tr>
<td>Number of neutrons</td>
<td></td>
<td>33</td>
</tr>
<tr>
<td>Number of electrons</td>
<td></td>
<td>27</td>
</tr>
</tbody>
</table>
(c) State the **full** electron configuration of $^{59}\text{Co}^{2+}$. 


Chem 2 Q# 13/ IB Chem/2011/s/TZ1/Paper 2 Section A/Higher Level/

(d) Identify a radioactive isotope of cobalt **and** state **one** of its uses. 


Chem 2 Q# 14/ IB Chem/2011/s/TZ1/Paper 2 Section A/Higher Level/

3. (a) Explain why the relative atomic mass of cobalt is greater than the relative atomic mass of nickel, even though the atomic number of nickel is greater than the atomic number of cobalt. 


(b) Deduce the numbers of protons and electrons in the ion $\text{Co}^{2+}$. 


(c) Deduce the electron configuration for the ion $\text{Co}^{2+}$. 


4. Magnesium is the eighth most abundant element in the earth's crust. The successive ionization energies of the element are shown below.

(a) (i) Define the term first ionization energy and state the equation for the first ionization of magnesium. [3]

(ii) Explain the general increase in successive ionization energies of the element. [2]

(iii) Explain the large increase between the tenth and eleventh ionization energies. [3]

(b) A sample of iron has the following isotopic composition by mass.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>$^{54}$Fe</th>
<th>$^{56}$Fe</th>
<th>$^{57}$Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative abundance / %</td>
<td>5.95</td>
<td>91.88</td>
<td>2.17</td>
</tr>
</tbody>
</table>

Calculate the relative atomic mass of iron based on this data, giving your answer to two decimal places. [2]
Chem 2 Q# 17/ IB Chem/2010/w/TZ0/Paper 2 Section A/Higher Level/Q3

(d) State the full electronic configurations of a Cu atom and a Cu\(^{+}\) ion. \([2]\) 

Cu: .................................................................

Cu\(^{+}\): .............................................................

Chem 2 Q# 18/ IB Chem/2010/s/TZ1/Paper 2 Section B/Higher Level/

4. (a) Define the term relative atomic mass (A\(_r\)). \([1]\) 

(c) The relative atomic mass of naturally occurring copper is 63.55. Calculate the abundances of \(^{63}\)Cu and \(^{65}\)Cu in naturally occurring copper. \([2]\) 

(d) The isotopes of some elements are radioactive. State a radioisotope used in medicine. \([1]\)

Chem 2 Q# 19/ IB Chem/2009/w/TZ0/Paper 2 Section A/Higher Level/

3. (a) Describe the emission spectrum of hydrogen. Outline how this spectrum is related to the energy levels in the hydrogen atom. \([3]\)
(iii) Strontium exists as four naturally-occurring isotopes. Calculate the relative atomic mass of strontium to two decimal places from the following data. [2]

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Percentage abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr-84</td>
<td>0.56</td>
</tr>
<tr>
<td>Sr-86</td>
<td>9.90</td>
</tr>
<tr>
<td>Sr-87</td>
<td>7.00</td>
</tr>
<tr>
<td>Sr-88</td>
<td>82.54</td>
</tr>
</tbody>
</table>

(b) The graph of the first ionization energy plotted against atomic number for the first twenty elements shows periodicity.

![Graph showing periodicity of first ionization energy](image)

(i) Define the term *first ionization energy* and state what is meant by the term *periodicity*. [2]

(ii) Explain how information from this graph provides evidence for the existence of main energy levels and sub-levels within atoms. [4]

(iii) State what is meant by the term *second ionization energy*. [1]

(iv) Sketch and explain the shape of the graph obtained for the successive ionization energies of potassium using a logarithmic scale for ionization energy on the y-axis against number of electrons removed on the x-axis. [4]
2. (a) Define the term *isotopes*.

(b) A sample of krypton contains these isotopes.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Percentage abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{12}\text{Kr}$</td>
<td>15.80</td>
</tr>
<tr>
<td>$^{36}\text{Kr}$</td>
<td>65.40</td>
</tr>
<tr>
<td>$^{38}\text{Kr}$</td>
<td>18.80</td>
</tr>
</tbody>
</table>

(i) Calculate the relative atomic mass of krypton in this sample. Give your answer to two decimal places.

(ii) Deduce the number of each sub-atomic particle in an atom of $^{36}\text{Kr}$.

<table>
<thead>
<tr>
<th>Protons</th>
<th>Neutrons</th>
<th>Electrons</th>
</tr>
</thead>
</table>

(c) Krypton and xenon are in the same group of the periodic table.

(i) Complete the following to show the electron configuration of krypton.

\[ 1s^22s^22p^4 \]

(ii) State the number of electrons in d orbitals in an atom of xenon in its ground state.
Chem 2 Q# 22/ IB Chem/2008/s/TZ1/Paper 2 Section A/Higher Level/Q2  
(b) Naturally occurring boron consists of the two isotopes, $^{10}$B and $^{11}$B. The relative atomic mass of boron is 10.81. Determine the percentage abundance of these isotopes.  


Topic 2 Mark Scheme  
Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/  
<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. a</td>
<td>$\text{Mg}$</td>
<td>✔️</td>
<td>1</td>
</tr>
<tr>
<td>4. b</td>
<td>$\frac{24 \times 78.60 + 25 \times 10.11 + 26 \times 11.29}{100}$</td>
<td>✔️</td>
<td>2</td>
</tr>
<tr>
<td>4. c</td>
<td>contamination with sodium/volatile compounds</td>
<td>✔️</td>
<td>1</td>
</tr>
<tr>
<td>4. d i</td>
<td>energy levels are closer together at high energy / high frequency / short wavelength</td>
<td>✔️</td>
<td>1</td>
</tr>
<tr>
<td>4. d ii</td>
<td>ionisation energy</td>
<td>✔️</td>
<td>1</td>
</tr>
</tbody>
</table>

Q# 2/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/Q2  
<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. e</td>
<td>ionic radius of nitrogen is 146 pm/146 x $10^{-10}$ m which is greater than atomic radius which is 71 pm/71 x $10^{-10}$ m due to increased repulsion between electrons</td>
<td>✔️</td>
<td>1</td>
</tr>
</tbody>
</table>

Q# 3/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/  
<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. e i</td>
<td>First: 4s AND Second: 4s AND Third: 3d AND Fourth: 3d</td>
<td>✔️</td>
<td>1</td>
</tr>
<tr>
<td>4. e ii</td>
<td>in the same sub-shell and 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</td>
<td>✔️</td>
<td>1</td>
</tr>
<tr>
<td>4. e iii</td>
<td>electron 5 is lost from the 3d orbital OR electron 5 is lost from the valence shell ✔️ OR electron 6 is lost from a 3p orbital OR electron 6 is lost from a complete inner shell ✔️ 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 ✔️</td>
<td>✔️</td>
<td>3</td>
</tr>
<tr>
<td>4. e iv</td>
<td>28 ✔️</td>
<td>✔️</td>
<td>1</td>
</tr>
</tbody>
</table>

Q# 4/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q7  
(g) 79.91 = 79x + 81(1 – x)  
Award M1 for any suitable calculation.  
(abundance $^{79}$Br =) 54.5 %;  
Award [2] for correct final answer.
8. (a) \[ \left( \frac{(77.44 \times 24) + (10.00 \times 25) + (12.56 \times 26)}{100} \right) \];

24.35;
Award 2 marks for correct final answer.
Two decimal places are required for M2.
Do not award any marks for 24.31 without showing method (as the value can be copied from the Data Booklet).

(ii) same atomic radius / 160 pm;
isotopes only differ by number of neutrons/size of nucleus / radius determined by electron shells and number of protons / OWTTE;
Accept neutrons do not affect distance of electrons / OWTTE.

(b) (i) decreasing repulsion between electrons / radius decreases as electrons are removed;
Accept increasing positive charge on ion attracts electrons more strongly.

(ii) 10th electron is in second energy level/shell while 11th electron is in first energy level/shell / 10th is removing electron from electronic arrangement 2,1 while 11th ionization energy is removing electron from electronic arrangement 2;
11th electron removed is much closer to the nucleus / 11th electron removed from a (much) lower energy level/shell;
Accept opposite statement for 10th electron.
Q# 6/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/

8. (a) **minimum** energy required to remove one electron / energy required to remove most loosely bound/outermost electron;
    from gaseous/isolated atom;
    Accept “gaseous state”.
    More extensive definitions involving one mole may be given. [2]

(b) (i) electrons lost in same orbital/valence shell;
    (second) electron/electron (being lost from Mg$^+$ is) closer to the nucleus;
    (second) electron/electron (being lost from Mg$^2+$) not subject to e-e repulsion
    from others in same level; [2 max]
    Apply OWTTE for all marking points.
    Do not accept “less electrons to share the charge” or answers employing
    this concept.

(ii) electron in lower energy level / more stable electron shell;
    electron closer to nucleus;
    less shielding by complete inner shells / increase in effective nuclear charge; [2 max]
    Apply OWTTE for all marking points.

(c) \( \Delta H_a (Cl) = \frac{1}{2} \times 243 \text{ (kJ mol}^{-1}) \text{);} \]
    Correct calculation of atomization enthalpy of Cl.
    \[
    \Delta H_f = +146 + \frac{1}{2} 243 + 738 + (-349) + (-790) ;
    \]
    Correct sign and magnitude of all terms.
    \[= -134 \text{ (kJ mol}^{-1}) \text{);} \]
    Award [3] for correct final answer.
    Final mark involves correct computation of equation the student has produced.
    Award [2] for –12 (bond enthalpy of Cl not halved) or +134 (signs wrong).
    Award [1] for +12 (bond enthalpy of Cl not halved and signs wrong).

(d) MgF$_2$–MgCl$_2$–CaCl$_2$;
    F$^-$ smaller (ionic radius) than Cl$^-$ / Cl$^-$ larger (ionic radius) than F$^-$;
    Mg$^{2+}$ smaller (ionic radius) than Ca$^{2+}$/ Ca$^{2+}$ larger (ionic radius) than Mg$^{2+}$; [3]
    Accept use of atomic radius rather than ionic radius.

(e) more soluble at low pH / less soluble at high pH;
    higher pH / OH$^-$ will shift the equilibrium to the left / lower pH / H$^+$ will (react
    with OH$^-$ and) shift the equilibrium to the right; [2]

(f) (i) lattice/layer/framework of cations/magnesium ions/Mg$^{2+}$;
    surrounded by delocalized electrons / in a sea/flux of delocalized electrons;
    Accept “mobile” instead of “delocalized”.
    [2]

(ii) Mg has more delocalized electrons (than Na);
    Accept “Mg has more valence electrons than Na” / “Mg is Mg$^{2+}$ but Na is
    only Na$^-$”.
    [1]

(iii) layers of ions/atoms/particles cannot slide over each other so easily (as
    different sized ions/atoms/particles) / OWTTE;
    [1]
(g) (i)

Diagram:
two electrodes connected to a power pack/battery and immersed in an electrolyte;
Do not award mark if salt bridge included in diagram.

Labelling:
anode/positive electrode, cathode/negative electrode, molten magnesium chloride/MgCl₂(l)/electrolyte correctly labelled;  [2]
Check candidates know which end of a battery symbol is which charge.

(ii) Negative electrode (cathode): \( \text{Mg}^{2+} (l) + 2e^- \rightarrow \text{Mg} (s) \);
Positive electrode (anode): \( 2\text{Cl}^- (l) \rightarrow \text{Cl}_2 (g) + 2e^- \);  [2]
Accept \( \text{Cl}^- (l) \rightarrow \frac{1}{2} \text{Cl}_2 (g) + e^- \).
Ignore state symbols.
Allow e instead of \( e^- \).
If both correct equations are given for the wrong electrodes award [1 max].

(iii) Negative electrode (cathode):
\( 2\text{H}_2\text{O} (l) + 2e^- \rightarrow \text{H}_2 (g) + 2\text{OH}^- (aq) / 2\text{H}^+ (aq) + 2e^- \rightarrow \text{H}_2 (g) \);
Accept \( 4\text{H}_2\text{O} (l) + 4e^- \rightarrow 2\text{H}_2 (g) + 4\text{OH}^- (aq) / 4\text{H}^+ (aq) + 4e^- \rightarrow 2\text{H}_2 (g) / \text{H}_2\text{O} (l) + e^- \rightarrow \frac{1}{2} \text{H}_2 (g) + \text{OH}^- (aq) / \text{H}^+ (aq) + e^- \rightarrow \frac{1}{2} \text{H}_2 (g) \).
Positive electrode (anode):
\( 2\text{H}_2\text{O} (l) \rightarrow \text{O}_2 (g) + 4\text{H}^+ (aq) + 4e^- / 4\text{OH}^- (aq) \rightarrow \text{O}_2 (g) + 2\text{H}_2\text{O} (l) + 4e^- \);  [2]
Accept \( \text{H}_2\text{O} (l) \rightarrow \frac{1}{2} \text{O}_2 (g) + 2\text{H}^+ (aq) + 2e^- / 2\text{OH}^- (aq) \rightarrow \frac{1}{2} \text{O}_2 (g) + \text{H}_2\text{O} (l) + 2e^- .\)
State symbols not required.
Allow e instead of \( e^- \).
If both correct equations are given for the wrong electrodes award [1 max].

(iv) water/hydrogen ions more easily reduced/better oxidizing agents/have a more positive \( E^\circ \) (than magnesium ions);  [1]
Accept converse statements for magnesium ions.
Accept "magnesium is very reactive/high in reactivity series" / OWTTE.

Q# 7/ IB Chem/2014/s/T22/Paper 2 Section A/Higher Level/
2. (a) \[ 63x + 65(100 - x) = 63.55 \times 100 ; \]
\( x = 72.50 \text{%} \);
Award [2] for correct final answer.
Q# 8/ IB Chem/2014/s/TZ1/Paper 2 Section A/Higher Level/Q3

(b) \( A_x = 0.7899 \times 24 + 0.1000 \times 25 + 0.1101 \times 26; \)
\[ 24.32 ; \]
Award [2] for correct final answer.
Award [1 max] for 24.31 with correct working.
Award [0] for 24.31 (Data Booklet value) if working is incorrect or no working is shown.
Final answer must be to 2 decimal places to score [2].

Q# 9/ IB Chem/2013/s/TZ1/Paper 2 Section B/Higher Level/
6. (a) (i) atoms of the same element with the same number of protons with same atomic number but different number of neutrons/mass number/mass:

(ii) \( 10x + 11(1-x) = 10.81 \), \( x = 0.19 \);
Accept similar method.

\(^{10}\text{B}: 19\% \text{ and } ^{11}\text{B}: 81\% ; \]

(iii) \(^{12}\text{C}/\text{carbon-12} ; \]

(c) (i) \( 1s^22s^22p^63s^23p^3 ; \]

Q# 10/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/Q2

(ii) | Mass number \((A)\) | Number of protons | Number of electrons | Number of neutrons |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Award [1 max] for correct number of neutrons for both isotopes if numbers of protons or electrons is not given.
Award [1 max] for correct number of protons and electrons for both isotopes if number of neutrons is not given or if numbers of neutrons are incorrect.

(iii) symmetrical shape of s orbital and dumbbell-shaped p orbital with electron density along x-axis:
Q# 11/ IB Chem/2012/s/TZ1/Paper 2 Section B/Higher Level/Q8a

(ii) the ratio of average/mass of an atom to the mass of C-12 isotope and mass of an atom on a scale where one atom of C-12 has a mass of 12 / sum of the weighted average/mass of isotopes of an element compared to C-12 / OWTTE; Award no mark if “element” is used instead of “atom”. [1]

(iii) \[ A_r = \frac{(46 \times 13.5) + (47 \times 7.4) + (48 \times 7.7) + (49 \times 5.4)}{100} \]

47.7;
Accept atomic mass units but award [1 max] if other units given. Answer must be given to one decimal place. [2]

(iv) prevents collisions/unintentional deflections / OWTTE; [1]

(b) (i) 1s\(^2\) 2s\(^2\) 2p\(^6\) 3s\(^2\) 3p\(^6\) 4s\(^2\) 3d\(^2\);
4s;

(ii) 4\(^{th}\) electron removed from 3d and 5\(^{th}\) electron removed from 3p; 10\(^{th}\) electron removed from 3p and 11\(^{th}\) electron removed from 3s;

Accept either of the following answers for the third mark: electrons removed from lower energy level / energy level closer to nucleus are attracted more strongly; greater effective nuclear charge / s electrons more penetrating; [3 max]

(iii) +2, +3, +4; [1]

(iv) (colour) due to partially filled/incomplete d sub-level/orbital; d sub-level is split / d orbitals are split;
Ni\(^{2+}\)(aq) has incomplete 3d sub-level/orbital but Sc\(^{3+}\)(aq) has no 3d electron/empty/d sub-level;
electrons move from lower to higher (sub)levels when they absorb energy/light;
Ni\(^{2+}\)(aq) (appears green because it) absorbs red; [5]

(c) (i) line spectrum;
(lines) converge at high energy/frequency/shorter wave length/blue end of spectrum;
Both marks can be awarded if suitable diagram is given. [2]

(ii) electron transition from higher to lower/second energy levels;
each transition causes emission of light of specific frequency/wavelength/energy;
each transition/line is related to energy difference / \( \Delta E = \frac{hf}{hc} \);
energy levels in hydrogen atom are closer/converge at higher energy; [3 max]
Q# 12/ IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/

2. (a) 

<table>
<thead>
<tr>
<th>Symbol</th>
<th>$^{29}$Co&lt;sup&gt;5+&lt;/sup&gt;</th>
<th>$^{60}$Co</th>
<th>$^{125}$I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of protons</td>
<td>27</td>
<td>27</td>
<td>53</td>
</tr>
<tr>
<td>Number of neutrons</td>
<td>32</td>
<td>33</td>
<td>72</td>
</tr>
<tr>
<td>Number of electrons</td>
<td>24</td>
<td>27</td>
<td>53</td>
</tr>
</tbody>
</table>

Award [2] for all four correct.
Award [1] for two or three correct.

(b) Co-60 emits (penetrating) gamma radiation/rays / OWTTE; 
Allow because Co-60 emits radiation which kills/treats cancer cells. 
Do not allow answers such as Co-60 is radioactive or Co-60 treats cancer as single statements.

(c) 1s<sup>2</sup>2s<sup>2</sup>2p<sup>6</sup>3s<sup>2</sup>3p<sup>6</sup>3d<sup>6</sup>;
Do not award mark for [Ar] 3d<sup>6</sup>. 
Do not allow 1s<sup>2</sup>2s<sup>2</sup>2p<sup>6</sup>3s<sup>2</sup>3p<sup>6</sup>4s<sup>1</sup>3d<sup>5</sup>.

Q# 13/ IB Chem/2011/s/TZ1/Paper 2 Section A/Higher Level/

3. (a) cobalt has a greater proportion of heavier isotopes / OWTTE / cobalt has greater number of neutrons;

(b) 27 protons and 25 electrons;

(c) 1s<sup>2</sup>2s<sup>2</sup>2p<sup>6</sup>3s<sup>2</sup>3p<sup>6</sup>3d<sup>7</sup>/ [Ar] 3d<sup>7</sup>;

(d) $^{60}$Co/Co-60/cobalt-60 and radiotherapy/sterilization of medical supplies/radiation treatment of food sterilizations/industrial radiography/density measurements in industry/(medical/radioactive) tracer;
Allow treatment of cancer.
Do not allow “just used in medicine”.

OR

$^{57}$Co/Co-57/cobalt-57 and medical tests/label for vitamin B<sub>12</sub> uptake;
Do not allow “just used in medicine”.

Q# 14/ IB Chem/2011/s/TZ1/Paper 2 Section A/Higher Level/

3. (a) cobalt has a greater proportion of heavier isotopes / OWTTE / cobalt has greater number of neutrons;

(b) 27 protons and 25 electrons;

(c) 1s<sup>2</sup>2s<sup>2</sup>2p<sup>6</sup>3s<sup>2</sup>3p<sup>6</sup>3d<sup>7</sup>/ [Ar] 3d<sup>7</sup>;
Q# 15/ IB Chem/2010/w/TZ0/Paper 2 Section B/Higher Level/
4. (a) (i) energy (per mole) needed to remove one/first/most loosely bound electron from a (neutral) atom;
in the gaseous state;
Mg (g) → Mg⁺ (g) + e⁻;
\[3\]
Gaseous state symbols needed.
Accept e instead of e⁻.
Only penalize omission of gas phase once in either the second marking point or the third marking point.

(ii) successive electrons (are more difficult to remove because each is) taken from more positively charged ion/OWTTE;
increased electrostatic attraction;

(iii) 10th electron comes from 2nd energy level/\( n = 2 \) and 11th electron comes from 1st first energy level/\( n = 1 \) /OWTTE;
electron in 1st energy level closer to nucleus;
electron in 1st energy level not shielded by inner electrons / exposed to greater effective nuclear charge;
\[3\]

Q# 16/ IB Chem/2010/w/TZ0/Paper 2 Section A/Higher Level/Q3

(b) \( \frac{(54 \times 5.95) + (56 \times 91.88) + (57 \times 2.17)}{100} \);
55.90;
Award 2 for correct final answer.
Answer must be to 2 d.p.
\[2\]

Q# 17/ IB Chem/2010/w/TZ0/Paper 2 Section A/Higher Level/Q3

(d) \( \text{Cu} \):

\[ 1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1 \];

\( \text{Cu}^+ \):

\[ 1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} \];
Ignore relative order of 3d and 4s.
Penalize only once if noble gas core is given.
\[2\]

Q# 18/ IB Chem/2010/s/TZ1/Paper 2 Section B/Higher Level/
4. (a) average mass of isotopes of an element compared to \((1/12 \text{ g of } ^{12}\text{C}) / \text{average mass of an atom relative to C-12 having a mass of exactly 12/OWTTE,}\)
Allow element instead of atom.
Must refer to average mass and C-12.
\[1\]

(c) \( 63x + 65(1-x) = 63.55 \);
(or some other mathematical expression).

\(^{63}\text{Cu} = 72.5 \% \text{ and } ^{65}\text{Cu} = 27.5 \% ;\)
Allow \(^{63}\text{Cu} = 0.725 \text{ and } ^{65}\text{Cu} = 0.275 .\)
Award 2 for correct final answer.

(d) \(^{60}\text{Co} / ^{131}\text{I};\)
Must contain correct mass numbers.
Allow other formats such as cobalt-60, Co-60 etc.
Award no marks if a correct radioisotope is given with an incorrect radioisotope.
Allow any other radioisotope if you can verify its use.
\[1\]
Q# 19/ IB Chem/2009/w/TZ0/Paper 2 Section A/Higher Level/

3. (a) series of lines/lines; electron transfer/transition between higher energy level to lower energy level / electron transitions into first energy level causes UV series / transition into second energy level causes visible series / transition into third energy level causes infrared series; convergence at higher frequency/energy/short wavelength; 

Allow any of the above points to be shown on a diagram. [3]

(b) \[\text{[Fe(CN)_6]^+} = +2; \]
\[\text{[FeCl}_3]^- = +3; \]

Award [1 max] if 2+ and 3+, 2 and 3 or II and III stated.

Q# 20/ IB Chem/2009/s/TZ1/Paper 2 Section B/Higher Level/Q8a

(iii) \[A_t = \frac{[(0.56 \times 84) + (9.90 \times 86) + (7.00 \times 87) + (82.54 \times 88)]}{100} \]

= 87.71; 

Award [1 max] if answer not given to two decimal places. Apply -I(U) if answer quoted in g or g mol\(^{-1}\).

(b) (i) first ionization energy: \(M(g) \rightarrow M^+(g) + e^-\); the (minimum) energy (in kJ mol\(^{-1}\)) to remove one electron from a gaseous atom; the energy required to remove one mole of electrons from one mole of gaseous atoms; periodicity: repeating pattern of (physical and chemical) properties; [2]

(ii) (evidence for main levels) highest values for noble gases / lowest values for alkali metals / OWTTE; general increase across a period;
(evidence for sub-levels) drop in I.E. from Be to B/Mg to Al/Group 2 to Group 3; drop in I.E. from N to O/P to S/Group 5 to Group 6; [4]

(iii) \(M^+(g) \rightarrow M^{2+}(g) + e^-\); OWTTE; 

Accept \(e^-\) instead of \(e^\).

(iv) Rough sketch to show:

Graph of successive ionization energies for potassium

![Graph of successive ionization energies for potassium](image.png)
correct use of axes and one electron relatively easy to remove; a jump in value then eight, another jump to another eight and finally another jump for the remaining two electrons;

electronic configuration of K=1s$^2$2s$^2$2p$^6$3s$^2$3p$^6$4s$^1$ / first electron due to removal of 4s$^1$. next eight due to third level/3s$^2$3p$^6$, next eight due to second level/2s$^2$2p$^6$ and last two due to removal of first level/1s$^2$; the more electrons removed the more the positive nucleus attracts the remaining electrons and each main energy level is closer to the nucleus / OWTTE. [4]

Q# 21/ IB Chem/2008/w/TZ0/Paper 2 Section A/Higher Level/

2. (a) (atoms of the) same element / atoms with same number of protons/atomic number/Z; Do not award mark if no mention of atom or element.

(b) (i) $(82 \times 0.1580) + (84 \times 0.6540) + (86 \times 0.1880)$ / other working:

84.06; Consider ECF for final answer if correct method is used but transcription or arithmetic error is present in the first stage. Award [2] for correct final answer with or without working.

(ii) 36 protons and 36 electrons; 48 neutrons; [2]

(c) (i) $(1s^2 2s^2 2p^6) 3s^2 3p^6 3d^{10} 4s^2 4p^6$; Accept 3d$^{10}$ and 4s$^2$ in reverse order. [1]

(ii) 20; [1]

Q# 22/ IB Chem/2008/s/TZ1/Paper 2 Section A/Higher Level/Q2

(b) $10x + (1 - x)11 = 10.81$; 19%; 81%;

Award [2] for two correct final answers.
(e) Magnesium burns in air to form a white compound, magnesium oxide. Formulate an equation for the reaction of magnesium oxide with water.

(f) Describe the trend in acid-base properties of the oxides of period 3, sodium to chlorine.

(g) In addition to magnesium oxide, magnesium forms another compound when burned in air. Suggest the formula of this compound.

This is the Lewis structure for the ethandioate ion:

(f) Explain how ethanedioate ions act as ligands.

4. Tin(II) chloride is a white solid that is commonly used as a reducing agent.
(c) Outline, giving the **full** electron configuration of the vanadium atom, what is meant by the term transition metal.

(d) In an aqueous solution of vanadium(III) chloride, the vanadium exists as \([\text{V(H}_2\text{O)}_6]^{3+}\), \([\text{VCl(H}_2\text{O)}_3]^{2+}\) or \([\text{VCl}_2(\text{H}_2\text{O})_2]^+\) depending on the concentration of chloride ions in the solution.

(i) Describe how \(\text{Cl}^-\) and \(\text{H}_2\text{O}\) bond to the vanadium ion.

(ii) Outline what would happen to the wavelength at which the vanadium complex ions would absorb light as the water molecules are gradually replaced by chloride ions, using section 15 of the data booklet.
Chem 3 4 Q# 4/ IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/Q8

(e) (i) State the acid-base character of the oxides of the period 3 elements Na to Ar. [2]

(ii) State balanced equations to illustrate the acid-base character of sodium oxide and sulfur trioxide. [2]

Sodium oxide:

Sulfur trioxide:

Chem 3 3 Q# 5/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/

5. (a) (i) Define the term electronegativity. [1]

(ii) Suggest why the noble gases are generally not assigned electronegativity values. [1]
(c) Outline one reason why the sodium ion, Na\(^+\), has a smaller radius than the sodium atom. [1]

Chem 3 6 Q# 6/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/
2. (a) State the full electron configurations of copper, Cu, and copper(II) ion, Cu\(^{2+}\). [2]

(c) Explain why complexes of Zn\(^{2+}\) (aq) are colourless whereas complexes of Cu\(^{2+}\) (aq) are coloured. [4]

Chem 3 4 Q# 7/ IB CHEM/2015/s/TZ2/Paper 2 Section B/Higher Level/Q9
(b) (i) Identify the acid-base character of the oxides of each of the elements from sodium to chlorine in period 3. [2]
(ii) State the equations for the separate reactions of sodium oxide and phosphorus(V) oxide with water.

\[ \text{Sodium oxide + Water} \rightarrow \text{Sodium hydroxide} \]
\[ \text{Phosphorus(V) oxide + Water} \rightarrow \text{Phosphoric acid} \]

(c) Chromium forms the complex ion \([\text{Cr(NH}_3)_2\text{Cl}_2]^+\).

(iv) Draw the structures of two possible isomers of this complex ion.
Chromium is a transition metal with many uses.

(a) (i) Draw an orbital diagram (using the arrow-in-box notation) showing the electrons in the 4s and 3d sub-levels in chromium metal. [1]

(b) (ii) Outline the nature of the metallic bonding present in chromium. [1]

(iii) Explain why chromium metal is malleable. [1]
(c) Chromium forms the complex ion \([\text{Cr}(\text{NH}_3)_2\text{Cl}_2]^+\).

(i) Deduce the oxidation number of chromium in this complex. \[1\]

(ii) Describe the nature of the ligand-chromium ion bonds in terms of acid-base theory. \[2\]

(iii) Explain why \([\text{Cr}(\text{NH}_3)_2\text{Cl}_2]^+\) is coloured. \[4\]

Chem 2 Q# 10/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/
(e) Describe how chlorine’s position in the periodic table is related to its electron arrangement. \[2\]
2. This question is about the compounds of some period 3 elements.

(a) State the equations for the reactions of sodium oxide with water and phosphorus(V) oxide with water. [2]

4. Copper is a metal that has been used by humans for thousands of years.

(a) State the full electron configuration of $^{65}\text{Cu}$. [1]

(b) State one difference in the physical properties of the isotopes $^{63}\text{Cu}$ and $^{65}\text{Cu}$ and explain why their chemical properties are the same. [2]
(f)  (i) Zinc is found in the d-block of the periodic table. Explain why it is not considered a transition metal. [2]

(ii) Explain why Fe$^{3+}$ is a more stable ion than Fe$^{2+}$ by reference to their electron configurations. [3]

(c) State the relationship between the electron arrangement of an element and its group and period in the periodic table. [2]

(d) Transition metals and their compounds often catalyse reactions. The catalyzed decomposition of hydrogen peroxide by CuO is an example. State two other examples of catalyzed reactions giving the transition metal or its compound acting as catalyst. [2]
Chem 3 3 Q# 15/ IB Chem/2014/s/TZ2/Paper 2 Section A/Higher Level/Q2

(b) State the full electronic configuration of a copper atom. [1]

(c) Explain why most copper(II) compounds are coloured, whereas most copper(I) compounds are not. [2]

Chem 3 10 Q# 16/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/

5. (a) The oxides and chlorides of period 3 elements exhibit periodicity.

(i) State the changes in the acid-base nature of the oxides across period 3 (from Na₂O to Cl₂O₅), including equations for the reactions of Na₂O and SO₃ with water. [3]
(d) Transition metals form complex ions which are usually coloured.

(i) State the full electron configurations of Cr and Cr\(^{3+}\).  

Cr:

.................................................................

Cr\(^{3+}\):

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(iii) Explain why the [Cr(H\(_2\)O)\(_6\)]\(^{3+}\) ion is coloured.

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(e) Explain how the number of electrons in the outer main energy level of phosphorus, P, can be determined using the data of successive ionization energies.

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4. EUK-134, the structure of which is shown below, is a complex ion of manganese(III) that is used in expensive sun-protection products because of its powerful antioxidant properties.

(a) State the electron configuration of the manganese ion in EUK-134. [1]

(b) State the name given to species that bond to a central metal ion, and identify the type of bond present. [2]

Name given:

Type of bond:

(c) Transition metals have certain characteristic properties. State two properties that are involved in EUK-134 rapidly decreasing the concentration of oxidizing agents. [2]
(d) Substances like EUK-134 are often coloured. Explain why compounds of transition metals absorb visible radiation.

...}

Chem 3 3 Q# 18/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/

1. Iron tablets are often prescribed to patients. The iron in the tablets is commonly present as iron(II) sulfate, FeSO₄.

Two students carried out an experiment to determine the percentage by mass of iron in a brand of tablets marketed in Cyprus.

Experimental Procedure:

- The students took five iron tablets and found that the total mass was 1.65 g.

- The five tablets were ground and dissolved in 100 cm³ dilute sulfuric acid, H₂SO₄(aq). The solution and washings were transferred to a 250 cm³ volumetric flask and made up to the mark with deionized (distilled) water.

- 25.0 cm³ of this Fe³⁺(aq) solution was transferred using a pipette into a conical flask. Some dilute sulfuric acid was added.

- A titration was then carried out using a 5.00 × 10⁻³ mol dm⁻³ standard solution of potassium permanganate, KMnO₄(aq). The end-point of the titration was indicated by a slight pink colour.
(h) (i) Following the experiment, the students proposed the following hypothesis:

“Since sulfuric acid is a strong acid, two other strong acids such as nitric acid, HNO₃(aq) or hydrochloric acid, HCl(aq), could also be used in this experiment”.

Suggest one problem with this hypothesis.  


(ii) The students also explored the role of sulfuric acid in everyday processes and found that sulfuric acid present in acid rain can damage buildings made of limestone. Predict the balanced chemical equation for the reaction between limestone and sulfuric acid, including state symbols.


Chem 3 5 Q# 19/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/

3. Carboplatin used in the treatment of lung cancer has the following three-dimensional structure.
(c) Elemental platinum has electrons occupying s, p, d and f atomic orbitals.

(i) Draw the shape of an s orbital and a p<sub>x</sub> orbital. Label the x, y and z axes on each diagram.

(ii) State the maximum number of orbitals in the n = 4 energy level.

(d) A number of ruthenium-based anti-cancer drugs have also been developed. State the full electron configuration of the ruthenium(II) ion, Ru<sup>2+</sup>.
(e) Iron is in the same group in the periodic table as ruthenium.

Construct the orbital diagram (using the arrow-in-box notation) for iron, showing the electrons in the $n = 3$ and $n = 4$ energy levels only and label each sub-level on the diagram.

[Diagram of orbital structure]
Chem 3 Q# 20/ IB Chem/2013/s/TZ1/Paper 2 Section B/Higher Level/

7. (a) Bromine is a member of group 7, the halogens.

(i) Explain the trend in reactivity of the halogens. [3]

(ii) Deduce, using equations where appropriate, if bromine reacts with sodium chloride solution and with sodium iodide solution. [2]

(b) Iron is a transition metal.

(i) Describe the bonding in metals and explain their malleability. [3]
(ii) List **three** characteristic properties of transition elements. [2]

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(iii) Identify the type of bonding between iron and cyanide in \([\text{Fe(CN)}_6]^{3-}\). [1]

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(iv) Deduce the oxidation number of iron in \([\text{Fe(CN)}_6]^{3-}\). [1]

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(v) Draw the abbreviated orbital diagram for an **iron atom** using the arrow-in-box notation to represent electrons. [1]
(vi) Draw the abbreviated orbital diagram for the **iron ion** in $[\text{Fe(CN)}_6]^{3-}$ using the arrow-in-box notation to represent electrons.  

2. Table 8 of the Data Booklet shows the atomic and ionic radii of the elements.

(a) Describe and explain the trend in atomic radius across period 3.

(b) A student formulates the following hypothesis: “If phosphorus were to form a positive ion, $\text{P}^{3+}$, its ionic radius would probably be between $110 \times 10^{-12}\text{ m}$ and $212 \times 10^{-12}\text{ m}$.” Evaluate this hypothesis.
(f) In this project the students explored several aspects of the chemistry of the halogens. In the original preparation of ICl(I), they observed the yellow-green colour of chlorine gas, Cl₂(g), reacting with solid iodine, I₂(s).

(i) State the **full** electron configuration of iodine (Z = 53). [1]

(ii) Chlorine can also react with water. State the balanced chemical equation for the reaction of Cl₂(g) with water. [1]

2. Lithium and boron are elements in period 2 of the periodic table. Lithium occurs in group 1 (the alkali metals) and boron occurs in group 3. Isotopes exist for both elements.

(a) (i) **Distinguish between the terms group and period.** [1]
(ii) Cobalt is a transition metal. One common ion of cobalt is $\text{Co}^{3+}$. Draw the orbital diagram (using the arrow-in-box notation) for the $\text{Co}^{3+}$ ion.

![Orbital Diagram]

(iii) State the other most common ion of cobalt.

(iv) Explain why the complex $[\text{Co(NH}_3)_6]\text{Cl}_3$ is coloured.
(iii) Predict the three stable oxidation numbers of titanium ions in aqueous solution. [1]

(iv) One characteristic of the d-block (transition) elements, like titanium, is that they form coloured compounds. With reference to the colour wheel below, explain why Ni^{2+}(aq) is green but Se^{3+}(aq) is colourless. [5]
(e) (i) State two characteristic properties of transition elements. [2]

(ii) State the type of bond formed by a ligand and identify the feature that enables it to form this bond. [2]

(iii) Explain why the complex $[\text{Cr(H}_2\text{O)}_6]^{3+}$ is coloured. [3]
(iv) Draw an orbital box diagram (arrow-in-box notation) showing the electrons in the 4s and 3d sub-levels in chromium metal.

6. (a) Describe the acid-base character of the oxides of the period 3 elements, Na to Cl. For the compounds sodium oxide and phosphorus(V) oxide, state the balanced chemical equations for the reaction of each oxide with water.

(b) Consider the structure and bonding in MgCl₂ and PCl₅.

   (i) State and explain the difference in the electrical conductivity in the liquid state of the two chlorides.
(ii) Samples of sodium oxide and solid sulfur trioxide are added to separate beakers of water. Deduce the equation for each reaction and predict the electrical conductivity of each of the solutions formed.

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Chem 3 7 Q# 28/ IB Chem/2010/w/TZ0/Paper 2 Section A/Higher Level/Q3

e) Explain the origin of colour in transition metal complexes and use your explanation to suggest why copper(II) sulfate, CuSO₄(aq), is blue, but zinc sulfate, ZnSO₄(aq), is colourless.

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Chem 3 2 Q# 29/ IB Chem/2010/s/TZ1/Paper 2 Section B/Higher Level/Q4
(c) Explain why copper is considered a transition metal while scandium is not. [3]

(f) State a balanced equation for the reaction of sodium with water. Include state symbols. [2]

(g) With reference to electronic arrangements, suggest why the reaction between rubidium and water is more vigorous than that between sodium and water. [2]

Chem 3 2 Q# 30/ IB Chem/2009/w/TZ0/Paper 2 Section A/Higher Level/Q3
(b) Transition elements form complexes such as [Fe(CN)$_6$]$^{3+}$ and [FeCl$_4$]$^-$. Deduce the oxidation number of iron in each of these complex ions. [2]


Chem 3 4 Q# 31/ IB Chem/2009/s/TZ1/Paper 2 Section B/Higher Level/Q8
(c) (i) State the full electronic configurations of copper, Cu, and the copper(I) ion, Cu$^+$. [2]

(ii) Explain why copper(II) compounds in aqueous solution are coloured whereas scandium(III) compounds in aqueous solution are colourless. [2]

Chem 3 7 Q# 32/ IB Chem/2008/w/TZ0/Paper 2 Section B/Higher Level/Q6
(f) Water acts as a ligand when it reacts with ions of both zinc and cobalt, forming the complexes [Zn(H$_2$O)$_4$]$^{2+}$ and [Co(H$_2$O)$_6$]$^{3+}$.

(i) Explain how water acts as a ligand in the formation of these complexes and predict the shape of [Co(H$_2$O)$_6$]$^{3+}$. [3]

(ii) Explain why solutions containing [Co(H$_2$O)$_6$]$^{3+}$ are coloured but solutions containing [Zn(H$_2$O)$_4$]$^{2+}$ are not. [4]

Chem 3 6 Q# 33/ IB Chem/2008/s/TZ1/Paper 2 Section B/Higher Level/Q6
(c) Transition elements form complexes such as [Fe(Cl)$_4$]$^-$ and [Fe(CN)$_6$]$^{3+}$.

(i) Identify the feature of both Cl$^-$ and CN$^-$ that enables them to form these complexes and name the type of bond formed. [2]

(ii) Deduce the oxidation state of iron in each of the complex ions. [2]

(iii) State two characteristic properties of transition metals other than complex formation and variable oxidation state. [2]
### Topic 3 Mark Scheme

#### Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

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<tr>
<td>4.</td>
<td></td>
<td>$\text{MgO}(s) + \text{H}_2\text{O}(l) \rightarrow \text{Mg(OH)}_2(s)$</td>
<td>OR</td>
<td>$\text{MgO}(s) + \text{H}_2\text{O}(l) \rightarrow \text{Mg}^2+(aq) + 2\text{OH}^-(aq)$</td>
<td>Accept</td>
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<td>1</td>
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<tr>
<td>4.</td>
<td>f</td>
<td>from basic to acidic ✓</td>
<td>through amphoteric ✓</td>
<td>Accept “alkaline” for “basic”. Accept “oxides of Na and Mg: basic AND oxide of Al: amphoteric” for Mg. Accept “oxides of non-metals/Si to Cl acidic” for Si. Do not accept just “become more acidic”.</td>
<td>2</td>
</tr>
<tr>
<td>4.</td>
<td>g</td>
<td>$\text{Mg}_2\text{N}_2$ ✓</td>
<td>Accept $\text{MgO}_2$, $\text{Mg(OH)}_2$, $\text{Mg(NO)}_3$, $\text{MgCO}_3$</td>
<td>1</td>
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#### Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

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<td>2.</td>
<td>f</td>
<td>coordinate/dative/covalent bond from O to transition metal ions ✓</td>
<td>OR</td>
<td>provides two electron pairs from different O ions</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>can occupy two positions OR</td>
<td>can provide two electron pairs from different O ions OR</td>
<td>form two coordinate/dative/covalent bonds with the metal ions OR</td>
<td>chelate “metallation” ✓</td>
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#### Q# 3/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

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<td>4.</td>
<td>c</td>
<td>1s$^2$2s$^2$2p$^6$3s$^2$3p$^6$3d$^5$</td>
<td>OR</td>
<td>1s$^2$2s$^2$2p$^6$3s$^2$3p$^6$3d$^3$ ✓</td>
<td>Accept “through the formation of a dative/coordinate bond”. Accept “by acting as Lewis bases”. Do not accept “act as ligands”.</td>
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<td></td>
<td>i</td>
<td>give/donate a lone/non-bonding electron pair ✓</td>
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<td>4.</td>
<td>d</td>
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#### Question | Answers | Notes | Total
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<td>4.</td>
<td>d i</td>
<td>more chlorido ligands smaller energy gap between split d-orbitals OR Cl$^-$ is lower than H$_2$O in spectrochemical series OR Cl$^-$ is a weaker ligand/has lower charge density ✓ the absorption will move to longer wavelengths OR the absorption wavelength will increase</td>
<td>Do not accept answers in terms of change of frequency.</td>
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<td>d ii</td>
<td></td>
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(e) (i) Na and Mg: basic  
Al: amphoteric  
Do not accept amphoteric.  

Si to Cl: acidic  
Ar: no oxide ;;  
Award [2] for three or four correct, award [1] for two correct.  
Award [1] for stating oxides become more acidic towards the right/chlorine  
or more basic towards the left/sodium.  
Do not penalize incorrect formulas of oxides.  

(ii) \( \text{Na}_2\text{O}(s) + \text{H}_2\text{O}(l) \rightarrow 2\text{NaOH}(aq) / \text{Na}_2\text{O}(s) + 2\text{HCl}(aq) \rightarrow 2\text{NaCl}(aq) + \text{H}_2\text{O}(l); \)

Accept a correct equation with any acid or acidic oxide.  

\( \text{SO}_2(l) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_4(aq) / \text{SO}_3(l) + 2\text{NaOH}(aq) \rightarrow \text{Na}_2\text{SO}_4(aq) + \text{H}_2\text{O}(l); \)  
[2]

Accept a correct equation with any metal hydroxide, metal oxide, metal carbonate or metal hydrogen carbonate.  

Do not accept equation with \( \text{SO}_2 \).  

Ignore state symbols.  
Accept ionic equations for M1 and/or M2.  

Q# 5/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/

5. (a) (i) ability of an atom to attract (a pair of) electrons in a covalent bond/molecule  
/ ability of an atom to attract a shared pair of electrons;  
Do not accept element/nucleus instead of atom.  

(ii) do not form bonds/compounds / do not share electrons / have (full/stable)  
octet / have full/stable outer shell;  
Accept (chemically) inert / do not react / stable electron arrangements/  
configurations.  

(c) Na\(^+\) has one less energy level/shell compared to Na atom / Na\(^+\) has 2 energy  
levels/shells compared to 3 in Na atom;  
(compared to Na atom) effective nuclear charge greater in Na\(^+\) (so valence  
electrons attracted more strongly to nucleus) / (compared to Na atom) more  
protons than electrons in Na\(^+\) (so valence electrons attracted more strongly to  
nucleus);  

Q# 6/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/

2. (a) \( \text{(Cu)} 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} / 1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1; \)

\( \text{(Cu}^{2+}\text{)} 1s^2 2s^2 2p^6 3s^2 3p^6 \);  
Do not accept [Ar] 4s\(^1\)3d\(^{10}\).  

[2]

(c) d orbitals are split (into two sets of different energies);  
(frequency/wavelength of visible) light absorbed by electrons moving between d  
levels/orbitals;  
colour due to remaining frequencies/complementary colour transmitted;  
Cu\(^{2+}\) has unpaired electrons/partially filled d sub-level / Zn\(^{2+}\) has filled d sub-level;  

Accept d-d transitions possible between orbitals for M2.  

[4]
Q# 7/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q9

(b) (i) Na, Mg (oxides): basic

Al (oxide): amphoteric
Do not accept amphiprotic.

Si to Cl (oxides): acidic

Award [2] for all three listed sets correct.
Award [1] for one or two listed sets correct.
Award [1] for stating oxides become more acidic towards right/Cl or more basic towards left/Na.
Do not penalize if reference is to Ar instead of Cl.
Do not penalize for incorrect formulas of oxides.

(ii) Na$_2$O(s) + H$_2$O(l) $\rightarrow$ 2NaOH(aq);

P$_4$O$_{10}$(s) + 6H$_2$O (l) $\rightarrow$ 4H$_3$PO$_4$(aq);

Ignore state symbols.
Accept P$_2$O$_5$(s) + 3H$_2$O (l) $\rightarrow$ 2H$_3$PO$_4$(aq).
Do not award marks if incorrect formulas of the oxides are used.

Q# 8/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q8

(iv) 

$\begin{array}{c}
\text{NH}_3 \\
\text{Cl} \\
\text{NH}_3 \\
\text{H}_3\text{N} \\
\text{Cl} \\
\text{H}_3\text{N}
\end{array}$

[2]

Accept any other octahedral arrangement of ligands.
Ignore missing square brackets and charge.

Q# 9/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/

8. (a) (i) 

$\begin{array}{c}
4s \\
3d
\end{array}$

[1]

Accept full-arrows.
Accept boxes in reverse order or at different energy levels.
Do not award the mark if sub-levels are incorrectly labelled or if no boxes are drawn.

(ii) (electrostatic) attraction between (lattice of) cations/positive/Cr$^{3+}$ ions and delocalized electrons;

(iii) (delocalized electrons allows) the layers/rows of cations/positive/Cr$^{3+}$ ions to slide past each other (without disrupting the metallic bonding);
Accept atoms instead of ions.
(c) (i) III / plus 3;  
 ***Do not accept incorrect notation such as 3+/3.***

(ii) ligand has lone/non-bonding electron pair / dative (covalent)/coordinate/coordination bond forms;  
ligand is **Lewis base** / ion is **Lewis acid**;  

(iii) partially filled/ incomplete d sub levels/orbitals;  
d orbitals split into two levels;  
extraordinary transitions occur from lower to higher energy level (within d sub-level);  
complementary colour/colour not absorbed is seen;  
***Do not accept complementary colour "emitted"***.  

Q# 10/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/  
(e) Cl has 7 valence electrons **and** is in group 7;  
Accept “group 17” as suggested by IUPAC.  
Cl has 3 occupied (electron) shells/energy levels **and** so is in period 3;  

Q# 11/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/  
2. (a) Na₂O(s) + H₂O(l) → 2NaOH(aq);  
Accept Na₂O(s) + H₂O(l) → 2Na⁺(aq) + 2OH⁻(aq).  

P₂O₁₀(s) + 6H₂O(l) → 4H₃PO₄(aq);  
Accept P₂O₈(s) + 3H₂O(l) → 2H₃PO₄(aq).  
Accept P₄O₁₀(s) + 6H₂O(l) → 4H⁺(aq) + 4H₂PO₄(aq).  
Ignore state symbols.

Q# 12/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/  
4. (a) 1s²2s²2p⁶3s²3p⁶3d¹⁰⁴s¹ / 1s²2s²2p⁶3s²3p⁶3d¹⁰⁴s¹³d¹⁰;  

(b) **Physical:**  
⁶³Cu lower boiling point/melting point/density/greater rate of diffusion than ⁶⁵Cu;  
Accept converse argument.  
Do not accept “different mass”.  

**Chemical:**  
(properties identical because) same electron configuration/arrangement of electrons;  
Accept “same number of protons and electrons”.  
Do not accept “same number of electrons” OR “same valence (electrons)” OR “same atomic number” only.
(e) (i) heat transferred/absorbed/released/enthalpy/potential energy change when 1 mol/molar amounts of reactant(s) react (to form products) / OWTTE; 
under standard conditions / at a pressure 100 kPa/101.3 kPa/1 atm and temperature 298 K/25 °C: [2]
Award [2] for difference between standard enthalpies of products and standard enthalpies of reactants / \( H^\circ \) (products) – \( H^\circ \) (reactants).
Award [2] for difference between standard enthalpies of formation of products and standard enthalpies of formation of reactants / \( \Sigma \Delta H^\circ_f \) (products) – \( \Sigma \Delta H^\circ_f \) (reactants).

(ii) \( (1.00 \times 0.0500 =) 0.0500 \text{ (mol)} \):
\( (0.0500 \times 57.9 =) 2.90 \text{ (kJ)} \); [2]
Ignore any negative sign.
Award [2] for correct final answer.
Award [1 max] for 2900 J.

(iii) \( \left( \frac{2.50}{40.00} = \right) 0.0625 \text{ (mol NaOH)} \);
\( 0.0500 \times 4.18 \times 13.3 = 2.78 \text{ (kJ)} \) / \( 50.0 \times 4.18 \times 13.3 = 2780 \text{ (J)} \);
\( \left( \frac{2.78}{0.0625} = \right) -44.5 \text{ (kJ mol}^{-1} \); [3]
Award [3] for correct final answer.
Negative sign is necessary for M3.
Award M2 and M3 if 52.5 g is used to obtain an enthalpy change of \(-46.7 \) (kJ mol\(^{-1}\)).

(iv) \(-44.5 - 57.9 \) / correct Hess’s Law cycle (as below) / correct manipulation of equations;
\( \text{NaOH(s)} + \text{HCl(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)} \)

\[ \begin{align*}
-44.5 \text{ kJ} & \\
\text{NaOH(aq)} + \text{HCl(aq)} & \\
\text{NaOH(aq)} + \text{HCl(aq)} & -102.4 \text{ kJ};
\end{align*} \]
Award [2] for correct final answer.

(f) (i) zinc (only) forms the ion \( \text{Zn}^{2+} \) / has the oxidation state +2;
Allow forms only one ion / has only one oxidation state.
has full d-subshell/orbitals / does not have a partially filled d-subshell/orbitals (needed to exhibit transition metal properties); [2]

(ii) \( \text{Fe}^{2+} \): \( 1s^2 \text{ } 2s^2 \text{ } 2p^6 \text{ } 3s^2 \text{ } 3p^6 \text{ } 3d^6 \) / \( \text{[Ar]} \text{ } 3d^6 \) and \( \text{Fe}^{3+} \): \( 1s^2 \text{ } 2s^2 \text{ } 2p^6 \text{ } 3s^2 \text{ } 3p^6 \text{ } 3d^5 \) / \( \text{[Ar]} \text{ } 3d^5 \); 
half-full sub-level/3d\(^{\text{6}}\) has extra stability;
less repulsion between electrons / electrons singly occupy orbitals / electrons do not have to pair with other electrons;
Accept converse points for \( \text{Fe}^{2+} \). [3]
Q# 14/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q10

(c) groups indicate the number of electrons in the highest energy level/outer/valence shell; periods indicate the number of (occupied) energy levels/shells (in the atom); [2]

(d) \( \text{V}_2\text{O}_5 \) catalyses oxidation of \( \text{SO}_2 / \text{V}_2\text{O}_5 \) is a catalyst in the Contact Process; Fe catalyses the reaction between \( \text{N}_2 \) and \( \text{H}_2 / \text{Fe} \) is a catalyst in the Haber Process; Ni/Pd/Pt catalyses hydrogenation / manufacture of margarine / addition of hydrogen to \( \text{C} = \text{C} / \) conversion of alkenes to alkanes; Pd/Pt is a catalyst in catalytic converters / Pd/Pt catalyzes reaction of \( \text{NO}_2 \) and CO/NO\(_2\) and (unburnt) fuel/exhaust gases; [2 max]

Accept other correct examples.
Accept formulas or names of substances.

Q# 15/ IB Chem/2014/s/TZ2/Paper 2 Section A/Higher Level/Q2

(b) \( 1s^2 \ 2s^2 \ 2p^6 \ 3s^2 \ 3p^6 \ 3d^{10} \ 4s^1 \ / \ 1s^2 \ 2s^2 \ 2p^6 \ 3s^2 \ 3p^6 \ 4s^1 \ 3d^{10} \); [1]

Do not accept upper case letters or numbers as subscripts.

(c) colour is due to movement of electrons (between d orbitals) / OWTTE; copper(I) has a full d sub-shell, hence electrons cannot move / copper(II) has an incomplete d sub-shell, hence electrons can move / OWTTE; [2]

Q# 16/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/

5. (a) (i) basic to acidic:
\[ \text{Na}_2\text{O}(s) + \text{H}_2\text{O}(l) \rightarrow 2\text{NaOH(aq)}; \]
\[ \text{SO}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_4(aq); \]    [3]

Ignore state symbols.

(d) (i) \( \text{Cr}^3+ \):
\[ 1s^2 \ 2s^2 \ 2p^6 \ 3s^2 \ 3p^6 \ 4s^1 \ 3d^{5} / 1s^2 \ 2s^2 \ 2p^6 \ 3s^2 \ 3p^6 \ 4s^1 \ 3d^{5} \ 4s^{1} \];
\[ \text{Cr}^{3+} : \ 1s^2 \ 2s^2 \ 2p^6 \ 3s^2 \ 3p^6 \ 3d^{3} \]; [2]

(iii) \( \text{Cr}^{3+} \) has partially filled d orbitals;
d orbitals split into two levels / three lower energy and two higher energy levels;
energy difference is in visible part of spectrum;
electrons absorb visible light / one colour/frequency/wavelength;
electron transitions occur from lower to higher energy level within d sub-level;
complementary colour/colour not absorbed is seen; [3 max]

(e) successive ionization energy values increase with removal of each electron;
large increase in ionization energy when sixth electron is removed;
as electron is one energy level/shell closer to the nucleus; [2 max]

Accept a suitably annotated diagram.
4. (a) \(1s^22s^22p^63s^23p^63d^1\) / [Ar]3d\(^1\);  
(b) ligand;  
dative/coordinate (covalent);  
Do not accept “covalent”.  
(c) variable oxidation state/number;  
catalytic properties;  
(d) d sublevel/orbitals split (into two levels by ligands);  
electrons absorb light/photons and move to the higher energy orbital;  
frequency of light/photons absorbed in the visible region;  

Q# 18/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/Q1

(h) (i) NO\(_3^-\) and Cl\(^-\) anions may also react with KMnO\(_4\) / HNO\(_3\) is an oxidizing agent / (HCl will not work as) Cl\(^-\) reacts with MnO\(_4^-\) (to form Cl\(_2\)) / HCl oxidized / OWTTE;  
For HCl, allow correctly balanced chemical equation:  
\(2\text{MnO}_4^- + 10\text{Cl}^- + 16\text{H}^+ \rightarrow 2\text{Mn}^{2+} + 5\text{Cl}_2 + 8\text{H}_2\text{O}\)  
Accept NO\(_3^-\) and Cl\(^-\) may react with KMnO\(_4\)/Fe\(^{2+}\).  

(ii) CaCO\(_3\)(s) + H\(_2\)SO\(_4\)(aq) \(\rightarrow\) CaSO\(_4\)(s) + H\(_2\)O(l) + CO\(_2\)(g)  
correct chemical equation;  
correct state symbols;  
Allow CaSO\(_4\)(aq) instead of CaSO\(_4\)(s).  
M2 can only be scored if M1 is correct.  
Award [1\(\text{max}\)] if H\(_2\)CO\(_3\)(aq) is given instead of H\(_2\)O(l) + CO\(_2\)(g).
Q# 19/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/Q3

(c) (i) 

\[ \text{symmetrical s orbital representation;} \]
\[ \text{Do not penalize if axes are not labelled for s orbital.} \]
\[ \text{x, y, z can be located in any direction.} \]

\[ \text{dumbbell-shaped p}_x \text{ orbital representation with electron density located} \]
\[ \text{along x-axis;} \]
\[ \text{x-axis must be labelled for p}_x \text{ orbital.} \]
\[ \text{Do not accept if p}_y \text{ and p}_z \text{ are also drawn as question asks for orbital not sub-level.} \]

(ii) 16; 

(d) \[1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 4d^6; \]
\[ \text{Order of 4s and 3d levels can be interchanged.} \]
\[ \text{Do not accept other notation such as subscripts.} \]

(e) 

\[ \begin{array}{c|c|c|c|c|c|c|c} 
 & 3s & 3p & 4s & 3d \\
\hline 
3s & \uparrow & \uparrow & \uparrow & \downarrow & \downarrow & \downarrow & \downarrow \\
3p & & & & & & & \\
4s & & & & & & & \\
3d & & & & & & & \\
\end{array} \]
\[ \text{Allow full arrows instead of half-arrows in orbital diagram.} \]
\[ \text{Sub-levels must be labelled for mark.} \]
Q# 20/ IB Chem/2013/s/TZ1/Paper 2 Section B/Higher Level/

7. (a) (i) Reactivity decreases down group; as atomic radius increases / more electron shells; attraction of nucleus on electrons decreases / electron affinity decreases; 
   *Accept opposite argument for “up the group”*.  
   [3]

   (ii) No reaction with NaCl; 
   Br\(_2\) (aq) + 2NaI (aq) \(\rightarrow\) 2NaBr (aq) + I\(_2\) (aq); 
   *Accept ionic equation.* 
   *Ignore state symbols.*  
   [2]

(b) (i) (Electrostatic attraction between a) lattice of positive ions/cations *and* delocalized/sea of electrons; 
   *Accept suitable diagram.*

   Atoms/ions/layers (of positive ions) can slide over each other / OWTTE; without change in the bonding forces / OWTTE;  
   [3]

   (ii) Variable oxidation numbers/valency 
   Form complex (ions) 
   Form coloured compounds/ions 
   Catalytic (behaviour) 
   [2]

(iii) Dative (covalent)/coordinate;  
   [1]

(iv) III / +3; 
   *Penalize incorrect format such as 3+ only if not penalized in 4 (b).*  
   [1]

(v) 

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[Ar] \[ \uparrow \!
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Q# 21/ IB Chem/2013/s/TZ1/Paper 2 Section A/Higher Level/
2. (a) decreases (from left to right/across period 3);
same number of shells/energy levels / shielding remains the same;
number of protons/nuclear charge increases so attraction of nucleus on outer electrons
increases / OWTTE; [3]
(b) hypothesis is wrong since ionic radius should be smaller than atomic radius/110 x 10^{-12} m;
greater attraction of the nucleus on outer electrons / effective charge of nucleus
greater / repulsive forces between electrons smaller; [2]

Q# 22/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/ Q1
(f) (i) 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^5 / 1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^5;
No mark for 2.8, 18, 18 or [Kr] 5s^2 4d^{10} 5p^5.
Allow electron configurations with order of sublevels interchanged.
Electrons must be represented as superscript to award mark. [1]
(ii) Cl_2(aq) + H_2O(l) ⇌ HCl(aq) + HOCl(aq);
Accept → .
Accept HCl(aq).
Allow H^+(aq) + Cl^-(aq) for HCl(aq) and H^+(aq) + OCl^-(aq)/OCl(aq)/ClO^-(aq)
for HOCl(aq).
Allow 2Cl_2(g) + 2H_2O(l) → 4HCl(aq) + O_2(g).
Ignore state symbols. [1]

Q# 23/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/
2. (a) (i) **Group:** (elements in vertical) columns in periodic table and **Period:** (elements
in horizontal) rows in periodic table; [1]
Allow elements in same group have similar chemical properties and within a
period, atoms have same number of shells/energy levels (but number of
electrons in valence/outer shell increases).
Allow groups distributed vertically and periods distributed horizontally / OWTTE.
Allow group number gives number of valence/outer shell electrons (for main-
group elements) and period gives same number of shells/energy levels.

(ii) [Diagram of electron configurations]
Allow full arrows instead of half-arrows for example ↑↓.
Do not allow arrows with the same spin for example ↑↑ or ↓↓ in the same
orbital.
Do not allow an orbital diagram with a 4s^1 3d^5 configuration. [1]

(iii) Co^{2+};
Accept +2, 2+, cobalt(II), II. [1]

(iv) partially filled/incomplete d subshell/sub-level/orbitals;
d orbitals split (into two sets of different energies);
(colour due to) electron transition between (split) d orbitals / d to d transitions / frequencies of visible light absorbed by electrons moving from lower to higher
d levels;
colour due to remaining frequencies / complementary colour seen; [3 max]
Allow wavelength as well as frequency.
Q# 24/ IB Chem/2012/s/TZ1/Paper 2 Section B/Higher Level/Q8b

(iii) +2, +3, +4;  \[1\]

(iv) (colour) due to partially filled/incomplete d sub-level/orbital; d sub-level is split / d orbitals are split; Ni\(^{2+}\)(aq) has incomplete 3d sub-level/orbital but Sc\(^{3+}\)(aq) has no 3d electron/empty d sub-level; electrons move from lower to higher (sub)levels when they absorb energy/light; Ni\(^{2+}\)(aq) (appears green because it) absorbs red; \[5\]

Q# 25/ IB Chem/2011/w/TZ0/Paper 2 Section B/Higher Level/Q7

(e) (i) catalysts; variable oxidation state/nnumbers; Allow variable valency.

magnetic (properties);
(form) coloured ions/compounds; Allow just coloured.
(form) complexes/complex ions; \[2 max\]
Allow other metallic physical properties such as high densities/high melting points etc.
Allow partially filled/incomplete d subshell/sub-level.

(ii) dative (covalent)/coordinate; Lewis base / (species/ion/molecule with) lone/non-bonding pair; \[2\]

(iii) partially filled/incomplete d subshell/sub-level/orbitals; d orbitals split (into two sets of different energies); colour due to electron transition between (split) d orbitals / frequencies of visible light absorbed by electrons moving from lower to higher d levels; colour due to remaining frequencies / complementary colour seen; \[3 max\]
Allow wavelength as well as frequency.

(iv) \[\begin{array}{c}
4s \\
\hline
\end{array}\]
\[\begin{array}{ccccccc}
\downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\
3d
\end{array}\]  \[1\]
Accept half-arrows or full arrows and boxes in reverse order.
Do not penalize if additional sub-levels are shown, if sub-levels are not labelled or if no boxes are drawn (providing system of arrows correct).
Do not award mark if sub-levels are incorrectly labelled.
Orbital diagram may also be represented with sub-levels shown at different relative energy positions.
Q# 26/ IB Chem/2011/w/TZ0/Paper 2 Section B/Higher Level/

6. (a) Na, Mg: basic
   Al: amphoteric
   Do not accept amphoteric.

   Si to Cl: acidic
   Award [2] for all three listed sets correct, [1] for one or two listed sets correct.
   Award [1] for stating oxides become more basic towards left/Na and more acidic towards right/Cl.
   Do not penalize incorrect formulas of oxides.

   \[\text{Na}_2\text{O} (s) + \text{H}_2\text{O} (l) \rightarrow 2\text{NaOH} (aq) ;\]
   \[\text{P}_2\text{O}_5(s) + 6\text{H}_2\text{O} (l) \rightarrow 4\text{H}_3\text{PO}_4(aq) ;\]
   Ignore state symbols.
   Allow \[\text{P}_2\text{O}_5(s) + 3\text{H}_2\text{O} (l) \rightarrow 2\text{H}_3\text{PO}_4(aq) .\]

(b) (i) MgCl\(_2\) conducts and PCl\(_3\) does not;
   MgCl\(_2\) ionic and PCl\(_3\) covalent/molecular/(consists of) molecules;
   Award [1 max] for MgCl\(_2\) conducts and ionic.
   Award [1 max] for PCl\(_3\) does not conduct and covalent/molecular/(consists of) molecules.

   ions can move in liquid (in MgCl\(_2\)) / OWTTE;

Q# 27/ IB Chem/2011/s/TZ1/Paper 2 Section B/Higher Level/Q6(f)

(ii) \[\text{Na}_2\text{O} (s) + \text{H}_2\text{O} (l) \rightarrow 2\text{NaOH} (aq) ;\]
    \[\text{SO}_2(l) + \text{H}_2\text{O} (l) \rightarrow \text{H}_2\text{SO}_4(aq) ;\]
    both solutions conduct;
    Ignore state symbols.

Q# 28/ IB Chem/2010/w/TZ0/Paper 2 Section A/Higher Level/Q3

(e) d orbitals are split (into two sets of different energies);
   frequencies of (visible) light absorbed by electrons moving from lower to higher d levels;
   colour due to remaining frequencies/complementary colour transmitted;
   Cu\(^{2+}\) has unpaired electrons/partially filled d sub-level;
   Zn\(^{2+}\) has filled d sub-shell;
   electronic transitions/d-d transitions possible for Cu\(^{2+}\) / no electronic/d-d transitions possible for Zn\(^{2+}\) ;
   Allow wavelength as well as frequency.

(f) NH\(_3\): Lewis base / Cu\(^{2+}\): Lewis acid;
   each NH\(_3\)/ligand donates an electron pair (to Cu\(^{2+}\));
   NH\(_3\) replace H\(_2\)O ligands around Cu\(^{2+}\) ion/around central ion;
   forming coordinate (covalent)/dative covalent bond;
Q# 29/ IB Chem/2010/s/TZ1/Paper 2 Section B/Higher Level/Q4

(e) Sc has no d electrons as an ion / Cu has d electrons;
   Cu compounds are coloured / Sc compounds are colourless;
   Cu has more than one oxidation state / Sc has only one oxidation state;
   Cu compounds can act as catalysts / Sc cannot act as catalysts; [3 max]

(f) \[2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)\] / \[Na(s) + H_2O(l) \rightarrow NaOH(aq) + \frac{1}{2}H_2(g)\] [2]

Award [1] for correct balanced equation.
Award [1] for correct state symbols for sodium, water, sodium hydroxide and hydrogen.
Second mark is not dependent on equation being correctly balanced.

(g) (Rb more reactive because) electron lost further from nucleus so less tightly held;
   Rb electron is in 5th energy level and (Na less reactive) as electron lost in 3rd energy level / OWTTE; [2]
   Allow [1 max] for electron arrangements of Na (e.g. 2,8,1) and Rb if second mark is not scored.

Q# 30/ IB Chem/2009/w/TZ0/Paper 2 Section A/Higher Level/Q3

(b) \([\text{Fe(CN)}_6]^{3-} = +2;\]
   \([\text{FeCl}_4]^- = +3;\) [2]

Award [1 max] if 2+ and 3+, 2 and 3 or II and III stated.

Q# 31/ IB Chem/2009/s/TZ1/Paper 2 Section B/Higher Level/Q8

(c) (i) \((\text{Cu}^+) 1s^22s^22p^63s^23p^64s^13d^{10} / 1s^22s^22p^63s^23p^64s^14s^1;\)
   Do not accept \([Ar]4s^13d^{10};\) [2]
   \((\text{Cu}^+) 1s^22s^22p^63s^23p^64s^13d^{10};\)
   Do not accept \([Ar]3d^{10}.\) [2]

(ii) Cu\(^{2+}\) has an incomplete d sub-level and Se\(^{3+}\) has no d electrons;
   the d sub-level is split so the d electrons (in copper) can be excited by visible light / OWTTE; [2]

Q# 32/ IB Chem/2008/w/TZ0/Paper 2 Section B/Higher Level/Q6

(f) (i) water has a non-bonding pair of electrons;
   donates to metal ion / forms co-ordinate / dative bond with metal ion / acts as Lewis base;
   octahedral;
   Allow square bipyramidal. [3]

(ii) in transition metal complexes the d orbitals/levels are split (into two levels of different energy):
   in cobalt the d levels are partially filled and in zinc they are completely filled;
   visible light absorbed when electrons move from lower to higher energy levels / d – d transitions (in cobalt);
   transmitted light is complementary colour / OWTTE; [4]
Q# 33/ IB Chem/2008/s/TZ1/Paper 2 Section B/Higher Level/Q6

(c) (i) (presence of) lone/non-bonding pairs; dative covalent / coordinate; [2]

(ii) \([\text{Fe(Cl)}_4]^- = +3;\) [2]
\([\text{Fe(CN)}_4]^{2-} = +2;\] 
Award [1 max] if 3+ and 2+, 3 and 2 or III and II stated.

(iii) catalytic activity/catalysts; coloured compounds; [2]
Accept paramagnetic

Topic 4
Chem 4 2 Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/Q4

(h) Describe the structure and bonding in solid magnesium oxide. [2]

Chem 4 3 Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/Q2

(c) 5.00g of an impure sample of hydrated ethanedioic acid, \((\text{COOH})_2\cdot2\text{H}_2\text{O}\), was dissolved in water to make 1.00 dm\(^3\) of solution. 25.0 cm\(^3\) samples of this solution were titrated against a 0.100 mol dm\(^{-3}\) solution of sodium hydroxide using a suitable indicator.

\[(\text{COOH})_2\text{(aq)} + 2\text{NaOH(aq)} \rightarrow (\text{COONa})_2\text{(aq)} + 2\text{H}_2\text{O(l)}\]

(d) Draw the Lewis (electron dot) structure of the ethanedioate ion, “OOCOOCO”. [1]
(e) Outline why all the C–O bond lengths in the ethanedioate ion are the same length and suggest a value for them. Use section 10 of the data booklet. [2]

(b) (i) Draw diagrams to show how sigma (σ) and pi (π) bonds are formed between atoms. [2]
(ii) State the number of sigma (σ) and pi (π) bonds in propane and propene. [2]

<table>
<thead>
<tr>
<th></th>
<th>Number of sigma (σ) bonds</th>
<th>Number of pi (π) bonds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane</td>
<td></td>
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<tr>
<td>Propene</td>
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<td></td>
</tr>
</tbody>
</table>

Chem 4 2 Q# 4/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

1. Ethene-1,2-diol, HOCH₂CH₂OH, has a wide variety of uses including the removal of ice from aircraft and heat transfer in a solar cell.

**Ethene has the formula CH₂CH₂**

(d) Explain why the boiling point of ethane-1,2-diol is significantly greater than that of ethene. [2]
6. Ozone, dinitrogen monoxide, CFCs, sulfur hexafluoride and methane are all examples of greenhouse gases.

(a) (i) Draw one valid Lewis (electron dot) structure for each molecule of the greenhouse gases listed below.

<table>
<thead>
<tr>
<th>Lewis (electron dot) structure</th>
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</thead>
<tbody>
<tr>
<td>Ozone</td>
</tr>
<tr>
<td>Sulfur hexafluoride</td>
</tr>
</tbody>
</table>

(ii) Deduce the name of the electron domain geometry and the molecular geometry for each molecule listed below.

<table>
<thead>
<tr>
<th>Electron domain geometry</th>
<th>Molecular geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone</td>
<td>. . . . . . . .</td>
</tr>
<tr>
<td>Sulfur hexafluoride</td>
<td>. . . . . . . .</td>
</tr>
</tbody>
</table>
(iii) Identify which molecule(s) given in part (a) (i) has/have an extended octet of electrons.

(iv) State the bond angles for each species in part (a) (ii).

Ozone:

Sulfur hexafluoride:

(v) Draw all the resonance structures of ozone. Lone pairs should be shown.
(b) Nitrous oxide can be represented by different Lewis (electron dot) structures.

(i) Deduce the formal charge (FC) of the nitrogen and oxygen atoms in three of these Lewis (electron dot) structures, A, B and C, represented below. \[2\]

*LHS: atom on left-hand side; RHS: atom on right-hand side.*

<table>
<thead>
<tr>
<th>Lewis (electron dot) structure</th>
<th>FC of O on LHS</th>
<th>FC of N on LHS</th>
<th>FC of central N</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>:\text{O}----\text{N}----\text{N}:</td>
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<tr>
<td>B</td>
<td>:\text{O}----\text{N}====\text{N}:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>:\text{O}====\text{N}--\text{N}:</td>
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</tbody>
</table>

(ii) FC can be useful in electron book-keeping, but electronegativity values are ignored when FCS are assigned.

Based on the assignment of FCS of the atoms in part (i), deduce which Lewis (electron dot) structure of N₂O (A, B or C) is expected to be the preferred structure. Explore why another factor needs to be considered. \[2\]
(d) (i) The concentration of ozone in the upper atmosphere is maintained by the following three reactions, I, II and III.

\[
\begin{align*}
\text{I} & \quad \text{O}_2 \xrightarrow{hv} 2\text{O}^* \\
\text{II} & \quad \text{O}_2 + \text{O}^* \rightarrow \text{O}_3 \\
\text{III} & \quad \text{O}_3 \xrightarrow{hv} \text{O}_2 + \text{O}^*
\end{align*}
\]

Explain by reference to the bonding in \( \text{O}_2 \) and \( \text{O}_3 \), which of the reactions, I or III, needs more energy. \[3\]

(ii) Using dichlorodifluoromethane, \( \text{CCl}_2\text{F}_2 \), as an example, outline the reactions in which ozone depletion occurs in the upper atmosphere. Formulate an equation for each step in this process and explain the initial step by reference to the bonds in \( \text{CCl}_2\text{F}_2 \). \[5\]
Chem 4 Q# 6/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/Q3

(c) One of the intermediates in the reaction between nitrogen monoxide and hydrogen is dinitrogen monoxide, \( \text{N}_2\text{O} \). This can be represented by the resonance structures below:

\[
\begin{align*}
\text{N} & \equiv \text{N} \quad \text{O}^- \\
\text{N} & \equiv \text{N} \\
\end{align*}
\]

(i) Analyse the bonding in dinitrogen monoxide in terms of \( \sigma \)-bonds and \( \pi \)-bonds. [3]

(ii) State what is meant by resonance. [1]

Chem 4 Q# 7/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula \( \text{PH}_3 \).

(a) (i) Draw a Lewis (electron dot) structure of phosphine. [1]

(ii) State the hybridization of the phosphorus atom in phosphine. [1]
(iv) Outline whether you expect the bonds in phosphine to be polar or non-polar, giving a brief reason. [1]

(v) Phosphine has a much greater molar mass than ammonia. Explain why phosphine has a significantly lower boiling point than ammonia. [2]

(c) (i) Deduce the type of hybridization shown by the nitrogen atoms in \( \text{NF}_4^+ \), \( \text{N}_2\text{H}_2 \) and \( \text{N}_2\text{H}_4 \). [3]

<table>
<thead>
<tr>
<th></th>
<th>( \text{NF}_4^+ )</th>
<th>( \text{N}_2\text{H}_2 )</th>
<th>( \text{N}_2\text{H}_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybridization</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(ii) Describe how sigma (\( \sigma \)) and pi (\( \pi \)) bonds form. [2]
(iii) Draw the Lewis (electron dot) structures of SF₄ and SF₅. Use the valence shell electron pair repulsion (VSEPR) theory to predict the name of the shape of each molecule.

(d) (i) List the following compounds in order of increasing boiling point:
CH₃CHO, CH₃CH₂CH₃, CH₃COOH, CH₃CH₂OH.

(iii) Explain the order of boiling points in the compounds listed in part (d) (i), in terms of intermolecular forces.
Chem 4 3 Q# 9/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/Q5
(b) Explain why the melting points of the group 1 metals (Li → Cs) decrease down the group whereas the melting points of the group 7 elements (F → I) increase down the group. [3]

Chem 4 14 Q# 10/ IB CHEM/2015/s/TZ2/Paper 2 Section B/Higher Level/Q9
(c) Consider the molecules PBr₃ and SF₄.

(i) Deduce the Lewis (electron dot) structure of both molecules. [2]

(ii) Predict the shapes of the two molecules, giving the Br–P–Br bond angle in PBr₃ and the F–S–F bond angles in SF₄. [4]
(iii) Explain why both $\text{PBr}_3$ and $\text{SF}_4$ are polar. [2]

\begin{center}
\begin{tabular}{|p{0.8\textwidth}|}
\hline
\textbf{Answer:} \\
\hline
\end{tabular}
\end{center}

(d) The structure of \textit{cis}-but-2-ene-1,4-dioic acid is shown below.

(i) Describe the covalent bond between carbon and hydrogen in the molecule above and how it is formed. [2]

\begin{center}
\begin{tabular}{|p{0.8\textwidth}|}
\hline
\textbf{Answer:} \\
\hline
\end{tabular}
\end{center}
(ii) Deduce the hybridization of the oxygen atoms labelled α and β.

α:

β:

(iii) Describe sigma (σ) and pi (π) bonds between atoms.

σ bond:

π bond:

(iv) Identify the number of sigma (σ) and pi (π) bonds present in a molecule of cis-but-2-ene-1,4-dioic acid.

(b) (i) State the name of Cr₂O₃.

(ii) Describe the ionic bonding present in Cr₂O₃ and how the ions are formed.
(iii) Suggest why solid Cr₂O₃ does not conduct electricity.

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Chem 4 2 Q# 12/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q7

(f) Describe the formation of σ and π bonds in an alkene.

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Chem 4 4 Q# 13/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q5

(g) Identify three allotropes of carbon and describe their structures.

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Chem 4 3 Q# 14/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/

(f) SCl₂ and SClF₅ are two sulfur chloride type compounds with sulfur having different oxidation states. Predict the name of the shape, the bond angle and polarity of these molecules.

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Shape</th>
<th>Bond angle</th>
<th>Polarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCl₂</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SClF₅</td>
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</table>

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(b) (i) Explain why the melting point of phosphorus(V) oxide is lower than that of sodium oxide in terms of their bonding and structure. [2]

(ii) Predict whether phosphorus(V) oxide and sodium oxide conduct electricity in their solid and molten states. Complete the boxes with “yes” or “no”. [2]

<table>
<thead>
<tr>
<th></th>
<th>Phosphorus(V) oxide</th>
<th>Sodium oxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid state</td>
<td>. . . . . . . . . .</td>
<td>. . . . . . .</td>
</tr>
<tr>
<td>Molten state</td>
<td>. . . . . . . . . .</td>
<td>. . . . . . .</td>
</tr>
</tbody>
</table>

(c) Describe the bonding in solid copper. [2]

Chem 4 Q# 17/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/

1. Ethanedioic acid is a diprotic acid. A student determined the value of x in the formula of hydrated ethanedioic acid, HOOC–COOH • xH₂O, by titrating a known mass of the acid with a 0.100 mol/dm³ solution of NaOH (aq).

(c) Identify the strongest intermolecular force in solid ethanedioic acid. [1]
(d) Deduce the Lewis (electron dot) structure of ethanedioic acid, HOOC–COOH. [1]

(e) Predict and explain the difference in carbon-oxygen bond lengths in ethanedioic acid and its conjugate base, "OOC–COO". [3]

(c) (i) Magnesium reacts with oxygen to form an ionic compound, magnesium oxide. Describe how the ions are formed, and the structure and bonding in magnesium oxide. [2]

(ii) Carbon reacts with oxygen to form a covalent compound, carbon dioxide. Describe what is meant by a covalent bond. [1]

(iii) State why magnesium and oxygen form an ionic compound while carbon and oxygen form a covalent compound. [1]
(d) (i) Predict the type of hybridization of the carbon and oxygen atoms in CO₂.  

(ii) Sketch the orbitals of an oxygen atom in CO₂ on the energy level diagram provided, including the electrons that occupy each orbital.  

(iii) Define the term electronegativity.  

(iv) Explain why oxygen has a larger electronegativity than carbon.
Chem 4 Q# 19/ IB CHEM/2014/w/T20/Paper 2 Section B/Higher Level/Q10

(b) The oxygen in half-equation 2 is atmospheric oxygen that is found dissolved in water in very small concentrations. Explain, in terms of intermolecular forces, why oxygen is not very soluble in water. [2]

Chem 4 Q# 20/ IB Chem/2014/w/T20/Paper 2 Section A/Higher Level/

5. Graphite has a layered structure of carbon atoms. A section of the structure is shown below.

(a) Identify the type of attraction represented by the dotted lines shown between the layers. [1]

(b) Graphite is used as a lubricant. Discuss two other uses of graphite with reference to its layered structure. [4]
(f) Magnesium metal is mainly used as a component in lightweight alloys, particularly in combination with aluminium and titanium.

(i) Describe the bonding present in magnesium metal.  

(ii) Suggest why magnesium is harder than sodium.  

(iii) Outline why alloys are generally less malleable than their component metals.
4. Ozone, $\text{O}_3$, in the upper atmosphere prevents harmful UV radiation reaching the surface of the Earth.

(a) Draw the Lewis structure for ozone.  

(b) State the shape of the ozone molecule and estimate the bond angle.  

Shape:  

Bond angle:  

(c) State the hybridization of the central oxygen atom.  

(d) In terms of $\sigma$ and $\pi$ bonds, describe the two oxygen-oxygen bonds in the Lewis structure.
(e) The two oxygen-oxygen bonds in ozone are in fact of equal length. Deduce why this is the case and how the length of these would compare to oxygen-oxygen bond lengths in hydrogen peroxide, $\text{H}_2\text{O}_2$, and in the oxygen molecule, $\text{O}_2$. [2]
The hydrogen halides do not show perfect periodicity. A bar chart of boiling points shows that the boiling point of hydrogen fluoride, HF, is much higher than periodic trends would indicate.

(i) Explain why the boiling point of HF is much higher than the boiling points of the other hydrogen halides.

(ii) Explain the trend in the boiling points of HCl, HBr and HI.
Magnesium sulfate is one of the products formed when acid rain reacts with dolomitic limestone. This limestone is a mixture of magnesium carbonate and calcium carbonate.

(i) State the equation for the reaction of sulfuric acid with magnesium carbonate.  \[1\]

(ii) Deduce the Lewis (electron dot) structure of the carbonate ion, giving the shape and the oxygen-carbon-oxygen bond angle.  \[3\]

Lewis (electron dot) structure:

Shape:

Bond angle:
(iii) There are three possible Lewis structures that can be drawn for the carbonate ion, which lead to a resonance structure. Explain, with reference to the electrons, why all carbon-oxygen bonds have the same length.

(iv) Deduce the hybridization of the carbon atom in the carbonate ion.
3. Calcium nitrate contains both covalent and ionic bonds.

(a) (i) State the formula of both ions present and the nature of the force between these ions.

Ions:

................................................

Nature of force:

................................................

(ii) State which atoms are covalently bonded.

................................................

(b) Bonding in the nitrate ion involves electron delocalization. Explain the meaning of electron delocalization and how it affects the ion.

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Chem 4 4 Q# 26/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/Q4

(b) Identify the intermolecular forces present in hydrogen iodide in the liquid state, HI(l).

................................................
(c) Consider the compounds \((\text{CH}_3)_2\text{NH}\) and \(\text{CH}_4\).

(i) State and explain which compound can form hydrogen bonds with water. \([2]\)

(ii) Draw a diagram showing the resulting hydrogen bonds between water and the compound chosen in (i). \([1]\)

3. Carboplatin used in the treatment of lung cancer has the following three-dimensional structure.
(b) State the type of bonding between platinum and nitrogen in carboplatin.  

........................................................................................................................................

(ii) Deduce the Lewis structures for $\text{PCl}_3$ and $\text{PCl}_5$.  

$\text{PCl}_3$  

$\text{PCl}_5$

(iii) Predict the shapes and the bond angles in the two molecules.  

<table>
<thead>
<tr>
<th></th>
<th>$\text{PCl}_3$</th>
<th>$\text{PCl}_5$</th>
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</thead>
<tbody>
<tr>
<td>Shape</td>
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<tr>
<td>Bond angles</td>
<td>................................................................</td>
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</tbody>
</table>
(iv) Identify the type of hybridization present in \( \text{PCl}_3 \). 

(v) Compare the melting points of \( \text{PCl}_3 \) and \( \text{PCl}_5 \) and explain the difference.

(e) Explain the delocalization of \( \pi \) electrons using the \( \text{O}_2 \) molecule as an example, including two facts that support the delocalization.
This molecule is needed in the question that follows.

1,3,5,7-tetranitro-1,3,5,7-tetrazocane, shown below, can be used as an explosive.

(ii) The CO molecule has dative covalent bonding. Identify a nitrogen-containing positive ion which also has this type of bonding. [1]
(iii) Describe in words and with the aid of a suitable diagram the difference between sigma (σ) and pi (π) bonds.

(iv) Determine the number of σ and π bonds in 1,3,5,7-tetranitro-1,3,5,7-tetrazocane, using the Lewis structure shown on page 16.
(v) Explain the term *hybridization* and deduce the hybridization (sp, sp² or sp³) of the atoms labelled A and B in the diagram on page 16. [3]

(b) (i) Explain why metals are good conductors of electricity and why they are malleable. [2]

(b) Although the molar masses of ICl and Br₂ are very similar, the boiling point of ICl is 97.4 °C and that of Br₂ is 58.8 °C. Explain the difference in these boiling points in terms of the intermolecular forces present in each liquid. [2]
(e) When iodine reacts with excess chlorine, ICl$_3$ can form. Deduce the Lewis (electron dot) structure of ICl$_3$ and ICl$_3^-$ and state the name of the shape of each species. \[4\]

<table>
<thead>
<tr>
<th></th>
<th>ICl$_3$</th>
<th>ICl$_3^-$</th>
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</thead>
<tbody>
<tr>
<td>Lewis structure</td>
<td></td>
<td></td>
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<tr>
<td>Name of shape</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Chem 4 Q# 33/ IB Chem/2012/s/TZ1/Paper 2 Section B/Higher Level/Q5

(d) Silicon tetrachloride, SiCl$_4$, is a volatile colourless liquid first prepared by Jöns Jakob Berzelius in 1823.

(d) (i) SiCl$_4$ for Mark Scheme an acidic solution when added to water

(ii) Explain why the aqueous solution formed in (d) (i) conducts electricity whereas liquid silicon tetrachloride does not. \[2\]
5. Ethane, C₂H₆, and disilane, Si₂H₆, are both hydrides of group 4 elements with similar structures but with different chemical properties.

(a) (i) Deduce the Lewis (electron dot) structure for Si₂H₆ showing all valence electrons. [1]

(ii) State and explain the H–Si–H bond angle in Si₂H₆. [2]

(iii) Identify the type of hybridization shown by the silicon atoms in Si₂H₆. [1]
(iv) State which of the bonds, Si–H or C–H, is more polar. Explain your choice.

(v) Predict, with an explanation, the polarity of the two molecules.

(vi) Explain why disilane has a higher boiling point than ethane.
(iii) Compare the structure and bonding in carbon dioxide and silicon dioxide.
For each of the species $\text{PBr}_3$ and $\text{SF}_6$:

(i) deduce the Lewis structure.

(ii) predict the shape and bond angle.

(iii) predict and explain the molecular polarity.

<table>
<thead>
<tr>
<th>$\text{PBr}_3$</th>
<th>$\text{SF}_6$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(i) Lewis structure:</strong></td>
<td><strong>(i) Lewis structure:</strong></td>
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<tr>
<td><strong>(ii) Shape:</strong></td>
<td><strong>(ii) Shape:</strong></td>
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<tr>
<td>Bond angle:</td>
<td>Bond angle:</td>
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<tr>
<td><strong>(iii) Polarity:</strong></td>
<td><strong>(iii) Polarity:</strong></td>
</tr>
<tr>
<td>Explanation:</td>
<td>Explanation:</td>
</tr>
</tbody>
</table>
(c) The chemistry of the airbag was found to involve three reactions. The first reaction involves the decomposition of sodium azide to form sodium and nitrogen. In the second reaction, potassium nitrate reacts with sodium.

\[ 2\text{KNO}_3(s) + 10\text{Na}(s) \rightarrow \text{K}_2\text{O}(s) + 5\text{Na}_2\text{O}(s) + \text{N}_2(g) \]

(i) Suggest why it is necessary for sodium to be removed by this reaction.

