Name

IB STANDARD Level Paper 2 Sections A and B 16w to 08s

IB Diploma Chemistry

Standard Level

Paper 2 Exam Questions

From summer 2008 to 2016 winter
1206 marks in total

Name:

Missing Papers 2013w, and all papers between 2014 and 2015 inclusive (7 papers in total missing)

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Graphs and statistical analysis for Topics examined in IB Chemistry Standard Level

All Topics all papers ranked

<table>
<thead>
<tr>
<th>Topic</th>
<th>Option</th>
<th>10</th>
<th>N.ofSci</th>
<th>8</th>
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<th>5</th>
<th>9</th>
<th>6</th>
<th>1</th>
<th>3</th>
<th>7</th>
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<tr>
<td>Rank</td>
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<td>6.3</td>
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<td>3.4</td>
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<td>Paper 2 A</td>
<td>11.1</td>
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<td>9.3</td>
<td>12.3</td>
<td>9.5</td>
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<td>6.1</td>
<td>6.0</td>
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<td>3.2</td>
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<td>Paper 2 B</td>
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<td>9.1</td>
<td>12.2</td>
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<td>5.8</td>
<td>6.9</td>
<td>2.9</td>
<td>5.7</td>
<td>2.9</td>
<td></td>
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<tr>
<td>Paper 2 ALL</td>
<td>15.6</td>
<td>10.9</td>
<td>11.2</td>
<td>10.7</td>
<td>10.8</td>
<td>9.4</td>
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<td>6.1</td>
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<td>3.1</td>
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<td>69.2</td>
<td>30.8</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

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.
STANDARD Level PAPER 2
Percentage of all marks awarded for each topic from s1999 to w2014 for Paper 2 sections A (compulsory), B (Choose 1 Q out of 3) and A+B. From s2016 onwards, all Paper 2 questions are compulsory

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
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<tbody>
<tr>
<td>SLP2a&amp;b 08to16</td>
<td>6.8</td>
<td>7.0</td>
<td>5.1</td>
<td>10.9</td>
<td>10.3</td>
<td>7.5</td>
<td>7.1</td>
<td>9.8</td>
<td>11.4</td>
<td>23.5</td>
<td>0.7</td>
</tr>
<tr>
<td>SLP2a&amp;b 99to07</td>
<td>4.1</td>
<td>4.9</td>
<td>12.5</td>
<td>12.6</td>
<td>9.8</td>
<td>7.3</td>
<td>9.5</td>
<td>12.1</td>
<td>5.9</td>
<td>21.4</td>
<td>0.0</td>
</tr>
<tr>
<td>SLP2 All</td>
<td>5.5</td>
<td>6.0</td>
<td>8.8</td>
<td>11.8</td>
<td>10.0</td>
<td>7.4</td>
<td>8.3</td>
<td>10.9</td>
<td>8.6</td>
<td>22.4</td>
<td>0.3</td>
</tr>
</tbody>
</table>
All topics Covered in IB STANDARD 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.
3. Sodium thiosulfate solution reacts with dilute hydrochloric acid to form a precipitate of sulfur at room temperature.

$$Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow S(s) + SO_2(g) + 2NaCl(aq) + X$$

(c) The precipitate of sulfur makes the mixture cloudy, so a mark underneath the reaction mixture becomes invisible with time.

10.0 cm$^3$ of 2.00 mol dm$^{-3}$ hydrochloric acid was added to a 50.0 cm$^3$ solution of sodium thiosulfate at temperature, $T_1$. 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>$[Na_2S_2O_3(aq)]$ / mol dm$^{-3}$</th>
<th>Time, t, for mark to disappear / s ± 1s</th>
<th>$\frac{1}{t} / 10^{-3}$ s$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.160</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.finnaci.com/]

Show that the hydrochloric acid added to the flask in experiment 1 is in excess. [2]
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) 5.00 g 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.

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

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

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

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

(iii) Determine the percentage purity of the hydrated ethanedioic acid sample. \([3]\]
(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>
<thead>
<tr>
<th>Element</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>73.99</td>
</tr>
<tr>
<td>H</td>
<td>6.55</td>
</tr>
<tr>
<td>N</td>
<td>9.09</td>
</tr>
<tr>
<td>O</td>
<td>Remainder</td>
</tr>
</tbody>
</table>

Calculate the empirical formula of bute, showing your working. [3]

(ii) The molar mass, $M$, of bute, is 308.37 g mol$^{-1}$. Calculate the molecular formula. [1]
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 cm\(^3\) of the bleach to a 250 cm\(^3\) volumetric flask. The solution was filled to the graduation mark with deionized water.

- 25.00 cm\(^3\) of this solution was then reacted with excess iodide in acid.

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

- The iodine formed was titrated with 0.100 mol dm\(^{-3}\) sodium thiosulfate solution, Na\(_2\)S\(_2\)O\(_3\)(aq), using starch indicator.

\[
I_{2}(\text{aq}) + 2S_{2}O_{3}^{2-}(\text{aq}) \rightarrow 2I^{-}(\text{aq}) + S_{4}O_{6}^{2-}(\text{aq})
\]

The following data were recorded for the titration:

<table>
<thead>
<tr>
<th></th>
<th>First titre</th>
<th>Second titre</th>
<th>Third titre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final burette reading</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of 0.100 mol dm(^{-3}) Na(_2)S(_2)O(_3)(aq) (in cm(^3) ± 0.05)</td>
<td>23.95</td>
<td>46.00</td>
<td>22.15</td>
</tr>
<tr>
<td>Initial burette reading</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of 0.100 mol dm(^{-3}) Na(_2)S(_2)O(_3)(aq) (in cm(^3) ± 0.05)</td>
<td>0.00</td>
<td>23.95</td>
<td>0.00</td>
</tr>
</tbody>
</table>

(i) Calculate the volume, in cm\(^3\), of 0.100 mol dm\(^{-3}\) Na\(_2\)S\(_2\)O\(_3\)(aq) required to react with the iodine to reach the end point.

[1]
(ii) Calculate the amount, in mol, of Na₂S₂O₃(aq) that reacts with the iodine.

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(iii) Calculate the concentration, in mol dm⁻³, of hypochlorite ions in the diluted bleach solution.

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(iv) Calculate the concentration, in mol dm⁻³, of hypochlorite ions in the undiluted bleach solution.