(ii) The metal oxides from the second reaction then react with silicon dioxide to form a silicate in the third reaction.

\[ \text{K}_2\text{O}(s) + \text{Na}_2\text{O}(s) + \text{SiO}_2(s) \rightarrow \text{Na}_2\text{K}_2\text{SiO}_4(s) \]

Draw the structure of silicon dioxide and state the type of bonding present.

Structure:

Bonding: .................................................................
1. Airbags are an important safety feature in vehicles. Sodium azide, potassium nitrate and silicon dioxide have been used in one design of airbag.

![Airbags Image]

(Source: www.hilalairbag.net)

Sodium azide, a toxic compound, undergoes the following decomposition reaction under certain conditions.

$$2\text{NaN}_3(s) \rightarrow 2\text{Na}(s) + 3\text{N}_2(g)$$

Two students looked at data in a simulated computer-based experiment to determine the volume of nitrogen generated in an airbag.

(a) Sodium azide involves ionic bonding, and metallic bonding is present in sodium. Describe ionic and metallic bonding.

[2]
6. Carbon and silicon belong to the same group of the periodic table.

(a) Describe and compare three features of the structure and bonding in the three allotropes of carbon: diamond, graphite and C_{60} fullerene. [6]

(b) Both silicon and carbon form oxides.

(i) Describe the structure and bonding in SiO_{2}. [2]
(ii) Explain why silicon dioxide is a solid and carbon dioxide is a gas at room temperature.

(c) Describe the bonding within the carbon monoxide molecule.

(d) Describe the delocalization of π (pi) electrons and explain how this can account for the structure and stability of the carbonate ion, \( \text{CO}_3^{2-} \).
(c) Explain the meaning of the term *hybridization*. State the type of hybridization shown by the carbon atoms in carbon dioxide, diamond, graphite and the carbonate ion.

(f)(i) Explain the electrical conductivity of molten sodium oxide and liquid sulfur trioxide.
(ii) Samples of sodium oxide and solid sulfur trioxide are added to separate beakers of water. Deduce the equation for each reaction and predict the electrical conductivity of each of the solutions formed.

7. Hydrazine, N₂H₄, is a valuable rocket fuel.

(a) (i) Draw the Lewis (electron dot) structure for N₂H₄ showing all valence electrons. [1]

(ii) State and explain the H–N–H bond angle in hydrazine. [3]

(b) Hydrazine and ethene, C₂H₄, are hydrides of adjacent elements in the periodic table. The boiling point of hydrazine is much higher than that of ethene. Explain this difference in terms of the intermolecular forces in each compound. [2]

(d) The reaction between N₂H₄(aq) and HCl(aq) can be represented by the following equation.

\[ \text{N}_2\text{H}_4(\text{aq}) + 2\text{HCl}(\text{aq}) \rightarrow \text{N}_2\text{H}_6^{2+}(\text{aq}) + 2\text{Cl}^{-}(\text{aq}) \]

(i) Identify the type of reaction that occurs. [1]

(ii) Predict the value of the H–N–H bond angle in N₂H₆²⁺. [1]

(iii) Suggest the type of hybridization shown by the nitrogen atoms in N₂H₆²⁺. [1]
Chem 4 Q# 40/ IB Chem/2010/w/TZ0/Paper 2 Section A/Higher Level/Q3

(c) Describe the bonding in iron and explain the electrical conductivity and malleability of the metal.

Chem 4 Q# 41/ IB Chem/2010/w/TZ0/Paper 2 Section A/Higher Level/

2. (a) But-2-ene is a straight-chain alkene with formula C₄H₈. The molecule contains both σ and π bonds.

(i) Explain the formation of the π bond.

(ii) For each of the carbon atoms, C(1) and C(2), identify the type of hybridization shown.
Chem 4 Q# 42/ IB Chem/2010/s/TZ1/Paper 2 Section B/Higher Level/Q4

(ii) Describe the acid-base behaviour of AlCl₃, Na₂O and P₄O₁₀. Include suitable equations in your answer. [4]

Chem 4 Q# 43/ IB Chem/2010/s/TZ1/Paper 2 Section B/Higher Level/Q4

(h) (i) Compare the structure and bonding in AlCl₃ and Al₂O₃. [2]

(ii) Explain whether AlCl₃ and Al₂O₃ will conduct in the solid or molten state. [3]

Chem 4 Q# 44/ IB Chem/2009/w/TZ0/Paper 2 Section A/Higher Level/

2. SF₂, SF₄ and SF₆ have different shapes. Draw their Lewis structures and use the VSEPR theory to predict the name of the shape of each molecule. [6]

<table>
<thead>
<tr>
<th></th>
<th>SF₂</th>
<th>SF₄</th>
<th>SF₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lewis structure</td>
<td></td>
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<td></td>
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<tr>
<td>Name of shape</td>
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</table>

Chem 4 Q# 45/ IB Chem/2009/s/TZ1/Paper 2 Section B/Higher Level/

6. (a) Draw the Lewis structures, state the shape and predict the bond angles for the following species.

(i) PCl₃ [3]

(ii) NH₂⁻ [3]

(iii) XeF₄ [3]
(c) (i) Compare the formation of a sigma (σ) and a pi (π) bond between two carbon atoms in a molecule. [2]

(ii) Identify how many sigma and pi bonds are present in propene, C₃H₆. [2]

(iii) Deduce all the bond angles present in propene. [2]

(iv) Explain how the concept of hybridization can be used to explain the bonding in the triple bond present in propyne. [3]

Chem 4 1 Q# 46/ IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/

5. Sodium oxide, Na₂O, is a white solid with a high melting point.

(a) Explain why solid sodium oxide is a non-conductor of electricity. [1]

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Chem 4 8 Q# 47/ IB Chem/2008/s/TZ1/Paper 2 Section B/Higher Level/Q6

(b) Draw the Lewis structures of the following molecules. Use the VSEPR theory to predict the shape of each molecule.

(i) XeF₄ and XeO₄ [4]

(ii) PF₅ and IF₃ [4]
### Topic 4 Mark Scheme

**Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. h</td>
<td>3-Dig&lt;br&gt;latt. regularly repeating arrangement of ions&lt;br&gt;OR&lt;br&gt;electrostatic attraction between oppositely charged ions&lt;br&gt;OR&lt;br&gt;electrostatic attraction between Mg&lt;sup&gt;2+&lt;/sup&gt; and O&lt;sup&gt;2-&lt;/sup&gt; ions ✓</td>
<td>Accept &quot;giant&quot; for H&lt;sub&gt;2&lt;/sub&gt;O unless &quot;giant covalent&quot; stated.&lt;br&gt;Do not accept &quot;ionic&quot; without description.</td>
<td>2</td>
</tr>
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</table>

**Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. d</td>
<td><img src="image1.png" alt="Image" /> OR <img src="image2.png" alt="Image" /></td>
<td>Accept single negative charges on two O atoms singly bonded to C.&lt;br&gt;Do not accept resonance structures.&lt;br&gt;Allow any combination of dots/crosses or lines to represent electron pairs.</td>
<td>1</td>
</tr>
<tr>
<td>2. e</td>
<td>Electrons delocalized across the O–C–O system&lt;br&gt;OR&lt;br&gt;resonance occurs ✓</td>
<td>Accept delocalized π-bond(s).&lt;br&gt;No ECF from (d).&lt;br&gt;Accept any answer in range 123 eV to 142 eV.&lt;br&gt;Accept &quot;bond intermediate between single and double bond&quot; or &quot;bond order 1.5&quot;.</td>
<td>2</td>
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</tbody>
</table>

**Q# 3/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. b i</td>
<td><img src="image3.png" alt="Image" /></td>
<td>Award [1] for two or three correct answers.&lt;br&gt;Award [2] for all four correct.</td>
<td>2</td>
</tr>
<tr>
<td>5. b ii</td>
<td></td>
<td>Number of sigma ((\sigma)) bonds</td>
<td>Number of pi ((\pi)) bonds</td>
</tr>
<tr>
<td></td>
<td>Propane</td>
<td>10</td>
<td>0</td>
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<tr>
<td></td>
<td>Propane</td>
<td>8</td>
<td>1</td>
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</table>

**Q# 4/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/**

<table>
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<th>Question</th>
<th>Answers</th>
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<tbody>
<tr>
<td>1. d</td>
<td>Ethene-1,2-diol can hydrogen bond to other molecules&lt;br&gt;OR&lt;br&gt;Ethene-1,2-diol has &quot;significantly&quot; greater van der Waals forces ✓</td>
<td>Accept converse arguments.&lt;br&gt;Award [2] if answer implies covalent bonds are broken.</td>
<td>2</td>
</tr>
</tbody>
</table>
### Q# 5/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. a i</td>
<td><img src="image" alt="Lewis structure of Ozone and Sulfur hexafluoride" /></td>
<td>Lines, x’s or dots may be used to represent electron pairs. Charges may be included in Lewis structures of ozone but are not required.</td>
<td>2</td>
</tr>
<tr>
<td>a ii</td>
<td></td>
<td>Electron domain geometry Molecular geometry</td>
<td>Award [1 max] for either both electron domain geometries correct OR for either both molecular geometries correct.</td>
</tr>
<tr>
<td>a iii</td>
<td>Sulfur hexafluoride</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a iv</td>
<td>Ozone: Accept any angle greater than 115° but less than 120° and Sulfur hexafluoride: 90° (and 180°) ✓</td>
<td>Experimental value of bond angle in O₃ is 117°...</td>
<td>1</td>
</tr>
<tr>
<td>6. a v</td>
<td><img src="image" alt="Double-headed arrow representation" /></td>
<td>Double-headed arrow not necessary for mark. Lines, x’s or dots may be used to represent electron pairs.</td>
<td>1</td>
</tr>
<tr>
<td>b i</td>
<td><img src="image" alt="Lewis structure of A, B, and C" /></td>
<td></td>
<td>Award [2] for all nine FCs correct. [1] for six to eight FCs correct.</td>
</tr>
<tr>
<td>b ii</td>
<td>smallest FC difference for A or B, so either is preferred ✓ however B is preferred as oxygen is more electronegative than nitrogen, even though FC per se ignores electronegativity ✓</td>
<td>Reason required for MI. OWITE</td>
<td>2</td>
</tr>
<tr>
<td>6. d i</td>
<td>O₃ has a double bond ✓ O₃ has intermediate bonds: between double and single bonds OR O₃ has a bond order of 1½ ✓ bond in O₃ is stronger therefore I needs more energy ✓</td>
<td>Do not award mark for I on its own with no justification.</td>
<td>3</td>
</tr>
<tr>
<td>d ii</td>
<td>C–Cl bond breaks since weakest bond ✓</td>
<td>Allow representation of radicals without • as long as consistent throughout.</td>
<td>5</td>
</tr>
</tbody>
</table>

[Image of a page from a chemistry textbook with chemical structures and text discussing Lewis structures, molecular geometries, and bond angles.]

### Q# 6/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. c i</td>
<td>ALTERNATIVE 1: α-bond from N to N AND from N to O ✓</td>
<td>Award [1 max] if candidate has identified both/either structure having 2 α-bonds and 2 π-bonds.</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>π-bond from N to N ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>delocalized π-bond/π-electrons extending over the oxygen and both nitrogens ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ALTERNATIVE 2: both have 2 α-bonds from N to N and from N to O AND π-bond from N to N ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>one structure has second π-bond from N to N and the other has π-bond from N to O ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>delocalized π-bond/π-electrons ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. c ii</td>
<td>more than one possible position for a multiple μ-pi-bond ✓</td>
<td>Accept &quot;more than one possible Lewis structure&quot;. Accept reference to delocalisation if M3 not awarded in c (i). Accept reference to fractional bond orders.</td>
<td>1</td>
</tr>
</tbody>
</table>

### Q# 7/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. a i</td>
<td>H P H</td>
<td>Accept structures using dots and/or crosses to indicate bonds and/or lone pair.</td>
<td>1</td>
</tr>
<tr>
<td>1. a ii</td>
<td>sp² ✓</td>
<td>Do not allow ECF from a (i).</td>
<td>1</td>
</tr>
<tr>
<td>1. a iii</td>
<td>Lewis base AND has a lone pair of electrons AND donor ✓</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1. a iv</td>
<td>non-polar AND P and H have the same electronegativity ✓</td>
<td>Accept &quot;similar electronegativities&quot;. Accept &quot;polar&quot; if there is a reference to a small difference in electronegativity and apply ECF in 1 a (v).</td>
<td>1</td>
</tr>
<tr>
<td>1. a v</td>
<td>PH₃ has London dispersion forces ✓</td>
<td>Accept van der Waals forces, dispersion forces and instantaneous dipole – induced dipole forces. Accept &quot;dipole-dipole forces&quot; as molecule is polar. H-bonds in NH₃ (only) must be mentioned to score [2]. Do not award M2 or M3 if: • implies covalent bond is the H-bond • implies covalent bonds break.</td>
<td>2 max</td>
</tr>
<tr>
<td></td>
<td>NH₃ forms H-bonds ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H-bonds are stronger OR London forces are weaker ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. a vi</td>
<td>Weak: only partially dissociated/ionized in dilute aqueous solutions ✓</td>
<td>Accept reaction with water is reversible/an equilibrium. Accept &quot;water is partially dissociated by the weak bases&quot;.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Bransted–Lowry base: an acceptor of protons/H⁺/hydrogen ions ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. b i</td>
<td>P₄ is a molecule comprising 4P atoms AND 4P is four/separate P atoms OR P₄ represents 4P atoms bonded together AND 4P represents 4P separate/non-bonded P atoms ✓</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
(c)(i) | | \( \text{NF}_4^+ \) | \( \text{N}_2\text{H}_2 \) | \( \text{N}_2\text{H}_4 \) \\
---|---|---|---
Hybridization | \( \text{sp}^3 \); | \( \text{sp}^2 \); | \( \text{sp}^3 \);  

*Do not penalize if it is not superscript.*

(ii) *sigma bond:* overlapping of orbitals end to end/head on / overlapping of orbitals along internuclear axis;

*Accept “axial overlapping of orbitals.”*

*pi bond:* side-ways/parallel overlapping of \( \text{p} \) orbitals (above and below internuclear axis);

*Accept “overlapping of \( \text{p} \) orbitals above and below the internuclear axis.”*  

Accept suitable labelled diagrams.
(iii) See saw; Octahedral; [4]

Accept any combination of lines, dots or crosses to represent electron pairs.  
Penalize missing lone pairs on fluorine atoms once only.  
For SF₄, lone pair on S required for the mark.  
Do not allow ECF for a wrong Lewis structure.  
Accept saw horse/distorted tetrahedron instead of see-saw.

(d) (i) CH₃CH₂CH₂ < CH₃CHO < CH₃CH₂OH < CH₃COOH ,,;  
Award [2] for correct order.  
Award [1] for CH₃COOH > CH₃CH₂OH > CH₃CHO > CH₃CH₂CH₃ as compounds are not listed in order of increasing boiling point.  
Award [1] if one error in the order.  

(ii) CH₃CH₂CH₂ /London/ dispersion/ instantaneous induced dipole-induced dipole forces  
CH₃CHO dipole-dipole forces (and London/ dispersion forces)  
CH₃CH₂OH H-bonding (and dipole-dipole and London/ dispersion forces)  
CH₃COOH H-bonding (and dipole-dipole and London/ dispersion forces);  
Award [2] for all four correct.  
Award [1] for two or three correct.  

H-bonding strongest / London/ dispersion forces weakest / dipole-dipole stronger than London/ dispersion / dipole-dipole weaker than H-bonding;  
Accept van der Waals’ forces for London/ dispersion forces.

CH₃COOH forms more/stronger H-bonds than CH₃CH₂OH / CH₃COOH is more polar than CH₃CH₂OH;  
Accept CH₃COOH has more electrons/ molar mass than CH₃CH₂OH. [4]

(e) ionization and (bombardment) by high energy/fast moving electrons/electron gun  
to form positive ions;  
acceleration and passing through electric field/ potential difference/ oppositely charged plates;  
deflection and passing through magnetic field/ electromagnet;  
Award [1] for naming 3 processes (ionization, acceleration, deflection) in the correct order with incorrect details.

Q# 9/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/Q5  
(b) (Li → Cs) atomic ionic radius increases;  
force of attraction between metal ions and delocalized electrons decreases;  
Accept metallic bonding gets weaker.

(F → I) London/ dispersion/ instantaneous induced dipole-induced dipole forces increase;  
Accept vdW/van der Waals’ forces for London/ dispersion forces.  
with increasing number of electrons/molar mass/surface area/ size of electron cloud;  
Do not accept “with increasing size” or “with increasing mass” only. [3 max]
(c) (i)

Penalize lone pairs missing on Br and F once only.
Accept any combination of lines, dots or crosses to represent electron pairs.
(ii)

<table>
<thead>
<tr>
<th></th>
<th>PBr&lt;sub&gt;3&lt;/sub&gt;</th>
<th>SF&lt;sub&gt;4&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape:</td>
<td>trigonal pyramidal; Accept triangular pyramidal.</td>
<td>Shape: see-saw/K-shaped; Accept distorted tetrahedral.</td>
</tr>
</tbody>
</table>

No ECF for shape if Lewis structure is incorrect.

<table>
<thead>
<tr>
<th>Bond angle:</th>
<th>PBr&lt;sub&gt;3&lt;/sub&gt;</th>
<th>SF&lt;sub&gt;4&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any value 99° &lt; 109°; Literature value = 101°.</td>
<td>Bond angle: Any two for [1] of:</td>
<td></td>
</tr>
<tr>
<td>(F&lt;sub&gt;a&lt;/sub&gt;S−F&lt;sub&gt;a&lt;/sub&gt;S): Any value 200° &lt; 210°; Literature value = 103°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(F&lt;sub&gt;a&lt;/sub&gt;S−F&lt;sub&gt;a&lt;/sub&gt;S): Any value 175° &lt; 185°; Literature value = 180°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(F&lt;sub&gt;a&lt;/sub&gt;S−F&lt;sub&gt;a&lt;/sub&gt;S): Any value 85° &lt; 95°; Literature value = 89°</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

No ECF for angle if shape is incorrect. Do not award mark for correct angles if shape is incorrect.

(iii) P−Br and S−F bonds are polar / bonds in both molecules are polar; non-symmetrical distribution of electron cloud / polar bonds/dipoles do not cancel because of non-symmetrical shape; M<sub>2</sub> may also be scored with a suitable diagram showing the vectorial addition of the individual S−F dipole moments to show a net dipole moment centred along the axis between the F<sub>a</sub>S−F<sub>a</sub>S bond.

(d) (i) **EITHER**
(electrostatic) attraction between (positively charged) nuclei and a pair of electrons; formed as a result of electron sharing (between the carbon and hydrogen nuclei):

OR

sigma bond formed by overlap of atomic orbitals; s orbital from H and p/sp<sup>3</sup> from carbon;

(ii) \( \alpha: sp^3 \) and \( \beta: sp^2 \), Accept if numbers are given as subscripts.

(iii) \( \sigma \) bond:
end-on / axial overlap of two orbitals;

\( \pi \) bond:
sideways overlap of two (parallel) p orbitals;
Accept suitable diagrams for both marks.

(iv) 11 \( \sigma \) and 3 \( \pi \).
Q# 11/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q8

(b) (i) chromium(III) oxide;

Do not award the mark for chromium oxide. [1]

(ii) (electrostatic) attraction between positive and negative ions/oppositely charged ions/\(\text{Cr}^{3+}\) and \(\text{O}^{2-}\);

formed as a result of electron transfer from chromium atoms to oxygen atoms / OWTTE;

Ignore reference to number of electrons transferred or charges of ion for M2. [2]

(iii) ions are not free to move (when solid) / ions in rigid lattice / OWTTE; [1]

Q# 12/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q7

(f) Sigma bonds:

\[
\begin{align*}
\sigma & \quad / \\
\sigma & \quad / \\
\end{align*}
\]

result from head-on/end-on overlap of orbitals / OWTTE;

Accept axial overlap of orbitals.

Accept “symmetric orbital” with respect to same plane / OWTTE. [2]

Pi bonds:

\[
\begin{align*}
\pi & \quad / \\
\end{align*}
\]

result from sideways overlap of orbitals / OWTTE;

Accept “antisymmetric orbitals” with respect to (defining) plane (containing at least one atom) / OWTTE.

Q# 13/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q5

(g) Allotropes:

Any three allotropes for [1] from:

diamond

graphite

fullerene

graphene;

Allow (carbon) nanotubes for graphene.

Accept \(C_{60}/C_{70}/\text{buckminsterfullerene}/\text{bucky balls}\) for fullerene.

Structures:

Any three for [3] from:

Diamond:

tetrahedral arrangement of (carbon) atoms/each carbon bonded to four others / sp\(^3\) and 3D/covalent network structure;

Graphite:

each carbon bonded to three others (in a trigonal planar arrangement) / sp\(^2\) and 2D / layers of (carbon) atoms;

Fullerene:

each (carbon) atom bonded to three others (in a trigonal arrangement) / sp\(^2\) and joined in a ball/cage/sphere/connected hexagons and pentagons;

Accept “trigonal planar” for “each carbon atom bonded to three others” part in M4.

Graphene:

each carbon bonded to three others (in a trigonal arrangement) / sp\(^2\) and 2D structure; [4]
Q# 14/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/
(e)  
Cl has 7 valence electrons and is in group 7; 
Accept “group 17” as suggested by IUPAC.

Cl has 3 occupied (electron) shells/energy levels and so is in period 3;  

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Shape</th>
<th>Bond angle</th>
<th>Polarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCl₂</td>
<td>bent/angular/</td>
<td>&lt; 109.5° Accept 100° – 108°. Literature value is 103°.</td>
<td>polar</td>
</tr>
<tr>
<td></td>
<td>v-shaped</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCl₅</td>
<td>Octahedral</td>
<td>90° (180°)</td>
<td>polar</td>
</tr>
<tr>
<td></td>
<td>Accept square</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>bipyramidal.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Do not accept ECF for bond angles and polarities from incorrect shapes.
Award [3] for all six correct.
Award [2] for four or five correct.
Award [1] for two or three correct.

Q# 15/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/Q2
(b)
(i)  
Na₂O ionic and P₄O₁₀ covalent (within molecule); 
Na₂O in giant/3D/network/lattice structure with strong (ionic) bonds and 
P₄O₁₀ has a (simple) molecular structure/weak intermolecular forces 
(between molecules); 
Award [4] for stating that bonds require more energy to break in Na₂O than 
in P₄O₁₀.

(ii)  

<table>
<thead>
<tr>
<th></th>
<th>Phosphorus(V) oxide</th>
<th>Sodium oxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid state</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Molen state</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

Award [2] for four correct.
Award [1] for two or three correct.

Q# 16/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/Q4
(c)  
electrostatic attraction; 
between (a lattice of) cations/positive ions and delocalized/sea of electrons; 
Award [2] for stating “metallic bonding”.

Q# 17/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/Q1
(c)  
hydrogen bonding;  

(d)  

Mark cannot be scored if lone pairs are missing on oxygens. 
Accept any combination of lines, dots or crosses to represent electron pairs.

(e)  
Acid: 
one double and one single bond / one shorter and one longer bond; 
Accept “double and two single”.

Conjugate base: 
two 1.5 bonds / both bonds same length; 
Accept “four / all”.

electrons delocalized / resonance forms; 
Award marks for suitable diagrams.
Q# 18/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q8

(c) (i) magnesium (atom) gives two electrons to oxygen (atom) / oxygen (atom) takes two electrons from magnesium (atom) / magnesium (atom) loses two electrons and oxygen (atom) gains two electrons;
3-dimensional/3-D arrangement of ions / lattice of ions;
(electrostatic) attraction between oppositely charged ions/Mg$^{2+}$ and O$^{2-}$; [2 max]

(ii) electrostatic attraction between a pair of electrons and (positively charged) nuclei;
Accept a/two pairs of shared electrons. [1]

(iii) difference in electronegativity is larger between Mg and O/smaller between C and O;
Accept reference to a numerical value of difference in electronegativity such as above and below 1.80. [1]

(d) (i) C: sp hybridization;
O: sp$^2$ hybridization;
Award [1] if the answer is sp without specifying C or O atoms. [2]

(ii) Energy

Before hybridization

\[
\begin{array}{ccc}
\downarrow & 1 & 1 \\
\downarrow & 2s & \text{2p}
\end{array}
\]

After hybridization

\[
\begin{array}{ccc}
\downarrow & 2p \\
\downarrow & 1 & 1 \\
\downarrow & \text{sp$^2$}
\end{array}
\]

three sp$^2$ orbitals and one p-orbital at higher energy;
sp$^2$ orbitals contain: two, two and one electron and p-orbital contains one electron;
Do not allow ECF from (d)(i). [2]

(iii) ability of atom/nucleus to attract bonding/shared pair of electrons / attraction of nucleus for bonding/shared pair of electrons / OWTE. [1]

(iv) (same number of shells but) increase in nuclear charge/atomic number/number of protons increases electronegativity / O has more protons than C;
Accept oxygen has a higher effective nuclear charge. [2]
decrease in radius along the period increases electronegativity / O has smaller radius than C;

Q# 19/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q10

(b) oxygen is non-polar;
needs to break strong hydrogen bonds/H–bonds between water molecules (to dissolve) / oxygen cannot form hydrogen bonds/H–bonds with water;
oxygen can only form (weak) van der Waals’/vdW/LDF/London dispersion forces with water; [2 max]
5. (a) van der Waals’/vdW/London/Dispersion (forces)/LDF / temporary/instantaneous/induced dipoles:  

(b) Two of the following pairs:

used as pencil (lead);
layers can flake off/slide off/break off/stick to paper / OWTTE;
M2 must contain concept of separation of layers, so do not award mark for phrases like "layers can slide over each other" on their own.

OR

used as carbon fibre / OWTTE;
bonding within layer is strong / layers are extensive / layers are strong;

OR

used as electrodes/conductor/in batteries;
has mobile/free/delocalized electrons (between layers) / electricity flows parallel to layers;

OR

used for thermal insulation;
vibrations are not easily passed between layers;[4 max]

Accept other valid uses of graphite along with a suitable explanation.

Q# 21/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/Q8

(f) (i) Lattice/layers/framework of cations/magnesium ions/Mg²⁺;
surrounded by delocalized electrons / in a sea/flux of delocalized electrons;[2]
Accept "mobile" instead of "delocalized".

(ii) Mg has more delocalized electrons (than Na);
Accept "Mg has more valence electrons than Na" / "Mg is Mg²⁺ but Na is only Na".[1]

(iii) layers of ions/atoms/particles cannot slide over each other so easily (as different sized ions/atoms/particles) / OWTTE;[1]
Q# 22/ IB Chem/2014/s/TZ2/Paper 2 Section A/Higher Level/

4. (a) 

Accept lines, dots or crosses to represent electron pairs.
Formal charges and arrow for dative bond not required.
If Lewis structure incorrect remember to take into account possible ECF on parts (b)–
(d) based on the number of electron domains and bond types in the Lewis diagram in
part (a) and do not award marks for these if they are inconsistent with the structure
given in (a).

(b) *Shape:* non-linear / bent / v-shaped / angular;

*Bond angle: 117°;*
Accept values from 115° to 119° / *just/slightly* less than 120° .

(c) *sp²*;

(d) one is just one σ and one has one σ and one π;
Accept "both bonds comprise one σ and a shared π " / *OWTTE.*

(e) delocalization occurs / delocalized π-bond / (has two) resonance structures / it is a
resonance hybrid;
length intermediate between H₂O₂ and O₂ / *OWTTE*;

Q# 23/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/

(c) (i) HF has hydrogen bonds (between molecules);

(ii) strength of van der Waals/London/Dispersion forces increases;
as mass/size/number of electrons of halogen atom/molecule increases;

Q# 24/ IB Chem/2014/s/TZ1/Paper 2 Section A/Higher Level/Q1

(d) (i) H₂SO₄(aq) + MgCO₃(s) → MgSO₄(aq) + CO₂(g) + H₂O(l);

Ignore state symbols.
Do not accept H₂CO₃.
(ii) \[
\begin{array}{c}
\begin{array}{c}
\text{O} \\
\text{O}
\end{array}
\end{array} \\
\begin{array}{c}
\text{O} \\
\text{C} \\
\text{O}
\end{array}
\] 2− / \[
\begin{array}{c}
\text{O} \\
\text{O}
\end{array} \\
\begin{array}{c}
\text{O} \\
\text{C} \\
\text{O}
\end{array}
\] 2− ;

Accept crosses, lines or dots as electron pairs.
Accept any correct resonance structure.
Award [0] if structure is drawn without brackets and charge.
Award [0] if lone pairs not shown on O atoms.

shape: trigonal/triangular planar;
bond angle: 120°;

Accept answers trigonal/triangular planar and 120° if M1 incorrect, but no other answers should be given credit. [3]

(iii) \((\pi/\pi)\) electrons are delocalized/spread over more than two nuclei / charge spread (equally) over all three oxygens; [1]

(iv) \(\text{sp}^2\); [1]

Q# 25/ IB Chem/2013/w/TZ0/Paper 2 Section A/Higher Level/
3. (a) (i) \(\text{Ca}^{2+}\) and \(\text{NO}_3^-\);

electrostatic (attraction);

Do not accept ionic. [2]

(ii) nitrogen/N and oxygen/O;

Do not accept nitrate/\(\text{NO}_3^-\).

Accept atoms in nitrate/\(\text{NO}_3^-\). [1]

(b) \(\pi/\pi\)-electrons shared by more than two atoms/nuclei / a \(\pi/\pi\)-bond/overlapping p-orbitals that extends over more than two atoms/nuclei;

all (N–O) bonds equal length/strength/bond-order / charge on all oxygen/O atoms equal / increases stability/lowers PE (of the ion);

Accept a diagram that clearly shows one or both points. [2]
Q# 26/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/Q4

(b) van der Waals’/London/displacement and dipole-dipole;  
   Allow abbreviations for van der Waals’ as vdW or for London/displacement as FDL.  

[1]

(c) (i) (CH₃)₂NH: 
   (intermolecular) attraction between hydrogen (atom) in O–H/N–H (polar) 
   bond and (lone pair on) electronegative N/O / hydrogen between two very 
   electronegative elements (nitrogen and oxygen) / OWTTE;  
   Accept hydrogen bonded to nitrogen which is electronegative/has 
   lone pair.  
   Do not allow ECF if M1 is incorrect.  

[2]

(ii) representative drawing showing hydrogen bond between (CH₃)₂NH and 
   H₂O:  

Do not penalize if lone pair as part of hydrogen bond is not shown.  
   Allow any representation of hydrogen bond (for example, dashed lines, dots 
   etc.) which differs from full stick representation of the other covalent bonds 
   in amine and water molecules.  
   Allow full line if labelled as hydrogen bond.  
   Lone pairs on oxygen not necessary.  
   Award mark if two hydrogen bonds drawn between the molecules from the 
   lone pair and the H on the N.

Q# 27/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/Q3

(b) dative (covalent) / coordinate;  
   Do not allow just covalent or co-dative.  

[1]
Q# 28/ IB Chem/2013/s/TZ1/Paper 2 Section B/Higher Level/Q6c

(c) (i) \(1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^3\). \[1\]

(ii) \[
\begin{array}{c}
\text{PCl}_3 \\
| \text{Cl} \text{---P---Cl|} \\
| \text{Cl} \\
\end{array} \\
\begin{array}{c}
\text{PCl}_3 \\
| \text{Cl} \text{---P---Cl|} \\
| \text{Cl} \\
\end{array}
\]

*Penalize missing lone pairs on chlorine only once.*
*Accept any combination of lines, dots or crosses to represent electron pairs.*

(iii)

\[
\begin{array}{|c|c|}
\hline
 & \text{PCl}_3 & \text{PCl}_5 \\
\hline
\text{Shape} & \text{trigonal/triangular pyramidal;} & \text{trigonal/triangular bipyramidal;} \\
\hline
\text{Bond angles} & \text{any angle between 99° and 108°; } & \text{90° and 120°; ignore 180°} \\
\hline
\end{array}
\]

*Shape and bond angle must be consistent with the number of electron domains given in the diagram in (ii).* \[4\]

(iv) \(\text{sp}^3\) (hybridization); \[1\]

(v) \(\text{PCl}_3\) has higher melting point than \(\text{PCl}_5\);
\(\text{PCl}_3\) has stronger intermolecular/London/dispersion/van der Waals’ forces;
(because of) more electrons/greater mass;
*Accept the opposite argument for \(\text{PCl}_3\).*
*Award [1 max] for answers suggesting \(\text{PCl}_3\) has higher melting point because it is polar and \(\text{PCl}_5\) is not.* \[3\]

(vi) \(\text{PCl}_3(\text{s}) + 4\text{H}_2\text{O(1)} \rightarrow \text{H}_3\text{PO}_4(\text{aq}) + 5\text{HCl(}\text{aq})\); \[1\]
*Ignore state symbols.*

(e) overlap of \(p\) orbitals / \(p\) electrons of double/\(\pi\) bond and non-bonding/lone pair on oxygen interact / \(\text{OWTTE}\);
\(\pi\) electrons not localized / different resonance structures possible / \[4\]

\[
\begin{array}{c}
\text{O} \text{---O} \\
\text{O} \text{---O} \\
\text{O} \text{---O} \\
\text{O} \text{---O} \\
\end{array}
\]
*both bonds/O−O and O=O have equal length / \(\text{OWTTE}\);*
*both bonds/O−O and O=O have equal bond energy / \(\text{OWTTE}\);*
(ii) \( \text{NH}_4^+ / \text{ammonium} / \text{N}_2\text{H}_5^+ / \text{hydrazinium} / \text{CH}_3\text{NH}_3^+ / \text{methylammonium/methanaminium} / \text{H}_2\text{NO}_3^+ / \text{nitrooxonium}; \) [1]

(iii) **Sigma bonds**:

\[ \text{\sigma} \quad \text{\sigma} \]

result from head-on/end-on overlap of orbitals / OWTTE;

*Allow symmetric (orbital) with respect to same plane / OWTTE.*

\[ \text{\pi} \quad \text{\pi} \]

result from sideways overlap of orbitals / OWTTE;

*Allow antisymmetric (orbitals) with respect to (defining) plane (containing at least one atom) / OWTTE.*

suitable diagrams showing \( \text{\sigma} \) and \( \text{\pi} \) bonds after formation: [3]

*Award [1 max] for correct diagram without description given or [2 max] for description given without diagram.*

(iv) \( \text{\sigma} \) bonds: 28;

\( \text{\pi} \) bonds: 4; [2]

(v) mixing/combining/merging of atomic orbitals to form new/molecular orbitals (for bonding):

A: \( \text{sp}^2 \);

B: \( \text{sp}^3 \);

*Award [1 max] for M2 and M3 for \( \text{sp}^2 \) and \( \text{sp}^3 \) if A and B are not identified explicitly but do not award M2 and M3 if \( \text{sp}^3 \) is given for A and \( \text{sp}^2 \) for B.* [3]

**Q# 30/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/Q2**

(b) (i) metals have delocalized electrons / sea of electrons which are mobile/can move / OWTTE;

layers/positive ions/cations/atoms slide past/over each other / OWTTE; [2]

*Do not accept nuclei for M2.*

**Q# 31/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/Q1**

(b) \( \text{Br}_2 \) has London/dispersion/van der Waals forces/vdW and ICl has (London/ dispersion/van der Waals’ forces/vdW and) dipole–dipole forces;

dipole–dipole forces are stronger than London/dispersion/van der Waals’/vdW forces;

*Allow induced dipole-induced dipole forces for London forces.

Allow interactions instead of forces.

Do not allow ICl polar and \( \text{Br}_2 \) non-polar for M1.

Name of IMF in both molecules is required for M1 and idea of dipole-dipole stronger than vdW is required for M2.* [2]
Q# 32/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/Q1

<table>
<thead>
<tr>
<th></th>
<th>ICl$_3$</th>
<th>ICl$_2^-$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lewis (electron dot) structure</td>
<td><img src="image" alt="Lewis structure of ICl$_3$" /></td>
<td><img src="image" alt="Lewis structure of ICl$_2^-$" /></td>
</tr>
<tr>
<td>Name of shape</td>
<td>T-shaped;</td>
<td>linear;</td>
</tr>
</tbody>
</table>

Do not penalize for an incorrect shape for Lewis structures. Accept lines, dots or crosses for electron pairs for both Lewis structures. Penalize missing lone pairs on Cl once only. Square brackets and negative charge must be shown for Lewis structure of [ICl$_2^-$.]

No ECF for shape if Lewis structure is incorrect.

Q# 33/ IB Chem/2012/s/TZ1/Paper 2 Section B/Higher Level/Q5d

(ii) **Aqueous solution:**

mobile ions/charged particles present;

**Liquid:**

molecular covalent / no (mobile) charged particles/ions;
Q# 34/ IB Chem/2012/s/TZ1/Paper 2 Section B/Higher Level/

5. (a) (i)

```
H     H
H — Si — Si — H
     H
```

Accept any combination of lines, dots or crosses to represent electron pairs. [1]

(ii) 109° / 109.5° / 109° 28';
four/tetrahedrally arranged negative charge centres/electron domains/electron pairs (around central/silicon atom) / equal repulsion between bonding pairs (around central/silicon atom) / OWTTE; [2]

M2 is an independent marking point.
Reference must be made to negative or electron.
Do not accept tetrahedral molecule.

(iii) sp³; [1]

(iv) C–H;
larger difference in electronegativity (for C–H bond) / smaller difference in electronegativity (for Si–H bond) / ΔEN (CH) = 0.4 and ΔEN (SiH) = 0.3; [2]

(v) both (molecules) non-polar;
both (molecules) symmetrical / polar bond effects cancel out / OWTTE; [2]

(vi) stronger/larger/greater van der Waals'/London dispersion forces;
Do not accept stronger/larger/greater intermolecular forces.
more electrons / stronger instantaneous dipole;
Do not accept larger mass. [2]

(b)

(iii) **Structure:**

CO₂ molecular and SiO₂ three-dimensional/network/giant lattice/giant covalent/macromolecular/repeating tetrahedral units;
CO₂ linear and SiO₂ tetrahedral;

**Intramolecular Bonding:**

covalent bonds in CO₂ and SiO₂;
double bonds in CO₂ and single bonds in SiO₂; [3 max]

Accept diagrams showing bonding types (double and single) within the structures.
Q# 35/ IB Chem/2011/w/TZ0/Paper 2 Section B/Higher Level/Q6

(c) | \( \text{PBr}_3 \) | \( \text{SF}_6 \) |
---|---|---|
(i) **Lewis structure:**
\[
\begin{array}{c}
\cdot \text{Br} \\
\cdot \text{Br} \\
\cdot \text{Br} \\
\cdot \text{P} \\
\cdot \text{Br} \\
\end{array}
\]
\[
\begin{array}{c}
\cdot \\
\cdot \\
\cdot \\
\cdot \\
\cdot \\
\end{array}
\]

*Allow x’s, dots or lines to represent electrons.*
*Penalize missing lone pairs on terminal atoms once only for the two Lewis structures.*

(ii) **Shape:**
- trigonal/triangular pyramidal;

*Bond angle:* 
less than 109.5;
*Allow any angle less than 109.5 but greater than or equal to 100* (experimental value is 101).

(iii) **Polarity:**
- polar and

*Explanation:* 
net dipole (moment) / polar PBr bonds *and* molecule non-symmetrical / bond dipoles do not cancel / asymmetric distribution of electron cloud /  
\[
\begin{array}{c}
\cdot \text{Br} \\
\cdot \text{Br} \\
\cdot \text{Br} \\
\cdot \text{P} \\
\cdot \text{Br} \\
\end{array}
\]

*/OWTTE;*

Do not allow ECF in this question from incorrect Lewis structure.
*Allow [1 max] for stating that \( \text{PBr}_3 \) is polar and \( \text{SF}_6 \) is non-polar without giving a reason or if explanations are incorrect.
*Allow polar bonds do not cancel for \( \text{PBr}_3 \) and polar bonds cancel for \( \text{SF}_6 \).
*Do not allow asymmetric molecule as reason for \( \text{PBr}_3 \) or symmetric molecule for \( \text{SF}_6 \) as reason alone.*

Q# 36/ IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/Q1

(c) (i) **sodium could react violently with any moisture present / sodium is (potentially) explosive / sodium (is dangerous since it is flammable when it) forms hydrogen on contact with water / OWTTE;**

*Do not accept answers such as sodium is dangerous or sodium is too reactive.*
(ii) *Structure:*

drawing of giant structure showing tetrahedrally arranged silicon:

*Minimum information required for mark is Si and 4 O atoms, in a tetrahedral arrangement (not 90° bond angles) but with each of the 4 O atoms showing an extension bond.*

\[
\text{Si} \quad \text{O} \quad \text{O} \quad \text{Si} \quad \text{O} \\
\text{O} \quad \text{O}
\]

*Bonding:*

(giant/network/3D) covalent; \[2\]

Q# 37 IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/

1. (a) *Ionic:*

(electrostatic) attraction between oppositely charged ions/cations and anions/positive and negative ions;

*Do not accept answers such as compounds containing metal and non-metal are ionic.*

*Metallic:*

(electrostatic attraction between lattice of) positive ions/cations/nuclei and delocalized electrons / (bed of) positive ions/cations/nuclei in sea of electrons / OWTT; \[2\]
Q# 38/ IB Chem/2011/s/TZ1/Paper 2 Section B/Higher Level/
6. (a) Award [2 max] for three of the following features:

Bonding

Graphite and C₆₀ fullerene: covalent bonds and van der Waals'/London/dispersion forces;
Diamond: covalent bonds (and van der Waals'/London/dispersion forces);

Delocalized electrons

Graphite and C₆₀ fullerene: delocalized electrons;
Diamond: no delocalized electrons;

Structure

Diamond: network/giant structure / macromolecular / three-dimensional structure and Graphite: layered structure / two-dimensional structure / planar;
C₆₀ fullerene: consists of molecules / spheres made of atoms arranged in hexagons/pentagons;

Bond angles

Graphite: 120° and Diamond: 109°;
C₆₀ fullerene: bond angles between 109–120°;
Allow Graphite: sp² and Diamond: sp³.
Allow C₆₀ fullerene: sp² and sp³.

Number of atoms each carbon is bonded to

Graphite and C₆₀ fullerene: each C atom attached to 3 others;
Diamond: each C atom attached to 4 atoms / tetrahedral arrangement of C (atoms); [6 max]

(b) (i) network/giant structure / macromolecular;
each Si bonded covalently to 4 oxygen atoms and each O atom bonded covalently to 2 Si atoms / single covalent bonds; [2]
Award [1 max] for answers such as network-covalent, giant-covalent or macromolecular-covalent.
Both M1 and M2 can be scored by a suitable diagram.

(ii) Silicon dioxide: strong/covalent bonds in network/giant structure/macromolecule;
Carbon dioxide: weak/van der Waals'/dispersion/London forces between molecules; [2]

(c) triple (covalent) bond;
one electron pair donated by oxygen to carbon atom / dative (covalent)/coordinate (covalent) bond; [2]
Award [1 max] for representation of C=O.
Award [2] if CO shown with dative covalent bond.
(d) delocalization/spread of $\pi$ electrons over more than two nuclei; equal bond order/strength/length/spreading charge (equally) over all three oxygens; gives carbonate ion a greater stability/lower potential energy; \[ \text{M3 can be scored independently.} \]

Accept suitable labelled diagrams for M1 and M2 e.g.

\[
\begin{align*}
&\text{O} &\text{C} &\text{O}^- \\
&\text{O}^- &\text{C} &\text{O} \\
\end{align*}
\]

OR

\[
\left[ \begin{array}{c}
\text{O} \\
\text{C} \\
\text{O}
\end{array} \right]^{2-}
\]

Do not penalize missing brackets on resonance structure but 2$^-$ charge must be shown.
Allow $-2$ for charge on resonance structure.

(e) mixing/combining/merging of (atomic) orbitals to form new orbitals (for bonding);
Allow molecular or hybrid instead of new.
Do not allow answers such as changing shape/symmetries of atomic orbitals.

- Carbon dioxide: sp;
- Diamond: $sp^3$;
- Graphite: $sp^2$;
- Carbonate ion: $sp^3$;

(f) (i) Molten sodium oxide: conducts because of free moving/mobile ions in molten state;
Sulfur trioxide: doesn’t conduct because no free moving/mobile charged particles-it has neutral molecules;
Award [1 max] for stating molten sodium oxide conducts but sulfur trioxide doesn’t.
Do not award M2 for “just sulfur trioxide does not conduct because it is molecular.”

(ii) $\text{Na}_2\text{O}(s) + \text{H}_2\text{O}(l) \rightarrow 2\text{NaOH}(aq)$;
$\text{SO}_3(l) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_4(aq)$;
both solutions conduct;
Ignore state symbols.
Q# 39/ IB Chem/2010/w/TZ0/Paper 2 Section B/Higher Level/

7. (a) (i) \[ \begin{align*}
\text{H} & \\
\text{H} \cdot \text{N} \cdot & \cdot \text{N} \cdot \text{H} \\
\cdot & \cdot \cdot \cdot \text{H} \\
\end{align*} \]

Accept x’s, dots or lines for electron pairs \[ [1] \]

(ii) \( \text{H–N–H} < 109^\circ \) any angle between \( 104^\circ \) and \( 109^\circ \); due to four centres of electron/negative charge / four electron pairs (one of which is a lone e- pair) / four electron domains; extra repulsion due to lone electron pairs. \[ [3] \]

Don’t allow ECF for wrong Lewis structures.

(b) weaker van der Waals/London/dispersion/intermolecular forces in ethene; stronger (intermolecular) hydrogen bonding in hydrazine; 

If no comparison between strengths then \([I \text{ max}]. \] \[ [2] \]

(d) (i) acid-base/neutralization; \[ [1] \]

(ii) \( 109^\circ / 109.5^\circ \); \[ [1] \]

(iii) \( \text{sp}^3 \); \[ [1] \]

No ECF if bond angle incorrect in (ii).

Q# 40/ IB Chem/2010/w/TZ0/Paper 2 Section A/Higher Level/Q3

(c) metallic (bonding);

positive ions/cations and delocalized/sea of electrons; electrostatic attraction between the two;

Award \([2 \text{ max}] \) for description of bonding

Conductivity:
electrons delocalized/free to move;

Malleability:
atoms/ions/cations can move without breaking bonds / atoms/ions/cations can slide past each other. \[ [4] \]

Q# 41/ IB Chem/2010/w/TZ0/Paper 2 Section A/Higher Level/

2. (a) (i) bond formed by) sideways overlap;

(overlap) p orbitals;

Marks awarded either from sketch or from explanation. \[ [2] \]

(ii) \( \text{C(1) is sp}^3 \text{ and C(2) is sp}^2 \); \[ [1] \]
(h) (i) AlCl₃ covalent and Al₂O₃ ionic; 
AlCl₃ (simple) molecular and Al₂O₃ (giant ionic) lattice; 

OR
AlCl₃ is covalent and simple molecular/small molecules held together by dipole–dipole attractions; 
Al₂O₃ is ionic and Al³⁺ and O²⁻ ions are held together in a (giant) lattice; [2 max]

(ii) AlCl₃ is acidic and Na₂O is basic and P₄O₁₀ is acidic; 
AlCl₃ + 3H₂O → Al(OH)₃ + 3HCl / AlCl₃ + 6H₂O → [Al(H₂O)₆]³⁺ + 3Cl⁻ and 
[Al(H₂O)₆]³⁺ + [Al(H₂O)₂OH]³⁻ + H⁺; 
Accept suitable alternative hydrolysis expressions or reactions with a base.

Na₂O + H₂O → 2NaOH ;
P₄O₁₀ + 6H₂O → 4H₃PO₄ ; [4] 
Accept suitable reactions with an acid or base.

(iii) AlCl₃ does not conduct in the solid/molten state; 
Al₂O₃ conducts when molten (but not when solid); 
Al₂O₃ contains mobile ions when molten and AlCl₃ has neither mobile ions nor delocalized electrons / OWTTE; [3]

Reference to mobile ions or electrons must be made.

Q# 43/ IB Chem/2010/s/TZ1/Paper 2 Section B/Higher Level/Q4

(h) (i) AlCl₃ covalent and Al₂O₃ ionic; 
AlCl₃ (simple) molecular and Al₂O₃ (giant ionic) lattice; 

OR
AlCl₃ is covalent and simple molecular/small molecules held together by dipole–dipole attractions; 
Al₂O₃ is ionic and Al³⁺ and O²⁻ ions are held together in a (giant) lattice; [2 max]

(iii) AlCl₃ does not conduct in the solid/molten state; 
Al₂O₃ conducts when molten (but not when solid); 
Al₂O₃ contains mobile ions when molten and AlCl₃ has neither mobile ions nor delocalized electrons / OWTTE; [3]

Reference to mobile ions or electrons must be made.
2. | SF₂ | SF₄ | SF₆ |
---|---|---|---|
Lewis structure | ![Lewis structure of SF₂](image1) | ![Lewis structure of SF₄](image2) | ![Lewis structure of SF₆](image3) |
Name of shape | bent/angular/V shaped; 2 lone pairs on S required for the mark | Seesaw/distorted tetrahedral; 1 lone pair on S required for the mark | octahedral; Accept square bipyramidal |

Penalise missing lone pairs on fluorine atoms once in correct structures only. For Lewis structures candidates are not expected to draw exact shapes of molecules. Do not allow ECF for wrong Lewis structures. Accept dots or crosses instead of lines.

Q# 45/ IB Chem/2009/s/TZ1/Paper 2 Section B/Higher Level/

6. (a) (i)

![Structure](image4)

trigonal pyramid;
in the range of 100°–108°; [3]

(ii)

![Structure](image5)

Must include minus sign for the mark.
bent/V-shaped;
in the range of 100°–106°; [3]

(iii)

![Structure](image6)

square planar;
90°;
Penalize once only if electron pairs are missed off outer atoms. [3]
(c) (i) sigma bonds are formed by end on/axial overlap of orbitals with electron density between the two atoms/nuclei; pi bonds are formed by sideways overlap of parallel p orbitals with electron density above and below internuclear axis/\(\sigma\) bond; [2]
Accept suitably annotated diagrams

(ii) 8 sigma/\(\sigma\);
1 pi/\(\pi\); [2]

(iii) 109°/109.5°;
120°; [2]

(iv) sp hybridization;
1 sigma and 2 pi;
sigma bond formed by overlap between the two sp hybrid orbitals (on each of the two carbon atoms) / pi bonds formed by overlap between remaining p orbitals (on each of the two carbon atoms) / diagram showing 2 sp hybrid orbitals and 2 p orbitals; [3]

Q# 46/ IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/

5. (a) in the solid state ions are in fixed positions / there are no moveable ions / OWTTE; [1]

Do not accept answer that refers to atoms or molecules.
Q# 47/ IB Chem/2008/s/TZ1/Paper 2 Section B/Higher Level/Q6

(b) (i) \[ \begin{array}{c}
\text{square planar/coplanar:}
\end{array} \]

\[ \begin{array}{c}
\text{Tetrahedral/tetrahedron:}
\end{array} \]

Do not accept two double and two single bonds around \( \text{Xe} \).

(ii) \[ \begin{array}{c}
\text{trigonal bipyramidal:}
\end{array} \]

\[ \begin{array}{c}
\text{square pyramidal/square-based pyramidal:}
\end{array} \]

In part (i) and (ii), penalize missing lone pairs on fluorine and oxygen atoms once only.
Penalize missing or extra lone pairs on central atom every time.
Do not allow ECF for wrong Lewis structure.
Accept correct Lewis structures that does not display 3D shape.
Accept dots or crosses instead of lines.

Topic 5
Chem 5 9 Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

1. Ethane-1,2-diol, \( \text{HOCH}_2\text{CH}_2\text{OH} \), has a wide variety of uses including the removal of ice from aircraft and heat transfer in a solar cell.

(a) Ethane-1,2-diol can be formed according to the following reaction.

\[ 2\text{CO} \quad (\text{g}) + 3\text{H}_2 \quad (\text{g}) \quad \rightleftharpoons \quad \text{HOCH}_2\text{CH}_2\text{OH} \quad (\text{g}) \]
(iii) Calculate the enthalpy change, $\Delta H^\circ$, in kJ, for this reaction using section 11 of the data booklet. The bond enthalpy of the carbon–oxygen bond in CO (g) is $1077 \text{kJ mol}^{-1}$.
(b) (i) Calculate $\Delta H^\circ$, in kJ, for this similar reaction below using $\Delta H^\circ$ data from section 12 of the data booklet. $\Delta H^\circ$ of HOCH$_2$CH$_2$OH (l) is $-454.8$ kJ mol$^{-1}$.  

$$2\text{CO (g)} + 3\text{H}_2(g) \rightleftharpoons \text{HOCH}_2\text{CH}_2\text{OH} (l)$$

(ii) Deduce why the answers to (a)(iii) and (b)(i) differ.

(iii) $\Delta S^\circ$ for the reaction in (b)(i) is $-620.1$ JK$^{-1}$. Comment on the decrease in entropy.

(iv) Calculate the value of $\Delta G^\circ$, in kJ, for this reaction at 298 K using your answer to (b)(i). (If you did not obtain an answer to (b)(i), use $-244.0$ kJ, but this is not the correct value.)

(v) Comment on the statement that the reaction becomes less spontaneous as temperature is increased.
Ozone in the atmosphere can be formed from the combustion of methane.

(i) State the equation for this combustion reaction. [1]

(ii) Calculate the standard enthalpy change for the reaction, \( \Delta H^\circ \), in kJ mol\(^{-1}\), using the thermodynamic data in section 12 of the data booklet and the information given below. [1]

\[
\begin{array}{|c|}
\hline
\text{O}_3(g) \\
\hline
\Delta H^\circ_f = +142.3 \text{ kJ mol}^{-1} \\
\hline
\end{array}
\]

(iii) State why the standard enthalpy change of formation, \( \Delta H^\circ_f \), for oxygen is not given. [1]
(iv) Calculate the standard entropy change for the reaction, $\Delta S^\circ$, in $\text{JK}^{-1}\text{mol}^{-1}$, using the thermodynamic data in section 12 of the data booklet and the information given below. [1]

<table>
<thead>
<tr>
<th>O$_3$(g)</th>
<th>O$_3$(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S^\circ = +205.0 \text{JK}^{-1}\text{mol}^{-1}$</td>
<td>$S^\circ = +237.6 \text{JK}^{-1}\text{mol}^{-1}$</td>
</tr>
</tbody>
</table>

(v) Deduce the standard change in Gibbs Free Energy, $\Delta G^\circ$, in kJ mol$^{-1}$, for this reaction at 298 K. [1]

(vi) Deduce, giving a reason, whether the reaction is spontaneous or non-spontaneous at this temperature. [1]
2. One of the main constituents of acid deposition is sulfuric acid, H₂SO₄. This acid is formed from the sulfur dioxide pollutant, SO₂.

(b) Consider the following equilibrium between the two oxides of sulfur, sulfur dioxide and sulfur trioxide:

\[ 2\text{SO}_2 (g) + \text{O}_2 (g) \rightleftharpoons 2\text{SO}_3 (g) \quad \Delta H = -198 \text{kJ} \]

(c) Sketch the potential energy profile for the forward reaction in part (b) to show the effect of a catalyst on the activation energy, \( E_{\text{act}} \). [2]
5. Many automobile manufacturers are developing vehicles that use hydrogen as a fuel.

(a) Suggest why such vehicles are considered to cause less harm to the environment than those with internal combustion engines.

(b) Hydrogen can react with ethene to form ethane.

\[ \text{H}_2(\text{g}) + \text{C}_2\text{H}_4(\text{g}) \rightarrow \text{C}_2\text{H}_6(\text{g}) \]

Using average bond enthalpies at 298 K from section 11 of the data booklet, calculate the change in enthalpy, \( \Delta H \), in kJ mol\(^{-1} \), for this reaction.
Chem 5 Q# 5/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/Q3

(b) The enthalpy change for the reaction between nitrogen monoxide and hydrogen is $-664 \text{kJ}$ and its activation energy is $63 \text{kJ}$.

---

(i) Sketch the potential energy profile for the overall reaction, using the axes given, indicating both the enthalpy of reaction and activation energy. [2]

(ii) This reaction is normally carried out using a catalyst. Draw a dotted line labelled “Catalysed” on the diagram above to indicate the effect of the catalyst. [1]

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Chem 5 Q# 6/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula PH$_3$.

   (d) Impurities cause phosphine to ignite spontaneously in air to form an oxide of phosphorus and water.

   (i) 200.0 g of air was heated by the energy from the complete combustion of 1.00 mol phosphine. Calculate the temperature rise using section 1 of the data booklet and the data below. [1]

   Standard enthalpy of combustion of phosphine, $\Delta H_f^0 = -750 \text{kJ mol}^{-1}$

   Specific heat capacity of air $= 1.00 \text{J g}^{-1} \text{K}^{-1} - 1.00 \text{kJ kg}^{-1} \text{K}^{-1}$

---
4. Tin(II) chloride is a white solid that is commonly used as a reducing agent.

(a) (i) State why you would expect tin(II) chloride to have a similar lattice enthalpy to strontium chloride, using section 9 of the data booklet.

(ii) Calculate the molar enthalpy change when strontium chloride is dissolved in water, using sections 18 and 20 of the data booklet.

2. Phosgene, COCl₂, is usually produced by the reaction between carbon monoxide and chlorine according to the equation:

\[ \text{CO (g)} + \text{Cl}_2 (g) \rightleftharpoons \text{COCl}_2 (g) \]

(a) (iii) The standard enthalpy change of formation of phosgene, \( \Delta H_f^{\circ} \), is \(-220.1 \text{ kJ mol}^{-1}\). Determine the standard enthalpy change, \( \Delta H^{\circ} \), for the forward reaction of the equilibrium, in kJ, using section 12 of the data booklet.
Patrick Brannac

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6. Iron(III) oxide is the main source of iron but the decomposition of Fe₂O₃(s) into its elements is extremely difficult due to a large positive value of ΔG°.

(a) Consider the following reactions:

\[
\begin{align*}
\text{Fe}_2\text{O}_3(s) & \rightarrow 2\text{Fe}(s) + \frac{3}{2}\text{O}_2(g) \quad \Delta G^\circ = +742 \text{kJ mol}^{-1} \\
\text{CO}(g) + \frac{1}{2}\text{O}_2(g) & \rightarrow \text{CO}_2(g) \quad \Delta G^\circ = -257 \text{kJ mol}^{-1}
\end{align*}
\]

Suggest, with a reason, whether it is possible to produce iron by reacting Fe₂O₃ with CO. [2]

(b) The thermite reaction is one of the most exothermic reactions.

\[
\text{Fe}_2\text{O}_3(s) + 2\text{Al}(s) \rightarrow 2\text{Fe}(l) + \text{Al}_2\text{O}_3(s) \quad \Delta H^\circ = -825.2 \text{kJ}
\]

<table>
<thead>
<tr>
<th>Species</th>
<th>(S^\circ / \text{JK}^{-1}\text{mol}^{-1})</th>
<th>(\Delta G^\circ / \text{kJ mol}^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al(s)</td>
<td>+28.3</td>
<td>0</td>
</tr>
<tr>
<td>Al₂O₃(s)</td>
<td>+50.9</td>
<td>-1582</td>
</tr>
<tr>
<td>Fe(l)</td>
<td>+34.8</td>
<td>+10.0</td>
</tr>
<tr>
<td>Fe₂O₃(s)</td>
<td>+87.5</td>
<td>-742</td>
</tr>
</tbody>
</table>

(i) Calculate the standard free energy change, ΔG°, in kJ mol⁻¹, by using values of the standard free energy change of formation, ΔG°, from the table above. [2]
(ii) Calculate the standard entropy change, $\Delta S^\circ$, in J K$^{-1}$ mol$^{-1}$, by using values of standard entropy, $S^\circ$, from the table. [1]

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(iii) Calculate the standard free energy change, $\Delta G^\circ$, for the reaction using $\Delta H^\circ$ and $\Delta S^\circ$ values at 25°C. [2]

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Chem 5 Q# 10/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/Table 11

3. Propane, $C_3H_8(g)$, undergoes complete combustion to form carbon dioxide, $CO_2(g)$, and water, $H_2O(g)$.

(a) State an equation for the complete combustion of propane, $C_3H_8(g)$. [1]

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..............................................................................................................................

(b) Calculate the standard enthalpy change for the reaction in part (a) using bond enthalpy values given in table 10 of the data booklet. [3]

..............................................................................................................................
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..............................................................................................................................
..............................................................................................................................
3. Carbon monoxide reacts with hydrogen to produce methanol.

\[ \text{CO (g)} + 2\text{H}_2(\text{g}) \rightarrow \text{CH}_3\text{OH (l)} \]

<table>
<thead>
<tr>
<th>Substance</th>
<th>( \Delta H^\Theta / \text{kJ mol}^{-1} )</th>
<th>( \Delta G^\Theta / \text{kJ mol}^{-1} )</th>
<th>( S^\Theta / \text{J mol}^{-1} \text{K}^{-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO (g)</td>
<td>-110.5</td>
<td>-137.2</td>
<td>+197.6</td>
</tr>
<tr>
<td>( \text{CH}_3\text{OH} ) (l)</td>
<td>-239.0</td>
<td>-166.0</td>
<td>+126.8</td>
</tr>
</tbody>
</table>

(a) Calculate the standard enthalpy change, \( \Delta H^\Theta \), in kJ mol\(^{-1} \), for the reaction.

(b) Calculate the standard free energy change, \( \Delta G^\Theta \), in kJmol\(^{-1} \), for the reaction \((\Delta G^\Theta (\text{H}_2) = 0 \text{ kJ mol}^{-1})\).

(c) Using the values obtained in parts (a) and (b), calculate the standard entropy change, \( \Delta S^\Theta \), in J mol\(^{-1} \text{K}^{-1} \), for the reaction at 298K.

(d) Determine the absolute entropy, \( S^\Theta \), in J mol\(^{-1} \text{K}^{-1} \), for \( \text{H}_2(\text{g}) \) at 298K.
1. A student carried out an experiment to determine the concentration of a hydrochloric acid solution and the enthalpy change of the reaction between aqueous sodium hydroxide and this acid by thermometric titration.

She added 5.0 cm$^3$ portions of hydrochloric acid to 25.0 cm$^3$ of 1.00 moldm$^{-3}$ sodium hydroxide solution in a glass beaker until the total volume of acid added was 50.0 cm$^3$, measuring the temperature of the mixture each time. Her results are plotted in the graph below.

![Graph of temperature vs. volume of hydrochloric acid added]

The initial temperature of both solutions was the same.

(a) (i) By drawing appropriate lines, determine the volume of hydrochloric acid required to completely neutralize the 25.0 cm$^3$ of sodium hydroxide solution. [2]
(ii) Determine the concentration of the hydrochloric acid, including units. [2]

(b) (i) Determine the change in temperature, $\Delta T$. [1]

(ii) Calculate the enthalpy change, in kJ mol$^{-1}$, for the reaction of hydrochloric acid and sodium hydroxide solution. [3]

(iii) The accepted theoretical value from the literature of this enthalpy change is $-58$ kJ mol$^{-1}$. Calculate the percentage error correct to two significant figures. [1]

(iv) Suggest the major source of error in the experimental procedure and an improvement that could be made to reduce it. [2]
(g) Determine the standard enthalpy change of formation, $\Delta H^\circ_f$, of NaCl (s), in kJ mol$^{-1}$, using a Born-Haber cycle and tables 7, 10 and 13 of the data booklet. The standard enthalpy change of atomization (standard enthalpy change of sublimation), $\Delta H^\circ_{at}$, of Na (s) is +108 kJ mol$^{-1}$.

(b) (i) Define the term average bond enthalpy.

(ii) Ethanol can be used as a fuel. Determine the enthalpy of combustion of ethanol at 298 K, in kJ mol$^{-1}$, using the values in table 10 of the data booklet, assuming all reactants and products are gaseous.
(c) Students can also measure the enthalpy of combustion of ethanol in the laboratory using calorimetry. Suggest the major source of systematic error in these procedures.

(f) (i) The standard enthalpy change of combustion, \( \Delta H^\circ \), of propanoic acid is \(-1527\) kJ mol\(^{-1}\). Determine the standard enthalpy change of formation of propanoic acid, in kJ mol\(^{-1}\), using this information and data from table 12 of the data booklet.

(ii) Deduce, giving a reason, the sign of the standard entropy change of the system for the formation of propanoic acid from its elements.
(e) Hydrochloric acid neutralizes sodium hydroxide, forming sodium chloride and water.

\[ \text{NaOH (aq)} + \text{HCl (aq)} \rightarrow \text{NaCl (aq)} + \text{H}_2\text{O (l)} \quad \Delta H^\circ = -57.9 \text{ kJ mol}^{-1} \]

(i) Define standard enthalpy change of reaction, \( \Delta H^\circ \). \[ \text{.................................................................} \]

.................................................................

(ii) Determine the amount of energy released, in kJ, when 50.0 cm\(^3\) of 1.00 mol dm\(^{-3}\) sodium hydroxide solution reacts with 50.0 cm\(^3\) of 1.00 mol dm\(^{-3}\) hydrochloric acid solution. \[ \text{.................................................................} \]

.................................................................
(iii) In an experiment, 2.50 g of solid sodium hydroxide was dissolved in 50.0 cm$^3$ of water. The temperature rose by 13.3 °C. Calculate the standard enthalpy change, in kJ mol$^{-1}$, for dissolving one mole of solid sodium hydroxide in water.

$$\text{NaOH (s)} \rightarrow \text{NaOH (aq)}$$

[3]

(iv) Using relevant data from previous question parts, determine $\Delta H^\circ$, in kJ mol$^{-1}$, for the reaction of solid sodium hydroxide with hydrochloric acid.

$$\text{NaOH (s)} + \text{HCl (aq)} \rightarrow \text{NaCl (aq)} + \text{H}_2\text{O (l)}$$

[2]
The reaction between ethene and steam is used in the industrial production of ethanol.

\[ \text{C}_2\text{H}_4(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightarrow \text{C}_2\text{H}_5\text{OH}(\text{g}) \]

The enthalpy change of the reaction can be calculated either by using average bond enthalpies or by using standard enthalpies of formation.

(a) Determine the enthalpy change of the reaction, in kJ mol\(^{-1}\), using the average bond enthalpies in Table 10 of the Data Booklet.

(b) (i) Define the term standard enthalpy change of formation.
(ii) Determine the enthalpy change of the reaction, in kJ mol\(^{-1}\), between ethene and steam using the enthalpy change of formation values given below.

<table>
<thead>
<tr>
<th>Compound</th>
<th>(\Delta H_f^\circ/\text{kJ mol}^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>C(_2)H(_5)OH(g)</td>
<td>(-235)</td>
</tr>
<tr>
<td>C(_2)H(_4) (g)</td>
<td>(+52)</td>
</tr>
<tr>
<td>H(_2)O (g)</td>
<td>(-242)</td>
</tr>
</tbody>
</table>

(c) Comment on which of the values obtained in (a) and (b)(ii) is more accurate, giving a reason.

(d) Predict the sign of the entropy change of the reaction, \(\Delta S\), giving a reason.
(c) Although magnesium is usually found as Mg$^{2+}$ in its compounds, it is possible to use the Born–Haber cycle to investigate the possibility of Mg$^{+}$ being able to form stable compounds.

Use the ionization energy data from part (b), along with the other data provided below, to determine the enthalpy change of formation of MgCl$_2$(s). Assume that, because Mg$^{+}$ would be similar in size to Na$^+$, MgCl$_2$ would have a similar lattice enthalpy to NaCl.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enthalpy of atomization of Mg</td>
<td>+146 kJ mol$^{-1}$</td>
</tr>
<tr>
<td>Bond enthalpy in Cl$_2$</td>
<td>+243 kJ mol$^{-1}$</td>
</tr>
<tr>
<td>Electron affinity of Cl</td>
<td>−349 kJ mol$^{-1}$</td>
</tr>
<tr>
<td>Lattice enthalpy of NaCl</td>
<td>+790 kJ mol$^{-1}$</td>
</tr>
</tbody>
</table>

(d) Consider the lattice enthalpies of MgF$_2$, MgCl$_2$ and CaCl$_2$. List these from the most endothermic to the least endothermic and explain your order.

Most endothermic  →  Least endothermic
(e) Magnesium hydroxide, \( \text{Mg(OH)}_2 \), is only sparingly soluble in water and the equilibrium below exists when excess solid is in contact with a saturated solution.

\[
\text{Mg(OH)}_2(s) \rightleftharpoons \text{Mg}^{2+}(aq) + 2\text{OH}^-(aq)
\]

Outline how the solubility of magnesium hydroxide will vary with pH. \[2\]

4. Buta-1,3-diene can be hydrogenated to produce butane, according to the reaction below.

\[
\text{C}_4\text{H}_6(g) + 2\text{H}_2(g) \rightarrow \text{C}_4\text{H}_{10}(g)
\]

(b) Determine the standard enthalpy change of reaction, \( \Delta H^\circ \), in kJ mol\(^{-1}\), at 298 K for the hydrogenation reaction, using Table 11 of the Data Booklet. \[1\]

(c) Calculate the standard free energy change, \( \Delta G^\circ \), in kJ mol\(^{-1}\), at 298 K for the hydrogenation reaction, using Table 11 of the Data Booklet. \[1\]
(d) (i) Determine the standard entropy change of the reaction, $\Delta S^\circ$, at 298 K, in kJ K$^{-1}$ mol$^{-1}$, using your answers from (b) and (c). [2]

(ii) Explain why the standard entropy change for the hydrogenation of buta-1,3-diene has a negative sign. [1]

(iii) Predict whether the hydrogenation reaction becomes more or less spontaneous as the temperature increases. [1]

(iv) Determine the temperature, in K, at which the spontaneity changes. [2]
(v) Determine the standard entropy, $S^\circ$, for hydrogen in JK$^{-1}$mol$^{-1}$, using Table 11 of the Data Booklet and your answer for (d)(i).

Chem 5 Q# 19/ IB Chem/2014/s/TZ1/Paper 2 Section A/Higher Level/  
1. (a) Two chemistry students wished to determine the enthalpy of hydration of anhydrous magnesium sulfate. They measured the initial and the highest temperature reached when anhydrous magnesium sulfate, MgSO$_4$(s), was dissolved in water. They presented their results in the table below.

| mass of anhydrous magnesium sulfate / g | 3.01 |
| volume of water / cm$^3$ | 50.0 |
| initial temperature / °C | 17.0 |
| highest temperature / °C | 26.7 |

(i) Calculate the amount, in mol, of anhydrous magnesium sulfate.

(ii) Calculate the enthalpy change, $\Delta H_f$, for anhydrous magnesium sulfate dissolving in water, in kJmol$^{-1}$. State your answer to the correct number of significant figures.
(b) The students repeated the experiment using 6.16 g of solid hydrated magnesium sulfate, MgSO₄•7H₂O(s), and 50.0 cm³ of water. They found the enthalpy change, ΔH₂, to be +18 kJ mol⁻¹.

The enthalpy of hydration of solid anhydrous magnesium sulfate is difficult to determine experimentally, but can be determined using the diagram below.

MgSO₄•7H₂O(s) \xrightarrow{ΔH₂ \text{ water}} Mg^{2+}(aq) + SO₄²⁻(aq)

(ΔH) MgSO₄(s) + 7H₂O(l)

(i) Determine the enthalpy change, ΔH, in kJ mol⁻¹, for the hydration of solid anhydrous magnesium sulfate, MgSO₄.

(ii) The literature value for the enthalpy of hydration of anhydrous magnesium sulfate is −103 kJ mol⁻¹. Calculate the percentage difference between the literature value and the value determined from experimental results, giving your answer to one decimal place. (If you did not obtain an answer for the experimental value in (b)(i) then use the value of −100 kJ mol⁻¹, but this is not the correct value.)

(c) Another group of students experimentally determined an enthalpy of hydration of −95 kJ mol⁻¹. Outline two reasons which may explain the variation between the experimental and literature values.
8. To determine the enthalpy change of combustion of methanol, CH₃OH, 0.230 g of methanol was combusted in a spirit burner. The heat released increased the temperature of 50.0 cm³ of water from 24.5 °C to 45.8 °C.

(a) (i) **Calculate the enthalpy change of combustion of methanol.**

(ii) **Using the theoretical value in Table 12 of the Data Booklet, discuss the experimental result, including one improvement that could be made.**
(b) Methanol can be produced according to the following equation.

\[ \text{CO(g)} + 2\text{H}_2(\text{g}) \rightarrow \text{CH}_3\text{OH(l)} \]

(i) Calculate the standard enthalpy change of this reaction, using the values of enthalpy of combustion in Table 12 of the Data Booklet.

(ii) Calculate the standard entropy change for this reaction, \( \Delta S^\circ \), using Table 11 of the Data Booklet and given:

\[ S^\circ (\text{CO}) = 198 \text{ JK}^{-1} \text{ mol}^{-1} \text{ and } S^\circ (\text{H}_2) = 131 \text{ JK}^{-1} \text{ mol}^{-1}. \]

(iii) Calculate, stating units, the standard free energy change for this reaction, \( \Delta G^\circ \), at 298 K.
(iv) Predict, with a reason, the effect of an increase in temperature on the spontaneity of this reaction. [2]

(c) Methanol reacts with carbon monoxide to form ethanoic acid, CH₃COOH (l).

\[ \text{CH}_3\text{OH} (l) + \text{CO} (g) \rightarrow \text{CH}_3\text{COOH} (l) \]

(i) Predict the sign of the entropy change, \( \Delta S \), of the system and explain your answer. [2]

(ii) Define the term standard enthalpy change of formation, \( \Delta H^\circ_f \). [2]
(iii) The standard enthalpy change of formation of CO (g) is $-111 \text{ kJ mol}^{-1}$. Using Table 11 of the Data Booklet, determine the enthalpy change of the reaction, in kJ mol$^{-1}$. [1]

(iv) The standard entropy of CO (g) is $198 \text{ J K}^{-1} \text{ mol}^{-1}$. Using Table 11 of the Data Booklet, determine the standard entropy change of the reaction, in J K$^{-1}$ mol$^{-1}$. [1]

(v) Determine the standard free energy change for the reaction at 298 K, in kJ mol$^{-1}$, using your answers from (iii) and (iv) and state whether the reaction is spontaneous or not. [2]
5. The strength of a covalent bond is measured in terms of its bond enthalpy.

(a) Define the term *average bond enthalpy.*

(b) 1,3,5,7-tetranitro-1,3,5,7-tetrazocane, shown below, can be used as an explosive.

\[
\begin{align*}
\text{C}_4\text{H}_4\text{N}_8\text{O}_8 (s) & \rightarrow 4\text{N}_2 (g) + 4\text{CO} (g) + 4\text{H}_2\text{O} (g)  
\end{align*}
\]
(i) Calculate the enthalpy change when 10.0 g of the compound decomposes, using average bond enthalpy data from Table 10 of the Data Booklet and the following additional average bond enthalpy data at 298 K.

<table>
<thead>
<tr>
<th>Bond</th>
<th>ΔH / kJ mol⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>C=O</td>
<td>1072</td>
</tr>
<tr>
<td>N=O</td>
<td>201</td>
</tr>
<tr>
<td>N=O</td>
<td>607</td>
</tr>
</tbody>
</table>
Chem 5 7 Q# 23/ IB Chem/2012/s/TZ1/Paper 2 Section B/Higher Level/Table 12 and 10 from the DATA BOOKLET is needed

5. Ethane, C₂H₆, and disilane, Si₂H₆, are both hydrides of group 4 elements with similar structures but with different chemical properties.

(b) Disilane undergoes complete oxidation to form silicon dioxide and water.

\[ 2\text{Si}_2\text{H}_6(g) + 7\text{O}_2(g) \rightarrow 4\text{SiO}_2(s) + 6\text{H}_2\text{O}(l) \]

(i) The standard enthalpy of formation of the silicon compounds is given below.

<table>
<thead>
<tr>
<th>Compound</th>
<th>( \Delta H_f^\circ ) / kJ mol(^{-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si₂H₆(g)</td>
<td>+80</td>
</tr>
<tr>
<td>SiO₂(s)</td>
<td>−911</td>
</tr>
</tbody>
</table>

Calculate the standard enthalpy change, in kJ, for this reaction using these data together with Table 12 of the Data Booklet. \([3]\)

(ii) Calculate the standard enthalpy change, in kJ, for the corresponding combustion reaction of 2 moles of ethane, using Table 12 of the Data Booklet. \([1]\)
(c) Disilane reacts with hydrogen to produce silane, SiH₄.

\[ \text{Si}_2\text{H}_6(g) + \text{H}_2(g) \rightarrow 2\text{SiH}_4(g) \]

Use values from Table 10 of the Data Booklet to calculate the enthalpy change, \( \Delta H^\circ \), for this reaction. \[3\]
3. (a) Define the term *average bond enthalpy*. [2]

(b) Deduce the balanced chemical equation for the complete combustion of butan-1-ol. [1]

(c) Determine the standard enthalpy change, in kJ mol\(^{-1}\), for the complete combustion of butan-1-ol using the information from Table 10 of the Data Booklet. [3]
5. (a) Deduce and explain the sign of the entropy change for the following reaction.

\[
\text{CO} (g) + 2\text{H}_2 (g) \rightarrow \text{CH}_3\text{OH} (l)
\]

(b) Consider the reaction:

\[
\text{CuS} (s) + \text{H}_2 (g) \rightarrow \text{Cu} (s) + \text{H}_2\text{S} (g)
\]

Given:

\[
\begin{array}{c|c|c}
 & \text{H}_2\text{S} (g) & \text{CuS} (s) \\
\hline
\Delta G^\circ & -33.6 & -53.6 \\
\Delta H^\circ & -20.6 & -53.1 \\
\end{array}
\]

(i) Suggest why the \( \Delta H^\circ \) values for \( \text{H}_2 (g) \) and \( \text{Cu} (s) \) are not given in the table.

(ii) Determine the standard enthalpy change at 298 K for the reaction.
(iii) Determine the standard free energy change at 298 K for the reaction. Deduce whether or not the reaction is spontaneous at this temperature. 

(iv) Determine the standard entropy change at 298 K for the reaction.

(v) Estimate the temperature, in K, at which the standard change in free energy equals zero. You should assume that the values of the standard enthalpy and entropy changes are not affected by the change in temperature.
1. Methanol is made in large quantities as it is used in the production of polymers and in fuels. The enthalpy of combustion of methanol can be determined theoretically or experimentally.

\[
\text{CH}_3\text{OH}(l) + 1\frac{1}{2}\text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(g)
\]

<table>
<thead>
<tr>
<th></th>
<th>CH(_3)OH(l)</th>
<th>O(_2)(g)</th>
<th>CO(_2)(g)</th>
<th>H(_2)O(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard enthalpy of formation, (\Delta H^\circ_f) / kJ mol(^{-1})</td>
<td>-239</td>
<td>0</td>
<td>-394</td>
<td>-242</td>
</tr>
<tr>
<td>Entropy, (S^\circ) / J K(^{-1}) mol(^{-1})</td>
<td>240</td>
<td>205</td>
<td>214</td>
<td>189</td>
</tr>
</tbody>
</table>

(a) Using the information from the table above, determine the theoretical enthalpy of combustion of methanol. [2]
(b) The enthalpy of combustion of methanol can also be determined experimentally in a school laboratory. A burner containing methanol was weighed and used to heat water in a test tube as illustrated below.

![Diagram of experiment setup]

The following data were collected.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial mass of burner and methanol / g</td>
<td>80.557</td>
</tr>
<tr>
<td>Final mass of burner and methanol / g</td>
<td>80.034</td>
</tr>
<tr>
<td>Mass of water in test tube / g</td>
<td>20.000</td>
</tr>
<tr>
<td>Initial temperature of water / °C</td>
<td>21.5</td>
</tr>
<tr>
<td>Final temperature of water / °C</td>
<td>26.4</td>
</tr>
</tbody>
</table>

(i) Calculate the amount, in mol, of methanol burned.  

[2]
(ii) Calculate the heat absorbed, in kJ, by the water. [3]

(iii) Determine the enthalpy change, in kJ mol\(^{-1}\), for the combustion of methanol. [2]
(c) The Data Booklet value for the enthalpy of combustion of methanol is \(-726\) kJ mol\(^{-1}\).
Suggest why this value differs from the values calculated in parts (a) and (b).

(i) Part (a) [1]

..............................................................................................................
..............................................................................................................

(ii) Part (b) [1]

..............................................................................................................
..............................................................................................................

(d) Determine the \(\Delta S^\circ\) for the combustion of methanol. [2]

\[
\text{CH}_3\text{OH}(l) + 1\frac{1}{2}\text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(g)
\]

..............................................................................................................
..............................................................................................................
..............................................................................................................
(e) Using the enthalpy of combustion for methanol from Table 12 of the Data Booklet and the $\Delta S^\circ$ determined in part (d), calculate the standard free energy change for the combustion of methanol.

\[ \text{[3]} \]

(f) Explain whether changing the temperature will alter the spontaneity of the reaction.

\[ \text{[1]} \]
(c) The lattice enthalpy of magnesium chloride can be calculated from the Born-Haber cycle shown below.

\[ \text{Mg}^{2+}(g) + 2e^- + 2\text{Cl}^-(g) \]

\[ \text{Mg(g)} + 2\text{Cl(g)} \]

III = +738 + 1451 kJ

\[ \text{Mg(g)} + \text{Cl}_2(g) \]

II = +148 kJ

\[ \text{Mg(s)} + \text{Cl}_2(g) \]

V = -642 kJ

\[ \text{MgCl}_2(s) \]

\[ \Delta H_{\text{fus}}^\circ(\text{MgCl}_2) \]

(i) Identify the enthalpy changes labelled by I and V in the cycle. [2]

(ii) Use the ionization energies given in the cycle above and further data from the Data Booklet to calculate a value for the lattice enthalpy of magnesium chloride. [4]

(iv) The experimental lattice enthalpy of magnesium oxide is given in Table 13 of the Data Booklet. Explain why magnesium oxide has a higher lattice enthalpy than magnesium chloride. [2]
(c) The equation for the reaction between hydrazine and oxygen is given below.

\[ \text{N}_2\text{H}_4(\text{l}) + \text{O}_2(\text{g}) \rightarrow \text{N}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \]

(i) The enthalpy change of formation, \( \Delta H_f^\circ \), of liquid hydrazine is 50.6 kJ mol\(^{-1}\). Use this value, together with data from Table 12 of the Data Booklet, to calculate the enthalpy change for this reaction.

(ii) Use the bond enthalpy values from Table 10 of the Data Booklet to determine the enthalpy change for this reaction.

(iii) Identify the calculation that produces the most accurate value for the enthalpy change for the reaction given and explain your choice.

(iv) Calculate \( \Delta S^\circ \) for the reaction using the data below and comment on its magnitude.

<table>
<thead>
<tr>
<th>Substance</th>
<th>( S^\circ / \text{J K}^{-1} \text{ mol}^{-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{O}_2(\text{g}) )</td>
<td>205</td>
</tr>
<tr>
<td>( \text{N}_2(\text{g}) )</td>
<td>191</td>
</tr>
<tr>
<td>( \text{H}_2\text{O}(\text{l}) )</td>
<td>69.9</td>
</tr>
<tr>
<td>( \text{N}_2\text{H}_4(\text{l}) )</td>
<td>121</td>
</tr>
</tbody>
</table>

(v) Calculate \( \Delta G^\circ \) for the reaction at 298 K.

(vi) Predict, giving a reason, the spontaneity of the reaction above at both high and low temperatures.
(a) The heat produced by the reaction can be calculated from the temperature change, $\Delta T$, using the expression below.

\[
\text{Heat change} = \text{Volume of CuSO}_4(\text{aq}) \times \text{Specific heat capacity of H}_2\text{O} \times \Delta T
\]

Describe two assumptions made in using this expression to calculate heat changes. \[2\]

(b) (i) Use the data presented by the data logging software to deduce the temperature change, $\Delta T$, which would have occurred if the reaction had taken place instantaneously with no heat loss. \[2\]

(ii) Calculate the heat, in kJ, produced during the reaction using the expression given in part (a). \[1\]

(c) The colour of the solution changed from blue to colourless. Deduce the amount, in moles, of zinc which reacted in the polystyrene cup. \[1\]

(d) Calculate the enthalpy change, in kJ mol$^{-1}$, for this reaction. \[1\]
5. (a) The production of ammonia is an important industrial process.

\[ \text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) \]

(i) Using the average bond enthalpy values in Table 10 of the Data Booklet, determine the standard enthalpy change for this reaction. \[3\] 

(ii) The standard entropy values, \( S \), at 298 K for \( \text{N}_2(g) \), \( \text{H}_2(g) \) and \( \text{NH}_3(g) \) are 193, 131 and 192 JK\(^{-1}\) mol\(^{-1}\) respectively. Calculate \( \Delta S^\circ \) for the reaction and with reference to the equation above, explain the sign of \( \Delta S^\circ \). \[4\] 

(iii) Calculate \( \Delta G^\circ \) for the reaction at 298 K. \[1\] 

(iv) Describe and explain the effect of increasing temperature on the spontaneity of the reaction. \[2\]
7. (a) The Born-Haber cycle for MgO under standard conditions is shown below.

```
\[ \text{Mg}^2+(g) + \text{O}^{2-}(g) \]
<table>
<thead>
<tr>
<th>D</th>
</tr>
</thead>
</table>
```

```
\[ \text{Mg}^2+(g) + \text{O}(g) \]
<table>
<thead>
<tr>
<th>C</th>
</tr>
</thead>
</table>
```

```
\[ \text{Mg}(g) + \text{O}(g) \]
<table>
<thead>
<tr>
<th>B</th>
</tr>
</thead>
</table>
```

```
\[ \text{Mg}(g) + \frac{1}{2}\text{O}_2(g) \]
<table>
<thead>
<tr>
<th>A</th>
</tr>
</thead>
</table>
```

```
\[ \text{Mg}(s) + \frac{1}{3}\text{O}_2(g) \]
<table>
<thead>
<tr>
<th>F</th>
</tr>
</thead>
</table>
```

Reactants

```
MgO(s) \]
<table>
<thead>
<tr>
<th>Product</th>
</tr>
</thead>
</table>
```

The values are shown in the table below.

<table>
<thead>
<tr>
<th>Process</th>
<th>Enthalpy change / kJ mol(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>+150</td>
</tr>
<tr>
<td>B</td>
<td>+248</td>
</tr>
<tr>
<td>C</td>
<td>+736 + (+1450)</td>
</tr>
<tr>
<td>D</td>
<td>-142 + (+844)</td>
</tr>
<tr>
<td>E</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>-602</td>
</tr>
</tbody>
</table>

(i) Identify the processes represented by A, B and D in the cycle.  

(ii) Define the enthalpy change, F.  

(iii) Determine the value of the enthalpy change, E.  

(iv) Define the enthalpy change C for the first value. Explain why the second value is significantly larger than the first.
(v) The inter-ionic distance between the ions in NaF is very similar to that between the ions in MgO. Suggest with a reason, which compound has the higher lattice enthalpy value.

(b) (i) The standard enthalpy change of three combustion reactions is given below in kJ.

\[
\begin{align*}
2C_2H_4(g) + 7O_2(g) & \rightarrow 4CO_2(g) + 6H_2O(l) \quad \Delta H^\circ = -3120 \\
2H_2(g) + O_2(g) & \rightarrow 2H_2O(l) \quad \Delta H^\circ = -572 \\
C_2H_4(g) + 3O_2(g) & \rightarrow 2CO_2(g) + 2H_2O(l) \quad \Delta H^\circ = -1411
\end{align*}
\]

Based on the above information, calculate the standard change in enthalpy, \(\Delta H^\circ\), for the following reaction.

\[
C_2H_6(g) \rightarrow C_2H_4(g) + H_2(g)
\]

(ii) Predict, stating a reason, whether the sign of \(\Delta S^\circ\) for the above reaction would be positive or negative.

(iii) Discuss why the above reaction is non-spontaneous at low temperature but becomes spontaneous at high temperatures.

(iv) Using bond enthalpy values, calculate \(\Delta H^\circ\) for the following reaction.

\[
C_2H_6(g) \rightarrow C_2H_4(g) + H_2(g)
\]

(v) Suggest with a reason, why the values obtained in parts (b) (i) and (b) (iv) are different.
(b) Consider the following Born-Haber cycle:

\[
\begin{align*}
K(s) & + \frac{1}{2}Br_2(l) \xrightarrow{\Delta H_f^{\circ}} KBr(s) \\
\text{a} = 90.0 & \quad \text{c} = 112 \\
K(g) & \quad Br(g) \\
\text{b} = 418 & \quad \text{d} = 342 \\
K^+(g) & + Br^-(g) \quad \text{e} = 670
\end{align*}
\]

The magnitudes for each of the enthalpy changes (a to e) are given in kJ mol\(^{-1}\) but their signs (+ or −) have been omitted.

(i) State the names for the enthalpy changes c and d. \([2]\)

(ii) Deduce which two of the enthalpy changes a to e have negative signs. \([1]\)

(iii) Determine the value for the enthalpy of formation of potassium bromide. \([2]\)

(iv) Explain why the quantitative value for the lattice enthalpy of calcium bromide is larger than the value for the lattice enthalpy of potassium bromide. \([2]\)
3. Two students were asked to use information from the Data Booklet to calculate a value for the enthalpy of hydrogenation of ethene to form ethane.

\[ \text{C}_2\text{H}_4(g) + \text{H}_2(g) \rightarrow \text{C}_2\text{H}_6(g) \]

John used the average bond enthalpies from Table 10. Marit used the values of enthalpies of combustion from Table 12.

(a) Calculate the value for the enthalpy of hydrogenation of ethene obtained using the average bond enthalpies given in Table 10. [2]

(b) Determine the value for the enthalpy of hydrogenation of ethene using the values for the enthalpies of combustion of ethene, hydrogen and ethane given in Table 12. [2]

(c) Suggest one reason why John’s answer is slightly less accurate than Marit’s answer and calculate the percentage difference. [2]
(d) John then decided to determine the enthalpy of hydrogenation of cyclohexene to produce cyclohexane.

\[ C_6H_{10}(l) + H_2(g) \rightarrow C_6H_{12}(l) \]

(i) Use the average bond enthalpies to deduce a value for the enthalpy of hydrogenation of cyclohexene. [1]

(ii) The percentage difference between these two methods (average bond enthalpies and enthalpies of combustion) is greater for cyclohexene than it was for ethene. John’s hypothesis was that it would be the same. Determine why the use of average bond enthalpies is less accurate for the cyclohexene equation shown above, than it was for ethene. Deduce what extra information is needed to provide a more accurate answer. [2]

5. (a) (i) Define the term **average bond enthalpy**. [2]

(ii) Explain why the H–H bond cannot be used as an example to illustrate average bond enthalpy. [1]

(b) The equation for the reaction between carbon dioxide and hydrogen is shown below.

\[ CO_2(g) + 4H_2(g) \rightarrow CH_4(g) + 2H_2O(g) \]

(i) Use information from Table 10 in the Data Booklet to calculate the enthalpy change for this reaction. [3]

(ii) The following table shows the standard entropy values of the substances in the reaction above.

<table>
<thead>
<tr>
<th>Substance</th>
<th>( CO_2(g) )</th>
<th>( H_2(g) )</th>
<th>( CH_4(g) )</th>
<th>( H_2O(g) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S^0 / JK^{-1}mol^{-1} )</td>
<td>214</td>
<td>131</td>
<td>186</td>
<td>189</td>
</tr>
</tbody>
</table>

Calculate the standard entropy change for this reaction. [3]
(iii) Explain how the sign of $\Delta S^\circ$ can be predicted from the equation for the reaction. \[2\]

(iv) Use your answers to parts (b) (i) and (b) (ii) to calculate the standard free energy change for the reaction, and so determine whether the above reaction is spontaneous at 298 K. (If you have not obtained answers to parts (b) (i) and (b) (ii), assume the following: $\Delta H^\circ = -120 \text{ kJ mol}^{-1}$ and $\Delta S^\circ = -80 \text{ J K}^{-1} \text{ mol}^{-1}$, although these are not the correct values.) \[3\]

(c) The standard enthalpy changes for the following reactions can be found in Table 13 of the Data Booklet.

\[
\begin{align*}
C(s) + O_2(g) &\rightarrow CO_2(g) \\
H_2(g) + \frac{1}{2}O_2(g) &\rightarrow H_2O(l) \\
C_8H_{18}(l) + 12 \frac{1}{2}O_2(g) &\rightarrow 8CO_2(g) + 9H_2O(l)
\end{align*}
\]

Use this information to determine the standard enthalpy change for the formation of octane from its elements.

\[8C(s) + 9H_2(g) \rightarrow C_8H_{18}(l)\] \[4\]

(d) A Born-Haber cycle can be used to calculate the lattice enthalpy of potassium fluoride, KF, from five known enthalpy changes. The equation for one of these enthalpy changes, the standard enthalpy change of formation, is shown below.

\[K(s) + \frac{1}{2}F_2(g) \rightarrow KF(s)\]

For each of the other four enthalpy changes, state the name of the enthalpy change and write an equation, including state symbols. \[4\]

(e) Lattice enthalpy values obtained from Born-Haber cycles are shown in Table 14 of the Data Booklet.

(i) Explain why sodium fluoride, NaF, has a greater lattice enthalpy value than potassium fluoride, KF. \[1\]

(ii) Explain why calcium fluoride, CaF$_2$, has a greater lattice enthalpy than potassium fluoride, KF. \[2\]
6. (a) The decomposition of solid barium carbonate is given by the following equation:

\[
\text{BaCO}_3(s) \rightleftharpoons \text{BaO}(s) + \text{CO}_2(g)
\]

<table>
<thead>
<tr>
<th>Compound</th>
<th>BaCO$_3$(s)</th>
<th>CO$_2$(g)</th>
<th>BaO(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta H_f^\circ$/kJ mol$^{-1}$</td>
<td>$-1219$</td>
<td>$-394$</td>
<td>$-558$</td>
</tr>
<tr>
<td>$S^\circ$/JK$^{-1}$mol$^{-1}$</td>
<td>$+112$</td>
<td>$+214$</td>
<td>$+70$</td>
</tr>
</tbody>
</table>

(i) Calculate the value of $\Delta G^\circ$ in kJ mol$^{-1}$ at 25°C. $[6]$  

(ii) State with a reason whether the reaction is spontaneous at 25°C. $[1]$  

(iii) Determine the minimum temperature above which this reaction is spontaneous. Explain your answer. $[4]$
**Topic 5 Mark Scheme**

**Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/**

1. a iii Bonds broken: \( 2\text{C}=\text{O} \rightarrow 2\text{H} + \text{H} \) / \( 2(1077 \text{ kJ mol}^{-1}) = 3(3436 \text{ kJ mol}^{-1}) / 3462 \text{kJ} \)
   
   Bonds formed: \( 2\text{H} + \text{C} + \text{O} \) / \( 2(358 \text{ kJ mol}^{-1}) + 2(144 \text{ kJ mol}^{-1}) + 346 \text{ kJ mol}^{-1} / 3644 \text{kJ} \)
   
   **Enthalpy change = bonds broken – bonds formed = 3462 kJ – 3644 kJ = –182 kJ**

   **Award [3] for correct final answer.**  
   **Award [2 max] for +182 kJ.**

1. b i \( \Delta H = \Sigma \Delta H_i \text{ products} – \Sigma \Delta H_i \text{ reactants} = -454.8 \text{ kJ mol}^{-1} – 2(-110.5 \text{ kJ mol}^{-1}) = -233.8 \text{ kJ} \)

   **Accept product is now a liquid.**

1. b ii in (a) gas is formed and in (b) liquid is formed
   
   OR products are in different states
   
   OR conversion of gas to liquid is exothermic
   
   OR conversion of liquid to gas is endothermic
   
   OR enthalpy of vapourisation needs to be taken into account

   **Accept answers referring to bond enthalpies being means/averages.**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
</table>
| 1. b iii | \( \Delta S = \left( \frac{-620.1}{1000} \right) \text{ kJ} \text{ K}^{-1} \text{ mol}^{-1} \) \( \checkmark \)  
   \( \Delta G = -233.8 \text{ kJ} - (298 \text{ K} \left( \frac{-620.1}{1000} \right) \text{ kJ} \text{ K}^{-1}) = -49.9 \text{ kJ} \) \( \checkmark \) | Accept fewer moles of gas but not fewer molecules. | 1 |
| 1. b iv | \( \Delta S = \left( \frac{-620.1}{1000} \right) \text{ kJ} \text{ K}^{-1} \text{ mol}^{-1} \) \( \checkmark \)  
   \( \Delta G = -233.8 \text{ kJ} - (298 \text{ K} \left( \frac{-620.1}{1000} \right) \text{ kJ} \text{ K}^{-1}) = -49.9 \text{ kJ} \) \( \checkmark \) | Award [2] for correct final answer.  
Award [1 max] for \( \approx 185 \times 10^4 \).  
If \(-244.0 \text{ kJ} \) used, answer is:
   
   \( \Delta G = -244.0 \text{ kJ} - (298 \text{ K} \left( \frac{-620.1}{1000} \right) \text{ kJ} \text{ K}^{-1}) = -59.2 \text{ kJ} \) \( \checkmark \) | 2 |
| 1. b v | Increasing \( T \) make \( \Delta G \) larger/more positive/less negative  
\(-T \Delta S \) will increase \( \checkmark \) | | 1 |

**Q# 2/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/**

<p>| c | i | ( \text{CH}_4(g) + \text{SO}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O(g)} + 2\text{O}_2(g) ) ( \checkmark ) | 1 |
| c | ii | ( \Delta H^\circ = [(+393.5) + (+241.9)] - [(+74.0)] = -660.8 \text{ kJ mol}^{-1} ) ( \checkmark ) | 1 |
| c | iii | Standard enthalpy change of formation ( \Delta H^\circ ) of an element (in most stable form) is always zero ( \checkmark ) | 1 |
| c | iv | ( \Delta S^\circ = [(+213.8) + (+248.8) + (+243.6)] - [(+186) + (+5) + (+205.0)] = -144.4 \text{ JK}^{-1} \text{ mol}^{-1} ) ( \checkmark ) | 1 |
| c | v | ( \Delta G^\circ = \left(\Delta H^\circ - T \Delta S^\circ\right) = -660.8 - (298 \left(\frac{-144.4}{1000}\right)) = -617.8 \text{ kJ mol}^{-1} ) ( \checkmark ) | 1 |
| c | vi | Spontaneous since negative ( \Delta G^\circ ) ( \checkmark ) | 1 |</p>
<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. d i</td>
<td>( \text{O}_2 ) has a double bond ✓ &lt;br&gt; ( \text{O}_2 ) has intermediate bonds between double and single bonds &lt;br&gt; <strong>OR</strong> &lt;br&gt; ( \text{O}_2 ) has a bond order of 1½ ✓ &lt;br&gt; bond in ( \text{O}_2 ) is stronger therefore I need more energy ✓</td>
<td>Do not award mark for ( \text{I} ) on its own with no justification.</td>
<td>3</td>
</tr>
<tr>
<td>d ii</td>
<td>C–Cl bond breaks since weakest bond ✓ &lt;br&gt; ( \text{CCl}_2\text{F}_2 \rightarrow \text{CCIF} + \text{Cl} \ ✓ &lt;br&gt; \text{Cl} + \text{O}_2 \rightarrow \text{ClO} + \text{O}_2 \ ✓ &lt;br&gt; \text{ClO} + \text{O} \rightarrow \text{O}_2 + \text{Cl} \ ✓ &lt;br&gt; \text{ClO} + \text{O}_2 \rightarrow \text{Cl}_2 + 2\text{O}_2 \ ✓</td>
<td>Allow representation of radicals without • as long as consistent throughout.</td>
<td>5</td>
</tr>
</tbody>
</table>

**Q# 3/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/Q2**

-Q# 4/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. a</td>
<td>Only water/H(_2)O produced &lt;br&gt; &lt;i&gt;(i.e. non-polluting)&lt;/i&gt; ✓</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>b</td>
<td>Bond breaking: &lt;br&gt; ( (1)(\text{H–H}) + (4)(\text{C–H}) + (1)(\text{C=C}) ) &lt;br&gt; <strong>OR</strong> &lt;br&gt; ( (1)(436) + (4)(14) - (1)(614) = 2706 \text{kJ mol}^{-1} ) ✓</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Bond formation: &lt;br&gt; ( (6)(\text{C–H}) + (3)(\text{C–C}) ) &lt;br&gt; <strong>OR</strong> &lt;br&gt; ( (6)(144) + (3)(346) = 2830 \text{kJ mol}^{-1} ) ✓</td>
<td>Award [2 max] for 124 \text{kJ mol}^{-1}. &lt;br&gt; Award [3] for correct final answer.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Q# 5/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. b i</td>
<td><img src="image" alt="Diagram" /></td>
<td>Activation energy $E_a = 63 \pm 14 \text{ } \text{kJ/mol}$&lt;br&gt;Enthalpy of reaction $\Delta H = -664 \text{ kJ/mol}$&lt;br&gt;Progress of reaction&lt;br&gt;Products lower than reactants AND enthalpy of reaction correctly marked and labelled with name or value ✓&lt;br&gt;Activation energy correctly marked and labelled with name or value ✓&lt;br&gt;</td>
<td>Accept other clear ways of indicating energy/enthalpy changes.</td>
</tr>
<tr>
<td>3. b ii</td>
<td><img src="image" alt="Diagram" /></td>
<td>Products lower than reactants AND enthalpy of reaction correctly marked and labelled with name or value ✓&lt;br&gt;Lower dotted curve, between same reactants and products levels, labelled &quot;Catalysed&quot; ✓&lt;br&gt;</td>
<td>Do not accept $-3750$.</td>
</tr>
</tbody>
</table>

### Q# 6/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. d i</td>
<td>temperature rise $\epsilon = \frac{750 \times 1.00}{0.2000 \times 1.00} = 3750 \text{ } \text{C/Ks}$ ✓&lt;br&gt;</td>
<td>Do not accept $-3750$.</td>
<td>1</td>
</tr>
</tbody>
</table>

### Q# 7/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. a i</td>
<td>same charge AND same/similar ionic radius ✓&lt;br&gt;</td>
<td>Award [2] for correct final answer.&lt;br&gt;Award [1 max] for $-31 \text{ kJ/mol}^\circ$.&lt;br&gt;Award [1 max] for $\pm 4371$.</td>
<td>2</td>
</tr>
</tbody>
</table>

### Q# 8/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
</table>
| 2. a iii | $\Delta H^\circ = -220.1 - (-110.5)^\circ$
$\Delta H^\circ = -109.6 \text{ kJ/mol}$ ✓<br>| Award [2] for correct final answer.<br>Award [1] for $-330.6$, or $+109.6 \text{ kJ/mol}$. | 2 |
| 2. a iv  | $\Delta G^\circ = -109.6 - (298 \times \Delta S^\circ) = -11.7 \text{ kJ/mol}$ ✓<br>$\Delta S^\circ = -\frac{(11.7 \times 109.6) \times 10^3}{298} = -407 \text{ } \text{J/K}^\circ$ ✓<br>| Award [2] for correct final answer.<br>Award [2] for $-470 \text{ } \text{kJ/K}^\circ$ (result from given values).<br>Do not penalize wrong value for T if already done in (a)(ii).<br>Award [1 max] for $-407 \text{ } \text{kJ/K}^\circ$.<br>Award [1 max] for $-138.9 \text{ } \text{kJ/K}^\circ$. | 2 |
Q# 9/ IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/

6. (a) possible to get iron and 3:1 ratio of the two equations;
The ratio may be shown in combining the equations/calculating overall
\( \Delta G \rightarrow -29 \text{ (kJ)} \);
possible to get iron and resultant \( \Delta G \) is negative/–29 (kJ);
“Possible to get iron” needs only to be stated once.
Do not accept “possible to get iron” without any reason.
Do not accept “it is not possible to get iron because \( \Delta G \) is positive”.

(b) (i) \( \Delta G^\circ = [-1582 + 2 \times 10] - [-742] \);
\( \Delta G^\circ = -820 \text{ (kJ mol}^{-1}) \);
Award [2] for the correct final answer.

(ii) \( (\Delta S^\circ = [50.9 + 2(34.8)] - [87.5 + 2(28.3)]) = -23.6 \text{ (JK}^{-1}\text{mol}^{-1}) \);
[1]

(iii) \( \Delta G^\circ = [-825.2 - (298 \times (-0.0236))] \);
\( \Delta G^\circ = -818 \text{ (kJ mol}^{-1}) / -8.18 \times 10^5 \text{ (J mol}^{-1}) \);
Award [2] for the correct final answer.
Award [0] if b(i) is repeated here.

Q# 10/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/

3. (a) \( \text{C}_2\text{H}_6(g) + 5\text{O}_2(g) \rightarrow 3\text{CO}_2(g) + 4\text{H}_2\text{O}(g) \);
Ignore state symbols.

(b) bonds broken: 2(C–C)/694 + 8(C–H)/3304 + 5(O=O)/2490 / 6488 (kJ);
bonds made: 6(C=O)/4476 + 8(O–H)/3712 / 8188 (kJ);
(6488 – 8188 =) -1700 (kJ mol}^{-1}) ;
Ignore signs in M1 and M2.
Award [3] for the correct final answer.
Award [2] for +1700 (kJ mol}^{-1}) ;
Accept values from 2016 data booklet to give 6494 (kJ) for M1, 8528 (kJ) for M2,
and –2034 (kJ) for M3.

Q# 11/ IB Chem/2015/s/TZ2/Paper 2 Section A/Higher Level/

3. (a) \( -239.0 - [-110.5] = -128.5 \text{ (kJmol}^{-1}) \);

(b) \( -166.0 - [-137.2] = -28.8 \text{ (kJmol}^{-1}) \);

(c) \( \left( \Delta G^\circ = -28.8 \text{ (kJmol}^{-1}) - \frac{298 \times \Delta S^\circ}{1000} \right) \)
\( \Delta S^\circ = -335 \text{ (J mol}^{-1}\text{K}^{-1}) \);
[1]

(d) \( \Delta S^\circ = \sum S^\circ_{\text{products}} - \sum S^\circ_{\text{reactants}} / -335 = 126.8 - 197.6 - 2S^\circ_{\text{H}_2} \);
\( S^\circ_{\text{H}_2} = (+)132 \text{ (J mol}^{-1}\text{K}^{-1}) \);
Award [2] for correct final answer.
Award [1 max] for \( S^\circ_{\text{H}_2} = (+)264 \text{ (J mol}^{-1}\text{K}^{-1}) \).
Q# 12/ IB Chem/2015/s/TZ2/Paper 2 Section A/Higher Level/

1. (a) (i)

![Graph showing temperature vs. volume of hydrochloric acid added.]

Drawing best-fit straight lines to show volume:
There should be approximately the same number of points above and below for both lines.

27.0 (cm³);
Accept any value in the range 26.0 to 28.0 (cm³) if consistent with student's annotation on the graph.
Accept ECF for volumes in the range 27.0–30.0 cm³ if it corresponds to maximum temperature of line drawn.
Volume should be given to one decimal place.

(ii) \[
[HCl] = \frac{1.00 \times 0.0250}{0.0270};
\]

= 0.926 mol dm⁻³;

Volume of 26.0 gives \([HCl] = 0.962 \text{ mol dm}^{-3}\). Volume of 28.0 gives \([HCl] = 0.893 \text{ mol dm}^{-3}\).
Award [2] for correct final answer with units.
Award [1 max] for correct concentration without units.
Accept \(M, \text{ mol L}^{-1}\), \text{mol/dm}³ as units.
(b) (i) \( (30.2 - 25.0 =) (+) 5.2 (^\circ \text{C}/\text{K}) \);
Any accepted value must be consistent with student’s annotation on the graph but do not accept \( \Delta T < 5.1 \).
Accept \((+5.6 (^\circ \text{C}/\text{K}) \) (ie, taking into account heat loss and using \( T \) when volume = 0.0 cm\(^3\)).

(ii) \[ Q = (m \times c \times \Delta T = (25.0 + 27.0) \times 4.18 \times 5.2 = 1130.272 \text{ J} =) 1.13 \text{ (kJ)}; \]
\[ n = (1.00 \times 0.0250 =) 0.0250 \text{ (mol)}; \]
\[ \Delta H = (-\frac{Q}{n} = -45210.88 \text{ Jmol}^{-1} =) -45 \text{ (kJmol}^{-1}) \];
Award [3] for correct final answer.
Award [2] for +45 (kJ mol\(^{-1}\)).
Apply ECF for M3 even if both \( m \) and \( \Delta T \) are incorrect in M1.
Accept use of \( c = 4.2 \text{ Jg}^{-1}\text{K}^{-1} \).

(iii) \[ \left( \frac{-45 - (-58)}{-58} \right) \times 100 = 22 \text{ (\%)} ; \]
Answer must be given to two significant figures.
Ignore sign.

(iv) heat losses;
better (thermal) insulation / using a polystyrene cup / putting a lid on the beaker;
Accept other suitable methods for better thermal insulation but do not accept just “use a calorimeter” without reference to insulation.
Q# 13/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q6

(g) atomization of chlorine \( = \frac{1}{2} \) bond enthalpy \( / \frac{1}{2} \) \( 243 / 121.5 \) (kJ mol\(^{-1}\));

correct values for ionization Na (+496 kJ mol\(^{-1}\)) and electron affinity Cl (−349 kJ mol\(^{-1}\))
and lattice enthalpy of NaCl (+790 kJ mol\(^{-1}\) / +769 kJ mol\(^{-1}\));
Born-Haber energy cycle;
Accept lines or arrows in energy cycle.

\[
\begin{align*}
\text{Na}(g) + e^- + \text{Cl}(g) \\
\text{Na}(g) + \text{Cl}(g) \\
\text{Na}^+(g) + \text{Cl}^{-}(g) \\
\text{Na}(g) + \frac{1}{2} \text{Cl}_2(g) \\
\text{Na}(s) + \frac{1}{2} \text{Cl}_2(g) \\
\text{NaCl}(s)
\end{align*}
\]

\( \Delta H^\circ (\text{NaCl}(s)) = -413.5 / -413 / -414 \) (kJ mol\(^{-1}\))
Accept −392.5 / −392 / −393 if +769 used for lattice enthalpy.
Award [4] for correct final answer.

Q# 14/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q5

(b) (i) energy needed to break (1 mol of) a bond in the gaseous state/phase;
(averaged over) similar compounds;
Do not accept “similar bonds” instead of “similar compounds”.
Concept of “similar” is important for M2.

(ii) \( \text{CH}_3\text{CH}_2\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O} \);
Bonds broken:
347 + (5 × 413) + 358 + 464 + (3 × 498) / 4728 (kJ) / 
C−C + 5C−H + C−O + O−H + 3O=O;
Bonds made:
(4 × 746) + (6 × 464) = 5768 (kJ) / 4C=O + 6O−H;
\( \Delta H = (4728 − 5768) = -1040 \) (kJ mol\(^{-1}\)) / bonds broken – bonds formed;
Award [4] for correct final answer.
Award [3] for (+)1040 (kJ mol\(^{-1}\)).

(c) heat loss (to the surroundings);
(f) (i) \[ 3\text{C}(s) + 3\text{H}_2(g) + \text{O}_2(g) \rightarrow \text{CH}_3\text{CH}_2\text{COOH(l)}; \]
\[ \Delta H_f^\circ = \sum \Delta H_f^\circ (\text{reactants}) - \sum \Delta H_f^\circ (\text{products}); \]
Accept any suitable energy cycle.
\[ \sum \Delta H_f^\circ (\text{reactants}) = 3 \times (-394) + 3 \times (-286) / -2040 \text{ (kJ mol}^{-1}\text{)}; \]
\[ (\Delta H_f^\circ = [3 \times (-394) + 3 \times (-286)] - (-1527) =) -513 \text{ (kJ mol}^{-1}\text{)}; \]

OR

\[ \text{CH}_3\text{CH}_2\text{COOH(l)} + 3.5\text{O}_2(g) \rightarrow 3\text{CO}_2(g) + 3\text{H}_2\text{O(g);} \]
\[ \Delta H_f^\circ = \sum \Delta H_f^\circ (\text{products}) - \sum \Delta H_f^\circ (\text{reactants}); \]
\[ \sum \Delta H_f^\circ (\text{products}) = 3 \times (-394) + 3 \times (-286) / -2040 \text{ (kJ mol}^{-1}\text{)}; \]
\[ (\Delta H_f^\circ = [3 \times (-394) + 3 \times (-286)] - (-1527) =) -513 \text{ (kJ mol}^{-1}\text{)}; \]

Ignore state symbols.
Award [4] for correct final answer.

(ii) negative;
reduction in the number of gaseous molecules;

**Q# 15/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q11**

(e) (i) heat transferred/absorbed/released/enthalpy/potential energy change when 1 mol/molar amounts of reactant(s) react (to form products) / OWTTE:
under standard conditions / at a pressure 100 kPa/101.3 kPa/1 atm and temperature 298 K/25 °C :

Award [2] for difference between standard enthalpies of products and standard enthalpies of reactants / \( H^\circ \) (products) – \( H^\circ \) (reactants).
Award [2] for difference between standard enthalpies of formation of products and standard enthalpies of formation of reactants / \( \Sigma \Delta H_f^\circ \) (products) – \( \Sigma \Delta H_f^\circ \) (reactants).

(ii) \[ 1.00 \times 0.0500 =) 0.0500 \text{ (mol)}; \]
\[ (0.0500 \times 57.9 =) 2.90 \text{ (kJ)}; \]
Ignore any negative sign.
Award [2] for correct final answer.
Award [1 max] for 2900 J.

(iii) \[ \frac{2.50}{40.00} =) 0.0625 \text{ (mol NaOH)}; \]
\[ 0.0500 \times 4.18 \times 13.3 = 2.78 \text{ (kJ)} / 50.0 \times 4.18 \times 13.3 = 2780 \text{ (J)}; \]
\[ \frac{2.78}{0.0625} =) -44.5 \text{ (kJ mol}^{-1}\text{)}; \]

Award [3] for correct final answer.
Negative sign is necessary for M3.
Award M2 and M3 if 52.5 g is used to obtain an enthalpy change of –46.7
\( \text{(kJ mol}^{-1}\text{)} \).
(iv) \(-44.5 - 57.9\) / correct Hess’s Law cycle (as below) / correct
manipulation of equations;
\[
\begin{align*}
\text{NaOH}(s) + \text{HCl}(aq) & \rightarrow \text{NaCl}(aq) + \text{H}_2\text{O}(l) \\
\end{align*}
\]
\[
\begin{align*}
-44.5 \text{ kJ} & \\
-57.9 \text{ kJ} \\
\end{align*}
\]
\[
\begin{align*}
\text{NaOH}(aq) + \text{HCl}(aq) & \\
\end{align*}
\]
\[-102.4 \text{ kJ} ;
\]
Award 2 for correct final answer.

(f) (i) zinc (only) forms the ion Zn\(^{2+}\) / has the oxidation state +2;
Allow forms only one ion / has only one oxidation state.
has full d-subshell/orbitals / does not have a partially filled d-subshell/orbitals
(necessary to exhibit transition metal properties);

(ii) Fe\(^{3+}\): 1s\(^2\) 2s\(^2\) 2p\(^6\) 3s\(^2\) 3p\(^6\) 3d\(^6\) /[Ar] 3d\(^6\) and Fe\(^{2+}\): 1s\(^2\) 2s\(^2\) 2p\(^6\) 3s\(^2\) 3p\(^6\) 3d\(^5\) /[Ar] 3d\(^5\);
half-full sub-level/3d\(^5\) has extra stability;
less repulsion between electrons / electrons singly occupy orbitals / electrons
do not have to pair with other electrons;
Accept converse points for Fe\(^{2+}\).

Q# 16/ IB Chem/2014/w/TZ0/Paper 2 Section A/Higher Level/
2. (a) (bonds broken) C=C and O–H / 612 + 464 / 1076 ;
(bonds formed) C–C and C–H and C–O / 347 + 413 + 358 / 1118 ;

OR
(bonds broken) C=C and two O–H and four C–H / 612 + 4(413) + 2(464) / 3192 ;
(bonds formed) C–C and five C–H and C–O and O–H / 347 + 5(413) + 358 + 464 / 3234 ;

Ignore signs (+ and –) in M1 and M2. These two marks are awarded for
recognizing the correct bonds.

enthalpy change = \(-42\) (kJ) ;
Correct sign is necessary for awarding M3.
Award 3 for the correct final answer.
Do not penalize candidates using the former Data Booklet bond energy values
(348, 412 and 463) (final answer will then be \(-45\) (kJ)).
(b) (i) heat/enthalpy change when 1 mol of a compound/substance is formed; from its elements in their standard states at 100 kPa/10^5 Pa; [2]

Allow 1.01×10^5 Pa/101 kPa/1 atm as an alternative to 100 kPa/10^5 Pa.
Allow under standard conditions or standard ambient temperature and pressure as an alternative to 100 kPa/10^5 Pa.
Allow “energy needed/absorbed” as an alternative to “heat/enthalpy change”.
Temperature is not required in definition, allow if quoted (e.g., 298 K/25 °C).

(ii) \(-235) - (52 - 242) / \Delta H = \Sigma \Delta H_f^{\circ} \text{(products)} - \Sigma \Delta H_f^{\circ} \text{(reactants)};
\quad -45 \text{(kJ)}; [2]

Award [2] for the correct final answer.
Award [1] for +45 or 45.

(c) value in (b)(ii) is more accurate) as values used in (a) are average values / value in (b)(ii) is more accurate) as exact bond enthalpy depends on the surroundings of the bond / OWTE; [1]

(d) negative and fewer number of moles/molecules (of gas); [1]

Q# 17/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/Q8

(c) \[\Delta H_a \text{ (Cl)} = \frac{1}{2} \times 243 \text{ (kJ mol}^{-1})\];
Correct calculation of atomization enthalpy of Cl.

\[\Delta H_f = +146 + \frac{1}{2}243 + 738 + (-349) + (-790);\]
Correct sign and magnitude of all terms.

\[= -134 \text{ (kJ mol}^{-1})\]; [3]
Award [3] for correct final answer.
Final mark involves correct computation of equation the student has produced.
Award [2] for -12 (bond enthalpy of Cl not halved) or +134 (signs wrong).
Award [1] for +12 (bond enthalpy of Cl not halved and signs wrong).

(d) MgF_2–MgCl_2–CaCl_2;
F^- smaller (ionic radius) than Cl^- / Cl^- larger (ionic radius) than F^-;
Mg^{2+} smaller (ionic radius) than Ca^{2+} / Ca^{2+} larger (ionic radius) than Mg^{2+}; [3]
Accept use of atomic radius rather than ionic radius.

(e) more soluble at low pH / less soluble at high pH:
higher pH / OH^- will shift the equilibrium to the left / lower pH / H^+ will (react with OH^- and) shift the equilibrium to the right; [2]
Q# 18/ IB Chem/2014/s/TZ1/Paper 2 Section A/Higher Level/Q4

(b) \[ \Delta H^\circ = (\Sigma \Delta H_f^\circ (\text{products}) - \Sigma \Delta H_f^\circ (\text{reactants}) = -127 - (110 + 0) = ) -237 \text{ (kJ mol}^{-1} \text{)} \] ; \[1\]

(c) \[ \Delta G^\circ = (\Sigma \Delta G_f^\circ (\text{products}) - \Sigma \Delta G_f^\circ (\text{reactants}) = -16 - (152 + 0) = ) -168 \text{ (kJ mol}^{-1} \text{)} \] ; \[1\]

(d) (i) \[ \Delta S^\circ = \left( \frac{\Delta H^\circ - \Delta G^\circ}{T} \right) = \frac{-237 - (-168)}{298} ; \]
\[= -0.232 \text{ (kJ K}^{-1} \text{ mol}^{-1} \text{)} ; \]

Award [2] for correct final answer.
Award [2] for "-232 J K}^{-1} \text{ mol}^{-1} (units must be given)."

(ii) 3 mol of gaseous reactants and 1 mol of gaseous products / fewer moles of gas in products; \[1\]

(iii) spontaneity decreases (as temperature increases because \(T \Delta S^\circ\) becomes a larger negative value/ \(\Delta G^\circ\) becomes positive at higher temperatures); \[1\]

(iv) \[ \Delta G^\circ = \Delta H^\circ - T \Delta S^\circ = 0 / -237 - T (-0.232) = 0 ; \]
\[T = 1020 \text{ (K)} ; \]

Remember to allow ECF from 4(d)(i). \[2\]

(v) \[ \Delta S^\circ = \Sigma S^\circ (\text{products}) - \Sigma S^\circ (\text{reactants}) / -232 = 310 - (279 + 2S^\circ (H_2)) ; \]
\[S^\circ (H_2) = \frac{1}{2}(310 - 279 + 232) = 132 \text{ J K}^{-1} \text{ mol}^{-1} ; \]

Award [2] for correct final answer.
Remember to allow ECF from 4(d)(i).
Q# 19/ IB Chem/2014/s/TZ1/Paper 2 Section A/Higher Level/

1. (a) (i) \[ n(\text{MgSO}_4) = \frac{2.41}{120.37} = 0.0250 \text{ (mol)}; \]  \[ \text{[1]} \]

(ii) \[ \text{energy released} = 50.0 \times 4.18 \times 9.7 = 2027 \text{ (J) / 2.027 (kJ)}; \]
\[ \Delta H_1 = -81 \text{ (kJ mol}^{-1}\text{)}; \]  \[ \text{[2]} \]
Award [2] for correct answer.
Award [2] if 53.01 is used giving an answer of \(-86 \text{ (kJ mol}^{-1}\text{)}.\)
Award [1 max] for \(+81/81/+86/86 \text{ (kJ mol}^{-1}\text{).}\)
Award [1 max] for \(-81000/-86000 \text{ if units are stated as J mol}^{-1}.\)
Allow answers to 3 significant figures.

(b) (i) \[ \Delta H = \Delta H_1 - \Delta H_2 = -99 \text{ (kJ mol}^{-1}\text{)}; \]  \[ \text{[1]} \]
Award [1] if \(-86 \text{ is used giving an answer of } -104 \text{ (kJ mol}^{-1}\text{).}\)

(ii) \[ \frac{(103-99)}{103} \times 100 = 3.9\%; \]  \[ \text{[1]} \]
Accept answer of 2.9\% if \(-100 \text{ used but only if a value for (b)(i) is not present.}\)
Award [1] if \(-104 \text{ is used giving an answer of 1.0}\%\).
Accept correct answers which are not to 1 decimal place.

(c) MgSO\text{4} \text{ not completely anhydrous / OWTTE},
MgSO\text{4} \text{ is impure;}
heat loss to the atmosphere/surroundings;
specific heat capacity of solution is taken as that of pure water;
experiment was done once only so it is not scientific;
density of solution is taken to be 1 g cm\text{3};
mass of 7H\text{2O} ignored in calculation;
uncertainty of thermometer is high so temperature change is unreliable;
literature values are carried out under standard conditions, but this experiment is not;
all solid not dissolved;  \[ \text{[2 max]} \]
Q# 20/ IB Chem/2013/s/TZ1/Paper 2 Section B/Higher Level/

8. (a) (i) \[ q = mc\Delta T = 0.0500 \times 4.18 \times 21.3 = 4.45 \text{ (kJ)}; \]
Do not accept \( m = 0.05023 \text{ kg}. \)

\[ (n \text{ methanol}) = \frac{0.230}{32.05} = 7.18 \times 10^{-3} \text{ (mol)}; \]
\[ \Delta H = \frac{4.45}{7.18 \times 10^{-3}}; \]
\[ \Delta H = -6.20 \times 10^2 \text{ kJ mol}^{-1}; \]
Accept integer values of molar mass.
Final answer must have negative sign and correct units.
Award [4] for correct final answer with correct units.

(ii) Less heat is liberated than theoretically\(-726 \text{ kJ mol}^{-1}\); probably due to heat loss/incomplete combustion; determine heat capacity of calorimeter and take heat absorbed by calorimeter into account / any suitable insulation method / measure temperature with time and extrapolation of graph to compensate heat loss / OWTTE; \[ 3 \]
If the value calculated in (a) (i) is more exothermic than theoretically, allow ECF for M1 and for improvement if consistent.

(b) (i) \[ \text{CH}_3\text{OH} + \frac{3}{2}\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \quad \Delta H^\circ_c = -726 \text{ (kJ mol}^{-1}\text{)} \]
\[ \text{CO} + \frac{1}{2}\text{O}_2 \rightarrow \text{CO}_2 \quad \Delta H^\circ_c = -283 \text{ (kJ mol}^{-1}\text{)} \]
\[ \text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O} \quad \Delta H^\circ_c = -286 \text{ (kJ mol}^{-1}\text{)} \]
Award [1 max] for three correct values.
Mark can be implicit in calculations.

\[ (\Delta H^\circ_r = 2(-286) + (-283) - (-726)); \]
\[ -129 \text{ (kJ mol}^{-1}\text{)}); \]
Award [3] for correct final answer.
Award [2 max] for +129 (kJ mol}^{-1}\text{).} \]

(ii) \[ \Delta S^\circ = 240 - 198 - 2 \times 131 = -220(\text{JK}^{-1}\text{ mol}^{-1}); \]
\[ 1 \]

(iii) \[ (-129 - 298(-0.220)) = -63.4 \text{ kJ mol}^{-1}; \]
Award [1] for correct numerical answer and [1] for correct unit if the conversion has been made from J to kJ for \( \Delta S^\circ \).

(iv) not spontaneous at high temperature;
\( T \Delta S^\circ < \Delta H^\circ \) and \( \Delta G^\circ \) positive; \[ 2 \]
Q# 21/ IB Chem/2012/w/TZ0/Paper 2 Section B/Higher Level/Q5

(c) (i) (entropy decreases) negative/- minus; gaseous reactant more disordered / product more ordered than reactants / amount of gas decreases / OWTTE; [2]
Allow number of moles of gas decreases.
M2 can only be scored if M1 is correct.

(ii) heat/enthalpy change when 1 mol of a compound is formed from its elements; in their standard states / at 100 kPa/10^5 Pa/1 bar (pressure); [2]
Allow 1.01×10^5 Pa / 101 kPa / 1 atm.
Allow under standard conditions or standard ambient temperature and pressure.
Temperatures not required in definition, allow if quoted (e.g. 298 K/25°C – most common) but correct pressure value must be stated if given.
Only award M2 for a correct M1 or a near miss at M1.

(iii) \( \Delta H^\circ = (-485 + 111 + 239 =) -135 \text{ (kJ mol}^{-1}\text{)}; \) [1]

(iv) \( \Delta S^\circ = (160-198-240) = -278 \text{ (J K}^{-1}\text{ mol}^{-1}\text{)}; \) [1]

(v) \( \Delta G^\circ = \left( \Delta H^\circ - T \Delta S^\circ = -135 + 298 \times \frac{278}{1000} \right) = -52.2 \text{ (kJ mol}^{-1}\text{)}; \)
spontaneous (since negative \( \Delta G^\circ \));
Answer to M2 depends on sign given in M1. [2]
5. (a) Energy needed to break (1 mol of) a bond in a gaseous molecule/state/phase; average calculated from a range of similar compounds / OWTE; 
Do not accept similar bonds instead of similar compounds. 
M2 can be scored independently.

(b) (i) Bonds breaking:
\[
4 \times (N=O) + 4 \times (N\equiv N) + 8 \times (C-H) + 4 \times (N-O) + 8 \times (C-N) / \\
= (4)(607) + (4)(158) + (8)(413) + (4)(201) + (8)(286) / \\
= 9456 (kJ \text{ mol}^{-1});
\]

Bonds forming:
\[
4 \times (N=N) + 4 \times (C=O) + 8 \times (O\equiv H) / \\
= (4)(945) + (4)(1072) + (8)(464) / =11780 (kJ \text{ mol}^{-1});
\]

Enthalpy change:
\[
(9456 - 11780 =) - 2324 (kJ \text{ mol}^{-1});
\]
M3 is scored from M1-M2. 
Award [2 max] for (+)2324 (kJ mol\(^{-1}\)).
Award [3] for −2324 (kJ mol\(^{-1}\)) without working.

\[
\left(10.0 \times \frac{-2324}{296.2} \right) = -78.5 (kJ);
\]
M4 is scored from 10.0/296.2 × M3.
Allow answers of −78.2, −78 and −79 (kJ), but negative sign must be included. 
Award [4] for correct final answer.

Q# 23/ IB Chem/2012/s/TZ1/Paper 2 Section B/Higher Level/Q5

(b) (i) \( \sum \bar{H}^\circ \) (products) = −5360 (kJ);
\[
\sum \bar{H}^\circ \) (reactants) = +160 (kJ);
= −5520 (kJ); 
\]

(ii) \(-1560 \times 2 =) −3120 (kJ);
\]

(c) Bonds broken:
6Si–H, Si–Si, H–H / (+)2570 (kJ);
Bonds formed:
8Si–H / (−)2544 (kJ);
+26 (kJ);
OR
Bonds broken:
Si–Si, H–H / (+)662 (kJ);
Bonds formed:
2Si–H / (−)636 (kJ);
+26 (kJ);
Q# 24/ IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/

3. (a) energy required to break (1 mol of) a bond in a gaseous molecule/state;
Accept energy released when (1 mol of) a bond is formed in a gaseous molecule/state / enthalpy change when (1 mol of) bonds are formed or broken in the gaseous molecule/state.

  average values obtained from a number of similar bonds/compounds / OWTTE; [2]

(b) \( \text{CH}_3(\text{CH}_2)_2\text{OH}(l) + 6\text{O}_2(g) \rightarrow 4\text{CO}_2(g) + 5\text{H}_2\text{O}(l) \);

  Allow \( \text{C}_4\text{H}_9\text{OH} \) or \( \text{C}_4\text{H}_8\text{O} \) for \( \text{CH}_3(\text{CH}_2)_2\text{OH} \).

  Ignore state symbols.

(c) **Bonds broken:**

  \( (6)(\text{O} = \text{O}) + (3)(\text{C} = \text{C}) + (1)(\text{O} = \text{H}) + (1)(\text{C} = \text{O}) + (9)(\text{C} = \text{H}) \) /  
  \( (6)(498) + (3)(347) + (1)(464) + (1)(358) + (9)(413) = 8568 \text{ (kJ mol}^{-1}) \);  

  **Bonds formed:**

  \( (8)(\text{C} = \text{O}) + (10)(\text{O} = \text{H}) / (8)(746) + (10)(464) = 10608 \text{ (kJ mol}^{-1}) \);

\( \Delta H = (8568 - 10608 =) - 2040 \text{ (kJ mol}^{-1}) \);

  Award [3] for correct final answer.

  Award [2] for \( +2040 \text{ (kJ mol}^{-1}) \).

Q# 25/ IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/

5. (a) negative;

  liquid more ordered than gaseous phase or vice-versa / OWTTE; [2]

(b) (i) \( \Delta H^\circ \) of an element (in its most stable state) is zero (since formation of an element from itself is not a reaction) / OWTTE; [1]

  Do not allow an answer such as because they are elements.

(ii) \( \Delta H^\circ = (1)(-20.6) - (1)(-53.1) = 32.5 \text{ (kJ mol}^{-1}) / 32500 \text{ (J mol}^{-1}) \);

  Allow 32.5 \text{ (kJ)} or \( 3.25 \times 10^4 \text{ (J)} \).

(iii) \( \Delta G^\circ = (1)(-33.6) - (1)(-53.6) = 20.0 \text{ (kJ mol}^{-1}) / 20000 \text{ (J mol}^{-1}) \);

  Allow 20.0 \text{ (kJ)} or \( 2.00 \times 10^4 \text{ (J)} \).

  non-spontaneous;

(iv) \( \Delta S^\circ = (\Delta H^\circ - \Delta G^\circ) / T = (32.5 - 20.0)(1000) / 298 = 41.9 \text{ (J K}^{-1} \text{ mol}^{-1}) / 4.19 \times 10^{-2} \text{ (kJ K}^{-1} \text{ mol}^{-1}) \);

  Allow 41.9 \text{ (J K}^{-1}) or \( 4.19 \times 10^{-2} \text{ (kJ K}^{-1}) \).

(v) \( T = \Delta H / \Delta S = (32.5 \times 1000) / (41.9) = 776 \text{ (K)} \); [1]
Q# 26/ IB Chem/2011/s/TZ1/Paper 2 Section A/Higher Level/

1. (a) \( \Delta H^\circ = \sum \Delta H_f^{\text{products}} - \sum \Delta H_f^{\text{reactants}} \)
\[
\Delta H^\circ = (2 \times -242 + (-394)) - (-239) \text{ (kJ mol}^{-1})
\]
\[
\Delta H^\circ = -639 \text{ (kJ mol}^{-1})
\]
Award [2] for correct final answer.

Do not award M2 if M1 incorrect.

(b) (i) \( m(\text{methanol}) = (80.557 - 80.034) = 0.523 \text{ (g)} \)
\[
n(\text{methanol}) = \left( \frac{0.523 \text{ g}}{32.05 \text{ g mol}^{-1}} \right) = 0.0163 \text{ (mol)} \]
Award [2] for correct final answer.

(ii) \( \Delta T = (26.4 - 21.5) = 4.9 \text{ (K)} \)
\[
g = (\text{mol} \Delta T) = 20.000 \times 4.18 \times 4.9 \text{ (J) / 20.000 \times 4.18 \times 4.9 \times 10^{-3} (kJ)}
\]
\[
0.41 \text{ (kJ)}
\]
Award [3] for correct final answer.

(iii) \( \Delta H^\circ = \frac{-0.41 \text{ (kJ)}}{0.0163 \text{ (mol)}} / -25153 \text{ (J mol}^{-1})
\]
\[
= -25 \text{ (kJ mol}^{-1})
\]
Award [2] for correct final answer.
Award [1] for (+)25 \text{ (kJ mol}^{-1})

(c) (i) not at standard conditions / atm and 298 K/25 \text{ °C} / \Delta H_{vap} \text{ for water} ;

(ii) not all heat produced transferred to water / heat lost to surroundings/environment / OWTTE / incomplete combustion (of methanol) / water forms as \text{H}_2\text{O(l)} instead of \text{H}_2\text{O(g)} ;

Do not allow just “heat lost”.

(d) \( \Delta S^\circ = \sum \Delta S_f^{\text{products}} - \sum \Delta S_f^{\text{reactants}} = 2 \times 189 + 214 - (240 + 1.5 \times 205)
\]
\[
= 44.5 \text{ J K}^{-1} \text{ mol}^{-1} / 0.0445 \text{ kJ K}^{-1} \text{ mol}^{-1}
\]
Award [2] for correct final answer.
Do not award M2 if M1 incorrect.

(e) temperature of 298 K;
\[
\Delta G^\circ = (\Delta H^\circ - T \Delta S^\circ) = -726 - 298 \times 44.5 \times 10^{-3} \text{ (kJ mol}^{-1})
\]
\[
= 726000 - 298 \times 44.5 \text{ (J mol}^{-1})
\]
\[
= -739 \text{ kJ mol}^{-1} / -7.39 \times 10^5 \text{ J mol}^{-1}
\]
Award [3] for correct final answer.

(f) \( \Delta G^\circ \) is always negative and temperature won’t alter spontaneity of reaction;
Q# 27/ IB Chem/2010/w/TZ0/Paper 2 Section B/Higher Level/4

(c) (i) \[ I: \text{atomization/sublimation (of Mg)} \ / \ \Delta H_{\text{atomization (Mg)}} \ / \ \Delta H_{\text{sublimation (Mg)}}; \]

\[ V: \text{enthalpy change of formation of (MgCl}_2) \ / \ \Delta H_{\text{formation (MgCl}_2)}; \]  

\[ 2 \]

(ii) \textit{Energy value for II:}

\[ +243; \]

\textit{Energy value for III:}

\[ 738 + 1451 = 2189; \]

\textit{Energy value for IV:}

\[ 2(-349); \]

\[ \Delta H_{\text{f}}^{\circ} \text{(MgCl}_2) = 642 + 148 + 243 + 2189 = (+)2252(KJ); \]

\[ 4 \]

(iv) oxide greater charge; oxide smaller radius; \textit{Accept opposite arguments.}  

\[ 2 \]

Q# 28/ IB Chem/2010/w/TZ0/Paper 2 Section B/Higher Level/Q7

(c) (i) \[ \Delta H_f^{\circ} = \Sigma \Delta H_f^{\circ} \text{ products} - \Sigma \Delta H_f^{\circ} \text{ reactants}; \]

\textit{Can be implied by working.}

\[ \Delta H_f^{\circ} \text{(H}_2\text{O (l))} = -286(kJ); \]

\[ \Delta H_f^{\circ} = 2(-286) - 50.6 = -622.6(kJ); \]

\textit{Award [3] for correct final answer.}  

\[ 3 \]

(ii) \textit{bonds broken:} 4 \text{N–H, N–N, O=O} / \ +2220 (kJ mol}^{-1} \text{);} 

\textit{bonds formed:} \text{N=N, 4 O–H} / \ -2801 (kJ mol}^{-1} \text{);} 

\[ -581(kJ \text{ mol}^{-1}); \]

\textit{Award [3] for correct final answer.}  

\[ 3 \]

(iii) \textit{value based on} \[ \Delta H_f \] \textit{more accurate;}

\[ \Delta H_f \text{ accurate for compounds in reaction; bond energy calculation assumes average bond energies; (bond energy calculation) only applies to gaseous states / ignores intermolecular bonds;} \]

\[ 3 \text{ max} \]

(iv) \[ \Delta S^{\circ} = \Sigma S^{\circ} \text{ (products)} - \Sigma S^{\circ} \text{ (reactants)}; \]

\textit{Can be implied by working.}

\[ = 191 + (2 \times 69.9) - 205 - 121 = +4.8(J \text{ K}^{-1} \text{mol}^{-1}); \]

\textit{Award [2] for correct final answer.}  

\[ 2 \]

\textit{small value since number of mol of g on both sides the same;}  

\[ 3 \]
(v)  \[ \Delta G^\circ = -622.6 - 298(0.0048) = -624.0 \text{ (kJ mol}^{-1}\text{)}; \]

*Award [2] for correct final answer.  Allow 623.9 to 624.1.*  

(vi) all reactions are spontaneous;  
\[ \Delta G \] is negative (at high temperatures and low temperatures);  

*Q# 29/ IB Chem/2010/w/TZ0/Paper 2 Section A/Higher Level/*

1.  (a) all heat is transferred to water/copper sulfate solution / no heat loss;  
specific heat capacity of zinc is zero/negligible / no heat is absorbed by the zinc;  
density of water/solution = 1.0 / density of solution = density of water;  
heat capacity of cup is zero / no heat is absorbed by the cup;  
specific heat capacity of solution = specific heat capacity of water;  
temperature uniform throughout solution;  

*Award [1] each for any two.*  
Accept energy instead of heat.  

(b) (i) \[ T_{\text{final}} = 73.0 \text{ (}^\circ\text{C)}; \]

*Allow in the range 72 to 74 (}^\circ\text{C}).*  
\[ \Delta T = 48.2 \text{ (}^\circ\text{C)}; \]

*Allow in the range 47 to 49 (}^\circ\text{C}).*  
*Award [1] for correct final answer  Allow ECF if \( T_{\text{final}} \) or \( T_{\text{initial}} \) correct.

(ii) 10.1 (kJ);  

*Allow in the range 9.9 to 10.2 (kJ).*

(c)  \[ \left( \frac{n_{\text{Zn}} - n_{\text{CuSO}_4}}{1000} \right) = 0.0500 \text{ (mol)}; \]

*1]*

(d) \(-201 \text{ (kJ mol}^{-1}\text{)}; \)

*Allow in the range \(-197 \text{ to } -206 \text{ (kJ mol}^{-1}\text{)}.  Value must be negative to award mark.*
Q# 30/ IB Chem/2010/s/TZ1/Paper 2 Section B/Higher Level/

5.  (a)  (i)  correct substitution of values and numbers of bonds broken / 
(1×945)+(3×436)/2253;
correct substitution of values and numbers of bonds made / (6×391)/2346;
\[ ΔH = \text{sum of energies of bonds broken} - \text{sum of energies of bonds formed} \]
= (2253–2346) −93 (kJ);
Ignore units.
Award [3] for correct final answer.
Award [2 max] for +93 or 93.

(ii)  entropy of products = 2 × 192 = 384;
entropy of reactants = 193+(3×131) = 586;
\[ ΔS^\circ = ΔH^\circ / (\text{sum of entropies of products}) - (\text{sum of entropies of reactants}) / \]
(384–586) =−202 (J K\(^{-1}\) mol\(^{-1}\));
Award [3] for correct final answer.
Award [2 max] for +202 or 202.
Ignore units.

negative as more ordered/less disordered / four moles become two moles / fewer molecules of gas;

(iii)  \( ΔG^\circ = ΔH^\circ - TΔS^\circ = -93 - 298(-0.202)) = -32.8\) (kJ mol\(^{-1}\));

(iv)  reaction becomes less spontaneous; 
\( ΔG \) becomes more positive/less negative / \( TΔS \) becomes larger;

Q# 31/ IB Chem/2009/w/TZ0/Paper 2 Section B/Higher Level/

7.  (a)  (i)  A: sublimation/atomization;
B: atomization/half dissociation enthalpy;
D: (sum of 1\(^{st}\) and 2\(^{nd}\) electron affinity);
Do not accept vaporization for A and B.
Accept Δ\( H_{AT} \) or Δ\( H_{EA} \)

(ii)  enthalpy change when one mole of the compound is formed from its elements (in their standard states);
under standard conditions / 25\(^\circ\)C/298 K and 1 atm/101.3 kPa/1.01 \times 105 Pa;

(iii)  \(-602 = 150 + 248 + 2186 + 702 + E\);
\(-3888\) (kJ mol\(^{-1}\));
Do not allow 3889 (given in data booklet).
Allow 3888 (i.e no minus sign).
Award [2] for the correct final answer.

(iv)  energy required to remove one electron; 
from an atom in its gaseous state;
electron removed from a positive ion; 
decrease in electron-electron repulsion / increase in nucleus-electron attraction;

(v)  MgO; 
double ionic charge / both ions carry +2 and –2 charge/greater charge compared to +1 and –1;
(b) (i) \( \text{C}_2\text{H}_4(g) + 3\frac{1}{2}\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 3\text{H}_2\text{O}(l) \) \( \Delta H^\circ = -1560 \); 
\( \text{H}_2\text{O}(l) \rightarrow \text{H}_2(g) + \frac{1}{2}\text{O}_2(g) \) \( \Delta H^\circ = +286 \); 
\( 2\text{CO}_2(g) + 2\text{H}_2\text{O}(l) \rightarrow \text{C}_2\text{H}_4(g) + 3\text{O}_2(g) \) \( \Delta H^\circ = +1411 \); 
\( \text{C}_2\text{H}_4(g) \rightarrow \text{C}_2\text{H}_4(g) + \text{H}_2(g) \) \( \Delta H^\circ = +137 \text{ (kJ)} \); 

Allow other correct methods.
Award [2] for -137.
Allow ECF for the final marking point.

(ii) positive, increase in number of moles of gas; [2]

(iii) at low temperature, \( \Delta H^\circ \) is positive and \( \Delta G \) is positive; at high temperature, factor T\( \Delta S^\circ \) predominates and \( \Delta G \) is negative; [2]

(iv) Bonds broken \( (1\text{C}–\text{C}, 6\text{C}–\text{H}, \text{or} 1\text{C}–\text{C}, 2\text{C}–\text{H}) = 2825/1173 \); 
Bonds made \( (1\text{C}=\text{C}, 1\text{H}–\text{H}, 4\text{C}–\text{H}) = 2700/1048 \); 
+125 (kJ); 

Allow 125 but not -125 (kJ) for the final mark.
Award [3] for the correct final answer.

(v) bond enthalpy values are average values; [1]

Q# 32/ IB Chem/2009/s/TZ1/Paper 2 Section B/Higher Level/Q6

(b) (i) c: atomization (enthalpy);
d: electron affinity; [2]

(ii) d and e; [1]

(iii) \( \Delta H_f = 90.0 + 418 + 112 + (-342) + (-670) \);

\[ = -392 \text{ kJ mol}^{-1} \]; [2]

(iv) Ca\(^{2+}\) is smaller than K\(^+\) and Ca\(^{2+}\) has more charge than K\(^+\). Ca\(^{2+}\) has a greater charge density; so the attractive forces between the ions are stronger. [2]

Do not accept ‘stronger ionic bonds’
Award [1 max] if reference is made to atoms or molecules instead of ions.
Q# 33/ IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/

3. (a) energy required = C≡C + H–H/612 + 436 and
energy released = C–C + 2(C–H)/347 + 2(413) /
energy required = C≡C + H–H + 4(C–H)/612 + 436 + 4(413) and
energy released = C–C + 6(C–H)/347 + 6(413);

\[ \Delta H = \frac{(1048-1173)(2700-2825)}{2} = -125 \text{ kJ mol}^{-1}; \]  \[2\]

(b) \[ \Delta H = \frac{-1411 + (-286) - (-1560)}{2} /\text{correct energy cycle drawn:} \]
\[ = -137 \text{ kJ mol}^{-1}; \]  \[2\]

Award [1 max] for incorrect or missing sign.

(c) the actual values for the specific bonds may be different to the average values / the combustion values referred to the specific compounds / OWTIE;

(percentage difference) = \[ \frac{(137-125)}{137} \times 100 = 8.76\%; \]  \[2\]

Accept \[ \frac{(137-125)}{125} \times 100 = 9.60\%. \]

(d) (i) \[ -125 \text{ kJ mol}^{-1}; \]  \[1\]

(ii) average bond enthalpies do not apply to the liquid state / OWTIE;
The enthalpy of vaporization/condensation of cyclohexene and cyclohexane / OWTIE; \[2\]
5. (a) (i) energy change to break/make (one mole) of bonds (in molecule) in gaseous state; averaged over similar compounds;  

(ii) H–H bond is only present in one molecule/OWTTE;  

(b) (i) bonds broken: 2 C=O and 4 H–H / 1486 + 1744 / 3230; 
bonds formed: 4 C–H and 4 O–H / 1648 + 1852 / 3500; 
\[\Delta H = 3230 - 3500 = -270 \text{ (kJ/kJ mol}^{-1}\text{)};\]  
270 kJ/kJ mol\(^{-1}\) or +270 kJ/kJ mol\(^{-1}\) scores [2] marks.  

(ii) reactants entropy = 214 + (4 \times 131) = 738;  
products entropy = 186 + (2 \times 189) = 564;  
\[\Delta S^\circ = 564 - 738 = -174 \text{ (J K}^{-1}\text{mol}^{-1});\]  
174 J K\(^{-1}\) mol\(^{-1}\) or +174 J K\(^{-1}\) mol\(^{-1}\) scores [2] marks.  

(iii) sign should be negative because of increase in order/decrease in disorder; fewer moles of gas on right;  

(iv) \[\Delta G^\circ = -270 - (298 \times -0.174);\]  
Mark is for correct use of \[\Delta G^\circ = \Delta H^\circ - T \Delta S^\circ\] and unit conversion.  
\[= -218 \text{ kJ mol}^{-1} / \text{kJ};\]  
spontaneous because \[\Delta G^\circ\] negative;  

(c) for first equation \[8 \times -394 / -3152;\]  
for second equation \[9 \times -286 / -2574;\]  
for third equation +5512;  
\[\Delta H^\circ = -214 \text{ (kJ or kJ mol}^{-1}\text{)};\]  
No penalty for missing units, but penalize wrong units by −I(U). Correct final answer award [4] marks.  
All marks can be scored from enthalpy cycle. Consider ECF for final mark.  

(d) atomization / sublimation / vaporization and \(K(s) \rightarrow K(g);\) 
ionization / first ionization energy and \(K(g) \rightarrow K^+(g) + e^-;\) 
atomization / \(\frac{1}{2}\) bond enthalpy and \(\frac{1}{2} F_2(g) \rightarrow F(g);\) 
electron affinity and \(F(g) + e^- \rightarrow F^-(g);\)  
No penalty for using \(e^-\) instead of \(e\). Penalize missing state symbols every time.  

(e) (i) \(Na^+\) smaller (ion/radius) / greater charge density than \(K^+;\)  

(ii) \(Ca^{2+}\) larger ionic charge / greater charge density (compared to \(K^+\)); stronger electrostatic attraction / stronger attraction between ions;  
Allow second marking point in (e)(i) if not given in (e)(ii).
Q# 35/ IB Chem/2008/s/TZ1/Paper 2 Section B/Higher Level/

6. (a) (i) \( \Delta H^\circ = [-394 + (-558)] - [-1219]; \)
\[ \Delta H^\circ = -394 - 558 + 1219; \]
\[ \Delta H^\circ = 267 \text{kJ mol}^{-1}; \]
\( \Delta S^\circ = [214 + 70] - [112]; \)
\[ \Delta S^\circ = 284 \text{ JK}^{-1} \text{ mol}^{-1}; \]
\( \Delta G^\circ = 267 - (298)(0.172); \)
\[ \Delta G^\circ = +216 \text{kJ mol}^{-1}; \] [6]

(ii) non-spontaneous as \( \Delta G^\circ \) is positive; [1]

(iii) \( \Delta G = O / T = \frac{\Delta H^\circ}{\Delta S^\circ}; \)
267/0.172;
1550 K/1552 K/1277° C/1279° C;
the factor \( T\Delta S^\circ \) predominates and \( \Delta G^\circ \) becomes negative / \( T\Delta S^\circ \) must be
greater than \( \Delta H^\circ \) for \( \Delta G^\circ \) to be negative; [4]
Topic 6
Chem 6 16 Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

3. Sodium thiosulfate solution reacts with dilute hydrochloric acid to form a precipitate of sulfur at room temperature.

\[ \text{Na}_2\text{S}_2\text{O}_3 (aq) + 2\text{HCl (aq)} \rightarrow \text{S (s)} + \text{SO}_2 (g) + 2\text{NaCl (aq)} + X \]

(a) Identify the formula and state symbol of X. [1]

(b) Suggest why the experiment should be carried out in a fume hood or in a well-ventilated laboratory. [1]
(c) The precipitate of sulfur makes the mixture cloudy, so a mark underneath the reaction mixture becomes invisible with time.

10.0 cm³ of 2.00 mol dm⁻³ hydrochloric acid was added to a 50.0 cm³ solution of sodium thiosulfate at temperature, T₁. Students measured the time taken for the mark to be no longer visible to the naked eye. The experiment was repeated at different concentrations of sodium thiosulfate.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>[Na₂S₂O₃(aq)] / mol dm⁻³</th>
<th>Time, t, for mark to disappear / s ± 1s</th>
<th>( \frac{1}{t} / 10^{-3} \text{s}^{-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.150</td>
<td>23</td>
<td>43.5</td>
</tr>
<tr>
<td>2</td>
<td>0.120</td>
<td>27</td>
<td>37.0</td>
</tr>
<tr>
<td>3</td>
<td>0.090</td>
<td>36</td>
<td>27.8</td>
</tr>
<tr>
<td>4</td>
<td>0.060</td>
<td>60</td>
<td>16.7</td>
</tr>
<tr>
<td>5</td>
<td>0.030</td>
<td>111</td>
<td>9.0</td>
</tr>
</tbody>
</table>

* The reciprocal of the time in seconds can be used as a measure of the rate of reaction.

[Source: Adapted from http://www.flinnsci.com/]

Show that the hydrochloric acid added to the flask in experiment 1 is in excess. [2]
(d) Draw the best fit line of $\frac{1}{t}$ against concentration of sodium thiosulfate on the axes provided. [2]

(e) (i) Using the graph, explain the order of reaction with respect to sodium thiosulfate. [2]
(ii) In a different experiment, this reaction was found to be first order with respect to hydrochloric acid. Deduce the overall rate expression for the reaction. [1]

(f) A student decided to carry out another experiment using 0.075 mol dm$^{-3}$ solution of sodium thiosulfate under the same conditions. Determine the time taken for the mark to be no longer visible. [2]

(g) An additional experiment was carried out at a higher temperature, $T_2$.

(i) On the same axes, sketch Maxwell–Boltzmann energy distribution curves at the two temperatures $T_1$ and $T_2$, where $T_2 > T_1$. [2]
(ii) Explain why a higher temperature causes the rate of reaction to increase. [2]

(h) Suggest one reason why the values of rates of reactions obtained at higher temperatures may be less accurate. [1]

Chem 6 3 Q# 2/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/Q4
(e) Describe what you understand by the term frequency (pre-exponential) factor, A. [1]

(f) The activation energy, $E_a$, for the reaction of 1-iodoethane with sodium hydroxide is 87.0 kJ mol$^{-1}$, and the frequency (pre-exponential) factor, $A$, is $2.10 \times 10^{11}$ mol$^{-1}$ dm$^3$ s$^{-1}$.

Calculate the rate constant, $k$, of the reaction at 25 °C, indicating the units of $k$, and giving a reason for your choice. [2]
3. The reaction between hydrogen and nitrogen monoxide is thought to proceed by the mechanism shown below:

\[
\begin{align*}
2\text{NO}(g) & \rightleftharpoons \text{N}_2\text{O}_2(g) & \text{fast equilibrium} \\
\text{N}_2\text{O}_2(g) + \text{H}_2(g) & \rightarrow \text{N}_2\text{O}(g) + \text{H}_2\text{O}(g) & \text{slow reaction} \\
\text{N}_2\text{O}(g) + \text{H}_2(g) & \rightarrow \text{N}_2(g) + \text{H}_2\text{O}(g) & \text{fast reaction}
\end{align*}
\]

(a) (i) State the equation for the overall reaction. [1]

(ii) Deduce the rate expression consistent with this mechanism. [1]

(iii) Explain how you would attempt to confirm this rate expression, giving the results you would expect. [3]
(iv) State, giving your reason, whether confirmation of the rate expression would prove that the mechanism given is correct. [1]

(v) Suggest how the rate of this reaction could be measured experimentally. [1]

(iii) Sketch and label a second Maxwell–Boltzmann energy distribution curve representing the same system but at a higher temperature, \( T_{\text{higher}} \). [1]

(iv) Explain why an increase in temperature increases the rate of this reaction. [2]
Chem 6 Q# 4/ IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/Q7

(c) The oxidation of nitrogen monoxide takes place as follows:

\[ 2\text{NO}(g) + \text{O}_2(g) \rightarrow 2\text{NO}_2(g) \]

The following experimental data was obtained at 101.3 kPa and 298 K.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Initial [NO] / mol dm(^{-3})</th>
<th>Initial [O(_2)] / mol dm(^{-3})</th>
<th>Initial rate / mol dm(^{-3}) s(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(2.30 \times 10^{-2})</td>
<td>(1.15 \times 10^{-2})</td>
<td>(1.05 \times 10^{-3})</td>
</tr>
<tr>
<td>2</td>
<td>(2.30 \times 10^{-2})</td>
<td>(2.30 \times 10^{-2})</td>
<td>(2.09 \times 10^{-3})</td>
</tr>
<tr>
<td>3</td>
<td>(4.60 \times 10^{-2})</td>
<td>(4.60 \times 10^{-2})</td>
<td>(1.68 \times 10^{-2})</td>
</tr>
</tbody>
</table>

(i) Deduce the orders of reaction with respect to O\(_2\) and NO.

Order with respect to O\(_2\):

……………………………………………………………………………………………………………………………………………………………………………………………………………………………………

Order with respect to NO:

……………………………………………………………………………………………………………………………………………………………………………………………………………………………………

(ii) State the rate expression for the reaction.

……………………………………………………………………………………………………………………………………………………………………………………………………………………………………

(iii) Calculate the value of the rate constant, \(k\), and include its units.

……………………………………………………………………………………………………………………………………………………………………………………………………………………………………
(iv) Suggest a mechanism that is consistent with the rate expression, indicating the rate-determining step. [3]

(f) The student found by further experimentation that oxidation of ascorbic acid follows first-order kinetics. The graph of $\ln k$ against $\frac{1}{T}$ is shown below.

Determine the activation energy to three significant figures, including units. [3]
2. (a) Define the term rate of reaction.

(b) Explain why increasing the particle size of a solid reactant decreases the rate of reaction.

(c) Nitrogen(II) oxide reacts with hydrogen according to the equation below.

\[ 2\text{NO}(g) + 2\text{H}_2(g) \rightarrow \text{N}_2(g) + 2\text{H}_2\text{O}(g) \]

A suggested mechanism for this reaction is:

Step 1: \[ \text{NO} + \text{H}_2 \rightleftharpoons X \quad \text{fast} \]
Step 2: \[ X + \text{NO} \rightarrow Y + \text{H}_2\text{O} \quad \text{slow} \]
Step 3: \[ Y + \text{H}_2 \rightarrow \text{N}_2 + \text{H}_2\text{O} \quad \text{fast} \]

(i) Identify the rate-determining step.

(ii) A student hypothesized that the order of reaction with respect to \( \text{H}_2 \) is 2. Evaluate this hypothesis.
(c) (i) Determine the orders of reaction of the reactants and the overall rate expression for the reaction between 2-bromobutane and aqueous sodium hydroxide using the data in the table.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>[NaOH] / mol dm$^{-3}$</th>
<th>[C$_4$H$_7$Br] / mol dm$^{-3}$</th>
<th>Rate / mol dm$^{-3}$s$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>1.00</td>
<td>$1.66 \times 10^{-3}$</td>
</tr>
<tr>
<td>2</td>
<td>0.50</td>
<td>1.00</td>
<td>$8.31 \times 10^{-4}$</td>
</tr>
<tr>
<td>3</td>
<td>0.25</td>
<td>0.25</td>
<td>$1.02 \times 10^{-4}$</td>
</tr>
<tr>
<td>4</td>
<td>1.00</td>
<td>0.50</td>
<td>$8.29 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

(ii) Determine the rate constant, $k$, with its units, using the data from experiment 3.

(iii) Identify the molecularity of the rate-determining step in this reaction.
3. The rate of reaction is an important factor in industrial processes such as the Contact process to make sulfur trioxide, \( \text{SO}_3 \) (g).

(a) Define the term *rate of reaction*. [1]

(b) Describe the collision theory. [3]
11. Hydrogen peroxide decomposes according to the equation below.

\[ 2\text{H}_2\text{O}_2(\text{aq}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g}) \]

The rate of the decomposition can be monitored by measuring the volume of oxygen gas released. The graph shows the results obtained when a solution of hydrogen peroxide decomposed in the presence of a CuO catalyst.

(a) (i) Outline how the initial rate of reaction can be found from the graph. [2]
(ii) Explain how and why the rate of reaction changes with time.

(b) A Maxwell–Boltzmann energy distribution curve is drawn below. Label both axes and explain, by annotating the graph, how catalysts increase the rate of reaction.
(c) (i) In some reactions, increasing the concentration of a reactant does not increase the rate of reaction. Describe how this may occur. 

(ii) Consider the reaction 

\[ 2 \, A + B \rightarrow C + D \]

The reaction is first order with respect to A, and zero order with respect to B. Deduce the rate expression for this reaction.

(d) Sketch a graph of rate constant \((k)\) versus temperature.
6. A group of students investigated the rate of the reaction between aqueous sodium thiosulfate and hydrochloric acid according to the equation below.

\[
\text{Na}_2\text{S}_2\text{O}_3\text{(aq)} + 2\text{HCl(aq)} \rightarrow 2\text{NaCl(aq)} + \text{SO}_2\text{(g)} + \text{S(s)} + \text{H}_2\text{O(l)}
\]

The two reagents were rapidly mixed together in a beaker and placed over a mark on a piece of paper. The time taken for the precipitate of sulfur to obscure the mark when viewed through the reaction mixture was recorded.

Initially they measured out 10.0 cm\(^3\) of 0.500 mol dm\(^{-3}\) hydrochloric acid and then added 40.0 cm\(^3\) of 0.0200 mol dm\(^{-3}\) aqueous sodium thiosulfate. The mark on the paper was obscured 47 seconds after the solutions were mixed.

(a) The teacher asked the students to measure the effect of halving the concentration of sodium thiosulfate on the rate of reaction.

(i) State the volumes of the liquids that should be mixed. \(1\)

<table>
<thead>
<tr>
<th>Liquid</th>
<th>0.500 mol dm(^{-3}) HCl</th>
<th>0.0200 mol dm(^{-3}) Na(_2)S(_2)O(_3)</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume / cm(^3)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(ii) State why it is important that the students use a similar beaker for both reactions. \(1\)

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(iii) If the reaction were first order with respect to the thiosulfate ion, predict the time it would take for the mark on the paper to be obscured when the concentration of sodium thiosulfate solution is halved. [1]

(b) One proposed mechanism for this reaction is:

\[ \text{S}_2\text{O}_3^{2-} (aq) + \text{H}^+ (aq) \rightleftharpoons \text{HS}_2\text{O}_3^- (aq) \]  Fast
\[ \text{HS}_2\text{O}_3^- (aq) + \text{H}^+ (aq) \rightarrow \text{SO}_2 (g) + \text{S} (s) + \text{H}_2\text{O} (l) \]  Slow

(i) Deduce the rate expression of this mechanism. [1]
(ii) The results of an experiment investigating the effect of the concentration of hydrochloric acid on the rate, while keeping the concentration of thiosulfate at the original value, are given in the table below.

<table>
<thead>
<tr>
<th>[HCl]/mol dm⁻³</th>
<th>0.020</th>
<th>0.040</th>
<th>0.060</th>
<th>0.080</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time/s</td>
<td>89.1</td>
<td>72.8</td>
<td>62.4</td>
<td>54.2</td>
</tr>
</tbody>
</table>

On the axes provided, draw an appropriate graph to investigate the order of the reaction with respect to hydrochloric acid. [3]
(iii) Identify two ways in which these data do not support the rate expression deduced in part (i).

(c) (i) Sketch and label, indicating an approximate activation energy, the Maxwell–Boltzmann energy distribution curves for two temperatures, $T_1$ and $T_2$ ($T_2 > T_1$), at which the rate of reaction would be significantly different.
Patrick Brannac

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2. Sodium thiosulfate solution, \( \text{Na}_2\text{S}_2\text{O}_3(\text{aq}) \), and hydrochloric acid, \( \text{HCl}(\text{aq}) \), react to produce solid sulfur as in the equation below.

\[
\text{S}_2\text{O}_3^{2-}(\text{aq}) + 2\text{H}^+(\text{aq}) \rightarrow \text{S(s)} + \text{SO}_2(\text{g}) + \text{H}_2\text{O(l)}
\]

The following results to determine the initial rate were obtained:

<table>
<thead>
<tr>
<th>Experiment</th>
<th>([\text{S}_2\text{O}_3^{2-}(\text{aq})] / \text{mol dm}^{-3})</th>
<th>([\text{H}^+(\text{aq})] / \text{mol dm}^{-3})</th>
<th>Initial rate / (\text{mol dm}^{-3} \text{s}^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.200</td>
<td>2.00</td>
<td>0.036</td>
</tr>
<tr>
<td>2</td>
<td>0.200</td>
<td>1.00</td>
<td>0.036</td>
</tr>
<tr>
<td>3</td>
<td>0.100</td>
<td>1.00</td>
<td>0.018</td>
</tr>
</tbody>
</table>

(a) Deduce, with a reason, the order of reaction with respect to each reactant. \([2]\)  

(b) State the rate expression for this reaction. \([1]\)  

(c) Determine the value of the rate constant, \(k\), and state its units. \([2]\)
(d) State an equation for a possible rate-determining step for the reaction. [1]

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1. Reaction kinetics can be investigated using the iodine clock reaction. The equations for two reactions that occur are given below.

   Reaction A: \[ \text{H}_2\text{O}_2 (aq) + 2\text{I}^- (aq) + 2\text{H}^+ (aq) \rightarrow \text{I}_2 (aq) + 2\text{H}_2\text{O} (l) \]

   Reaction B: \[ \text{I}_2 (aq) + 2\text{S}_2\text{O}_3^{2-} (aq) \rightarrow 2\text{I}^- (aq) + \text{S}_4\text{O}_6^{2-} (aq) \]

Reaction B is much faster than reaction A, so the iodine, \( \text{I}_2 \), formed in reaction A immediately reacts with thiosulfate ions, \( \text{S}_2\text{O}_3^{2-} \), in reaction B, before it can react with starch to form the familiar blue-black, starch-iodine complex.

In one experiment the reaction mixture contained:

- \( 5.0 \pm 0.1 \text{ cm}^3 \) of \( 2.00 \text{ mol dm}^{-3} \) hydrogen peroxide (\( \text{H}_2\text{O}_2 \))
- \( 5.0 \pm 0.1 \text{ cm}^3 \) of 1\% aqueous starch
- \( 20.0 \pm 0.1 \text{ cm}^3 \) of \( 1.00 \text{ mol dm}^{-3} \) sulfuric acid (\( \text{H}_2\text{SO}_4 \))
- \( 20.0 \pm 0.1 \text{ cm}^3 \) of \( 0.0100 \text{ moldm}^{-3} \) sodium thiosulfate (\( \text{Na}_2\text{S}_2\text{O}_3 \))
- \( 50.0 \pm 0.1 \text{ cm}^3 \) of water with \( 0.0200 \pm 0.0001 \text{ g} \) of potassium iodide (KI) dissolved in it.

After 45 seconds this mixture suddenly changed from colourless to blue-black.

(a) The concentration of iodide ions, \( \text{I}^- \), is assumed to be constant. Outline why this is a valid assumption. \([1]\)

(b) For this mixture the concentration of hydrogen peroxide, \( \text{H}_2\text{O}_2 \), can also be assumed to be constant. Explain why this is a valid assumption. \([2]\)
(c) Explain why the solution suddenly changes colour.

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(e) The colour change occurs when $1.00 \times 10^{-4}$ mol of iodine has been formed. Use the total volume of the solution and the time taken, to calculate the rate of the reaction, including appropriate units.

(f) The activation energy can be determined using the Arrhenius equation, which is given in Table 1 of the Data Booklet. The experiment was carried out at five different temperatures. An incomplete graph to determine the activation energy of the reaction, based on these results, is shown below.
(i) State the labels for each axis.  

\begin{align*}
\text{\(x\)-axis:} & \\
\text{\(y\)-axis:} & 
\end{align*}

(ii) Use the graph to determine the activation energy of the reaction, in \(\text{kJ}\text{ mol}^{-1}\), correct to three significant figures.  

(g) In another experiment, 0.100 g of a black powder was also added while all other concentrations and volumes remained unchanged. The time taken for the solution to change colour was now 20 seconds. Outline why you think the colour change occurred more rapidly and how you could confirm your hypothesis.
2. Consider the following graph of $\ln k$ against $\frac{1}{T}$.

(a) A catalyst provides an alternative pathway for a reaction, lowering the activation energy, $E_a$. Define the term activation energy, $E_a$. [1]

(b) State how the rate constant, $k$, varies with temperature, $T$. [1]
(c) Determine the activation energy, $E_a$, correct to three significant figures and state its units. [3]
(c) The time taken to produce a certain amount of product using different initial concentrations of \( \text{C}_4\text{H}_9\text{Br} \) and \( \text{NaOH} \) is measured. The results are shown in the following table.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>( [\text{C}_4\text{H}_9\text{Br}] / 10^{-2} \text{ mol dm}^{-2} )</th>
<th>( [\text{NaOH}] / 10^{-3} \text{ mol dm}^{-3} )</th>
<th>( t / \text{s} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.0</td>
<td>2.0</td>
<td>46</td>
</tr>
<tr>
<td>B</td>
<td>2.0</td>
<td>2.0</td>
<td>23</td>
</tr>
<tr>
<td>C</td>
<td>2.0</td>
<td>4.0</td>
<td>23</td>
</tr>
</tbody>
</table>

(i) Deduce the order of reaction with respect to \( \text{C}_4\text{H}_9\text{Br} \) and \( \text{NaOH} \), using the data above. \([3]\)

C\(_4\)H\(_9\)Br:

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NaOH:

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(ii) Deduce the rate expression. \([1]\)

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(iii) Based on the rate expression obtained in (c) (ii) state the units of the rate constant, \( k \). \([1]\)

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3. To determine the activation energy of a reaction, the rate of reaction was measured at different temperatures. The rate constant, $k$, was determined and $\ln k$ was plotted against the inverse of the temperature in Kelvin, $T^{-1}$. The following graph was obtained.

(a) Define the term activation energy, $E_a$. [1]
(b) Use the graph on page 8 to determine the value of the activation energy, $E_a$, in $\text{kJ mol}^{-1}$. [2]

(c) On the graph on page 8, sketch the line you would expect if a catalyst is added to the reactants. [1]
6. Chemical kinetics involves an understanding of how the molecular world changes with time.

(a) (i) Define the term *rate of reaction.*

(ii) Temperature and the addition of a catalyst are two factors that can affect the rate of a reaction. State two other factors.

(iii) In the reaction represented below, state one method that can be used to measure the rate of the reaction.

\[ \text{ClO}_3^- (aq) + 5\text{Cl}^- (aq) + 6\text{H}^+ (aq) \rightarrow 3\text{Cl}_2 (aq) + 3\text{H}_2\text{O} (l) \]
(b) A catalyst provides an alternative pathway for a reaction, lowering the activation energy, $E_a$.

(i) Define the term activation energy, $E_a$. \[1\]

(ii) Sketch the two Maxwell–Boltzmann energy distribution curves for a fixed amount of gas at two different temperatures, $T_1$ and $T_2$ ($T_2 > T_1$). Label both axes. \[3\]
(c) Sketch graphical representations of the following reactions, for $X \rightarrow \text{products}$.

(i) Concentration of reactant $X$ against time for a zero-order reaction.

(ii) Rate of reaction against concentration of reactant $X$ for a zero-order reaction.

(iii) Rate of reaction against concentration of reactant $X$ for a first-order reaction.
(d) For the reaction below, consider the following experimental data.

\[ 2\text{ClO}_2(aq) + 2\text{OH}^-(aq) \rightarrow \text{ClO}_3^-(aq) + \text{ClO}_2^-(aq) + \text{H}_2\text{O}(l) \]

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Initial $[\text{ClO}_2(aq)]$ / mol dm$^{-3}$</th>
<th>Initial $[\text{OH}^-(aq)]$ / mol dm$^{-3}$</th>
<th>Initial rate / mol dm$^{-3}$ s$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$1.00 \times 10^{-1}$</td>
<td>$1.00 \times 10^{-1}$</td>
<td>$2.30 \times 10^{-1}$</td>
</tr>
<tr>
<td>2</td>
<td>$5.00 \times 10^{-2}$</td>
<td>$1.00 \times 10^{-1}$</td>
<td>$5.75 \times 10^{-2}$</td>
</tr>
<tr>
<td>3</td>
<td>$5.00 \times 10^{-2}$</td>
<td>$3.00 \times 10^{-2}$</td>
<td>$1.73 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

(i) Deduce the rate expression. [2]

..................................................................................................................
(ii) Determine the rate constant, \( k \), and state its units, using the data from Experiment 2. \([2]\)

\[
\begin{array}{|c|c|}
\hline
\text{(ii)} & \text{Determine the rate constant, } k, \text{ and state its units, using the data from Experiment 2.} \quad [2] \\
\hline
\end{array}
\]

(iii) Calculate the rate, in \( \text{mol dm}^{-3} \text{ s}^{-1} \), when \([\text{ClO}_2(aq)] = 1.50 \times 10^{-2} \text{mol dm}^{-3}\) and \([\text{OH}^- (aq)] = 2.35 \times 10^{-2} \text{mol dm}^{-3}\). \([1]\)

\[
\begin{array}{|c|c|}
\hline
\text{(iii)} & \text{Calculate the rate, in } \text{mol dm}^{-3} \text{ s}^{-1}, \text{ when } [\text{ClO}_2(aq)] = 1.50 \times 10^{-2} \text{mol dm}^{-3} \text{ and } [\text{OH}^- (aq)] = 2.35 \times 10^{-2} \text{mol dm}^{-3}. \quad [1] \\
\hline
\end{array}
\]

(ii) Describe \textit{qualitatively} the relationship between the rate constant, \( k \), and temperature, \( T \). \([1]\)

\[
\begin{array}{|c|c|}
\hline
\text{(ii)} & \text{Describe \textit{qualitatively} the relationship between the rate constant, } k, \text{ and temperature, } T. \quad [1] \\
\hline
\end{array}
\]

(e)
(iii) The rate of this reaction was measured at different temperatures and the following data were recorded.

\[ \ln k \] versus \[ \frac{1}{T} \times 10^{-3} \]

Using data from the graph, determine the activation energy, \( E_a \), correct to three significant figures and state its units. [4]
(f) A two-step mechanism has been proposed for the following reaction.

Step 1: \( \text{ClO}^- \text{(aq)} + \text{ClO}^- \text{(aq)} \rightarrow \text{ClO}_2^- \text{(aq)} + \text{Cl}^- \text{(aq)} \)

Step 2: \( \text{ClO}_2^- \text{(aq)} + \text{ClO}^- \text{(aq)} \rightarrow \text{ClO}_3^- \text{(aq)} + \text{Cl}^- \text{(aq)} \)

(i) Deduce the overall equation for the reaction. \([1]\)

(ii) Deduce the rate expression for each step. \([2]\)

(iv) Using a digital thermometer, the students discovered that the reaction was exothermic. State the sign of the enthalpy change of the reaction, \(\Delta H\). \([1]\)
(e) \( \text{BF}_3(\text{g}) \) reacts with \( \text{NH}_3(\text{g}) \) to form \( \text{F}_2\text{BNH}_3(\text{g}) \) according to the equation below.

\[
\text{BF}_3(\text{g}) + \text{NH}_3(\text{g}) \rightarrow \text{F}_2\text{BNH}_3(\text{g})
\]

(i) Identify the type of bond present between \( \text{BF}_3 \) and \( \text{NH}_3 \) in \( \text{F}_2\text{BNH}_3(\text{g}) \) and state another example of a compound with this type of bonding. \([2]\)

(ii) The table below shows initial rates of reaction for different concentrations of each reactant for this reaction at temperature, \( T \).

<table>
<thead>
<tr>
<th>Experiment</th>
<th>([\text{BF}_3(\text{g})] / \text{mol dm}^{-3})</th>
<th>([\text{NH}_3(\text{g})] / \text{mol dm}^{-3})</th>
<th>Initial rate / (\text{mol dm}^{-3} \text{s}^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(1.00 \times 10^{-1})</td>
<td>(6.67 \times 10^{-2})</td>
<td>(2.27 \times 10^{-2})</td>
</tr>
<tr>
<td>2</td>
<td>(1.00 \times 10^{-1})</td>
<td>(3.75 \times 10^{-2})</td>
<td>(1.28 \times 10^{-2})</td>
</tr>
<tr>
<td>3</td>
<td>(2.50 \times 10^{-1})</td>
<td>(2.50 \times 10^{-1})</td>
<td>(2.13 \times 10^{-1})</td>
</tr>
<tr>
<td>4</td>
<td>(3.00 \times 10^{-1})</td>
<td>(1.00 \times 10^{-1})</td>
<td>(1.02 \times 10^{-1})</td>
</tr>
</tbody>
</table>

Deduce the rate expression, the overall order of the reaction and determine the value of \( k \), the rate constant, with its units, using the data from Experiment 4. \([3]\)
(f) The following is a proposed mechanism for the reaction of NO (g) with H₂ (g):

Step 1: \(2\text{NO}(g) \rightarrow \text{N}_2\text{O}_2(g)\)
Step 2: \(\text{N}_2\text{O}_2(g) + \text{H}_2(g) \rightarrow \text{N}_2\text{O}(g) + \text{H}_2\text{O}(g)\)

(i) Identify the intermediate in the reaction. [1]

(ii) The observed rate expression is rate = \(k[\text{NO}]^2[\text{H}_2]\). Assuming that the proposed mechanism is correct, comment on the relative speeds of the two steps. [1]

(g) The following two-step mechanism has been suggested for the reaction of NO₂(g) with CO(g), where \(k_2 \gg k_1\).

Step 1: \(\text{NO}_2(g) + \text{NO}_2(g) \rightarrow \text{NO}(g) + \text{NO}_3(g)\)
Step 2: \(\text{NO}_3(g) + \text{CO}(g) \rightarrow \text{NO}_2(g) + \text{CO}_2(g)\)
Overall: \(\text{NO}_2(g) + \text{CO}(g) \rightarrow \text{NO}(g) + \text{CO}_2(g)\)

The experimental rate expression is rate = \(k_1[\text{NO}_2]^2\). Explain why this mechanism produces a rate expression consistent with the experimentally observed one. [2]
(h) HI(g) decomposes into H₂(g) and I₂(g) according to the reaction below.

\[ 2\text{HI}(g) \rightarrow \text{H}_2(g) + \text{I}_2(g) \]

The reaction was carried out at different temperatures and a value of the rate constant, \( k \), was obtained for each temperature. A graph of \( \ln k \) against \( \frac{1}{T} \) is shown below.

\[
\frac{1}{T} \times 10^{-3} \text{K}^{-1}
\]

\[
\begin{array}{cccccccc}
0 & 1.20 & 1.30 & 1.40 & 1.50 & 1.60 & 1.70 & 1.80 \\
\ln k & -5 & \text{ } & \text{ } & \text{ } & \text{ } & \text{ } & \text{ }
\end{array}
\]

Calculate the activation energy, \( E_a \), for the reaction using these data and Table 1 of the Data Booklet showing your working. [4]
8.  (a) Define the term activation energy, $E_a$.  

(b) Nitrogen monoxide, NO, is involved in the decomposition of ozone according to the following mechanism.

\[
\begin{align*}
O_3 & \rightarrow O_2 + O* \\
O_3 + NO & \rightarrow NO_2 + O_2 \\
NO_2 + O* & \rightarrow NO + O_2 \\
\text{Overall:} & \quad 2O_3 \rightarrow 3O_2
\end{align*}
\]

State and explain whether or not NO is acting as a catalyst.