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

Chem 1 Q# 5/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q2

2. Impurities cause phosphine to ignite spontaneously in air to form an oxide of phosphorus and water.

(a)

(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.

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

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Chem 1 Q# 6/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q1

(c) 2.473 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. [1]

(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. [1]

(iii) Determine the excess amount, in mol, of the other reagent. [1]

(iv) Determine the volume of phosphine, measured in cm$^3$ at standard temperature and pressure, that was produced. [1]
Chem 1 Q# 7/ IB Chem/2013/s/TZ1/Paper 2 Section A/Standard Level/

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.

<table>
<thead>
<tr>
<th>Description</th>
<th>Mass (g ± 0.001 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of bottle</td>
<td>1.737</td>
</tr>
<tr>
<td>Mass of bottle + acid HA</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 cm$^3$ solution in a volumetric flask. A 25.0 cm$^3$ sample of this solution reacted with 12.1 cm$^3$ 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. [2]
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 I₂(s)</th>
<th>10.00 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of Cl₂(g)</td>
<td>2.24 g</td>
</tr>
<tr>
<td>Mass of ICl(l) obtained</td>
<td>8.60 g</td>
</tr>
</tbody>
</table>

(i) State the number of significant figures for the masses of I₂(s) and ICl(l). [1]

I₂(s): .................................................................
ICl(l): .................................................................

(ii) The iodine used in the reaction was in excess. Determine the theoretical yield, in g, of ICl(l). [3]

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(iii) Calculate the percentage yield of ICl(l). [1]

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Chem 1 Q# 9/ IB Chem/2012/TZ0/Paper 2 Section A/Standard Level/Q1

(c) The students reacted ICl(l) with CsBr(s) to form a yellow solid, CsICl₂(s), as one of the products. CsICl₂(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 CsICl₂(s) by titrating it with 0.0500 mol dm⁻³ Na₂S₂O₃(aq). The following data were recorded for the titration.

<table>
<thead>
<tr>
<th>Mass of CsICl₂(s) taken (in g ± 0.0001)</th>
<th>0.2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial burette reading of 0.0500 mol dm⁻³ Na₂S₂O₃(aq) (in cm³ ± 0.05)</td>
<td>1.05</td>
</tr>
<tr>
<td>Final burette reading of 0.0500 mol dm⁻³ Na₂S₂O₃(aq) (in cm³ ± 0.05)</td>
<td>25.25</td>
</tr>
</tbody>
</table>

(i) Calculate the percentage of iodine by mass in CsICl₂(s), correct to three significant figures.

(ii) State the volume, in cm³, of 0.0500 mol dm⁻³ Na₂S₂O₃(aq) used in the titration.
(iii) Determine the amount, in mol, of 0.0500 mol dm$^{-3}$ Na$_2$S$_2$O$_3$(aq) added in the titration.  

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

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

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

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

(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, CsICl₂(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. [1]

Chem 1 Q# 10/IB Chem/2012/s/TZ1/Paper 2 Section A/Standard Level/

2. In 1921 Thomas Midgley discovered that the addition of a lead compound could improve the combustion of hydrocarbons in automobile (car) engines. This was the beginning of the use of leaded gasoline (petrol).

The percentage composition, by mass, of the lead compound used by Midgley is shown below.

<table>
<thead>
<tr>
<th>Mass composition / %</th>
<th>Pb</th>
<th>C</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>64.052</td>
<td>29.703</td>
<td>6.245</td>
</tr>
</tbody>
</table>

(a) (i) Determine the empirical formula of the lead compound. [3]

(ii) Leaded gasoline has been phased out because the lead(IV) oxide, PbO₂, produced as a side product in the combustion reaction, may cause brain damage in children.

0.01 mol of Midgley’s lead compound produces 0.01 mol of lead(IV) oxide. Deduce the molecular formula of Midgley’s compound. [1]
(iii) Determine the equation for the complete combustion of Midgley’s compound.  

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\[
\text{\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots}\n\]

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\text{\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots}\n\]

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\text{\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots}\n\]

10
Chem 1 Q# 155/ IB Chem/2011/w/tz0/Paper 2 Section B/Standard Level/

(d) 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.

\[\text{Combustion Reaction:}\]

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

\[\text{Precipitation Reaction with AgNO₃(aq):}\]

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.  

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\text{\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots}\n\]

\[
\text{\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots}\n\]

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\text{\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots}\n\]

\[
\text{\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots}\n\]

(ii) Determine the percentage by mass of chlorine in J, using the precipitation data.  

\[
\text{\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots}\n\]

\[
\text{\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots}\n\]
(iii) The molar mass was determined to be 131.38 g mol\(^{-1}\). Deduce the molecular formula of J.

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

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 NaN$_3$(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]

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(iii) Determine the volume of nitrogen gas, in dm$^3$, produced under these conditions based on this reaction. [4]

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1. The diagram shows the apparatus used to study the rate of reaction between calcium carbonate and hydrochloric acid.

\[ \text{CaCO}_3(s) + 2\text{HCl(aq)} \rightarrow \text{CaCl}_2(aq) + \text{H}_2\text{O(l)} + \text{CO}_2(g) \]

(a) 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 g
- volume of 1.00 mol dm\(^{-3}\) \( \text{HCl(aq)} \) = 50.0 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 1.
(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]

Chem 1 Q# 13/IB Chem/2008/s/TZ1/Paper 2 Section A/Standard Level/

1. A 0.265 g sample of a mixture of calcium chloride, CaCl₂, and potassium nitrate, KNO₃, is dissolved in 50.0 cm³ of water. This mixture is titrated with 0.100 mol dm⁻³ silver nitrate, AgNO₃, which reacts with the chloride ions present to form insoluble silver chloride, AgCl. The titration required 38.5 cm³ of silver nitrate.

(a) Write an equation for the reaction between calcium chloride and silver nitrate. [2]

(b) Calculate the amount, in moles, of silver nitrate used in the reaction. [2]

(c) Calculate the amount, in moles, of calcium chloride titrated and the mass of calcium chloride present in the original sample. [3]

(d) Calculate the percentage of calcium chloride in the original sample. [1]
1. 0.502 g of an alkali metal sulfate is dissolved in water and excess barium chloride solution, \( \text{BaCl}_2(\text{aq}) \), is added to precipitate all the sulfate ions as barium sulfate, \( \text{BaSO}_4(\text{s}) \). The precipitate is filtered and dried and weighs 0.672 g.