(c) (i) Define the term endothermic reaction.
(ii) Sketch the Maxwell-Boltzmann energy distribution curve for a reaction with and without a catalyst, and label both axes. \[3\]

(d) Nitrogen reacts with hydrogen to form ammonia in the Haber process, according to the following equilibrium.

\[
\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g}) \quad \Delta H^\circ = -92.6 \text{ kJ}
\]

(i) Define the term **rate of reaction**. \[1\]
Total amount of gas produced = 34.1dm³

(d) An airbag inflates very quickly.

(i) It takes just 0.0400 seconds to produce nitrogen gas in the simulation. Calculate the average rate of formation of nitrogen in (b) (iii) and state its units. [1]

(ii) The students also discovered that a small increase in temperature (e.g. 10 °C) causes a large increase (e.g. doubling) in the rate of this reaction. State one reason for this. [1]
Consider the following graph of $\ln k$ against $\frac{1}{T}$ (temperature in Kelvin) for the second order decomposition of $N_2O$ into $N_2$ and $O$.

$$N_2O \rightarrow N_2 + O$$

(a) State how the rate constant, $k$, varies with temperature, $T$.  

(b) Determine the activation energy, $E_a$, for this reaction.
(c) The rate expression for this reaction is \( \text{rate} = k [\text{N}_2\text{O}]^2 \) and the rate constant is 0.244 \( \text{dm}^3 \text{ mol}^{-1} \text{ s}^{-1} \) at 750 \( ^\circ \text{C} \).

A sample of \( \text{N}_2\text{O} \) of concentration 0.200 \( \text{mol dm}^{-3} \) is allowed to decompose. Calculate the rate when 10% of the \( \text{N}_2\text{O} \) has reacted.

\[
\text{rate} = k [\text{N}_2\text{O}]^2
\]
2. Alex and Hannah were asked to investigate the kinetics involved in the iodination of propanone. They were given the following equation by their teacher:

\[ \text{CH}_3\text{COCH}_3\text{(aq)} + \text{I}_2\text{(aq)} \xrightarrow{\text{H}^+\text{(aq)}} \text{CH}_2\text{ICOCH}_3\text{(aq)} + \text{HI}\text{(aq)} \]

Alex’s hypothesis was that the rate will be affected by changing the concentrations of the propanone and the iodine, as the reaction can happen without a catalyst. Hannah’s hypothesis was that as the catalyst is involved in the reaction, the concentrations of the propanone, iodine and the hydrogen ions will all affect the rate.

They carried out several experiments varying the concentration of one of the reactants or the catalyst whilst keeping other concentrations and conditions the same, and obtained the results below.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Composition by volume of mixture / cm(^3)</th>
<th>Initial rate / mol dm(^{-3}) s(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.00 mol dm(^{-3}) CH(_3)COCH(_3) (aq)</td>
<td>1.00 mol dm(^{-3}) H(^+) (aq)</td>
</tr>
<tr>
<td>1</td>
<td>10.0</td>
<td>60.0</td>
</tr>
<tr>
<td>2</td>
<td>10.0</td>
<td>50.0</td>
</tr>
<tr>
<td>3</td>
<td>5.0</td>
<td>65.0</td>
</tr>
<tr>
<td>4</td>
<td>10.0</td>
<td>65.0</td>
</tr>
</tbody>
</table>

(a) Explain why they added water to the mixtures. [1]
(b) (i) Deduce the order of reaction for each substance and the rate expression from the results. [2]
(ii) Comment on whether Alex’s or Hannah’s hypothesis is correct. [1]
Chem 6 9 Q# 23/ IB Chem/2009/w/TZ0/Paper 2 Section B/Higher Level/

6. (a) Consider the following reaction studied at 263 K.

$$2\text{NO}(g) + \text{Cl}_2(g) \rightleftharpoons 2\text{NOCl}(g)$$

It was found that the forward reaction is first order with respect to Cl$_2$ and second order with respect to NO. The reverse reaction is second order with respect to NOCl.

(i) State the rate expression for the forward reaction.

(ii) Predict the effect on the rate of the forward reaction and on the rate constant if the concentration of NO is halved.
(b) Consider the following reaction.

\[ \text{NO}_2(g) + \text{CO}(g) \rightarrow \text{NO}(g) + \text{CO}_2(g) \]

Possible reaction mechanisms are:

Above 775 K: \[ \text{NO}_2 + \text{CO} \rightarrow \text{NO} + \text{CO}_2 \quad \text{slow} \]

Below 775 K: \[ 2\text{NO}_2 \rightarrow \text{NO} + \text{NO}_3 \quad \text{slow} \]
\[ \text{NO}_2 + \text{CO} \rightarrow \text{NO}_2 + \text{CO}_2 \quad \text{fast} \]

Based on the mechanisms, deduce the rate expressions above and below 775 K. 

(c) State two situations when the rate of a chemical reaction is equal to the rate constant.

(d) Consider the following graph of \( \ln k \) against \( \frac{1}{T} \) for the first order decomposition of \( \text{N}_2\text{O}_4 \) into \( \text{NO}_2 \). Determine the activation energy in kJ mol\(^{-1}\) for this reaction.
1. (a) The diagram shows the apparatus used to study the rate of reaction between calcium carbonate and hydrochloric acid.

\[ \text{CaCO}_3(s) + 2\text{HCl}(aq) \rightarrow \text{CaCl}_2(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \]

cotton wool

dilute hydrochloric acid

calcium carbonate

The quantities of reactants added to the flask in one experiment carried out at room temperature were:

- mass of single piece of \( \text{CaCO}_3(s) = 5.00 \text{ g} \)
- volume of 1.00 mol dm\(^{-3}\) \( \text{HCl}(aq) = 50.0 \text{ cm}^3 \)

The balance was set to zero at the start of the experiment.

The graph shows how the mass of the flask and contents changed during Experiment.

![Graph showing mass of flask and contents over time](image-url)
(i) Explain why the mass decreased. [1]

(ii) Calculate the amount, in moles, of each reactant at the start of Experiment 1. [2]

(iii) Use your answers to (a)(ii), and the equation for the reaction, to deduce which reactant was added in excess. [1]

(iv) The experiment was repeated with small pieces of calcium carbonate. Draw two lines (labelled 2 and 3) on the graph to show how the mass of the flask and contents changes in the following experiments at the same temperature.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Mass of small pieces of CaCO₃(s)/g</th>
<th>Volume of 1.00 mol dm⁻³ HCl(aq)/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.50</td>
<td>50.0</td>
</tr>
<tr>
<td>3</td>
<td>5.00</td>
<td>25.0</td>
</tr>
</tbody>
</table>

[4]

(b) For the reaction between compounds A and B the initial rate was measured in a series of reactions carried out at the same temperature.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Initial [A] / mol dm⁻³</th>
<th>Initial [B] / mol dm⁻³</th>
<th>Initial rate / mol dm⁻³ min⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.2 × 10⁻²</td>
<td>7.8 × 10⁻²</td>
<td>8.8 × 10⁻⁴</td>
</tr>
<tr>
<td>2</td>
<td>4.2 × 10⁻²</td>
<td>3.9 × 10⁻²</td>
<td>2.2 × 10⁻⁴</td>
</tr>
<tr>
<td>3</td>
<td>8.4 × 10⁻²</td>
<td>3.9 × 10⁻²</td>
<td>2.2 × 10⁻⁴</td>
</tr>
</tbody>
</table>

(i) Deduce the order of reaction with respect to A and to B, giving a reason in each case. [2]
(ii) Deduce the rate expression for the reaction. \[1\]

\[
\text{Chem 6 15 Q# 25/ IB Chem/2008/s/TZ1/Paper 2 Section B/Higher Level/}
\]

7. (a) The oxidation of nitrogen monoxide takes place as follows:

\[
2\text{NO (g)} + \text{O}_2 (g) \rightarrow 2\text{NO}_2 (g)
\]

The following experimental data was obtained at a constant temperature.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Initial [NO] / mol dm(^{-3})</th>
<th>Initial [O(_2)] / mol dm(^{-3})</th>
<th>Initial rate / mol dm(^{-3}) s(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.50\times10^{-2}</td>
<td>1.75\times10^{-2}</td>
<td>3.75\times10^{-3}</td>
</tr>
<tr>
<td>2</td>
<td>3.50\times10^{-2}</td>
<td>3.50\times10^{-2}</td>
<td>7.50\times10^{-3}</td>
</tr>
<tr>
<td>3</td>
<td>7.00\times10^{-2}</td>
<td>7.00\times10^{-2}</td>
<td>6.00\times10^{-2}</td>
</tr>
</tbody>
</table>

(i) Deduce the order of reaction with respect to O\(_2\) and with respect to NO. \[2\]

(ii) State the rate expression for the reaction. \[1\]

(iii) Calculate the value of the rate constant and state the units. \[2\]

(iv) Calculate the expected rate of reaction if the reactants from experiment 2 were placed in a container of twice the original volume. Explain your answer. \[2\]

(v) Suggest a possible two step mechanism that is consistent with the rate expression. Identify the rate-determining step. \[3\]

(b) The reaction in (a) is faster at 323 K than at 298 K. Explain the increase in rate in terms of collision theory and Maxwell-Boltzmann energy distribution curves. \[5\]
### Topic 6 Mark Scheme

#### Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. a</td>
<td>$\text{H}_2\text{O AND (i)} \checkmark$</td>
<td>Do not accept $\text{H}_2\text{O} \text{ (aq)}$.</td>
<td>1</td>
</tr>
<tr>
<td>3. b</td>
<td>$\text{SO}_2(g)$ is an irritant/causes breathing problems OR $\text{SO}_2(g)$ is poisonous/toxic $\checkmark$</td>
<td>Accept $\text{SO}_2(g)$ is acidic but do not accept “causes acid rain”. Accept $\text{SO}_2(g)$ is harmful. Accept $\text{SO}_2(g)$ has a foul/pungent smell.</td>
<td>1</td>
</tr>
<tr>
<td>3. c</td>
<td>$n(\text{HCl}) = \frac{10.0}{1000} \text{ dm}^3 \times 2.00 \text{ mol dm}^{-3} = 0.0200 \div 2.00 \times 10^{-3} \text{ mol}$ AND $n(\text{Na}_2\text{S}_2\text{O}_3) = \frac{50}{1000} \text{ dm}^3 \times 0.150 \text{ mol dm}^{-3} = 0.00750 \div 7.50 \times 10^{-3} \text{ mol} \checkmark$</td>
<td>Accept answers based on volume of solutions required for complete reaction. Award [2] for second marking point. Do not award M2 unless factor of 2 (or half) is used.</td>
<td>2</td>
</tr>
<tr>
<td>3. d</td>
<td>[Graph showing rate of reaction vs. $[\text{Na}_2\text{S}_2\text{O}_3]$]</td>
<td>Five points plotted correctly $\checkmark$. Best fit line drawn with ruler, going through the origin $\checkmark$.</td>
<td>2</td>
</tr>
<tr>
<td>Question</td>
<td>Answers</td>
<td>Notes</td>
<td>Total</td>
</tr>
<tr>
<td>----------</td>
<td>---------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>3. e i</td>
<td>first order ✓&lt;br&gt;because [Na₂S₂O₃] is «directly» proportional to rate of reaction&lt;br&gt;&lt;br&gt;( 1 ) ✓&lt;br&gt;&lt;br&gt;Award [2] for correct final answer.&lt;br&gt;Accept value based on candidate’s graph.</td>
<td>Do not accept “linear” for M2.</td>
<td>2</td>
</tr>
<tr>
<td>3. e ii</td>
<td>rate = ( k [\text{Na}_2\text{S}_2\text{O}_3][\text{HCl}] ) ✓&lt;br&gt;&lt;br&gt;( 22.5 \times 10^{-2} \text{s}^{-1} ) ✓&lt;br&gt;&lt;br&gt;( \text{Time} = \frac{1}{22.5 \times 10^{-2}} = 44.4 \times 10^2 ) ✓&lt;br&gt;&lt;br&gt; Award M2 as ECF from M1. Award [1 max] for methods involving taking mean of appropriate pairs of ( \frac{1}{t} ) values. Award [3] for taking mean of pairs of time values.</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3. f</td>
<td><img src="image" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. g i</td>
<td><img src="image" alt="Graph" /></td>
<td>Accept “probability density” / number of&lt;br&gt;particles / N / fraction” on y-axis. Accept “kinetic E/KE/Eₗ” but not just “Energy/E” on x-axis.</td>
<td>2</td>
</tr>
<tr>
<td>3. g ii</td>
<td>greater proportion of molecules have ( E \geq E₂ ) or ( E &gt; E₂ )&lt;br&gt;greater area under curve to the right of the ( E₂ ) ✓&lt;br&gt;greater frequency of collisions «between molecules»&lt;br&gt;more collisions per unit time/second ✓&lt;br&gt;&lt;br&gt;Accept more molecules have energy greater than ( E₂ ).&lt;br&gt;Do not accept just “particles have greater kinetic energy”&lt;br&gt;Accept “rate/chance/probability/likelihood” instead of “frequency”&lt;br&gt;Accept suitably shaded/annotated diagram.&lt;br&gt;Do not accept just “more collisions”.&lt;br&gt;&lt;br&gt;Accept cooling of reaction mixture during course of reaction.</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3. h</td>
<td>shorter reaction time so larger «%» error in timing/seeing when mark disappears ✓&lt;br&gt;&lt;br&gt;Accept reaction mixture during course of reaction.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>4. f</td>
<td>( a ) is indicative of frequency of collisions and probability that collisions have proper orientation ✓&lt;br&gt;&lt;br&gt;( k = \left( \frac{\exp \left[ \frac{-(-7.0 \times 10^8)}{8.31 \times 298} + \ln (2.10 \times 10^{13}) \right]}{8.31 \times 298} \right) = 1.2 \times 10^{-4} ) ✓&lt;br&gt;&lt;br&gt;( S_{\text{H}_2} ) implies second-order so mol^{-1} dm³ s^{-1} ✓</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Q# 3/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

3. a i \(2\text{NO}(g) + 2\text{H}_2(g) \rightarrow \text{N}_2(g) + 2\text{H}_2\text{O}(g)\) ✓

3. a ii \(\text{rate} = k[\text{NO}]^2[\text{H}_2]\) ✓

\[\text{Remember to refer back to a (i) for ECF.}\]

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 [H₂] constant AND test the effect of varying [H₂] on rate, whilst keeping [NO] constant ✓

\[\text{rate proportional to } [\text{NO}]^2 \text{ OR doubling [NO] quadruples rate ✓}\]

\[\text{rate proportional to } [\text{H}_2] \text{ OR doubling [H}_2\text{] doubles rate ✓}\]

\[\text{If only one species in rate expression, third mark can be awarded for zero order discussion.}\]

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 ✓

\[\text{Accept other methods where rate can be monitored with time.}\]

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. b iii</td>
<td><img src="image" alt="Graph" />second curve at a higher temperature is correctly drawn (maximum lower and to right of original) ✓</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
| 3. b iv | greater proportion of molecules have \(E \leq E_0\), or \(E > E_0\), OR greater area under curve to the right of the \(E_0\) ✓

\[\text{greater frequency of collisions between molecules} \text{ OR more collisions per unit time/second ✓}\]

\[\text{Do not accept just particles have greater kinetic energy.}\]

\[\text{Do not accept just "more collisions".}\] | | 2 |

Q# 4/ IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/Q7

(c) (i) Order with respect to \(\text{O}_2\): first (order); Order with respect to \(\text{NO}\): second (order); [2]

(ii) \((\text{rate} = k[\text{NO}]^2[\text{O}_2])\); [1]

(iii) \(172.6 \div 173\)

\[\text{mol}^{-2} \text{dm}^6 \text{s}^{-1};\]

\[\text{Accept } M^{-2} \text{ s}^{-1} \text{ mol}^{-2} \text{ L}^2 \text{ s}^{-1}.\] [2]
(iv) \[ \text{NO} + \text{NO} \rightleftharpoons \text{N}_2\text{O}_2 \text{ (fast)}; \]
\[ \text{N}_2\text{O}_2 + \text{O}_2 \rightarrow 2\text{NO}_2 \text{ (slow)}; \]
second step is rate determining step;

OR

\[ \text{NO} + \text{O}_2 \rightleftharpoons \text{O} + \text{NO}_2 \text{ (fast)}; \]
\[ \text{O} + \text{NO} \rightarrow \text{NO}_2 \text{ (slow)}; \]
second step is rate determining step;

OR

\[ \text{NO} + \text{O}_2 \rightleftharpoons \text{NO}_3 \text{ (fast)}; \]
\[ \text{NO}_3 + \text{NO} \rightarrow 2\text{NO}_2 \text{ (slow)}; \]
second step is rate determining step;

*Accept single arrow instead of reversible sign.*

*Accept fast/slow next to the equations.*

*Do not accept the following mechanisms:*

\[ \text{NO} + \text{NO} \rightleftharpoons \text{NO}_2 + \text{N} \text{ (fast)} \]
\[ \text{N} + \text{O}_2 \rightarrow \text{NO}_2 \text{ (slow)} \]

OR

\[ \text{NO} + \text{NO} + \text{O}_2 \rightleftharpoons \text{N}_2\text{O}_4 \text{ (slow)} \]
\[ \text{N}_2\text{O}_4 \rightarrow 2\text{NO}_2 \text{ (fast)} \]

\[ \text{gradient} = -\frac{E_a}{R} / -1233 \text{ (K)}; \]

*Accept value from \(-1200\) to \(-1260\) (K).*

\[ E_a = (1233 \times 8.31) = 1.02 \times 10^4 \text{ Jmol}^{-1} / 10.2 \text{kJ mol}^{-1} \]

correct \(E_a\) value;

correct units;

*Allow value in range \(9.97 - 10.5 \text{ kJ mol}^{-1}\).*

*Answer must be given to three significant figures.*

Award [3] for correct final answer and units.

Accept J or kJ instead of J mol\(^{-1}\) or kJ mol\(^{-1}\).
Q# 6/ IB Chem/2015/s/TZ2/Paper 2 Section A/Higher Level/

2. (a) change in concentration of reactant/product with time / rate of change of concentration;
   Accept “increase” instead of “change” for product and “decrease” instead of “change” for reactant.
   Accept “mass/amount/volume” instead of “concentration”.
   Do not accept substance. [1]

(b) surface area decreases;
   frequency/probability of collisions decreases;
   Accept number of collisions per unit time decreases. [2]

(c) (i) step 2 / X + NO → Y + H₂O / slow; [1]

   (ii) invalid / unlikely as order most likely one (with respect to hydrogen);
   rate = k[NO]²[H₂] / H₂ only involved once in the formation of the intermediate before the slow step / OWTTE;
   Award M2 only if M1 is correct. [2]

Q# 7/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q7

(c) (i) [NaOH] / [OH⁻] is 1/first order and [C₆H₆Br] is 1/first order;
   rate = k [OH⁻][C₆H₆Br] / rate = k[NaOH][C₆H₆Br];
   Square brackets must be used for M2. [2]

   (ii) \[
   \frac{1.02 \times 10^{-4}}{0.25 \times 0.25} = 0.0016 / 1.6 \times 10^{-3};
   \]
   mol⁻¹ dm⁻³ s⁻¹;
   Accept M⁻¹ s⁻¹.
   Ignore order of units.
   Must use experiment 3 data. [2]

   (iii) bimolecular/2;
   Accept dimolecular. [1]
Q# 8/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/

3. (a) change in concentration of reactant/product with time / rate of change of concentration; 
   Accept “increase” instead of “change” for product and “decrease” instead of “change” for reactant. 
   Accept “mass/amount/volume” instead of “concentration”. 
   Do not accept substance. 

   (b) collision frequency; 
   two particles must collide; 
   particles must have sufficient energy to overcome the activation energy/ $E \geq E_a$; 
   Concept of activation energy must be mentioned. 

   appropriate collision geometry/orientation; 

   (c) (i) increases yield; 
   (equilibrium shifts to the right/products as) more gaseous moles in reactants/on left / fewer gaseous moles in products/on right; 

   (ii) Eqm[O$_2$] = 2.6 (mol dm$^{-3}$); 
   Eqm[SO$_2$] = 1.2 (mol dm$^{-3}$); 
   
   $K_c = \frac{[SO_2]^2}{[SO_2]^2[O_2]}$; 
   $K_c = 0.17$; 
   Award [4] for correct final answer. 
   Ignore units. 

   (iii) $(K_c)$ decreases; 

   (d) catalyst increases rate of reaction / equilibrium reached faster / increases yield of product per unit time; 
   reduces costs / reduces energy needed; 
   Do not accept just “increases the yield”. 

Q# 9/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/

11. (a) (i) (draw a) tangent to the curve at origin/time = 0/start of reaction; 
   (calculate) the gradient/slope (of the tangent); 

   (ii) rate decreases (with time); 
   concentration/number of (reactant) molecules per unit volume decreases (with time); 
   Do not accept “number of molecules decreases” or “amount of reactant decreases”.

   collisions (between reactant molecules/reactant and catalyst) become less frequent; 
   Do not accept “fewer collisions” without reference to frequency (eg, no. collisions per second).
(b)  \( y\)-axis: probability / fraction of molecules/particles / probability density
Allow "number of particles/molecules" on \( y\)-axis.
and
\( x\)-axis: (kinetic) energy;
Accept "speed/velocity" on \( x\)-axis.

![Graph showing probability of molecules vs. (Kinetic) Energy]

- correct relative position of \( E_a\) catalysed and \( E_a\) uncatalysed;
- more/greater proportion of molecules/collisions have the lower/required/catalysed \( E_a\) (and can react upon collision);
- \( M3\) can be scored by stating or shading and annotating the graph.
  Accept "a greater number/proportion of successful collisions as catalyst reduces \( E_a\)."

(c)  

(i) reactant not involved in (or before) the slowest/rate-determining step/RDS;
  reactant is in (large) excess;  \([1\ max]\)

(ii) \( (rate =) k[A]; \)
  \( k = k[A]^j[B]^0.\)  \([1]\)

(d) curve with a positive slope curving upwards;
**Do not penalize if curve passes through the origin.**  \([1]\)
Q# 10/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/

6. (a) (i) | Liquid | 0.500 mol dm\(^{-3}\) HCl | 0.0200 mol dm\(^{-3}\) Na\(_2\)S\(_2\)O\(_3\) | Water |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume / cm(^3)</td>
<td>10(0)</td>
<td>20(0)</td>
<td>20(0)</td>
</tr>
</tbody>
</table>

Accept other volumes in a 1:2:2 ratio. [1]

(ii) depth of liquid in the beaker must remain constant / OWTTE; [1]
Accept “same thickness of glass” and any other valid point, such as answers framed around minimizing uncontrolled variables / making it a “fair test”.

(iii) 94 s / 1 min 34 s; [1]

(b) (i) \[ \text{rate} = k[S_2O_3^{2-}][H^+]^2 / \text{rate} = k[Na_2S_2O_3][HCl]^2; \] [1]

(ii) correct scale and units on y-axis; [1]
Accept other suitable scales (such as 1/t) and units (such as ms\(^{-1}\)).
Axes do not have to show origin/start at zero.

Correct calculation of rate in s\(^{-1}\): [3]

<table>
<thead>
<tr>
<th>[HCl] / mol dm(^{-3})</th>
<th>0.02</th>
<th>0.04</th>
<th>0.06</th>
<th>0.08</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time / s</td>
<td>89.1</td>
<td>72.8</td>
<td>62.4</td>
<td>54.2</td>
</tr>
<tr>
<td>Rate / s(^{-1})</td>
<td>0.0112</td>
<td>0.0137</td>
<td>0.0161</td>
<td>0.0185</td>
</tr>
</tbody>
</table>

If graph correct, assume this has been done on calculator and not written down.

Correct plotting of points that the student decides to use and a connecting line; [3]
Award final mark if 3 or more points are correct, irrespective of what is plotted on y-axis.
If line goes through the correct values at given concentrations of HCl, assume that points are marked there.
(iii) linear dependence on [HCl] (so not second order in [H⁺]);
*Accept that doubling of concentration does not result in quadrupling of rate / OWTTE.*
does not go through origin;
*Remember to allow ECF from (b) (i).*

(c) (i) 

![Graph showing kinetic energy vs. number of particles](image)

*labelled y-axis: number of particles / probability of particles (with that kinetic energy) and labelled x-axis: (kinetic) energy;*  
*Allow fraction/proportion/amount of particles (with kinetic energy) for y-axis label.*  
*Allow speed/velocity for x-axis label.*

*T₂ curve broader and with maximum lower and to right of T₁ curve;  
Do not award this mark if both curves not asymmetric.*  
*Curves must pass through the origin and be asymptotic to x axis.*  
*Do not award this mark if curves not labelled.*

*Eₐ marked on graph:*  

(ii) kinetic energy of molecules increases;  
*This may be answered implicitly in the final marking point.*

*frequency of collision/number of collisions per unit time increases;  
Do not accept “number of collisions increases”.*

*greater proportion of molecules have energy greater than/equal to activation energy / rate related to temperature by the Arrhenius equation;  
Award [1 max] for statements such as “there will be more successful collisions” if neither of last two marking points awarded.*
Q# 11/ IB Chem/2014/s/TZ1/Paper 2 Section A/Higher Level/

2. (a) experiments 1 and 2 ([S₂O₃²⁻] remains constant) change in [H⁺] does not affect the rate so zero order with respect to H⁺(aq) / OWTTE;
   experiment 1/2 and 3 ([H⁺] has no effect) [S₂O₃²⁻] is halved and rate is also halved so first order with respect to [S₂O₃²⁻] / OWTTE; [2]

   Accept explanation given in mathematical terms.

   Award [1 max] if both [S₂O₃²⁻] is first order, and [H⁺] is zero order are stated without reason.

(b) rate = \( k[S₂O₃²⁻] \); [1]

(c) 0.18;
   s⁻¹; [2]

(d) \( S₂O₃²⁻ \rightarrow S + SO₃²⁻ \); [1]

   Accept any balanced equation that starts with only one \( S₂O₃²⁻ \).

   Equations must be balanced in terms of number of atoms and charge.

(e) determine rate at a range of temperatures (while keeping concentrations constant);
    calculate \( k \) for each temperature;
    plot graph of ln \( k \) against \( T \);\(^⁻¹\);
    gradient is \( \frac{-E_a}{R} \) / OWTTE; [3 max]
Q# 12/ IB Chem/2013/w/TZ0/Paper 2 Section A/Higher Level/

1. (a) KI/I\textsubscript{2}/potassium iodide/iodide (ion) (rapidly) reformed (in second stage of reaction):

(b) amount (in mol) of H\textsubscript{2}O\textsubscript{2}/hydrogen peroxide >> amount (in mol) Na\textsubscript{2}S\textsubscript{2}O\textsubscript{3}/S\textsubscript{2}O\textsubscript{3}\textsuperscript{2-}/sodium thiosulfate/thiosulfate (ion);
Accept amount (in mol) of H\textsubscript{2}O\textsubscript{2}/hydrogen peroxide >> amount (in mol) KI/I\textsubscript{2}/potassium iodide/iodide (ion).
Accept “H\textsubscript{2}O\textsubscript{2}/hydrogen peroxide is in (large) excess/high concentration”.

(at end of reaction) [H\textsubscript{2}O\textsubscript{2}] is only slightly decreased/virtually unchanged;

(c) all Na\textsubscript{2}S\textsubscript{2}O\textsubscript{3}/sodium thiosulfate/S\textsubscript{2}O\textsubscript{3}\textsuperscript{2-}/thiosulfate consumed/used up;
Accept “iodine no longer converted to iodide”.

(free) iodine is formed / iodine reacts with starch / forms iodine-starch complex;

(d) (i)  \( (5 \times 0.1) = (\pm) 0.5 \text{ (cm}^3 \text{)} \);  
(ii) \( (\pm) 0.7 \text{ (\%)} \);
Comprises both mass of KI = \( \pm 0.5 \text{ \%} \) and volume of KI = \( \pm 0.2 \text{ \%} \).
(iii) \( 0.5 + 0.7 = (\pm) 1.2 \text{ \%} \);
Sum of (i) and (ii) (percentage uncertainty of total volume = absolute uncertainty as 100 cm\textsuperscript{3}.

(e) total volume = 0.100(dm\textsuperscript{3})/100(cm\textsuperscript{3});

(change in concentration = \( \frac{1.00 \times 10^{-4}}{0.100} \rightarrow 1.00 \times 10^{-3} \text{ (mol dm}^{-3}) \);
rate = \( \frac{1.00 \times 10^{-3}}{45} \rightarrow 2.2 \times 10^{-5} \text{ mol dm}^{-3} \text{ s}^{-1} \);
Award [3] for the correct final answer.

mol dm\textsuperscript{-3} s\textsuperscript{-1},

[1] [2] [3] [4]
(f) (i) x-axis: \( \frac{1}{\text{Temperature}} \) / \( \frac{1}{T} \) / \( T^{-1} \);  
Ignore units.  
y-axis: ln rate/log\( \text{a} \) rate / ln rate constant/log\( \text{a} \) rate constant / ln \( k \)/log\( \text{a} \)\( k \);  

(ii) gradient = \( \frac{-E_a}{R} \);  

\[
\text{gradient} = \frac{-4.00}{(3.31 \times 10^{-3} - 2.83 \times 10^{-3})} = \frac{-8333}{(3.41 \times 10^{-3} - 2.83 \times 10^{-3})} = -8276;
\]

\[
E_a = \left( \frac{8.31 \times 8333}{1000} \right) = 69.3 \text{(kJ mol}^{-1} \text{)} = \left( \frac{8.31 \times 8276}{1000} \right) = 68.8 \text{(kJ mol}^{-1} \text{)}; \quad [3]
\]

Award [3] for correct final answer.  
Accept values from 65.0 to 73.0 kJ mol\(^{-1}\).  
Deduct [1] for final answer in J mol\(^{-1}\).  
Deduct [1] for final answer not to 3 significant figures.  

(g) acting as a catalyst / black powder reacts with thiosulfate ions / solid dissolves to give blue-black solution;  
Accept any other valid suggestion which will make colour change more rapid.  

For catalyst: amount/mass of black powder remains constant / no new/different products formed / activation energy decreased;  
For other suggestions: any appropriate way to test the hypothesis;  

Award [1] for valid hypothesis, [1] for appropriate method of testing the stated hypothesis.  

Q# 13/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/  
2. (a) minimum energy needed (by reactants/colliding particles) to react/start/initiate a reaction / for a successful collision;  
Allow energy difference between reactants and transition state.  

(b) \( k \) increases with \( T \);  
Do not accept \( k \) proportional to \( T \) or statement of Arrhenius equation from Data booklet.  

(c) slope/gradient/m = \( -\frac{E_a}{R} \) / -6.20\( \times 10^{-3} \);  
Allow range of \( m \) from -5.96\( \times 10^{-3} \) to -6.44\( \times 10^{-3} \).  
Award M1 for \( m = \frac{-E_a}{R} \) even if gradient is out of range.  

\[
E_a = (6.20 \times 10^{3} \times 8.31) = 51.5 \text{kJ mol}^{-1} / 5.15 \times 10^{4} \text{J mol}^{-1}
\]

\( E_a \) value correct;  
units correct;  
Award [3] for correct final answer.  
Allow range of \( E_a \) from 49.5 to 53.5 kJ mol\(^{-1}\)/4.95\( \times 10^{4} \) to 5.35\( \times 10^{4} \) J mol\(^{-1}\).  
Answer must be given correct to three significant figures.  
M3 can be scored independently.  

Q# 14/ IB Chem/2013/s/TZ1/Paper 2 Section B/Higher Level/Q9
(c)  (i) \( C_4H_9Br: \)
\[ [C_4H_9Br] \text{ doubles and time halves/rate doubles/rate proportional to } [C_4H_9Br]; \]
\text{Do not accept rate increases when } [C_4H_9Br] \text{ increases.} \]

\text{NaOH:}
\[ [\text{NaOH}] \text{ doubles and time/rate does not change/rate independent of } [\text{NaOH}]; \]

\text{\( C_4H_9Br: \) first order and \( \text{NaOH: zero order}; \) \[3\]}

(ii) \[ \text{rate} = k[C_4H_9Br]; \]
\text{Accept ECF.} \[1\]

(iii) \[ s^{-1}; \]
\text{Accept ECF.} \[1\]

Q# 15/ IB Chem/2013/s/TZ1/Paper 2 Section A/Higher Level/

3.  (a) \text{minimum energy needed to react/start a reaction / energy difference between reactants and transition state; } \[1\]

(b) \text{gradient of the line: \( -63; \)}
\text{Accept \( -60 \) to \( -65. \)}

\[ E_s (= -R \times \text{gradient}) = 0.52 (\text{kJ mol}^{-1}); \]
\text{Accept 0.50 to 0.54.} \[2\]

(c) \text{gradient of the line less steep (less negative);}
\text{Accept any position as long as gradient less steep.} \[1\]
6. (a) (i) change in concentration of reactant/product with time / rate of change of concentration;  
Increase can be used instead of change for product or decrease can be used instead of change for reactant.  
Allow mass/amount/volume instead of concentration.  
Do not accept substance.  

(ii) concentration:  
particle size / surface area;  
heat;  
pressure;  
Allow pH.  

(iii) (measuring electrical) conductivity / (measuring) pH;  
Accept other suitable method. 

(b) (i) minimum/least/smallest energy needed (by reactants/colliding particles) to react/start/initiate a reaction;  
Allow energy difference between reactants and transition state.  
Minimum/least/smallest required for the mark.  

(ii) x-axis label: (kinetic) energy (K)E and y-axis label: probability/fraction of molecules/particles / probability density;  
Allow number of molecules/particles for y-axis.  

correct shape of a typical Maxwell–Boltzmann energy distribution curve;  
Do not award mark if curve is symmetric, does not start at zero or if it crosses x-axis.

two curves represented with second curve for $T_2 > T_1$ to right of first curve. peak maximum lower than first curve and after the curves cross going to the right, $T_2$ curve needs to be above $T_1$ curve as illustrated;  
$M2$ and $M3$ can be scored independently.
(c) (i) second order in ClO\textsubscript{2} and first order in OH\textsuperscript{-};
\[ \text{rate} = k[\text{ClO}_2][\text{OH}^-]; \]
Award [2] for correct final answer.

(ii) \[ k = 2.30 \times 10^5 / 230; \]
\[ \text{mol}^2 \text{dm}^4 \text{ s}^{-1}; \]

(iii) \[ 1.22 \times 10^{-1}/0.00122 \text{ (mol dm}^{-3} \text{ s}^{-1}); \]

(d) (i) ethyl ethanoate;
\[ \text{Do not allow ethyl acetate.} \]

(ii) as temperature \( T \) increases, (value of) rate constant \( k \) increases (exponentially);
\[ \text{Do not allow answers involving } \ln k \text{ from the Arrhenius equation.} \]
\[ \text{Do not allow } T \text{ directly proportional to } k. \]
(iii) \( \text{slope} = -5.6 \times 10^3 / -5600 \) (K);
\[
E_a = -\text{slope} \times R / \text{slope} = -E_a / R ;
\]
\[
E_a(-5.60 \times 10^3 \text{K} \times 8.31 J \text{K}^{-1} \text{mol}^{-1}) = 4.65 \times 10^4 (J \text{ mol}^{-1}) / 46.5 (kJ \text{ mol}^{-1});
\]
Accept answers in range \(4.60 \times 10^4 \text{ J mol}^{-1}\) to \(4.67 \times 10^4 \text{ J mol}^{-1}\).

\(\text{J mol}^{-1} / \text{kJ mol}^{-1}\);

Accept J or kJ.

Unit mark can be scored independently but correct \(E_a\) values with incorrect units scores only [3 max] (for example 46.5 J mol\(^{-1}\)).

Award [4] for correct final answer.

(f) (i) \(3\text{ClO}^-\text{(aq)} \rightarrow \text{ClO}_3^-\text{(aq)} + 2\text{Cl}^-\text{(aq)};\)

Ignore state symbols.

(ii) \(\text{Step 1: rate} = k[\text{ClO}^-]^2;\)

Step 2: rate \(= k[\text{ClO}_2^-][\text{ClO}^-];\)

Penalize missing \(k\) once only.

Q# 17/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/Q1a

(iv) negative/\~{-}/minus/\(<\ 0;\)

Q# 18/ IB Chem/2011/w/TZ0/Paper 2 Section B/Higher Level/Q8

(e) (i) dative (covalent) coordinate;

\(\text{carbon monoxide/CO / hydronium (ion)/H}_3\text{O}^+ / \text{ammonium (ion)/NH}_4^+ / \text{aluminium chloride/AlCl}_6 / \text{any relevant transition metal complex (e.g. } [\text{Ni(NH}_3)_6^{2+}]^{-};\)

Accept \(\text{AlCl}_3\).

(ii) rate \(= k[\text{BF}_3][\text{NH}_3];\)

second (order)/2°;

\(k = 3.40 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1};\)

Allow units of \(L \text{ mol}^{-1} \text{ s}^{-1}\) or \(M^{-1} \text{ s}^{-1}\).

Units required for mark.

(i) \(\text{N}_2\text{O}_2;\)

(ii) \(([\text{H}_2\text{]} \text{ appears in rate expression so}) \text{ step 2 rate-determining/rd/s/slow step;}\)

Allow “since step 1 involves 2\text{NO and step 2 involves H}_2\text{ and as all 3 molecules are involved in rate expression, then two steps must have approximately same rate” / OWTTE."

(g) \((k_2 \gg k_1 \text{ so}) \text{ step 1 rate-determining/rd/s/slow step; two molecules of NO}_2 \text{ involved in step 1 consistent with rate expression / rate of overall reaction must equal rate of step 1 which is rate } = k_1 [\text{NO}_2]^2 / OWTTE;\)
(h) \( E_a = -R \times m \):
measurement of gradient from two points on line:
Accept a gradient in range \(-2.14 \times 10^4\) \( K \) to \(-2.27 \times 10^4\) \( K \).

- correct answer for \( E_a \):
- correct units \( \text{kJ mol}^{-1} / \text{J mol}^{-1} \) corresponding to answer; \([4]\)
- Allow \( \text{kJ} \) or \( \text{J} \).
- A typical answer for \( E_a = 1.85 \times 10^4 \) \( \text{kJ mol}^{-1} \).
- Allow answers for \( E_a \) in range \( 1.75 \times 10^4 \) \( \text{kJ mol}^{-1} \) to \( 1.91 \times 10^4 \) \( \text{kJ mol}^{-1} \).
- Award [4] for correct final answer with some working shown.
- Award [2 max] for correct final answer without any working shown.

**Q# 19/ IB Chem/2011/w/TZ0/Paper 2 Section B/Higher Level/**

8. (a) minimum energy needed (by reactants/colliding particles) to react/start/initiate a reaction;
- Allow energy difference between reactants and transition state. \([1]\)

(b) catalyst;
- regenerated at end of reaction / \( \text{OWTTE} \); \([2]\)

(c) (i) (system) absorbs/takes in heat from surroundings / \( \text{OWTTE} \);
- Allow standard enthalpy change/ \( \Delta H^\circ \) positive.
- Allow bond breaking more energetic then bond formation / \( \text{OWTTE} \).
- Absorbs/takes in heat alone not sufficient for mark.

(ii) Curve showing:
- general shape of Maxwell-Boltzmann energy distribution curve;
- correct position of \( E_a \) (catalysed) and \( E_a \) (uncatalysed);
- labelled y-axis: probability of particles (with that kinetic energy) and labelled x-axis: (kinetic) energy;
- Allow number/fraction/proportion of particles (with kinetic energy) for y-axis label, but do not allow amount or particles. \([3]\)

![Diagram of probability distribution curve](image)

Award [2 max] if a second curve is drawn, but at a higher temperature, \( M^2 \) will not be scored here.

(d) (i) change in concentration of reactant/product with time / rate of change of concentration:
- Increase can be used instead of change for product or decrease can be used instead of change for reactant.
- Allow mass/amount/volume instead of concentration.
- Do not accept substance. \([1]\)
Q# 20/ IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/Q1

(d) (i) \[
\left( \frac{34.1}{0.0400} \right) \text{ dm}^3 \text{ s}^{-1} \left( \frac{1.50}{0.0400} \right) = 37.5 \text{ mol s}^{-1};
\]

Accept 851 dm$^3$ s$^{-1}$.
Units required for mark.

(ii) more energetic collisions / more species have energy \( \geq E_a \);
Allow more frequent collisions / species collide more often.

Q# 21/ IB Chem/2011/s/TZ1/Paper 2 Section A/Higher Level/

2. (a) \( k \) increases with increase in \( T \) / \( k \) decreases with decrease in \( T \);
Do not allow answers giving just the Arrhenius equation or involving ink relationships.

(b) gradient = \(-E_a/R\);
\(-30000 \text{ (K)} = -E_a/R; \)
Allow value in range \(-28800–31300 \text{ (K)}\).

\[
E_a = (30000 \times 8.31 =) \text{ 2.49} \times 10^5 \text{ J mol}^{-1}/249 \text{ kJ mol}^{-1};
\]
Allow value in range 240–260 kJ mol$^{-1}$.

(c) \( 0.9 \times 0.200 = 0.180 \text{ (mol dm}^{-3}\text{)}; \)

rate = \((0.244 \times (0.180)^2 =) \text{ 7.91} \times 10^{-3} \text{ mol dm}^{-3} \text{ s}^{-1}; \)
Award [2] for correct final answer.
Award [1 max] for either \( 9.76 \times 10^{-3} \text{ mol dm}^{-3} \text{ s}^{-1} \) or \( 9.76 \times 10^{-5} \text{ mol dm}^{-3} \text{ s}^{-1} \).
Q# 22/ IB Chem/2010/s/TZ1/Paper 2 Section A/Higher Level/

2. (a) to maintain a constant volume / \textit{OWTTE},

(b) (i) \([H^+]\) order 1, \([\text{CH}_3\text{COCH}_3]\) order 1, \([\text{I}_2]\) order 0;
(rate \(= k [H^+][\text{CH}_3\text{COCH}_3]\));
\textit{Award [2] for correct rate expression.}
\textit{Allow expressions including \([\text{I}_2]^2\).}

(ii) neither were correct / Alex was right about propanone and wrong about iodine / Hannah was right about propanone and hydrogen ions but wrong about iodine / \textit{OWTTE}.

(c) \([\text{CH}_3\text{COCH}_3] = 0.100 \text{ mol dm}^{-3}\) and \([H^+] = 0.100 \text{ mol dm}^{-3}\); \[ k = \frac{4.96 \times 10^{-9}}{0.100 \times 0.100} = 4.96 \times 10^{-4} \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}; \]
\textit{Ignore calculation of \([\text{I}_2]\).}
\textit{No ECF here for incorrect units.}

(d) (i) \[
\begin{array}{c}
\text{Number of particles} \\
E_a (\text{with catalyst}) \\
E_a (\text{no catalyst}) \\
\text{Energy}
\end{array}
\]
\text{axes correctly labelled \(x = \text{energy/velocity/speed}, y = \text{number/\% of molecules/particles/probability};\)}
\text{graph showing correct curve for Maxwell-Boltzmann distribution;}
\text{\textit{If two curves are drawn, first and second marks can still be scored, but not third.}}
\text{\textit{Curve(s) must begin at origin and not go up at high energy.}}
\text{two activation energies shown with \(E_{act}\) shown lower;}
\textit{Award the mark for the final point if shown on an enthalpy level diagram.}

(ii) catalyst provides an alternative pathway of lower energy / \textit{OWTTE};
\textit{Accept catalyst lowers activation energy (of reaction).}

Q# 23/ IB Chem/2009/w/TZ0/Paper 2 Section B/Higher Level/

6. (a) (i) \(\text{rate} = k[\text{NO}]^2[\text{Cl}_2]\); \[ [1] \]

(ii) rate of reaction will decrease by a factor of 4;
\text{no effect on the rate constant;} \[ [2] \]
(b) Above 775 K: rate = \( k [N O_2][C O] \);
Below 775 K: rate = \( k [N O_2]^2 \); \[2\]

(c) zero order reaction;
all concentrations are 1.0 mol dm\(^{-3}\); \[2\]

(d) slope = \( \frac{9.2 - 8.4}{(3.53 - 3.65) \times 10^3} = -6.67 \times 10^3 \);
\( (E_a = 6.67 \times 10^3 \times 8.31) \)
55.4 (kJ mol\(^{-1}\)) \[2\]

Accept in range 55.0 – 56.0
Award [1] if 55454 (J) stated
Award [2] for the correct final answer
Q# 24/ IB Chem/2008/w/TZ0/Paper 2 Section A/Higher Level/

1. (a) (i) gas/carbon dioxide/\( \text{CO}_2 \) is given off/evolves/escapes/formed; \[1\]

(ii) \( n(\text{CaCO}_3) \left( \frac{5.00}{100.09} \right) = 0.0500; \)

\( n(\text{HCl}) \left( \frac{1.00 \times 50.0}{1000} \right) = 0.0500; \) \[2\]

_Do not penalize significant figures.
No penalty for using 100 instead of 100.09.

(iii) CaCO\(_3\) because twice as much acid needed/\( OWTTE; \)

.Allow HCl is limiting.
Allow HCl in excess as correct deduction from wrong values in (a)(ii).

(iv) (line 2) steeper;
levels off at same mass as Experiment 1;
Apply ECF from part (ii).

(line 3) steeper;
levels off halfway between zero and Experiment 1; \[4\]

Allow ECF for lines on graph from HCl in excess in (a)(iii). This means that the lines are the same but numbered the other way round.
If lines are unlabelled allow \( 2 \text{ max} \).

(b) (i) order wrt A is zero because increasing/doubling [A] has no effect on rate/\( OWTTE; \)
order wrt B is 2 because doubling [B] quadruples rate/halving [B] quarters rate/\( OWTTE. \)
If explanations missing or incorrect but both orders correct, award \( 1 \text{ mark} \).
Accept other mathematical explanations.

(ii) rate = \( k[B]^2 \); rate = \( k[A]^0[B]^2; \)
ECF from (b)(i) \[1\]

(iii) \( k = \frac{8.8 \times 10^{-4}}{(7.8 \times 10^{-2})^2} = 0.14; \)
\( \text{mol}^{-1} \text{dm}^3 \text{ min}^{-1}; \) \[2\]
ECF from (b)(ii)
Q# 25/ IB Chem/2008/s/TZ1/Paper 2 Section B/Higher Level/

7. (a) (i) (exp. 1 and 2, [NO] constant, [O₂] doubled rate doubles) first order with respect to O₂;
(exp. 2 and 3, [O₂] doubled, [NO] doubled, rate increases by a factor of 8)
second order with respect to NO:
Accept alternative mathematical method [2]

(ii) \( \text{rate} = k[\text{NO}]^2[\text{O}_2] \); [1]
Allow ECF from (i).

(iii) \( k = \frac{3.75 \times 10^{-2}}{(3.50 \times 10^{-2})^2(1.75 \times 10^{-2})} \); [2 max]
=1.75 \times 10^3; dm³ mol⁻² s⁻¹;
Allow ECF from (ii).

(iv) \( 9.38 \times 10⁻^4 \) (mol dm⁻³ s⁻¹);
(since the volume is doubled), concentration is halved; [2]
Allow ECF from (ii).

(v) \( \text{NO} + \text{NO} \rightleftharpoons \text{N}_2\text{O}_2 \) (fast):
\( \text{N}_2\text{O}_2 + \text{O}_2 \rightarrow 2\text{NO}_2 \) (slow);
second step is rate-determining step/ıds;
OR
\( \text{NO} + \text{O}_2 \rightleftharpoons \text{NO}_3 \) (fast);
\( \text{NO}_3 + \text{NO} \rightarrow 2\text{NO}_2 \) (slow);
second step is rate determining step/ıds; [3 max]

Do not allow the following 2 mechanisms.

\( \text{NO} + \text{NO} \rightleftharpoons \text{NO}_2 + \text{N} \) slow
\( \text{N} + \text{O}_2 \rightarrow \text{NO}_2 \) fast

\( \text{NO} + \text{NO} + \text{O}_2 \rightarrow \text{N}_2\text{O}_2 \) slow
\( \text{N}_2\text{O}_4 \rightarrow 2\text{NO}_2 \) fast
(b) kinetic energy of molecules increases; frequency of collision increases; greater proportion of molecules have energy greater than/equal to activation energy; correct Boltzmann-energy distribution curves showing curve at higher temperature on the right side; broadening of the curve.

![Boltzmann distribution curve]

**Topic 7**

**Chem 7 3 Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/**

1. Ethane-1,2-diol, HOCH₂CH₂OH, has a wide variety of uses including the removal of ice from aircraft and heat transfer in a solar cell.

   (a) Ethane-1,2-diol can be formed according to the following reaction:

   \[ 2\text{CO}(g) + 3\text{H}_2(g) \rightleftharpoons \text{HOCH}_2\text{CH}_2\text{OH}(g) \]

   (i) Deduce the equilibrium constant expression, \( K_c \), for this reaction. [1]

   ... ...

   ... ...

   ... ...

   ... ...

   (ii) State how increasing the pressure of the reaction mixture at constant temperature will affect the position of equilibrium and the value of \( K_c \). [2]

   **Position of equilibrium:**

   ... ...

   \( K_c \):

   ... ...
2. One of the main constituents of acid deposition is sulfuric acid, H₂SO₄. This acid is formed from the sulfur dioxide pollutant, SO₂.

   A mechanism proposed for its formation is:
   \[
   \begin{align*}
   \text{HO}^\bullet(\text{g}) + \text{SO}_2(\text{g}) & \rightarrow \text{HOSO}_2(\text{g}) \\
   \text{HOSO}_2(\text{g}) + \text{O}_2(\text{g}) & \rightarrow \text{HO}^\bullet(\text{g}) + \text{SO}_3(\text{g}) \\
   \text{SO}_3(\text{g}) + \text{H}_2\text{O}(\text{l}) & \rightarrow \text{H}_2\text{SO}_4(\text{aq})
   \end{align*}
   \]

(b) Consider the following equilibrium between the two oxides of sulfur, sulfur dioxide and sulfur trioxide:

\[
2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g}) \quad \Delta H = -198 \text{ kJ}
\]

Predict, with a reason, in which direction the position of equilibrium will shift for each of the changes listed below.

<table>
<thead>
<tr>
<th>Change</th>
<th>Shift</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase in pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Addition of a catalyst</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Chem 7 4 Q# 3/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

2. Phosgene, COCl₂, is usually produced by the reaction between carbon monoxide and chlorine according to the equation:

\[ \text{CO (g)} + \text{Cl}_2 (g) \rightleftharpoons \text{COCl}_2 (g) \]

(a) (i) Deduce the equilibrium constant expression, \( K_c \), for this reaction. [1]

(ii) At exactly 600 °C the value of the equilibrium constant is 0.200. Calculate the standard Gibbs free energy change, \( \Delta G^\circ \), for the reaction, in kJ, using sections 1 and 2 of the data booklet. State your answer to three significant figures. [3]
7. (a) The following reaction is used in industry to obtain hydrogen from natural gas by partial oxidation with steam.

\[ \text{CH}_4(g) + \text{H}_2\text{O}(g) \rightleftharpoons 3\text{H}_2(g) + \text{CO}(g) \quad \Delta H^\circ = +206 \text{ kJ} \]

(i) Describe the effect, if any, of each of the following changes on the equilibrium amount of hydrogen, giving a reason in each case.

Increasing the pressure, at constant temperature:

Increasing the temperature, at constant pressure:

(ii) Discuss the effects of adding a solid catalyst to the mixture of methane and steam, at constant pressure and temperature.

(iii) Deduce the equilibrium constant expression, \( K_c \), for the reaction.
(iv) Identify which of the changes in part (a) (i) will affect the value of $K_c$ and whether the value will increase or decrease.

(b) The equilibrium constant, $K_c$, for the reaction

$$\text{CO}(g) + \text{H}_2\text{O}(g) \rightleftharpoons \text{H}_2(g) + \text{CO}_2(g)$$

was found to be 10.0 at 420°C.

1.00 mol of CO(g) and 1.00 mol of H$_2$O(g) are mixed in a 1.00 dm$^3$ container at 420°C. Calculate the equilibrium concentration of each component in the mixture, showing your working.

7. When nitrogen gas and hydrogen gas are allowed to react in a closed container the following equilibrium is established.

$$\text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) \quad \Delta H = -92.6 \text{ kJ}$$
The above equation is needed in question (d)(i)

(d) (i) Deduce the equilibrium constant expression, \( K_c \), for the reaction on page 10. \([1]\)

(ii) When 1.00 mol of nitrogen and 3.00 mol of hydrogen were allowed to reach equilibrium in a 1.00 dm\(^3\) container at a temperature of 500 °C and a pressure of 1000 atm, the equilibrium mixture contained 1.46 mol of ammonia.

Calculate the value of \( K_c \) at 500 °C. \([2]\)
7. When nitrogen gas and hydrogen gas are allowed to react in a closed container the following equilibrium is established.

\[ \text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) \quad \Delta H = -92.6 \text{ kJ} \]

(a) (i) Outline two characteristics of a reversible reaction in a state of dynamic equilibrium. [2]

(ii) Predict, with a reason, how each of the following changes affects the position of equilibrium. [2]

- The volume of the container is increased.
- Ammonia is removed from the equilibrium mixture.

(iii) Define the term activation energy, \( E_a \). [1]
(b) Ammonia is manufactured by the Haber process in which iron is used as a catalyst. Explain the effect of a catalyst on the rate of reaction.

(i) Explain why a temperature lower than 500 °C is not used.

(ii) Outline why a pressure higher than 200 atm is not often used.

(c) Typical conditions used in the Haber process are 500 °C and 200 atm, resulting in approximately 15 % yield of ammonia.

3. The rate of reaction is an important factor in industrial processes such as the Contact process to make sulfur trioxide, SO₃ (g).
   (c) The Contact process involves this homogeneous equilibrium:

   \[ 2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g) \quad \Delta H = -198 \text{kJ} \]

   (i) State and explain how increasing the pressure of the reaction mixture affects the yield of SO₃.
(ii) 2.00 mol of SO₂(g) are mixed with 3.00 mol of O₂(g) in a 1.00 dm³ container until equilibrium is reached. At equilibrium there are 0.80 mol of SO₃(g).

Determine the equilibrium constant (Kₑ) assuming all gases are at the same temperature and pressure.

(iii) State the effect of increasing temperature on the value of Kₑ for this reaction.

(d) Outline the economic importance of using a catalyst in the Contact process.
7. The Contact process involves an exothermic reversible reaction.

\[ 2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g) \quad K_c \gg 1 \text{ at } 200 \degree C \text{ and } 1 \text{ atm} \]

(a) Deduce the extent of the reaction at 200 \degree C and 1 atm.  \[1\]

(b) An engineer at a Contact process plant hypothesized that using pure oxygen, instead of air, would increase the profits. Comment on whether or not her hypothesis is valid, giving your reasons.  \[2\]
1. A class studied the equilibrium established when ethanoic acid and ethanol react together in the presence of a strong acid, using propanone as an inert solvent. The equation is given below.

\[
\text{CH}_3\text{COOH} + \text{C}_2\text{H}_5\text{OH} \rightleftharpoons \text{CH}_3\text{COOC}_2\text{H}_5 + \text{H}_2\text{O}
\]

One group made the following initial mixture:

<table>
<thead>
<tr>
<th>Liquid</th>
<th>Volume / cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanoic acid</td>
<td>5.00 ± 0.05</td>
</tr>
<tr>
<td>Ethanol</td>
<td>5.00 ± 0.05</td>
</tr>
<tr>
<td>6.00 mol dm⁻³ aqueous hydrochloric acid</td>
<td>1.00 ± 0.02</td>
</tr>
<tr>
<td>Propanone</td>
<td>39.0 ± 0.5</td>
</tr>
</tbody>
</table>

(a) The density of ethanoic acid is 1.05 g cm⁻³. Determine the amount, in mol, of ethanoic acid present in the initial mixture. [3]

(b) After one week, a 5.00 ± 0.05 cm³ sample of the final equilibrium mixture was pipetted out and titrated with 0.200 mol dm⁻³ aqueous sodium hydroxide to determine the amount of ethanoic acid remaining. The following titration results were obtained:

<table>
<thead>
<tr>
<th>Titration number</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial reading / cm³ ± 0.05</td>
<td>1.20</td>
<td>0.60</td>
<td>14.60</td>
</tr>
<tr>
<td>Final reading / cm³ ± 0.05</td>
<td>28.80</td>
<td>26.50</td>
<td>40.70</td>
</tr>
<tr>
<td>Titre / cm³</td>
<td>27.60</td>
<td>25.90</td>
<td>26.10</td>
</tr>
</tbody>
</table>
(ii) Suggest the average volume of alkali, required to neutralize the 5.00 cm$^3$ sample, that the student should use.

(iii) 3.00 cm$^3$ of the 0.200 mol dm$^{-3}$ aqueous sodium hydroxide reacted with the hydrochloric acid present in the 5.00 cm$^3$ sample. Determine the concentration of ethanoic acid in the final equilibrium mixture.

(iv) Deduce the equilibrium constant expression for the reaction.
(v) The other concentrations in the equilibrium mixture were calculated as follows:

<table>
<thead>
<tr>
<th>Compound</th>
<th>C$_2$H$_5$OH</th>
<th>CH$_3$COOC$_2$H$_5$</th>
<th>H$_2$O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration / mol dm$^{-3}$</td>
<td>0.884</td>
<td>0.828</td>
<td>1.80</td>
</tr>
</tbody>
</table>

Use these data, along with your answer to part (iii), to determine the value of the equilibrium constant. (If you did not obtain an answer to part (iii), assume the concentrations of ethanol and ethanoic acid are equal, although this is not the case.) [1]

(d) Outline how you could establish that the system had reached equilibrium at the end of one week. [1]

(e) Outline why changing the temperature has only a very small effect on the value of the equilibrium constant for this equilibrium. [1]
(f) Outline how adding some ethyl ethanoate to the initial mixture would affect the amount of ethanoic acid converted to product. [2]

.................................................................
.................................................................
.................................................................

(g) Propanone is used as the solvent because one compound involved in the equilibrium is insoluble in water.

(h) Suggest one other reason why using water as a solvent would make the experiment less successful. [1]

.................................................................
.................................................................
7. (a) An equilibrium exists between nitrosyl chloride, NOCl, nitrogen oxide, NO, and chlorine, Cl₂.

\[ 2\text{NOCl}(g) \rightleftharpoons 2\text{NO}(g) + \text{Cl}_2(g) \]

(i) Deduce the equilibrium constant expression for this reaction. \[1\]

(ii) Explain the effect on the position of equilibrium and the value of \( K_c \) when pressure is decreased and temperature is kept constant. \[2\]

(iii) 2.00 mol of NOCl was placed in a 1.00 dm³ container and allowed to reach equilibrium at 298 K. At equilibrium, 0.200 mol of NO was present. Determine the equilibrium concentrations of NOCl and Cl₂, and hence calculate the value of \( K_c \) at this temperature. \[3\]
4. (a) Hydrogen gas reacts with iodine gas to form hydrogen iodide gas. A 2.00 dm$^3$ flask was filled with $1.50 \times 10^{-2}$ mol of hydrogen and $1.50 \times 10^{-2}$ mol of iodine at a temperature, $T$. The equilibrium constant, $K_c$, has a value of 53.0 at this temperature.

(i) Deduce the equilibrium constant expression, $K_c$, for the formation of HI(g). [1]

(ii) Determine the equilibrium concentrations, in mol dm$^{-3}$, of hydrogen, iodine and hydrogen iodide. [4]
(c) The manufacture of gaseous methanol from CO and H₂ involves an equilibrium reaction.

\[ \text{CO}(g) + 2\text{H}_2(g) \rightleftharpoons \text{CH}_3\text{OH}(g) \quad \Delta H^\circ < 0 \]

(i) Outline the characteristics of a chemical equilibrium. \[2\]

(ii) Deduce the equilibrium constant expression, \( K_c \), for this reaction. \[1\]

(iii) 1.00 mol of \( \text{CH}_3\text{OH} \) is placed in a closed container of volume 1.00 dm³ until equilibrium is reached with CO and H₂. At equilibrium 0.492 mol of \( \text{CH}_3\text{OH} \) are present. Calculate \( K_c \).

\[3\]
(d) State and explain the effect of the following changes on the equilibrium position of the reaction in part (c).

(i) Increase in temperature. [2]

(ii) Increase in pressure. [2]

Methanol reacts with carbon monoxide to form ethanoic acid, CH₃COOH (l).

\[ \text{CH}_3\text{OH}(l) + \text{CO}(g) \rightarrow \text{CH}_3\text{COOH}(l) \]

\[ \Delta H = (-485 + 111 + 239 =) -135 \text{ (kJ mol}^{-1}\text{)} \]

(vi) In industry, this reaction is carried out at a temperature greater than 298 K. State and explain the effect of increasing the temperature on the value of the equilibrium constant, \( K_c \). [2]
6. Consider the two equilibrium systems involving bromine gas illustrated below.

(a) State equations to represent the equilibria in A and B with Br₂(g) on the left-hand side in both equilibria.

(b) (i) Describe what you would observe if a small amount of liquid bromine is introduced into A.
(ii) Predict what happens to the position of equilibrium if a small amount of hydrogen is introduced into B.

(iii) State and explain the effect of increasing the pressure in B on the position of equilibrium.

(c) (i) Deduce the equilibrium constant expression, $K_c$, for the equilibrium in B.

(ii) State the effect of increasing $[H_2]$ in B on the value of $K_c$.

(e) When bromine dissolves in water, 1% of the original bromine molecules react according to the following equation.

$$\text{Br}_2(\text{aq}) + \text{H}_2\text{O}(l) \rightleftharpoons \text{HOB}_\text{r}(\text{aq}) + \text{HBr}(\text{aq})$$
(iii) Estimate the magnitude of $K_c$ for this reaction. Choose your value from the following options:

\[ K_c = 0 \quad K_c < 1 \quad K_c = 1 \quad K_c > 1 \]

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(d) Nitrogen reacts with hydrogen to form ammonia in the Haber process, according to the following equilibrium.

\[ \text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) \quad \Delta H^\circ = -926 \text{ kJ} \]

(i) Define the term *rate of reaction.*

(ii) A high pressure such as 1000 atm and a low temperature such as 300 K can produce a high yield of ammonia. Discuss how these conditions compare with the actual conditions of pressure and temperature used in the Haber process.
(c) In an experiment conducted at 25.0°C, the initial concentration of propanoic acid and methanol were 1.6 mol dm$^{-3}$ and 2.0 mol dm$^{-3}$ respectively. Once equilibrium was established, a sample of the mixture was removed and analysed. It was found to contain 0.80 mol dm$^{-3}$ of compound X.

(i) Calculate the concentrations of the other three species present at equilibrium.  

(ii) State the equilibrium constant expression, $K_c$, and calculate the equilibrium constant for this reaction at 25.0°C.
4. Methanol may be produced by the exothermic reaction of carbon monoxide gas and hydrogen gas.

\[ \text{CO}(g) + 2\text{H}_2(g) \rightleftharpoons \text{CH}_3\text{OH}(g) \quad \Delta H^\circ = -103 \text{ kJ} \]

(a) State the equilibrium constant expression, \(K_e\), for the production of methanol. \([1]\)

(b) State and explain the effect of changing the following conditions on the amount of methanol present at equilibrium:

(i) increasing the temperature of the reaction at constant pressure. \([2]\)

(ii) increasing the pressure of the reaction at constant temperature. \([2]\)
(c) The conditions used in industry during the production of methanol are a temperature of 450°C and pressure of up to 220 atm. Explain why these conditions are used rather than those that could give an even greater amount of methanol.

(d) A catalyst of copper mixed with zinc oxide and alumina is used in industry for this production of methanol. Explain the function of the catalyst.
6. The Haber process enables the large-scale production of ammonia needed to make fertilizers.

(a) The equation for the Haber process is given below.

\[ \text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g}) \]

The percentage of ammonia in the equilibrium mixture varies with temperature.

(i) Use the graph to deduce whether the forward reaction is exothermic or endothermic and explain your choice. \[2\]

(ii) State and explain the effect of increasing the pressure on the yield of ammonia. \[2\]

(iii) Deduce the equilibrium constant expression, \(K_c\), for the reaction. \[1\]

(iv) A mixture of 1.00 mol \(\text{N}_2\) and 3.00 mol \(\text{H}_2\) was placed in a 1.0 dm\(^3\) flask at 400 °C. When the system was allowed to reach equilibrium, the concentration of \(\text{NH}_3\) was found to be 0.062 mol dm\(^{-3}\). Determine the equilibrium constant, \(K_c\), of the reaction at this temperature. \[3\]

(v) Iron is used as a catalyst in the Haber process. State the effect of a catalyst on the value of \(K_c\). \[1\]
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5. (a) The production of ammonia is an important industrial process.

\[ \text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) \]

(b) The reaction used in the production of ammonia is an equilibrium reaction. Outline the characteristics of a system at equilibrium. [2]

(c) Deduce the equilibrium constant expression, \( K_c \), for the production of ammonia. [1]

(d) (i) 0.20 mol of \( \text{N}_2(g) \) and 0.20 mol of \( \text{H}_2(g) \) were allowed to reach equilibrium in a 1 dm\(^3\) closed container. At equilibrium the concentration of \( \text{NH}_3(g) \) was 0.060 mol dm\(^{-3}\). Determine the equilibrium concentrations of \( \text{N}_2(g) \) and \( \text{H}_2(g) \) and calculate the value of \( K_c \). [3]

(ii) Predict and explain how increasing the temperature will affect the value of \( K_c \). [2]

(e) Consider the following equilibrium reaction.

\[ \text{Cl}_2(g) + \text{SO}_2(g) \rightleftharpoons \text{SO}_2\text{Cl}_2(g) \quad \Delta H^\circ = -84.5 \text{ kJ} \]

In a 1.00 dm\(^3\) closed container, at 375 °C, 8.60×10\(^{-3}\) mol of \( \text{SO}_2 \) and 8.60×10\(^{-3}\) mol of \( \text{Cl}_2 \) were introduced. At equilibrium, 7.65×10\(^{-4}\) mol of \( \text{SO}_2\text{Cl}_2 \) was formed.

(i) Deduce the equilibrium constant expression, \( K_c \), for the reaction. [1]

(ii) Determine the value of the equilibrium constant, \( K_c \). [3]

(iii) If the temperature of the reaction is changed to 300 °C, predict, stating a reason in each case, whether the equilibrium concentration of \( \text{SO}_2\text{Cl}_2 \) and the value of \( K_c \) will increase or decrease. [3]

(iv) If the volume of the container is changed to 1.50 dm\(^3\), predict, stating a reason in each case, how this will affect the equilibrium concentration of \( \text{SO}_2\text{Cl}_2 \) and the value of \( K_c \). [3]

(v) Suggest, stating a reason, how the addition of a catalyst at constant pressure and temperature will affect the equilibrium concentration of \( \text{SO}_2\text{Cl}_2 \). [2]
6. (a) Consider the following reaction studied at 263 K.

\[ 2\text{NO}(g) + \text{Cl}_2(g) \rightleftharpoons 2\text{NOCl}(g) \]

(iii) 1.0 mol of \text{Cl}_2 and 1.0 mol of \text{NO} are mixed in a closed container at constant temperature. Sketch a graph to show how the concentration of \text{NO} and \text{NOCl} change with time until after equilibrium has been reached. Identify the point on the graph where equilibrium is established. [4]

Chem 7 1 Q# 22/ IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/

5. Sodium oxide, \text{Na}_2\text{O}, is a white solid with a high melting point.

(b) Molten sodium oxide is a good conductor of electricity. State the half-equation for the reaction occurring at the positive electrode during the electrolysis of molten sodium oxide. [1]

Chem 7 5 Q# 23/ IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/

1. Biodiesel makes use of plants’ ability to fix atmospheric carbon by photosynthesis. Many companies and individuals are now using biodiesel as a fuel in order to reduce their carbon footprint. Biodiesel can be synthesized from vegetable oil according to the following reaction.

\[
\begin{align*}
\text{H} & \quad \text{O} \\
\text{H–C–O–C–R} & \quad \text{H–C–OH} \\
\text{H–C–O–C–R} & \quad \text{H–C–OH} \\
\text{H–C–O–C–R} & \quad \text{H–C–OH} \\
\text{H} & \quad \text{H}
\end{align*}
\]

vegetable oil   methanol   glycerol   biodiesel

(c) The reversible arrows in the equation indicate that the production of biodiesel is an equilibrium process.

(i) State what is meant by the term dynamic equilibrium. [1]

(ii) Using the abbreviations [vegetable oil], [methanol], [glycerol] and [biodiesel] deduce the equilibrium constant expression \((K_c)\) for this reaction. [1]
(iii) Suggest a reason why excess methanol is used in this process. [1]


(iv) State and explain the effect that the addition of the sodium hydroxide catalyst will have on the position of equilibrium. [2]


Chem 7 5 Q# 24/ IB Chem/2008/w/TZ0/Paper 2 Section A/Higher Level/

4. Much of the hydrogen used to manufacture ammonia is made using the following reaction between methane and steam.

\[
\text{CH}_4(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}(\text{g}) + 3\text{H}_2(\text{g}) \quad \Delta H^\circ = +210 \text{ kJ}
\]

(a) In an experiment using a nickel catalyst, 1.0 mol of methane and 2.0 mol of steam were added to a container of volume 20 dm\(^3\) and heated to a constant temperature. When equilibrium was reached the mixture contained 0.50 mol of carbon monoxide.

(i) Calculate the amount, in moles, of each of the other substances present. [2]

Methane

Steam

Hydrogen

(ii) Deduce the equilibrium constant expression, \(K_c\), for this reaction. [1]


(iii) Calculate a value for \(K_c\) for this reaction and deduce its units. [2]
(c) The following equilibrium is involved in the industrial production of nitric acid from ammonia.

\[ 4\text{NH}_3(g) + 5\text{O}_2(g) \rightleftharpoons 4\text{NO}(g) + 6\text{H}_2\text{O}(g) \quad \Delta H^\circ = -910 \text{ kJ mol}^{-1} \]

Describe the effect, if any, of each of the following changes on the equilibrium concentration of nitrogen monoxide in a particular equilibrium mixture, give a reason in each case.

(i) Increasing the pressure, at constant temperature \[2\]

(ii) Increasing the temperature, at constant pressure \[2\]

(iii) Addition of a heterogeneous catalyst, at constant pressure and temperature \[2\]

(d) Deduce the equilibrium constant expression, \(K_c\), including units for the forward reaction in part (c). \[2\]

(e) Identify which of the changes in part (c) will affect the value of \(K_c\) and predict whether the value of \(K_c\) will increase or decrease. \[2\]
### Topic 7 Mark Scheme

#### Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. a i</td>
<td>$K_c = \frac{[\text{HOCH}_2\text{CH}_2\text{OH}]}{[\text{CO}]^r \times [\text{H}_2]^s}$ ✓</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1. a ii</td>
<td>Position of equilibrium: moves to right OR favours product ✓ &lt;br&gt; $K_c$ no change OR is a constant at constant temperature ✓</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

#### Q# 2/ IB Chem/2016/s/TZ0SP/Paper 2 Section A/Higher Level/Q2

<table>
<thead>
<tr>
<th>Change</th>
<th>Shift</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in temperature</td>
<td>LHS</td>
<td>since &lt;forward&gt; exothermic reaction/ $\Delta H &lt; 0$ ✓</td>
</tr>
<tr>
<td>Increase in pressure</td>
<td>RHS</td>
<td>since fewer &lt;gaseous&gt; molecules on RHS ✓</td>
</tr>
<tr>
<td>Addition of a catalyst to the mixture</td>
<td>No change</td>
<td>since affects rate of forward and reverse reactions equally ✓</td>
</tr>
</tbody>
</table>

#### Q# 3/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. a i</td>
<td>$K_c = \frac{[\text{COCl}_2]}{[\text{CO}][\text{Cl}_2]}$ ✓</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>2. a ii</td>
<td>$T = 600 + 273 \Rightarrow 873K$ ✓ &lt;br&gt; $\Delta G^\circ = -6.31 \times 873 \times \ln(0.200)$ OR $\Delta G^\circ = -11676 \times \ln(0.200)$ ✓ &lt;br&gt; $\Delta G^\circ = -117.2 \times \ln(0.200)$ ✓</td>
<td>Accept 11.5 to 12.0. Award final mark only if correct sig fig. Award [3] for correct final answer.</td>
<td>3</td>
</tr>
</tbody>
</table>

#### Q# 4/ IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/

7. (a) (i) **Increasing the pressure, at constant temperature:** decreases; more (gas) molecules/moles on the right / fewer (gas) molecules/moles on the left; *Increasing the temperature, at constant pressure:* increases; (forward) reaction is endothermic;  

(ii) equilibrium reached faster; no change in the concentration of reactants/products/yield (at equilibrium) / position of equilibrium is not affected; rates of forward and reverse reactions increase (equally); reduces activation energy; no change in $K_c$:  

(iii) $(K_c) = \frac{[\text{H}_2]^r [\text{CO}]}{[\text{CH}_2][\text{H}_2\text{O}]}$.
(iv) (increasing) temperature and \( K_c \) increases; \[ \text{Award [1] if both temperature and pressure stated.} \]

(b) \( \text{CO}(g) + \text{H}_2\text{O}(g) \rightleftharpoons \text{H}_2(g) + \text{CO}_2(g) \)
\[
(1.00 - x) \quad x \quad x
\]
\[
K_c = 10.0 = \frac{x^2}{(1.00 - x)^2} / \sqrt{10.0} = \frac{x}{(1.00 - x)};
\]
\[
x = 0.760 / (1.00 - x) = 0.240;
\]
\[
[\text{CO}] = 0.240(\text{mol dm}^{-3}) \quad \text{and} \quad [\text{H}_2\text{O}] = 0.240(\text{mol dm}^{-3}) \quad \text{and} \quad [\text{H}_2] = 0.760(\text{mol dm}^{-3})
\]
\[
\text{and} \quad [\text{CO}_2] = 0.760(\text{mol dm}^{-3});
\]

Q# 5/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q7

(d) (i) \[
(K_c) = \frac{[\text{NH}_3(g)]^2}{[\text{N}_2(g)] \times [\text{H}_2(g)]^3};
\]
\[ \text{Ignore state symbols.} \]
\[ \text{Concentrations must be represented by square brackets.} \]

(ii) moles at equilibrium: nitrogen 0.27, hydrogen 0.81 / concentrations at equilibrium: nitrogen 0.27 (mol dm\(^{-3}\)) hydrogen 0.81 (mol dm\(^{-3}\)) (and ammonia 1.46 (mol dm\(^{-3}\)));
\[
K_c = 15;
\]
Actual calculation gives \( K_c = 14.86 \).
\[ \text{Award [2] for correct final answer.} \]
\[ \text{Award [1 max] if } K_c = \frac{1.46}{3 \times 1} = 0.079 \]

Q# 6/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/

7. (a) (i) rates of forward and reverse reactions are equal / opposing changes occur at equal rates;
the concentrations of all reactants and products remain constant / macroscopic properties remain constant;
closed/isolated system;
\[ \text{Accept “the same” for “equal” in M1 and for “constant” in M2.} \]

(ii) \text{The volume of the container is increased:} \]
\[
\text{position of equilibrium shifts to the left/reactants and fewer moles of gas on the right hand side/pressure decreases / OWITTE;} \]
\[
\text{Ammonia is removed from the equilibrium mixture;} \]
\[
\text{position of equilibrium shifts to the right/products and } [\text{NH}_3] \text{ decreases so } [\text{N}_2] \text{ and } [\text{H}_2] \text{ must also decrease to keep } K_c \text{ constant} \]
\[
\text{OR} \]
\[
\text{position of equilibrium shifts to the right/products and rate of reverse reaction decreases / OWITTE;} \]
\[ \text{Award [1 max] if both predicted changes are correct.} \]
\[ \text{Do not accept “to increase } [\text{NH}_3] \text{” or reference to LCP without explanation.} \]

(iii) minimum energy needed (by reactants/colliding particles) to react/start/ initiate a reaction;
\[ \text{Accept “energy difference between reactants and transition state”.} \]
(b) rate increases; more effective/successful collisions per unit time / greater proportion of collisions effective; alternative pathway and a lower activation energy

OR

lowers activation energy so that more particles have enough energy to react; Do not accept just “lowers/reduces the activation energy”. Accept “provides a surface for reacting/reactants/reaction”.

(c) (i) slower rate / OWTTE; uneconomic / OWTTE;

(ii) high cost for building/maintaining plant / high energy cost of compressor / OWTTE;

Do not accept “high pressure is expensive” without justification. Accept high pressure requires high energy.

Q# 7/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/Q3
(c) (i) increases yield; (equilibrium shifts to the right/products as) more gaseous moles in reactants/on left / fewer gaseous moles in products/on right;

(ii) \( \text{Eqm}[O_2] = 2.6 \text{ (mol dm}^{-3}\); \( \text{Eqm}[SO_2] = 1.2 \text{ (mol dm}^{-3}\);

\[
K_c = \frac{[SO_3]^2}{[SO_2][O_2]}
\]

\( K_c = 0.17 \);

Award [4] for correct final answer. Ignore units.

(iii) \( K_c \) decreases;

(d) catalyst increases rate of reaction / equilibrium reached faster / increases yield of product per unit time; reduces costs / reduces energy needed; Do not accept just “increases the yield”.

Q# 8/ IB Chem/2014/w/TZ0/Paper 2 Section A/Higher Level/
7. (a) concentration of products is much higher than the concentration of reactants / reaction nearly/almost goes to completion / position of equilibrium lies very far to the right / OWTTE;

Response must indicate the position of equilibrium is far to the right, but not complete conversion.

(b) (hypothesis is not valid as) equilibrium already nearly goes to completion / OWTTE;

(hypothesis is not valid as increase in yield may not be worth) expense of using pure oxygen / OWTTE;

(hypothesis is valid as pure oxygen) increases the rate of (the forward) reaction / more \( \text{SO}_3 \) produced per day/hour;

(hypothesis is valid as pure oxygen) shifts equilibrium to the right/products/\( \text{SO}_3 \) / increases the equilibrium concentration of \( \text{SO}_3 \);

Award [1 max] if no reference to “hypothesis”.

Q#9/ IB Chem/2014/s/TZ2/Paper 2 Section A/Higher Level/Q1

1. (a) \( \text{M}(\text{CH}_3\text{COOH}) = (4 \times 1.01) + (2 \times 12.01) + (2 \times 16.00) = 60.06 \text{ g mol}^{-1} \)

   Accept 60 \( \text{g mol}^{-1} \).

   mass \( \text{CH}_3\text{COOH} \) \( = 5.00 \times 1.05 \) = 5.25 (g)

   \[
   \frac{5.25}{60.06} = 0.0874 \text{ (mol)}; \\
   \text{Award } [3] \text{ for correct final answer.} \\
   \text{Accept 0.0875 (comes from using Mr } = 60 \text{ g mol}^{-1}).
   \]

(c)

(ii) \( 26.00 \text{ (cm}^{3}) \);

(3) \( 26.00 - 3.00 = 23.00 \text{ (cm}^{3}) \);

   If other methods used, award M1 for calculating amount of NaOH reacting with CH\(_3\)COOH.

   \[
   0.200 \times \frac{23.00}{5.00} = 0.920 \text{ (mol dm}^{-3}); \\
   \text{Award } [2] \text{ for correct final answer.}
   \\
   \text{If (ii) given as mean titre (26.5 cm}^{3}) \text{ then ECF answer comes to } 0.94 \text{ (mol dm}^{-3}).
   \]

(iv) \( \text{ } \text{K}_e = \frac{[\text{CH}_3\text{COOC}_2\text{H}_5][\text{H}_2\text{O}]}{[\text{C}_2\text{H}_5\text{OH}][\text{CH}_3\text{COOH}]} \);

   Do not penalize minor errors in formulas.

   Accept \( \text{K}_e = \frac{[\text{ester}][\text{water}]}{[\text{ethanol / alcohol}][\text{(ethanoic acid)}]} \).

(v) \( \text{K}_e = \frac{0.828 \times 1.80}{0.884 \times 0.920} = 1.83 \);

   If assumed \( [\text{CH}_3\text{COOH}] = 0.884 \text{ mol dm}^{-3} \), answer is 1.91 – allow this even if an answer was obtained for (iii).

   If (ii) given as mean titre (26.5 cm\(^3\)) then ECF answer comes to 1.79.

(d) Repeat the titration a day/week later (and result should be the same) / OWTTE;

   Accept “concentrations/physical properties/macroscopic properties of the system do not change”.

www.SmashingScience.org
(e) enthalpy change/\( \Delta H \) for the reaction is (very) small / \( OWTTE \); \[1\]

(f) decreases (the amount of ethanoic acid converted);
Accept “increases amount of ethanoic acid present at equilibrium” / \( OWTTE \).
(adding product) shifts position of equilibrium towards reactants/LHS / increases
the rate of the reverse reaction / \( OWTTE \); \[2\]

(g) ethyl ethanoate/\( \text{CH}_3\text{COOC}_2\text{H}_5 \)/ester;
forms only weak hydrogen bonds (to water);
Allow “does not hydrogen bond to water” / “hydrocarbon sections too long” / \( OWTTE \).
\( M2 \) can only be given only if \( M1 \) correct. \[2\]

(h) (large excess of) water will shift the position of equilibrium (far to the left) / \( OWTTE \);
Accept any other chemically sound response, such as “dissociation of ethanoic
acid would affect equilibrium”. \[1\]

Q# 10/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/

7. (a) (i) \( K_c = \frac{[\text{Cl}_2(\text{g})][\text{NO}(\text{g})]^2}{[\text{NOCl}(\text{g})]^2} \); \[1\]

Ignore state symbols.

(ii) equilibrium shifts to right as there are more moles (of gas) on product side;
no change to \( K_c \) as it is a constant at fixed temperature / \( OWTTE \); \[2\]

(iii) \[ \text{[NOCl(g)]} = 1.80 (\text{mol dm}^{-3}) \];
\[ \text{[Cl}_2(\text{g})] = 0.100 (\text{mol dm}^{-3}) \];
\[ K_c = \frac{0.100 \times (0.200)^2}{(1.80)^3} = 1.23 \times 10^{-3} (\text{mol dm}^{-3}) \]; \[3\]

Award [3] for correct final answer.

(iv) exothermic as \( K_c \) is lower at higher temperature; \[1\]
Q# 11/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/

4. (a) (i) \( K_c = \frac{[HI]^2}{[H_2][I_2]} \);

\( [HI] \) do not award mark if brackets are omitted or incorrect.

(ii) \( H_2 + I_2 \rightarrow 2HI \)

\( (7.50 \times 10^{-3} - x) \quad (7.50 \times 10^{-3} - x) \quad 2x / \)

\( (1.50 \times 10^{-2} - x) \quad (1.50 \times 10^{-2} - x) \quad 2x / \)

\( [H_2]_{\text{initial}} - x \quad [I_2]_{\text{initial}} - x \quad 2x; \)

Accept \( [H_2]_{\text{initial}} = [I_2]_{\text{initial}} = 7.50 \times 10^{-3} \text{ (mol dm}^{-3} \text{)} \) for M1.

\[
S_3 = \frac{(2x)^2}{(7.50 \times 10^{-3} - x)^2} / \sqrt{S_3} = \frac{(2x)}{(7.50 \times 10^{-3} - x)};
\]

Accept \( S_3 = \frac{(2x)^2}{(1.50 \times 10^{-2} - x)^2} / \sqrt{S_3} = \frac{(2x)}{(1.50 \times 10^{-2} - x)} \).

\( [H_2] = 1.62 \times 10^{-3} \text{ (mol dm}^{-3} \text{)} \) and \( [I_2] = 1.62 \times 10^{-3} \text{ (mol dm}^{-3} \text{)} \);

\( [HI] = 1.18 \times 10^{-3} \).

Award \( [4] \) for correct final answer for values given in M3 and M4.

Award \( [2 \text{ max]} \) for \( [H_2] = [I_2] = 7.50 \times 10^{-3} \text{ (mol dm}^{-3} \text{)} \) and \( [HI] = 5.46 \times 10^{-3} \text{ mol dm}^{-3} \).

OR

If \( K_c = \frac{[HI]}{[H_2][I_2]} \) is given in (i).

\[
\frac{1}{2} H_2 + \frac{1}{2} I_2 \rightarrow HI
\]

\( (7.50 \times 10^{-3} - x) \quad (7.50 \times 10^{-3} - x) \quad 2x / \)

\( (1.50 \times 10^{-2} - x) \quad (1.50 \times 10^{-2} - x) \quad 2x / \)

\( [H_2]_{\text{initial}} - x \quad [I_2]_{\text{initial}} - x \quad 2x; \)

Accept \( [H_2]_{\text{initial}} = [I_2]_{\text{initial}} = 7.50 \times 10^{-3} \text{ (mol dm}^{-3} \text{)} \) for M1.

\[
S_3 = \frac{(2x)}{(7.50 \times 10^{-3} - x)};
\]

Accept \( S_3 = \frac{(2x)}{(1.50 \times 10^{-2} - x)} \).

\( [H_2] = 2.73 \times 10^{-4} \text{ mol dm}^{-3} \) and \( [I_2] = 2.73 \times 10^{-4} \text{ mol dm}^{-3} \);

\( [HI] = 1.45 \times 10^{-3} \text{ mol dm}^{-3} \).

Award \( [4] \) for correct final answer for values given in M3 and M4.

Award \( [2 \text{ max]} \) for \( [H_2] = [I_2] = 7.50 \times 10^{-3} \text{ (mol dm}^{-3} \text{)} \) and \( [HI] = 5.46 \times 10^{-3} \text{ mol dm}^{-3} \).
Q# 12/ IB Chem/2013/s/TZ1/Paper 2 Section B/Higher Level/Q8

(c) (i) rate of forward reaction equals rate of backward reaction; concentrations of reactants and products do not change / constant macroscopic properties;  

(ii) \[ K_c = \frac{[\text{CH}_3\text{OH}]}{[\text{CO}][\text{H}_2]^2}; \]  

*Do not award mark if incorrect brackets are used or brackets omitted.

(iii) \[ n(\text{CO}) = 0.508 \text{ (mol)}; \]
\[ n(\text{H}_2) = 2 \times 0.508 \text{ (mol)}; \]
\[ K_c = \frac{0.492}{0.508 \times (2 \times 0.508)^2} = 0.938; \]

*Accept answer in range between 0.930 and 0.940.*
*Award [3] for correct final answer.*
*Award [2] for \( K_c = 1.066 \) if (c)(ii) is correct.

(d) (i) shifts to left/reactants; to endothermic side / (forward) reaction is exothermic;  

(ii) shifts to the right/products; to the side with fewer gas molecules/moles of gas;  

Q# 13/ IB Chem/2012/w/TZ0/Paper 2 Section B/Higher Level/Q5

(vi) \( K_c \) decreases;  
exothermic / \( \Delta H < 0; \]
*M1 and M2 depend on sign of \( \Delta H \) in (iii).*

Q# 14/ IB Chem/2012/s/TZ1/Paper 2 Section B/Higher Level/

6. (a) \( \text{Br}_2(\text{g}) \rightleftharpoons \text{Br}_2(\text{l}); \]
\( \text{H}_2(\text{g}) + \text{Br}_2(\text{g}) \rightleftharpoons 2\text{HBr}(\text{g}); \]

(b) (i) increase volume of liquid / no change of colour of vapour;  

(ii) shifts to right/toward products/forward reaction favoured;  

*Accept reverse statement if process written the other way around. Answer must match stated equation.*

(iii) no effect;  
same amounts/number of (gaseous) moles/molecules on both sides;  

(c) (i) \( K_c = \frac{[\text{HBr}]^2}{[\text{H}_2][\text{Br}_2]}; \]

(ii) no effect (only depends on the temperature);  

(iii) \( K_c < 1; \)
Q# 15/ IB Chem/2011/w/TZ0/Paper 2 Section B/Higher Level/Q8

(d) (i) change in concentration of reactant/product with time / rate of change of concentration; 
Increase can be used instead of change for product or decrease can be used instead of change for reactant. 
Allow mass/amount/volume instead of concentration. 
Do not accept substance. 

(ii) pressure is lower/moderate and temperature is higher in Haber process / ~ 200 atm (pressure) and ~ 700 K (temperature) used in Haber process; 

Pressure: 
high pressure shifts equilibrium to right; 
high pressure (faster rate but) expensive/dangerous / greater capital and running costs; 

Temperature: 
low temperature shifts equilibrium (even further) to right; 
low temperature gives slower rate (but high yield); 

high pressure increases yield and lower temperature decreases rate; 
Accept converse argument. 