(a) Calculate the amount (in mol) of barium sulfate formed.  

(b) Determine the amount (in mol) of the alkali metal sulfate present.  

(c) Determine the molar mass of the alkali metal sulfate and state its units.  

(d) Deduce the identity of the alkali metal, showing your working.  

(e) Write an equation for the precipitation reaction, including state symbols.
Topic 1: Mark Scheme

Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q3

\[ n(\text{HCl}) = \frac{10.0 \text{ dm}^3 \times 2.00 \text{ mol dm}^{-3}}{1000} = 0.0200 \text{ mol} \]

AND

\[ n(\text{Na}_2\text{S}_2\text{O}_3) = \frac{50}{1000} \text{ dm}^3 \times 0.150 \text{ mol dm}^{-3} = 0.00750 \text{ mol} \]

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.

Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q2

2. c i \[ n(\text{NaCl}) = \frac{44.0}{1000} \text{ dm}^3 \times 0.100 \text{ mol dm}^{-3} = 1.40 \times 10^{-2} \text{ mol} \]

2. c ii \[ n = \frac{1}{2} \times 1.40 \times 10^{-2} \rightarrow 7.00 \times 10^{-3} \text{ mol} \]

Question | Answers | Notes | Total
--- | --- | --- | ---
2. c iii | **ALTERNATIVE 1:**

mass of pure hydrated ethanediol acid in each titration = 7.00 \times 10^{-2} \text{ mol} \times 126.08 \text{ g mol}^{-1} = 0.8883 \text{ g}

mass of sample in each titration = \frac{25}{1000} \times 5.00 \text{ g} = 0.125 \text{ g}

\% purity = \frac{0.8883}{0.125} \times 100 = 70.6 \%

**ALTERNATIVE 2:**

mol of pure hydrated ethanediol acid in 1 dm\(^3\) solution = 7.00 \times 10^{-2} \text{ mol} \times 126.08 \text{ g mol}^{-1} = 8.883 \text{ g}

mol of pure hydrated ethanediol acid in sample = 2.80 \times 10^{-2} \text{ dm}^3 \times 126.08 \text{ g mol}^{-1} = 3.53 \text{ g}

\% purity = \frac{3.53}{5.00} \times 100 = 70.6 \%

**ALTERNATIVE 3:**

mol of hydrated ethanediol acid (assuming sample to be pure) = \frac{5.00 \text{ g}}{126.08 \text{ g mol}^{-1}} = 0.03986 \text{ mol}

actual amount of hydrated ethanediol acid = \frac{7.00 \times 10^{-2} \times 1000}{25} = 2.80 \times 10^{-2} \text{ mol}

\% purity = \frac{2.80 \times 10^{-2}}{0.03986} \times 100 = 70.6 \%

Award suitable part marks for alternative methods.

Award (3) for correct final answer.

Award (2 max) for 50.4% if anhydrous ethanediol acid assumed.

Q# 3/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q4

| b | i | \( n_1 = \frac{73.99}{12.01} = 6.161(\text{mol}) \) and \( n_2 = \frac{6.52}{1.01} = 6.49(\text{mol}) \) and \( n_3 = \frac{9.89}{14.01} = 0.694(\text{mol}) \) and \( n_4 = \frac{10.67}{16.00} = 0.668(\text{mol}) \) \checkmark \n| b | ii | Empirical formula: \( \text{C}_2\text{H}_2\text{O}_2 \) \checkmark |

Award (2 max) for correct final answer without working.

Q# 4/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q1

<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>( \langle 22.05 + 22.12 \rangle/0.2 = 22.10(\text{cm}^3) ) \checkmark</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1. a ii</td>
<td>( \frac{22.10 \times 0.100}{3000} = 2.21 \times 10^{-3} / 0.00221(\text{mol}) ) \checkmark</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1. a iii</td>
<td>( 0.5 \times 2.21 \times 10^2 / 1000 \rightarrow 4.42 \times 10^2 / 0.0442(\text{mol} \text{ dm}^{-3}) ) \checkmark</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1. a iv</td>
<td>( 4.42 \times 10^{-2} \rightarrow 4.42 \times 10^{-3} / 0.442(\text{mol} \text{ dm}^{-3}) ) \checkmark</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Q# 5/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q2

2. a. i. \( n(P) = \frac{43.6}{30.97} = 1.41 \text{ mol} \) 
   \( n(O) = \frac{100 - 43.6}{16.00} = 3.53 \text{ mol} \)

   \( \frac{n(O)}{n(P)} = \frac{3.53}{1.41} = 2.50 \) so empirical formula is \( P_2O_5 \)

   Accept other methods where the working is shown.

   3

b. ii. \( \frac{285}{141.9} = 2.00 \) so molecular formula is \( 2 \times P_2O_5 \Rightarrow P_2O_4 \)

   1

Q# 6/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q1

<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>( \frac{2.478}{2 \times 38.97} ) = 0.020009 mol</td>
<td>✓</td>
<td>1</td>
</tr>
<tr>
<td>1. a. ii</td>
<td>( n(\text{NaOH}) = 0.01000 \times 5.00 = 0.5000 \text{ mol} ) AND ( P_2O_5/\text{phosphorus} ) is limiting reagent</td>
<td>✓</td>
<td>1</td>
</tr>
<tr>
<td>1. a. iii</td>
<td>Amount in excess = ( 0.5000 - (3 \times 0.020009) = 0.440 \text{ mol} )</td>
<td>✓</td>
<td>1</td>
</tr>
<tr>
<td>1. a. iv</td>
<td>( 22.7 \times 1000 \times 0.020009 = 454 \text{ cm}^3 )</td>
<td>✓</td>
<td>1</td>
</tr>
</tbody>
</table>

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 dam\(^3\).

Q# 7/ IB Chem/2013/s/TZ1/Paper 2 Section A/Standard Level/

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

   (b) In 25.0 cm\(^3\): \( n_{\text{HA}} = 1.21 \times 10^{-3} \text{ (mol)} \);
   
   In 100 cm\(^3\): \( n_{\text{HA}} = 4.84 \times 10^{-3} \text{ (mol)} \);
   
   \( M = \frac{0.675}{4.84 \times 10^{-3}} = 139 \text{ (g mol}^{-1}) \);

   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 \( n_{\text{H}}: \frac{5.94}{1.01} = 5.88 \);

   \( \text{CaH}_2\text{O}_4 \)

   Award [2] for correct final answer. Accept answers using integer values of molar mass.