(not possible to have high yield and fast rate simultaneously therefore) compromise needed / OWTE; 

[4 max]

Q# 16/ IB Chem/2011/s/TZ1/Paper 2 Section B/Higher Level/Q7

(e) (i) \([\text{CH}_3\text{CH}_2\text{COOH}]:\) 
\((1.6 - 0.80 =) 0.8 \text{ (mol dm}^{-3}\text{);}\) 
\([\text{CH}_3\text{OH}]:\) 
\((2.0 - 0.80 =) 1.2 \text{ (mol dm}^{-3}\text{);}\) 
\([\text{H}_2\text{O}]:\) 
\(0.80 \text{ (mol dm}^{-3}\text{);}\) 

\([\text{CH}_3\text{CH}_2\text{COOCH}_2\text{]} \cdot [\text{H}_2\text{O}] \) 
\([\text{CH}_3\text{CH}_2\text{COOH}] \cdot [\text{CH}_3\text{OH}]\):

\((K_c = \frac{[\text{CH}_3\text{CH}_2\text{COOCH}_2\]}{[\text{CH}_3\text{CH}_2\text{COOH}] \cdot [\text{CH}_3\text{OH}]})\;\)

\((K_c = \frac{[0.80]^2}{(1.2 \times 0.8)} = 0.7\); 

Allow 0.67. 
Award [1 max] for 0.83.
Q# 17/ IB Chem/2011/s/TZ1/Paper 2 Section A/Higher Level/

4. (a) \[ K_c = \frac{[CH_3OH]}{[CO][H_2]_3} \] ; \[1\]  
   Do not award mark if incorrect brackets are used or brackets are missing.

(b) (i) amount (of methanol)/product decreases / less methanol;  
   (forward reaction) exothermic / reverse reaction endothermic / OWTTE; \[2\]

(ii) amount (of methanol)/product increases / more methanol;  
   3 gas molecules/mol \( \rightarrow \) 1 / decrease in volume / fewer gas molecules on right  
   hand side/products / more gas molecules on left hand side/reactants; \[2\]

(c) high pressure expensive / greater cost of operating at high pressure;  
   lower temperature – lower (reaction) rate; \[2\]

(d) increases rate of forward and reverse reactions (equally) / lowers activation energy/\( E_a \)  
   (of both forward and reverse reaction equally) / provides alternative path with lower  
   activation energy/\( E_a \);  
   *Accept reactants adsorb onto the catalyst surface and bonds weaken resulting in a  
   decrease in activation energy.* \[1\]

Q# 18/ IB Chem/2010/w/TZ0/Paper 2 Section B/Higher Level/

6. (a) (i) exothermic;  
   *Accept either of the following for the second mark:  
   increasing temperature favours endothermic/reverse reaction;  
   as yield decreases with increasing temperature;* \[2\]

(ii) yield increases / equilibrium moves to the right / more ammonia;  
   increase in pressure favours the reaction which has fewer moles of gaseous  
   products; \[2\]

(iii) \[ K_c = \frac{[NH_3]^3}{[N_2][H_2]^3} \] ; \[1\]

(iv) \([N_2]: \) (at equilibrium = \( 1.00 - 0.031 = \) 0.969 \( \text{mol dm}^{-3} \));  
   \([H_2]: \) (at equilibrium = \( 3.00 - 3(0.031) = \) 2.91 \( \text{mol dm}^{-3} \));  
   \[ K_c = \frac{(0.062)^3}{(0.969)(2.91)^3} = 1.6(1) \times 10^{-4} ; \] \[3\]  
   *Ignore units.*  
   *Award [1] for \( K_c = 1.4 \times 10^{-4} \)

(v) no effect; \[1\]
(b) macroscopic properties remain constant / concentrations remain constant / no change to copper solution seen; rate of reverse/backwards reaction = rate of forward reaction; [2]

(c) \(K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]}\); [1]

*Do not award mark if [] missing or round brackets used.*

(d) (i) \([\text{H}_2] = 0.11 / 0.11 \text{ (mol dm}^{-3}\); \([\text{N}_2] = 0.17 / 0.17 \text{ (mol dm}^{-3}\); \(K_c = 16\);

*Ignore units.*

*Allow ECF from incorrect equilibrium expression and incorrect concentrations for third mark.*

(ii) decrease; heat is a product/reaction is exothermic so equilibrium moves to left / OWTTE; [2]

(e) yield increases / equilibrium moves to the right / more ammonia;

4 gas molecules \(\rightarrow\) 2 / decrease in volume / fewer gas molecules on right hand side; [2]

(f) high pressure expensive / greater cost of operating at high pressure / reinforced pipes etc. needed;

*Do not accept “high pressure is dangerous” without further explanation.*

lower temperature – greater yield, but lowers rate; [2]

*Do not award a mark just for the word “compromise”.*

(g) \(K_c\) unaffected;

position of equilibrium unaffected;

rate of forward and reverse reactions are increased (equally); [3]
Q# 20/ IB Chem/2009/w/TZ0/Paper 2 Section B/Higher Level/Q6

(e) (i) \( K_c = \frac{[SO_2Cl_2]}{[Cl_2][SO_2]} \); \[1\]

Ignore state symbols.
Square brackets [ ] required for the equilibrium expression.

(ii) \( 7.84 \times 10^{-3} \) mol of \( SO_2 \) and \( 7.84 \times 10^{-3} \) mol of \( Cl_2 \);
\( 7.84 \times 10^{-3} \) mol dm\(^{-3}\) of \( SO_2 \), \( 7.84 \times 10^{-3} \) mol dm\(^{-3}\) of \( Cl_2 \) and
\( 7.65 \times 10^{-4} \) mol dm\(^{-3}\) of \( SO_2Cl_2 \);
12.5;
Award \[1\] for 10.34
Award \[3\] for the correct final answer

(iii) value of \( K_c \) increases;
[\( SO_2Cl_2 \)] increases;
decrease in temperature favours (forward) reaction which is exothermic;
Do not allow ECF.

(iv) no effect on the value of \( K_c \); depends only on temperature;
[\( SO_2Cl_2 \)] decreases;
increase in volume favours the reverse reaction which has more gaseous moles;
Do not allow ECF.

(v) no effect;
catalyst increases the rate of forward and reverse reactions (equally); catalyst decreases activation energies (equally);

Q# 21/ IB Chem/2009/w/TZ0/Paper 2 Section B/Higher Level/Q6

(iii)

\[\text{Concentration / mol dm}^{-3}\]
\[\text{Time / s}\]
\(y\) axis labelled concentration/mol dm\(^{-3}\) and \(x\) axis is labelled time/s;
gradient for [NO];
gradient for [NOCl] will be equal and opposite;
equilibrium point identified / two curves level off at same time;

Q# 22/ IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/Q5

(b) \( 2O^{2-} \rightarrow O_2 + 4e^- / O^{2-} \rightarrow \frac{1}{2}O_2 + 2e^- \);

Accept \( e \) instead of \( e^- \).
Q# 23/ IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/Q1

(c) (i) rate of the forward reaction is equal to the rate of the reverse reaction / forward and reverse reactions occur and the concentrations of the reactants and products do not change / OWTTE; [1]

(ii) \[ K_c = \frac{[\text{glycerol}] \times [\text{biodiesel}]^2}{[\text{vegetable oil}] \times [\text{methanol}]^2}; \] [1]

(iii) to move the position of equilibrium to the right/product side / increase the yield of biodiesel; [1]

(iv) no effect (on position of equilibrium); increases the rate of the forward and the reverse reactions equally (so equilibrium reached quicker) / it lowers \( E_a \) for both the forward and reverse reactions by the same amount / OWTTE; [2]

No ECF for explanation.

Q# 24/ IB Chem/2008/w/TZ0/Paper 2 Section A/Higher Level/

4. (a) (i) (methane) 0.50 (mol)
    (steam) 1.5 (mol)
    (hydrogen) 1.5 (mol)
    Three correct award [2], two correct award [1], one or zero correct award [0]. [2]

(ii) \[ K_c = \frac{[\text{CO}] \times [\text{H}_2]^2}{[\text{CH}_4] \times [\text{H}_2\text{O}]}; \] [1]

(iii) \[ K_c = \frac{(0.50 + 20) \times (1.5 + 20)^2}{(0.50 + 20) \times (1.5 + 20)} = 5.6 \times 10^{-3}; \]
    mol\(^2\) dm\(^{-6}\); equilibrium constants have no units; [2]

    Apply ECF from (a)(i) and (ii).

Q# 25/ IB Chem/2008/s/TZ1/Paper 2 Section B/Higher Level/Q7

(c) (i) (equilibrium shifted to the left) equilibrium concentration of \( \text{NO}/[\text{NO}] \) is reduced;
    more gas molecules on the right hand side than on the left; [2]

(ii) (equilibrium shifted to the left) equilibrium concentration of \( \text{NO}/[\text{NO}] \) is reduced;
    forward reaction is exothermic; [2]

(iii) no effect on the equilibrium concentration of \( \text{NO}/[\text{NO}] \);
    catalyst increases the rate of forward and reverse reaction equally; [2]

(d) \[ K_c = \frac{[\text{NO}] \times [\text{H}_2\text{O}]^4}{[\text{NH}_3]^4 \times [\text{O}_2]^5}; \]
    mol dm\(^{-3}\); [2]

(e) increase in temperature; \( K_c \) decreases; [2]
Topic 8
Chem 8 Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

2. The concentration of a solution of a weak acid, such as ethanedioic acid, can be determined by titration with a standard solution of sodium hydroxide, NaOH(aq).

(a) Distinguish between a weak acid and a strong acid. [1]

Weak acid:


Strong acid:


(b) Suggest why it is more convenient to express acidity using the pH scale instead of using the concentration of hydrogen ions. [1]


(c) 5.00g of an impure sample of hydrated ethanedioic acid, (COOH)₂·2H₂O, was dissolved in water to make 1.00 dm³ of solution. 25.0 cm³ samples of this solution were titrated against a 0.100 mol dm⁻³ solution of sodium hydroxide using a suitable indicator.

\[(\text{COOH})_2(aq) + 2\text{NaOH}(aq) \rightarrow (\text{COONa})_2(aq) + 2\text{H}_2\text{O}(l)\]

The mean value of the titre was 14.0 cm³.

(i) Suggest a suitable indicator for this titration. Use section 22 of the data booklet. [1]


Chem 8 Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/
7. This question is about the weak acid methanoic acid, HCOOH.

(a) Calculate the pH of 0.0100 mol dm$^{-3}$ methanoic acid stating any assumption you make. $K_a = 1.6 \times 10^{-5}$. [3]

Calculation:

Assumption:


(b) (i) Sketch a graph of pH against volume of a strong base added to a weak acid showing how you would determine $pK_a$ for the weak acid. [2]
(ii) Explain, using an equation, why the pH increases very little in the buffer region when a small amount of alkali is added. [2]

Chem 8 2 Q# 3/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

2. One of the main constituents of acid deposition is sulfuric acid, H₂SO₄. This acid is formed from the sulfur dioxide pollutant, SO₂.

A mechanism proposed for its formation is:

\[
\begin{align*}
\text{HO}^\bullet(g) + \text{SO}_2(g) & \rightarrow \text{HOSO}_2(g) \\
\text{HOSO}_2(g) + \text{O}_2(g) & \rightarrow \text{HOO}^\bullet(g) + \text{SO}_3(g) \\
\text{SO}_3(g) + \text{H}_2\text{O}(l) & \rightarrow \text{H}_2\text{SO}_4(aq)
\end{align*}
\]

(a) State what the symbol (•) represents in the species shown in this mechanism. [1]

(d) Other compounds present in acid rain are formed from nitrogen dioxide, NO₂. Formulate an equation for the reaction of nitrogen dioxide with water. [1]
3. A 0.12 mol dm$^{-3}$ sodium methanoate solution dissociates completely into its ions.

   (a) Formulate the equation, including state symbols, for the equilibrium reaction of the hydrolysis of the methanoate anion. [$1$]

   ........................................................................................................

*Sections 1 and 21 of the data booklet may be used for parts (b) to (e).*

(b) Calculate the value of $K_a$, the acid dissociation constant at 298 K, for an aqueous solution of methanoic acid. [$1$]

   ........................................................................................................

   ........................................................................................................

(c) Calculate the value of $K_b$, the base dissociation constant, for the conjugate base. [$1$]

   ........................................................................................................

   ........................................................................................................

   ........................................................................................................
(d) Determine the concentration, in mol dm$^{-3}$, of hydroxide ion, [OH$^{-}\text{(aq)}$], in the original 0.12 mol dm$^{-3}$ sodium methanoate solution, mentioning one assumption made. [3]


(e) Calculate the pH of the 0.12 mol dm$^{-3}$ sodium methanoate solution. [2]


Chem 8 4 Q# 5/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/Q2
(d) Phenylamine can act as a weak base. Calculate the pH of a 0.0100 mol.dm$^{-3}$ solution of phenylamine at 298 K using section 21 of the data booklet. [4]
1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula $\text{PH}_3$.

It’s Lewis structure is this:

\[
\begin{array}{c}
\text{H} \\
\text{P} \\
\text{H} \\
\text{H}
\end{array}
\]

(iii) Deduce, giving your reason, whether phosphine would act as a Lewis acid, a Lewis base, or neither.

(vi) Ammonia acts as a weak Brønsted–Lowry base when dissolved in water.

\[
\text{NH}_3(\text{aq}) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq})
\]

Outline what is meant by the terms “weak” and “Brønsted–Lowry base”.

Weak:

Brønsted–Lowry base:

(b) Phosphine is usually prepared by heating white phosphorus, one of the allotropes of phosphorus, with concentrated aqueous sodium hydroxide. The equation for the reaction is:

\[
P_4(\text{s}) + 3\text{OH}^-(\text{aq}) + 3\text{H}_2\text{O}(l) \rightarrow \text{PH}_3(\text{g}) + 3\text{H}_3\text{PO}_4^-(\text{aq})
\]

(ii) The ion $\text{H}_3\text{PO}_4^-$ is amphiprotic. Outline what is meant by amphiprotic, giving the formulas of both species it is converted to when it behaves in this manner.
(iv) State the equation for the reaction of this oxide of phosphorus with water.  
……………………………………………………………………………………………………………………………………………………………

(v) Suggest why oxides of phosphorus are not major contributors to acid deposition.  
……………………………………………………………………………………………………………………………………………………………

(vi) The levels of sulfur dioxides, a major contributor to acid deposition, can be minimized by either pre-combustion and post-combustion methods. Outline one technique of each method.  
………………………………………………………………………………………………………………………………………………………………

Pre-combustion:  
……………………………………………………………………………………………………………………………………………………………

Post-combustion:  
……………………………………………………………………………………………………………………………………………………………

Chem 8 1 Q# 7/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

4. Tin(II) chloride is a white solid that is commonly used as a reducing agent.
   (a)  
   (iii) Tin(II) chloride reacts with water to precipitate the insoluble basic chloride, Sn(OH)Cl.

\[ \text{SnCl}_2(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{Sn(OH)}\text{Cl}(s) + \text{H}^+(aq) + \text{Cl}^-(aq) \]

Suggest why tin(II) chloride is usually dissolved in dilute hydrochloric acid.  
……………………………………………………………………………………………………………………………………………………………

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Chem 8 5 Q# 8/ IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/Q7

(d) Consider the following spontaneous reactions.

\[
\begin{align*}
\text{Fe(s)} + \text{Ni}^{2+} (aq) & \rightarrow \text{Fe}^{2+} (aq) + \text{Ni(s)} \\
\text{Zn(s)} + \text{Fe}^{2+} (aq) & \rightarrow \text{Zn}^{2+} (aq) + \text{Fe(s)} \\
\text{Ni(s)} + \text{Pb}^{2+} (aq) & \rightarrow \text{Ni}^{2+} (aq) + \text{Pb(s)}
\end{align*}
\]

(i) Deduce the order of increasing reactivity of the metals based on the reactions above. [2]

(ii) Identify the strongest oxidizing agent in the reactions above. [1]

(e) Deduce the half-equations for the formation of the major product at the positive electrode (anode) when the following aqueous solutions are electrolysed. [2]

Dilute sodium chloride:

Concentrated sodium chloride:
8. (a) 20.0 cm$^3$ aqueous solutions of two bases, each with a concentration of 0.100 mol dm$^{-3}$ were separately titrated with 0.100 mol dm$^{-3}$ hydrochloric acid, HCl (aq), and the following graph was obtained.
(i) Deduce the pH at the equivalence points for base I and base II. [2]

(ii) Suggest why the titration curve for base I is different from base II. [1]

(iii) State the formulas of two possible bases which could be used as base I. [1]

(iv) Calculate, using data from the graph, the dissociation constant, $K_b$, of base II, showing your working. [3]

(v) Suggest an indicator that can be used for both titrations. [1]
(b) (i) State what is meant by the term buffer solution.

(ii) Calculate the pH of a solution prepared by mixing 40.0 cm$^3$ of 0.200 mol dm$^{-3}$ NH$_3$ (aq) and 40.0 cm$^3$ of 0.100 mol dm$^{-3}$ HCl (aq), showing your working.
($pK_b$ NH$_3$ = 4.75 at 298K)

(c) The equations of two acid-base reactions are given below.

Reaction A: $\text{H}_2\text{CO}_3$ (aq) + $\text{H}_2\text{O}$ (l) $\rightleftharpoons$ HCO$_3^-$ (aq) + H$_3$O$^+$ (aq)

Reaction B: $\text{HCO}_3^-$ (aq) + $\text{H}_2\text{O}$ (l) $\rightleftharpoons$ CO$_3^{2-}$ (aq) + H$_3$O$^+$ (aq)

(i) Explain whether HCO$_3^-$ (aq) behaves as an acid or a base in each of the reactions A and B.
(ii) Deduce two conjugate acid-base pairs from reactions A and B. [2]

<table>
<thead>
<tr>
<th>Acid</th>
<th>Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conjugate acid-base pair 1</td>
<td></td>
</tr>
<tr>
<td>Conjugate acid-base pair 2</td>
<td></td>
</tr>
</tbody>
</table>

(d) Nitric acid, $\text{HNO}_3$, and nitrous acid, $\text{HNO}_2$, are described as strong and weak acids respectively.

(i) Distinguish between strong and weak acids. [1]

(ii) A 1.00 g sample of solid magnesium carbonate, $\text{MgCO}_3$, is added to separate solutions of $\text{HNO}_3$ and $\text{HNO}_2$ of the same concentration and temperature. State one similarity and one difference in the observations made in these reactions. [2]

Similarity:

Difference:

(iii) A solution of $\text{HNO}_3$ has a pH of 1, while a solution of $\text{HNO}_2$ has a pH of 5. Determine the ratio of the hydrogen ion concentration in $\text{HNO}_3$:$\text{HNO}_2$. [1]
Chem 8 3 Q# 10/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/Q2

(b) Cu²⁺(aq) reacts with ammonia to form the complex ion \([\text{Cu(NH}_3\text{)}_2]^2-\). Explain this reaction in terms of acid-base theory, and outline the bonding in the complex formed between Cu²⁺ and NH₃.

Chem 8 12 Q# 11/ IB CHEM/2015/s/TZ2/Paper 2 Section B/Higher Level/Q7

(e) (i) Define the term base according to the Lewis theory.

(ii) Define the term weak base according to the Brønsted–Lowry theory.
(iii) Deduce the formulas of conjugate acid-base pairs in the reaction below.

\[ \text{CH}_3\text{NH}_2(\text{aq}) + \text{H}_2\text{O}(l) \rightleftharpoons \text{CH}_3\text{NH}_3^+(\text{aq}) + \text{OH}^- (\text{aq}) \]  \[2\]

<table>
<thead>
<tr>
<th>Acid</th>
<th>Conjugate base</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(f) Determine the pH of a 0.100 mol dm\(^{-3}\) solution of ammonia, \(\text{NH}_3(\text{aq})\), using tables 2 and 15 of the data booklet.  \[4\]
(g)  (i) Sketch the pH titration curve obtained when 50.0 cm³ of 0.100 mol dm⁻³ NH₃ (aq) is added to 25.0 cm³ of 0.100 mol dm⁻³ HCl (aq).

(ii) Identify an indicator from table 16 of the data booklet that could be used for this titration.
Chem 8 8 Q# 12/ IB Chem/2015/s/TZ2/Paper 2 Section A/Higher Level/

4. A buffer solution with a pH of 3.87 contains 7.41 g dm$^{-3}$ of propanoic acid, CH$_3$CH$_2$COOH, together with an unknown quantity of sodium propanoate, CH$_3$CH$_2$COONa.

(a) Define the term buffer solution. [2]

(b) Explain, using appropriate equations, how this solution acts as a buffer solution. [2]

(c) Calculate the concentration, in mol dm$^{-3}$, of sodium propanoate in this buffer solution. The pK$_a$ of propanoic acid is 4.87 at 298 K. [4]
8. Acids can be described as strong or weak.

(a) (i) Outline the difference in dissociation between strong and weak acids of the same concentration.

(ii) Describe three tests that can be carried out in the laboratory, and the expected results, to distinguish between 0.10 mol dm\(^{-3}\) HCl (aq) and 0.10 mol dm\(^{-3}\) CH\(_3\)COOH (aq).

(b) Calculate the pH, using table 15 of the data booklet, of a solution of ethanoic acid made by dissolving 1.40 g of the acid in distilled water to make a 500 cm\(^3\) solution.
(c) (i) Determine the pH at the equivalence point of the titration and the $pK_a$ of an unknown acid using the acid-base titration curve below. [3]

(ii) Identify, using table 16 of the data booklet, a suitable indicator to show the end-point of this titration. [1]
(iii) Describe how an indicator, that is a weak acid, works. Use Le Chatelier’s principle in your answer.  

(i) State the formula of the conjugate base of chloroethanoic acid, CH₂ClCOOH.  

(ii) Identify, with a reason, whether chloroethanoic acid is weaker or stronger than ethanoic acid using Table 15 of the data booklet.  

(iii) Determine the pH of the solution resulting when 100 cm³ of 0.50 mol dm⁻³ CH₂ClCOOH is mixed with 200 cm³ of 0.10 mol dm⁻³ NaOH.
Chem 8 4 Q# 14/IB Chem/2015/sTZ1/Paper 2 Section A/Higher Level/Q2
(c) Predict and explain the pH of the following aqueous solutions, using equations to support your answer.

Ammonium chloride, NH₄Cl(aq):

Sodium methanoate, HCOONa(aq):

Chem 8 3 Q# 15/IB CHEM/2014/wTZ0/Paper 2 Section B/Higher Level/Q9
(g) Describe what is meant by a weak Brønsted–Lowry base, including an equation for the reaction of ammonia with water.

Chem 8 3 Q# 16/IB CHEM/2014/wTZ0/Paper 2 Section B/Higher Level/Q9
(g) Describe what is meant by a weak Brønsted–Lowry base, including an equation for the reaction of ammonia with water.
Chem 8 Q# 17/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q8

(f) (i) Most indicators are weak acids. Describe qualitatively how indicators work. [2]

(ii) Identify a suitable indicator for a titration between a weak acid and a strong base, using Table 16 of the Data Booklet. [1]

Chem 8 Q# 18/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q10

(e) (i) State a chemical equation for the partial dissociation of water into ions, including state symbols. [1]
(ii) The dissociation of water into ions is reversible. State the expression for the ionic product constant of water.

\[ \text{[1]} \]

\[ \text{-----------------------------} \]

(iii) The ionic product constant of water was measured at three different temperatures.

<table>
<thead>
<tr>
<th>Temperature / K</th>
<th>( K_w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>298</td>
<td>( 1.00 \times 10^{-14} )</td>
</tr>
<tr>
<td>313</td>
<td>( 2.92 \times 10^{-14} )</td>
</tr>
<tr>
<td>373</td>
<td>( 5.13 \times 10^{-13} )</td>
</tr>
</tbody>
</table>

Deduce whether the ionization of water is exothermic or endothermic, giving your reason.

\[ \text{[2]} \]

\[ \text{-----------------------------} \]

(iv) Use the data in part (iii) to determine the pH of water at 373 K, correct to two decimal places.

\[ \text{[2]} \]

\[ \text{-----------------------------} \]

Chem 8 1 Q# 19/ IB Chem/2014/w/TZ0/Paper 2 Section A/Higher Level/Q4

(c) Phosphoric(V) acid, \( \text{H}_3\text{PO}_4 \), has a \( pK_a \) of 2.12 (\( pK_{a1} \)) while phosphoric(III) acid, \( \text{H}_3\text{PO}_3 \), has a \( pK_a \) of 1.23 (\( pK_{a1} \)). Identify the weaker of the two acids, giving a reason for your choice.

\[ \text{[1]} \]

\[ \text{-----------------------------} \]
1. A student used a pH meter to measure the pH of different samples of water at 298 K.

<table>
<thead>
<tr>
<th>Sample</th>
<th>pH ± 0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain water</td>
<td>5.1</td>
</tr>
<tr>
<td>River water</td>
<td>4.4</td>
</tr>
<tr>
<td>Tap water</td>
<td>6.5</td>
</tr>
<tr>
<td>Bottled water</td>
<td>7.1</td>
</tr>
</tbody>
</table>

(a) Use the data in the table to identify the most acidic water sample. [1]

(b) Determine the ratio of [H⁺] in bottled water to that in rain water.

\[
\frac{[\text{H}^+] \text{ in bottled water}}{[\text{H}^+] \text{ in rain water}}
\] [2]

(d) Determine the concentration of hydroxide ions in the sample of river water. [2]

(e) The acidity of non-polluted rain water is caused by dissolved carbon dioxide. State an equation for the reaction of carbon dioxide with water. [1]
(e) Magnesium hydroxide, Mg(OH)₂, is only sparingly soluble in water and the equilibrium below exists when excess solid is in contact with a saturated solution.

\[ \text{Mg(OH)}_2(s) \rightleftharpoons \text{Mg}^{2+}(aq) + 2\text{OH}^-(aq) \]

Outline how the solubility of magnesium hydroxide will vary with pH. \[2\]

(b) In aqueous chlorine the equilibrium below produces chloric(I) acid (hypochlorous acid), HOCl, the active bleach.

\[ \text{Cl}_2(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{HOCl}(aq) + \text{H}^+(aq) + \text{Cl}^-(aq) \]

(i) Chloric(I) acid is a weak acid, but hydrochloric acid is a strong acid. Outline how this is indicated in the equation above. \[1\]
(iii) Outline, in terms of the equilibrium in aqueous chlorine, why it is dangerous to use an acidic toilet cleaner in combination with this kind of bleach. [2]

(iv) Suggest why a covalent molecule, such as chloric(I) acid, is readily soluble in water. [2]
(v) Partial neutralization of chloric(1) acid creates a buffer solution. Given that the $pK_a$ of chloric(1) acid is 7.53, determine the pH of a solution that has $[HOCl] = 0.100 \text{ mol dm}^{-3}$ and $[ClO^-] = 0.0500 \text{ mol dm}^{-3}$. 

(vi) Describe, using HIn to represent the indicator in its acid form, why an indicator changes colour when excess alkali is added.
6. A group of students investigated the rate of the reaction between aqueous sodium thiosulfate and hydrochloric acid according to the equation below.

\[ \text{Na}_2\text{S}_2\text{O}_3 (aq) + 2\text{HCl} (aq) \rightarrow 2\text{NaCl} (aq) + \text{SO}_2 (g) + \text{S} (s) + \text{H}_2\text{O} (l) \]

The two reagents were rapidly mixed together in a beaker and placed over a mark on a piece of paper. The time taken for the precipitate of sulfur to obscure the mark when viewed through the reaction mixture was recorded.

Initially they measured out 10.0 cm³ of 0.500 mol dm⁻³ hydrochloric acid and then added 40.0 cm³ of 0.0200 mol dm⁻³ aqueous sodium thiosulfate. The mark on the paper was obscured 47 seconds after the solutions were mixed.
(d) The teacher asked the students to devise another technique to measure the rate of this reaction.

(i) One group suggested recording how long it takes for the pH of the solution to change by one unit. Calculate the initial pH of the original reaction mixture.  

(ii) Deduce the percentage of hydrochloric acid that would have to be used up for the pH to change by one unit.
(e) Another group suggested collecting the sulfur dioxide and drawing a graph of the volume of gas against time.

(i) Calculate the volume of sulfur dioxide, in cm³, that the original reaction mixture would produce if it were collected at $1.00 \times 10^5$ Pa and 300 K. 

(ii) Sulfur dioxide, a major cause of acid rain, is quite soluble in water and the equilibrium shown below is established.

$$\text{SO}_2(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{HSO}_3^-(\text{aq}) + \text{H}^+(\text{aq})$$

Given that the $K_a$ for this equilibrium is $1.25 \times 10^{-2}$ mol dm⁻³, determine the pH of a 2.00 mol dm⁻³ solution of sulfur dioxide.

You will need table 21 from Data Booklet from 2016 for the next question.

(iii) Using Table 15 of the Data Booklet, identify an organic acid that is a stronger acid than sulfur dioxide.
Ammonia is a weak base.

(i) Calculate the pH of a 1.50 mol dm\(^{-3}\) solution of ammonia at 298 K to two decimal places, using Table 15 of the Data Booklet. \[2\]

(ii) A buffer solution is made using 25.0 cm\(^3\) of 0.500 mol dm\(^{-3}\) hydrochloric acid, HCl(aq), and 20.0 cm\(^3\) of 1.50 mol dm\(^{-3}\) ammonia solution, NH\(_3\)(aq).

Describe the meaning of the term buffer solution. \[2\]
(iii) Determine the pH of the buffer solution at 298K.

(iv) A 1.50 mol dm$^{-3}$ solution of ammonia is added to 25.0 cm$^3$ of a 0.500 mol dm$^{-3}$ hydrochloric acid solution in a titration experiment.

Calculate the total volume of the solution at the equivalence point.
(v) Calculate the pH of the solution at the equivalence point, using Table 15 of the Data Booklet. [4]

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(iv) Outline, including a relevant equation, whether the \([\text{Cr(H}_2\text{O)}_6]^3+\) ion is acidic, basic or neutral. \([1]\)

Chem 8 2 Q# 26/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/

8. (a) Outline how electrical conductivity can be used to distinguish between a 0.200 mol dm\(^{-3}\) solution of ethanoic acid, \(\text{CH}_3\text{COOH}\), and a 0.200 mol dm\(^{-3}\) solution of hydrochloric acid, \(\text{HCl}\). \([1]\)

(b) 25.0 cm\(^3\) of 0.200 mol dm\(^{-3}\) ethanoic acid was added to 30.0 cm\(^3\) of a 0.150 mol dm\(^{-3}\) sodium hydrogen carbonate solution, \(\text{NaHCO}_3(\text{aq})\).

(i) State an equation for the reaction of ethanoic acid with a solution of sodium hydrogen carbonate. \([1]\)
Chem 8 3 Q# 27/ IB Chem/2013/w/TZ0/Paper 2 Section A/Higher Level/Q3
(c) Nitrogen also forms oxides, which are atmospheric pollutants.

(i) Outline the source of these oxides. [1]

(ii) State one product formed from their reaction with water. [1]

(iii) State one environmental problem caused by these atmospheric pollutants. [1]

Chem 8 3 Q# 28/ IB Chem/2013/s/TZ1/Paper 2 Section B/Higher Level/Q6
(d) (i) Define an acid according to the Lewis theory. [1]

(ii) State and explain the acid–base character of PCl₃ according to the Lewis theory. [2]
(e) A solution of HA is a weak acid. Distinguish between a weak acid and a strong acid. [1]

(f) To investigate the effect of temperature on the effectiveness of a buffer solution, the student placed 20.0 cm$^3$ of the buffer solution in a water bath at 24°C. He added small portions of hydrochloric acid, stirring after each addition, until a total of 10 cm$^3$ was added, and measured the pH continuously during the addition. The procedure was repeated at different temperatures, and the results are shown in the following graph.

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Key:

- 24°C
- 35°C
- 40°C
- 50°C
- 70°C
(i) State what is meant by a buffer solution.

(ii) With reference to the graph on page 4, describe the effect of increasing temperature on the effectiveness of the buffer solution.
3. Buffer solutions are widely used in both chemical and biochemical systems.

(a) Describe the composition of an acidic buffer solution.

(b) Determine the pH of a buffer solution, correct to two decimal places, showing your working, consisting of 10.0 g of CH₃COOH and 10.0 g of CH₃COONa in 0.250 dm³ of solution. $K_a$ for CH₃COOH = $1.8 \times 10^{-5}$ at 298 K.
(d) (i) Hydrogen bromide forms a strong acid when dissolved in water whereas hydrogen fluoride forms a weak acid. Distinguish between the terms strong acid and weak acid. State equations to describe the dissociation of each acid in aqueous solution. [3]
(ii) A student titrated 25.00 cm$^3$ of a 0.100 mol dm$^{-3}$ solution of hydrofluoric acid, HF(aq), with 0.100 mol dm$^{-3}$ NaOH(aq). Some of his data are presented below.

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Two different data points can be used to determine a value for the $pK_a$ of HF (aq).
Identify the data points and determine the $pK_a$ using two different calculations.

(iii) Identify an indicator which could be used to find the equivalence point of the
titration using Table 16 of the Data Booklet and explain your choice.
4. Hypochlorous acid, HOCl(aq), is an example of a weak acid.

(a) State the expression for the ionic product constant of water, \( K_w \). [1]

\[
\text{.................}.
\]

(b) A household bleach contains sodium hypochlorite, NaOCl(aq), at a concentration of 0.705 mol dm\(^{-3}\). The hypochlorite ion, \( \text{OCl}^- \text{(aq)} \), is a weak base.

\[
\text{OCl}^- \text{(aq)} + \text{H}_2\text{O(l)} \rightleftharpoons \text{HOCl(aq)} + \text{OH}^- \text{(aq)}
\]

(i) The \( pK_a \) value of \( \text{HOCl(aq)} \) is 7.52. Determine the \( K_a \) value of \( \text{OCl}^- \text{(aq)} \) assuming a temperature of 298 K. [1]

\[
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\]

(ii) Determine the concentration of \( \text{OH}^- \text{(aq)} \), in mol dm\(^{-3}\), at equilibrium and state one assumption made in arriving at your answer other than a temperature of 298 K. [3]
(iii) Calculate the pH of the bleach. [2]

8. (a) (i) Define the terms *acid* and *base* according to the Bronsted-Lowry theory. Distinguish between a weak base and a strong base. State **one** example of a weak base. [3]

(ii) Weak acids in the environment may cause damage. Identify a weak acid in the environment and **outline one** of its effects. [2]
(iii) The graph below indicates the pH change during the titration of 20.0 cm$^3$ of 0.100 mol dm$^{-3}$ of CH$_3$COOH(aq) with 0.100 mol dm$^{-3}$ KOH(aq). From the graph, identify the volume of KOH(aq) and the pH at the equivalence point. [2]

(iv) Explain how the graph could be used to determine the $pK_a$ of ethanoic acid and determine the $pK_a$ value for these data. [2]
(v) Sketch a graph, similar to the graph on the previous page, to indicate the change in pH during a titration of 25.0 cm³ of 0.100 mol dm⁻³ HNO₃ (aq) with 0.100 mol dm⁻³ KOH (aq). On your graph, clearly indicate the starting pH value, the equivalence point, the pH at the equivalence point and the final pH reached.

(b) (i) Describe how an indicator works.
(ii) Using Table 16 of the Data Booklet, identify the most appropriate indicator for the titration of ethanoic acid with potassium hydroxide. Explain your choice. [2]

(c) Explain, using an equation, whether a solution of 0.10 mol dm$^{-3}$ FeCl$_3$(aq) would be acidic, alkaline or neutral. [2]

(d) Determine the pH of the solution resulting when 100 cm$^3$ of 0.50 mol dm$^{-3}$ HCl(aq) is mixed with 200 cm$^3$ of 0.10 mol dm$^{-3}$ NaOH(aq). [5]
(b) Ammonia can be converted into nitric acid, HNO₃(aq), and hydrocyanic acid, HCN(aq). The pKₐ of hydrocyanic acid is 9.21.

(i) Distinguish between the terms strong and weak acid and state the equations used to show the dissociation of each acid in aqueous solution. [3]

(ii) Deduce the expression for the ionization constant, Kₐ, of hydrocyanic acid and calculate its value from the pKₐ value given. [2]

(iii) Use your answer from part (b) (ii) to calculate the [H⁺] and the pH of an aqueous solution of hydrocyanic acid of concentration 0.108 mol dm⁻³. State one assumption made in arriving at your answer. [4]

(c) A small piece of magnesium ribbon is added to solutions of nitric and hydrocyanic acid of the same concentration at the same temperature. Describe two observations that would allow you to distinguish between the two acids. [2]

(d) A student decided to investigate the reactions of the two acids with separate samples of 0.20 mol dm⁻³ sodium hydroxide solution.

(i) Calculate the volume of the sodium hydroxide solution required to react exactly with a 15.0 cm³ solution of 0.10 mol dm⁻³ nitric acid. [1]

(ii) The following hypothesis was suggested by the student: “Since hydrocyanic acid is a weak acid it will react with a smaller volume of the 0.20 mol dm⁻³ sodium hydroxide solution.” Comment on whether or not this is a valid hypothesis. [1]

(iii) Use Table 16 of the Data Booklet to identify a suitable indicator for the titration of sodium hydroxide and hydrocyanic acid. [1]

(e) The graph below shows how the conductivity of the two acids changes with concentration.

![Graph showing conductivity vs concentration](image)

*Identify Acid 1 and explain your choice.* [2]
Chem 8 2 Q# 35/ IB Chem/2010/w/TZ0/Paper 2 Section B/Higher Level/Q4

(d) (i) State whether aqueous solutions of magnesium oxide and magnesium chloride are acidic, alkaline or neutral. [1]

(ii) State an equation for the reaction between magnesium oxide and water. [1]

Chem 8 10 Q# 36/ IB Chem/2010/s/TZ1/Paper 2 Section A/Higher Level/Q3

(d) (i) State an equation for the reaction of ethanoic acid with water. [1]

(ii) Calculate the pH of 0.200 mol dm$^{-3}$ ethanoic acid ($pK_a = 4.76$). [3]

(e) Determine the pH of a solution formed from adding 50.0 cm$^3$ of 1.00 mol dm$^{-3}$ ethanoic acid, CH$_3$COOH (aq), to 50.0 cm$^3$ of 0.600 mol dm$^{-3}$ sodium hydroxide, NaOH (aq). [4]

(f) Explain how the solution formed in part (e) can act as a buffer. Use equations to support your answer. [2]
8. (a) A 25.0 cm$^3$ solution of a weak monoprotic acid, HA (aq), is titrated with 0.155 mol dm$^{-3}$ sodium hydroxide, NaOH (aq), and the following graph is obtained.

![Graph showing pH vs. Volume of NaOH]

(i) Determine the pH at the equivalence point. [1]

(ii) Explain, using an equation, why the equivalence point is not at pH = 7. [3]

(iii) Calculate the concentration of the weak acid before the addition of any NaOH(aq). [2]

(iv) Estimate, using data from the graph, the dissociation constant, $K_a$, of the weak acid, HA, showing your working. [3]

(v) Suggest an appropriate indicator for this titration. [1]

(b) Describe qualitatively the action of an acid-base indicator. [3]

(c) (i) Explain what is meant by the term buffer solution. [2]

(ii) Calculate the pH of a solution prepared by mixing 50.0 cm$^3$ of 0.200 mol dm$^{-3}$ CH$_3$COOH (aq) and 50.0 cm$^3$ of 0.100 mol dm$^{-3}$ NaOH (aq), showing your working. [3]
(d) State whether AlCl₃ is acidic, basic or neutral in an aqueous solution. Write an equation to support your answer. [2]

(e) 0.100 mol of ammonia, NH₃, was dissolved in water to make 1.00 dm³ of solution. This solution has a hydroxide ion concentration of 1.28×10⁻³ mol dm⁻³.

(i) Determine the pH of the solution. [2]

(ii) Calculate the base dissociation constant, K_b, for ammonia. [3]

2. (a) The pKₐ value for propanoic acid is given in Table 15 of the Data Booklet.

(i) State the equation for the reaction of propanoic acid with water. [1]

(ii) Calculate the hydrogen ion concentration (in mol dm⁻³) of an aqueous solution of 0.100 mol dm⁻³ propanoic acid. [2]

(b) The graph below shows a computer simulation of a titration of 25.0 cm³ of 0.100 mol dm⁻³ hydrochloric acid with 0.100 mol dm⁻³ sodium hydroxide and the pH range of phenol red indicator.

![Graph showing pH range and indicator change](image-url)
Sketch the graph that would be obtained for the titration of 25.0 cm\(^3\) of 0.100 mol dm\(^{-3}\) propanoic acid with 0.100 mol dm\(^{-3}\) potassium hydroxide using bromophenol blue as an indicator. (The pH range of bromophenol blue can be found in Table 16 of the Data Booklet). [3]

![Graph showing pH vs. volume of KOH](image)

Volume of 0.100 mol dm\(^{-3}\) KOH (aq) added / cm\(^3\)

5. Sodium oxide, Na\(_2\)O, is a white solid with a high melting point.

(c) (i) State the acid-base nature of sodium oxide. [1]

(ii) State the equation for the reaction of sodium oxide with water. [1]

Chem 8 Q# 39/ IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/

For the following questions use information from Tables 16 and 17 in the Data Booklet where relevant.

(g) A 25.0 cm\(^3\) sample of an aqueous solution of benzoic acid needed 17.0 cm\(^3\) of 0.0300 mol dm\(^{-3}\) aqueous sodium hydroxide for complete neutralization.

(i) Calculate the acid dissociation constant, \(K_a\), for benzoic acid. [1]

(ii) Write an equation for the neutralization reaction. [1]

(iii) Identify a suitable indicator for the titration and explain your choice. [2]

(iv) Calculate the concentration, in mol dm\(^{-3}\), of the benzoic acid solution. [3]
3. (a) The equation for the reaction that occurs when ammonia gas dissolves in water is shown below:

\[ \text{NH}_3(g) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq) \]

(i) Define the term *Brønsted-Lowry acid.*

(ii) Identify a conjugate pair present in the above equation.

(iii) Identify one species in the equation above that acts as a Lewis base and name the type of bond it forms in the reaction.

(b) The ionization constant expression for methylamine is shown below.

\[ K_b = \frac{[\text{CH}_3\text{NH}_2^+][\text{OH}^-]}{[\text{CH}_3\text{NH}_2]} = 4.37 \times 10^{-4} \text{ mol dm}^{-3} \]

(i) Write an equation for the reaction between methylamine and water.

(ii) Calculate the pH of a 0.0500 mol dm\(^{-3}\) aqueous solution of methylamine. State any assumptions made in your calculation.
(iii) Calculate the pH of a buffer solution made by mixing together 0.025 mol of \( \text{CH}_3\text{NH}_2 \) and 0.010 mol of \( \text{HCl} \) in 1.0 dm\(^3\) of solution. [5]
3. Lactic acid, CH$_2$CH(OH)COOH, is a weak monoprotic acid ($K_a = 1.40 \times 10^{-4}$ mol dm$^{-3}$).

(a) Write an equation for the reaction of lactic acid with water. \[ \text{[2]} \]

(b) State the ionization constant expression, $K_a$, for lactic acid. \[ \text{[1]} \]

(c) Calculate the [H$^+$] of a 0.250 mol dm$^{-3}$ solution of lactic acid. \[ \text{[2]} \]

(d) Calculate the [H$^+$] of a buffer solution of 1.00 dm$^3$ volume, containing 0.250 mol dm$^{-3}$ of lactic acid and 0.125 mol dm$^{-3}$ of sodium lactate. \[ \text{[2]} \]

(e) Explain why the two values of [H$^+$] in (c) and (d) are different using Le Chatelier’s principle. \[ \text{[2]} \]
**Topic 8 Mark Scheme**

**Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
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<tbody>
<tr>
<td>2. a</td>
<td>Weak acid: partially dissociated/ionized in solution/water AND Strong acid: assumed to be almost completely/100% dissociated/ionized in solution/water</td>
<td>Accept answers relating to pH, conductivity, reactivity if solutions of equal concentrations stated.</td>
<td>1</td>
</tr>
</tbody>
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<tr>
<th>Question</th>
<th>Answers</th>
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<th>Total</th>
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<tbody>
<tr>
<td>2. b</td>
<td>log scales reduces a wide range of numbers to a small range OR simple/easy to use OR converts exponential expressions into a linear scale/simple numbers</td>
<td>Do not accept &quot;easy for calculations&quot;.</td>
<td>1</td>
</tr>
</tbody>
</table>

**Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/**

<table>
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<tbody>
<tr>
<td>7. a</td>
<td>Calculation: <strong>ALTERNATIVE 1:</strong> [ [H^+] = (K_a \times [H^+])^{1/2} / (1.6 \times 10^{-4} \times 0.0100)^{1/2} / 1.3 \times 10^{-3} \text{mol dm}^{-3} ] [ \text{pH} = -\log [H^+] = 2.9 ] <strong>ALTERNATIVE 2:</strong> [ \text{pH} = 0.5(pK_a - \log[H^+]) ] [ \text{pH} = 2.9 ]</td>
<td>Award [2] for correct final answer.</td>
<td>3</td>
</tr>
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</table>

**Q# 3/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/**

<table>
<thead>
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<th>Notes</th>
<th>Total</th>
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<tbody>
<tr>
<td>b i</td>
<td><img src="image" alt="Graph" /></td>
<td>Volume V_s at neutralization Volume of strong base added [ \text{pH} ] at half neutralization/equivalence</td>
<td>2</td>
</tr>
</tbody>
</table>

**Q# 4/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/**

<table>
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<th>Question</th>
<th>Answer</th>
<th>Notes</th>
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<tbody>
<tr>
<td>1. a</td>
<td>radical/unpaired electron</td>
<td></td>
<td>1</td>
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<tr>
<th>Question</th>
<th>Answers</th>
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<th>Total</th>
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<tbody>
<tr>
<td>4 d</td>
<td>[ 2\text{NO}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{HNO}_3(aq) + \text{HNO}_3(aq) ]</td>
<td>Ignore state symbols.</td>
<td>1</td>
</tr>
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</table>
Q# 5/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

2. d

\[ K_s = \frac{[\text{H}^+]^2}{[\text{C}_4\text{H}_2\text{N}_2\text{H}_2]} = 10^{-4.13} \div 7.413 \times 10^{-10} \]

\[ [\text{OH}^-] = \sqrt{0.0100 \times 10^{-3}} = 2.2 \times 10^{-5} \]

\[ [\text{H}^+] = 2.72 \times 10^{-9} = 3.67 \times 10^{-9} \]

OR

pOH = 5.57

pH = -\log [\text{H}^+] = 8.44

Accept other approaches to the calculation. Award [4] for correct final answer. Accept any answer from 8.4 to 8.5.

Q# 6/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/Q1(a)

1. a iii Lewis base AND has a lone pair of electrons \& donate

1

1. a vi Weak: only partially dissociated/fionized in dilute aqueous solution

Bransted-Lowry base: acid acceptor of protons/H+/hydrogen ions

Accept reaction with water is reversible/lan equilibrium. Accept “water is partially dissociated by the weak bases”.

2

1. b i \( P_4 \) is a molecule comprising 4P atoms AND 4P is four/separate \( \text{P} \) atoms

OR

\( P_4 \) represents 4\( \text{P} \) atoms bonded together AND 4\( \text{P} \) represents 4 separate/non-bonded \( \text{P} \) atoms

1

Question | Answers | Notes | Total
--- | --- | --- | ---
1. b ii can act as both a \( \text{Bransted-Lowry} \) acid and a \( \text{Bransted-Lowry} \) base

OR

can accept and/or donate a hydrogen ion/proton/H+ \( \text{H}_2\text{PO}_4^- \) \& \( \text{H}_2\text{PO}_4^- \)

Accept “hydrochloric acid reacts with \( \text{basic} \) chloride” OR “hydrochloric acid suppresses salt hydrolysis”.

2

Q# 7/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

4. a iii hydrochloric acid shifts equilibrium to left

OR

hydrochloric acid prevents the basic chloride forming/precipitating

1
Q# 8/ IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/Q7

(d) (i) Pb < Ni < Fe < Zn;
Award [2] for the correct order.
Award [1] for Zn > Fe > Ni > Pb as metals not listed in order of increasing reactivity.
Award [1] if one error in the order.

(ii) Pb$^{2+}$ lead(II) (ions);
Do not accept Pb/lead.

(e) Dilute sodium chloride:
$\frac{1}{2}$O$_2$ (g) + 2H$^+$ (aq) + 2e$^-$ / 2OH$^-$ (aq) $\rightarrow$ $\frac{1}{2}$O$_2$ (g) + H$_2$O (l) + 2e$^-$;

Concentrated sodium chloride:
Cl$^-$ (aq) $\rightarrow$ $\frac{1}{2}$Cl$_2$ (g) + e$^-$;

Award [1 max] if equations are given the wrong way round.
Accept e instead of e$^-$.
Ignore state symbols and equilibrium sign.
Accept correct half-equations balanced with different coefficients.
Q# 9/ IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/

8. (a) (i) base I: 7.0;
   base II: 5.5; [2]

(ii) base I: strong base and base II: weak base; [1]

(iii) NaOH and KOH;
   Accept LiOH. [1]

(iv) (from the graph: initial pH = 11, pOH = 3) \([\text{OH}^-] = 10^{-3} \text{mol dm}^{-3}\); \(K_b = \frac{10^{-3} \times 10^{-3}}{0.100 - x} / \frac{10^{-3} \times 10^{-3}}{0.100} \); 
   \(K_b = 1.0 \times 10^{-5}\);

OR

at half-equivalence point, pH = 9.0 = pK_b for base II;
   pK_b = 14.0 - 9.0 = 5.0;
   Award M1 and M2 for stating: “at half-equivalence point pOH = 5 = pK_b for base II”.
   
   \(K_b = 1.0 \times 10^{-5}\); [3]
   Accept other valid methods of working.
   Accept a slightly different value of pK_b and so K_b if the student uses the pH at the end point, rather than the initial or half-neutralisation values.

(v) methyl red;
   Do not accept bromocresol green (since from table 16 data booklet pH range, 3.8 is too low). [1]

(b) (i) resists change in pH;
   on addition of small amounts of acid and base; [2]

(ii) (after mixing) \([\text{NH}_3] = [\text{NH}_4^+] / n \text{NH}_3 = n \text{NH}_4^+ / n = 4.00 \times 10^{-3} \text{mol} \);
   \[[\text{OH}^-] = K_b \frac{[\text{base}]}{[\text{salt}]} / \text{pOH} = \text{pK}_b = 4.75; \]
   pH = 9.25;
   Award [1 max] if no working shown.
   Accept other valid methods of working. [3]

(c) (i) Reaction A: base and accepts a proton/H^+;
   Accept donates a pair of electrons.
   
   Reaction B: acid and donates a proton/H^+;
   
   Award [1] if acid and base identified correctly without a reason.

(ii) | Acid | Base |
     |------|------|
     | Conjugate acid-base pair 1/2 | \(\text{H}_2\text{CO}_3\) and \(\text{HCO}_3^-\); |
     | Conjugate acid-base pair 2/1 | \(\text{HCO}_3^-\) and \(\text{CO}_3^{2-}\); |
     | Conjugate acid-base pair 1/2 | \(\text{H}_3\text{O}^+\) and \(\text{H}_2\text{O}\); |

[2 max]
(d) (i) strong acid: (assumed to be) completely/100% dissociated/ionized and weak acid: partially dissociated/ionized; [1]

(ii) Similarity: bubbling/effervescence/gas / heat/increase in temperature / solid dissolves;
Difference: strong acid more vigorous / faster reaction / greater temperature increase;
Accept converse statements for weak acid. [2]

(iii) $10^4(\ 1) / 10^{-1}:10^{-5} / 1:10^{-4};$
Do not accept inverse ratio, $1:10^4$. [1]

Q# 10/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/Q2

(b) (NH₃) Lewis base and (Cu²⁺) Lewis acid;
NH₃/ligand donates an electron pair (to Cu²⁺) / Cu²⁺ accepts an electron pair (from NH₃);
forming coordinate/dative (covalent) bond;
Accept coordination bond.
Do not accept just covalent bond. [3]

Q# 11/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q7

(e) (i) electron pair donor;
Accept lone pair donor. [1]

(ii) proton acceptor and partially/slightly ionized;
Accept “proton acceptor and partially/slightly dissociated”. [1]

(iii) | Acid    | Conjugate base |
<table>
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<tbody>
<tr>
<td>CH₃NH₃⁺</td>
<td>and</td>
</tr>
<tr>
<td>CH₃NH₂;</td>
<td></td>
</tr>
<tr>
<td>H₂O</td>
<td>and</td>
</tr>
<tr>
<td>OH⁻;</td>
<td></td>
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Award [1 max] for two correct acids OR two correct conjugate bases. [2]

(f) $K_b = \frac{[\text{NH}_4^+][\text{OH}^-]}{[\text{NH}_3]} = 1.8 \times 10^{-5} / 10^{-4.75};$

$[\text{NH}_4^+] = [\text{OH}^-] \text{ and } [\text{NH}_3] \approx 1.00 \times 10^{-1} \text{ (mol dm}^{-3});$

$[\text{OH}^-] = (\sqrt{1.8 \times 10^{-5}} = )1.3 \times 10^{-3} \text{ (mol dm}^{-3}) \text{ / } \text{pOH} = 2.89 ;$

$pH = (14.0 - 2.89 = )11.1;$

Q# 12/ IB Chem/2015/s/TZ2/Paper 2 Section A/Higher Level/

4. (a) a solution that resists changes in pH / changes pH slightly / OWTTE; when small amounts of an acid/H⁺ or a base/alkali/OH⁻ are added; [2]

(b) addition of acid:
CH₃CH₂COO⁻(aq) + H⁺(aq) → CH₃CH₂COOH(aq) / propanoate ions combine with H⁺ ions to form undissociated propanoic acid;

addition of base:
CH₃CH₂COOH(aq) + OH⁻(aq) → CH₃CH₂COO⁻(aq) + H₂O(l) / addition of OH⁻ removes H⁺ and more propanoic acid dissociates/ionizes; [2]

Ignore state symbols.
Accept reversible arrows.
Award [1 max] if correct equations are given without reference to addition of acid or alkali.
(c) \[ K_a = \frac{[H^+(aq)][CH_3CH_2COO^- (aq)]}{[CH_3CH_2COOH(aq)]} \] / pH = pK_a + log \left( \frac{[base]}{[acid]} \right); 
\[ K_a = 1.3 \times 10^{-5} / 10^{-4.87} \text{ and } [H^+] = 1.3 \times 10^{-4} / 10^{-3.87} \text{ (mol dm}^{-3}\text{)} / \]
\[ \log \frac{[CH_3CH_2COO^- ]}{[CH_3CH_2COOH]} = 3.87 - 4.87 = -1; \]
\[ \left( \frac{[CH_3CH_2COOH]}{[CH_3CH_2COONa]} = \frac{7.41}{74.09} \right) 0.100 / 1.00 \times 10^{-1} \text{ (mol dm}^{-3}\text{)}; \]
\[ ([CH_3CH_2COONa] = 0.010 / 1.0 \times 10^{-2} \text{ (mol dm}^{-3}\text{)}); \]

Award [4] for correct final answer. 
Accept corresponding use of \([H_2O]^+\) for \([H^+]\), \([acid]\) for \([CH_3CH_2COOH]\), and \([base]\) or \([salt]\) for \([CH_3CH_2COO^-]\) throughout. 

**Q# 13/** IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/ 

**8. (a) (i)** weak acids dissociate only partially and strong acids (are assumed to) dissociate fully; 

(ii) measuring electrical conductivity and strong acids have greater electrical conductivity/weak acids have lower electrical conductivity; 

*Do not accept conductivity for electrical conductivity.* 

Accept explanation in terms of light bulb in circuit. 

measure pH/use universal indicator and pH higher for weak acid/pH lower for strong acid; 

conduct titration with a strong base and equivalence point higher for weak acid / buffer region for weak acid; 

adding a reactive metal/carbonate/hydrogen carbonate and stronger effervescence/faster reaction with strong acids; 

Accept converse argument. 

Accept correct example. 

adding a strong base and strong acid would increase more in temperature/weak acids increase less in temperature; 

[3 max] 

Accept correct example. 

Award [1 max] for three suitable tests without correct results. 

Accept specific examples with given strong acid and weak acid. 

Accept “addition of AgNO₃ (aq) and white precipitate with HCl (aq)”.* 

Do not accept “smell.”
(b) \[
\frac{1.40}{60.06} = 0.0233 \text{ (mol)} \quad \text{and} \quad \frac{0.0233}{0.500} = 0.0466 \text{ (mol dm}^{-3})
\];
\(pK_a = 4.76\) \(K_a = 1.7 \times 10^{-5}\);
\[H^+] = \sqrt{K_a[H_A]} = 8.9 \times 10^{-4} ;
\]
Accept \(9.0 \times 10^{-4}\).
\(\text{pH} = 3.05\);
Award [4] for correct final answer.
Accept alternative methods.

(c) (i) Equivalence point: pH of 9.5;
Accept values between 9 and 10.
\(pK_a = \text{pH at half equivalence point};\)
\(pK_a = 5.4\);
Accept any value between 5.2 and 5.6.
Award [2] for M2 and M3 if correct \(pK_a\) given without explanation.

(ii) phenolphthalein;

(iii) \(HIn (aq) \rightleftharpoons H^+ (aq) + In^- (aq) \quad \text{and} \quad HIn \text{ and } In^- \) have different colours;
Ignore state symbols.
equilibrium shifts depending on addition of \(H^+\) and \(OH^-\) / more \(HIn\) in acid/low pH / more \(In^-\) in alkali/high pH;

(d) (i) \(\text{CH}_2\text{CICOO}^-\);

(ii) stronger because \(pK_a\) of chloroethanoic acid is < \(pK_a\) of ethanoic acid;

(iii) Concentration of acid: \[
\frac{0.030}{0.300} = 0.10 \text{ (mol dm}^{-3})
\];
Concentration of base/salt: \[
\frac{0.020}{0.300} = 0.067 \text{ (mol dm}^{-3})
\];
\[H^+] = \frac{K_a \times [H_A]}{[A^-]} = \frac{1.3 \times 10^{-3} \times 0.10}{0.067} = 1.9 \times 10^{-3} \text{ (mol dm}^{-3})
\];
\(\text{pH} = 2.72\);
Award [4] for correct final answer.
Accept 2.69, 2.70 or 2.7.
Alternative for M3 and M4 if Henderson-Hasselbalch equation used:
\(M3: \text{pH} = pK_a + \log \frac{[\text{base}]}{[\text{acid}]} / 2.87 + \log \left(\frac{0.067}{0.10}\right)\)
\(M4: \text{pH} = 2.70\).
Award [1 max] for \(n_{\text{acid}} = 100 \times 0.50 = 50\) and \(n_{\text{base}} = 200 \times 0.10 = 20\) mol.
Q# 14/ IB Chem/2015/s/TZ1/Paper 2 Section A/Higher Level/Q2

(c) Ammonium chloride:
Accept any value in the range: $3 < \text{pH} < 7$;
\[ \text{NH}_4^+ (aq) \rightleftharpoons \text{NH}_3(aq) + \text{H}^+ (aq); \]

Sodium methanoate:
$7 < \text{pH} < 11$;
\[ \text{HCOO}^- (aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{HCOOH}(aq) + \text{OH}^- (aq); \]
Award [1 max] for both M1 and M3 combined if stated “pH < 7/acidic for ammonium chloride and pH > 7/alkaline/basic for sodium methanoate”.

Accept alternative suitable equations.
Award [1 max] for two correct explanations, such as “salt of weak acid and strong base” or “salt of weak base and strong acid”, without equations. Penalize missing equilibrium sign once only.
Ignore state symbols.

Q# 15/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q9

(g) a base is a proton acceptor;
weak means it is only partially ionized/dissociated (in solution/water);
\[ \text{NH}_3 + \text{H}_2\text{O} \rightleftharpoons \text{NH}_4^+ + \text{OH}^-; \]
Reversible arrow is required for M3.

Q# 16/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q9

(g) a base is a proton acceptor;
weak means it is only partially ionized/dissociated (in solution/water);
\[ \text{NH}_3 + \text{H}_2\text{O} \rightleftharpoons \text{NH}_4^+ + \text{OH}^-; \]
Reversible arrow is required for M3.

Q# 17/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q8

(f) (i) equilibrium between HIn and In$^-$/HIn \[ \rightleftharpoons \text{In}^- + \text{H}^+; \]
the colours of HIn and In$^-$ are different;
if added to acid, the equilibrium shifts to the left and the colour of HIn is seen / OWTTE;
if added to base/alkali, the equilibrium shifts to the right and the colour of In$^-$ is seen / OWTTE; [2 max]

(ii) phenolphthalein;
Accept phenol red. [1]

Q# 18/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/Q10

(e) (i) \[ \text{H}_2\text{O}(l) \rightleftharpoons \text{H}^+ (aq) + \text{OH}^- (aq) / 2\text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+ (aq) + \text{OH}^- (aq); \]
\[ \text{and state symbols are necessary for the mark.} \]

(ii) \[ K_W = [\text{H}^+] [\text{OH}^-] / K_W = [\text{H}_3\text{O}^+] [\text{OH}^-]; \]
[1]

(iii) at higher temperatures ionization increases / at higher temperatures equilibrium shifts to right;
ionization is endothermic;
Do not allow ECF for M2.
[2]

(iv) \[ 5.13 \times 10^{-13} = [\text{H}_3\text{O}^+]^2 /[\text{H}^+]^2 / [\text{H}_3\text{O}^+] / [\text{H}^+] = 7.16 \times 10^{-7} (\text{mol dm}^{-3}); \]
pH = 6.14/6.15;
Award [2] for correct final answer.
Q# 19/ IB Chem/2014/w/TZ0/Paper 2 Section A/Higher Level/Q4

(c) $\text{H}_3\text{PO}_4$ is the weaker acid \textbf{and} higher $K_a$/lower $K_a$; [1]

Q# 20/ IB Chem/2014/w/TZ0/Paper 2 Section A/Higher Level/

1. (a) river (water); [1]

(c) recognition that values differ by 2 pH units / calculation of both $[\text{H}^+]$ values;

\[
\text{ratio = } 1 : 100 / \frac{1}{100} / 10^{-2} / 0.01; \]

Award [2] for correct final answer.
Award [I max] for 100:1/100/10^2. [2]

(d) $\text{pOH} = (14.0 - 4.4 =) 9.6 / [\text{H}^+] = 4 \times 10^{-5} \text{ (mol dm}^{-3}\text{)}$ ;

Accept $[\text{H}^+] = 3.98 \times 10^{-5} \text{ (mol dm}^{-3}\text{)}$ .

$[\text{OH}^-] = 3 \times 10^{-10} \text{ (mol dm}^{-3}\text{)}$ ;

Accept $2.51 \times 10^{-10} \text{ (mol dm}^{-3}\text{)}$ .

Award [2] for correct final answer. [2]

(e) \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^- + \text{H}^+ / \text{CO}_2 + 2\text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{O}^+ / \text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3$; [1]

\text{Do not penalize missing reversible arrow.}
\text{Do not accept equations with the carbonate ion as a product.}

Q# 21/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/Q8

(e) more soluble at low pH / less soluble at high pH;
higher pH / OH$^-$ will shift the equilibrium to the left / lower pH / H$^+$ will (react with OH$^-$ and) shift the equilibrium to the right; [2]
(b) (i) chloric(I) acid (shown as) a molecule/molecular, but hydrochloric acid (shown as being) split into ions / OWTTTE; [1]
Accept “chloric(I) acid is partially dissociated and hydrochloric acid is fully dissociated”.
Reference needed to both acids for mark.

(ii) \( \text{HOCl}(aq) \rightleftharpoons \text{H}^+(aq) + \text{ClO}^-(aq) / \text{HOCl}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{ClO}^-(aq) \); [1]
Equilibrium sign required for the mark.
Ignore state symbols.

(iii) acid displaces the equilibrium to the left (to form chlorine);
chlorine is toxic/poisonous/harmful/lung irritant; [2]
Accept answers that refer to the (b) (ii) equilibrium.

(iv) chloric(I) acid has –OH group / hydrogen attached to a very electronegative atom;
Accept polar molecule.

can form hydrogen bonds to water;
hydrogen bonding to water increases its solubility;
(as a weak acid it is) in equilibrium with ions; [2 max]

(v) \( K_a = 10^{-7.53} \rightleftharpoons 2.95 \times 10^{-8} (\text{mol dm}^{-3}) \);
\( K_a = \frac{[\text{H}^+][\text{ClO}^-]}{[\text{HOCl}]} = \frac{[\text{H}^+](0.05)}{0.1} \approx \frac{[\text{H}^+]}{2} = 2.95 \times 10^{-8} (\text{mol dm}^{-3}) \);
\( [\text{H}^+] = 2 \times 2.95 \times 10^{-8} = 5.9 \times 10^{-8} (\text{mol dm}^{-3}) \);
pH \( = -\log(5.9 \times 10^{-8}) = 7.23 \); [4]
Accept other methods of carrying out the calculation.
Award [4] for correct final answer.

(vi) \( \text{HIn} \rightleftharpoons \text{H}^+ + \text{In}^- \);
Do not accept equation without equilibrium arrow.
(weak acid in which the) acid/HIn and conjugate base/In\(^-\) have different
colours / OWTTTE;
excess alkali shifts the equilibrium to the RHS/towards the conjugate base; [3]

Q# 23/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/

(d) (i) \( [\text{H}^+] = 0.5 \times \frac{10}{50} = 0.1 (\text{mol dm}^{-3}) \);
\( \text{pH} \left( = -\log[\text{H}^+] = -\log(0.10) \right) = 1 \); [2]

(ii) 90%; [1]
(e) (i) \( \text{mol Na}_2\text{S}_2\text{O}_3 = \text{mol SO}_2 = 0.0400 \times 0.0200 = 0.000800 \); 
\[
V = \frac{n \times R \times T}{P \times 10^5} / 0.000800 \times 8.31 \times 300 
\]
(1.99 \times 10^{-5} \text{ m}^3) = 19.9 (\text{cm}^3); 
Note that two errors involving a factor of 1000 can also produce the correct answer. If this is the case award [1] not [3]. 
Accept 20.0 cm\(^3\) if \( R = 8.314 \) is used. 
Award [2] for 17.9 cm\(^3\) or 19.2 cm\(^3\) (result from using molar volume at standard temperature and pressure or at room temperature and pressure).

OR

\[
\text{mol Na}_2\text{S}_2\text{O}_3 = \text{mol SO}_2 = 0.0400 \times 0.0200 = 0.000800 
\]
\[
V = 0.00080 \times 2.24 \times 10^{-2} \times \left[ \frac{1.00 \times 10^5}{1.01 \times 10^5} \right] \times \frac{300}{273} 
\]
(1.95 \times 10^{-5} \text{ m}^3) = 19.5 (\text{cm}^3); 
Note that two errors involving a factor of 1000 can also produce the correct answer. If this is the case award [1] not [3]. 
Deduct [1] for answers based on amount of HCl, so correct calculation would score [2 max].

(ii) \( K_a = \frac{[H^+] \times [\text{HSO}_3^-]}{[\text{H}_2\text{SO}_3]} = \frac{x^2}{2-x} \times \frac{x^2}{2} = 1.25 \times 10^{-2} (\text{mol dm}^{-3}); 
\]
\([H^+] = \sqrt{2.50 \times 10^{-2}} = 0.158 (\text{mol dm}^{-3}); 
\]
pH = -log(0.158) = 0.80; 
Award [3] for correct final answer.

(iii) dichloroethanoic acid / trichloroethanoic acid / 2,4,6-trinitrophenol; 

Q# 24/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/Q7

(b) (i) hexane has lower boiling point and enthalpy of vaporization than pentan-1-ol / OWTTE; 
hexane has higher vapour pressure than pentan-1-ol / OWTTE; 

(ii) hexane is non-polar / has only van der Waals/London/dispersion forces / has weaker intermolecular forces than pentan-1-ol; 
pentan-1-ol has hydrogen bonding between molecules; 

(c) (i) \( [\text{OH}^-] = \sqrt{1.50 \times 1.78 \times 10^{-5}} = 5.17 \times 10^{-3} (\text{mol dm}^{-3}); 
\]
pH = (14 – pH) = 14 – 2.29 = 11.71; 
Award [2] for correct final answer. 
Accept correct answer with more than 2 decimal places.

(ii) solution which resists change in pH / changes pH slightly / OWTTE; 
when small amounts of acid or base are added;
(iii) \[ \text{[NH}_3\text{]} = \frac{(1.50 \times 0.0200) - (0.500 \times 0.0250)}{0.0450} = 0.389 \text{ (mol dm}^{-2}\text{)}; \]

\[ \text{[NH}_4^+\text{]} = \frac{(0.500 \times 0.0250)}{0.0450} = 0.278 \text{ (mol dm}^{-2}\text{)}; \]

\[ \text{[OH}^-\text{]} = \frac{K_b \times \text{[NH}_3\text{]}}{\text{[NH}_4^+\text{]}} = \frac{1.78 \times 10^{-5} \times 0.389}{0.278} = 2.49 \times 10^{-5} \text{ (mol dm}^{-2}\text{)}; \]

\[ \text{pH} = (14.0 - \text{pOH}) = 14.0 - 4.60 = 9.40; \]

OR

\[ \text{pOH} = pK_b + \log \frac{\text{[NH}_4^+\text{]}}{\text{[NH}_3\text{]}} = pK_b + \log \frac{12.5}{17.5}; \]

\[ \text{pOH} = 4.75 + \log \frac{12.5}{17.5} = 4.75 - 0.146 = 4.604; \]

\[ \text{pH} = 14.0 - 4.604 = 9.40; \]

Award [4] for the correct final answer.

(iv) \[ V(\text{NH}_3) = \frac{25.0 \times 0.500}{1.50} = 8.33 \text{ cm}^3 \]

\[ V = V(\text{NH}_3) + V(\text{HCl}) = 8.33 + 25.0 = 33.3 \text{ cm}^3 / 0.0333 \text{ dm}^3; \]

Award [1] for the correct final answer.

(v) \( \text{NH}_4^+ \) ions are present at equivalence point \( \text{NH}_3 + \text{HCl} \rightarrow \text{NH}_4^+ + \text{Cl}^- \) at equivalence \( n(\text{NH}_4^+ \text{ produced}) = n(\text{NH}_3 \text{ added}) = n(\text{HCl}) \)

\[ \text{[NH}_4^+\text{]} = \frac{0.500 \times 0.0250}{0.0333} = 0.375 \text{ (mol dm}^{-2}\text{)}; \]

\( \text{(NH}_4^+\text{)(aq) \rightleftharpoons NH}_3\text{(aq) + H}^+\text{(aq) / NH}_4^+\text{(aq) + H}_2\text{O(l) \rightleftharpoons NH}_3\text{(aq) + H}_3\text{O}^+\text{(aq)} \)

\[ pK_a(\text{NH}_4^+) = 14 - pK_b(\text{NH}_3) = 14.00 - 4.75 = 9.25 \]

\[ K_a = \frac{[\text{NH}_3\text{(aq)}][\text{H}^+(\text{aq})]}{[\text{NH}_4^+(\text{aq})]} = 5.62 \times 10^{-10}; \]

\[ [\text{H}^+(\text{aq})] = \sqrt{5.62 \times 10^{-10} \times 0.375} = 1.45 \times 10^{-5} \text{ (mol dm}^{-2}\text{)}; \]

\[ \text{pH} = 4.84; \]

Award [4] for the correct final answer.

(vi) bromocresol green / methyl red; \[ ECF \text{ for answer in 7(c)(v) if pH given is below 7.} \]

Q# 25/ IB CHEM/2014/5sTZ1/Paper 2 Section B/Higher Level/

(ii) \( \text{H}_2\text{O} \) is a ligand / has lone (electron) pair;

forms dative (covalent)/coordinate bond / donates a lone (electron) pair;

ligand is Lewis base / \( \text{Cr}^{3+} \) is Lewis acid; \[ [\text{Cr(\text{H}_2\text{O})_6}^3+\text{(aq) \rightarrow [Cr(\text{H}_2\text{O})_2(\text{OH})]^2+\text{(aq) + H}^+(\text{aq})}; \]

Allow answers with further equations.

Accept any other valid equations.

Ignore state symbols.
Q# 26 / IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level /
8. (a) HCl is a strong acid and CH₃COOH is a weak acid so HCl has higher conductivity / HCl dissociates completely in water and CH₃COOH does not, so HCl has higher conductivity / HCl is a stronger acid (than CH₃COOH) so has higher [H⁺] and higher conductivity; [1]

(b) (i) CH₃COOH(aq) + HCO₃⁻(aq) → CH₃COO⁻(aq) + H₂O(l) + CO₂(g); [1]

Accept NaHCO₃(aq) and CH₃COONa(aq) instead of ions. Ignore state symbols.

Q# 27 / IB Chem/2013/s/TZ0/Paper 2 Section A/Higher Level/Q3
(c) (i) produced by high temperature combustion; [1]

Accept combustion/jet/car engines / car exhaust/emissions / lightning / action of bacteria/microorganisms.

Do not accept combustion/burning, cars, planes, jets, factories, power plants etc.

(ii) nitric acid/HNO₃ / nitrous acid/nitric(III) acid/HNO₂; [1]

Accept “form acidic solutions / acid rain”.

(iii) acid deposition/rain / respiratory problems / corrosion problems / decomposition of ozone layer / photochemical smog / acidification/pollution of lakes / damage to plants/ trees; [1]

Accept “acid rain” in either part (ii) or part (iii) but not both.

Do not accept air pollution.

Q# 28 / IB Chem/2013/s/TZ1/Paper 2 Section B/Higher Level/Q6
(d) (i) electron pair acceptor; [1]

(ii) Lewis base;

has non-bonding/lone pair of electrons; [2]

No ECF from (i).

Q# 29 / IB Chem/2013/s/TZ1/Paper 2 Section A/Higher Level/Q1
(e) weak acids partially dissociated/ionized and strong acids completely dissociated/ionized (in solution/water) / OWTTE; [1]

(f) (i) solution which resists change in pH / changes pH slightly / keeps pH constant / OWTTE;

when small amounts of acid or base are added; [2]

(ii) less effective at higher temperatures / more effective between 24 °C and 40 °C than > 40 °C;

pH changes more if the same volume of acid is added at high(er) temperature / OWTTE; [2]
3. (a) (solution containing significant/equal amounts of a) weak acid and its salt / (solution containing) strong base to which excess of weak acid has been added / OWTTE; [1]

Accept (solution containing) weak acid and conjugate base.
Do not accept descriptions with specific compounds alone (e.g. CH₃COOH and CH₃COONa) unless compounds are stated as weak acid and its salt.
Accept answer such as (solution containing) \(x\) mol of weak acid and \(\frac{1}{2}x\) mol of strong base.

(b) \(M_r(CH₃COOH) = 60.06\) and \(M_r(CH₃COONa) = 82.04\);

\([CH₃COOH] = 6.66 \times 10^{-1}/0.666\) mol dm\(^{-3}\);

\([CH₃COO^-] = 4.88 \times 10^{-1}/0.488\) mol dm\(^{-3}\);

\([H₂O^+] / [H^+] = (1.8 \times 10^{-5} \times 6.66 \times 10^{-3}) / 4.88 \times 10^{-1} = 2.46 \times 10^{-5} / 0.0000246\) mol dm\(^{-3}\);

\(pH - \left(-\log[H₂O^+] - \log(2.46 \times 10^{-5})\right) = 4.61\) (2dp);

Award [5] for correct final answer of \(pH = 4.61\) with some working shown.
Award [2 max] for \(pH = 4.61\) without any working at all shown.
Two decimal places are required for M5.

OR

\(M_r(CH₃COOH) = 60.06\) and \(M_r(CH₃COONa) = 82.04\);

\([CH₃COOH] = 6.66 \times 10^{-1}/0.666\) mol dm\(^{-3}\);

\([CH₃COO^-] = 4.88 \times 10^{-1}/0.488\) mol dm\(^{-3}\);

\(pH = -\log(1.8 \times 10^{-5}) + \log\left(\frac{\text{[salt]}}{\text{[acid]}}\right);

= \left(4.74 + \log\left(\frac{0.488}{0.666}\right) = 4.74 - 0.135 = \right) 4.61\) (2dp);

\(M4\) can be scored even if not explicitly stated if M5 is correct based on previous values.

Award [5] for correct final answer of \(pH = 4.61\) with some working shown.
Award [2 max] for \(pH = 4.61\) without any working at all shown.
Two decimal places are required for M5.

Q# 31/ IB Chem/2012/s/TZ1/Paper 2 Section B/Higher Level/ Q6

(d) (i) Strong acid: acid/electrolyte (assumed to be almost) 100%/completely dissociated/ionized (in solution/water) / OWTTE and Weak acid: acid/electrolyte only partially/slightly dissociated/ionized (in solution/water) / OWTTE;

\(\text{HBr(aq)} \rightarrow \text{H}^+(aq) + \text{Br}^-(aq);\)

\(\text{HF(aq)} \rightleftharpoons \text{H}^+(aq) + \text{F}^-(aq);\) [3]
(ii) Data points:
(0.00, 2.88) and (12.50, 4.77);

For first point also accept volume = 0.00 with pH in range 2.8–2.9.
For second point also accept either:
volume in range between 12.5–12.6 and pH 4.8–4.9
OR
volume in range between 25.0–25.2 and pH 8.0–10.0

For (0.00, 2.88):
\[ [\text{H}^+] = \text{[F}^-] \]
\[ \text{pK}_a = 2\text{pH} - 1 / \text{K}_a = \frac{[\text{H}^+]}{0.100} \]

For (12.50, 4.77):
\[ [\text{HF}] = \text{[F}^-] \]
\[ \text{pK}_a = \text{pH} \]
\[ \text{pK}_a = 4.77; \]
Accept any value in range 4.7–4.9 if consistent with data points.
Accept alternative calculation method if other data points from the table or graph are used and the pK_a in correct range.

(iii) bromothymol blue / phenol red / phenolphthalein;
pK_b/end point of indicator in range 7–10 as pH at equivalence in range 7–10;

Q# 32/ IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/
4. (a) \( K_w = [\text{H}^+(\text{aq})][\text{OH}^-(\text{aq})] \):
Do not penalize if (aq) not stated.
H_3O^+ may be given instead of H^+.
Do not mark awarded if square brackets are omitted or are incorrect.

(b) (i) \( \text{pK}_b = (14.00 - 7.52 =) 6.48 \) and \( \text{K}_b = (10^{-6.48}) = 3.3 \times 10^{-7} \);
Do not award mark if answer just left as 10^{-6.48}.

(ii) \( \text{K}_b = \frac{[\text{HOCl}][\text{OH}^-]}{[\text{OCl}^-]} = \frac{x^2}{0.705} = 3.3 \times 10^{-7}; \)
\[ [\text{OH}^-] = 4.8 \times 10^{-4} \text{(mol dm}^{-3}) \];
Award [2] for correct value of [OH^-].

\[ \text{OCl}^- \text{ only partially hydrolysed / x negligible (compared to [OCl^-]) / OWTTE; } \]
Accept [HOCl]=[OH^-].

(iii) \( \frac{[\text{H}_3\text{O}^+]}{[\text{H}^-]} = \frac{K_w}{[\text{OH}^-]} = \frac{1.00 \times 10^{-14}}{4.8 \times 10^{-4}} = 2.1 \times 10^{11}; \)
pH = \(-\log_{10}[\text{H}_3\text{O}^+] / -\log_{10}[\text{H}^-] = -\log_{10}(2.1 \times 10^{11}) =) 10.68 ; \)
Award [2] for correct final answer.
Q# 33/ IB Chem/2011/s/TZ1/Paper 2 Section B/Higher Level/

8.  (a)  (i)  Acid: proton/H⁺ donor and Base: proton/H⁺ acceptor; 
Do not accept OH⁻ for base.

Weak base: (base/electrolyte) partially dissociated/ionized (in solution/water) and Strong base: (base/electrolyte assumed to be almost) completely/100% dissociated/ionized (in solution/water) / OWTTE; 
NH₃ / CH₃CH₂NH₂;  [3]
Allow either name or formula or other suitable example.

(ii)  sulfurous acid/H₂SO₃;
corrodes marble/limestone buildings/statues / leaching in soils / harms/kills plants;
OR
nitrous acid/HNO₂;
corrodes marble/limestone buildings/statues / leaching in soils / harms/kills plants;
OR
carbonic acid/H₂CO₃;
corrodes marble/limestone buildings/statues / acidification of lakes;  [2]

Do not allow oxides (e.g. CO₂ etc.).
Do not accept just corrodes or damages.

(iii)  Volume of KOH: 20 (cm³);
Allow any value between 20 and 21 (cm³).

pH at the equivalence point: 8.0–10.0;  [2]

(iv)  At half-equivalence point [CH₃COOH] = [CH₃COO⁻] so pH = pKₐ; 
pKₐ = 4.7;  [2]
Accept in range 4.2 to 5.2.
M₂ can only be scored if M₁ correct (i.e. no marks for just Data Booklet value of 4.76).
Starting pH: 1;
Equivalence point: pH = 7 and 25 cm³;
Final pH reached: 12–13;
correct curve shape;
Do not award M4 if turn in curve is seen at low volumes (suggesting weak acid–strong base titration).
Award [4] if values corresponding to M1, M2 and M3 are labelled on graph (e.g using X) and correct shape of curve shown.

(b) (i) HIn is a weak acid / weak base;
HIn ⇌ H⁺ + In⁻;
colour 1 ⇒ colour 2
⇒ required.
Award [2] for M2 alone.
in base equilibrium moves to right / in acid equilibrium moves to left;

(ii) phenolphthalein;
indicator colour change occurs in range of pH at the equivalence point / OWTTE;
M2 can be scored independently even if indicator is incorrect.
(c) acidic:
\[ \text{[Fe(H}_2\text{O)}_6\text{]}^{3+} \rightleftharpoons \text{[Fe(H}_2\text{O)}_5\text{(OH)}\text{)]^{2+}} + \text{H}^+ / \text{[Fe(H}_2\text{O)}_6\text{]}^{3+} + \text{H}_2\text{O} \rightleftharpoons \text{[Fe(H}_2\text{O)}_5\text{(OH)}\text{)]^{2+}} + \text{H}_3\text{O}^+ ; \]

Accept equations indicating the formation of
\[ \text{[Fe(H}_2\text{O)}_4\text{(OH)}\text{)}^{2+} \]
\[ \text{[Fe(H}_2\text{O)}_3\text{(OH)}\text{)}^+ \]
Do not penalize →.

(d) \( n(\text{HCl}) = (0.100 \times 0.50) = 0.050 \) (mol);
\( n(\text{NaOH}) = (0.200 \times 0.10) = 0.020 \) (mol);
\( n(\text{HCl})_{\text{remaining}} = (0.050 - 0.020) = 0.030 \) (mol);
\[ \text{[HCl]} = \left( \frac{0.030}{0.30} \right) = 0.10 \text{ (mol dm}^{-3} \text{)} ; \]
\[ \text{pH} = 1.0; \]
Award [2 max] for just \( \text{pH} = 1.0 \) without working.

Q# 34/ IB Chem/2010/w/TZ0/Paper 2 Section B/Higher Level/Q6

(b) (i) strong acid completely dissociated/ionized and weak acid partially dissociated/ ionized:
\[ \text{HNO}_3 \text{(aq)} \rightarrow \text{H}^+ \text{(aq)} + \text{NO}_3^- \text{(aq)} ; \]
\[ \text{HCN(aq)} \rightleftharpoons \text{H}^+ \text{(aq)} + \text{CN}^- \text{(aq)} ; \]
Insist on both arrows as shown.
State symbols not needed.
Accept \( \text{H}_2\text{O}^+ \) and \( \text{H}_2\text{O}^- \).

(ii) \( K_a = \left[ \frac{\text{H}^+ \text{[CN}^- \right]}{\text{[HCN]} \right] ; \]
Allow \( \text{H}_2\text{O}^- \) instead of \( \text{H}^+ \).
\[ K_a = 10^{9.21} = 6.17 \times 10^{-10} ; \]
[2]
(iii) \[ [H^+] = \sqrt{K_a[H\text{CN}]} / \sqrt{(6.17 \times 10^{-10} \times 0.108)}; \]
\[ = 8.16 \times 10^{-6}; \]
Allow in the range \( 8.13 \times 10^{-6} \) to \( 8.16 \times 10^{-6} \).
pH = 5.09;

**OR**

\[ \text{pH} = \frac{1}{2}(pK_a - \log[H\text{CN}])/\frac{1}{2}(9.21-\log 0.108); \]
\[ = 5.09; \]
\[ [H^+] = 10^{-5.09} = 8.16 \times 10^{-6}; \]
Allow in the range \( 8.13 \times 10^{-6} \) to \( 8.16 \times 10^{-6} \).

*If expression for \([H^+]\) missing but both answers correct, award [3]. If one answer correct, award [2].

**assume** \([H^+] \ll 0.108 / \text{negligible dissociation}; \)

(c) *With HNO\(_3\) :

faster rate of bubble/hydrogen/gas production;
faster rate of magnesium dissolving;
higher temperature change; \quad [2 \ max]

*Accept opposite argument for HCN.*

*Reference to specific observations needed.*

*Award [1] if 2 observations given but acid is not identified.*

(d) (i) (nitric acid) \( 7.5 \text{ cm}^3; \)

(ii) not valid as hydrocyanic acid reacts with same volume/ \( 7.5 \text{ cm}^3; \)

(iii) bromothymol blue / phenol red / phenolphthalein;

(e) *HNO\(_3\) :

(higher conductivity for solutions with same concentration as) there are more ions in solution; \quad [2]*
Q# 36/ IB Chem/2010/s/TZ1/Paper 2 Section A/Higher Level/Q3

(d) (i) \[ \ce{CH_3COOH(aq) + H_2O(l) <=> CH_3COO^-(aq) + H_3O^+(aq)} \]

OR

\[ \ce{CH_3COOH(l) + H_2O(l) <=> CH_3COO^-(aq) + H_3O^+(aq)} \]

OR

\[ \ce{CH_3COO^2-(aq) <=> CH_3COO^-(aq) + 2H^+(aq)} \]

*Must include \[\rightleftharpoons\].
*Ignore state symbols.

(ii) \[ K_a = 10^{-7.6} / 1.74 \times 10^{-5} \]

\[ 1.74 \times 10^{-5} = \frac{[H^+]^2}{0.200} \]

\[ [H^+] = 0.00187 \]

pH = 2.73;

*Award [3] for correct final answer, allow mark for correct conversion of \([H^+]\) to pH even if \([H^+]\) incorrect.

(e) (initial) \([\ce{CH_3COOH}] = 0.500 \text{ mol dm}^{-3}\) and eqm \([\ce{CH_3COOH}] = 0.200 \text{ mol dm}^{-3}\);

(initial) \([\ce{CH_3COO^-}] = 0.300 \text{ mol dm}^{-3}\) and eqm \([\ce{CH_3COO^-}] = 0.300 \text{ mol dm}^{-3}\);

*Allow 0.02 moles and 0.03 moles instead of 0.200 and 0.300 moles dm\(^{-3}\).

\[ [H^+] = K_a \frac{[\ce{CH_3COOH}]}{[\ce{CH_3COO^-}]} = 1.16 \times 10^{-5} \text{ mol dm}^{-3}/ \]

\[ \text{pH} = pK_a + \log \frac{[\text{SALT}]}{[\text{ACTD}]} \]

pH = 4.94;

*Award [3 max] for correct final answer if no working shown.

(f) (if acid added) \(\ce{CH_3COO^- + H^+ -> CH_3COOH}\);

(if alkali added) \(\ce{CH_3COOH + OH^- -> CH_3COO^- + H_2O}\);

*Explanation marks cannot be awarded without equations.

Accept \(H^+ + OH^- \rightarrow H_2O\) as \(OH^-\) reacts with \(H^+\) in the buffer to form water.

Q# 37/ IB Chem/2009/w/TZ0/Paper 2 Section B/Higher Level/

8. (a) (i) 9.5;

*Accept any value in the range 9.4–9.6.

(ii) titration involves a weak acid and a strong base;

salt formed at equivalence point is basic due to hydrolysis;

\(A^- (aq) + H_2O(l) \rightleftharpoons HA (aq) + OH^- (aq)\);

*Ignore state symbols.

(iii) \[ 0.155 \times 22.0 \times 1 \]

\[ 25.0 \times 1 \]

\[ - 0.136 (\text{mol dm}^{-3}) \]

*Allow 0.134 (mol dm\(^{-3}\)).

(iv) at half neutralization point, pH = \(pK_a\);

\(pK_a = 5.3\);

*Accept any value in the range 5.2–5.4.

\[ K_a = 5.0 \times 10^{-6} (\text{mol dm}^{-3}) \]

*Accept calculations based on initial pH or on pH of salt.

(v) phenolphthalein;

*Accept thymolphthalein.

*Allow ECF from (a)(i).
(b) \( \text{H}^+ (aq) \rightleftharpoons \text{H}^+ (aq) + \ln^+ (aq) \);

Colour A colour B

In presence of acid/H\(^+\), equilibrium shifts to left, colour A;

In presence of base/OH\(^-\), equilibrium shifts to right, colour B. \([3]\)

(c) (i) buffer solution resists change in pH:

On addition of small amount of acid or base; \([2]\)

(ii) after mixing \([\text{CH}_3\text{COO}^-] = [\text{CH}_3\text{COOH}] = 0.050 \text{ mol dm}^{-3}\);

\(K_a = \frac{[\text{H}^+][\text{CH}_3\text{COO}^-]}{[\text{CH}_3\text{COOH}]} = 1.8 \times 10^{-5}\);

\(pH = 4.76\);

Working must be shown to score [3].