Q# 8/ IB Chem/2012/w/TZ0/Paper 2 Section A/Standard Level/

1. (a) (i) \( I_2(s): \text{Four/4 and ICl(l): three/3}; \)

   (ii) \( n(\text{Cl}_2) = \left( \frac{2.24}{2 \times 35.45} \right) 0.0316/3.16 \times 10^{-2} \text{ (mol)} \);

   Allow answers such as 3.2 \times 10^{-3}/0.032/3.15 \times 10^{-2}/0.0315 \text{ (mol)}.

   \( n(\text{ICl}) = 2 \times 0.0316/0.0632/6.32 \times 10^{-2} \text{ (mol)}; \)

   Allow answers such as 6.4 \times 10^{-2}/0.064/6.3 \times 10^{-2}/0.063 \text{ (mol)}.

   \( m(\text{ICl}) = (0.0632 \times 162.35 - 10.3) \text{ (g)}; \)

   Allow answers in range 10.2 to 10.4 \text{ (g)}.

   Award [3] for correct final answer.

   (iii) \( \frac{8.60}{10.5} \times 100 = 83.5\% \);

   Allow answers in the range of 82.5 to 84.5\%.

   (iv) negative/−/minus/ < 0;
Q# 9/ IB Chem/2012/TZ0/Paper 2 Section A/Standard Level/Q1

(c) (i) \[ \left( \frac{126.90}{330.71} \times 100 \right) = 38.4\% ; \] [1]

(ii) \((25.25 - 1.05) - 24.20\) \(\text{cm}^3\);
Accept 24.2 \(\text{cm}^3\) but not 24 \(\text{cm}^3\). [1]

(iii) \(\left( \frac{24.20 \times 5.00 \times 10^{-2}}{1000} \right) = 1.21 \times 10^{-3}/0.00121\) (mol); [1]

(iv) \((0.5 \times 1.21 \times 10^{-3}) = 6.05 \times 10^{-4}/0.000605\) (mol);
Accept alternate method e.g. \((0.384/126.9 \times 0.2015) = 6.10 \times 10^{-4}/0.000610\) (mol). [1]

(v) \((126.90 \times 6.05 \times 10^{-4}) = 7.68 \times 10^{-2}/0.0768\) (g);
Accept alternate method e.g. \((6.10 \times 10^{-4} \times 126.9)\) or \((0.2015 \times 0.384) = 7.74 \times 10^{-2}/0.0774\) (g). [1]

(vi) \(\left( \frac{7.68 \times 10^{-2}}{0.2015} \times 100 \right) = 38.1\% ; \] [1]

Answer must be given to three significant figures.

(d) ICl / iodine monochloride;
Do not accept iodine or bromine. [1]

Q# 10/ IB Chem/2012/s/TZ1/Paper 2 Section A/Standard Level/2.

(a) (i) \(n(\text{Pb}): \left( \frac{64.052}{207.19} \right) = 0.30915\) (mol)

\(n(\text{C}): \left( \frac{29.703}{12.01} \right) = 2.473\) (mol)

\(n(\text{H}): \left( \frac{6.245}{1.01} \right) = 6.18\) (mol)

Do not penalize if integer values of atomic masses used.
Accept alternative calculation method.
Award [2] for three correct.
Award [1] for any two correct.

PbC$_3$H$_{20}$; [3]

(ii) PbC$_3$H$_{20}$; [1]

(iii) PbC$_2$H$_{20}$ + 14O$_2$ → PbO$_2$ + 8CO$_2$ + 10H$_2$O
correct reactants and products;
correct coefficients;
M2 can only be scored if M1 correct. [2]
Q# 155/ IB Chem/2011/wtz0/Paper 2 Section B/Standard Level/

(d) (i) \( \left( \frac{2 \times 1.01}{18.02} \right) (0.089) = 1.0 \times 10^{-2} \text{ g H} \text{ and } \left( \frac{12.01}{44.01} \right) (0.872) = 2.38 \times 10^{-1} \text{ g C}; \)
\[ \left( \frac{0.238}{1.30} \right) (100) = 18.3\% \text{ C}; \]
\[ \left( \frac{1.0 \times 10^{-2}}{1.30} \right) (100) = 0.77\% \text{ H}; \]

Award [3] for correct final answer of 18.3 % C and 0.77 % H without working.
Allow whole numbers for molar masses.

(ii) \( \left( \frac{1.75}{143.32} \right) (35.45) = 0.433 \text{ g (Cl)} \text{ and } \left( \frac{0.433}{0.535} \right) (100) = 80.9\% \text{ (Cl)}; \)

Allow whole numbers for molar masses.

(iii) \( \left( \frac{18.3}{12.01} \right) = 1.52 \text{ mol C and } \left( \frac{0.77}{1.01} \right) = 0.76 \text{ mol H and } \left( \frac{80.9}{35.45} \right) = 2.28 \text{ mol Cl}; \)

Allow whole numbers for atomic masses.

Empirical formula = C₂HCl₃;
Award [2] for correct empirical formula without working.

\[ M_r = (24.02 + 1.01 + 106.35) = 131.38 \text{, so molecular formula is } C_2HCl_3; \]
Award [3] for correct final answer without working.
Allow whole numbers for atomic masses.

Q# 11/ IB Chem/2011wQ1

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

(ii) \( n = (65.0 / 65.02) = 1.00 \text{ (mol)}; \)

No penalty for using whole number atomic masses.