Award [1] if 4.76 stated with no working.

(d) acidic;

\([\text{Al(H}_2\text{O})_6]^{3+} (aq) \rightleftharpoons [\text{Al}(\text{OH})_2]^{3+} (aq) + \text{H}^+ (aq)\):

Accept \(\text{AlCl}_3 + 3\text{H}_2\text{O} \rightarrow \text{Al(OH)}_3 + 3\text{HCl}\). \([2]\)

(e) (i) \( \frac{1.00 \times 10^{-14}}{1.28 \times 10^{-12}} = 7.81 \times 10^{-12} \text{ mol dm}^{-3} \)/pOH = \(-\log 1.28 \times 10^{-3} = 2.90\):

\(pH = (4.0 - 2.90) = 1.11\); \([2]\)

Award [2] for the correct final answer

(ii) \(K_a = \frac{[\text{NH}_3^+][\text{OH}^-]}{[\text{NH}_3]}\):

\(= \frac{(1.28 \times 10^{-3})^2}{0.100 - 0.00128} \div 0.100\)

\(= 1.60 \times 10^{-5} \div 1.04 \times 10^{-5}\); \([3]\)

Q#38/ IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/

2. (a) (i) \(\text{CH}_3\text{CH}_2\text{COOH} + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{CH}_2\text{COO}^- + \text{H}_3\text{O}^+\)

\(\text{CH}_3\text{CH}_2\text{COOH} \rightleftharpoons \text{CH}_3\text{CH}_2\text{COO}^- + \text{H}^+\); \([1]\)

\(\rightleftharpoons \text{required for mark.}\)

(ii) (\(pK_a\) for propanoic acid = 4.87)

\([\text{H}^+] = 0.100 \times K_a\);

\([\text{H}^+] = 1.16 \times 10^{-3} \text{ (mol dm}^{-3}\); \([2]\)

(b) sketch to show:

![Graph showing pH and volume of KOH added](image-url)
indicator range between pH 3.0 and pH 4.6 (with “yellow” at pH 3.0 and “blue” at pH 4.6);
initial pH of acid at 2.9 ± 1.0 (when no KOH has been added);
half-equivalence point (does not need to be named) at pH 4.9 when 12.5 cm$^3$ of KOH have been added;
equivalence point at approx pH 8.5 – 9.0 when 25.0 cm$^3$ of KOH(aq) added;
upper part of curve from 25.0 – 50.0 cm$^3$ added identical to original curve;  

[3 max] Award [1] each for any three points.

Q# 39/ IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/Q5c
(c) (i) basic;  
Allow alkaline  

(ii) $Na_2O + H_2O \rightarrow 2NaOH / Na_2O + H_2O \rightarrow 2Na^+ + 2OH^-$;  

Do not accept $\Rightarrow$

Q# 40/ IB Chem/2008/w/TZ0/Paper 2 Section B/Higher Level/Q8
(g) (i) $K_a (= 10^{-4.20}) = 6.31 \times 10^{-5}$ (mol dm$^{-3}$);  

(ii) $C_6H_5COOH + NaOH \rightarrow C_6H_5COONa + H_2O$;  

(iii) phenolphthalein;  
Accept phenol red.  
weak acid-strong base titration / OWLTE;

(iv) $n \text{ NaOH} = 0.0300 \times 0.0170 = 5.10 \times 10^{-4}$ (mol) = $n$ benzoic acid;  

$[\text{HA}] = \frac{5.10 \times 10^{-4}}{0.0250};$  

$= 0.0204$ (moldm$^{-3}$) ;  


Q# 41/ IB Chem/2008/w/TZ0/Paper 2 Section A/Higher Level/
3. (a) (i) proton / $H^+$ / hydrogen ion donor;  

(ii) $NH_3$ and $NH_4^+$ / $H_2O$ and $OH^-$;  

(iii) $NH_3$ / $OH^-$;  
covalent / dative / co-ordinate;  

(b) (i) $CH_3NH_2 + H_2O \rightleftharpoons CH_3NH_3^+ + OH^-;$  

Do not accept $\rightarrow$ in place of $\Rightarrow$  
Ignore state symbols.

(ii) $[OH^-] = \sqrt{K_b \ [CH_3NH_2]} / \sqrt{ (4.37 \times 10^{-4}) \times 0.0500};$  

$[OH^-] = 4.67 \times 10^{-3}$ (mol dm$^{-3}$);  
$pOH = 2.33;$  

Correct final answer scores [3] marks

$[CH_3NH_2]$ does not change / OWLTE / appropriate mathematical abbreviation;  

If quadratic equation used award final mark.
(iii) \( n \text{ CH}_3\text{NH}_3^+ \text{ at eq (=} n \text{ HCl added)} = 0.010; \)
\( n \text{ CH}_3\text{NH}_3 \text{ at eq (=} 0.025 - 0.010) = 0.015; \)
\[
[\text{OH}^-] = \frac{K_w \times [\text{CH}_3\text{NH}_3^+]}{[\text{CH}_3\text{NH}_3]} = 4.37 \times 10^{-4} \times 0.015 \times \frac{1}{0.010} = 6.6 \times 10^{-4} \text{ (mol dm}^{-3});
\]
pOH = 3.2; \([\text{H}^+] = 1.5 \times 10^{-11}; \)
\( \text{pH} = 10.8; \)  

Correct final answer scores full marks.

Q# 42/ IB Chem/2008/s/TZ1/Paper 2 Section A/Higher Level/

3. (a) \( \text{CH}_3\text{CH(OH)COOH} + \text{H}_2\text{O} \rightleftharpoons \text{CH}_3\text{CH(OH)COO}^- + \text{H}_3\text{O}^+ \)

Award [1] for correct reactants and products and [1] for \( \rightleftharpoons \) sign.
Accept \( \text{CH}_3\text{CH(OH)COO}^- \rightleftharpoons \text{CH}_3\text{CH(OH)COO}^+ + \text{H}^+ \).

(b) \( K_a = \frac{[\text{CH}_3\text{CH(OH)COO}^-][\text{H}_3\text{O}^+]}{[\text{CH}_3\text{CH(OH)COOH}]} \).

Accept \( [\text{H}^+] \) instead of \( [\text{H}_3\text{O}^+] \).

(c) \( 1.40 \times 10^{-4} = \frac{[\text{H}^+]}{0.250} \); \( [\text{H}^+] = 5.92 \times 10^{-3} \text{ (mol dm}^{-3}); \)

Award [2] for the correct final answer.

(d) \( 1.40 \times 10^{-4} \times \frac{0.250}{0.125} \); \( [\text{H}^+] = 2.80 \times 10^{-4} \text{ (mol dm}^{-3}); \)

Award [2] for the correct final answer.

(e) equilibrium shifts to the left side of the reactants;
increase in the concentration of lactate ions reduces the \( [\text{H}^+] \) in (b) / OWTE;
### Topic 9
Chem 9 Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/Q4

(i) Magnesium chloride can be electrolysed.

(i) Deduce the half-equations for the reactions at each electrode when molten magnesium chloride is electrolysed, showing the state symbols of the products. The melting points of magnesium and magnesium chloride are 922K and 987K respectively.

<table>
<thead>
<tr>
<th>Anode (positive electrode):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cathode (negative electrode):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

(ii) Identify the type of reaction occurring at the cathode (negative electrode).

<table>
<thead>
<tr>
<th>Anode (positive electrode):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

(iii) State the products when a very dilute aqueous solution of magnesium chloride is electrolysed.

<table>
<thead>
<tr>
<th>Anode (positive electrode):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cathode (negative electrode):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>
(j) Standard electrode potentials are measured relative to the standard hydrogen electrode. Describe a standard hydrogen electrode.

(k) A magnesium half-cell, Mg(s)/Mg^{2+}(aq), can be connected to a copper half-cell, Cu(s)/Cu^{2+}(aq).

(i) Formulate an equation for the spontaneous reaction that occurs when the circuit is completed.

(ii) Determine the standard cell potential, in V, for the cell. Refer to section 24 of the data booklet.

(iii) Predict, giving a reason, the change in cell potential when the concentration of copper ions increases.
1. Ethane-1,2-diol, HOCH₂CH₂OH, has a wide variety of uses including the removal of ice from aircraft and heat transfer in a solar cell.
   (c) Determine the average oxidation state of carbon in ethene and in ethane-1,2-diol. [2]

<table>
<thead>
<tr>
<th>Ethene:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Ethane-1,2-diol:</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Chem 9 Q# 3/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

1. Two IB students carried out a project on the chemistry of bleach.
   (a) The bleach contained a solution of sodium hypochlorite, NaClO(aq). The students determined experimentally the concentration of hypochlorite ions, ClO⁻, in the bleach:

   **Experimental procedure:**
   - The bleach solution was first diluted by adding 25.00 cm³ of the bleach to a 250 cm³ volumetric flask. The solution was filled to the graduation mark with deionized water.
   - 25.00 cm³ of this solution was then reacted with excess iodide in acid.

   \[
   \text{ClO}^- (aq) + 2\text{I}^- (aq) + 2\text{H}^+ (aq) \rightarrow \text{Cl}^- (aq) + \text{I}_2 (aq) + \text{H}_2\text{O (l)}
   \]

   - The iodine formed was titrated with 0.100 mol dm⁻³ sodium thiosulfate solution, Na₂S₂O₃(aq), using starch indicator.

   \[
   \text{I}_2 (aq) + 2\text{S}_2\text{O}_3^{2-} (aq) \rightarrow 2\text{I}^- (aq) + \text{S}_4\text{O}_6^{2-} (aq)
   \]

   The following data were recorded for the titration:

<table>
<thead>
<tr>
<th>First titre</th>
<th>Second titre</th>
<th>Third titre</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.95</td>
<td>46.00</td>
<td>22.15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Initial burette reading of 0.100 mol dm⁻³ Na₂S₂O₃(aq) (in cm³ ± 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
</tr>
</tbody>
</table>
(b) Some of the group 17 elements, the halogens, show variable valency.

(i) Deduce the oxidation states of chlorine and iodine in the following species. \[1\]

\[
\text{NaClO:} \\
\text{I}_2: \\
\]

(ii) Deduce, with a reason, the oxidizing agent in the reaction of hypochlorite ions with iodide ions in part (a). \[1\]

(iii) From a health and safety perspective, suggest why it is not a good idea to use hydrochloric acid when acidifying the bleach. \[1\]
(iv) The thiosulfate ion, $S_2O_3^{2-}$, is an interesting example of oxidation states. The sulfur atoms can be considered to have an oxidation state of +6 on one atom and −2 on the other atom. Discuss this statement in terms of your understanding of oxidation state.
(c) The various changes that have been made to the definitions of oxidation and reduction show how scientists often broaden similarities to general principles.

Combustion is also a redox type of reaction.

With reference to the combustion reaction of methane, explore two different definitions of oxidation, choosing one which is valid and one which may be considered not valid. \[2\]

\[
\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})
\]

Valid:

\[
\text{...}
\]

Not valid:

\[
\text{...}
\]

(d) (i) State the condensed electron configuration of sulfur. \[1\]

\[
\text{...}
\]

(ii) Deduce the orbital diagram of sulfur, showing all the orbitals present in the diagram. \[1\]
4. Tin(II) chloride is a white solid that is commonly used as a reducing agent.

   (b) Tin can also exist in the +4 oxidation state.

\[ \text{Sn}^{4+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Sn}^{2+}(\text{aq}) \quad E^\circ = +0.15 \text{ V} \]

Vanadium can be reduced from an oxidation state of +4 to +3 according to the equation:

\[ \text{VO}^{2+}(\text{aq}) + 2\text{H}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{V}^{3+}(\text{aq}) + \text{H}_2\text{O}(l) \quad E^\circ = +0.34 \text{ V} \]

(i) Calculate the cell potential, \( E^\circ \), and the standard free energy, \( \Delta G^\circ \), change for the reaction between the \( \text{VO}^{2+} \) and \( \text{Sn}^{2+} \) ions, using sections 1 and 2 of the data booklet.

\[ E^\circ: \]

.......................................................... ..........................................................

\[ \Delta G^\circ: \]

.......................................................... ..........................................................

(ii) Deduce, giving your reason, whether a reaction between \( \text{Sn}^{2+}(\text{aq}) \) and \( \text{VO}^{2+}(\text{aq}) \) would be spontaneous.
1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula PH₃.

(b) 

(iii) State the oxidation state of phosphorus in P₄ and H₂PO₂⁻. [2] 

P₄⁻: 

H₂PO₂⁻: 

(iv) Oxidation is now defined in terms of change of oxidation number. Explore how earlier definitions of oxidation and reduction may have led to conflicting answers for the conversion of P₄ to H₂PO₂⁻ and the way in which the use of oxidation numbers has resolved this. [3]
1. A student used the technique of titration to determine the concentration of ascorbic acid \((C_6H_8O_6)\) in a sample of orange juice. Excess potassium iodide, \(K\text{I} (aq)\), was added to acidified orange juice. The resulting solution was titrated with potassium iodate, \(K\text{IO}_3 (aq)\), in the presence of starch as an indicator. The end-point of the titration was shown by a blue-black colour.

Step 1 \[ \text{IO}_3^- (aq) + 5\text{I}^- (aq) + 6\text{H}^+ (aq) \rightarrow 3\text{I}_2 (aq) + 3\text{H}_2\text{O} (l) \]

Iodine is only slightly soluble in water; but in the presence of excess iodide ions, \(\text{I}^- (aq)\), it forms the soluble tri-iodide ion, \(\text{I}_3^- (aq)\).

Step 2 \[ \text{I}_2 (aq) + \text{I}^- (aq) \rightleftharpoons \text{I}_3^- (aq) \]

Ascorbic acid reacts with tri-iodide ions as follows.

Step 3 \[ \text{C}_6\text{H}_8\text{O}_6 (aq) + \text{I}_3^- (aq) \rightarrow \text{C}_6\text{H}_8\text{O}_6 (aq) + 2\text{H}^+ (aq) + 3\text{I}^- (aq) \]

(a) (i) Deduce the changes in oxidation number of iodine in step 1. [2]

\[ \text{IO}_3^- \text{ to I}_2^- \]

.......................................................... ..........................................................

\[ \text{I}^- \text{ to I}_2^- \]

.......................................................... ..........................................................

(ii) Identify the oxidizing and reducing agents in step 1. [1]

Oxidizing agent:

.......................................................... ..........................................................

Reducing agent:

.......................................................... ..........................................................
Q# 7/ IB CHEM/2015/s/TZ2/Paper 2 Section B/Higher Level/Q8

(d) (i) The dichromate ion, $\text{Cr}_2\text{O}_7^{2-}(aq)$, and the iodide ion, $\Gamma^-(aq)$, react together in the presence of an acid to form $\text{Cr}^{3+}(aq)$ and $\text{IO}_3^-(aq)$ ions. Deduce the half-equation for the reaction of $\Gamma^-$ to $\text{IO}_3^-$ and the overall equation for this reaction.

\[
\text{Half-equation:}
\]

\[
\text{Overall equation:}
\]

(ii) Explain in terms of oxidation numbers whether iodine is oxidized or reduced in part (d) (i).

(e) A voltaic cell is constructed as follows. One half-cell contains a chromium electrode immersed in a solution containing $\text{Cr}^{3+}(aq)$ ions. The other half-cell contains a copper electrode immersed in a solution containing $\text{Cu}^{2+}(aq)$ ions. The two electrodes are connected to a voltmeter and the two solutions by a salt bridge.
(i) Define the term *standard electrode potential*.

(ii) Calculate the cell potential, in V, under standard conditions, for this voltaic cell, using Table 14 of the data booklet and \( E^{\circ}_{\text{Cr}^{3+}/\text{Cr}} = -0.74 \) V.

(iii) Predict the balanced equation for the spontaneous reaction which will produce a current in this voltaic cell.

(iv) Identify the negative and the positive electrodes in this cell.

(v) Predict the direction of movement of electrons in the external circuit.
(vi) State the directions in which the negative ions (anions) and the positive ions (cations) flow in the salt bridge.

Chem 9 4 Q# 8/ IB Chem/2015/s/TZ2/Paper 2 Section A/Higher Level/

6. Electrolysis is an important industrial process used to obtain very reactive elements from their common ores.

(a) Molten magnesium chloride can be electrolysed using inert graphite electrodes at 800 °C.

Deduce the half-equations, including state symbols, for the reactions occurring at each electrode. (The melting points of MgCl₂ and Mg are 714 °C and 649 °C respectively.)

Positive electrode (anode):

Negative electrode (cathode):

(b) Aluminium can also be obtained by electrolysis. Suggest one reason why aluminium is often used instead of iron by engineers.

Chem 9 5 Q# 9/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q7

The structure of

Ethanal

Ethanol
(ii) Determine the oxidation number of carbon in ethanol and ethanal. [2]

Ethanol:

Ethanal:

(iii) Deduce the half-equation for the oxidation of ethanol to ethanal. [1]

(iv) Deduce the overall redox equation for the reaction of ethanol to ethanal with acidified potassium dichromate(VI). [2]

Chem 9 13 Q# 10/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q6
(d) (i) Bromine can be produced by the electrolysis of molten sodium bromide. Deduce the half-equation for the reaction at each electrode. [2]

Positive electrode (anode):

Negative electrode (cathode):

(ii) Predict the products formed at the electrodes during the electrolysis of concentrated aqueous sodium bromide. [2]

Positive electrode (anode):

Negative electrode (cathode):
(e) Bromine reacts with aqueous sodium iodide.

\[ \text{Br}_2(\text{aq}) + 2\text{NaI}(\text{aq}) \rightarrow \text{I}_2(\text{aq}) + 2\text{NaBr}(\text{aq}) \]

Identify the oxidizing agent in this reaction.  

(f) (i) Define the term standard electrode potential, \( E^\circ \).

(ii) Draw a labelled diagram for the voltaic cell in which the following reaction occurs.

\[ \text{Mg}(s) + \text{Cu}^{2+}(\text{aq}) \rightarrow \text{Mg}^{2+}(\text{aq}) + \text{Cu}(s) \]

Include in your answer the direction of electron flow and the polarity of the electrodes.
(iii) A student measures a voltage of 2.65V in the voltaic cell formed between magnesium and copper half-cells using a digital voltmeter.

State the random uncertainty of this value, in V, and the number of significant figures in the answer. [2]

Random uncertainty:


Significant figures:


(iv) Outline how the student can reduce the random error in her results. [1]
10. Iron rusts in the presence of oxygen and water. Rusting is a redox process involving several steps that produces hydrated iron(III) oxide, Fe$_2$O$_3$·nH$_2$O, as the final product. The half-equations involved for the first step of rusting are given below.

Half-equation 1: Fe(s) → Fe$^{2+}$(aq) + 2e$^-$
Half-equation 2: O$_2$(aq) + 4e$^-$ + 2H$_2$O(l) → 4OH$^-$(aq)

(a) (i) Identify whether half-equation 1 represents oxidation or reduction, giving a reason for your answer.  

(b) Identify the oxidation number of each atom in the three species in half-equation 2.  

(iii) Deduce the overall redox equation for the first step of rusting by combining half-equations 1 and 2.  

(iv) Identify the reducing agent in the redox equation in part (iii).
(f) (i) An aqueous solution of sodium chloride is electrolysed using inert electrodes. Explain which product is obtained at the positive electrode (anode) if the concentration of sodium chloride is high.

(ii) State the half-equations occurring at the electrodes during the electrolysis of the concentrated aqueous solution of sodium chloride.

Negative electrode (cathode):

Positive electrode (anode):

(g) Describe how electrolysis can be used to electroplate a bracelet with a layer of silver metal. Include the choice of electrodes and electrolyte needed in your description.
Magnesium is usually produced by the electrolysis of molten magnesium chloride.

(i) Draw a labelled diagram of a suitable apparatus for the electrolysis.
(ii) State equations for the reactions that take place at the electrodes.

Negative electrode (cathode) reaction:

Positive electrode (anode) reaction:

(iii) When dilute aqueous magnesium chloride is used as the electrolyte, the reactions at both electrodes are different. State equations for the reactions that occur in aqueous solution.

Negative electrode (cathode) reaction:

Positive electrode (anode) reaction:

(iv) Outline why magnesium metal is not produced in the electrolysis of aqueous magnesium chloride.

..........................................................................................................................................................................................
Chem 9 Q# 13/ IB CHEM/2014/s/TZ2/Paper 2 Section B/Higher Level/Q5

(c) Aqueous sodium chlorate(I), NaOCl, the most common active ingredient in chlorine based bleaches, oxidizes coloured materials to colourless products while being reduced to the chloride ion. It will also oxidize sulfur dioxide to the sulfate ion.

(i) Deduce a balanced equation for the reaction between the chlorate(I) ion and sulfur dioxide from the appropriate half-equations.  

(ii) State the initial and final oxidation numbers of both chlorine and sulfur in the final equation.

<table>
<thead>
<tr>
<th>Element</th>
<th>Initial oxidation number</th>
<th>Final oxidation number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfur</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(d) The standard electrode potential for the reduction of the chlorate(V) ion to the chloride ion is +1.49 V.

(i) Define the term standard electrode potential.
Table 24 from the 2016 data booklet is needed in the next question.

(ii) Referring to Table 14 of the Data Booklet, deduce, giving a reason, whether the oxidation of the chromium(III) ion to the dichromate(VI) ion by the chlorate(V) ion is energetically feasible. [2]

5. Bleaches in which chlorine is the active ingredient are the most common, although some environmental groups have concerns about their use.

(a) (i) Describe the colour change that occurs when aqueous chlorine is added to aqueous sodium bromide. [1]

(ii) Outline, with the help of a chemical equation, why this reaction occurs. [2]
A chemist considered preparing a copper(I) salt by reacting copper metal with the corresponding copper(II) salt according to the equation below.

\[ \text{Cu}^{2+} (aq) + \text{Cu} (s) \rightarrow 2\text{Cu}^+ (aq) \]

(i) Using data from Table 14 of the Data Booklet, calculate the cell potential for this reaction. \[2\] 

(ii) Use this result to predict, with a reason, whether this reaction will be spontaneous. \[1\]
Chem 9 Q# 16/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/Q5

(b) Chlorine gas, Cl₂(g), is bubbled through separate solutions of aqueous bromine, Br₂(aq), and potassium bromide, KBr(aq).

(i) Predict any changes that may be observed in each case. [2]

\[
\begin{align*}
\text{Br}_2(\text{aq}): & \\
\text{KBr}(\text{aq}): & 
\end{align*}
\]

(ii) State the half-equations for the reactions that occur. [2]

Chem 9 Q# 17/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/

6. Oxidation and reduction can be defined in terms of electron transfer or oxidation numbers.

(b) A reactivity series can be experimentally determined by adding the metals W, X, Y and Z to solutions of these metal ions. The following reactions were observed:

\[
\begin{align*}
\text{W}^{2+}(\text{aq}) + \text{X(s)} & \rightarrow \text{W(s)} + \text{X}^{2+}(\text{aq}) \\
\text{Y(s)} + \text{W}^{2+}(\text{aq}) & \rightarrow \text{Y}^{2+}(\text{aq}) + \text{W(s)} \\
\text{Z}^{2+}(\text{aq}) + \text{W(s)} & \rightarrow \text{Z(s)} + \text{W}^{2+}(\text{aq}) \\
\text{Y(s)} + \text{X}^{2+}(\text{aq}) & \rightarrow \text{Y}^{2+}(\text{aq}) + \text{X(s)}
\end{align*}
\]

(i) Deduce the order of reactivity of these four metals, from the least to the most reactive. [1]
(ii) A voltaic cell is made by connecting a half-cell of X in XCl₂(aq) to a half-cell of Z in ZCl₂(aq). Deduce the overall equation for the reaction taking place when the cell is operating. [1]

.................................................................................................................................

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(iii) The standard electrode potential for Z²⁺(aq) + 2e⁻ ⇌ Z(s) is +0.20 V. State which species is oxidized when this half-cell is connected to a standard hydrogen electrode. [1]

.................................................................................................................................

.................................................................................................................................

(iv) Describe the standard hydrogen electrode including a fully labelled diagram. [3]
(c) A student carries out the electrolysis of aqueous potassium iodide, KI, using inert electrodes.

(i) State the half-equation for the reaction that occurs at each electrode. \[2\]

<table>
<thead>
<tr>
<th>Positive electrode (anode):</th>
</tr>
</thead>
<tbody>
<tr>
<td>__________________________</td>
</tr>
<tr>
<td>__________________________</td>
</tr>
<tr>
<td>__________________________</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Negative electrode (cathode):</th>
</tr>
</thead>
<tbody>
<tr>
<td>__________________________</td>
</tr>
<tr>
<td>__________________________</td>
</tr>
<tr>
<td>__________________________</td>
</tr>
</tbody>
</table>

(ii) Suggest, giving a reason, what would happen if the electrodes were changed to aluminium. \[2\]

| \__________________________|
| \__________________________|
| \__________________________|
| \__________________________|
| \__________________________|
| \__________________________|
| \__________________________|
(d) Three electrolytic cells were set up in series (one cell after the other), as shown below. All of the solutions had a concentration of 1.00 mol dm$^{-3}$.

![Diagram of electrolytic cells](image)

(i) Determine the mass of copper produced at one of the electrodes in cell 2 if the tin electrode in cell 1 decreased in mass by 0.034 g. [2]

(ii) Compare the colour and the pH of the solutions in cells 2 and 3 after the current has been flowing for one hour. [2]
(iii) Explain your answer given for part (d) (ii).

Colour:

.................................................................

.................................................................

.................................................................

pH:

.................................................................

.................................................................

.................................................................

Chem 9 14 Q# 18/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/

1. Iron tablets are often prescribed to patients. The iron in the tablets is commonly present as iron(II) sulfate, FeSO₄.

Two students carried out an experiment to determine the percentage by mass of iron in a brand of tablets marketed in Cyprus.

Experimental Procedure:

• The students took five iron tablets and found that the total mass was 1.65 g.

• The five tablets were ground and dissolved in 100 cm³ dilute sulfuric acid, H₂SO₄(aq). The solution and washings were transferred to a 250 cm³ volumetric flask and made up to the mark with deionized (distilled) water.

• 25.0 cm³ of this Fe²⁺(aq) solution was transferred using a pipette into a conical flask. Some dilute sulfuric acid was added.

• A titration was then carried out using a 5.00 × 10⁻³ mol dm⁻³ standard solution of potassium permanganate, KMnO₄(aq). The end-point of the titration was indicated by a slight pink colour.

The following results were recorded.

<table>
<thead>
<tr>
<th></th>
<th>Rough titre</th>
<th>First accurate titre</th>
<th>Second accurate titre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial burette reading / cm³ ± 0.05</td>
<td>1.05</td>
<td>1.20</td>
<td>0.00</td>
</tr>
<tr>
<td>Final burette reading / cm³ ± 0.05</td>
<td>20.05</td>
<td>18.00</td>
<td>16.80</td>
</tr>
</tbody>
</table>
(e) This experiment involves the following redox reaction.

\[ 5\text{Fe}^{2+}(aq) + \text{MnO}_4^{-}(aq) + 8\text{H}^+(aq) \rightarrow 5\text{Fe}^{3+}(aq) + \text{Mn}^{2+}(aq) + 4\text{H}_2\text{O}(l) \]

(i) Define the term \textit{reduction} in terms of electrons. \[1]\]

(ii) Deduce the oxidation number of manganese in the \text{MnO}_4^{-}(aq) ion. \[1]\]
(f) (i) Determine the amount, in mol, of $\text{MnO}_4^-$ (aq), used in each accurate titre. \[2\]

(ii) Calculate the amount, in mol, of $\text{Fe}^{2+}$ (aq) ions in 250 cm$^3$ of the solution. \[1\]

(iii) Determine the total mass of iron, in g, in the 250 cm$^3$ solution. \[1\]

(iv) Determine the percentage by mass of iron in the tablets. \[1\]
(g) During the rough titration, the students found that a brown precipitate, X, formed.

(i) When the students discussed the nature of the precipitate with their teacher, they were told that X is the same compound as that used as a catalyst in the decomposition of hydrogen peroxide, \( \text{H}_2\text{O}_2(\text{aq}) \), to prepare oxygen, \( \text{O}_2(\text{g}) \). Suggest the chemical formula and name of X.  \[2\]

Chemical formula:

...................................................................................................................

Name:

...................................................................................................................

(ii) State the balanced chemical equation for the decomposition of hydrogen peroxide. \[1\]

...................................................................................................................

(iii) Suggest how the formation of the brown precipitate might be prevented. \[1\]

...................................................................................................................
...................................................................................................................
(h) (i) Following the experiment, the students proposed the following hypothesis:

"Since sulfuric acid is a strong acid, two other strong acids such as nitric acid, HNO₃(aq) or hydrochloric acid, HCl(aq), could also be used in this experiment".

Suggest one problem with this hypothesis. [1]

(ii) The students also explored the role of sulfuric acid in everyday processes and found that sulfuric acid present in acid rain can damage buildings made of limestone. Predict the balanced chemical equation for the reaction between limestone and sulfuric acid, including state symbols. [2]
Chem 9 14 Q# 19/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/

1. Iron tablets are often prescribed to patients. The iron in the tablets is commonly present as iron(II) sulfate, FeSO₄.

   Two students carried out an experiment to determine the percentage by mass of iron in a brand of tablets marketed in Cyprus.

   **Experimental Procedure:**
   - The students took five iron tablets and found that the total mass was 1.65 g.
   - The five tablets were ground and dissolved in 100 cm³ dilute sulfuric acid, H₂SO₄(aq). The solution and washings were transferred to a 250 cm³ volumetric flask and made up to the mark with deionized (distilled) water.
   - 25.0 cm³ of this Fe²⁺(aq) solution was transferred using a pipette into a conical flask. Some dilute sulfuric acid was added.
   - A titration was then carried out using a 5.00 × 10⁻³ mol dm⁻³ standard solution of potassium permanganate, KMnO₄(aq). The end-point of the titration was indicated by a slight pink colour.

   The following results were recorded.

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<td>0.00</td>
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<tr>
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<td>20.05</td>
<td>18.00</td>
<td>16.80</td>
</tr>
</tbody>
</table>

   (e) This experiment involves the following redox reaction.

   \[5\text{Fe}^{2+}(\text{aq}) + \text{MnO}_4^{-}(\text{aq}) + 8\text{H}^+(\text{aq}) \rightarrow 5\text{Fe}^{3+}(\text{aq}) + \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(l)\]

   (i) Define the term *reduction* in terms of electrons. [1]

   .................................................................................................................................

   (ii) Deduce the oxidation number of manganese in the MnO₄⁻(aq) ion. [1]

   .................................................................................................................................
(f) (i) Determine the amount, in mol, of MnO₄⁻(aq), used in each accurate titre. \[2\]

(ii) Calculate the amount, in mol, of Fe²⁺(aq) ions in 250 cm³ of the solution. \[1\]

(iii) Determine the total mass of iron, in g, in the 250 cm³ solution. \[1\]

(iv) Determine the percentage by mass of iron in the tablets. \[1\]
(g) During the rough titration, the students found that a brown precipitate, X, formed.

(i) When the students discussed the nature of the precipitate with their teacher, they were told that X is the same compound as that used as a catalyst in the decomposition of hydrogen peroxide, $\text{H}_2\text{O}_2(\text{aq})$, to prepare oxygen, $\text{O}_2(\text{g})$. Suggest the chemical formula and name of X. [2]

Chemical formula:

Name:

(ii) State the balanced chemical equation for the decomposition of hydrogen peroxide. [1]

(iii) Suggest how the formation of the brown precipitate might be prevented. [1]

(h) (i) Following the experiment, the students proposed the following hypothesis:

"Since sulfuric acid is a strong acid, two other strong acids such as nitric acid, $\text{HNO}_3(\text{aq})$ or hydrochloric acid, $\text{HCl(aq)}$, could also be used in this experiment".

Suggest one problem with this hypothesis. [1]
(ii) The students also explored the role of sulfuric acid in everyday processes and found that sulfuric acid present in acid rain can damage buildings made of limestone. Predict the balanced chemical equation for the reaction between limestone and sulfuric acid, including state symbols. [2]

(c) Freshly prepared iron(II) bromide can be electrolysed both in the liquid state and in aqueous solution.

(i) Describe, using a diagram, the essential components of an electrolytic cell. [3]
(ii) Describe the **two** ways in which current is conducted in an electrolytic cell. [2]

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(iii) Predict and explain the products of electrolysis of a **dilute** iron(II) bromide solution. [4]

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(iv) Identify another product that is formed if the solution of iron(II) bromide is concentrated.

..............................................................

(v) Explain why this other product is formed.

..............................................................

..............................................................

..............................................................
4. Ethanedioic acid (oxalic acid), \((\text{COOH})_2\), reacts with acidified potassium permanganate solution, \(\text{KMnO}_4\), according to the following equation.

\[
5(\text{COOH})_2(aq) + 2\text{MnO}_4^-(aq) + 6\text{H}^+(aq) \rightarrow 10\text{CO}_2(g) + 2\text{Mn}^{2+}(aq) + 8\text{H}_2\text{O}(l)
\]

The reaction is a redox reaction.

(a) Define oxidation in terms of electron transfer. 

.................................................................................................................................
.................................................................................................................................
.................................................................................................................................

(b) Calculate the change in oxidation numbers of carbon and manganese. 

Carbon:
.................................................................................................................................
.................................................................................................................................

Manganese:
.................................................................................................................................
.................................................................................................................................
.................................................................................................................................

(c) Identify the oxidizing and reducing agents. 

Oxidizing agent:
.................................................................................................................................

Reducing agent:
.................................................................................................................................
(d) Deduce the half-equation involving ethanedioic acid.

\[ \begin{align*} 
\end{align*} \]

(e) (i) The standard electrode potential for the half-equation involving ethanedioic acid is \( E^\circ = -0.49 \text{ V} \). Using Table 14 of the Data Booklet, calculate the standard electrode potential for the equation on page 10.

\[ \begin{align*} 
\end{align*} \]

(ii) Explain the sign of the calculated standard electrode potential.

\[ \begin{align*} 
\end{align*} \]

(f) Predict the sign of \( \Delta G^\circ \) for this reaction.

\[ \begin{align*} 
\end{align*} \]
4. Arsenic and nitrogen play a significant role in environmental chemistry. Arsenous acid, H₃AsO₃, can be found in oxygen-poor (anaerobic) water, and nitrogen-containing fertilizers can contaminate water.

(a) (i) Define oxidation and reduction in terms of electron loss or gain. [1]

Oxidation:

.................................................................

Reduction:

.................................................................

(ii) Deduce the oxidation numbers of arsenic and nitrogen in each of the following species. [4]

As₂O₃: .................................................................

NO₂⁻: .................................................................

H₃AsO₃: .................................................................

N₂O₅: .................................................................

(iii) Distinguish between the terms oxidizing agent and reducing agent. [1]

.................................................................

.................................................................
(iv) In the removal of arsenic from contaminated groundwater, \( \text{H}_2\text{AsO}_3 \) is often first oxidized to arsenic acid, \( \text{H}_3\text{AsO}_4 \).

The following **unbalanced** redox reaction shows another method of forming \( \text{H}_3\text{AsO}_4 \):

\[
\text{As}_2\text{O}_3 (s) + \text{NO}_3^- (aq) \rightarrow \text{H}_3\text{AsO}_4 (aq) + \text{N}_2\text{O}_3 (aq)
\]

Deduce the balanced redox equation in acid, and then identify both the oxidizing and reducing agents. [3]

(b) The **electrolysis** of aqueous copper(II) sulfate is an example of an electrolysis process where the nature of the electrodes can determine which products form. Platinum electrodes were used in process 1 and copper electrodes in process 2.

(i) Draw an annotated diagram of the electrolytic cell in process 1 and identify the direction of electron flow. [2]
(ii) For **process 1** (platinum electrodes), state the half-equations occurring at the positive electrode (anode) and negative electrode (cathode). **Include state symbols for all species.** Describe what is observed at each electrode and comment on any change in the colour and the acidity of the solution.

<table>
<thead>
<tr>
<th>Half-equation at positive electrode (anode):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Half-equation at negative electrode (cathode):</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Observation at positive electrode (anode):</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Observation at negative electrode (cathode):</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Change in colour (if any) of the solution:</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Change in acidity (if any) of the solution:</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
(iii) For process 2 (copper electrodes), state the half-equations occurring at the positive electrode (anode) and negative electrode (cathode). Include state symbols for all species. Describe what is observed at each electrode and comment on any change in the colour and the acidity of the solution.

Half-equation at positive electrode (anode):

............................................................

............................................................

Half-equation at negative electrode (cathode):

............................................................

............................................................

Observation at positive electrode (anode):

............................................................

............................................................

Observation at negative electrode (cathode):

............................................................

............................................................

Change in colour (if any) of the solution:

............................................................

............................................................

Change in acidity (if any) of the solution:

............................................................

............................................................
(e) When bromine dissolves in water, 1% of the original bromine molecules react according to the following equation.

\[ \text{Br}_2(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{HOBr}(aq) + \text{HBr}(aq) \]

(i) Deduce the oxidation numbers of bromine in the reactant and products. \[2\]

(ii) Explain the changes in the oxidation numbers of bromine. \[1\]

(f) Fluorine reacts with water to produce oxygen.

\[ 2\text{F}_2(g) + 2\text{H}_2\text{O}(l) \rightarrow 4\text{HF}(g) + \text{O}_2(g) \]

(i) Identify the oxidizing agent in the reaction. \[1\]

(ii) 100 cm³ of fluorine gas is added to water. Calculate the volume of oxygen produced at the same temperature and pressure. \[1\]
7. Chromium is a typical transition metal with many uses.

(a) Distinguish between the terms *oxidation* and *reduction* in terms of oxidation numbers. [1]

(b) State the names of Cr₂O₃ and CrO₃. [2]

Cr₂O₃:

CrO₃:

(c) (i) Define the term *oxidizing agent*. [1]

(ii) Cr₂O₇²⁻(aq) and I⁻(aq) ions react together in the presence of acid to form Cr³⁺(aq) and IO₃⁻(aq) ions. Deduce the balanced chemical equation for this redox reaction and identify the species that acts as the oxidizing agent. [3]
(d) A voltaic cell is constructed as follows. One half-cell contains a platinum electrode in a solution containing $\text{K}_2\text{Cr}_2\text{O}_7$ and $\text{H}_2\text{SO}_4$. The other half-cell contains an iron electrode in a solution containing $\text{Fe}^{2+}$ ions. The two electrodes are connected to a voltmeter and the two solutions by a salt bridge.

(i) Draw a diagram of the voltaic cell, labelling the positive and negative electrodes (cathode and anode) and showing the direction of movement of the electrons and ions. Deduce an equation for the reaction occurring in each of the half-cells, and the equation for the overall cell reaction. 

(ii) Define the term *standard electrode potential*. 

(iii) Calculate the cell potential, in V, under standard conditions, using information from Table 14 of the Data Booklet.
(f) Chromium is often used in electroplating. State what is used as the positive electrode (anode), the negative electrode (cathode) and the electrolyte in the chromium electroplating process.
9. (a) The conditions used in an electrolytic cell can determine the products formed.

(i) Draw an electrolytic cell illustrating the electrolysis of molten nickel(II) bromide, NiBr₂. Include in the diagram the direction of the electron flow, the polarity of electrodes and state the half-equations for the product formed at each electrode.

(ii) Deduce the equations for the formation of the major product at the positive electrode (anode) when the following aqueous solutions are electrolysed.
- dilute sodium chloride
- concentrated sodium chloride

..............................................................
..............................................................
..............................................................
..............................................................
..............................................................
(b) A voltaic cell is constructed from two half-cells as illustrated below.

\[ \text{Sn}^{2+}(aq) \quad \text{Cu}^{2+}(aq) \]

(i) Use Table 14 of the Data Booklet to deduce the equation for the spontaneous reaction occurring in this cell.

(ii) Calculate the standard potential for this cell.

(iii) State the conditions necessary for the potential of the cell to equal that calculated in part (b) (ii) using the data from Table 14.
(c) Using the data below and data from Table 14 of the Data Booklet, predict and explain which metal, cadmium or chromium, may be obtained by electrolysis of separate aqueous solutions of \( \text{Cd}^{2+} \) (aq) ions and \( \text{Cr}^{3+} \) (aq) ions.

\[
\begin{array}{|c|c|}
\hline
\text{Reaction} & E^\circ / \text{V} \\
\hline
\text{Cd}^{2+} (\text{aq}) + 2e^- \rightarrow \text{Cd} (s) & -0.40 \\
\text{Cr}^{3+} (\text{aq}) + 2e^- \rightarrow \text{Cr} (s) & -0.91 \\
\hline
\end{array}
\]

(d) (i) Electrolysis is used in the electroplating of metals. The same amount of current is passed through separate aqueous solutions of \( \text{NiSO}_4 \), \( \text{SnSO}_4 \), and \( \text{Cr}_2(\text{SO}_4)_3 \) in separate electrolytic cells for the same amount of time. State and explain which cell would deposit the greatest amount (in mol) of metal. Identify the electrode at which the metal is deposited.
(ii) For the Sn(SO₄)₂ cell, suggest two factors, other than time and current, that would affect the amount of metal deposited during electroplating.

(e) Nitrogen monoxide may be removed from industrial emissions via a reaction with ammonia as shown by the equation below.

\[ 4\text{NH}_3(g) + 6\text{NO}(g) \rightarrow 5\text{N}_2(g) + 6\text{H}_2\text{O}(l) \]

(i) Deduce the oxidation number of the nitrogen in the reactants and product.
(ii) Deduce the oxidation and reduction half-equations and identify the oxidizing agent for the reaction. [3]

(b) Magnesium can be produced from the electrolysis of molten magnesium chloride, MgCl₂.

(i) Explain how molten magnesium chloride conducts an electric current. [2]

(ii) Identify the electrode where oxidation occurs during electrolysis of molten magnesium chloride and state an equation for the half-reaction. [2]

(iii) Explain why magnesium is not formed during the electrolysis of aqueous magnesium chloride solution. [1]
(e) An experiment was designed to investigate how the enthalpy change for a displacement reaction relates to standard electrode potentials. The standard electrode potentials of some half reactions, \(M^{n+}(aq) + ne^- \rightleftharpoons M(s)\), are listed in Table 14 of the Data Booklet. The following metals were available: copper, iron, magnesium, silver and zinc. Excess amounts of each metal were added to 1.00 mol dm\(^{-3}\) copper(II) sulfate solution. The temperature change was measured and the enthalpy change calculated.

(i) Suggest a possible hypothesis for the relationship between the enthalpy change that occurs when the metal, \(M\), is added to copper(II) sulfate (aq) and the standard electrode potential for the half reaction \(M^{n+}(aq) + ne^- \rightleftharpoons M(s)\). \[1\]

(ii) Sketch a graph on the diagram below to illustrate your hypothesis. \[2\]
6. (a) (i) Draw an annotated diagram of a voltaic cell composed of a magnesium electrode in 1.0 mol dm$^{-3}$ magnesium nitrate solution and a silver electrode in 1.0 mol dm$^{-3}$ silver nitrate solution. State the direction of electron flow on your diagram. [4] 

(ii) Deduce half-equations for the oxidation and reduction reactions. [2] 

(iii) Using Table 14 of the Data Booklet, calculate the cell potential for this cell. [2] 

(b) The standard electrode potentials for three other electrode systems are given below. 

<table>
<thead>
<tr>
<th>Electrode Reaction</th>
<th>$E^\circ$ / V</th>
</tr>
</thead>
<tbody>
<tr>
<td>MnO$_4^-$ (aq) + 8H$^+$ (aq) + 5e$^-$ $\rightleftharpoons$ Mn$^{2+}$ (aq) + 4H$_2$O (l)</td>
<td>+1.51</td>
</tr>
<tr>
<td>Fe$^{3+}$ (aq) + e$^-$ $\rightleftharpoons$ Fe$^{2+}$ (aq)</td>
<td>+0.77</td>
</tr>
<tr>
<td>Cd$^{2+}$ (aq) + 2e$^-$ $\rightleftharpoons$ Cd (s)</td>
<td>-0.40</td>
</tr>
</tbody>
</table>

(i) Identify which species in the table above is the best reducing agent. [1] 

(ii) Deduce the equation for the overall reaction with the greatest cell potential. [2] 

(c) These values were obtained using a standard hydrogen electrode. Describe the materials and conditions used in the standard hydrogen electrode. (A suitably labelled diagram is acceptable). [4] 

(d) (i) Solid sodium chloride does not conduct electricity but molten sodium chloride does. Explain this difference. [2] 

(ii) Outline what happens in an electrolytic cell during the electrolysis of molten sodium chloride using inert electrodes. Deduce equations for the reactions occurring at each electrode. [4] 

(iii) Two electrolytic cells are connected in series as shown in the diagram below. In one there is molten magnesium chloride and in the other, dilute sodium hydroxide solution. Both cells have inert electrodes. If 12.16 g of magnesium is produced in the first cell, deduce the identity and mass of products produced at the positive and negative electrodes in the second cell. [4]
1. Brass is a copper containing alloy with many uses. An analysis is carried out to determine the percentage of copper present in three identical samples of brass. The reactions involved in this analysis are shown below.

   Step 1: Cu(s) + 2HNO₃(aq) + 2H⁺(aq) → Cu²⁺(aq) + 2NO₃⁻(g) + 2H₂O(l)
   Step 2: 4I⁻(aq) + 2Cu²⁺(aq) → 2CuI(s) + I₂(aq)
   Step 3: I₂(aq) + 2S₂O₃²⁻(aq) → 2I⁻(aq) + S₄O₆²⁻(aq)

(a) (i) Deduce the change in the oxidation numbers of copper and nitrogen in step 1. [2]

   Copper:
   ............................................................... .

   Nitrogen:
   ............................................................... .

   (ii) Identify the oxidizing agent in step 1. [1]

   ............................................................... .

(b) A student carried out this experiment three times, with three identical small brass nails, and obtained the following results.

   Mass of brass = 0.456 g ± 0.001 g

<table>
<thead>
<tr>
<th>Titre</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial volume of 0.100 mol dm⁻³ S₂O₃²⁻ (±0.05 cm³)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Final volume of 0.100 mol dm⁻³ S₂O₃²⁻ (±0.05 cm³)</td>
<td>28.50</td>
<td>28.60</td>
<td>28.40</td>
</tr>
<tr>
<td>Volume added of 0.100 mol dm⁻³ S₂O₃²⁻ (±0.10 cm³)</td>
<td>28.50</td>
<td>28.60</td>
<td>28.40</td>
</tr>
<tr>
<td>Average volume added of 0.100 mol dm⁻³ S₂O₃²⁻ (±0.10 cm³)</td>
<td>28.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
(i) Calculate the average amount, in mol, of \( \text{S}_2\text{O}_3^{2-} \) added in step 3. [2]

(ii) Calculate the amount, in mol, of copper present in the brass. [1]

(iii) Calculate the mass of copper in the brass. [1]

(iv) Calculate the percentage by mass of copper in the brass. [1]

(v) The manufacturers claim that the sample of brass contains 44.2% copper by mass. Determine the percentage error in the result. [1]

(c) In step 1 the copper reacts to form a blue solution.

(i) State the full electronic configuration of \( \text{Cu}^{2+} \). [1]

(ii) Explain why the copper solution is coloured. [2]
1. The data below is from an experiment used to determine the percentage of iron present in a sample of iron ore. This sample was dissolved in acid and all of the iron was converted to Fe$^{2+}$. The resulting solution was titrated with a standard solution of potassium manganate(VII), KMnO$_4$. This procedure was carried out three times. In acidic solution, MnO$_4^-$ reacts with Fe$^{2+}$ ions to form Mn$^{2+}$ and Fe$^{3+}$ and the end point is indicated by a slight pink colour.

<table>
<thead>
<tr>
<th>Titre</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial burette reading / cm$^3$</td>
<td>1.00</td>
<td>23.60</td>
<td>10.00</td>
</tr>
<tr>
<td>Final burette reading / cm$^3$</td>
<td>24.60</td>
<td>46.10</td>
<td>32.50</td>
</tr>
</tbody>
</table>

| Mass of iron ore / g | 3.682×10$^{-1}$ |
| Concentration of KMnO$_4$ solution / mol dm$^{-3}$ | 2.152×10$^{-2}$ |

(a) Deduce the balanced redox equation for this reaction in acidic solution. [2]

(b) Identify the reducing agent in the reaction. [2]

(c) Calculate the amount, in moles, of MnO$_4^-$ used in the titration. [2]
4. (a) Outline two differences between an electrolytic cell and a voltaic cell. [2]

(b) Consider the following half-cell reactions and their standard electrode potentials.

\[ \text{Ni}^{2+} (aq) + 2e^- \rightleftharpoons \text{Ni} (s) \quad E^\circ = -0.26 \text{ V} \]
\[ \text{Al}^{3+} (aq) + 3e^- \rightleftharpoons \text{Al} (s) \quad E^\circ = -1.66 \text{ V} \]

(i) Deduce a balanced equation for the overall reaction which will occur spontaneously when these two half-cells are connected. [2]

(ii) Determine the cell potential when the two half-cells are connected. [1]

(iii) On the cell diagram below, label the negative electrode (anode), the positive electrode (cathode) and the directions of the movement of electrons and ion flow. [4]
7. (a) An electrochemical cell is made from an iron half-cell connected to a cobalt half-cell:

\[
\begin{align*}
\text{voltmeter} & \\
\text{Co} & \text{Co}^{2+} (aq) \\
\text{salt bridge} & \\
\text{Fe} & \text{Fe}^{2+} (aq) \\
\end{align*}
\]

The standard electrode potential for \( \text{Fe}^{2+} (aq) + 2e^- \rightarrow \text{Fe} (s) \) is \(-0.45\) V. The total cell potential obtained when the cell is operating under standard conditions is \(0.17\) V. Cobalt is produced during the spontaneous reaction.

(i) Define the term *standard electrode potential* and state the meaning of the minus sign in the value of \(-0.45\) V. \([3]\]

(ii) Calculate the value for the standard electrode potential for the cobalt half-cell. \([1]\]

(iii) Deduce which species acts as the oxidizing agent when the cell is operating. \([1]\]

(iv) Deduce the equation for the spontaneous reaction taking place when the iron half-cell is connected instead to an aluminium half-cell. \([2]\]

(v) Explain the function of the salt bridge in an electrochemical cell. \([2]\]

(b) Deduce the oxidation number of cobalt in the following species.

(i) \([\text{Co(H}_2\text{O)}_6]^{2+}\) \([1]\]

(ii) \(\text{Co}_2(\text{SO}_4)_3\) \([1]\]

(iii) \([\text{CoCl}_4]^{-}\) \([1]\)
(c) An electrolytic cell is made using a very dilute solution of sodium chloride.

(i) Draw a labelled diagram of the cell. Use an arrow to show the direction of the electron flow and identify the positive and negative electrodes. [3]

(ii) Give the formulas of all the ions present in the solution. [2]

(iii) Predict the products obtained at each electrode and state the half-equation for the formation of each product. [3]

(iv) Deduce the molar ratios of the products obtained at the two electrodes. [1]

(d) Predict the products by giving the relevant half-equation for the reaction occurring at each electrode if the electrolyte of the cell described in part (c) was changed to:

(i) concentrated sodium chloride [2]

(ii) molten sodium bromide [2]

Chem 9 7 Q# 33/ IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/

4. The percentage of iron(II) ions, Fe^{2+}, in a vitamin tablet can be estimated by dissolving the tablet in dilute sulfuric acid and titrating with standard potassium manganate(VII) solution, KMnO₄(aq). During the process iron(II) is oxidized to iron(III) and the manganate(VII) ion is reduced to the manganese(II) ion, Mn²⁺(aq). It was found that one tablet with a mass of 1.43 g required 11.6 cm³ of 2.00 × 10⁻³ mol dm⁻³ KMnO₄(aq) to reach the end-point.

(a) (i) State the half-equation for the oxidation of the iron(II) ions. [1]

(ii) State the half-equation for the reduction of the MnO₄⁻ ions in acidic solution. [1]

(iii) Deduce the overall redox equation for the reaction. [1]

(b) (i) Calculate the amount, in moles, of MnO₄⁻ ions present in 11.6 cm³ of 2.00 × 10⁻³ mol dm⁻³ KMnO₄(aq). [1]
(ii) Calculate the amount, in moles, of Fe$^{2+}$ ions present in the vitamin tablet. [1]

............................................................................................................................
............................................................................................................................

(iii) Determine the percentage by mass of Fe$^{2+}$ ions present in the vitamin tablet. [2]

............................................................................................................................
............................................................................................................................

Chem 9 4 Q# 34/ IB Chem/2008/w/TZ0/Paper 2 Section B/Higher Level/DATA BOOKLET/Q6

(e) Some standard electrode potentials are shown in Table 15 of the Data Booklet.

(i) From this table, identify a species that will reduce bromine to bromide ions but not iodine to iodide ions under standard conditions. Deduce the redox equation for the spontaneous reaction that occurs. [2]

(ii) Calculate the cell potential of a cell set up by connecting half-cells of aluminium and silver together under standard conditions. [1]

(iii) The cell potential of the cell represented below, under standard conditions is +0.48 V.

\[
\text{Zn}(s) \mid \text{Zn}^{2+}(aq) || \text{Co}^{2+}(aq) \mid \text{Co}(s)
\]

Deduce the standard electrode potential for the following half-reaction.

\[
\text{Co}^{2+}(aq) + 2e^- \rightleftharpoons \text{Co}(s)
\] [1]
6. (a) The reaction between chlorine and bromide ions is a redox reaction.

\[ \text{Cl}_2(g) + 2\text{Br}^-(aq) \rightarrow \text{Br}_2(aq) + 2\text{Cl}^-(aq) \]

Define the term *oxidation* in terms of electron transfer and identify the species that is oxidized in this reaction. \[2\]

(b) The oxidation number of oxygen is \(-2\) in most compounds containing oxygen. Identify the oxidation numbers of all the other elements in both reactants and products in the following equation.

\[ \text{TiO}_2(s) + 2\text{Cl}_2(g) + \text{C}(s) \rightarrow \text{TiCl}_4(l) + \text{CO}_2(g) \] \[3\]

(c) By referring to oxidation numbers, deduce what happens, if anything, in terms of oxidation and reduction, to the named element in each of these reactions.

(i) Chromium in
\[ 2\text{K}_2\text{CrO}_4(aq) + 2\text{HCl}(aq) \rightarrow \text{K}_2\text{Cr}_2\text{O}_7(aq) + 2\text{KCl}(aq) + \text{H}_2\text{O}(l) \] \[2\]

(ii) Chlorine in
\[ \text{Cl}_2(g) + \text{H}_2\text{O}(l) \rightarrow \text{HCl}(aq) + \text{HClO}(aq) \] \[2\]

(d) The table shows some reactions involving the metals W, X, Y and Z.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Reactants</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>W + Z(NO\textsubscript{3})\textsubscript{2}</td>
<td>Z + W(NO\textsubscript{3})\textsubscript{2}</td>
</tr>
<tr>
<td>2</td>
<td>X + YCl\textsubscript{2}</td>
<td>no reaction</td>
</tr>
<tr>
<td>3</td>
<td>Y + ZSO\textsubscript{4}</td>
<td>no reaction</td>
</tr>
<tr>
<td>4</td>
<td>Z + XO</td>
<td>X + ZO</td>
</tr>
</tbody>
</table>

(i) Use the information to arrange the four metals in a reactivity series, starting with the most reactive. Explain with reference to each of the metals how you decided which metal was the least reactive. \[4\]

(ii) Metal V forms compounds in which it has an oxidation number of +3. It is more reactive than any of the metals in the table. Predict the equation for the reaction between metal V and the oxide of metal X. \[1\]
8. (a) Electrolysis of an aqueous solution of copper(II) sulfate, CuSO₄, can be carried out using platinum electrodes.

(i) State an equation for the half-reaction occurring at the positive electrode (anode) and one observation that could be made as a result. [2]

(ii) State an equation for the half-reaction occurring at the negative electrode (cathode) and one observation that could be made as a result. [2]

(iii) Describe two changes or observations in the electrolyte as result of these half reactions. [2]

(iv) Determine the relative amount, in moles, of products formed at each electrode. [1]

(v) Identify another compound which will form the same products at the positive and negative electrodes. [1]

(vi) The same process is carried out using copper electrodes instead of the platinum electrodes. Describe the changes or observations that take place at both the electrodes and in the electrolyte. [3]

(b) Identify two factors that affect the quantity of copper produced during the electrolysis of an aqueous copper(II) sulfate solution. [1]

(c) Consider the following half cell reactions and their standard electrode potentials.

\[
\begin{align*}
\text{Ni}^{2+} (aq) + 2e^- &\rightleftharpoons \text{Ni} (s) \quad E^\circ = -0.23 \text{V} \\
\text{MnO}_4^-(aq) + 8H^+ (aq) + 5e^- &\rightleftharpoons \text{Mn}^{2+} (aq) + 4H_2O (l) \quad E^\circ = +1.51 \text{V}
\end{align*}
\]

(i) State the conditions needed for the electrode potentials to be described as standard. [1]

(ii) Deduce a balanced equation for the overall reaction which will occur spontaneously when the two half cells are connected. [2]

(iii) Identify the reducing agent in the above reaction and determine the change in oxidation number for the oxidizing agent. [2]

(iv) Determine the cell potential when the two half cells are connected. [1]

(v) Draw and label a diagram of the voltaic cell from part (c). Indicate the anode, cathode, the direction of the electron movement and ion flow. [5]

(d) Outline two differences between an electrolytic cell and a voltaic cell. [2]
### Topic 9 Mark Scheme

#### Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. i</td>
<td>i</td>
<td><strong>Anode (positive electrode):</strong>&lt;br&gt;2Cl(^{-}) → Cl(_2)(g) + 2e(^{-}) ✓&lt;br&gt;Cathode (negative electrode):&lt;br&gt;Mg(^{2+}) + 2e(^{-}) → Mg(l) ✓</td>
</tr>
<tr>
<td></td>
<td>ii</td>
<td>reduction ✓</td>
</tr>
<tr>
<td>4. i</td>
<td>iii</td>
<td><strong>Anode (positive electrode):</strong>&lt;br&gt;oxygen(\text{O}_2) OR hydrogen ion/proton/H(^+) AND oxygen(\text{O}_2) ✓&lt;br&gt;Cathode (negative electrode):&lt;br&gt;hydrogen(\text{H}_2) OR hydroxide ion/OH(^-) AND hydrogen(\text{H}_2) ✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. j</td>
<td></td>
<td><strong>Any two of:</strong>&lt;br&gt;inserts Pt electrode OR platinum black conductor ✓&lt;br&gt;H(_2)(g) at 100 kPa ✓</td>
</tr>
<tr>
<td>4. k</td>
<td>i</td>
<td>Mg(_2)(s) → Cu(^{2+})(aq) → Mg(^{2+})(aq) = Cu(s) ✓</td>
</tr>
<tr>
<td>4. k</td>
<td>ii</td>
<td>e = -0.34 V = (2.37 V) = ±2.71 eV ✓</td>
</tr>
<tr>
<td>4. k</td>
<td>iii</td>
<td>cell potential increases ✓&lt;br&gt;reaction sin Q4(k)(ii) moves to the right OR potential of the copper half-cell increases/becomes more positive ✓</td>
</tr>
</tbody>
</table>

#### Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. c</td>
<td>Ethene: -2 ✓&lt;br&gt;Ethene-1,2-diol: -1 ✓</td>
<td>Do not accept 2, 1 respectively. 2</td>
</tr>
</tbody>
</table>

#### Q# 3/ IB Chem/2016/s/TZ0SP/Paper 2 Section A/Higher Level/Q1

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>b i</td>
<td>Na(_2\text{ClO}_3): +1 &lt; for chlorine &gt; and I(_2): 0 &lt; for iodine &gt; ✓</td>
<td>1</td>
</tr>
<tr>
<td>b ii</td>
<td>Cl(^{2+}) since chlorite reduced/gains electrons OR Cl(^{2+}) since oxidation state of chlorine changes from +1 to -1 decreases OR Cl(^{2+}) since it loses oxygen / causes iodide to be oxidized ✓</td>
<td>1</td>
</tr>
<tr>
<td>b iii</td>
<td>produces chlorine &lt;gas&gt;(\text{Cl}_2) &lt;on reaction with Cl(^{2+}) &gt; which is toxic ✓</td>
<td>OWITE 1</td>
</tr>
<tr>
<td>b iv</td>
<td>oxidation states are not real OR oxidation states are just used for electron book-keeping purposes ✓&lt;br&gt;average oxidation state of sulfur calculated to be +2 ✓&lt;br&gt;but the two sulfurs are bonded differently in different environments in thiosulfate so have different oxidation states ✓</td>
<td>OWITE 2 max</td>
</tr>
<tr>
<td>Question</td>
<td>Answers</td>
<td>Notes</td>
</tr>
<tr>
<td>----------</td>
<td>---------</td>
<td>-------</td>
</tr>
<tr>
<td>c</td>
<td>Valid: addition of oxygen signifies an oxidation reaction so C is oxidized OR loss of hydrogen signifies an oxidation reaction so C is oxidized OR oxidation state of C changes from −4 to +4 increases ✓</td>
<td>OWTT</td>
</tr>
<tr>
<td>d i</td>
<td>[Ne]3s^2 3p^5 ✓</td>
<td>Electrons must be given as superscript.</td>
</tr>
<tr>
<td>d ii</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q# 4/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

4. b i $E^\circ = 0.34 - 0.15 - 0.19 eV ✓$
$$\Delta G^\circ = -nFE^\circ = -2 \times 96500 \times 0.19\text{eV} = -38970 \text{kJ/mol}$$
Accept $-18335 \text{kJ/mol} or -18 \text{kJ/mol}$ as equation not specified. | 2 |
4. b ii yes AND $\Delta G^\circ$ is negative OR yes AND $E^\circ$ for the cell is positive OR yes AND $E^\circ$ Sn^{2+} (aq) is a stronger reducing agent than $V^{3+} (aq)$ OR yes AND $E^\circ$ for $Sn^{2+} (aq)$ is more negative than $E^\circ$ for VO^{2+} (aq) OR yes AND $VO^{2+} (aq)$ is a stronger oxidizing agent than $Sn^{2+} (aq)$ OR yes AND $E^\circ$ for $VO^{2+} (aq)$ is more positive than $E^\circ$ for $Sn^{2+} (aq)$ ✓ | Do not accept reference to anti-clockwise rule. |

Q# 5/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

1. b iii $P_4$: 0 ✓
$H_3PO_4$: +1 ✓ | Do not accept 1 or 1+ for $H_3PO_4$; |
2 |
1. b iv oxygen gained, so could be oxidation ✓
hydrogen gained, so could be reduction OR negative charge on product or $H_3PO_4$, 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 changed". |
3 |

Q# 6/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/

1. (a) (i) \(IO_3^-\) to \(I_2:\) $V/+5$ to $0$;
\(I^-\) to \(I_2: -\)/$1$ to $0$;
Accept change in oxidation number $−5$ and $+1$.
Penalize incorrect notation such as $5+$ or $5$ once only. [2]


Q# 7/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q8

(d) (i) Half equation:
\(I^- (aq) + 3H_2O (l) \rightarrow IO_3^- (aq) + 6H^+ (aq) + 6e^-;\)
Accept $e^{-}$ instead of $e^-$. Accept reversible arrows.

Overall equation:
\(Cr_2O_7^{2-} (aq) + I^- (aq) + 8H^+ (aq) \rightarrow 2Cr^{3+} (aq) + IO_3^- (aq) + 4H_2O (l);\) [2]

Ignore state symbols.

(ii) oxidized and increase (in oxidation number) of $6$ from $−1/−1$ to $+5/+5$; [1]
(e) (i) potential (of reduction half-reaction) under standard conditions measured relative to standard hydrogen electrode/SHE / OWTTE;
Accept “solute concentration of 1 mol dm$^{-3}$ or “1 bar/1 atm (pressure)” for gases” instead of “standard conditions”.
Accept voltage/emf for potential.

(ii) (+)1.08 (V);

(iii) $2\text{Cr} (s) + 3\text{Cu}^{2+} (aq) \rightarrow 2\text{Cr}^{3+} (aq) + 3\text{Cu}(s)$;
Ignore state symbols.
Do not accept reversible arrows.

(iv) Negative electrode: chromium/Cr and Positive electrode: copper/Cu;
Accept “Cr is the anode and Cu the cathode”.

(v) from chromium/Cr to copper/Cu;
Accept “from negative electrode/anode to positive electrode/cathode” if electrodes correctly identified in (iv).

(vi) negative ions/anions towards the chromium(III) solution and positive ions/cations towards the copper(II) solution / OWTTE;

Q# 8/ IB Chem/2015/s/TZ2/Paper 2 Section A/Higher Level/
6. (a) Positive electrode (anode):
$2\text{Cl}^{-} (l) \rightarrow \text{Cl}_2 (g) + 2e^{-} / \text{Cl}^{-} (l) \rightarrow \frac{1}{2}\text{Cl}_2 (g) + e^{-}$;
Negative electrode (cathode):
$\text{Mg}^{2+} (l) + 2e^{-} \rightarrow \text{Mg}(l)$;
Accept e$^{-}$ instead of e$^{-}$.
Award [1 max] for correct half-equations given at the wrong electrode.
Penalize use of reversible arrows once only;
correct state symbols in both equations;

(b) aluminium/Al is less dense (compared to iron/Fe) / Al is more ductile or malleable / aluminium forms a protective oxide layer / Al does not corrode / iron/Fe rusts / OWTTE;
Do not accept “Al is lighter” OR “less expensive” OR “Al can be recycled”.

Q# 9/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q7
(ii) Ethanol: $-2/-II$;
Ethanal: $-1/-I$;
Do not accept 2–, 1– but penalize once only.

(iii) $\text{CH}_3\text{CH}_2\text{OH} \rightarrow \text{CH}_3\text{CHO} + 2\text{H}^+ + 2e^{-}$;
Half-equation required. Do not accept $C_2H_5\text{OH} + 2[O] \rightarrow \text{CH}_3\text{CHO} + H_2O$ .
Accept e for e$^{-}$.

(iv) $3\text{CH}_3\text{CH}_2\text{OH}(aq) + Cr_2O_7^{2-} (aq) + 8H^+ (aq) \rightarrow 2\text{Cr}^{3+} (aq) + 3\text{CH}_3\text{CHO (l)} + 7H_2O (l)$
correct reactants and products;
correct balancing;
M2 can only be scored if M1 correct.
Ignore state symbols.
Q# 10/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/Q6

6. (a) \[ \text{CH}_3 + \text{Br}_2 \rightarrow \text{CH}_3\text{Br} + \text{HBr} \] \[ \text{[1]} \]

(b) (i) \text{Initiation:} \[ \text{Br}_2 \rightarrow 2\text{Br}^-; \]
\text{Reference to UV/light or high temperatures must be included.}

\text{Propagation:}
\[ \text{Br}^- + \text{CH}_3 \rightarrow \text{CH}_3\text{•} + \text{HBr}; \]
\[ \text{CH}_3\text{•} + \text{Br}_2 \rightarrow \text{CH}_3\text{Br} + \text{Br}^-; \]

\text{Termination:}
\text{Award [1 max] for any one of:}
\[ \text{Br}^- + \text{Br}^- \rightarrow \text{Br}_2; \]
\[ \text{CH}_3\text{•} + \text{Br}^- \rightarrow \text{CH}_3\text{Br}; \]
\[ \text{CH}_3\text{•} + \text{CH}_3\text{•} \rightarrow \text{C}_2\text{H}_6; \]
\[ \text{[4 max]} \]
\text{Allow representation of radical without \text{•} (eg Br, CH$_3$) if consistent throughout mechanism.}
\text{Award [3 max] if initiation, propagation and termination are not stated or are incorrectly labelled for equations.}

(ii) methanol/CH$_3$OH; \[ \text{[1]} \]

(c) C–I bond is weaker than the C–Br bond so more easily broken;
C–I bond is longer than the C–Br bond / I larger than Br so bonding electrons not as tightly held / I$^-$ is better leaving group than Br$^-$; \[ \text{[2]} \]

(d) (i) \text{Positive electrode (anode):}
\[ 2\text{Br}^- \rightarrow \text{Br}_2(g) + 2\text{e}^- / \text{Br}^- \rightarrow \frac{1}{2}\text{Br}_2(g) + \text{e}^-; \]

\text{Negative electrode (cathode):}
\[ \text{Na}^+ + \text{e}^- \rightarrow \text{Na}(l); \]
\[ \text{[2]} \]

\text{Award [1 max] for correct equations at incorrect electrodes.}
\text{Ignore state symbols.}
\text{Accept e instead of e$^-$}
\text{Penalize use of equilibrium signs once only.}

(ii) \text{Positive electrode (anode):}
\text{bromine/Br$_2$;}

\text{Negative electrode (cathode):}
\text{hydrogen/H$_2$;}
\text{[2]}
\text{Allow sodium hydroxide/NaOH/hydroxide/OH$^-$ formation.}
(e) bromine/Br₂;
   Do not accept bromide/Br⁻.

(f) (i) potential of reduction half-reaction under standard conditions measured relative to standard hydrogen electrode/SHE; potential under standard conditions relative to standard hydrogen electrode/SHE;
   Instead of standard state allow either solute concentration of 1 mol dm⁻³ or 100 kPa/1.00 × 10⁵ Pa for gases.
   Allow 1 bar for 100 kPa/1.00 × 10⁵ Pa.
   Allow 1 atm.
   Allow voltage instead of potential.

(ii) correct diagram including (voltmeter), 4 correct species (state symbols not required) and connecting wires;
   No credit if wires to electrodes immersed in the solutions.
   Accept ammeter/meter/lamp instead of voltmeter.

   labelled salt bridge;
   Accept an appropriate salt (name or formula) instead of salt bridge (e.g., potassium nitrate).

   correctly labelled electrodes as +/cathode and −/anode;
   flow of electrons from Mg to Cu in external circuit;

(iii) Random uncertainty: (±) 0.01 (V);
   Significant figures: 3;

(iv) repeat readings and take an average / use more precise equipment;
Q# 11/ IB CHEM/2014/w/TZ0/Paper 2 Section B/Higher Level/

10. (a) (i) oxidation and (iron/Fe) loses electrons/increases in oxidation number/state; [1]

(ii) \[ \text{O}_2(aq) + 4e^- + 2\text{H}_2\text{O}(l) \rightarrow 4\text{OH}^- (aq) \]

\[ 0 \quad \boxed{1} \quad \boxed{1} \quad \boxed{1} \] \;

Award [2] for five correct.
Award [1] for four correct.
Accept use of oxidation states (0, +1, −2, −2, +1) for oxidation numbers.
Penalize once for incorrect notation (e.g. 2, 2−).

(iii) \[ \text{O}_2(aq) + 2\text{H}_2\text{O}(l) + 2\text{Fe} (s) \rightarrow 2\text{Fe}^{2+} (aq) + 4 \text{OH}^- (aq) ; \]

Ignore state symbols. [1]

(iv) Fe/iron; [1]

(b) oxygen is non-polar;
needs to break strong hydrogen bonds/H–bonds between water molecules (to dissolve) / oxygen cannot form hydrogen bonds/H–bonds with water;
oxygen can only form (weak) van der Waals’/vdW/LDF/London dispersion forces with water. [2 max]

c) groups indicate the number of electrons in the highest energy level/outer/valence shell;
periods indicate the number of (occupied) energy levels/shells (in the atom); [2]

d) \[ \text{V}_2\text{O}_3 \text{ catalyses oxidation of } \text{SO}_2 / \text{V}_2\text{O}_3 \text{ is a catalyst in the Contact Process; } \]
Fe catalyses the reaction between \( \text{N}_2 \) and \( \text{H}_2 / \text{Fe} \text{ is a catalyst in the Haber Process; } \]
Ni/Pd/Pt catalyses hydrogenation / manufacture of margarine / addition of hydrogen
to \( \text{C}=\text{C} / \text{conversion of alkenes to alkanes; } \]
Pd/Pt is a catalyst in catalytic converters / Pd/Pt catalyzes reaction of \( \text{NO}_2 \) and
\( \text{CO/NO}_2 \) and (unburnt) fuel/exhaust gases;

Accept other correct examples.
Accept formulas or names of substances. [2 max]

(e) (i) \[ \text{H}_2\text{O}(l) \rightleftharpoons \text{H}^+(aq) + \text{OH}^-(aq) / 2\text{H}_2\text{O}(l) \rightleftharpoons \text{H}_2\text{O}^+(aq) + \text{OH}^-(aq) ; \]

\[ \rightleftharpoons \text{ and state symbols are necessary for the mark.} \] [1]

(ii) \[ K_w = [\text{H}^+][\text{OH}^-] / K_w = [\text{H}_2\text{O}^+][\text{OH}^-] ; \]

\[ = 1.0 \times 10^{-13} \] [1]

(iii) at higher temperatures ionization increases / at higher temperatures
equilibrium shifts to right;
ionization is endothermic;
Do not allow ECF for M2. [2]

(iv) \[ \frac{5.13 \times 10^{-13}}{2} = \frac{[\text{H}_3\text{O}^+]^2}{[\text{H}^+]^2} / \frac{[\text{H}_3\text{O}^+]}{[\text{H}^+]} = 7.16 \times 10^{-7} (\text{mol dm}^{-3}) ; \]
pH = 6.14/6.15 ;

Award [2] for correct final answer.
(f) (i) chlorine/\text{Cl}_2\text{ (is produced at the positive electrode/anode):} \\
according to electrochemical series/\text{E}^+\text{ values/ease of oxidation OH}^-/\text{H}_2\text{O} \\
reacts/oxygen is released /\text{OWTIE} /\text{ at low chloride concentration OH}^-/\text{H}_2\text{O} \\
reacts/oxygen is released; \\
high concentration makes \text{Cl}^-\text{ oxidize/react in preference to OH}^-/\text{H}_2\text{O} /\text{OWTIE}; [3] \\

(ii) \textit{Negative electrode (cathode):} \\
\begin{align*}
2\text{H}^+(\text{aq}) + 2\text{e}^- & \rightarrow \text{H}_2(\text{g}) / \text{H}^+(\text{aq}) + \text{e}^- & \rightarrow \frac{1}{2}\text{H}_2(\text{g}) / 2\text{H}_2\text{O(l)} + 2\text{e}^- & \rightarrow \text{H}_2(\text{g}) + 2\text{OH}^-(\text{aq}); \\
\end{align*}

\textit{Positive electrode (anode):} \\
\begin{align*}
2\text{Cl}^-\text{(aq)} & \rightarrow \text{Cl}_2(\text{g}) + 2\text{e}^- / \text{Cl}^-\text{(aq)} & \rightarrow \frac{1}{2}\text{Cl}_2(\text{g}) + \text{e}^- / 2\text{Cl}^-\text{(aq)} - 2\text{e}^- & \rightarrow \text{Cl}_2(\text{g}) / \\
\text{Cl}^-\text{(aq)} - \text{e}^- & \rightarrow \frac{1}{2}\text{Cl}_2(\text{g}); [2] \\
\end{align*}

\textit{Ignore state symbols.}

Accept e instead of \text{e}^-.

Award [1] if half-equations are correct but placed at the wrong electrodes.

(g) bracelet/object to be electroplated is the cathode/negative electrode; \\
silver anode/positive electrode; \\
Accept Pt anode.

\textit{Electrolyte:} liquid \text{Na[Ag(CN)_2]} /\text{sodium dicyanoargentate[Ag(CN)_2]}/ solution of \\
an appropriate silver salt; \\
Accept \text{AgNO}_3/silver nitrate.
All marks can be scored with a labelled diagram. [3]

Q# 12/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/Q8

(g) (i) 

\begin{center}
\begin{tikzpicture}
\node [left] at (-2,0) {Negative electrode / cathode};
\node [right] at (2,0) {Positive electrode / anode};
\node [below] at (0,-2) {Molten magnesium chloride / electrolyte};
\end{tikzpicture}
\end{center}

\textit{Diagram:} \\
two electrodes connected to a power pack/battery and immersed in an \\
electrolyte; \\
\textit{Do not award mark if salt bridge included in diagram.}

\textit{Labelling:} \\
anode/positive electrode, cathode/negative electrode, \textit{molten} magnesium \\
chloride/MgCl_2(l)/electrolyte correctly labelled; [2] \\
\textit{Check candidates know which end of a battery symbol is which charge.}
(ii) Negative electrode (cathode): \( \text{Mg}^{2+}(l) + 2e^- \rightarrow \text{Mg}(s) \);  
Positive electrode (anode): \( 2\text{Cl}^-(l) \rightarrow \text{Cl}_2(g) + 2e^- \);  
\[ 2 \]
Accept \( \text{Cl}^-(l) \rightarrow \frac{1}{2} \text{Cl}_2(g) + e^- \).  
Ignore state symbols.  
Allow \( e^- \) instead of \( e^- \).  
If both correct equations are given for the wrong electrodes award [1 max].

(iii) Negative electrode (cathode):  
\( 2\text{H}_2\text{O}(l) + 2e^- \rightarrow \text{H}_2(g) + 2\text{OH}^-(aq) / 2\text{H}^+(aq) + 2e^- \rightarrow \text{H}_2(g) \);  
Accept \( 4\text{H}_2\text{O}(l) + 4e^- \rightarrow 2\text{H}_2(g) + 4\text{OH}^-(aq) / 4\text{H}^+(aq) + 4e^- \rightarrow 2\text{H}_2(g) \)  
\( \text{H}_2\text{O}(l) + e^- \rightarrow \frac{1}{2} \text{H}_2(g) + \text{OH}^-(aq) / \text{H}^+(aq) + e^- \rightarrow \frac{1}{2} \text{H}_2(g) \).
Positive electrode (anode):  
\( 2\text{H}_2\text{O}(l) \rightarrow \text{O}_2(g) + 4\text{H}^+(aq) + 4e^- / 4\text{OH}^-(aq) \rightarrow \text{O}_2(g) + 2\text{H}_2\text{O}(l) + 4e^- \);  
[2]  
Accept \( \text{H}_2\text{O}(l) \rightarrow \frac{1}{2} \text{O}_2(g) + 2\text{H}^+(aq) + 2e^- / 2\text{OH}^-(aq) \rightarrow \frac{1}{2} \text{O}_2(g) + \text{H}_2\text{O}(l) + 2e^- \).  
State symbols not required.  
Allow \( e^- \) instead of \( e^- \).  
If both correct equations are given for the wrong electrodes award [1 max].

(iv) water/hydrogen ions more easily reduced/better oxidizing agents/have a  
more positive \( E^\circ \) (than magnesium ions);  
\[ 1 \]
Accept converse statements for magnesium ions.  
Accept “magnesium is very reactive/high in reactivity series” / OWTTE.

Q# 13/ IB CHEM/2014/s/TZ2/Paper 2 Section B/Higher Level/Q5

(c) (i) \( \text{ClO}^-(aq) + 2\text{H}^+(aq) + 2e^- \Leftrightarrow \text{H}_2\text{O}(l) + \text{Cl}^-(aq) \);  
\( \text{SO}_4^{2-}(aq) + 4\text{H}^+(aq) + 2e^- \Leftrightarrow \text{SO}_2(aq) + 2\text{H}_2\text{O}(l) \);  
Accept \( \text{SO}_4^{2-}(aq) + 4\text{H}^+(aq) + 2e^- \Leftrightarrow \text{H}_2\text{SO}_4(aq) + \text{H}_2\text{O}(l) \).

For final equation:  
\( \text{ClO}^-(aq) + \text{SO}_2(aq) + \text{H}_2\text{O}(l) \Leftrightarrow \text{SO}_4^{2-}(aq) + 2\text{H}^+(aq) + \text{Cl}^-(aq) \)  
Accept \( \text{ClO}^-(aq) + \text{H}_2\text{SO}_4(aq) \Leftrightarrow \text{SO}_4^{2-}(aq) + 2\text{H}^+(aq) + \text{Cl}^-(aq) \).  
Correct reactants and products; balancing and cancelling \( e^- \), \( \text{H}^+ \) and \( \text{H}_2\text{O} \);  
[4]  
Apply ECF if incorrect half-equations written.

Ignore state symbols and absence of equilibrium arrow for all equations and  
accept inclusion of \( \text{Na}^+ \) in any equation.


<table>
<thead>
<tr>
<th>Element</th>
<th>Initial oxidation number</th>
<th>Final oxidation number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine</td>
<td>+I / +1;</td>
<td>-I / -1;</td>
</tr>
<tr>
<td>Sulfur</td>
<td>+IV / +4;</td>
<td>+VI / +6;</td>
</tr>
</tbody>
</table>

Remember to apply ECF from final (c) (i) equation.  
Penalise incorrect notation (eg, 4 or 4+ rather than +4) once only, so  
award [1] for a fully correct answer in an incorrect format.
Q# 14/ IB CHEM/2014/s/TZ2/Paper 2 Section B/Higher Level/
5. (a) (i) from (pale) green/colourless to yellow/orange/brown;
   Initial colour must be stated.
   Do not accept “clear/translucent” instead of “colourless”.

(ii) chlorine more reactive/more powerful oxidizing agent (than bromine);
   Accept opposite statements for bromine.
   Accept “chloride ion a weaker reducing agent” / “bromide ion a stronger
   reducing agent”.
   Accept “chlorine more electronegative than bromine”.

\[
\text{Cl}_2(aq) + 2\text{NaBr}(aq) \rightarrow \text{Br}_2(aq) + 2\text{NaCl}(aq);
\]

Ignore state symbols.
Do not accept with equilibrium sign.

Q# 15/ IB Chem/2014/s/TZ2/Paper 2 Section A/Higher Level/Q2
(d) (i) \( E_{\text{cell}}^\circ = 0.15 - 0.52 = -0.37 \) (V)

choosing correct \( E_{\text{cell}}^\circ \) values;
combining in correct way;
Award [2] for correct final answer.
Award [1] for -0.18 (0.34 instead of 0.15) and -0.19 (0.34 instead of 0.52).

(ii) not spontaneous because \( E^\circ \) negative / OWTTE;

Q# 16/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/
(b) (i) \( \text{Br}_2(aq) \): no change;
KBr (aq): colour change / from colourless to red/yellow/orange/brown;

(ii) \( 2\text{Br}^-(aq) \rightarrow \text{Br}_2(aq) + 2e^- ; \)
\( \text{Cl}_2(g) + 2e^- \rightarrow 2\text{Cl}^-(aq) ; \)
Ignore state symbols.
Accept e instead of e^-.
Q# 17/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/Q6

(b)  (i)  \( Z < W < X < Y \);
Accept \( Y > X > W > Z \).  \[1\]

(ii)  \( X(s) + Z^{2+}(aq) \rightarrow X^{2+}(aq) + Z(s) \);
Ignore state symbols.
Accept \( X(s) + ZCl_2(aq) \rightarrow XCl_2(aq) + Z(s) \).  \[1\]

(iii)  \( H_2(g) \)/hydrogen;
\[1\]

(iv)  diagram showing gas, solution and solid electrode:

For example,

\[ \text{H}_2(\text{g}) \text{ at 100 kPa, 298 K} \]

1 mol dm\(^{-3}\) \( H^+(aq) \) and Pt;
Allow 1 mol L\(^{-1}\) or 1 M.
Allow 1 mol dm\(^{-3}\) HCl (aq) or other source of 1 mol dm\(^{-3}\) \( H^+(aq) \) ions.

100 kPa/10\(^5\) Pa/1 bar (\( H_2(g) \) pressure) and 298K/25\(^\circ\)C;  \[3\]
Ignore state symbols throughout.
Allow 1.01 \times 10^5 \text{ Pa}/1 \text{ atm}.

(c)  (i)  Positive electrode (anode):
\( \Gamma(aq) \rightarrow \frac{1}{2} I_2(aq) + e^- \);
Accept correct equation involving 2 mols of \( \Gamma \).

Negative electrode (cathode):
\( H_2O(l) + e^- \rightarrow \frac{1}{2} H_2(g) + OH^-(aq) \) / \( H^+(aq) + e^- \rightarrow \frac{1}{2} H_2(g) \)/
\( H_2O^+(aq) + e^- \rightarrow H_2O(l) + \frac{1}{2} H_2(g) \);  \[2\]
Award [1 max] if correct equations are given at the wrong electrodes.
Ignore state symbols.
Allow \( e \) instead of \( e^- \).
Penalize equilibrium sign once only.
Accept correct equation involving 2 mols of \( H^+ \).

(ii)  aluminium will be oxidized (instead of \( \Gamma \) ) at positive electrode (anode);
aluminium is a reactive metal / oxidation of aluminium has a positive \( E^0 \)/
aluminium is higher on the reactivity series than \( \Gamma \) / OWTTE;  \[2\]
(d) (i) \( n_{\text{Sn}} = n_{\text{Cu}} = \frac{2.86 \times 10^{-4}}{0.000286} \text{(mol)} \);
\[ m(\text{Cu}) = 2.86 \times 10^{-4} \times 63.55 = 0.0182 \text{(g)} \] [2]

(ii) blue colour persists in second cell and fades in third cell;
pH does not change in second cell and decreases in third cell; [2]
Award [1 max] if both colour and pH are correctly stated for one only of either second or third cell.

(iii) \textbf{Colour:}
positive Cu electrode (anode) is oxidized to maintain colour in second cell / 
\( \text{Cu}(s) \rightarrow \text{Cu}^{2+}(aq) + 2e^- \);
\textbf{pH:}
in third cell, \( \text{H}^+ \) ions are produced as water is oxidized at positive electrode
(anode) / \( \text{H}_2\text{O}(l) \rightarrow \frac{1}{2} \text{O}_2(g) + 2\text{H}^+(aq) + 2e^- \) / solution becomes acidic as
hydroxide ions are oxidized at positive electrode (anode) / 
\( 2\text{OH}^-(aq) \rightarrow \frac{1}{2} \text{O}_2(g) + \text{H}_2\text{O}(l) + 2e^- \) [2]
\textit{Ignore state symbols}

Q# 18/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/Q1

(e) (i) gain (of electrons); [1]

(ii) VII / +7; [1]
\textit{Do not accept 7 or 7+}.

(f) (i) volume = \( 16.80 \text{(cm}^3) / 18.00 - 1.20 \text{(cm}^3) \); 
amount \( \left( = \frac{16.80 \times 5.00 \times 10^{-3}}{1000} \right) = 8.40 \times 10^{-5} \text{(mol)} \); [2]
\textit{Award [2] for correct final answer.}

(ii) \( 8.40 \times 10^{-5} \times 5 \times 10 = 4.20 \times 10^{-3} \text{(mol per 250 cm}^3 \text{)} \); [1]

(iii) \( (55.85 \times 4.20 \times 10^{-3}) = 0.235 \text{(g)} \); [1]
\textit{Do not penalize if 56 g mol}^{-1} \text{is used for atomic mass of iron.}

(iv) \( \left( \frac{0.235 \times 100}{1.65} \right) = 14.2\% \); [1]
\textit{No ECF if answer >100 \%.}

(g) (i) \textit{Chemical formula: MnO}_2; 
\textit{Name: manganese(IV) oxide;}
\textit{Allow manganese dioxide.}
\textit{No ECF if formula is incorrect.} [2]

(ii) \( 2\text{H}_2\text{O}_2(aq) \rightarrow 2\text{H}_2\text{O}(l) + \text{O}_2(g) / \text{H}_2\text{O}_2(aq) \rightarrow \text{H}_2\text{O}(l) + \frac{1}{2} \text{O}_2(g) \); [1]
\textit{Ignore state symbols.}

(iii) add more (sulphuric) acid/H\textsubscript{2}SO\textsubscript{4} / ensure enough (sulphuric) acid/H\textsubscript{2}SO\textsubscript{4} is present / \textit{OWTTE;}
\textit{Award [0] if reference made to HCl or HNO}_3. [1]
(h) (i) NO$_3^-$ and Cl$^-$ anions may also react with KMnO$_4$ / HNO$_3$ is an oxidizing agent / (HCl will not work as) Cl$^-$ reacts with MnO$_4^-$ (to form Cl$_2$) / HCl oxidized / OWTTE; 
For HCl, allow correctly balanced chemical equation:

$$2\text{MnO}_4^- + 10\text{Cl}^- + 16\text{H}^+ \rightarrow 2\text{Mn}^{2+} + 5\text{Cl}_2 + 8\text{H}_2\text{O}$$

Accept NO$_3^-$ and Cl$^-$ may react with KMnO$_4$/Fe$^{2+}$.

(ii) CaCO$_3$(s) + H$_2$SO$_4$(aq) $\rightarrow$ CaSO$_4$(s) + H$_2$O(l) + CO$_2$(g)
correct chemical equation; correct state symbols; 
Allow CaSO$_4$(ag) instead of CaSO$_4$(s).
M2 can only be scored if M1 is correct.
Award [1max] if H$_2$CO$_3$(aq) is given instead of H$_2$O(l) + CO$_2$(g).

Q# 19/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/Q1
(e) (i) gain (of electrons);

(ii) VII /+7; 
Do not accept 7 or 7+.

(f) (i) volume $= 16.80$ (cm$^3$) / 18.00 $- 1.20$ (cm$^3$);
amount $= \frac{16.80 \times 5.00 \times 10^{-3}}{1000} = 8.40 \times 10^{-5}$ (mol);

Award [2] for correct final answer.

(ii) $8.40 \times 10^{-5} \times 5 \times 10 = 4.20 \times 10^{-3}$ (mol per 250 cm$^3$);

(iii) $55.85 \times 4.20 \times 10^{-3} = 0.235$ (g);
Do not penalize if 56 g mol$^{-1}$ is used for atomic mass of iron.

(iv) $\frac{0.235 \times 100}{1.65} = 14.2\%$;

No ECF if answer $>100\%$.

(g) (i) Chemical formula: MnO$_2$;
Name: manganese(IV) oxide;
Allow manganese dioxide.
No ECF if formula is incorrect.

(ii) $2\text{H}_2\text{O}_2$(aq) $\rightarrow$ $2\text{H}_2\text{O}$ (l) + O$_2$(g) / $\text{H}_2\text{O}_2$(aq) $\rightarrow$ H$_2$O(l) + $\frac{1}{2}$O$_2$(g);
Ignore state symbols.

(iii) add more (sulphuric) acid/H$_2$SO$_4$ / ensure enough (sulphuric) acid/H$_2$SO$_4$ is present / OWTTE;
Award [0] if reference made to HCl or HNO$_3$.
(i) NO$_3^-$ and Cl$^-$ anions may also react with KMnO$_4$ / HNO$_3$ is an oxidizing agent / (HCl will not work as) Cl$^-$ reacts with MnO$_4^-$ (to form Cl$_2$) / HCl oxidized / OWTTE; [1]

For HCl, allow correctly balanced chemical equation:

$$2\text{MnO}_4^- + 10\text{Cl}^- + 16\text{H}^+ \rightarrow 2\text{Mn}^{2+} + 5\text{Cl}_2 + 8\text{H}_2\text{O}$$

Accept NO$_3^-$ and Cl$^-$ may react with KMnO$_4$/Fe$^{2+}$.

(ii) CaCO$_3$(s) + H$_2$SO$_4$(aq) → CaSO$_4$(s) + H$_2$O(l) + CO$_2$(g)

correct chemical equation;
correct state symbols; [2]

Allow CaSO$_4$(aq) instead of CaSO$_4$(s).

M2 can only be scored if M1 is correct.

Award [1max] if H$_2$CO$_3$(aq) is given instead of H$_2$O(l) + CO$_2$(g).
Q# 20/ IB Chem/2013/s/TZ1/Paper 2 Section B/Higher Level/Q7

(c) (i)

![Diagram of a voltaic cell with negative and positive electrodes and an electrolyte]

A clear diagram containing all elements (power supply, connecting wires, electrodes, container and electrolyte);

*Accept power supply if shown as conventional long/short lines (as in diagram above) or clearly labelled DC power supply.*

labelled positive electrode/anode and negative electrode/cathode;

*Accept positive and negative by correct symbols near power supply.*

labelled electrolyte/FeBr₂(1)/FeBr₂(aq);

*State must be included for FeBr₂.*

(ii) Electrolyte: positive ions/cations move to negative electrode/cathode and negative ions/anions to positive electrode/anode;

Conductors: electrons flow from negative pole of battery to positive pole of battery / OWTTE;

*Look at diagram in (i) for possible clarification of electron flow.*

Award [1 max] for “electrons in wire/external circuit and ions in solution”.

(iii) Negative electrode/cathode:

H₂;

\[ E^{\circ}(H_2) \text{ is less negative than } E^{\circ}(Fe) / Fe \text{ is more reactive than } H_2 / H_2 \text{ is lower in reactivity series / } H^+ \text{ is more easily reduced than } Fe^{2+} / OWTTE; \]

Positive electrode/anode:

O₂;

\[ E^{\circ}(O_2) \text{ is less positive than } E^{\circ}(Br_2) / in a dilute Br^- solution OH^-/H_2O is preferably discharged / OWTTE; \]

Award [3 max] if electrodes reversed or omitted.

(iv) Br₂;

Accept Fe.

[1]

(v) \( 2Br^- \rightleftharpoons Br_2 + 2c^- \) shifts to the right;

*Accept similar reason for Fe.*

[1]
Q# 21/ IB Chem/2013/s/TZ1/Paper 2 Section A/Higher Level/

4. (a) loss of electrons; [1]

(b) Carbon:  
III to IV / +3 to +4 / (+)1;  

Manganese:  
VII to II / +7 to +2 / −5;  
Penalize incorrect notation such as 3+ once only in all the paper. [2]

(c) Oxidizing agent: MnO₄⁻ and Reducing agent: (COOH):  
Accept correct names instead of formulas.  
Do not accept Mn and C. [1]

(d) (COOH)₂ ⇌ 2CO₂ + 2H⁺ + 2e⁻;  
Accept either → or ⇄.  
Allow equation times 5.  
Allow e⁻ instead of e⁻. [1]

(e) (i) MnO₄⁻(aq) + 8H⁺(aq) + 5e⁻ ⇌ Mn²⁺(aq) + 4H₂O(l)  
E° = 1.51 V;  
ΔE°(= 1.51 + 0.49) = 2.00 V;  
First mark may be implied in the calculation.  
Allow e⁻ instead of e⁻.  
Accept either → or ⇄. [2]

(ii) positive sign, spontaneous reaction;  
Allow ECF from (e) (i). [1]

(f) negative/ < 0;  
Do not allow ECF. This mark is independent of the answer in (e)(ii). [1]

Q# 22/ IB Chem/2012/w/TZ0/Paper 2 Section B/Higher Level/

4. (a) (i) Oxidation: loss of electrons and Reduction: gain of electrons; [1]

(ii) As₂O₃: +3;  
NO₂⁻: +5;  
H₃AsO₃: +3;  
N₂O₃: +3;  
Penalize incorrect notation e.g. III, V, 3+, 5+, 3, 5 once only. [4]

(iii) Oxidizing agent: substance reduced / removes electrons from another substance / causes some other substance to be oxidized / OWTEE and Reducing agent: substance oxidized / gives electrons to another substance / causes some other substance to be reduced / OWTEE;  
Accept Oxidizing agent: electron/e⁻ acceptor / causes oxidation / oxidation number/state decreases and Reducing agent: electron/e⁻ donor / causes reduction / oxidation number/state increases. [1]
(iv) \[ \text{As}_2\text{O}_3 (s) + 2\text{NO}_3^- (aq) + 2\text{H}^+ (aq) + 2\text{H}_2\text{O(l)} \rightarrow 2\text{H}_3\text{AsO}_4 (aq) + \text{N}_2\text{O}_5 (aq) \]
correct coefficients for \( \text{As}_2\text{O}_3 \), \( \text{H}_3\text{AsO}_4 \) and \( \text{NO}_3^- \), \( \text{N}_2\text{O}_5 \);
correct balanced equation; 
*Ignore state symbols. 
M1 must be correct to award M2.*

**Oxidizing agent:** \( \text{NO}_3^- (aq) / \text{nitrate} \) **and** **Reducing agent:** \( \text{As}_2\text{O}_3 (s) / \text{arsenic(III) oxide} \);
Accept \( \text{HNO}_3 (aq) / \text{nitric acid} \).
Accept arsenic oxide.
Species must be fully correct to score M3.
*Ignore state symbols.*

(b) (i) **Diagram to show:**

```
\begin{center}
\[ + \quad \text{electron flow} \quad - \]
\end{center}
```

Labels are not required.
one container, two electrodes, battery (and electrolyte);

Allow + and – for representation of battery (could be long and short lines for example) but M1 is not scored if a voltmeter/V if shown or labelled.
Ignore designation of electrodes (e.g. do not penalize Cu electrodes).

correct direction of electron flow (from negative pole to positive pole); 

Allow arrow without stating e\(^-\) explicitly.
To score M2, the polarity of the battery or the cathode and anode must be shown.
If a voltmeter/V is shown, M1 is not awarded but M2 may be scored if the cathode and anode are identified with the correct direction of electron flow.
(ii) **Half-equation at positive electrode (anode):**

\[ 4\text{OH}^- (aq) \rightarrow 2\text{H}_2\text{O} (l) + \text{O}_2(g) + 4e^- \quad / \quad 2\text{H}_2\text{O} (l) \rightarrow \text{O}_2(g) + 4\text{H}^+ (aq) + 4e^- / \]

\[ 2\text{OH}^- (aq) \rightarrow \frac{1}{2}\text{O}_2(g) + \text{H}_2\text{O} (l) + 2e^- ; \]

*Allow e instead of e*.

**Half-equation at negative electrode (cathode):**

\[ \text{Cu}^{2+} (aq) + 2e^- \rightarrow \text{Cu} (s) ; \]

*Allow e instead of e*.

*Award [1 max] for M1 and M2 if correct equations are given but at wrong electrodes.*

*Penalize = once only in (b)(ii) and (b)(iii).*

*Correct state symbols in all equations; M3 can only be scored if the correct species are given in M1 and M2 (i.e. do not award ECF from M1 and M2 for incorrect species).*

**Observation at positive electrode (anode):**

bubbles / gas;

*Award mark for observation even if type of gas is incorrect (e.g. hydrogen).*

**Observation at negative electrode (cathode):**

red/brown/copper/metal (deposit);

*Allow mass increases / gets thicker/larger / OWTTE.*

*Change in colour (in any) of the solution:*

solution loses blue colour/becomes paler;

*Change in acidity (if any) of the solution:*

becomes (more) acidic / pH decreases; [*]

(iii) **Half-equation at positive electrode (anode):**

\[ \text{Cu} (s) \rightarrow \text{Cu}^{2+} (aq) + 2e^- ; \]

*Allow e instead of e*.

**Half-equation at negative electrode (cathode):**

\[ \text{Cu}^{2+} (aq) + 2e^- \rightarrow \text{Cu} (s) ; \]

*Allow e instead of e*.

*Award [1 max] for M1 and M2 if correct equations are given but at wrong electrodes.*

*Penalize = once only in (b)(ii) and (b)(iii).*

*Correct state symbols in all equations; M3 can only be scored if the correct species are given in M1 and M2 (i.e. do not award ECF from M1 and M2 for incorrect species).*

**Observation at positive electrode (anode):**

(slowly) dissolves / OWTTE;

*Allow mass decreases / gets smaller/thinner / OWTTE; Accept impurities deposited under positive electrode/anode.
Observation at negative electrode (cathode):
red/brown/copper/metal deposit;
Allow mass increases / gets thicker/larger / OWTTE.

Change in colour (if any) of the solution:
blue colour remains;
Allow no change or solution remains same colour.

Change in acidity (if any) of the solution:
solution does not become (more) acidic / no change / OWTTE;

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(e) (i) Br₂: 0
HBr: −1
HOBr: +1
Award [2] for three correct.
Award [1] for any two correct.

(ii) bromine is oxidized and reduced / disproportionation;

Q# 24/ IB Chem/2011/w/TZ0/Paper 2 Section B/Higher Level/
7. (a) Oxidation: increase in oxidation number and Reduction: decrease in oxidation number / OWTTE;

(b) Cr₂O₇²⁻:
chromium(III) oxide;
Do not award mark for chromium oxide.
CrO₃:
chromium(VI) oxide;
Do not award mark for chromium oxide.
Do not award any marks if chromium oxide without Roman numerals is given for both.

(c) (i) substance reduced / causes other substance to be oxidized / increase oxidation number of another species / gains electrons / OWTTE;

(ii) Oxidizing agent:
Cr₂O₇²⁻ / dichromate (ion);

\[
\text{Cr}_2\text{O}_7^{2-} (aq) + 1 (aq) + 8\text{H}^+ (aq) \rightarrow 2\text{Cr}^{3+} (aq) + 1\text{O}_5^-(aq) + 4\text{H}_2\text{O}(l)
\]
Award [1] for coefficients: \(\text{Cr}_2\text{O}_7^{2-}(aq), 1 (aq), 2\text{Cr}^{3+}(aq), 1\text{O}_5^-(aq)\).
Award [1] for coefficients: \(8\text{H}^+(aq), 4\text{H}_2\text{O}(l)\).
Award [1 max] if coefficients of reactants only correct i.e. \(\text{Cr}_2\text{O}_7^{2-}, 1\) and \(8\text{H}^+\).
Award [1 max] if coefficients of products only correct i.e. \(2\text{Cr}^{3+}, 1\text{O}_5^-\) and \(4\text{H}_2\text{O}\).
Award [1 max] for correct reactants and products.
Ignore state symbols.
Voltaic cell showing:
labelled positive electrode (cathode) and negative electrode (anode);
direction of electrons in external circuit and direction of ions in salt bridge;
Award mark if correct direction of electrons is indicated but $e^-$ not labelled in external circuit.
Allow $e^-$ instead of $e^-$.  
Cations/positive ions and anions/negative ions must be identified in salt bridge.
Allow correct movement of ions in electrolyte instead of movement of ions in salt bridge (e.g. $Fe^{2+}$ from Fe at negative electrode/anode etc.).
If both movement of ions in salt bridge and movement of ions in electrolyte is given but one is incorrect do not award mark.

Positive electrode (cathode):
$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)$;  

Negative electrode (anode):
$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-;$

Penalize $\implies$ once only.
Penalize once only if electrodes or equations reversed.
For both electrodes allow $e^-$ instead of $e^-$. 

Overall cell reaction:
$Cr_2O_7^{2-}(aq) + 3Fe(s) + 14H^+(aq) \rightarrow 2Cr^{3+}(aq) + 3Fe^{2+}(aq) + 7H_2O(l);$  

Ignore state symbols throughout (d) (i).  

(ii) potential under standard conditions relative to standard hydrogen electrode/SHE:  
Reference must be made to standard conditions.
Instead of standard conditions allow either solute concentration of $1 \text{ mol dm}^{-3}/1 \text{ M}$ or $100 \text{ kPa}/10^5 \text{ Pa}$ for gases.
Allow 1 bar for $100 \text{ kPa}/10^5 \text{ Pa}$.
Allow 1 atm/1.01 x $10^5 \text{ Pa}$.
Allow voltage instead of potential.

(iii) (+)1.78 (V);
(f) *Positive electrode (anode)*: chromium;  
*Allow lead/titanium/platinum/graphite.*

*Negative electrode (cathode):* object to be plated;  
*Allow specific example here e.g. spoon.*

*Electrolyte:* Cr$^{3+}$ (aq);  
[3]  
*Allow (mixture of) Cr$^{3+}$ (aq) and CrO$_4^{2-}$ (aq)/chromate/chronic acid/H$_2$CrO$_4$.*  
*Ignore state symbols.*  
*Allow any soluble salt of Cr$^{3+}$.***
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9. (a) (i) 

![Diagram of electrochemical cell with labeled polarities of positive and negative electrodes;](image)

Electrodes can be labelled positive or negative or + and - signs can be used.

direction of electron flow;
e\(^{-}\) does not have to be labelled but arrow essential.

power source and molten electrolyte/Ni\(^{2+}\) (l) and Br\(^{-}\) (l)/NiBr\(_2\) (l);
State symbol necessary for M3 unless molten electrolyte stated.
Power source does not need to be labelled if correct symbol used (i.e. short line and long line).

Cathode/negative electrode equation:
Ni\(^{2+}\) + 2e\(^{-}\) → Ni;
Anode/positive electrode equation:
2Br\(^{-}\) → Br\(_2\) + 2e\(^{-}\);

Accept balanced half-equation with one e\(^{-}\).
Award [1 max] for M4 and M5 if electrodes are not identified or if equations are given wrong way round or incorrectly labelled.
Penalize ⇔ once only in Q.9.
Allow e instead of e\(^{-}\).
Ignore state symbols for M4 and M5.

(ii) Dilute sodium chloride:
2H\(_2\)O → O\(_2\) + 4H\(^+\) + 4e\(^-\) / 4OH\(^-\) → O\(_2\) + 2H\(_2\)O + 4e\(^-\);

Concentrated sodium chloride:
2Cl\(^-\) → Cl\(_2\) + 2e\(^-\);

Accept alternative balanced half-equations with correct number of electrons.
Award [1 max] if equations are given the wrong way round.
Award [2] if correct equations are written in order with dilute sodium chloride first and concentrated sodium chloride second but processes not stated explicitly.
Penalize ⇔ once only in Q.9.
Allow e instead of e\(^{-}\).
Ignore state symbols.
(b) (i) $\text{Sn} + \text{Cu}^{2+} \rightarrow \text{Sn}^{2+} + \text{Cu}$;  
*Ignore state symbols.*  
*Penalize* $\Rightarrow$ *once only in Q.9.*  

(ii) $0.34 - (-0.14) = (+) 0.48$ V;  

(iii) $1.0 \text{ mol dm}^{-3}$ solutions and $25^\circ \text{C}/298 \text{ K}.$  

(c) Cd$^{2+}$ is a stronger oxidizing agent than H$_2$O and will be displaced to produce Cd / OWTTE;  
Cr$^{3+}$ is a weaker oxidizing agent than H$_2$O and H$_2$ will displace in preference to Cr / OWTTE;  
*Award [1 max] for stating Cd$^{2+}$ stronger oxidizing agent than H$_2$O and Cr$^{2+}$ weaker oxidizing agent than H$_2$O / OWTTE.*  

(d) (i) Ni;  
only requires 2 mol of $e^-$ for each mol of Ni / Sn requires 4 mol of $e^-$ / Cr requires 3 mol of $e^-$/ Ni$^{2+}$ needs least number of $e^-$ to produce 1 mol of Ni metal;  
*Allow e instead of $e^-$.*  
*cathode / negative electrode;*  
*Do not award M3 for “metal deposited at cathode where oxidation occurs”.*  

(ii) temperature of solution;  
[Sn$^{4+}$];  
surface area/size of electrode;  
material of electrodes;  
*Do not allow nature of electrodes.*  

(e) (i) NH$_2$: $-3$;  
NO: $+2$;  
N$_2$: 0;  
*Penalize incorrect notation such as $3\rightarrow$, III, 2+, 2, II once only.*  

(ii) *Oxidation:*  
$2\text{NH}_3 \rightarrow \text{N}_2 + 6\text{H}^+ + 6e^-;$  
*Reduction:*  
$2\text{NO} + 4\text{H}^+ + 4e^- \rightarrow \text{N}_2 + 2\text{H}_2\text{O};$  
*Award [1 max] for M1 and M2 if redox processes are not identified or if equations are given wrong way round.*  
*Penalize* $\Rightarrow$ *once only in Q.9.*  
*Allow e instead of $e^-$.  
*Ignore state symbols.*  
*Oxidizing agent: NO;*  
*Allow either formula or name.*  

(iii) NH$_3$/ammonia (in excess by) and 10 (dm$^3$);  
25.0 (dm$^3$);  
*SMASHING111*
Q# 26/ IB Chem/2010/w/TZ0/Paper 2 Section B/Higher Level/Q4

(b) (i) contains ions which are free to move (only) in molten state;
Mg$^{2+}$ move to cathode/negative electrode and Cl$^{-}$ move to anode/positive electrode / OWTTE; [2]

(ii) anode/positive electrode:
2Cl$^{-} \rightarrow$ Cl$_2$ + 2e$^{-}$ / Cl$^{-} \rightarrow \frac{1}{2}$Cl$_2$ + e$^{-}$; [2]
Accept e instead of e$^{-}$.
Do not accept Cl$^{-}$ → Cl + e$^{-}$.
Ignore state symbols.

(iii) magnesium has large negative electrode potential / $E^{\circ}$;
reduction of H$_2$O/H$^+$ to H$_2$ has less negative electrode potential;
Mg$^{2+}$ not readily reduced (in comparison to H$_2$O);
if formed, magnesium would (immediately) react with water to form Mg$^{2+}$; magnesium more reactive than hydrogen; [1 max]
Do not accept Mg too reactive.

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(e) (i) the more negative the electrode potential the more negative the enthalpy change / the more exothermic the reaction / OWTTE; [1]
Accept electrode potential proportional to the enthalpy change.
Do not accept greater enthalpy change.

(ii) any line (straight or curve) with positive gradient;
Accept if curve becomes flat for electrode potentials above 0.25.

which passes through $\Delta H = 0$ at standard electrode potentials between 0.25 and 0.50; [2]
Accept either positive or zero enthalpy change for electrode potentials greater than value of copper (in range 0.25 to 0.50).
6. (a) (i) Direction of electron flow; [4]

(ii) Oxidation:
Mg (s) → Mg²⁺(aq) + 2e⁻;

Reduction:
Ag⁺(aq) + e⁻ → Ag(s); [2]

Ignore state symbols.
Award [1 max] if equations not labelled reduction or oxidation or labelled the wrong way round.
Allow e⁻ instead of e⁻.
Penalize equilibrium sign or reversible arrows once only in parts (a) (ii) and (d) (ii).

(iii) +0.80 – (–2.37) = 3.17 V
Correct data;
Answer with unit; [2]
Award [1] for –3.17 V or correct working of wrong values.

(b) (i) Cd/Cd(s);
Do not allow Cd²⁺. [1]

(ii) 5Cd(s) + 2MnO₄⁻(aq) + 16H⁺(aq) → 5Cd²⁺(aq) + 2Mn²⁺(aq) + 8H₂O(l)
Correct reactants and products;
correct balancing of this equation; [2]
Ignore state symbols.
(c) Accept suitable diagram with the following indicated:
Pt electrode;
\([\text{H}^+ (aq)] = 1 \text{ mol dm}^{-3} / 0.5 \text{ mol dm}^{-3} \text{ H}_2\text{SO}_4;\)

\[ \text{H}_2 \text{ gas}; \]
at 1 atm / 1.01\times10^5 \text{ Pa};
Do not award mark for pressure if no hydrogen gas given.

\[ 298 \text{ K} / 25 ^\circ \text{C}; \]

(d) (i) sodium chloride crystals consist of ions in a (rigid) lattice / ions cannot move (to electrodes) / \textit{OWTIE};
when melted ions free to move / ions move when potential difference/voltage applied;

(ii) positive sodium ions/Na\(^+\) move to the negative electrode/cathode \textbf{and} negative chloride ions/Cl\(^-\) move to the positive electrode/anode;

electrons are released to positive electrode/anode by negative ions and accepted from negative electrode/cathode by positive ions / reduction occurs at the negative electrode/cathode \textbf{and} oxidation occurs at the positive electrode/anode / Na\(^+\) ions are reduced \textbf{and} Cl\(^-\) ions are oxidized;

\[ (\text{Positive electrode/anode}): \]
\[ 2\text{Cl}^- \rightarrow \text{Cl}_2 + 2e^- / \text{Cl}^- \rightarrow \frac{1}{2}\text{Cl}_2 + e^-; \]

\[ (\text{Negative electrode/cathode}) \]
\[ 2\text{Na}^+ + 2e^- \rightarrow 2\text{Na} / \text{Na}^+ + e^- \rightarrow \text{Na}; \]

Award \[ 1 \max \] if equations not labelled or labelled wrong way round.
Allow \( e \) instead of \( e^- \).
Penalize equilibrium sign or reversible arrows once only in parts (a) (ii) and (d) (ii).

(iii) Products:
oxygen at positive electrode and hydrogen at negative electrode;
moles of \( \text{Mg} = 0.5 \) / mole ratio of \( \text{O}_2:\text{H}_2 \) is 1:2;
\textbf{Can be implied by calculation.}

\[ \text{mass oxygen} = \left( \frac{1}{2} \times \frac{12.16}{24.31} \times 32.00 \right) = 8.00 \text{ g}; \]

\[ \text{mass hydrogen} = \left( \frac{12.16}{24.31} \times 2.02 \right) = 1.01 \text{ g}; \]

\[ \text{Do not apply SD rule here.} \]
Q# 29/ IB Chem/2010/s/TZ1/Paper 2 Section A/Higher Level/

1. (a) (i) Copper:
0 to +2 / increases by 2 / +2 / 2+;
Allow zero/hought for 0.

Nitrogen:
+5 to +4 / decreases by 1 / −1 / 1−;
Penalize missing + sign or incorrect notation such as 2+, 2+ or II, once only.

(ii) nitric acid/HNO₃ / NO₃⁻ / nitrate;
Allow nitrogen from nitric acid/nitrate but not just nitrogen.

(b) (i) 0.100 × 0.0285 ;
2.85 × 10⁻³ (mol);
Award [2] for correct final answer.

(ii) 2.85 × 10⁻³ (mol),

(iii) (63.55 × 2.85 × 10⁻³) = 0.181 g ;
Allow 0.33.

(iv) \[ \frac{0.181}{0.456} \times 100 = 39.7 \% ; \]

(v) \[ \frac{44.2 - 39.7}{44.2} \times 100 = \frac{10}{10.2} \% ; \]
Allow 11.3 % i.e. percentage obtained in (iv) is used to divide instead of 44.2 %.

(c) (i) 1s²2s²2p⁶3s²3p⁶3d⁶;
Do not allow [Ar]3d⁶;

(ii) d orbitals are split;
(3d) electrons move between orbitals and absorb light/energy / complementary colour is transmitted when energy absorbed by d electrons moving;
Accept levels instead of orbitals.

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1. (a) MnO₄⁻ (aq) + 5Fe²⁺ (aq) + 8H⁺ (aq) → Mn²⁺ (aq) + 5Fe³⁺ (aq) + 4H₂O (i)

Award (2) if correctly balanced.
Award (1) for correctly placing H⁺ and H₂O.
Award (1 max) for correct balanced equation but with electrons shown. Ignore state symbols.

(b) Fe²⁺ / iron(II);
Do not accept iron.

(c) n = 2.152 × 10⁻² × 2.250 × 10⁻²;
4.842 × 10⁻¹ (mol);
Award (1) for correct volume
Award (1) for correct calculation.
Q# 31/ IB Chem/2009/w/TZ0/Paper 2 Section A/Higher Level/

4. (a) electrolytic cell converts electrical energy to chemical energy and voltaic cell converts chemical energy to electrical energy / electrolytic cell uses electricity to carry out a (redox) chemical reaction and voltaic cell uses a (redox) chemical reaction to produce electricity / electrolytic cell requires a power supply and voltaic cell does not;

electrolytic cell involves a non-spontaneous (redox) reaction and voltaic cell involves a spontaneous (redox) reaction;

in an electrolytic cell, cathode is negative and anode is positive and vice-versa for a voltaic cell / electrolytic cell, anode is positive and voltaic cell, anode is negative / electrolytic cell, cathode is negative and voltaic cell, cathode is positive;

voltaic cell has two separate solutions and electrolytic cell has one solution / voltaic cell has salt bridge and electrolytic cell has no salt bridge;

electrolytic cell, oxidation occurs at the positive electrode/anode and voltaic cell, oxidation occurs at the negative electrode/anode vice-versa;

[2 max]

If descriptions are reversed for electrolytic and voltaic cell, penalize first marking point but award second marking point as ECF.

(b) (i) $2\text{Al}(s) + 3\text{Ni}^{2+}(\text{aq}) \rightarrow 2\text{Al}^{3+}(\text{aq}) + 3\text{Ni}(s)$;
Correct reactants and products, award [1]
Balancing award [1].
Ignore state symbols and equilibrium sign.

[2]

(ii) (+) 1.40 (V);

[1]

(iii) aluminium anode/negative electrode;
nickel cathode/positive electrode;
electron movement from Al to Ni;
correct movement of cations and anions through salt bridge;

If electron movement shown correctly but not labelled, award the mark

[4]
Q# 32/ IB Chem/2009/s/TZ1/Paper 2 Section B/Higher Level/

7. (a) (i) the voltage obtained when the half-cell is connected to the standard hydrogen electrode:
under standard conditions of 298 K and 1 mol dm⁻³ solutions;
electrons flow (in the external circuit) from the half-cell to the hydrogen electrode / the metal in the half-cell is above hydrogen in the ECE / Fe is a better reducing agent than H₂ / Fe is oxidised more readily than H₂;

(ii) −0.28 V ;

(iii) Co²⁺/cobalt(II) ion ;

(iv) \( 2\text{Al} + 3\text{Fe}^{3+} \rightarrow 3\text{Fe} + 2\text{Al}^{3+} \);
Award [1] for correct reactants and products and [1] for correctly balanced,
ignore states.
Do not accept ⇨

(v) to complete the electrical circuit / OWITE;
by allowing the movement of ions;

(b) (i) +2 ;

(ii) +3 ;

(iii) +2 ;

Only penalize once if roman numerals are used or if written as 2+ or 3+.

(c) (i) diagram to show:

![Electrode Diagram]

battery/source of electricity connected to two electrodes in the solution with positive and negative electrodes correctly labelled;
electrons/current flowing from the cell to the negative electrode;
labelled solution of sodium chloride;
If the connecting wires to electrodes are immersed in the solution [1 max].

(ii) \( \text{Na}^+, \text{H}^+ / \text{H}_2\text{O}^+, \text{Cl}^-, \text{OH}^- \)
All four correct [2], any three correct [1].
(iii) hydrogen at (−)/cathode and oxygen at (+)/anode:
\[ 2H^+ + 2e^- \rightarrow H_2 / 2H_2O + 2e^- \rightarrow H_2 + 2OH^-; \]
\[ 4OH^- \rightarrow O_2 + 2H_2O + 4e^- / 2H_2O \rightarrow O_2 + 4H^+ + 4e^-; \]
Accept e instead of e\(^-\).
If electrodes omitted or wrong way round [2 max].

(iv) Ratio of H\(_2\) : O\(_2\) is 2 : 1;
[1]

(d)  
(i) (−)/(cathode) 2H\(^+\) + 2e\(^-\) \rightarrow H\(_2\) / 2H\(_2\)O + 2e\(^-\) \rightarrow H\(_2\) + 2OH\(^-\);
Accept e instead of e\(^-\).
If electrodes omitted or wrong way round [1 max].

(ii) (−)/(cathode) Na\(^+\) + e\(^-\) \rightarrow Na ;
Accept e instead of e\(^-\).
If electrodes omitted or wrong way round [1 max].

Q# 33/ IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/
4. (a)  
(i) Fe\(^{3+}\) \rightarrow Fe\(^{2+}\) + e\(^-\);
[1]

(ii) MnO\(_4^-\) + 8H\(^+\) + 5e\(^-\) \rightarrow Mn\(^{2+}\) + 4H\(_2\)O;
[1]

(iii) MnO\(_4^-\) + 5Fe\(^{2+}\) + 8H\(^+\) \rightarrow Mn\(^{2+}\) + 5Fe\(^{3+}\) + 4H\(_2\)O;
Accept e instead of e\(^-\).
[1]

(b)  
(i) amount of MnO\(_4^-\) = \( \frac{11.6}{1000} \times 0.0200\) = 2.32 \times 10^{-4} mol;
[1]

(ii) amount of Fe\(^{3+}\) = 5 \times 2.32 \times 10^{-4} = 1.16 \times 10^{-3} mol;
[1]

(iii) mass of Fe\(^{2+}\) = 55.85 \times 1.16 \times 10^{-3} = 6.48 \times 10^{-3} g;
percentage of Fe\(^{2+}\) in tablet = \( \frac{6.48 \times 10^{-3}}{1.43} \times 100 = 4.53\% ; \)
[2]

Q# 34/ IB Chem/2008/w/TZ0/Paper 2 Section B/Higher Level/Q6
(e)  
(i) Fe\(^{2+}\)/Ag;
\[ 2Fe^{2+} + Br_2 \rightarrow 2Fe^{3+} + 2Br^- / 2Ag + Br_2 \rightarrow 2Ag^+ + 2Br^- / 2Ag + Br_2 \rightarrow 2AgBr ; \]
Ignore state symbols.
[2]

(ii) \( E^\circ = +0.80 \rightarrow (-1.66) = (+)2.46\ V ; \)
[1]

(iii) \( E^\circ = +0.48 \rightarrow (-0.76) = 0.28\ V ; \)
[1]
Q# 35/ IB Chem/2008/w/TZ0/Paper 2 Section B/Higher Level/

6. (a) (oxidation is) loss of electron(s);
    Br⁻ / bromide (ion);

(b) Ti  +4 and +4;
    Cl  0 and −1;
    C  0 and +4;
    Penalty missing +, or answers written as 4+ once only.
    If no marks scored allow [1] if all oxidation numbers for reactants or for products are correct.

(c) (i) Cr oxidation number +6/same on both sides/does not change;
    neither oxidation nor reduction occur;
    No ECF

(ii) Cl oxidation number 0 on left and −1 and +1 on right;
    both oxidation and reduction occur/disproportionation;
    No ECF

(d) (i) W > Z > Y > X;
    Award [1] mark for correct order.
    X below Y because of reaction 2/because X will not displace Y;
    X below Z because of reaction 4/because X displaced by Z;
    X below W because of reaction 1/because X displaced by W and Z displaces X;
    Y below Z because of reaction 3/because Y will not displace Z; [4 max]
    Give credit for OWTE in this part.
    Any three of last four score [1] each.

(ii) 2V + 3XO → V₂O₃ + 3X ; [1]

Q# 36/ IB Chem/2008/s/TZ1/Paper 2 Section B/Higher Level/

8. (a) (i) 2H₂O → O₂ + 4H⁺ + 4e⁻ /4OH⁻ → O₂ + 2H₂O + 4e⁻;
    bubbles (of colourless gas) evolved;
    Do not accept oxygen evolved as an observation.

(ii) Cu²⁺ + 2e⁻ → Cu ;
    brown deposit;
    Accept copper deposited [2]

(iii) electrolyte becomes acidic / pH decreases;
    blue colour becomes lighter / concentration of Cu²⁺ decreases;
    Do not accept colour change.

(iv) Cu = 1 mol and O₂ = ½ mol ; [1]

(v) copper(II) nitrate / Cu(NO₃)₂ ;
    Accept any soluble copper(II) salt e.g. copper(II) ethanoate [1]

(vi) copper anode: positive electrode dissolves / decrease in mass;
    copper cathode: negative electrode increases in mass / brown deposit on cathode;
    no change in colour of the electrolyte / no change in the concentration of Cu²⁺ /
    no change in pH;
    current I and time t; [3]

(b) current I and time t; [1]
(c)  
(i) \[25 \text{°C} \text{ and } 1.0 \text{ mol dm}^{-2} \]

Accept 298 K or 1.0 M but not 1 atm/101kPa

(ii) \[2\text{MnO}_4^{-}(aq) + 16\text{H}^+(aq) + 5\text{Ni(s)} \rightarrow 2\text{Mn}^{2+}(aq) + 5\text{Ni}^{2+}(aq) + 8\text{H}_2\text{O(l)}\]

correct reactants and products;
balancing;
Ignore if state symbols not written.
Do not accept electrons in the final equation.

(iii) reducing agent \(\text{Ni(s)/Ni/Nickel}\);
Do not accept \(\text{Ni}^{2+}\).
change in oxidation number 5 \(\rightarrow\) +7 \(\rightarrow\) +2 decreases by 5;

(iv) \[+1.74 \text{ V}\];

(v) A clear-labelled diagram consisting of:

nickel anode;
platinum cathode;
electron movement from \(\text{Ni to Pt}\);
salt bridge;
correct movement of cations / anions through salt bridge;

\[e.g.\]

\[\begin{array}{c}
\text{Ni}^{2+}(aq) \\
\text{Ni anode} \\
\text{Salt bridge} \\
\text{Pt cathode} \\
\text{MnO}_4^-/\text{H}^+(aq)
\end{array}\]

(d) (voltaic cell)-spontaneous redox reaction / (electrolytic cell)-non-spontaneous redox reaction;

(voltaic cell)-chemical energy converted to electrical energy / (electrolytic cell)-electrical energy converted to chemical energy;

Accept anode is the positive electrode in an electrolytic cell and the negative electrode in a voltaic cell / cathode is the negative electrode in an electrolytic cell and the positive electrode in a voltaic cell.

For statements such as one electrolyte/two electrolyte and salt bridge/no salt bridge, award [1 max].
Table 10
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6. One structural isomer of C₄H₅Br is a chiral molecule.

(a) Draw the three-dimensional shape of each enantiomer of this isomer showing their spatial relationship to each other. [2]

(b) When one enantiomer undergoes substitution by alkaline hydrolysis approximately 75% of the product molecules show inversion of configuration. Comment on the mechanisms that occur. [2]

(c) Suggest why the rate of alkaline hydrolysis of an enantiomer of iodopropane is greater than that of an enantiomer of bromopropane. [1]
5. Propane and propene are members of different homologous series.

(a) Draw the full structural formulas of propane and propene.

Propane:

Propene:

(c) Both propane and propene react with bromine.

(i) State an equation and the condition required for the reaction of 1 mol of propane with 1 mol of bromine.

(ii) State an equation for the reaction of 1 mol of propene with 1 mol of bromine.
(iii) State the type of each reaction with bromine.

Propane:

---------------------------------

Propene:

---------------------------------

(d) Construct the mechanism of the formation of 2-bromopropane from hydrogen bromide and propene using curly arrows to denote the movement of electrons.

---------------------------------
(d) X is an alcohol with the following formula:

![Chemical structure of X]

Y is an isomer of X but has a different functional group

(v) Both X and Y are soluble in water. Deduce whether or not both X and Y show hydrogen bonding with water molecules, representing any hydrogen bonding present by means of a diagram.
(iv) Compare and contrast the bonding types formed by nitrogen in \([\text{PtCl}_2(\text{NH}_3)_2]\). [2]

Similarity:

.................................................................
.................................................................
.................................................................

Difference:

.................................................................
.................................................................
.................................................................

(v) Deduce all of the intermolecular forces present for the ammonia molecule. [2]
7. The biopharmaceutical industry is now a global contributor to the world economy.

(a) Atorvastatin, a drug used to lower cholesterol, recently gained attention from the global media.

Atorvastatin has the structure shown below.

(b) Bute is a chemical with the following molecular formula:

\[ \text{C}_{19}\text{H}_{20}\text{N}_{2}\text{O}_{2} \]

(iii) Deduce the degree of unsaturation (index of hydrogen deficiency – IHD) of bute.
(d) The two isomers of \([\text{Pt(NH}_3\text{)}_2\text{Cl}_2]\) are crystalline. One of the isomers is widely used as a drug in the treatment of cancer.

(i) Draw both isomers of the complex. \([1]\)

(ii) Explain the polarity of each isomer, using a diagram for each isomer to support your answer. \([2]\)
4. 1-iodoethane reacts with sodium hydroxide.

(a) Explain the mechanism of this reaction, using curly arrows to represent the movement of electron pairs and showing any stereochemical features of the reaction mechanism. [4]

(b) State the rate expression for this reaction and identify the molecularity of the rate-determining step (RDS). [2]

Rate expression:

Molecularity of RDS:
(c) Suggest why polar, aprotic solvents are more suitable for $S_N2$ reactions whereas polar, protic solvents favour $S_N1$ reactions.

\[ \text{ } \]

\[ S_N2: \]

\[ \text{ } \]

\[ S_N1: \]

\[ \text{ } \]

(d) Deduce, with a reason, if water or DMF (N,N-Dimethylformamide, HCON(CH$_3$)$_2$) is a better solvent for this reaction.

\[ \text{ } \]

\[ \text{ } \]
5. Compound A and compound B are hydrocarbons.

(a) (i) State the term that is used to describe molecules that are related to each other in the same way as compound A and compound B. [1]

(b) (ii) Suggest a chemical test to distinguish between compound A and compound B, giving the observation you would expect for each. [2]

Test:

Observation with A:

Observation with B:
2. Phosgene, COCl₂, is usually produced by the reaction between carbon monoxide and chlorine according to the equation:

\[ \text{CO} (g) + \text{Cl}_2 (g) \rightleftharpoons \text{COCl}_2 (g) \]

(b) One important industrial use of phosgene is the production of polyurethanes. Phosgene is reacted with diamine X, derived from phenylamine.

\[ \text{H}_2\text{N} - \text{CH}_2 - \text{H}_2\text{N} \]

\[ \text{O} \quad \text{X} \quad \text{NH}_2 \]

(i) Classify diamine X as a primary, secondary or tertiary amine. \[ \text{[1]} \]

(ii) Phenylamine, C₆H₅NH₂, is produced by the reduction of nitrobenzene, C₆H₅NO₂. Suggest how this conversion can be carried out. \[ \text{[2]} \]
(iii) Nitrobenzene can be obtained by nitrating benzene using a mixture of concentrated nitric and sulfuric acids. Formulate the equation for the equilibrium established when these two acids are mixed.

(iv) Deduce the mechanism for the nitration of benzene, using curly arrows to indicate the movement of electron pairs.

(c) The other monomer used in the production of polyurethane is compound Z shown below.

(i) State the name, applying IUPAC rules, of compound Z and the class of compounds to which it belongs.

Name:

Class:
Chem 10 21 Q# 9/ IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/

9. (a) A 0.842 g sample of a liquid halogenoalkane, RBr(l), was heated under reflux with 1.35 \times 10^{-2} \text{ mol} of aqueous sodium hydroxide, NaOH(aq). After cooling the mixture, the excess NaOH was titrated with hydrochloric acid, HCl(aq), and required 7.36 \times 10^{-3} \text{ mol} of the acid.

(i) State the equation for the substitution reaction of the halogenoalkane with sodium hydroxide. [1]

(ii) Calculate the amount, in mol, of sodium hydroxide that reacted with the halogenoalkane. [1]

(iii) Calculate the molar mass of the halogenoalkane. [1]

(iv) Given that each molecule of the halogenoalkane contains one bromine atom, determine its molecular formula. [1]
(v) Deduce the structural formulas of four structural isomers of the halogenoalkane based on the molecular formula and label each isomer as primary, secondary or tertiary.
(If you have not been able to determine the molecular formula in part (a) (iv), use $C_6H_{11}Br$ to deduce the four structural isomers.)

(b) The reaction between a primary halogenoalkane drawn in part (a) (v) and potassium cyanide follows an $S_N2$ mechanism.

(i) State the importance of this reaction in organic synthesis.
(ii) Explain the mechanism of the reaction using curly arrows to represent the movement of electron pairs.

(iii) The organic product obtained in part (b) (ii) can be reduced to form an amine. State an equation for this reaction and a suitable catalyst.

(d) This molecule is needed in the question that follows it:

(ii) Under certain conditions, the major product obtained in the elimination reaction can undergo polymerization. Identify the type of polymerization and draw a section of the polymer consisting of two repeating units.

Type of polymerization:

Section of polymer:
(d) Ethane can react with chlorine. Explain the free-radical mechanism of this reaction, including any necessary reaction conditions.
10. Some reactions of but-2-ene are given below.

\[
\begin{align*}
\text{Poly(but-2-ene)} & \\
\text{Compound A} & \xrightarrow{\text{Br}_2(\text{I})} \text{H}_3C-\text{CH=CH}-\text{CH}_3 \quad \text{But-2-ene} & \xrightarrow{\text{concentrated H}_2\text{SO}_4} \text{C}_4\text{H}_9\text{OH} \\
& \quad \text{in the absence of UV} & \text{Compound C} \\
& \xrightarrow{\text{HBr}} \text{H}_2\text{C}-\text{CHBr}-\text{CH}_2-\text{CH}_3 \quad \text{Compound B}
\end{align*}
\]

(a) (i) Deduce the full structural formula of compound A. \[1\]

(ii) Apply IUPAC rules to name compound A. \[1\]

(iii) Describe the colour change observed when excess but-2-ene reacts with bromine to form compound A. \[1\]
(b) (i) Outline two reasons why the polymerization of alkenes is of economic importance. [2]

(ii) Identify the structure of the repeating unit of poly(but-2-ene). [1]

(c) (i) Compound C, C₂H₂OH, can also be formed by reacting compound B, CH₃CHBrCH₂CH₃, with aqueous potassium hydroxide. This reaction proceeds by both S_N1 and S_N2 mechanisms. Explain the S_N2 mechanism, using curly arrows to represent the movement of electron pairs. [4]
(ii) Explain why the hydroxide ion is a better nucleophile than water. [2]

(d) (i) Compound B, CH₂CHBrCH₂CH₃, also reacts with potassium cyanide. Apply IUPAC rules to name the organic product formed. [1]

(ii) The organic product of the reaction in part (d) (i) can be reduced to:

\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{N} \\
\text{H} \\
\end{array}
\]

State the two reagents required. [1]

(iii) Deduce the full structural formula of the organic product formed when the compound in part (d) (ii) reacts with ethanoic acid in the presence of an acid catalyst. [1]
(e) Compound C, C₂H₆OH, can be oxidized by acidified potassium dichromate(VI) to form compound F.

(i) State the name of the functional group present in compound F. [1]

(ii) Deduce the structural formula of an alcohols which is a structural isomer of compound C and cannot be oxidized by acidified potassium dichromate(VI). [1]

(f) Explain why but-2-ene is more volatile than compound C. [2]

(g) Deduce the equation for the complete combustion of compound C. [1]
(h) But-2-ene can exist as two geometrical isomers. Geometrical isomerism is a form of stereoisomerism.

(i) Define the term *stereoisomers*. [1]

(ii) State the conditions needed for a compound to show geometrical isomerism. [2]

(iii) Draw the structures of the two geometrical isomers of but-2-ene, clearly identifying each as *cis* or *trans*. [2]
Chem 10 6 Q# 11/ IB Chem/2015/s/TZ2/Paper 2 Section A/Higher Level/
5. (a) State two features of a homologous series. [2]

(b) Ethane, a member of the homologous series of alkanes, can react with bromine. Explain the free-radical mechanism of this reaction, including any necessary reaction conditions. [4]

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5. Ethanol has many industrial uses.

(a) State an equation for the formation of ethanol from ethene and the necessary reaction conditions. [3]

Equation:

Conditions:
(d) State the equation for the acid-catalysed reaction of ethanol with propanoic acid and state the name of the organic product. [2]

Equation:

Name of the organic product

(e) (i) A polyester can be formed when ethane-1,2-diol reacts with benzene-1,4-dicarboxylic acid.

Deduce the structure of the repeating unit and state the other product formed. [2]

Repeating unit:

Other product:

(ii) State the type of polymerization that occurs. [1]
6. Bromomethane was used as a pesticide until it was found to be ozone-depleting.

(a) State the equation for the reaction between methane and bromine to form bromomethane. [1]

(b) (i) Explain, using equations, the complete free-radical mechanism for the reaction of methane with bromine, including necessary reaction conditions. [4]

(ii) Bromomethane reacts with aqueous sodium hydroxide. State the organic product of this reaction. [1]

(c) Explain why the rate of the reaction between iodomethane, CH₃I, and NaOH (aq) is faster than the rate of the reaction between CH₃Br and NaOH (aq). [2]
7. (a) (i) Ethanol is a primary alcohol that can be oxidized by acidified potassium dichromate(VI). Distinguish between the reaction conditions needed to produce ethanal and ethanoic acid. [2]

- Ethanal:

- Ethanoic acid:

(b) Ethanol can be made by reacting aqueous sodium hydroxide with bromoethane. Explain the mechanism for this reaction, using curly arrows to represent the movement of electron pairs. [4]

(d) 2-bromobutane exists as optical isomers.

(i) State the essential feature of optical isomers. [1]

(ii) Outline how a polarimeter can distinguish between these isomers. [2]
9. Consider the following list of organic compounds:

   Compound 1: CH$_3$CH$_2$CH(OH)CH$_3$
   Compound 2: CH$_3$CH$_2$COCH$_3$
   Compound 3: CH$_3$CH$_2$CH$_2$OH
   Compound 4: CH$_3$CH$_2$CH$_2$CHO

(a) Apply IUPAC rules to state the names of the four compounds.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH$_3$CH$_2$CH(OH)CH$_3$</td>
<td>.................................................</td>
</tr>
<tr>
<td>CH$_3$CH$_2$COCH$_3$</td>
<td>.................................................</td>
</tr>
<tr>
<td>CH$_3$CH$_2$CH$_2$OH</td>
<td>.................................................</td>
</tr>
<tr>
<td>CH$_3$CH$_2$CH$_2$CHO</td>
<td>.................................................</td>
</tr>
</tbody>
</table>

(b) (i) Define the term structural isomers.

(ii) Identify the two compounds in the list that are structural isomers of each other.
(c) (i) Determine the organic product formed when each of the compounds is heated under reflux with excess acidified potassium dichromate(VI). If no reaction occurs write NO REACTION in the table. [4]

<table>
<thead>
<tr>
<th>Compound</th>
<th>Organic product</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₃CH₂CH(OH)CH₃</td>
<td></td>
</tr>
<tr>
<td>CH₃CH₂COCH₂</td>
<td></td>
</tr>
<tr>
<td>CH₃CH₂CH₂OH</td>
<td></td>
</tr>
<tr>
<td>CH₃CH₂CH₂CHO</td>
<td></td>
</tr>
</tbody>
</table>

(ii) Describe the colour change during the reactions that occur in part (i). [1]

..................................................................................................................

(d) Deduce the two-stage reaction pathway for converting 1-bromobutane into 1-pentanamine (1-pentylamine). Include reagents and structural formulas of organic products for each stage. [4]

<table>
<thead>
<tr>
<th>Stage</th>
<th>Reagent</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
(f) (i) Pentanoic acid reacts with ethanol. State the structural formula of the organic product and the name of the functional group it contains. [2]

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(ii) State the type of reaction in part (i). [1]

........................................................................................................................................

Chem 10 1 Q# 16/ IB Chem/2014/w/TZ0/Paper 2 Section A/Higher Level/
6. The open-chain structure of D-fructose is shown below.

(a) State the names of two functional groups in D-fructose. [1]

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(e) In the gas phase, A reacts with hydrogen to form D:

![Chemical structure of A and D]

(i) State the conditions required for this reaction to occur.  

(ii) Outline a use for hydrogenation reactions like this in the manufacture of foodstuffs.  

(iii) State, with a reason, whether you would expect the entropy change for this reaction to be positive or negative.
(iv) Given that the enthalpy change of formation of compounds A and D, in the gas phase, is $-68 \text{ kJ mol}^{-1}$ and $-178 \text{ kJ mol}^{-1}$, respectively, calculate the enthalpy change for the reaction of A with hydrogen. [2]

(v) Explain how the spontaneity of this reaction would depend on the temperature at which it was carried out. [2]

(vi) The standard enthalpy change of combustion of A is $-4000 \text{ kJ mol}^{-1}$. Calculate the amount of A, in mol, that would have to be burned to raise the temperature of 1 dm$^3$ of water from 20 °C to 100 °C. [2]
(vii) Compound D is isomeric with hexane. Predict, giving reasons, how the boiling points of these compounds would compare. [2]

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7. Alkenes, such as A (shown below), are important intermediates in the petrochemical industry because they undergo addition reactions to produce a wide variety of products, such as the conversion shown below.

\[ \text{A} \quad \rightarrow \quad \text{B} \]

(a) State the reagent required to convert A into B. [1]
(c) Another way to make B is the reaction shown below.

\[
\begin{array}{c}
\text{H}_3\text{C} & \text{CH}_3 \\
\text{H} & \text{C} & \text{C} & \text{H} & \text{Br}_2 \\
\text{H}_3\text{C} & \text{CH}_3 & \rightarrow & \text{H}_3\text{C} & \text{C} & \text{Br} & \text{C}_3 & \text{H}_3 \\
\text{H}_3\text{C} & \text{CH}_3 & & & & & & \\
\end{array}
\]

(i) State the conditions required for this reaction to occur. \[1\]

(ii) Outline why it would give a poor yield of the desired product. \[1\]

(d) B can be converted into C.

\[
\begin{array}{c}
\text{H}_3\text{C} & \text{CH}_3 \\
\text{H} & \text{C} & \text{C} & \text{OH} & \text{C}_3 & \text{H}_3 \\
\text{H}_3\text{C} & \text{CH}_3 & & & & \\
\end{array}
\]

(i) State the reagent required. \[1\]
(ii) State the rate expression that you would expect for the conversion of B to C.  

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(e) In the gas phase, A reacts with hydrogen to form D:

\[
\begin{align*}
\text{H}_3\text{C} & \quad \text{C} = \text{C} & \quad \text{CH}_3 \\
\text{H}_3\text{C} & \quad \text{CH}_3 & \quad + \quad \text{H}_2 \\
\text{A} & & \rightarrow \quad \text{H}_3\text{C} & \quad \text{C} \quad \text{C} & \quad \text{H}_3\text{C} & \quad \text{CH}_3 \\
& & & \quad \text{D}
\end{align*}
\]

(i) State the conditions required for this reaction to occur. \[1\]

(ii) Outline a use for hydrogenation reactions like this in the manufacture of foodstuffs. \[1\]

(vii) Compound D is isomorphic with hexane. Predict, giving reasons, how the boiling points of these compounds would compare. \[2\]
1. A class studied the equilibrium established when ethanoic acid and ethanol react together in the presence of a strong acid, using propanone as an inert solvent. The equation is given below.

\[ \text{CH}_3\text{COOH} + \text{C}_2\text{H}_5\text{OH} \rightleftharpoons \text{CH}_3\text{COOC}_2\text{H}_5 + \text{H}_2\text{O} \]

(e) Outline why changing the temperature has only a very small effect on the value of the equilibrium constant for this equilibrium. [1]

(g) Propanone is used as the solvent because one compound involved in the equilibrium is insoluble in water. Identify this compound and explain why it is insoluble in water. [2]
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(d) Bromoethane, CH₂CH₂Br, undergoes a substitution reaction to form ethylamine, CH₃CH₂NH₂.

(i) Deduce the mechanism for the reaction using equations and curly arrows to represent the movement of electron pairs. [3]

(ii) Ethylamine can be produced in two stages starting with iodomethane. Deduce the reaction pathway and state any necessary conditions. [3]

(iii) Bromoethane can also be converted to ethene. Identify the type of reaction and state which reagent(s) and conditions are necessary. [3]
Many organic compounds exist as stereoisomers.

(i) Outline the meaning of the term *stereoisomers.*

(ii) Draw the structures of the two stereoisomers of dichloroethene, $\text{C}_2\text{H}_2\text{Cl}_2$.

(iii) Explain why this type of stereoisomerism exists in $\text{C}_2\text{H}_2\text{Cl}_2$. 
(iv) Draw the structures of the two stereoisomers of 1-chloro-1-fluoroethane, C₂H₃FCl, showing the relationship between them. [1]

(v) Outline how the two isomers of C₂H₃FCl could be distinguished from each other. [2]
6. Oxidation and reduction can be defined in terms of electron transfer or oxidation numbers.

(a) Alcohols with the molecular formula \(C_4H_9OH\) occur as four structural isomers. Three of the isomers can be oxidized with acidified potassium dichromate solution to form compounds with the molecular formula \(C_4H_5O\).

(i) Deduce the half-equation for the oxidation of the alcohol \(C_4H_9OH\). \[1\]

(ii) Deduce the overall equation for the redox reaction. \[1\]

(iii) Two of the isomers with the molecular formula \(C_4H_9OH\) can be oxidized further to form compounds with the molecular formula \(C_4H_5O_2\). Deduce the structural formulas of these two isomers. \[2\]
(iv) One isomer cannot be oxidized by acidified potassium dichromate solution. Deduce its structural formula, state its name and identify it as a primary, secondary or tertiary alcohol.

Name: ..................................................................................
Alcohol: .............................................................................

(v) All isomers of the alcohol C₄H₉OH undergo complete combustion. State an equation for the complete combustion of C₄H₉OH.

..........................................................................................
....................................................................................... 

Chem 10 2 Q# 22/ IB Chem/2014/s/TZ1/Paper 2 Section A/Higher Level/
4. Buta-1,3-diene can be hydrogenated to produce butane, according to the reaction below.

C₄H₆(g) + 2H₂(g) → C₄H₁₀(g)

(a) State the conditions necessary for this reaction.

..................................................................................
2. Consider the two-stage reaction pathway below.

\[
\begin{array}{c}
\text{ClCH}_2 \quad \text{CH}_2\text{Cl} \quad \xrightarrow{\text{I}} \quad X \quad \xrightarrow{\text{II}} \quad \text{HOOC} \quad \text{COOH}
\end{array}
\]

(a) Deduce the structural formula of compound X. \([1]\)

(b) State the reagents and conditions required for stage II of the pathway. \([2]\)

Reagents:

\[\ldots\]

Conditions:

\[\ldots\]
(c) The final product can react with ethane-1,2-diol, HOCH₂–CH₂OH, to produce a polymer.

(i) State the type of polymerization involved. [1]

(ii) Draw the structure of a section of the polymer produced containing two molecules of each monomer. [1]

(iii) Apply IUPAC rules to state the name of (CH₃)₂NH. [1]
Given that a halogenoalkane reagent reacts with OH to give the following rate equation:

$$\text{rate} = k[C_4H_9Br];$$

(iv) Deduce whether C_4H_9Br is a primary or tertiary halogenoalkane.

$$\begin{align*}
\text{C}_{4}\text{H}_{9}\text{Br} & = \text{primary} \\
\text{C}_{4}\text{H}_{9}\text{Br} & = \text{tertiary}
\end{align*}$$

(v) Determine the structural formula of C_4H_9Br.
(d) (i) Explain the mechanism for the reaction in (c), of \( \text{C}_4\text{H}_9\text{Br} \) with \( \text{NaOH} \), using curly arrows to represent the movement of electron pairs.

(ii) Halogenalkanes can react with \( \text{NaOH} \) via \( S_N1 \) and \( S_N2 \) type mechanisms. Explain why \( \text{C}_4\text{H}_9\text{Br} \) reacts via the mechanism described in (d) (i).

(iii) Identify the rate-determining step of this mechanism.

(a) (i) Outline three features of a homologous series. [3]

(ii) Describe a test to distinguish but-2-ene from butane, including what is observed in each case. [2]

(iii) 2-bromobutane can be produced from but-2-ene. State the equation of this reaction using structural formulas. [1]
(iv) State what is meant by the term *stereoisomers*. [1]

(v) Explain the existence of geometrical isomerism in but-2-ene. [2]

(b) A bromoalkane, C₄H₉Br, reacts with a warm aqueous sodium hydroxide solution, NaOH.

(i) State the equation for the reaction of C₄H₉Br with NaOH. [1]

(ii) Suggest what would happen to the pH of the solution as the reaction proceeds. [1]
5. The following diagram shows the three-dimensional structure of a molecule.

(a) Apply IUPAC rules to state the name of this molecule.

(b) Deduce the structural formula of two isomers of the molecule above with the same functional group.
(c) Some organic nitrogen compounds have economic importance.

(i) Apply IUPAC rules to state the name of CH$_3$CH$_2$CH$_2$NH$_2$.  

(ii) Describe, using an equation, how CH$_3$CH$_2$CH$_2$NH$_2$ can be prepared from a nitrile.

(iii) Some polymers can be produced by the reaction of amines and carboxylic acids. Identify what type of reaction this is.

(iv) State one important feature monomers must have to be able to produce such polymers.

(v) Outline the economic importance of this type of polymer.
Chem 10 Q# 29/ IB Chem/2012/w/TZ0/Paper 2 Section B/Higher Level/Q6e

(i) Apply IUPAC rules to name the ester, CH$_3$COOH$_2$CH$_3$(aq).

Chem 10 Q# 30/ IB Chem/2012/w/TZ0/Paper 2 Section B/Higher Level/

7. Alkenes, alcohols and esters are three families of organic compounds with many commercial uses.

(a) (i) State what is meant by the term stereoisomers.

(ii) X is an isomer of C$_4$H$_8$ and has the structural formula shown below.

![Structural formula of C$_4$H$_8$ isomer]

Apply IUPAC rules to name this isomer. Deduce the structural formulas of two other isomers of C$_4$H$_8$. [3]
(iii) State the balanced chemical equation for the reaction of X with HBr to form Y. [1]

(iv) Y reacts with aqueous sodium hydroxide, NaOH(aq), to form an alcohol, Z. Identify whether Z is a primary, secondary or tertiary alcohol. [1]

(v) Explain one suitable mechanism for the reaction in (iv) using curly arrows to represent the movement of electron pairs. [4]
(vi) Deduce the structural formula of the organic product formed when \( Z \) is oxidized by heating under reflux with acidified potassium dichromate(VI).  

\[
\text{[1]}
\]

\[
\text{[1]}
\]

7b

(iii) Other than its use in food flavouring, state one use of esters.  

\[
\text{[1]}
\]

\[
\text{[1]}
\]

(iii) 2-bromobutane is optically active. Draw the two enantiomers of 2-bromobutane and compare their physical and chemical properties.  

\[
\text{[2]}
\]

\[
\text{[2]}
\]
(iii) One important use of chlorine is in the synthesis of poly(chloroethene), PVC. Identify the monomer used to make PVC and state one of the uses of PVC. [2]

Monomer:

Use:

Chem 10 2 Q# 31/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/Q1f

7. A student prepared hex-1-ene, \( C_6H_{12} \), from hexan-1-ol, \( C_6H_{13}OH \), by a dehydration reaction.

\[
C_6H_{13}OH (l) \rightarrow C_6H_{12} (l) + H_2O (l)
\]

The apparatus for this preparation is shown below. The reaction mixture contains 5.00 g of hexan-1-ol and an excess of concentrated sulfuric acid, which removes the water from the organic compound.

The distillate was dried to obtain 2.62 g of hex-1-ene.
(a) (i) Determine the amount, in mol, of hexan-1-ol present in the reaction mixture. [2]

(ii) Calculate the percentage yield of hex-1-ene produced. [2]

(iii) Another student repeated the experiment and reported a yield of 5.24 g of organic product. Comment on this result. [2]
(c) (i) Unlike 1-bromohexane, 2-bromohexane exists as a pair of optically active isomers. Draw diagrams to show the relationship between the two isomers of 2-bromohexane. [2]

(ii) Outline briefly an experimental technique which could be used to distinguish the two isomers in (c) (i). [2]

(d) Identify the type of isomerism present in hex-2-ene. [1]
(e) Both hex-2-ene and hex-1-ene can be converted to hexane by a reaction with hydrogen in the presence of a nickel catalyst.

(i) Deduce the names of three isomers of hexane.  

(ii) Identify the compound with the molecular formula \( \text{C}_6\text{H}_{14} \) which has the highest boiling point and explain your choice.
Hexane reacts with chlorine to form different products. The reactions can be represented by the following equation, where R is an alkyl chain.

\[ R-H + Cl_2 \rightarrow R-Cl + HCl \]

Describe the stepwise mechanism by giving one equation for each step and state the essential condition in the initiation step.

Initiation:

..........................................................

Essential condition:

..........................................................

Propagation:

..........................................................

Termination:

..........................................................

[4]
(d) (i) Compare the formation of sigma (σ) and pi (π) bonds between the carbon atoms in a molecule of ethyne. [2]

(ii) Identify the number of sigma and pi bonds present in trans-but-2-ene-1,4-dioic acid. [1]

(iii) Explain why the melting point of trans-but-2-ene-1,4-dioic acid is higher than that of cis-but-2-ene-1,4-dioic acid. [1]
(iv) Explain why cis-but-2-ene-1,4-dioic acid forms cis-but-2-ene-1,4-dioic anhydride when heated, whereas no cyclic anhydride forms when trans-but-2-ene-1,4-dioic acid is heated.

\[ \text{cis-but-2-ene-1,4-dioic anhydride} \]

(e) Deduce the hybridization of each oxygen atom in cis-but-2-ene-1,4-dioic acid.

\[ \]
Chem 10 Q# 34/ IB Chem/2011/w/TZ0/Paper 2 Section B/Higher Level/

9. (a) One example of a homologous series is the alcohols. Describe two features of a homologous series.

(b) Consider the following reactions.

\[
\begin{align*}
(CH_3)_2CHCH_2CH_2CH_2OH \xrightleftharpoons[CH_3COOH/H^+]{D} & \xrightarrow{G} CH_2COOCH_2CH_2CH_2CH(CH_3)_2 \\
(CH_3)_2CHCH_2CH_2CHO \xrightarrow{E} & \\
(CH_3)_2CHCH_2CH_2COOH \xrightarrow{(CH_3)_2NH}{F} & \xrightarrow{H}
\end{align*}
\]

(i) State the IUPAC names of each of the compounds, D, E, F and G.

D: .................................................................
E: .................................................................
F: .................................................................
G: .................................................................
(ii) Deduce the structural formula of H.

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(iii) State the reagents and reaction conditions used to convert D to E and D to F directly.

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(iv) Discuss the volatility of E compared to F.

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Chem 10 2 Q# 35/ IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/
(d) Based on the types of intermolecular forces present, explain why butan-1-ol has a higher boiling point than butanal.

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7. (a) Two compounds, A and D, each have the formula C₄H₇Cl.

Compound A is reacted with dilute aqueous sodium hydroxide to produce compound B with a formula of C₅H₁₀O. Compound B is then oxidized with acidified potassium manganate(VII) to produce compound C with a formula of C₄H₈O. Compound C resists further oxidation by acidified potassium manganate(VII).

Compound D is reacted with dilute aqueous sodium hydroxide to produce compound E with a formula of C₄H₁₆O. Compound E does not react with acidified potassium manganate(VII).

Deduce the structural formulas for compounds A, B, C, D and E. [5]
(b) Deduce an equation for the reaction between propanoic acid and methanol. Identify the catalyst and state the name of the organic compound, X, formed.

(d) (i) 2-chloro-3-methylbutane reacts with sodium hydroxide via an S\textsubscript{N}2 mechanism. Explain the mechanism by using curly arrows to represent the movement of electron pairs.
(ii) Explain why the hydroxide ion is a better nucleophile than water.

(iii) 1-chlorobutane can be converted to a pentylamine via a two stage process. Deduce equations for each step of this conversion including any catalyst required and name the organic product produced at each stage.
5. Consider the following sequence of reactions.

\[ \text{RCH}_3 \xrightarrow{\text{reaction 1}} \text{RCH}_2\text{Br} \xrightarrow{\text{reaction 2}} \text{RCH}_2\text{OH} \]

RCH$_3$ is an unknown alkane in which R represents an alkyl group.

(a) The alkane contains 82.6 % by mass of carbon. Determine its empirical formula, showing your working.

(b) A 1.00 g gaseous sample of the alkane has a volume of 385 cm$^3$ at standard temperature and pressure. Deduce its molecular formula.

(c) State the reagent and conditions needed for reaction 1.

(d) Reaction 1 involves a free-radical mechanism. Describe the stepwise mechanism, by giving equations to represent the initiation, propagation and termination steps.

(e) The mechanism in reaction 2 is described as S$_2$2. Explain the mechanism of this reaction using curly arrows to show the movement of electron pairs, and draw the structure of the transition state.

(f) There are four structural isomers with the molecular formula C$_4$H$_9$Br. One of these structural isomers exists as two optical isomers. Draw diagrams to represent the three-dimensional structures of the two optical isomers.

(g) All the isomers can be hydrolysed with aqueous sodium hydroxide solution. When the reaction of one of these isomers, X, was investigated the following kinetic data were obtained.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Initial [X] / moldm$^{-3}$</th>
<th>Initial [OH$^{-}$] / moldm$^{-3}$</th>
<th>Initial rate of reaction / moldm$^{-3}$ min$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$2.0 \times 10^{-2}$</td>
<td>$2.0 \times 10^{-2}$</td>
<td>$4.0 \times 10^{-3}$</td>
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<tr>
<td>2</td>
<td>$2.0 \times 10^{-2}$</td>
<td>$4.0 \times 10^{-2}$</td>
<td>$4.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>3</td>
<td>$4.0 \times 10^{-2}$</td>
<td>$4.0 \times 10^{-2}$</td>
<td>$8.0 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

(i) Deduce the rate expression for the reaction.

(ii) Determine the value of the rate constant for the reaction and state its units.

(iii) State the name of isomer X and explain your choice.

(iv) State equations for the steps that take place in the mechanism of this reaction and state which of the steps is slow and which is fast.
2. (a) But-2-ene is a straight-chain alkene with formula C$_4$H$_8$. The molecule contains both σ and π bonds.

![But-2-ene structure]

(b) But-2-ene shows geometrical isomerism. Draw the structural formula and state the name of the other geometrical isomer. [2]
(c) Identify the structural formula of an isomer of but-2-ene which does not decolourize bromine water, Br₂(aq).

(d) The polymerization of the alkenes is one of the most significant reactions of the twentieth century.

(i) Outline two reasons why the polymers of the alkenes are of economic importance.

(ii) State the type of polymerization reaction shown by the alkene in part (a).

(iii) Deduce the structure of the resulting polymer showing three repeating units.

(iv) Explain why monomers are often gases or volatile liquids, but polymers are solids.
7. (a) Below are four structural isomers with molecular formula C₂H₅Br. State the name of each of the isomers A, B, C and D. [4]

(b) (i) Identify the isomer(s) which will react with aqueous sodium hydroxide almost exclusively by an S₉1 mechanism. State the meaning of the symbols in the term S₉1 mechanism. [2]

(ii) Using the formula RBr to represent a bromoalkane, state an equation for the rate determining step of this S₉1 reaction. [1]

(iii) Identify one isomer that will react with aqueous sodium hydroxide almost exclusively by an S₉2 mechanism. Draw the mechanism for this reaction using curly arrows to represent the movement of electron pairs. Include the structural formulas of the transition state and the organic product. [4]

(c) State and explain how the rates of the reactions in parts (b) (i) and (b) (iii) are affected when the concentration of the sodium hydroxide is doubled. [2]
Chem 10 Q# 40/ IB Chem/2010/s/TZ1/Paper 2 Section A/Higher Level/

3. Chloroethene, C₂H₂Cl, is an important organic compound used to manufacture the polymer poly(chloroethene).

(a) Draw a section of poly(chloroethene) containing six carbon atoms.

(b) Outline why the polymerization of alkenes is of economic importance and why the disposal of plastics is a problem.

(c) (i) Chloroethene can be converted to ethanol in two steps. For each step deduce an overall equation for the reaction taking place.

Step 1:

Step 2:
(ii) State the reagents and conditions necessary to prepare ethanoic acid from ethanol in the laboratory. [2]

9. (a) The compound C₄H₅Cl can exhibit stereoisomerism.

(i) Draw the structural formulas of the two geometrical isomers of 1-chloro-but-2-ene. [2]

(ii) Explain why 1-chloro-but-2-ene shows geometrical isomerism. [1]

(iii) Draw the structural formula of one isomer of C₄H₅Cl that shows optical isomerism and identify the chiral carbon atom with an asterisk (*). [2]

(b) The compound but-2-ene-1,4-dioic acid forms two geometrical isomers which have different physical and chemical properties.

(i) Explain the difference in the melting points of the two isomers. [3]

(ii) Outline how the two isomers behave differently when gently heated. [1]

(c) The reaction between bromoethane, CH₃CH₂Br, and potassium cyanide is an example of a nucleophilic substitution reaction.

(i) State whether this reaction is S₈1 or S₈2. [1]

(ii) Explain the mechanism of the reaction using curly arrows to represent the movement of electron pairs. [4]

(iii) The organic product obtained in part (c) (ii) can be reduced to form an amine. State an equation for the reaction, naming the catalyst involved. [2]
Chem 10 11 Q# 42/ IB Chem/2009/w/TZ0/Paper 2 Section A/Higher Level/

5. (a) The boiling points of the isomers of pentane, \( \text{C}_5\text{H}_{12} \), shown are 10, 28 and 36 °C, but not necessarily in that order.

(i) Identify the boiling points for each of the isomers A, B and C and state a reason for your answer. [3]

<table>
<thead>
<tr>
<th>Isomer</th>
<th>A</th>
<th>B</th>
<th>C</th>
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<tbody>
<tr>
<td>Boiling point</td>
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</table>

(ii) State the IUPAC names of isomers B and C. [2]

B: ..............................................................

C: ..............................................................

(b) Both \( \text{C}_5\text{H}_{12} \) and \( \text{C}_5\text{H}_{11}\text{OH} \) can be used as fuels. Predict which compound would release a greater amount of heat per gram when it undergoes complete combustion. Suggest two reasons to support your prediction. [3]

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</table>
(c) In many cities around the world, public transport vehicles use diesel, a liquid hydrocarbon fuel, which often contains sulfur impurities and undergoes incomplete combustion. All public transport vehicles in New Delhi, India, have been converted to use compressed natural gas (CNG) as fuel. Suggest two ways in which this improves air quality, giving a reason for your answer. [3]

9. (a) But-1-ene and 1-aminobutane (1-butylamine) can both be prepared from 1-bromobutane.

(i) State the equation (using structural formulas) and the necessary reagents and conditions for the preparation of but-1-ene from 1-bromobutane. [3]

(ii) State the equation (using structural formulas) for the preparation of 1-aminobutane from 1-bromobutane. State the necessary reagents and conditions of the reaction. [3]

(iv) Explain the mechanism for the preparation of 1-aminobutane from 1-bromobutane using curly arrows to represent the movement of electron pairs. [4]

(b) 2-bromobutane and 2-bromo-2-methylpropane are two isomers of 1-bromobutane.

(i) Draw the structures of the two mirror images of the isomer that can exhibit optical isomerism. [2]

(ii) Describe how the two optical isomers can be distinguished practically using plane-polarized light. [2]

(iii) Explain why the mechanism of the reaction will be different if 1-bromobutane is replaced by 2-bromo-2-methylpropane to form 2-amino-2-methylpropane in the reaction in part (a) (iv). [3]
1. Biodiesel makes use of plants’ ability to fix atmospheric carbon by photosynthesis. Many companies and individuals are now using biodiesel as a fuel in order to reduce their carbon footprint. Biodiesel can be synthesized from vegetable oil according to the following reaction.

\[
\begin{align*}
\text{vegetable oil} & \quad \text{methanol} & \quad \text{glycerol} & \quad \text{biodiesel} \\
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} \\
\text{H} - \text{C} - \text{O} - \text{C} - \text{R} & \quad \text{H} - \text{C} - \text{O} - \text{H} & \quad \text{H} - \text{C} - \text{O} - \text{H} & \quad \text{H} - \text{C} - \text{O} - \text{C} - \text{R} \\
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} \\
\text{H} - \text{C} - \text{O} - \text{C} - \text{R} & \quad \text{H} - \text{C} - \text{O} - \text{H} & \quad \text{H} - \text{C} - \text{O} - \text{H} & \quad \text{H} - \text{C} - \text{O} - \text{C} - \text{R} \\
\end{align*}
\]

(a) Identify the organic functional group present in both vegetable oil and biodiesel. \[1\]

(b) For part of her extended essay investigation into the efficiency of the process, a student reacted a pure sample of a vegetable oil (where \( R = \text{C}_{17}\text{H}_{35} \)) with methanol. The raw data recorded for the reaction is below:

- Mass of oil = 1013.0 g
- Mass of methanol = 200.0 g
- Mass of sodium hydroxide = 3.5 g
- Mass of biodiesel produced = 811.0 g

The relative molecular mass of the oil used by the student is 885.6. Calculate the amount (in moles) of the oil and the methanol used, and hence the amount (in moles) of excess methanol. \[3\]
(d) The reactants had to be stirred vigorously because they formed two distinct layers in the reaction vessel. Explain why they form two distinct layers and why stirring increases the rate of reaction.

(e) Calculate the percentage yield of biodiesel obtained in this process.

(f) When biodiesel is combusted it produces carbon dioxide. Explain why the use of biodiesel as a fuel does not significantly contribute to global warming.
8. This question is concerned with the following compounds.

- Benzene $\text{C}_6\text{H}_6$
- Benzoic acid $\text{C}_6\text{H}_5\text{COOH}$
- Cyclohexane $\text{C}_6\text{H}_{12}$
- Cyclohexene $\text{C}_6\text{H}_{10}$
- Ethyne $\text{C}_2\text{H}_2$
- Sodium benzoate $\text{C}_6\text{H}_5\text{COO}^- \text{Na}^+$

The electron configuration of carbon is $1s^22s^22p^2$.

(a) Use the idea of hybridization to discuss the formation of the two different types of bond between carbon atoms in a molecule of ethyne. [4]

(b) Identify the two types of hybridization present in cyclohexene and predict the two different bond angles in the molecule. [4]

(c) The symbol $\bigcirc$ is sometimes used to represent benzene. Explain, with reference to the following data, why the symbol $\bigcirc$ is often considered to be a better way to represent benzene.

\[
\begin{align*}
\text{C}_6\text{H}_{10}(g) + \text{H}_2(g) & \rightarrow \text{C}_6\text{H}_{12}(g) \quad \Delta H^\circ = -120 \text{ kJ} \\
\text{C}_6\text{H}_{6}(g) + 3\text{H}_2(g) & \rightarrow \text{C}_6\text{H}_{12}(g) \quad \Delta H^\circ = -208 \text{ kJ}
\end{align*}
\] [3]

(d) Explain how the carbon-to-carbon bond lengths also support the use of the $\bigcirc$ symbol in preference to the $\bigbox$ symbol. [2]

(e) (i) Discuss the bonding in the COO$^-$ part of the benzoate ion in terms of delocalization of electrons. [1]

(ii) Compare the carbon-to-oxygen bond lengths in benzoic acid and in the benzoate ion. [2]

(f) Explain, with reference to the types of reaction and your answer to part (c), why reaction I is more likely to occur than reaction II.

I $\text{C}_6\text{H}_6 + \text{Cl}_2 \rightarrow \text{C}_6\text{H}_5\text{Cl} + \text{HCl}$

II $\text{C}_6\text{H}_6 + \text{Cl}_2 \rightarrow \text{C}_6\text{H}_6\text{Cl}_2$ [2]
7. (a) Several straight-chain organic compounds have the molecular formula C₆H₆O₂. Compound A is acidic but compounds B, C and D are neutral liquids with characteristic smells. None of the compounds contain C=C bonds.

(i) Deduce the structural formula and name of compound A. [2]

(ii) State the name of the functional group present in compounds B, C and D. [1]

(b) The following is a sequence of reactions starting from butane.

\[
\begin{align*}
\text{C}_4\text{H}_{10} & \xrightarrow{\text{Br}_3} \text{C}_4\text{H}_2\text{Br} & \text{S}_{\text{N}2}^2 & \text{C}_4\text{H}_10\text{O} & \rightarrow \text{C}_4\text{H}_2\text{O} \\
\text{butane} & \rightarrow \text{E} & \rightarrow \text{F} & \rightarrow \text{G} & \text{butan-2-ol}
\end{align*}
\]

(i) The reaction of butane with bromine involves the species Br⁺, but the species Br⁻ is formed in the Sₙ²⁻ reaction. State the name of each of these species and describe the two types of bond fission responsible for their formation. [3]

(ii) State the meaning of each of the three symbols in the term Sₙ²⁻. [2]

(iii) Use curly arrows to describe the mechanism of this Sₙ²⁻ reaction. [4]

(iv) Some butan-2-ol (compound F) is also formed by an Sₙ₁ reaction. Draw the structure of the intermediate formed in this reaction. [1]

(v) Deduce the structure of compound G and identify the reagents used in its formation. [3]

(vi) An isomer of compound G can be directly converted into compound A. Draw the structure of this isomer. [1]

(c) (i) Predict which of the compounds E, F or G has the highest boiling point and identify the strongest intermolecular force in this compound. [2]

(ii) Predict which of the compounds E, F or G has the lowest solubility in water, and explain your choice with reference to intermolecular forces. [2]

(d) The compound butan-2-ol exists as optical isomers. Describe the molecular feature responsible for this and draw 3-dimensional structures for each optical isomer, showing the relationship between them. State how separate samples of each isomer could be distinguished using plane polarized light. [4]

CHEM 10 21 Q# 47/ IB Chem/2008/s/TZ1/Paper 2 Section B/Higher Level/

9. (a) A hydrocarbon contains 85.6% by mass of carbon and has a molar mass of 56.1 g mol⁻¹.

(i) Determine the empirical and molecular formulas of the hydrocarbon. [3]
The first structural isomer is benzene

(iii) The second structural isomer of the hydrocarbon is unsaturated and symmetrical. Draw its structure and state its name. [2]

(iv) Draw the structure of the third structural isomer of this hydrocarbon which is unsaturated, unbranched and unsymmetrical. This isomer is formed when an alcohol is heated with concentrated sulfuric acid. Identify the type of reaction occurring and deduce the structure of an alcohol that forms this isomer. [3]

(b) The hydrolysis of 2-bromo-2-methylbutane by 0.10 mol dm⁻³ potassium hydroxide solution to form 2-methylbutan-2-ol is an example of an S₅¹ reaction.

(i) Explain how this S₅¹ reaction occurs, using curly arrows to represent the movement of electron pairs, and showing the structure of the organic intermediate. [4]

(ii) Identify the rate determining step and state a reason for your choice. [1]

(c) State and explain whether the rate of each of the following reactions is greater than, less than or equal to the rate of the reaction in part (b).

(i) 2-chloro-2-methylbutane is reacted with 0.10 mol dm⁻³ KOH (aq) at the same temperature. [1]

(ii) 2-bromo-2-methylbutane is reacted with 0.20 mol dm⁻³ KOH (aq) at the same temperature. [1]

(d) (i) Discuss the structure of benzene including the hybridization and bond angles present. [4]

(e) (i) Cyclohexene reacts with hydrogen to form cyclohexane. [1]

(ii) The experimental value for the hydrogenation of benzene to cyclohexane is \(-207\) kJ mol⁻¹. Explain why this value differs from the value calculated in (e) (i). [1]

\[
\text{\begin{align*}
\text{C}_6\text{H}_6 + \text{H}_2 & \rightarrow \text{C}_6\text{H}_{12} \\
\Delta H^0 & = -120 \text{ kJ mol}^{-1}
\end{align*}}
\]
4. (a) Explain what is meant by the term isomers? 

(b) Draw two structural isomers for each of the following with different functional groups. In each case, describe a chemical test and the results obtained, which would distinguish between the two structural isomers.

(i) C₃H₅O 

(ii) C₄H₆O₂
### Topic 10 Mark Scheme

#### Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
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</tr>
</thead>
</table>
| 6. a     | ![Image of isomers]  
correct isomer ✓  
mirror image shown clearly ✓ |       | 2     |
| 6. b     | S<sub>0</sub> would give inversion of configuration «almost 100%»  
OR  
S<sub>2</sub> would give «approximately» 50% of each ✓  
so mechanism is a mixture of both mechanisms ✓ |       | 2     |
| 6. c     | C-I bond «longer, so» weaker «than C-Br bonds»  
OR  
I<sup>-</sup> is a better leaving group than Br ✓ |       | 1     |

#### Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
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<th>Total</th>
</tr>
</thead>
</table>
| 5. a     | ![Image of propene]  
AND  
Propene: ![Image of propene structure] ✓ |       | 1     |
| 5. c i   | C<sub>3</sub>H<sub>8</sub> + Br<sub>2</sub> → C<sub>3</sub>H<sub>7</sub>Br + HBr ✓  
«sunlight/UV/hv  
OR  
high temperature ✓ | Do not accept «reflux» for M2. | 2     |
| 5. c ii  | C<sub>3</sub>H<sub>8</sub> + Br<sub>2</sub> → C<sub>3</sub>H<sub>7</sub>Br<sub>2</sub> ✓ |       | 1     |
| 5. c iii | Propane: «free radicals» substitution / S<sub>a</sub>  
AND  
Propene: «electrophilic» addition / A<sub>e</sub> ✓ |       | 1     |
| 5. d     | ![Image of reaction mechanism]  
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<sup>-</sup> to C<sup>-</sup> ✓ |       | 3     |
**Q# 3/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/Q7**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>c v</td>
<td>both X and Y will exhibit hydrogen bonding with water molecules ✓ diagrams showing hydrogen bonding ✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

|   |   |   |   |
|   |   |   |   |
|   |   |   |   |

OR

|   |   |   |   |
|   |   |   |   |
|   |   |   |   |


**Q# 4/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/Q7**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>d iv</td>
<td>Similarity: both involve shared pair of electrons / both are covalent ✓</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

|   |   |   |   |
|   |   |   |   |

Difference:
Pr-N pair of electrons comes from nitrogen / coordinate bond and N-H: one electron comes from each bonded atom ✓

|   |   |   |   |
|   |   |   |   |

2 max

**Q# 5/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>I: carboxamide ✓ II: phenyl ✓ III: carboxyl / carboxy ✓ IV: hydroxyl ✓</td>
<td>Award [1] for all four correct, [1] for two or three correct.</td>
<td>2 max</td>
</tr>
</tbody>
</table>

|   |   |   |   |
|   |   |   |   |

|   |   |   |   |

b iii (0.5)(40 - 20 - 2) ✓  ✓ | Do not allow alcohol or hydroxide. | 1 |
### Q# 6/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. d i</td>
<td><img src="image1.png" alt="Chemical Structures" /> and <img src="image2.png" alt="Chemical Structures" /></td>
<td>Names of complexes are not required. Complexes may be drawn without tapered bonds.</td>
<td>1</td>
</tr>
<tr>
<td>d ii</td>
<td><img src="image3.png" alt="Chemical Structures" /> and <img src="image4.png" alt="Chemical Structures" /></td>
<td>Cisplatin polar and trans: non-polar ✓</td>
<td>2</td>
</tr>
</tbody>
</table>

**Q# 6/ IB Chem/2016/s/TZoSP/Paper 2 Section A/Higher Level/**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. a</td>
<td><img src="image5.png" alt="Chemical Structures" /></td>
<td>Do not allow curly arrow originating on H in HO⁻. Accept curly arrow going from bond between C and I to I in 1-iodoethane or in the transition state. Do not allow arrow originating from C to C—I bond. Inversion of configuration must be shown to score M4.</td>
<td>4</td>
</tr>
</tbody>
</table>
| b        | Rate expression: 
rate = \( k[OH^-][\text{CH}_3\text{CH}_2\text{I}] \) ✓
Molecularity of RDS: 
bimolecular ✓ | | 2 |
<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
</table>
| c        | *Sn2:* polar; protic solvents decrease nucleophilic reactivity due to hydrogen bonding  
OR  
polar; protic solvents have a cage of solvent molecules surrounding anionic nucleophile resulting in increased stabilization  
<so are slower>  
OR  
polar; aprotic solvents have no hydrogen bonding so *Sn2* reactions are favored since nucleophiles do not solvate effectively so have an enhanced/pronounced effect on nucleophilicity of anionic nucleophiles  
<so are faster> ✓  
*Sn1:* polar; protic solvents favor *Sn1* reactions since the carbocation <intermediate> is solvated by ion-dipole interactions by the polar solvent ✓  |       | 2     |
| d        | DMF since aprotic solvent so favours *Sn2* ✓  |       | 1     |

Q#7/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

| a i | structural-functional isomers ✓  | Accept other correct reagents; such as manganate(VII) or iodine solutions, and descriptions of the corresponding changes observed.  
Accept "decoloured" for A and "not decolourized/unchanged" for B. Don not accept "clear/translucent" instead of "colourless". | 1     |
| a ii | Test  
react with bromine/Br₂, in the darks  
OR  
react with bromine water/Br₂(aq) in the darks ✓  
A: from yellow/orange/brown to colourless AND B: colour remains/slowly decoloured ✓  |       | 2     |

Q#8/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/

| b i | primary ✓  | Accept specific equations having correct reactants. 
Do not accept LiAlH₄ or NaBH₄. 
Accept Pt or Pd catalyst. | 1     |
| b ii | **ALTERNATIVE 1:**  
heat with trio/Sn AND hydrochloric acid/HCl ✓  
aqueous alkali/OH⁻(aq) ✓  
**ALTERNATIVE 2:**  
hydrogen/H₂ ✓  
nickel/Ni catalyst ✓  | Accept equations having correct reactants. | 2     |

<table>
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</tr>
</thead>
</table>
| 2 b iii | HNO₃ + 2H₂SO₄ ⇌ NO₂⁻ + 2H₂SO₄⁻ + H₂O ✓  | Accept: HNO₃ + H₂SO₄ ⇌ NO₂⁻ + H₂SO₄⁻ + H₂O  
Accept HNO₃ + H₂SO₄ ⇌ H₃NO₃⁻ + HSO₄⁻  
Accept equivalent two step reactions in which sulfonic 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 | ![Diagram](image)  
curly arrow going from benzene ring to N of *NO₂/NO₃* ✓  
carboxcation with correct formula and positive charge on ring ✓  
curly arrow going from C–H bond to benzene ring of cation ✓  
formation of organic product nitrobenzene AND H⁺ ✓  | 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 C₆H₅NO₂ + H₂SO₄ if HSO₄⁻ used in M3. | 4     |
Q# 9/ IB CHEM/2015/w/TZ0/Paper 2 Section B/Higher Level/

9. (a) (i) \[ \text{RBr (l) + NaOH (aq) } \rightarrow \text{ ROH (aq) + NaBr (aq); } \]
\[ \text{RBr (l) + OH}^- \text{ (aq) } \rightarrow \text{ ROH(aq) + Br}^- \text{ (aq); } \]
Ignore state symbols.

(ii) \[ (1.35 \times 10^{-2} - 7.36 \times 10^{-3} =) 6.14 \times 10^{-3} / 6.1 \times 10^{-3} \text{ (mol); } \]

(iii) \[ \text{molar mass } = \frac{0.642}{6.14 \times 10^{-3}} = 137 \text{ (g mol}^{-1}) ; \]
Accept 138.