(iii) \( n(N_2) = \left( \frac{3}{2} \times 1.00 \right) = 1.50 \text{ (mol)}; \)
\[ T = (25.00 + 273.15) = 298.15 \text{ K} / (25.00 + 273) = 298 \text{ K}; \]
\[ p = 1.08 \times 10^5 \text{ Pa} / 1.08 \times 1.01 \times 10^5 \text{ kPa} / 1.09 \times 10^5 \text{ Pa} / 1.09 \times 10^5 \text{ kPa}; \]
\[ V = \frac{nRT}{p} = \left( \frac{(10^5)(1.50)(8.31)(298.15 / 298) }{ (1.08 \times 1.01 \times 10^5) } \right) = 34.1 \text{ (dm}^3); \]

Award [4] for correct final answer.
Award [3 max] for 0.0341 (dm³) or 22.7 (dm³).
Award [3 max] for 34.1 (dm³).
Award [2 max] for 22.9 (dm³).
Award [2 max] for 0.0227 (dm³).
Award [2 max] for 0.034 (dm³).
Q# 12/ IB Chem/2008/w/TZ0/Paper 2 Section A/Standard Level/

1. (a) (i) gas/carbon dioxide/CO₂ is given off/evolves/escapes/formed; [1]

(ii) \( n(\text{CaCO}_3) = \frac{5.00}{100.09} = 0.0500 \); [2]
\( n(\text{HCl}) = \frac{1.00 \times 50.0}{1000} = 0.0500 \);

Do not penalize significant figures.
No penalty for using 100 instead of 100.09.

(iii) \( \text{CaCO}_3 \) (because twice as much acid needed / OWTE); [1]
Allow HCl is limiting.
Allow HCl in excess as correct deduction from wrong values in (a)(ii).

Q# 13/ IB Chem/2008/s/TZ1/Paper 2 Section A/Standard Level/

1. (a) \( \text{CaCl}_2 + 2\text{AgNO}_3 \rightarrow 2\text{AgCl} + \text{Ca(NO}_3)_2 \); [2]
 Allow a correct ionic equation
Award [1] for correct reactants and products and [1] for balanced equation.

(b) \( 0.100 \times 0.0385 \text{ dm}^3; \)
\( = 3.85 \times 10^{-3} \text{ mol}; \) [2]

(c) \( 1.92 \times 10^{-3} \text{ mol} / 1.93 \times 10^{-3} \text{ mol}; \)
\( 1.92 \times 10^{-3} \times 110.98 / 111; \)
\( = 0.214 / 0.213 \text{ (g)}; \) [3]

(d) \( \frac{0.214}{0.265} \times 100 = \frac{0.213}{0.265} \times 100 = 80.7 / 80.8 / 80.4(\%); \) [1]

Allow ECF throughout question one.

Q# 14/ IB Chem/2007/w/TZ0/Paper 2 Section A/Standard Level/

1. (a) \( M(\text{BaSO}_4) = (-137.34 + 32.06 + 4(16.00)) = 233.40(\text{g/mol}^{-1}); \)
\( n(\text{BaSO}_4) = \frac{0.672 \text{ g}}{235.40 \text{ g/mol}^{-1}} = 0.00288 / 2.88 \times 10^{-3} \text{ (mol)}; \) [2]
ECF from \( M \) value

(b) \( n(\text{alkali metal sulfate}) = 0.00288 / 2.88 \times 10^{-3} \text{ (mol)}; \) [1]
ECF

(c) \( M = \left( \frac{m}{n} - \frac{0.502 \text{ g}}{0.00288 \text{ mol}} \right) 174.31 / 174.3 / 174; \)
ECF units: g mol⁻¹; [2]

(d) \( (2A_1 + 32 + 4(16) = 174, \text{ thus}) A_1 = 39 / A_1 = \frac{174 - (32 + (4 \times 16))}{2} = 39; \)
Accept answer between 39 and 39.16
ECF
potassium / K;
ECF from \( A_1 \) value [2]

(e) \( \text{K}_2\text{SO}_4(\text{aq}) + \text{BaCl}_2(\text{aq}) \rightarrow \text{BaSO}_4(s) + 2\text{KCl(}aq); \)
Award [1] for balanced equation and [1] for state symbols
ECF if another alkali metal arrived at in (d)
Accept net ionic equation
If no answer arrived at in (d), but correct equation given involving any alkali metal, then award [1 max].
4. Magnesium is a group 2 metal which exists as a number of isotopes and forms many compounds.

(a) State the nuclear symbol notation, \( ^{26}_{12}X \), for magnesium-26.  

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

<table>
<thead>
<tr>
<th></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.

(d) (i) State the condensed electron configuration of sulfur.  

(ii) Deduce the orbital diagram of sulfur, showing all the orbitals present in the diagram.
Chem 2 Q# 3/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q4(c)

(ii) State the structure of the nucleus and the orbital diagram of $^{13}\text{C}$ in its ground state. [2]

<table>
<thead>
<tr>
<th>No. protons</th>
<th>No. neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Orbital diagram:

- 1s
- 2s
- 2p

(d) Draw a 1s atomic orbital and a 2p atomic orbital. [1]

1s:

2p:

Chem 2 Q# 4/ IB Chem/2013/s/tz1/Paper 2 Section B/Standard Level/

6. The element boron has two naturally occurring isotopes, $^{10}\text{B}$ and $^{11}\text{B}$.

(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]
(ii) Deduce the number of protons, neutrons and the electron arrangement of the main ion of $^{11}$B formed in stage Q. \[2\]

| Protons: | ................................. |
| Neutrons: | ................................. |
| Electron arrangement: | ................................. |

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

---

4. 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) Define the terms atomic number, mass number and isotopes of an element. \[3\]

| Atomic number: | ................................. |
| Mass number: | ................................. |
| Isotopes of an element: | ................................. |
(iii) Deduce the electron arrangements of the lithium ion, Li$^+$, and the boron atom, B.  

Li$^+$: .................................................................

B: .................................................................

(iv) Naturally occurring boron exists as two isotopes with mass numbers of 10 and 11. Calculate the percentage abundance of the lighter isotope, using this information and the relative atomic mass of boron in Table 5 of the Data Booklet.

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

(v) 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>
(b) Every element has its own unique line emission spectrum.