(iv) \[ (137 - 80 = 57 \text{ which corresponds to C}_4\text{H}_8, \text{ hence molecular formula}) \]
\[ \text{C}_4\text{H}_8\text{Br; } \]
Accept correct structural formula of one of the isomers as molecular formula.
Do not accept ECF from 9a(iii) for an impossible molecular formula, such as \text{C}_4\text{H}_{10}\text{Br.}

(v) \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br and primary; } \]
\[ \text{(CH}_3\text{)}_2\text{CHCH}_2\text{Br and primary; } \]
\[ \text{CH}_3\text{CHBrCH}_2\text{CH}_3 \text{ and secondary; } \]
\[ \text{(CH}_3\text{)}_2\text{CBr and tertiary. } \]
Penalize missing hydrogens once only.
Accept either full or condensed structural formulas.

If \text{C}_4\text{H}_{11}\text{Br was used, accept any correct structural formulas. } \]
\[ \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br and primary; } \]
\[ \text{(CH}_3\text{)}_2\text{CHCH}_2\text{Br and primary; } \]
\[ \text{CH}_3\text{CH}_2\text{CH(CH}_3\text{)}\text{CH}_2\text{Br and primary; } \]
\[ \text{(CH}_3\text{)}_2\text{CCH}_2\text{Br and primary; } \]
\[ \text{CH}_3\text{CHBrCH}_2\text{CH}_3 \text{ and secondary; } \]
\[ \text{CH}_3\text{CH}_{2}\text{CHBrCH}_2\text{CH}_3 \text{ and secondary; } \]
\[ \text{CH}_3\text{CHBrCH(CH}_3\text{)}_2 \text{ and secondary; } \]
\[ \text{CH}_3\text{CH}_2\text{C(CH}_3\text{)}_2\text{Br and tertiary; } \]
Penalize missing hydrogens once only.
Accept either full or condensed structural formulas.
(b) (i) increase in carbon chain;

(ii) 

\[
\begin{align*}
\text{NC}^- & \quad \text{Br} \\
\text{CH}_3\text{CH}_2\text{CH}_2\text{H} & \quad \text{H} \\
\text{C} & \quad \text{H} \\
\text{NC}^- & \quad \text{Br} \\
\text{CH}_3\text{CH}_2\text{CH}_2\text{H} & \quad \text{H} \\
\end{align*}
\]

OR

\[
\begin{align*}
\text{NC}^- & \quad \text{Br} \\
\text{(CH}_3\text{)_2CH} & \quad \text{H} \\
\text{C} & \quad \text{H} \\
\text{NC}^- & \quad \text{Br} \\
\text{(CH}_3\text{)_2CH} & \quad \text{H} \\
\end{align*}
\]

curly arrow going from lone pair/negative charge on NC\(^-\) to C;
curly arrow showing Br leaving;
Accept curly arrow either going from bond between C and Br to Br in
1-bromobutane/1-bromo-2-methylpropane or in the transition state.

representation of transition state showing negative charge, square brackets
and partial bonds;
Do not penalize if NC and Br are not at 180° to each other.

Products: CH\(_3\)CH\(_2\)CH\(_2\)CH\(_2\)CN/(CH\(_3\))\(_2\)CHCH\(_2\)CN and Br\(^-\)/KBr;  
Penalize missing hydrogens and/or incorrect bond linkages (eg CN–C
instead of NC–C) only once in this question.
Remember to apply ECF from part (a)(v).

(iii) CH\(_3\)CH\(_2\)CH\(_2\)CH\(_2\)CN + 2H\(_2\) \rightarrow CH\(_3\)CH\(_2\)CH\(_2\)CH\(_2\)CH\(_2\)NH\(_2\)

OR

(\(\text{CH}_3\)\(_2\)CHCH\(_2\)CN + 2H\(_2\) \rightarrow (\(\text{CH}_3\)\(_2\)CHCH\(_2\)CH\(_2\)NH\(_2\);

Ni / Co / Ru;  
Accept Pt/Pd/Cu/Rh.
Accept either chemical symbol or name.

(c)

(ii) addition;

\(-\text{CH(CH}_3\text{)}\text{CH}_2\text{CH(CH}_3\text{)}\text{CH}_2\text{CH}_2\text{CH}_2\text{-} / -\text{C(CH}_3\text{)}\text{CH}_2\text{CH}_2\text{-C(CH}_3\text{)}\text{CH}_2\text{-CH}_2-\)

Continuation bonds required for the mark.
(d) Initiation:
\[ \text{Cl}_2 \xrightarrow{\text{UV/If/heat}} 2\text{Cl}^\bullet; \]
Reference to UV light or high temperatures must be included.

Propagation:
\[ \text{Cl}^\bullet + \text{C}_2\text{H}_6 \rightarrow \text{C}_2\text{H}_5^\bullet + \text{HCl}; \]
\[ \text{C}_2\text{H}_5^\bullet + \text{Cl}_2 \rightarrow \text{C}_2\text{H}_6\text{Cl} + \text{Cl}^\bullet; \]

Termination:
\[ \text{Cl}^\bullet + \text{Cl}^\bullet \rightarrow \text{Cl}_2 / \text{C}_2\text{H}_5^\bullet + \text{Cl}^\bullet \rightarrow \text{C}_2\text{H}_6\text{Cl} / \text{C}_2\text{H}_5^\bullet + \text{C}_2\text{H}_5^\bullet \rightarrow \text{C}_4\text{H}_{10}; \]

Accept representation of radical without \( \bullet \) (eg, Cl, CzH5) if consistent throughout mechanism.
Accept further chlorination.
Award [3 max] if initiation, propagation and termination are not stated or are incorrectly labelled for equations.
Accept correct description of processes without equations.
Award [3 max] if Br used correctly instead of Cl.
Q# 10/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/
Penalize missing hydrogens only once in Question 10.

10. (a) (i) 
\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{H} \\
\text{H} \\
\text{Br} \\
\text{H} \\
\text{H}
\end{array}
\]

Accept bromine atoms cis to each other.  

(ii) 2,3-dibromobutane;
Do not penalize the incorrect use of spaces, comma or hyphen.  

(iii) red/brown/orange/yellow to colourless/decolourized;
Do not accept clear.
Do not accept just “decolorized”.

(b) (i) (synthesis of) plastics/polymers/organic materials not naturally available / synthetic materials;
wide range of uses/physical properties / versatile;
large industry / many tons of plastics consumed by society / OWTTE;
Do not accept “useful” for M2.
Award [1 max] if specific addition polymer and its use is given.
Penalize reference to condensation polymers once only.

(ii) 
\[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{C} \\
\text{H} \\
\text{CH}_3 \\
\text{CH}_3
\end{array}
\]_n

Ignore n.
Brackets are not required for the mark, but continuation bonds are.
Do not penalize if methyl groups are trans to each other.

(c) (i) 
\[
\text{HO}^-
\]
\[
\begin{array}{c}
\text{H}_3\text{C} \\
\text{C} \\
\text{H}
\end{array}
\]
\[
\begin{array}{c}
\text{Br} \\
\text{H}
\end{array}
\]
\[
\rightarrow
\begin{array}{c}
\text{HO} \\
\text{C} \\
\text{CH}_2\text{CH}_3 \\
\text{CH}_2\text{CH}_3
\end{array}
\]
\[
\rightarrow
\begin{array}{c}
\text{HO} \\
\text{C} \\
\text{CH}_2\text{CH}_3 \\
\text{CH}_2\text{CH}_3
\end{array}
\]
\[
+ \text{Br}^-
\]

curly arrow going from lone pair/negative charge on O in HO^- to C;
Do not accept curly arrow originating on H in HO^-.

curly arrow showing Br leaving;
Accept curly arrow either going from bond between C and Br to Br in 2-bromobutane or in the transition state.
Accept if arrow goes from C–Br bond to/or beyond Br.

representation of transition state showing negative charge, square brackets 
and partial bonds;
Do not penalize if HO and Br are not at 180° to each other.
Do not award M3 if OH-----C bond is represented.

formation of organic product CH_3CHOHCH_2CH_3 and KBr/Br^-;  

[4]
(ii) OH\(^-\) has a negative charge/higher electron density; stronger attraction to the carbon atom with the partial positive charge / OWTTE;[2]

*Do not accept just stronger attraction.*

Reference to carbon atom needed for M2.

(d) (i) 2-methylbutanenitrite;[1]

*Accept small errors in spelling.*

Accept 2-cyanobutane.

*Do not accept butan-2-nitrite.*

(ii) hydrogen/H\(_2\) and nickel/Ni;[1]

Accept other suitable metal catalysts such as platinum/Pt, palladium/Pd.

(iii)

![Chemical structure](image)

*Accept condensed CH\(_3\) branch in structural formula as this was present in structure given in question.*

(e) (i) carbonyl;[1]

*Accept ketone.*

(ii)

![Chemical structure](image)

*Accept condensed or full structural formula.*

(f) hydrogen bonding in compound C; dipole-dipole forces in C / C is more polar; C has greater molar mass/more dispersion/London/instantaneous induced dipole-induced dipole forces/van der Waal forces;[2 max]

*Accept converse argument.*

Award [1 max] for stronger intermolecular forces.

(g) C\(_2\)H\(_5\)OH(l) + 6O\(_2\)(g) → 4CO\(_2\)(g) + 5H\(_2\)O(l);[1]

*Ignore state symbols.*
(h) (i) compounds with the same structural formula and different arrangement in space/3D structures; Accept molecular formula instead of structural formula. Do not accept “similar” instead of “same”.

(ii) restricted rotation around a (double) bond; carbon atoms of the C=C/carbon-carbon double bond (in alkene)/carbon atoms of the C–C/carbon-carbon single bond (in cycloalkane) must have two different atoms/groups of atoms / OWTTE. Do not accept “functional groups” for “groups of atoms” in M2.

(iii) \[
\begin{align*}
\text{CH}_3 & \quad \text{and} \quad \text{CH}_3 \\
\text{C} &= \text{C} \\
\text{H} & \quad \text{and} \quad \text{H} \\
\text{CH}_3 & \quad \text{and} \quad \text{CH}_3
\end{align*}
\]

\textit{cis and trans;}

Award \([1 \text{ max}]\) if cis and trans isomers are correctly drawn and identified for alkene other than but-2-ene.

Award \([1 \text{ max}]\) if student draws and labels one structure correctly but not the other.

Q# 11/ IB Chem/2015/s/TZ2/Paper 2 Section A/Higher Level/

5. (a) same functional group; same general formula; (successive members) differ by \(\text{CH}_2\); similar chemical properties; gradation in physical properties; Do not accept “same” instead of “similar”, or vice-versa.

(b) Initiation:
\[\text{Br}_2 \xrightarrow{\text{UV/heat}} 2\text{Br}^-;\]
Reference to UV light or high temperatures must be included.

Propagation:
\[
\begin{align*}
\text{Br}^- + \text{C}_2\text{H}_6 & \rightarrow \text{C}_2\text{H}_5^- + \text{HBr} \\
\text{C}_2\text{H}_5^- + \text{Br}_2 & \rightarrow \text{C}_2\text{H}_5\text{Br} + \text{Br}^-
\end{align*}
\]

Termination:
\[
\begin{align*}
\text{Br}^- + \text{Br}^- & \rightarrow \text{Br}_2 / \text{C}_2\text{H}_5^- + \text{Br}^- \rightarrow \text{C}_2\text{H}_5\text{Br} / \text{C}_2\text{H}_5^- + \text{C}_2\text{H}_3^- & \rightarrow \text{C}_4\text{H}_{10};
\end{align*}
\]
Accept representation of radical without \(\cdot\) (eg, \(\text{Br, C}_2\text{H}_3\)) if consistent throughout mechanism.
Penalize reference to heterolytic fission once only.
Award \([0\text{ to any mechanism involving ions.}];\) Accept further bromination.
Award \([3\text{ max}]\) if initiation, propagation and termination are not stated or are incorrectly labelled for equations.
Accept correct description of processes without equations.
Q# 12/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/

5. (a) **Equation:**
   \[ \text{CH}_2\text{CH}_3 + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{CH}_2\text{OH} / \text{C}_2\text{H}_4 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH}; \]

   **Conditions:**
   (concentrated) sulfuric acid/\(\text{H}_2\text{SO}_4\);
   Do not accept dilute sulfuric acid.
   Accept phosphoric acid/\(\text{H}_3\text{PO}_4\) (on pellets of silicon dioxide) (for industrial preparation).

   heat / high temperature; \[3\]
   Do not accept warm.
   Accept high pressure (for industrial preparation) for M3 only if \(\text{H}_3\text{PO}_4\) is given for M2.

(b) \(\text{CH}_3\text{CH}_2\text{OH} + \text{CH}_3\text{CH}_2\text{COOH} \rightleftharpoons \text{CH}_3\text{CH}_2\text{OCOCCH}_3\text{CH}_3 + \text{H}_2\text{O}; \)

   ethyl propanoate;
   Do not penalize if equilibrium arrow missing. \[2\]

5. (e) (i) **Repeating unit:**
   [Diagram of repeating unit]

   Continuation lines must be shown.
   Ignore brackets and \(n\).
   Accept condensed formulas such as \(\text{CH}_2\) and \(\text{C}_6\text{H}_4\).

   Other product:
   \(\text{H}_2\text{O}/\text{water}; \)

   (ii) condensation; \[1\]
6. (a) \[ \text{CH}_4 + \text{Br}_2 \rightarrow \text{CH}_3\text{Br} + \text{HBr} \] \[ \text{[1]} \]

(b) (i) \[ \text{Initiation:} \]
\[ \text{Br}_2 \rightarrow 2\text{Br}\cdot; \]
Reference to UV/light or high temperatures must be included.

Propagation:
\[ \text{Br}\cdot + \text{CH}_4 \rightarrow \text{CH}_3\cdot + \text{HBr} \]
\[ \text{CH}_3\cdot + \text{Br}_2 \rightarrow \text{CH}_3\text{Br} + \text{Br}\cdot; \]

Termination:
Award \[ \text{[1 max]} \] for any one of:
\[ \text{Br}\cdot + \text{Br}\cdot \rightarrow \text{Br}_2 \]
\[ \text{CH}_3\cdot + \text{Br}\cdot \rightarrow \text{CH}_3\text{Br} \]
\[ \text{CH}_3\cdot + \text{CH}_3\cdot \rightarrow \text{C}_2\text{H}_6 \]
[4 max]
Allow representation of radical without \( \cdot \) (eg \( \text{Br}, \text{CH}_3 \)) if consistent throughout mechanism.
Award \[ \text{[3 max]} \] if initiation, propagation and termination are not stated or are incorrectly labelled for equations.

(ii) methanol/\( \text{CH}_3\text{OH} \); \[ \text{[1]} \]

(c) C–I bond is weaker than the C–Br bond so more easily broken; C–I bond is longer than the C–Br bond / I larger than Br so bonding electrons not as tightly held / I– is better leaving group than Br–; \[ \text{[2]} \]

(d) (i) Positive electrode (anode):
\[ 2\text{Br}^- \rightarrow \text{Br}_2(g) + 2\text{e}^- / \text{Br}^- \rightarrow \frac{1}{2}\text{Br}_2(g) + \text{e}^-; \]

Negative electrode (cathode):
\[ \text{Na}^+ + \text{e}^- \rightarrow \text{Na}(l); \]
[2]
Award \[ \text{[1 max]} \] for correct equations at incorrect electrodes.
Ignore state symbols.
Accept \( \text{e}^- \) instead of \( \text{e}^- \).
Penalize use of equilibrium signs once only.

(ii) Positive electrode (anode):
bromine/\( \text{Br}_2 \);

Negative electrode (cathode):
hydrogen/\( \text{H}_2 \);
Allow sodium hydroxide/\( \text{NaOH} \)/hydroxide/\( \text{OH}^- \) formation.
[2]

Q# 14/ IB CHEM/2015/s/TZ1/Paper 2 Section B/Higher Level/

7. (a) (i) Ethanal: distill off product as it forms;
Accept distillation.
Ethanoic acid: (heat under) reflux / use excess oxidizing agent;
curly arrow going from lone pair/negative charge on O in HO⁻ to C;
*Do not allow curly arrow originating on H in HO⁻.*

curly arrow showing Br leaving;
*Accept curly arrow either going from bond between C and Br to Br in bromoethane or in the transition state.*

representation of transition state showing negative charge, square brackets and partial bonds;
*Do not penalize if HO and Br are not at 180° to each other.*
*Do not award M3 if OH—C bond is represented.*

formation of organic product CH₃CH₂OH and Br⁻;
*Award [3 max] for correct Sₐₙ₁ mechanism.*

9. (a) | Compound       | Name                      |
      | CH₃CH₂CH(OH)CH₃ | butan-2-ol/2-butanol;     |
      | CH₃CH₂COCH₃     | butanone;                |
      | CH₃CH₂CH₂OH     | propan-1-ol/1-propanol;  |
      | CH₃CH₂CH₂CHO    | butanal       |

(b) (i) *same molecular formula but differ in arrangement of their atoms;*
  *Allow “different structures/structural formulas” instead of “different arrangement of atoms”.*

(ii) (compounds) 2 and 4 / butanone and butanal;

(c) (i) | Compound       | Organic Product |
       | CH₃CH₂CH(OH)CH₃ | butanone/CH₃CH₂COCH₃;  |
       | CH₃CH₂COCH₃     | no reaction;        |
       | CH₃CH₂CH₂OH     | propanoic acid/CH₃CH₂COOH; |
       | CH₃CH₂CH₂CHO    | butanoic acid/CH₃CH₂CH₂COOH; |

(ii) orange to green;
(d) | Reagent | Product |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>CN⁻ / NaCN / KCN / HCN;</td>
</tr>
<tr>
<td>Stage 2</td>
<td>H₂ (with Ni/Pd/Pt catalyst) / LiAlH₄;</td>
</tr>
</tbody>
</table>

Accept formulas or names of reagents but only structural formulas (condensed or displayed) of products.
Penalize wrong bonding and/or missing hydrogens once only.
Accept other valid reduction reagents for Stage 2 such as hydrides.

(f) (i) CH₃CH₂CH₂CH₂COOCH₃CH₃; ester; [2]

(ii) condensation / addition-elimination; [1]
Accept esterification.

Q# 16/ IB Chem/2014/w/TZ0/Paper 2 Section A/Higher Level/
6. (a) hydroxyl and carbonyl; [1]
Accept alcohol as an alternative to hydroxyl and/or ketone as an alternative to carbonyl.
Allow hydroxy, but not hydroxide, as an alternative to hydroxyl.

Q# 17/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/Q7(e)
(iii) negative and decrease in number of molecules/particles/moles in the gas phase; [1]

(iv) \( \Delta H = \sum \Delta H_f \text{(products)} - \sum \Delta H_f \text{(reactants)} = -178 - (-68) \)
\[ = -110 \text{(kJ mol}^{-1}\text{)}; \]
Award [2] for correct final answer.
Award [1] for +110 (kJ mol⁻¹).

(v) reaction is exothermic/\( \Delta H \) is negative and involves a decrease in entropy/\( \Delta S \) is negative;
reaction will be spontaneous/\( \Delta G \) negative at low temperatures / non-
spontaneous/\( \Delta G \) positive at high temperatures; [2]
Accept correct explanations using \( \Delta G = \Delta H - T\Delta S \).
Remember to apply ECF from (e) (iii) and (iv) – award both these marks in accordance with what the candidate has written there.

(vi) energy required to heat water \((= m \times s \times \Delta T = 1 \times 4.18 \times (100 - 20)) = 334.4 \text{(kJ)}\);
Ignore sign of energy change.

amount required = \( \frac{334.4}{4000} = 0.0836 \text{(mol)}; \) [2]
Award [2] for correct final answer.

(vii) D lower/hexane higher and van der Waals'/London/ dispersion forces between molecules weaker in D/stronger in hexane;
Accept "intermolecular forces" instead of dispersion forces.

D is more branched / D has a lower surface area / D has a more
spherical shape / does not pack as closely; [2]
Accept opposite statements for hexane.
Q# 18/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/

7. (a) hydrogen bromide / hydrobromic acid / HBr; [1]
    (c) (i) ultraviolet light/sunlight; [1]
        Accept “very high temperature”.
        (ii) random/further/multiple substitution (so low probability of desired product)
            / would give a mixture of many different products / OWTTE; [1]
    (d) (i) (aqueous) sodium hydroxide/NaOH / potassium hydroxide/KOH; [1]
        Accept hydroxide ion/OH⁻.
        (ii) rate = \( k[B] \) / rate = \( k[C₆H₅Br] \); [1]
        (iii) optical activity requires a chiral/asymmetric centre / OWTTE;
            there are no C-atoms that have 4 different groups bonded to them / mirror image identical to original molecule / OWTTE; [2]
        (iv) (it is a) tertiary/3° alcohol / carbon of C–OH is not bonded to a hydrogen;
            Accept “it is not a primary or secondary alcohol”.
    (v)
    \[
    \begin{align*}
    \text{CH₃} & \quad \text{CH₃} \\
    \text{CH₃–CH₂–CH₂–CH–CH₂–OH} & \quad \text{CH₃–CH₂–CH–CH₂–CH₂–OH} \\
    \text{CH₃} & \quad \text{CH₃}
    \end{align*}
    \]
    Accept abbreviated formulas involving C₂H₅⁻ and C₃H⁻.
    primary alcohol with formula C₆H₁₃OH;
    optically active compound with formula C₈H₁₇OH;
    Penalise minor errors in structures (such as missing H-atoms) once only. [2]
    (e) (i) Ni/Pt/Pd catalyst; [1]
        (ii) conversion of vegetable oil to margarine;
            Accept “manufacture of margarine” / “saturation of vegetable oils” / OWTTE.

Q# 19/ IB Chem/2014/s/TZ2/Paper 2 Section A/Higher Level/Q1

(e) enthalpy change/\( \Delta H \) for the reaction is (very) small / OWTTE; [1]
(g) ethyl ethanoate/CH₃COOC₂H₅/ester;
    forms only weak hydrogen bonds (to water); [2]
    Allow “does not hydrogen bond to water” / “hydrocarbon sections too long” / OWTTE.
    M2 can only be given only if M1 correct.
(d) (i) curly arrow going from lone pair on N in NH$_3$ to C;
curly arrow showing Br leaving.
Accept curly arrow going from bond between C and Br to Br on
1-bromoethane or on the transition state.
representation of transition state showing square brackets, two partial bonds
and curly arrow going from NH bond to NC partial bond/curly arrow going
from NH bond to N;
Do not penalize if NH$_3$ and Br are not at 180° to each other.
Do not award M3 if NH$_3$—C bond is represented.

(ii) react CH$_3$I with CN$^-$/KCN solution to form ethananitrile;
(reduce nitrile by heating with) H$_2$;
Ni (catalyst);

(iii) elimination;
NaOH/KOH dissolved in (hot) ethanol/alcohol;
heat/hot/reflux;

(e) (i) compounds with same structural formula but different arrangements of
atoms in space;

(ii) \[
\begin{align*}
\text{Cl} & \quad \text{Cl} \\
\text{H} & \quad \text{Cl}
\end{align*}
\]
\[
\begin{align*}
\text{H} & \quad \text{C} = \text{C} \\
\text{Cl} & \quad \text{Cl}
\end{align*}
\]

(iii) restricted rotation around (C=C) double bond;

(iv) \[
\begin{align*}
\text{Cl} & \quad \text{Cl} \\
\text{H} & \quad \text{H}
\end{align*}
\]

\[
\begin{align*}
\text{Cl} & \quad \text{H} \\
\text{C} & \quad \text{F}
\end{align*}
\]

The two structures must be clear 3D representations of mirror images.
Tapered (wedge/dash) notation not necessary.

(v) the two enantiomers rotate the plane of plane-polarized light by equal
amounts, but in opposite directions;
using a polarimeter;
Q# 21/ IB CHEM/2014/s/TZ1/Paper 2 Section B/Higher Level/

6. (a) (i)  \( \text{C}_4\text{H}_9\text{OH} (l) \rightarrow \text{C}_4\text{H}_8\text{O} (l) + 2\text{H}^+ (aq) + 2e^-; \)  
   Ignore state symbols.  
   \[1\]

(ii)  \( 3\text{C}_4\text{H}_9\text{OH} (l) + \text{Cr}_2\text{O}_7^{2-} (aq) + 8\text{H}^+ (aq) \rightarrow 3\text{C}_4\text{H}_8\text{O} (l) + 2\text{Cr}^{3+} (aq) + 7\text{H}_2\text{O} (l); \)
   Ignore state symbols.  
   \[1\]

(iii)  \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}; \)
   (\( \text{CH}_3 \))\(_2\text{CHCH}_2\text{OH}; \)
   Accept full or condensed structural formulas.  
   \[2\]

(iv)  \( (\text{CH}_3)_3\text{COH}; \)
   2-methylpropan-2-ol;  
   Allow 2-methyl-2-propanol, methylpropan-2-ol, methyl-2-propanol.  
   tertiary;  
   \[3\]

(v)  \( \text{C}_6\text{H}_5\text{OH} + 6\text{O}_2 \rightarrow 4\text{CO}_2 + 5\text{H}_2\text{O}; \)
   (\( \text{CH}_3 \))\(_2\text{COH} + 6\text{O}_2 \rightarrow 4\text{CO}_2 + 5\text{H}_2\text{O} \)
   correct reactants and products;  
   correct balancing;  
   \[2\]

Q# 22/ IB Chem/2014/s/TZ1/Paper 2 Section A/Higher Level/

4. (a)  heat/warm/ 140 – 225 °C;  
   Do not accept high temperature.  
   (finely divided) catalyst / Zn/Cu/Ni/Pd/Pt;  
   \[2\]

Q# 23/ IB Chem/2013/w/TZ0/Paper 2 Section A/Higher Level/

2. (a)  \( \text{HOCH}_2-\text{CH}_2\text{OH} / \text{HOCH}_2-\text{C}_6\text{H}_5-\text{CH}_2\text{OH}; \)
   Accept left hand end written as \( \text{CH}_3\text{(OH)}^- \).  
   \[1\]

(b)  Reagents: acidified/H\(^+\) dichromate ion/\( \text{Cr}_2\text{O}_7^{2-} \)/potassium dichromate/\( \text{K}_2\text{Cr}_2\text{O}_7 \)/sodium dichromate/\( \text{Na}_2\text{Cr}_2\text{O}_7 \);
   Accept acidified/H\(^+\) permanganate ion/\( \text{MnO}_4^- \)/potassium permanganate/\( \text{KMnO}_4 \).
   Conditions: reflux;
   Accept “heat” (as the intermediate aldehyde will not be volatile enough to vaporize significantly) unless distillation mentioned.  
   \[2\]

(c)  (i)  condensation;  
   \[1\]

(ii)  \( \text{OC} - \text{CO} - \text{O} - \text{CH}_2\text{-CH}_2\text{-O} - \text{CO} - \text{O} - \text{O} - \text{CH}_2\text{-CH}_2\text{-O} - \text{CO} \);
   Extended bonds and two molecules of both monomers must be included.
   Monomers can occur in the opposite order to that shown (glycerol part on left).
   Accept repeating units starting and ending at any point in the chain.  
   \[1\]
Q# 24/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/Q4(c)

(iii) N-methylmethanamine / methylmethanamine / dimethylamine;

Do not accept N-N dimethylamine.

Q# 25/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/

3. (a) ester;

Do not accept just carbonyl.

Allow carboxylate (ligand)/carboxylate (ligand) but not carboxyl/carboxy.

Q# 26/ IB Chem/2013/s/TZ1/Paper 2 Section B/Higher Level/Q9c

(iv) rate depends on \([\text{C}_4\text{H}_9\text{Br}]\) only / rate does not depend on \([\text{OH}^-]\) / \(S_N1\) reaction / first order reaction / if it was primary, reaction would be \(S_N2\); tertiary;

Accept ECF.

(v) \((\text{CH}_3)_2\text{CBr}\);

Allow both condensed and full structural formula.

Accept ECF.

(d) (i)

\[
\begin{align*}
\text{H}_3\text{C} & \text{C-Br} \\
\text{H} & \text{C-Br}
\end{align*}
\]

curly arrow showing \(\text{Br}^-\) leaving;

representation of tertiary carbocation;

curly arrow going from lone pair/negative charge on O in \(^{-}\text{OH}\) to \(\text{C}^+\);

Do not allow arrow originating on \(\text{H}\) in \(^{-}\text{OH}\).

formation of \((\text{CH}_3)_2\text{COH}\) and \(\text{Br}^-\);

Accept \(\text{Br}^-\) anywhere on product side in the reaction scheme.

If primary halogenoalkane has been answered in (c)(iv) apply ECF for the mechanism.

\[
\begin{align*}
\text{H-C-Br} & \rightarrow \\
\text{H-C-Br} & \rightarrow
\end{align*}
\]

curly arrow going from lone pair/negative charge on O in \(^{-}\text{OH}\) to \(\text{C}\);

Do not allow curly arrow originating on \(\text{H}\) in \(^{-}\text{OH}\).

curly arrow showing \(\text{Br}^-\) leaving;

Accept curly arrow either going from bond between \(\text{C}\) and \(\text{Br}\) to \(\text{Br}\) in bromobutane or in the transition state.

representation of transition state showing negative charge, square brackets and partial bond;

Do not penalize if \(\text{HO}\) and \(\text{Br}\) are not at 180° to each other.

Do not award M3 if \(\text{OH}--\text{C}\) bond is represented.

formation of organic product \(\text{C}_4\text{H}_9\text{OH}\) and \(\text{Br}^-\);

Accept \(\text{Br}^-\) anywhere on product side in the reaction scheme.
(ii) greater stability of tertiary carbocation; 
steric hindrance for $S_N2$ mechanism; 
positive inductive effect (of alkyl groups); 

*Do not allow ECF.*

[1 max]

(iii) the first step / $Br^-$ leaving / formation of carbocation; 

*Do not allow ECF.*

[1]

Q# 27/ IB Chem/2013/s/TZ1/Paper 2 Section B/Higher Level/

9. (a) (i) *same functional group / same general formula;* 

difference between successive members is $CH_2$; 
similar chemical properties; 

*Do not accept “same” chemical properties.*

gradually changing physical properties; 

[3 max]

(ii) adding bromine (water); 

*but-2-ene: brown/orange to colourless / decolourizes bromine water and butane: does not change colour;* 

OR

adding *acidified* potassium permanganate solution/KMnO$_4$(aq); 

*but-2-ene: purple to colourless/brown and butane: does not change colour;* 

OR

adding Baeyer’s reagent: 

*but-2-ene: purple/pink to brown and butane: does not change colour;* 

*Do not accept “clear” or “transparent” for “colourless”.*

(iii)

$$
\begin{align*}
\text{H} & - \text{C} - \text{C} = \text{C} - \text{H} + \text{HBr} & \rightarrow & & \text{H} - \text{C} - \text{C} = \text{C} - \text{H} \\
\text{H} & & & & \text{H} - \text{Br} - \text{H} \\
\end{align*}
$$

Accept condensed structural formula. 

*Penalise missing H atoms or incorrect bonds (such as $C-HO$, $C-H_2C$) once only in the whole paper.*

(iv) compounds with the same structural formula but different arrangement of atoms (in space); 

[1]

(v) *but-2-ene exists as* *cis-but-2-ene and trans-but-2-ene /* 

$$
\begin{align*}
\text{H}_3\text{C} & - & \text{C} & - & \text{H}_3\text{C} & \text{H} \\
\text{H}_3\text{C} & & \text{CH}_3 & & \text{H} & \text{CH}_3 \\
\end{align*}
$$

* cis 

* trans 

restricted rotation of $C=C$/double bond; 

[2]
(b) (i) \( \text{C}_4\text{H}_9\text{Br} + \text{OH}^- \rightarrow \text{C}_4\text{H}_9\text{OH} + \text{Br}^- \); 
Accept \textit{NaOH} in the equation. 

(ii) decreases; 

Q# 28/ IB Chem/2013/s/TZ1/Paper 2 Section A/Higher Level/
5. (a) butan-2-ol/2-butanol; 

(b) \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}; \)
\( (\text{CH}_3)_2\text{CHCH}_2\text{OH}; \)
\( (\text{CH}_3)_2\text{COH}; \)
Accept condensed or full structural formulas. 
Penalise missing \( H \) atoms or incorrect bonds (such as \( \text{C}–\text{HO} \), \( \text{C}–\text{H}_2\text{C} \)) once only in the whole paper.

(c) (i) 1-aminopropane/propylamine/1-propanamine; 

(ii) \( \text{CH}_3\text{CH}_2\text{CN} + 2\text{H}_2 \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2; \)
Accept condensed or full structural formulas.

(iii) condensation (polymerization) / polycondensation, 

(iv) \text{two reactive/functional groups}; 

(v) production of nylon/clothes/carpets/ropes/Kevlar; 
Accept other uses of nylon.

Q# 29/ IB Chem/2012/w/TZ0/Paper 2 Section B/Higher Level/Q6e

(c) (i) ethyl ethanoate; 
Do not allow \textit{ethyl acetate}.

Q# 30/ IB Chem/2012/w/TZ0/Paper 2 Section B/Higher Level/

\textit{Penalize missing hydrogens or incorrect bonding (e.g. C–H}_2\text{C)} one only in 7.

7. (a) (i) compounds with same structural/displayed formula but different arrangements of atoms (in space); 
Do not accept different 3D structures. 
Do not allow similar instead of same.

(ii) (cis-)but-2-ene / (Z)but-2-ene / but-2-ene; 
Accept (cis-)2-butene / Z-2-butene. 
Ignore missing hyphens.
\( \text{CH}_3\text{CH}_2\text{CH}=\text{CH}_2; \)
\( \text{H}_3\text{C}=\text{C}(\text{CH}_3)_2; \)
Accept either full or condensed structural formulas. 
Allow structural formula of trans-but-2-ene. Accept other alternative suitable isomers.

(iii) \( (\text{CH}_3)\text{CH}=\text{CH}(\text{CH}_3) + \text{HBr} \rightarrow \text{CH}_3\text{CHBrCH}_2\text{CH}_3; \)
Allow \( \text{C}_4\text{H}_8 + \text{HBr} \rightarrow \text{C}_4\text{H}_9\text{Br} \).

(iv) secondary/\( ^{2}\);
(v) Since secondary could be either S_N1 or S_N2 so allow S_N1 or S_N2 for M1–M4.

S_N1:

\[ \text{CH}_3\text{CHBrC}_2\text{H}_5 \rightarrow \text{CH}_3\text{CH}^+\text{Br}^- + \text{C}_2\text{H}_5OH \]

curly arrow showing Br leaving;
Do not allow arrow originating from C to C–Br bond.

representation of secondary carboxcation;
curly arrow going from lone pair/negative charge on O in HO⁻ to C⁺;
Do not allow arrow originating on H in HO⁻.

formation of organic product CH₃CH(OH)C₂H₅/C₂H₅OH and Br⁻;
Allow formation of NaBr instead of Br⁻.

OR

S_N2:

\[ \text{HO}^-+\text{CH}_3\text{CHBrC}_2\text{H}_5 \rightarrow \text{CH}_3\text{CH}^-\text{Br}^- + \text{C}_2\text{H}_5\text{OH} \]

curly arrow going from lone pair/negative charge on O in HO⁻ to C;
Do not allow curly arrow originating on H in HO⁻.

curly arrow showing Br leaving;
Accept curly arrow either going from bond between C and Br to Br in 2-bromobutane or in the transition state.
Do not allow arrow originating from C to C–Br bond.

representation of transition state showing negative charge, square brackets and partial bonds;
Do not penalize if HO and Br are not at 180° to each other.
Do not award M3 if OH ---- C bond is represented.

formation of organic product CH₃CH(OH)C₂H₅/C₂H₅OH and Br⁻;
Allow formation of NaBr instead of Br⁻. [4]

For primary Z from (iv), for ECF S_N2 required.
For tertiary Z from (iv), for ECF S_N1 required.
But curly arrow showing Br leaving and formation of C₂H₅OH and Br⁻ can be scored for either mechanism (even if incorrect type).

For primary Z from (iv) with 1-bromobutane stated in (v), correct S_N2 can score full marks.
If (iv) is not answered and incorrect starting reagent is given in (v), M1, M2 and M3 may be scored but not M4 for either correct S_N1 or S_N2.
(vi) CH₃COCH₂CH₃;  
*Full or condensed structural formula may be given.*  
For primary Z from (iv), accept CH₃CH₂CH₂COOH/C₃H₇COOH but not CH₃CH₂CH₂CHO.

7b

(iii) fragrances/perfumes / solvents / plasticizers / adhesives/glue / biodiesel;  
*Accept a named painkiller (e.g. aspirin) or anaesthetic (e.g. procaine, benzocaine) containing the ester functional group.*  
Accept “some painkillers”.
*Allow a specific named polyester (e.g. polyethylene terephthalate/PET), but polyester alone is not sufficient to score the mark.*

(iii) 3D representation of two enantiomers of 2-bromobutane:

```
\begin{align*}
\text{CH}_2\text{CH}_3 & \quad \text{CH}_2\text{CH}_3 \\
\text{Br} & \quad \text{Br} \\
\text{C} & \quad \text{C} \\
\text{H} & \quad \text{H} \\
\text{CH}_3 & \quad \text{CH}_3
\end{align*}
```

*Tapered (wedge/dash) notation not necessary but non-superimposeable mirror images must be shown clearly.*

two optical isomers rotate plane of plane-polarized light in (equal and) opposite directions (all other physical properties identical) and identical chemical properties (in reactions with non-chiral compounds) / OWTTE;  
*Allow different chemical properties only if reference is made to their reaction with other optically active compounds/chiral reagents / biological sensors / OWTTE.*

Q# 31/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/Q1f

(iii) *Monomer:*

```
\begin{align*}
\text{H} & \quad \text{Cl} \\
\text{C}=\text{C} & \quad \text{H} \\
\text{H} & \quad \text{H}
\end{align*}
```

*Accept vinyl chloride or chloroethylene.*  
*Allow C₂H₃Cl.*

*Use:*
raincoats / packaging / window frames / pipes / carpets / gutters / electrical cable sheathing / covers for electrical wires / rope / bottles;  
*Accept suitable alternatives.*  
*Do not allow glue.*  
*Do not allow just plastic(s) or just windows.*  
*Allow plastic bag.*
7. (a) (i) molar mass = 102.20 (g mol\(^{-1}\));
amount \(= \frac{5.00}{102.20}\) = 0.0489 (mol);

(ii) theoretical yield = \((84.18 \times 0.0489) = 4.12\) (g);
percentage yield = \(\frac{2.62}{4.12} \times 100 = 63.6\%\);
Accept alternative calculation method.

(iii) yield above 100% not possible / experimental yield > theoretical yield / OWTTE;
Must have reference to a final yield.

sample contaminated with hexan-1-ol/water / inadequate drying / OWTTE;
Do not accept error in reading balance/weighing scale.

(c) (i) \[
\begin{align*}
&\text{Br} \\
&C_4H_9 &\text{C} &\text{Br} \\
&\text{C} &\text{H} &\text{C} &\text{C}_4H_9 \\
&\text{CH}_3 &\text{H} &\text{H}_3C &\text{C}_4H_9
\end{align*}
\]

(ii) use a polarimeter / polarimetry;
isomers rotate plane of polarized light in equal, but opposite directions;

(d) geometric / cis-trans / E-Z;

(c) (i) 2-methylpentane;
3-methylpentane;
2,2-dimethylbutane;
2,3-dimethylbutane;

(ii) hexane:
Accept the molecular structure, full structural formula or condensed structural formula.

straight chain/no branches, hence increased surface area/more closely packed;
stronger/larger/greater London/dispersion/van der Waals’;
Accept the opposite arguments.
Do not accept stronger/larger/greater intermolecular forces.
(ii) use a polarimeter/polarimetry; isomers rotate plane of polarized light in equal, but opposite directions; [2]

d) geometric/cis-trans/E-Z; [1]

e) (i) 2-methylpentane;
3-methylpentane;
2,2-dimethylbutane;
2,3-dimethylbutane; [3 max]

(ii) hexane;
Accept the molecular structure, full structural formula or condensed structural formula.

straight chain/no branches, hence increased surface area/more closely packed;
stronger/larger/greater London /dispersion/van der Waals';
Accept the opposite arguments.
Do not accept stronger/larger/greater intermolecular forces.

(f) Initiation:
Cl₂ → 2Cl•;

Essential condition:
UV/sunlight/hf/ hv;

Propagation:
Cl• + R-H → HCl + R• / R• + Cl₂ → RCl + Cl•;

Termination:
Cl• + Cl• → Cl₂ / Cl• + R• → RCl / R• + R• → R₂; [4]
Allow more specific detail of R based on hexane (e.g. CH₃(CH₂)₄CH₂–H) in mechanistic steps.
(d) (i) $\sigma$ bond:
end-on/axial overlap with electron density between the two carbon atoms/nuclei / end-on/axial overlap of orbitals so shared electrons are between atoms / OWTE;

$\pi$ bond:
sideways/parallel overlap of p orbitals with electron density above and below internuclear axis/$\sigma$ bond / sideways/parallel overlap of p orbitals so shared electrons are above and below internuclear axis/$\sigma$ bond / OWTE; \[2\]

Marks can be scored from a suitable diagram.
Award [1 max] for stating end-on/axial overlap for $\sigma$ and sideways/parallel overlap for $\pi$ only i.e. without mentioning electron density OR stating electron density between the two atoms/nuclei for $\sigma$ and above and below internuclear axis for $\pi$.

\[ \text{Diagram of C=C bond} \]

(ii) 11 $\sigma$ and 3 $\pi$; \[1\]

(iii) (strong) intermolecular hydrogen bonding in trans but (strong) intramolecular hydrogen bonding in cis so attraction between different molecules is less (hence lower melting point); \[1\]
Allow between molecules for intermolecular and within molecules for intramolecular.

(iv) in cis two carboxylic acid groups close together so on heating cyclic anhydride forms (with elimination of water) / OWTE; \[1\]
Allow converse argument for trans.

(e) O of OH $sp^3$ and O of C=O $sp^2$; \[1\]
Oxygens must be identified.
9. (a) same functional group; successive neighbouring members differ by CH₂; 
same general formula; similar chemical properties; gradation in physical properties; [2 max]

(b) (i) D: 4-methylpentan-1-ol; 
Allow 4-methyl-1-pentanol.

E: 4-methylpentanal;

F: 4-methylpentanoic acid;

G: 4-methylpentyl ethanoate; [2 max]

Allow 4-methylpentyl acetate.

Award [2] for all four correct. [1 max] for two or three correct.

Award [1 max] if all suffices correct but prefix (4-methyl or pent) not correct.

(ii) (CH₃)₂CHCH₂CH₂CON(CH₃)₂; [1]

Allow full or condensed structural formula.

Allow formation of (CH₃)₂CHCH₂CH₂CO₂⁻ (CH₃)₂NH₂⁺ salt (as amide only forms on strong heating at ~200°C).

Penalize missing hydrogens or incorrect bonds (e.g. C=HO, N-HC) once only in (b) (ii), (d) (i) and (e).

(iii) For both reactions reagents: named suitable acidified oxidizing agent:

Suitable oxidizing agents are potassium dichromate(VI)/K₂Cr₂O₇ / sodium dichromate(VI)/Na₂Cr₂O₇ / dichromate/Cr₂O₇²⁻ / potassium manganate(VII)/ potassium permanganate/KMnO₄ / permanganate/manganate/VII)/MnO₄⁻.

Accept H²/HSO₄⁻ instead of sulfuric acid and acidified.

Allow potassium dichromate or sodium dichromate (i.e. without VI) or potassium manganate (i.e. without VII).

Conditions:
distillation for D to E and reflux for D to F; [2]

Award [1 max] if correct reagents and conditions identified for one process only.

(iv) Volatility:

E more volatile than F; hydrogen bonding in carboxylic acid F; [2]

Accept converse argument.

Q# 35/ IB Chem/2011/w/TZ0/Paper 2 Section A/Higher Level/

(d) hydrogen bonding in butan-1-ol: stronger than dipole-dipole attractions in butanal; [2]

Accept converse argument.

Do not penalize dipole-dipole bonding instead of dipole-dipole attractions.
Q# 36/ IB Chem/2011/s/TZ1/Paper 2 Section B/Higher Level/

7. (a) 

A: 
\begin{align*}
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{C} & \quad \text{C} \\
\text{Cl} & \quad \text{Cl}
\end{align*}

B: 
\begin{align*}
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{C} & \quad \text{C} \\
\text{OH} & \quad \text{OH}
\end{align*}

C: 
\begin{align*}
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{C} & \quad \text{C} \\
\text{O} & \quad \text{O}
\end{align*}

D: 
\begin{align*}
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{C} & \quad \text{C} \\
\text{Cl} & \quad \text{Cl}
\end{align*}

E: 
\begin{align*}
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{C} & \quad \text{C} \\
\text{OH} & \quad \text{OH}
\end{align*}

Accept condensed formulas. [5]

Award [1 max] if A and D are other way round (and nothing else correct).
Award [2 max] if A and D are other way round but one substitution product B or E is correct based on initial choice of A and D.
Award [3 max] if A and D are other way round but both substitution products B and E are correct based on initial choice of A and D.
M2 (for B) and M5 (for E) may also be scored for substitution product if primary chloroalkane used.
Penalize missing hydrogens once only in Q.7.

(b) \( \text{CH}_3\text{CH}_2\text{COOH} + \text{CH}_3\text{OH} \rightarrow \text{CH}_3\text{CH}_2\text{COOCH}_3 + \text{H}_2\text{O} \)


(concentrated) sulfuric acid/H\(_2\)SO\(_4\);
Do not accept just H\(^+\) or acid.

methyl propanoate; [4]
(d) (i) 

\[
\begin{align*}
\text{HO}^- & \quad \text{CH}_2(\text{CH}_3)_2 \quad \text{Cl} \\
\text{H}_3\text{C} & \quad \text{H} \quad \text{H} \\
\end{align*}
\]

curly arrow going from lone pair/negative charge on O in HO\(^-\) to C;  
*Do not allow curly arrow originating on H in HO\(^-\).*

curly arrow showing Cl leaving;  
*Accept curly arrow either going from bond between C and Cl to Cl in 2-chloro-3-methylbutane or in the transition state.*

representation of transition state showing negative charge, square brackets and partial bonds;  
*Do not penalize if HO and Cl are not at 180\(^\circ\) to each other.*  
*Do not award M\(^3\) if OH ---- C bond is represented.*

formation of organic product 3-methylbutan-2-ol and Cl\(^-\);  

(ii) OH\(^-\) has a negative charge/higher electron density;  
greater attraction to the carbon atom (with the partial positive charge) / OWTTE;  
*Do not allow just greater attraction.*

(iii) CH\(_3\)CH\(_2\)CH\(_2\)Cl + KCN → CH\(_3\)CH\(_2\)CH\(_2\)CH\(_2\)CN + KCl;  
*Accept CN\(^-\) for KCN and Cl\(^-\) for KCl.*

pentanenitrile;  
*Allow 1-cyanobutane.*

CH\(_3\)CH\(_2\)CH\(_2\)CH\(_2\)CN + 2H\(_2\) → CH\(_3\)CH\(_2\)CH\(_2\)CH\(_2\)CH\(_2\)NH\(_2\);  
pentan-1-amine / 1-aminopentane / 1-pentylamine / 1-pentanamine;  
*Catalyst: nickel/Ni / palladium/Pd / platinum/Pt;*  
*Penalise missing hydrogen once only in Q.7.*
Q# 37/ IB Chem/2010/w/TZ0/Paper 2 Section B/Higher Level/

5. (a) \[ \frac{n_c}{12.01} = 82.6 \quad \text{and} \quad \frac{n_H}{1.01} = 17.4 \]
   ratio is 1:2.5;
   C<sub>2</sub>H<sub>5</sub> ;

\[ \text{No penalty for using 12 and 1.} \] \[ \text{[3]} \]

(b) \[ \left( M = \frac{22400}{385} \right) = 58.2 \quad \text{or} \quad \left( M = \frac{mRT}{PV} \right) = 58.3 \]
   C<sub>4</sub>H<sub>10</sub> ;

\[ \text{[2]} \]

(c) Br<sub>2</sub>/bromine;
   UV/ultraviolet light;
   Accept hν/hv/sunlight.

\[ \text{[2]} \]

(d) \[ \text{Initiation:} \]
   Br<sub>2</sub> → 2Br<sup>•</sup> ;

\[ \text{Propagation:} \]
   Br<sup>•</sup> + RCH<sub>3</sub> → HBr + RCH<sub>2</sub>• ;
   RCH<sub>1</sub>• + Br<sub>2</sub> → RCH<sub>2</sub>Br + Br<sup>•</sup> ;

\[ \text{Termination: [1 max]} \]
   Br<sup>•</sup> + Br<sup>•</sup> → Br<sub>2</sub> ;
   RCH<sub>1</sub>• + Br<sub>2</sub> → RCH<sub>2</sub>Br ;
   RCH<sub>1</sub>• + RCH<sub>2</sub>• → RCH<sub>2</sub>CH<sub>2</sub>R ;

\[ \text{[4 max]} \]

\[ \text{Award 1/1 for any termination step.} \]
\[ \text{Accept radical with or without • throughout.} \]
\[ \text{Do not penalise the use of an incorrect alkane in the mechanism.} \]
curly arrow going from lone pair/negative charge on O in OH⁻ to C;
*Do not allow curly arrow originating on H in OH⁻.*

curly arrow showing Br leaving;
*Accept curly arrow either going from bond between C and Br to Br in bromoethane or in the transition state.*

representation of transition state showing negative charge, square brackets and partial bonds;
*Do not penalise if HO and Br are not at 180° to each other.*
*Do not award M3 if OH ---- C bond is represented unless already penalised in M1.*
*Do not penalise the use of an incorrect alkyl chain in the mechanism*

First and second structures should be mirror images. Tetrahedral arrangement around carbon must be shown.

(i) order with respect to OH⁻ = 0;
order with respect to X = 1;
rate = \( k[X] \);
*Award 3 for final correct answer.*

(ii) 0.2(0);
min⁻¹;

(iii) 2-bromo-2-methyl-propane;
*Do not penalize missing hyphens or added spaces.*
*Accept 2-bromomethylpropane.*

tertiary (structure);

(iv) \( \text{C}_4\text{H}_2\text{Br} \rightarrow \text{C}_4\text{H}_2^+ + \text{Br}^- \) / in equation with curly arrows and slow;
\( \text{C}_4\text{H}_2^+ + \text{OH}^- \rightarrow \text{C}_4\text{H}_2\text{OH}^- \) / in equation with curly arrows and fast;
*No penalty if primary structure is shown.*
*No credit for Sn2 mechanism, except by ECF.*
2. (a) (i) (bond formed by) sideways overlap; (of) p orbitals; 
Marks awarded either from sketch or from explanation. [2]

(ii) C(1) is sp^1 and C(2) is sp^3; [1]

(b) \[ \text{cis but-2-ene/Z-but-2-ene;} \] [2]

(c) \[ \text{H}_2C= \text{CH} \quad / \quad \text{H}_2C= \text{CH}_2 \] [1]

(d) (i) synthesis of materials not naturally available/plastics; 
chemically unreactive materials produced; 
wide range of uses/physical properties / versatile; 
cheap; 
large industry; 
uses a limited natural resource; [2 max]
Award [2] for any two.

(ii) addition; [1]

(iii) \[ \text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_3 \] \[ \text{C} \quad \text{C} \quad \text{C} \quad \text{C} \quad \text{C} \quad \text{C} \] \[ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \] [1]
Must show continuation bonds. 
Ignore bracket around the 6 carbons. 
Must have 6 carbons joined to each other along chain.

(iv) monomers are smaller molecules/ have smaller surface area than polymers; 
Accept monomers have lower molecular mass.

with weaker intermolecular/Van der Waals'/London/dispersion forces; [2]
Accept opposite argument for polymers.
7. (a) A: 1-bromobutane;
   B: 2-bromobutane;
   C: 2-bromo-2-methylpropane;
   D: 1-bromo-2-methylpropane;
   
   Penalize incorrect punctuation, e.g. commas for hyphens, only once.
   Accept 2-bromomethylpropane and 1-bromomethylpropane for C and D respectively.

(b) (i) C/2-bromo-2-methylpropane;
   unimolecular nucleophilic substitution;

   (ii) RBr → R^- + Br^-;
   Allow use of 2-bromo-2-methylpropane instead of RBr.

(iii) A/1-bromobutane/D/1-bromo-2-methylpropane;

   \[ \text{curly arrow going from lone pair/negative charge on } O \text{ in } OH^- \text{ to } C; \]
   Do not allow curly arrow originating on H in OH^-.

   \[ \text{curly arrow showing } Br \text{ leaving;} \]
   Accept curly arrow either going from bond between C and Br to Br in 1-
   bromobutane or in the transition state.

   representation of transition state showing negative charge, square brackets and
   partial bonds;
   Do not penalize if HO and Br are not at 180° to each other.
   Do not award fourth mark if OH--C bond is represented.
(c) (i) no change as [OH⁻] does not appear in rate equation/in the rate determining step;
(b) (iii) rate doubles as the rate is proportional to [OH⁻] / OH⁻ appears in the rate
determining/slow step / first order with respect to OH⁻;

Award [2] if correctly predicts no rate change for SnI and doubling of rate for Sn2 of
without suitable explanation.

(d) rate of 1-bromobutane is faster;
C−Br bond is weaker/breaks more easily than C−Cl bond;

(e) 2-bromobutane/B;
(plain-) polarized light shone through;
Enantiomers rotate plane of plane-polarized light to left or right/opposite directions
(by same amount);
Accept “turn” instead of “rotate” but not “bend/reflect”.

Physical properties identical (apart from effect on plane-polarized light);
Chemical properties are identical (except with other chiral compounds);

Do not accept “similar” in place of “identical”.

Q# 40/ IB Chem/2010/s/TZ1/Paper 2 Section A/Higher Level/
3. (a) \[
\begin{array}{cccccc}
H & H & H & H & H & H \\
C & C & C & C & C & C \\
H & Cl & H & Cl & H & Cl
\end{array}
\]

Brackets not required for mark.
Allow correct condensed structural formula.
Continuation bonds from each carbon are required.
Cl atoms can be above or below carbon spine or alternating above and below.

(b) plastics are cheap/versatile/a large industry / plastics have many uses / OWTTE;
Plastics are not biodegradable / plastics take up large amounts of space in landfill /
pollution caused by burning of plastics / OWTTE;

Do not accept plastics cause litter.
Allow plastics don’t decompose quickly / OWTTE.

(c) (i) Step 1:
CH₂CHCl + H₂ → CH₂CH₂Cl;

Step 2:
CH₂CH₂Cl + OH⁻ → CH₂CH₂OH + Cl⁻;
Accept NaOH or NaCl etc. instead of OH⁻ and Cl⁻.
Allow abbreviated formulas C₂H₅Cl, C₂H₅OH.

(ii) H₂SO₄/H⁺/acidified and Cr₂O₇²⁻/(potassium/sodium) dichromate;
Accept suitable oxidizing agents (e.g. KMnO₄ etc.) but only with acid.
Ignore missing or incorrect oxidation states in reagents.

(Heat under) reflux;
Second mark can be scored even if reagent is incorrect.
Q# 41/ IB Chem/2009/w/TZ0/Paper 2 Section B/Higher Level/

9. (a) (i) 
\[ \text{cis} \quad \begin{array}{c}
    \text{CH}_3 \\
    \text{C} = \text{C} \\
    \text{CH}_3 \text{Cl}
\end{array} \quad ; \\
\text{trans} \quad \begin{array}{c}
    \text{H} \\
    \text{C} = \text{C} \\
    \text{CH}_2 \text{Cl}
\end{array} \]

(ii) no rotation possible due to double bond/\pi bond;  
Accept hindered or restricted rotation.  [1]

(iii) \[
\begin{array}{c}
    \text{H} \\
    \text{C} = \text{C} \\
    \text{H} \\
    \text{Cl} \\
    \text{CH}_3
\end{array}
\]

correct structural formula;  
chiral carbon atom identified;  [2]

(b) (i) trans has the higher melting point;  
trans isomer has (predominantly) intermolecular hydrogen bonding;  
cis isomer has (predominantly) intramolecular hydrogen bonding;  [3]

(ii) cis isomer readily releases water (vapour forming a cyclic anhydride);  
Accept opposite arguments for trans isomer.  [1]

(c) (i) \( S_n 2 \) ;  [1]

(ii) 
\[
\begin{array}{c}
    \text{NC}^- \\
    \text{C} \quad \text{Br} \\
    \text{H} \\
    \text{H}
\end{array} \quad \rightarrow \quad \begin{array}{c}
    \text{NC}^- \\
    \text{C} \quad \text{C} \\
    \text{H} \\
    \text{H}
\end{array}^- \quad \rightarrow \quad \begin{array}{c}
    \text{NC}^- \\
    \text{C} \\
    \text{H} \\
    \text{H}
\end{array} \quad + \text{Br}^- \\
\]

curly arrow going from \( \text{CN}^- \) to C;  
curly arrow showing Br leaving;  
Curly arrow may be represented on transition state.

representation of transition state, showing negative charge and dotted lines;  products;  [4]

(iii) \( \text{CH}_3\text{CH}_2\text{CN} + 2\text{H}_2 \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2 \);  
\( \text{Ni} / \text{Pt} / \text{Pd} \);  [2]
Q# 42/ IB Chem/2009/w/TZ0/Paper 2 Section A/Higher Level/

5. (a) (i) Isomer | A | B | C  
--- | --- | --- | ---  
Boiling point | 36 °C | 28 °C | 10 °C 

Award [1] if correct boiling points are assigned to 3 isomers.

- increase in branching / more side chains / more spherical shape
- reduced surface contact / less closely packed;
- weaker intermolecular force / van der Waals / London / dispersion forces;  

Accept the opposite arguments

(ii) B: 2-methylbutane / methybutane;  
C: 2,2-dimethyl propane / dimethyl propane;  

Do not penalize missing commas, hyphens or added spaces.  
Do not accept 2-dimethylpropane or 2,2-methylpropane.

(b) C\textsubscript{7}H\textsubscript{14}

Accept any two of the following explanations.

- C\textsubscript{7}H\textsubscript{11}OH has greater molar mass / produces less grams of CO\textsubscript{2} and H\textsubscript{2}O per gram of the compound / suitable calculations to show this;
- C\textsubscript{7}H\textsubscript{11}OH contains an O atom which contributes nothing to the energy released / partially oxidized / OWTTE;
- analogous compounds such as butane and butan-1-ol show a lower value for the alcohol per mole in the data book / OWTTE;
- the total bond strength in the pentanol molecule is higher than the total bond strength in pentane;
- the total amount of energy produced in bond formation of the products per mole is the same;
- fewer moles of pentanol in 1 g;
- pentanol requires more energy to break intermolecular forces / H bonding / OWTTE;  

(c) Improvements [2]

less/no particulates/C/CO/VOC’s produced with CNG;
less/no SO\textsubscript{2}/SO\textsubscript{3} produced;

Reasons [1 max]

CO/SO\textsubscript{2} toxic / poisonous;
SO\textsubscript{2} causes acid rain;
CNG is likely to undergo complete/more combustion;
CNG has no/less sulfur impurities;  

Q# 43/ IB Chem/2009/s/TZ1/Paper 2 Section B/Higher Level/

9. (a) (i) CH\textsubscript{3}CH\textsubscript{2}CH\textsubscript{2}CH\textsubscript{2}Br → CH\textsubscript{3}CH\textsubscript{2}CH=CH\textsubscript{2} + HBr  
CH\textsubscript{3}CH\textsubscript{2}CH\textsubscript{2}CH\textsubscript{2}Br + OH\textsuperscript{-} → CH\textsubscript{3}CH\textsubscript{2}CH=CH\textsubscript{2} + H\textsubscript{2}O + Br\textsuperscript{-}  
- alcoholic NaOH/OH\textsuperscript{-}  
- reflux / heat;  

Penalize missing Hs once only throughout question 9

(iii) CH\textsubscript{3}CH\textsubscript{2}CH\textsubscript{2}CH\textsubscript{2}Br + NH\textsubscript{3} → CH\textsubscript{3}CH\textsubscript{2}CH\textsubscript{2}CH\textsubscript{2}NH\textsubscript{2} + HBr  
- ammonia/NH\textsubscript{3};  
- warm / excess ammonia (to prevent secondary amines etc.);  

[3]
(iv)

\[
\begin{align*}
\text{H}_3\text{N}: & \quad \text{H} & \quad \text{H} \\
\text{H}_\text{C}_3\text{H}_7 & \quad \text{Br} & \quad \text{Br}
\end{align*}
\]

curly arrow from ammonia (to form transition state);
correct transition state;
curly arrow from bond to Br atom in either the first or second step;
formation of HBr and organic product;
Accept a second molecule of NH$_3$ removing H$^+$ from the transition state to give NH$_4^+$ and Br$^-$ as products.[4]

(b) (i)

\[
\begin{align*}
\text{C}_2\text{H}_5 & \quad \text{H}_3\text{C} \\
\text{Br} & \quad \text{C}_2\text{H}_5
\end{align*}
\]

Award [1] for correct structure and [1] for correct 3-D representation of both enantiomers.[2]

(ii) polarimeter (to measure angle of rotation);
the plane of plane-polarized light rotates in opposite directions (by the different enantiomers);[2]

(iii) 2-bromo-2-methylpropane is tertiary / 1-bromobutane is primary;
2-bromo-2-methylpropane goes by S$_{N}$1 / 1-bromobutane by S$_{N}$2;
itro compound more stable for tertiary;
no space around tertiary carbon for five groups (in S$_{N}$2 transition state);[3 max]

Q# 44/ IB Chem/2009/s/TZ1/Paper 2 Section A/Higher Level/

1. (a) ester;[1]

(b) amount of oil $= \frac{1013.0}{885.6} = 1.144$ mol;

amount of methanol $= \frac{200.0}{32.05} = 6.240$ mol;
since three mol of methanol react with one mol of vegetable oil the amount of excess methanol $= 6.240 - (3 \times 1.144) = 2.808$ mol;[3]
(d) vegetable oil is mainly non-polar and methanol is polar. Stirring brings them into more contact with each other, increasing the frequency of collisions. Do not allow simply mixing.

(e) (Relative molecular mass of biodiesel, $C_{19}H_{40}O_2 = 296.55$)
maximum yield of biodiesel = $3.432$ mol / $1018$ g ;
percentage yield $= \frac{811.0}{1018} \times 100 = 79.67\%$;
Allow 80% for percentage yield.

(f) the carbon dioxide was absorbed by plants initially so there is no net increase. Vegetable oil is not a fossil fuel. Vegetable oil is formed from (atmospheric) carbon dioxide. OWTTE.

Q# 45/ IB Chem/2008/w/TZ0/Paper 2 Section B/Higher Level/

8. (a) electron moves from 2s to 2p;
(one) (2)s and (one) (2)p orbital hybridize / mix / combine;
sp (hybrid) orbital forms sigma bonds with C and H / C and C;
two electrons in (unhybridized) (2)p orbitals overlap sideways;
If 2 not mentioned, award [3 max] for above marks.

to form (two) pi bonds; [4 max]
Any four for [1] each.
If no marks scored, award [1] for sp hybridization.

(b) $sp^2$;
$120^\circ$;
$sp^3$;
$109.5^\circ$;

(c) if benzene had 3 C=C bonds enthalpy of reaction should be $-360$ kJ;
(real) benzene is (152 kJ) more stable than structure with 3 C=C bonds suggests;
circle-in-hexagon symbol represents delocalized electrons / resonance hybrids;

(d) benzene with alternate single and double bonds should have two different carbon to carbon bond lengths / carbon to carbon bond lengths of 0.134 and 0.134 nm / OWTTE;
(all) bonds in benzene are same length / all 0.139 nm;

(e) (i) electrons in p-orbitals overlap to form delocalized orbital extending over three atoms;

(ii) (in COOH) two different bond lengths / C=O shorter than C–O;
(in COO⁻) both the same / intermediate between the values for C–O and C=O in COOH;

(f) $I$ is substitution and $II$ is addition;
$II$ loses delocalization and decreases stability / $I$ keeps delocalization / $II$ needs more energy to overcome delocalization;
Q# 46/ IB Chem/2008/w/TZ0/Paper 2 Section B/Higher Level/

7. (a) (i) \( \text{CH}_2\text{CH}_3\text{CH}_2\text{COOH} / \text{CH}_3\text{CH}_2\text{CH}_3\text{CO}_2\text{H} \); butanoic acid; [2]

(ii) ester. [1]

(b) (i) \( \text{Br}^- = \text{bromine (free) radical/atom and Br}^- = \text{bromide (ion)} \); 
\( \text{Br}^- \text{ homolytic fission / involves equal division of electron pair / OWTTE} \); 
\( \text{Br}^- \text{ heterolytic fission / involves electron pair remaining with one species / OWTTE} \); [3]

(ii) \( S = \text{substitution} \)
\( N = \text{nucleophilic} \)
\( 2 = \text{molecularity of 2 / reaction is bimolecular} \) [2]

*Three correct award [2], two correct award [1], one or none correct award [0].*

(iii)

\[
\begin{align*}
\text{H} & \quad \text{H} \\
& \quad \text{C} \\
\text{C} & \quad \text{H} \\
\text{H} & \quad \text{Br}
\end{align*}
\]

\[
\begin{array}{c}
\text{O} \\
\text{H}
\end{array}
\]

\[
\begin{array}{c}
\text{CH}_3 \\
\text{C} \\
\text{H}
\end{array}
\]

\[
\begin{array}{c}
\text{C} \\
\text{Br}
\end{array}
\]

\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{H}
\end{array}
\]

\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H}
\end{array}
\]

\[
\begin{array}{c}
\text{H} \\
\text{H}
\end{array}
\]

\[
\begin{array}{c}
\text{H} \\
\text{H}
\end{array}
\]

curly arrow from \( \text{O} \) or negative charge on \( \text{OH}^- \) to \( \text{C} \) of \( \text{C}-\text{Br} \) bond;
structure of transition state showing charge and partial bonds;

*Do not penalise missing square brackets.*

curly arrow from \( \text{C}-\text{Br} \) bond to \( \text{Br}^- \) (on reactant or on transition state);
structure of butan-2-ol and \( \text{Br}^- \); [4]

*If mechanism shown for 1-bromobutene, then all marks except the last can be awarded.*

(iv)

\[
\begin{array}{c}
\text{CH}_3 \\
\text{CH}_2 \\
\text{C} \\
\text{H}
\end{array}
\]

\[
\text{C}^+ \\
\text{H}
\]

[1]

(v)

\[
\begin{array}{c}
\text{CH}_3 \\
\text{CH}_2 \\
\text{C} \\
\text{CH}_3
\end{array}
\]

\[
\text{O}
\]

dichromate / \( \text{Cr}_2\text{O}_7^{2-} \); potassium dichromate / \( \text{K}_2\text{Cr}_2\text{O}_7 \); sodium dichromate / \( \text{Na}_2\text{Cr}_2\text{O}_7 \);
acidified/sulfuric acid / \( \text{H}_2\text{SO}_4 / \text{H}^+ \); [3]

(vi)

\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{C}
\end{array}
\]

\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{H}
\end{array}
\]

\[
\begin{array}{c}
\text{O}
\end{array}
\]

*Accept condensed structural formula* [1]
(c) (i) \( \text{F / butan-2-ol; hydrogen bonding;} \)

(ii) \( \text{E / 2-bromobutane; cannot hydrogen bond with water;} \)

(d) \( \text{chiral/asymmetric carbon atom / carbon atom joined to 4 different groups; } \)

\[
\begin{align*}
\text{CH}_3 & \quad \text{CH}_3 \\
\text{C}_2\text{H}_5 & \quad \text{OH} \\
\text{CH}_3 & \quad \text{C}_2\text{H}_5
\end{align*}
\]

\( \text{correct 3-D structure of either isomer; other correct 3-D structure clearly showing relationship; planes rotated in opposite directions;} \)

**Q# 47/ IB Chem/2008/s/TZ1/Paper 2 Section B/Higher Level/**

9. (a) (i) \( \text{C}_{8}\text{H}_{16} ; \)

\( \text{H}_{12.01} \text{ H}_{1.01} ; \)

\text{No penalty for using integer } A \text{, values.}

\( \text{Empirical formula } \text{CH}_2 ; \)

\( \text{Molecular formula } \text{C}_4\text{H}_8 ; \)

(iii) \( \text{CH}_3\text{CH} = \text{CHCH}_3 ; \)

\( \text{but-2-ene/2-butene;} \)

(iv) \( \text{dehydration / elimination;} \)

\( \text{CH}_3 \text{ = CHCH}_2\text{CH}_3 ; \)

\( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH ;} \)

\( \text{Accept butan-2-ol} \)

(b) (i)

\( \text{curly arrow showing } \text{C–Br bond fission; formation of carbonium ion; curly arrow showing attack by } \text{OH}^- \text{ on carbon atom; product;} \)

(ii) \( \text{step 1 and because it is a slow step / because it has high activation energy / because it involves bond breaking;} \)

(c) (i) \( \text{less because } \text{C–Br bond is stronger;} \)

(ii) \( \text{equal because first order kinetics / rate determining step does not involve } \text{KOH / OWTTE;} \)
(d) (i) \( \text{sp}^2 \) (hybridization);
angle 120°;
symmetrical / planar / flat / hexagonal structure;
delocalization of electrons / resonance hybrid / all carbon to carbon bonds are equal; [4]

(ii) one;
all the hydrogen in benzene are equivalent / OWTTE; [2]
Accept two for the first mark if TMS / reference is mentioned for the second mark.

(e) (i) \(-360 \text{ (kJ mol}^{-1}\)); [1]

(ii) benzene is more stable because of delocalization / does not contain three double bonds / delocalization energy is 153 kJ/mol; [1]

4. (a) compounds with the same molecular formula and different structural formula / different structures; [1]
Accept “same molecular formula but atoms orientated differently in space”

(b) (i) \( \text{CH}_3\text{CH}_2\text{CHO} \);
\( \text{CH}_3\text{COCH}_3 \);
acidified and \( \text{K}_2\text{Cr}_2\text{O}_7 / \text{potassium dichromate / dichromate / Cr}_2\text{O}_7^{2-} \);
\( \text{CH}_3\text{CH}_2\text{CHO} \) orange to green and \( \text{CH}_3\text{COCH}_3 \) no effect; [4]
Accept Fehling’s solution test or tollen’s reagent test with appropriate results.
Accept any other correct isomer but the functional groups must be different and appropriate chemical test must be stated.

(ii) \( \text{CH}_3\text{CH}_2\text{COOH} \);
\( \text{CH}_3\text{COOCH}_3 \) / \( \text{HCOOC}_2\text{H}_5 \);
\( \text{Na}_2\text{CO}_3 / \text{sodium carbonate / reactive metal} \);
\( \text{CH}_3\text{CH}_2\text{COOH} \) – evolution of gas / fizzing / OWTTE and
\( \text{CH}_3\text{COOCH}_3 \) / \( \text{HCOOC}_2\text{H}_5 \) no effect; [4]
Accept appropriate named indicator with correct colour change e.g. blue litmus turns red for the acid and no effect for the ester.
Accept any correct isomer but the functional groups must be different and appropriate chemical test must be stated.
Do not accept IR spectra or NMR as chemical tests.
Both isomers should be mentioned in the chemical test.
### Topic 11

#### Q# 1
Ethane-1,2-diol, HOCH₂CH₂OH, has a wide variety of uses including the removal of ice from aircraft and heat transfer in a solar cell.

(f) Predict the $^1$H NMR data for ethanedioic acid and ethane-1,2-diol by completing the table.

<table>
<thead>
<tr>
<th></th>
<th>Number of signals</th>
<th>Splitting pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanedioic acid:</td>
<td>···················</td>
<td>···················</td>
</tr>
<tr>
<td>Ethane-1,2-diol:</td>
<td>···················</td>
<td>Not required</td>
</tr>
</tbody>
</table>

#### Q# 2
(b) Bute is a chemical with the following molecular formula:

$$C_{19}H_{20}N_2O_2$$

It has an unsaturation index of 9.
(iv) The infrared (IR) spectrum of bute is shown below.

[Source: SDBS web: www.sdb.siosdb.jst.go.jp (National Institute of Advanced Industrial Science and Technology, 2014)]

Using information from section 26 of the data booklet, identify the bonds corresponding to A and B. [1]

A:  

B:  

(v) Based on analysis of the IR spectrum, predict, with an explanation, one bond containing oxygen and one bond containing nitrogen that could not be present in the structure. [2]

Bond containing oxygen not present in structure:

---------------------------------------------------------------------------------

Bond containing nitrogen not present in structure:

---------------------------------------------------------------------------------

Explanation:

---------------------------------------------------------------------------------
(c) An alcohol, \( X \), of molecular formula \( \text{C}_2\text{H}_5\text{O} \), used as a disinfectant in hospitals, has the following \(^1\)HNMR spectrum:

![HNMR spectrum](image)

Chemical shift / ppm

[Source: SDBS web: www.sdb.siodb.aist.go.jp (National Institute of Advanced Industrial Science and Technology, 2014)]

The three peaks in the \(^1\)HNMR spectrum of \( X \) have chemical shift values centred at \( \delta = 4.0 \), 2.3 and 1.2 ppm.

(i) From the integration trace, estimate the ratio of hydrogen atoms in different chemical environments.  

(ii) Deduce the full structural formula of \( X \).
(iii) Y is an isomer of X containing a different functional group. State the condensed structural formula of Y.

........................................................................................................................................
........................................................................................................................................

(iv) Compare and contrast the expected mass spectra of X and Y using section 28 of the data booklet.

One similarity:
........................................................................................................................................
........................................................................................................................................
........................................................................................................................................

One difference:
........................................................................................................................................
........................................................................................................................................
........................................................................................................................................

Chem 11 3 Q# 3/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/Q2

(c) The other monomer used in the production of polyurethane is compound Z shown below.

(ii) Deduce the number of signals you would expect to find in the $^1$H NMR spectrum of compound Z, giving your reasons.
The mass spectrum and infrared (IR) spectrum of compound Z are shown below:

Mass spectrum

![Mass spectrum graph]

[Source: http://sdb.s.db.aist.go.jp]

IR spectrum

![IR spectrum graph]

(iii) Identify the species causing the large peak at \( m/z = 31 \) in the mass spectrum. [1]

(iv) Identify the bond that produces the peak labelled Q on the IR spectrum, using section 25 of the data booklet. [1]
5. Compound A and compound B are hydrocarbons.

(b) Outline how you could use the IR spectra of compounds A and B and section 26 of the data booklet to identify them.

(c) Two signals occur in the $^1$H NMR spectrum of compound A. Deduce their expected chemical shift and their splitting pattern, using section 27 of the data booklet.

<table>
<thead>
<tr>
<th>Signal</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical shift / ppm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Splitting pattern</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1. A student used the technique of titration to determine the concentration of ascorbic acid (C₆H₈O₆) in a sample of orange juice. Excess potassium iodide, KI(aq), was added to acidified orange juice. The resulting solution was titrated with potassium iodate, KIO₃(aq), in the presence of starch as an indicator. The end-point of the titration was shown by a blue-black colour.

(c) The concentration of KIO₃ used in the titration was $2.00 \times 10^{-3}$ mol dm$^{-3}$. The titration produced the following results.

<table>
<thead>
<tr>
<th></th>
<th>Titration 1</th>
<th>Titration 2</th>
<th>Titration 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final volume of KIO₃ (± 0.05 cm$^3$)</td>
<td>7.10</td>
<td>14.40</td>
<td>21.60</td>
</tr>
<tr>
<td>Initial volume of KIO₃ (± 0.05 cm$^3$)</td>
<td>0.00</td>
<td>7.10</td>
<td>14.40</td>
</tr>
<tr>
<td>Volume added of KIO₃ (± 0.10 cm$^3$)</td>
<td>7.10</td>
<td>7.30</td>
<td>7.20</td>
</tr>
<tr>
<td>Mean volume added of KIO₃ (± 0.10 cm$^3$)</td>
<td></td>
<td></td>
<td>7.20</td>
</tr>
</tbody>
</table>

(i) Calculate the percentage uncertainty associated with the mean volume of KIO₃(aq). [1]

(ii) The colour of orange juice interfered with the blue-black colour at the equivalence point. State the name of this type of error and suggest how this can be minimized. [2]
1. A student used a pH meter to measure the pH of different samples of water at 298 K.

<table>
<thead>
<tr>
<th>Sample</th>
<th>pH ± 0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain water</td>
<td>5.1</td>
</tr>
<tr>
<td>River water</td>
<td>4.4</td>
</tr>
<tr>
<td>Tap water</td>
<td>6.5</td>
</tr>
<tr>
<td>Bottled water</td>
<td>7.1</td>
</tr>
</tbody>
</table>

(b) Calculate the percentage uncertainty in the measured pH of the rain water sample. [1]

Chem 11 Q# 7/ IB Chem/2014/s/TZ2/Paper 2 Section A/Higher Level/

1. A class studied the equilibrium established when ethanoic acid and ethanol react together in the presence of a strong acid, using propanone as an inert solvent. The equation is given below.

\[ \text{CH}_3\text{COOH} + \text{C}_2\text{H}_5\text{OH} \rightleftharpoons \text{CH}_3\text{COOC}_2\text{H}_5 + \text{H}_2\text{O} \]

One group made the following initial mixture:

<table>
<thead>
<tr>
<th>Liquid</th>
<th>Volume / cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanoic acid</td>
<td>5.00 ± 0.05</td>
</tr>
<tr>
<td>Ethanol</td>
<td>5.00 ± 0.05</td>
</tr>
<tr>
<td>6.00 mol dm⁻³ aqueous hydrochloric acid</td>
<td>1.00 ± 0.02</td>
</tr>
<tr>
<td>Propanone</td>
<td>39.0 ± 0.5</td>
</tr>
</tbody>
</table>
(b) The concentration of ethanoic acid can be calculated as 1.748 mol dm\(^{-3}\). Determine the percentage uncertainty of this value. (Neglect any uncertainty in the density and the molar mass.)

\[
\begin{array}{llll}
\text{Table}
\end{array}
\]

\[\text{(c) After one week, a } 5.00 \pm 0.05 \text{ cm}^3 \text{ sample of the final equilibrium mixture was pipetted out and titrated with } 0.200 \text{ mol dm}^3 \text{ aqueous sodium hydroxide to determine the amount of ethanoic acid remaining. The following titration results were obtained:}
\]

<table>
<thead>
<tr>
<th>Titration number</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial reading / cm(^3) ± 0.05</td>
<td>1.20</td>
<td>0.60</td>
<td>14.60</td>
</tr>
<tr>
<td>Final reading / cm(^3) ± 0.05</td>
<td>28.80</td>
<td>26.50</td>
<td>40.70</td>
</tr>
<tr>
<td>Titre / cm(^3)</td>
<td>27.60</td>
<td>25.90</td>
<td>26.10</td>
</tr>
</tbody>
</table>

(i) Calculate the absolute uncertainty of the titre for Titration 1 (27.60 cm\(^3\)).
1. Reaction kinetics can be investigated using the iodine clock reaction. The equations for two reactions that occur are given below.

Reaction A: \( \text{H}_2\text{O}_2(\text{aq}) + 2\text{I}^- (\text{aq}) + 2\text{H}^+ (\text{aq}) \rightarrow \text{I}_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l}) \)

Reaction B: \( \text{I}_3^- (\text{aq}) + 2\text{S}_2\text{O}_3^{2-} (\text{aq}) \rightarrow 2\text{I}^- (\text{aq}) + \text{S}_4\text{O}_6^{2-} (\text{aq}) \)

Reaction B is much faster than reaction A, so the iodine, \( \text{I}_2 \), formed in reaction A immediately reacts with thiosulfate ions, \( \text{S}_2\text{O}_3^{2-} \), in reaction B, before it can react with starch to form the familiar blue-black, starch-iodine complex.

In one experiment the reaction mixture contained:

5.0 ± 0.1 cm\(^3\) of 2.00 mol dm\(^{-3}\) hydrogen peroxide (\( \text{H}_2\text{O}_2 \))
5.0 ± 0.1 cm\(^3\) of 1% aqueous starch
20.0 ± 0.1 cm\(^3\) of 1.00 mol dm\(^{-3}\) sulfuric acid (\( \text{H}_2\text{SO}_4 \))
20.0 ± 0.1 cm\(^3\) of 0.0100 mol dm\(^{-3}\) sodium thiosulfate (\( \text{Na}_2\text{S}_2\text{O}_3 \))
50.0 ± 0.1 cm\(^3\) of water with 0.0200 ± 0.0001 g of potassium iodide (KI) dissolved in it.

After 45 seconds this mixture suddenly changed from colourless to blue-black

(d) (i) Calculate the total uncertainty, in cm\(^3\), of the volume of the reaction mixture. \([1]\)

(ii) Calculate the percentage uncertainty of the concentration of potassium iodide solution added to the overall reaction mixture. \([1]\)

(iii) Determine the percentage uncertainty in the concentration of potassium iodide in the final reaction solution. \([1]\)
1. Iron tablets are often prescribed to patients. The iron in the tablets is commonly present as iron(II) sulfate, FeSO₄.

(b) When the Fe²⁺(aq) solution was made up in the 250 cm³ volumetric flask, deionized (distilled) water was added until the bottom of its meniscus corresponded to the graduation mark on the flask. It was noticed that one of the two students measured the volume of the solution from the top of the meniscus instead of from the bottom. State the name of this type of error.

(c) State what is meant by the term *precision*.

(d) When the students recorded the burette readings, following the titration with KMnO₄(aq), the top of the meniscus was used and not the bottom. Suggest why the students read the top of the meniscus and not the bottom.
1. Two groups of students (Group A and Group B) carried out a project on the chemistry of some group 7 elements (the halogens) and their compounds.

(a) In the first part of the project, the two groups had a sample of iodine monochloride (a corrosive brown liquid) prepared for them by their teacher using the following reaction.

\[ \text{I}_2(s) + \text{Cl}_2(g) \rightarrow 2\text{ICl}(l) \]

The following data were recorded.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of I(_2)(s)</td>
<td>10.00 g</td>
</tr>
<tr>
<td>Mass of Cl(_2)(g)</td>
<td>2.24 g</td>
</tr>
<tr>
<td>Mass of ICl(l)</td>
<td>8.60 g</td>
</tr>
</tbody>
</table>

(i) State the number of significant figures for the masses of I\(_2\)(s) and ICl(l).

\[ I_2(s): \text{.................................................................} \]
\[ \text{ICl}(l): \text{.................................................................} \]

(ii) State, with a reason, the number of main peaks in the \(^1\text{H}\) NMR spectrum of benzene.
### Topic 11 Mark Scheme

**Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Higher Level/**

<table>
<thead>
<tr>
<th>1. f</th>
<th>Number of signals</th>
<th>Splitting pattern</th>
<th>Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanediol acid:</td>
<td>1</td>
<td>AND</td>
<td>singlet ✓</td>
</tr>
<tr>
<td>Ethene-1,2-diol:</td>
<td>2</td>
<td></td>
<td>Not required</td>
</tr>
</tbody>
</table>

**Q# 2/ IB Chem/2016/s/TZ0SP/Paper 2 Section A/Higher Level/Q7**

<table>
<thead>
<tr>
<th>b iv A: C-H and B: C=O ✓</th>
<th>Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>b v O-H and N-H ✓</td>
<td>1</td>
</tr>
<tr>
<td>frequencies/stretches due to O-H and N-H occur above 3200 (cm⁻¹) which are not present in IR of bute ✓</td>
<td>2</td>
</tr>
<tr>
<td>c i 1:1:6 ✓</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. c ii</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c iii CH₃CH₂CH₂OH ✓</td>
<td>Allow &quot;both have same molecular ion peak/M⁺/bots have m/z = 60&quot;. However in practice the molecular ion peak is of low abundance and difficult to observe for propan-1-ol.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>c iv</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. 2. c ii</td>
<td>two AND two hydrogen environments in the molecule OR two AND both CH₃ and OH present ✓</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. 2. d iii</td>
<td>&quot;CH₃OH ✓ Accept CH₃O⁻. Accept [CH₃(OH)]⁻ and [CH₃OH]⁻. Do not accept answers in which the charge is missing.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>8. 2. d iv</td>
<td>oxygen-hydrogen bond O-H in hydroxy</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

**Q# 3/ IB Chem/2016/s/TZ1/Paper 2 Section A/Higher Level/**

| 5. b | | | |
| 5. c | | | |

| 5. b | Compound A would absorb at 1620–1680 cm⁻¹ ✓ | Mark |
| 5. c | | | |
| | | | |

| 5. d | | | |
| 5. e | | | |

<table>
<thead>
<tr>
<th>Signal</th>
<th>1/2</th>
<th>Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical shift / ppm</td>
<td>0.0 – 1.0 AND 4.5 – 6.0 ✓</td>
<td>1</td>
</tr>
<tr>
<td>Splitting pattern</td>
<td>singlet AND singlet ✓</td>
<td>2</td>
</tr>
</tbody>
</table>

Accept any value in range 1620 – 1680 cm⁻¹. Accept 0.9 to 2.0 for the first signal as the C=O affects the CH₃ shift (actually 1.7). Accept "none/no splitting" for both splitting patterns. Award [1 max] for the correct deduction (both shift and splitting) of signal 1 or 2.
Q# 5/ IB Chem/2015/w/TZ0/Paper 2 Section A/Higher Level/Q1
(c) (i) 1.4 (%);
Accept 1 (%).

(ii) systematic;
dilute the orange juice;
Accept other valid suggestions, eg. compare with a standard (showing
colour at equivalence) / look at mixture through a yellow filter / add more
starch (for a sharper colour change) / filter orange juice (through charcoal).
Do not accept repeat titrations or alternative indicator.

(iii) $1.44 \times 10^{-5}$ (mol);

Q# 6/ IB Chem/2014/w/TZ0/Paper 2 Section A/Higher Level/Q1
(b) $\left( \frac{0.1}{5.1} \times 100 \right) = 2 \%$;

Q# 7/ IB Chem/2014/s/TZ2/Paper 2 Section A/Higher Level/Q1
(b) percentage uncertainty in volume of ethanoic acid = $100 \times \frac{0.05}{5.00} = 1 \%$;
percentage uncertainty in total volume = $100 \times \frac{0.62}{50} = 1.24 \%$;
total percentage uncertainty = $1 + 1.24 = 2.24 \%$;
Accept rounding down to 2.2/2%.

(c) (i) $\pm 0.1 / 0.10 (cm^3)$;
Do not accept without $\pm$

Q# 8/ IB Chem/2013/w/TZ0/Paper 2 Section A/Higher Level/Q1
(d) (i) $(5 \times 0.1) = (\pm) 0.5 (cm^3)$;

(ii) $(\pm) 0.7 (\%)$;
Comprises both mass of $KI = \pm 0.5 \%$ and volume of $KI = \pm 0.2 \%$.

(iii) $0.5 + 0.7 = (\pm) 1.2 \%$;
Sum of (i) and (ii) (percentage uncertainty of total volume = absolute
uncertainty as $100 cm^3$).

Q# 9/ IB Chem/2013/s/TZ2/Paper 2 Section A/Higher Level/
1. (a) for hemoglobin / myoglobin / transport of oxygen / enzyme / catalase / catalyst;
Allow heme instead of hemoglobin.

(b) systematic (error);
Do not accept parallax.

(c) closeness of agreement of a set of measurements to each other / OWTTE;
Allow reproducibility/consistency of measurement / measurements with small
random errors/total amount of random errors/standard deviation / a more precise
value contains more significant figures / OWTTE.

(d) potassium permanganate has a very dark/deep (purple) colour so cannot read
bottom of meniscus / OWTTE;
Q# 10/ IB Chem/2012/w/TZ0/Paper 2 Section A/Higher Level/

1. (a) (i) \( I_2(s) \): four/4 and \( ICl(l) \): three/3; [1]

(ii) \( n(Cl_2) = \left( \frac{2.24}{2 \times 35.45} \right) \times 0.0316/3.16 \times 10^{-2} \text{ (mol)} \);

Allow answers such as \( 3.2 \times 10^{-2}/0.032/3.15 \times 10^{-2}/0.0315 \text{ (mol)} \).

\( n(ICI) = \frac{2 \times 0.0316}{6.32} / 6.32 \times 10^{-2} \text{ (mol)} \);

Allow answers such as \( 6.4 \times 10^{-2}/0.064/6.3 \times 10^{-2}/0.063 \text{ (mol)} \).

\( m(ICI) - (0.0632 \times 162.35 \text{ } g) = 10.3 \text{ (g)} \); [3]

Allow answers in range 10.2 to 10.4 (g).

Award [3] for correct final answer.

(iii) \( \left( \frac{8.60}{10.3} \times 100 \text{ } \right) = 83.5\% \);

Allow answers in the range of 82.5 to 84.5%.

Q# 11/ IB Chem/2008/s/TZ1/Paper 2 Section B/Higher Level/Q9

(ii) one:

all the hydrogen in benzene are equivalent / OWTTE; [2]

Accept two for the first mark if TMS / reference is mentioned for the second mark.