(i) Distinguish between a *continuous spectrum* and a *line spectrum*. [2]

(ii) Draw a diagram to show the electron transitions between energy levels in a hydrogen atom that are responsible for the two series of lines in the ultraviolet and visible regions of the spectrum. Label your diagram to show three transitions for each series. [4]

(f) Silicon has three stable isotopes, $^{28}\text{Si}$, $^{29}\text{Si}$ and $^{30}\text{Si}$. The heaviest isotope, $^{30}\text{Si}$, has a percentage abundance of 3.1%. Calculate the percentage abundance of the lightest isotope to one decimal place. [2]

(g) Identify a radioactive isotope of carbon and state one of its uses. [1]
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>$^{59}\text{Co}^{5+}$</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>33</td>
<td>72</td>
</tr>
<tr>
<td>Number of electrons</td>
<td>27</td>
<td>53</td>
</tr>
</tbody>
</table>

(b) State why the Co-60 radioisotope is used in radiotherapy. [1]

............................................................................................................................
............................................................................................................................
............................................................................................................................
Chem 2 Q# 8/ IB Chem/2011/s/TZ1/Paper 2 Section A/Standard Level/

2. (a) Explain why the relative atomic mass of argon is greater than the relative atomic mass of potassium, even though the atomic number of potassium is greater than the atomic number of argon. \[1\]

(b) Deduce the numbers of protons and electrons in the K\(^+\) ion. \[1\]

(c) Deduce the electron arrangement for the K\(^+\) ion. \[1\]
3. Iron has three main naturally occurring isotopes which can be investigated using a mass spectrometer.

(a) The first stage in the operation of the mass spectrometer is vaporization. The iron is then ionized.

(i) Explain why the iron is ionized. \[2\]

(ii) Explain why a very low pressure is maintained inside the mass spectrometer. \[1\]

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

<table>
<thead>
<tr>
<th>Isotope</th>
<th>(^{54}\text{Fe})</th>
<th>(^{56}\text{Fe})</th>
<th>(^{57}\text{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. \[2\]

(c) Calculate the number of electrons in the ion \(^{56}\text{Fe}^{2+}\). \[1\]

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

(b) Relative atomic masses are obtained using a mass spectrometer. Draw a simple annotated diagram of the mass spectrometer. \[5\]

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

(d) The isotopes of some elements are radioactive. State a radioisotope used in medicine. \[1\]
5. (a) (i) Describe and explain the operation of a mass spectrometer.

(ii) State three factors that affect the degree of deflection of ions in a mass spectrometer.

(iii) Strontium exists as four naturally-occurring isotopes. Calculate the relative atomic mass of strontium to two decimal places from the following data.

<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>

Chem 2 Q# 11/ IB Chem/2009/s/tz1/Paper 2 Section B/Standard Level/

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>$^{82}$Kr</td>
<td>15.80</td>
</tr>
<tr>
<td>$^{84}$Kr</td>
<td>65.40</td>
</tr>
<tr>
<td>$^{86}$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 $^{84}$Kr.

Protons
Neutrons
Electrons
2. (a) In a sample of gallium, the percentage abundance of \( ^{69}\text{Ga} \) is 60.4 and \( ^{71}\text{Ga} \) is 39.6. Determine the relative atomic mass of gallium.

(b) State the electron arrangement of the following species.

(i) A potassium ion

(ii) A sulfide ion

(c) Describe the difference between a continuous spectrum and a line spectrum.
2. Naturally occurring copper has a relative atomic mass \( A_e \) of 63.55 and consists of two isotopes \(^{63}\text{Cu}\) and \(^{65}\text{Cu}\).

(a) Define the term relative atomic mass, \( A_e \). 

(b) State and explain which is the more abundant isotope. 

(c) Describe and explain how the physical and chemical properties of the two isotopes compare.
### Topic 2 Mark Scheme

#### Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q4

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. b</td>
<td>$\alpha_{A} = \frac{24 \times 78.60 + 26 \times 10.11 + 28 \times 11.29}{100}$ ✓</td>
<td>Award 2(2) for correct final answer. Do not accept data booklet value (24.31).</td>
<td>2</td>
</tr>
</tbody>
</table>

#### Q# 2/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q1

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>d ii</td>
<td>$1s^2 \ 2s^2 \ \ 1p^3 \ \ 2p^2 \ 3s^2 \ \ 1s^2 \ 2p^3 \ \ 3p^2$ ✓</td>
<td>Electrons must be given as superscript.</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Q# 3/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q4

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>d ✓</td>
<td>1s$^2$ AND 2p$^5$</td>
<td>Accept p orbitals aligned on y- and z-axes, or diagrams correctly showing all three p-orbitals. Do not accept p-orbitals without a node.</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Q# 4/ IB Chem/2013/s/tz1/Paper 2 Section B/Standard 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; [1]

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

   $^{10}\text{B}: 19\% \text{ and } ^{11}\text{B}: 81\%$; [2]

(b) (i) **R**: acceleration and **S**: deflection; [1]

   (ii) **Protons**: 5 and **Neutrons**: 6;
   Electron arrangement: $2s^2 \ 1s^2 \ 2s^2$;
   Allow suitable diagram. [2]

   (iii) $^{12}\text{C}/\text{carbon-12}$; [1]

#### Q# 5/ IB Chem/2012/w/tz0/Paper 2 Section B/Standard Level/

4. (a) (i) **Atomic number**: number of protons (in nucleus/atom);

   **Mass number**: (sum of) number of protons and neutrons (in nucleus/atom);

   **Isotopes of an element**: atoms of same element / atoms with same number of protons/atomic number/Z but different number of neutrons/mass number/A;

   **Penalize once only use of the term element in the three definitions, for example, number of protons in an element or number of protons and neutrons in an element or element with the same atomic number but different mass number.** [3]
(ii) $Li^+: 2/1s^2$; $B: 2.3/1s^22s^22p^1$; $[2]

(iv) correct mathematical expression set-up (e.g. $\frac{x}{100}(10) + \frac{(100-x)}{(100)}(11) = 10.81$);
19%:
Award [2] for correct final answer. $[2]

(v) Mass number $(A)$ | Number of protons | Number of electrons | Number of neutrons |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
Award [1 mark] for correct number of neutrons for both isotopes if numbers of protons or electrons is not given.
Award [1 mark] for correct number of protons and electrons for both isotopes if number of neutrons is not given or if numbers of neutrons are incorrect. $[2]

(b) (i) Continuous spectrum: radiation spread over all wavelengths/frequencies/energies/colours / OWTTE;
Line spectrum: radiation (absorbed/emitted) at certain/specific wavelengths/frequencies/energies/colours / OWTTE;
Allow series of (separate/discrete) lines which converge/get closer together at high energy / OWTTE. $[2]

(ii) $n = \infty$

\[ n = 3 \]
visible series
\[ n = 2 \]
UV series
\[ n = 1 \]

showing y-axis labelled as energy/E or labelling at least two energy levels $(n = 1, n = 2$ etc. but not for $n = 0$);
showing energy levels converging;
showing jumps to $n = 1$ for ultraviolet series;
showing jumps to $n = 2$ for visible series;
$UV$ and $visible$ must be labelled. $[4]
Q# 6/ IB Chem/2011sq7

(f) \[ 2809 = 3.10 \times 30 + 28x + 29 (96.9 - x) \]
\[
% \text{^{28}Si} = \frac{93 + 2810.1 - 2809}{96.9} = 94.1 \%;
\]
\textit{Award [2] for correct final answer.}

(g) \( ^{14}\text{C} \text{ and } \text{radiocarbon dating/(tracer in) medical/scientific tests}; \)
\( ^{11}\text{C} \text{ and (tracer in) medical/scientific tests}; \)

Q# 7/ IB Chem/2011/w/TZ0/Paper 2 Section A/Standard Level/  

2. (a)\[
\begin{array}{|c|c|c|}
\hline
\text{Symbol} & ^{59}\text{Co}^{2+} & ^{60}\text{Co} \\
\hline
\text{Number of protons} & 27 & 27 \\
\hline
\text{Number of neutrons} & 32 & 33 \\
\hline
\text{Number of electrons} & 24 & 27 \\
\hline
\end{array}
\]
\textit{Award [2] for all four correct.}
\textit{Award [1] for two or three correct.}

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

Q# 8/ IB Chem/2011/s/TZ1/Paper 2 Section A/Standard Level/  

2. (a) \text{argon has a greater proportion of heavier isotopes / OWTTE / argon has a greater number of neutrons;}

(b) \( 19 \text{ protons and 18 electrons; } \)

(c) \( 2, 8, 8; \)
\textit{Accept 1s^2 2s^2 2p^6 3s^2 3p^6.}

Q# 9/ IB Chem/2010/w/TZ0/Paper 2 Section A/Standard Level/  

3. (a) (i) \text{ions/particles accelerated by electric field;}
\text{ions/particles deflected by magnetic field;}
\textit{Award [1 max] for acceleration and deflection of ions without reference to fields.}

(ii) \text{prevents collisions / avoid false readings due to presence of other particles;}

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

(c) \( 24; \)
Q# 10/ IB Chem/2010/s/tz1/Paper 2 Section B/Standard Level/

4. (a) average mass of isotopes of an element compared to (1/12 g of) $^{12}$C / 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.

(b) Diagram of mass spectrometer containing in the correct sequence:  
   vaporization/vaporized sample;  
   ionization/electron gun;  
   acceleration/oppositely charged plates;  
   deflection/magnetic field;  
   detection.  
   Award [1] for correct order for at least 4 correct labels.  
   Award [1] for diagram, which must at least show ionization (e.g. electron beam),  
   acceleration (e.g. charged plates) and deflection (e.g. magnetic field) even if these  
   are incorrectly labelled.

(c) $63x + 65(1–x) = 63.55$:  
   (or some other mathematical expression).

   $^{65}$Cu = 72.5 % and $^{63}$Cu = 27.5 %;  
   Allow $^{63}$Cu = 0.725 and $^{65}$Cu = 0.275.  
   Award [2] for correct final answer.

(d) $^{60}$Co/$^{131}$I/$^{125}$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.

Q# 11/ IB Chem/2009/s/tz1/Paper 2 Section B/Standard Level/

5. (a) (i) a vaporized sample must be used;  
   bombarded with (high energy) electrons to form positive ions;  
   accelerated by passing through an electric field;  
   deflected by passing through a magnetic field;  
   detected by producing a current;  
   Award [2 max] if just the words vaporization, ionization, acceleration,  
   deflection and detection are used with no explanation.

(ii) (size of the positive) charge (on the ion);  
   mass (of the ion);  
   strength of the magnetic field;  
   velocity/speed (of the ions) / strength of electric field;  
   $m/z$ scores the first two marking points.  
   Award [3 max]

(iii) $A_r = \frac{[(0.56 \times 84) + (9.90 \times 86) + (7.00 \times 87) + (82.54 \times 88)]}{100}$  
   = 87.71 ;  
   Award [1 max] if answer not given to two decimal places.  
   Award [2] for correct final answer.  
   Apply –1(U) if answer quoted in g or g mol$^{-1}$.  
   Award [2] for correct final answer.  
   Apply –1(U) if answer quoted in g or g mol$^{-1}$. 

Patrick Brannac  
www.SmashingScience.org
Q# 12/ IB Chem/2008/w/TZ0/Paper 2 Section A/Standard 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. 
   (but) different numbers of neutrons/mass number/A; 
   
   (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; 
   
Q# 13/ IB Chem/2008/s/TZ1/Paper 2 Section A/Standard Level/

2. (a) \(\frac{0.69 \times 0.4}{100} + \frac{1 \times 39.6}{100}\); 
   69.8; 
   
   (b) (i) Potassium ion 2.8.8; 
   (ii) Sulfide ion 2.8.8; 
   Allow electron configuration in terms of spdf. 
   
   (c) (continuous spectrum) has all colours/wavelengths/frequencies; 
   (line spectrum) has only lines of specific colours/wavelengths/frequencies; has some colours missing; 
   
Q# 14/ IB Chem/2007/w/TZ0/Paper 2 Section A/Standard Level/

2. (a) ratio of average mass of an atom to \(\frac{1}{12}\) the mass of C-12 isotope / average 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 in place of ‘atom’ 
   
   (b) \(^{63}\)Cu (more abundant) since \(A_e\) (Cu) is closer in mass to 63; 
   Explanation needed for mark 
   
   (c) different physical properties/melting points/boiling points/density/reaction rate/mass; 
   due to different masses/more neutrons/nucleons; 
   same/similar chemical properties/reactivity; 
   due to same arrangement of valence electrons; 
   
Topic 3

Chem 3 Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q4

(c) Magnesium burns in air to form a white compound, magnesium oxide. Formulate an equation for the reaction of magnesium oxide with water. [1]

(d) Describe the trend in acid-base properties of the oxides of period 3, sodium to chlorine. [2]

(e) In addition to magnesium oxide, magnesium forms another compound when burned in air. Suggest the formula of this compound. [1]

Chem 3 Q# 2/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q2(a)

(ix) Other compounds present in acid rain are formed from nitrogen dioxide, NO₂. Formulate an equation for the reaction of nitrogen dioxide with water. [1]

Chem 3 Q# 3/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q2

2. Impurities cause phosphine to ignite spontaneously in air to form an oxide of phosphorus and water.

(b) (i) State the equation for the reaction of this oxide of phosphorus with water. [1]
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. [3]

(b) A student formulates the following hypothesis: “If phosphorus were to form a positive ion, $P^{+}$, its ionic radius would probably be between $110 \times 10^{-12}$ m and $212 \times 10^{-12}$ m.” Evaluate this hypothesis. [2]

(ii) Distinguish between the terms group and period. [1]
Chem 3 Q# 6/ IB Chem/2012/s/tz1/Paper 2 Section B/Standard Level/q6f

(iii) The reactions between the halogens and water show that fluorine is more reactive than bromine. Explain why, on an atomic level, fluorine is the more reactive element. [3]

Chem 3 Q# 7/ IB Chem/2011/w/tz0/Paper 2 Section B/Standard Level/q5

(b) 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. [4]
7. Carbon and silicon belong to the same group of the periodic table.

(a) Distinguish between the terms *group* and *period* in terms of electron arrangement.

(b) State the period numbers of both carbon and silicon.

5. (a) (i) Define the term *first ionization energy*.

(ii) Explain why the first ionization energy of magnesium is higher than that of sodium.
(b) Explain why:

(i) calcium has a higher melting point than potassium. \[2\]

(ii) sodium oxide has a higher melting point than sulfur trioxide. \[3\]

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

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

(g) Describe and explain what you will see if chlorine gas is bubbled through a solution of

(i) potassium iodide. \[2\]
(ii) potassium fluoride. \[1\]

(h) Explain why the melting points of the elements decrease down group 1 and increase down group 7. \[4\]
(b) The graph of the first ionization energy plotted against atomic number for the first twenty elements shows periodicity.

![Graph of first ionization energy vs. atomic number](image)

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

(ii) State the electron arrangement of argon and explain why the noble gases, helium, neon and argon show the highest first ionization energies for their respective periods.

(iii) A graph of atomic radius plotted against atomic number shows that the atomic radius decreases across a period. Explain why chlorine has a smaller atomic radius than sodium.

(iv) Explain why a sulfide ion, $S^{2-}$, is larger than a chloride ion, $Cl^{-}$.

(v) Explain why the melting points of the Group 1 metals ($Li \rightarrow Cs$) decrease down the group whereas the melting points of the Group 7 elements ($F \rightarrow I$) increase down the group.

(c) The oxides of magnesium, aluminium and phosphorus illustrate the change in nature of elements from metallic to non-metallic. Each of the three oxides is mixed with separate samples of pure water. For each of the oxides, state whether the resulting solution is acidic, basic or neutral. Write an equation for each reaction that occurs.
2. (a) State the meaning of the term electronegativity. [1]

(b) State and explain the trend in electronegativity across period 3 from Na to Cl. [2]

(c) Explain why Cl₂ rather than Br₂ would react more vigorously with a solution of I⁻. [2]

---

**Topic 3 Mark Scheme**

**Q# 1**/IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q4

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4.</td>
<td>c</td>
<td>MgO(s) + H₂O(l) → MgOH₂(s) OR MgO(s) + H₂O(l) → Mg²⁺(aq) + 2OH⁻(aq)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Correct answer.</td>
</tr>
<tr>
<td>4.</td>
<td>d</td>
<td>from basic to acidic ☑ through amphoteric ☑</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Accept “alkali/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 Mg₂. Do not accept just “become more acidic”.</td>
</tr>
<tr>
<td>4.</td>
<td>e</td>
<td>Mg₅N₂ ☑</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Accept MgO₂, Mg(OH)₂, Mg(NO₃)₂, MgCO₃.</td>
</tr>
</tbody>
</table>

**Q# 2**/IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q2

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2.</td>
<td>a</td>
<td>2NO₂(g) + H₂O(l) → HNO₃(aq) + HNO₂(aq) ☑</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ignore state symbols.</td>
</tr>
</tbody>
</table>

**Q# 3**/IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q2

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2.</td>
<td>b</td>
<td>P₂O₅(s) + 5H₂O(l) → 2H₃PO₄(aq) ☑</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Accept P₂O₅(s) + 2H₂O(l) → 4H₃PO₄(aq) (initial reaction). Accept P₂O₅(s) + 4H₂O(l) → 2H₃PO₄(aq). Accept equations for P₂O₅/P₂O₄ if given in a (ii). Accept any ionized form of the acids as the products.</td>
</tr>
</tbody>
</table>

**Q# 4**/IB Chem/2013/s/TZ1/Paper 2 Section A/Standard Level/

2. (a) decreases (from left to right across period 3):
   - same number of shells/energy levels / shielding effect remains the same;
   - number of protons/nuclear charge increases so attraction of nucleus on outer electrons increases / **OWTE**; [3]

(b) hypothesis is wrong since ionic radius should be smaller than atomic radius/110×10⁻¹² m;
   - greater attraction of the nucleus on outer electrons / effective charge of nucleus greater / repulsive forces between electrons smaller; [2]
Q# 5 / IB Chem/2012/w/tz0/Paper 2 Section B/Standard Level/q4a

(ii) **Group**: (elements in vertical) columns in periodic table and **Period**: (elements in horizontal) rows in periodic table;

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 / OWTE.

Allow group number gives number of valence/outer shell electrons (for main-group elements) and period gives same number of shells/energy levels.

Q# 6 / IB Chem/2012/s/tz1/Paper 2 Section B/Standard Level/q6f

(iii) fluorine accepts/attracts electrons more readily/strongly / is a better oxidizing agent;

fluorine has smaller atomic radius/fewer energy levels/shells;

*Do not allow fluorine atom smaller.*

so nucleus attracts electrons more strongly; **[3]**

Allow opposite argument for bromine.

Q# 7 / IB Chem/2011/w/tz0/Paper 2 Section B/Standard Level/q5

(b) **Na, Mg**: basic

**Al**: amphoteric

*Do not accept amphotropic.*

**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.

\[
\text{Na}_2\text{O}(s) + \text{H}_2\text{O}(l) \rightarrow 2\text{NaOH}(aq); \\
\text{P}_2\text{O}_{10}(s) + 6\text{H}_2\text{O}(l) \rightarrow 4\text{H}_3\text{PO}_4(aq); \\
\]

*Ignore state symbols.*

*Allow \(\text{P}_2\text{O}_6(s) + 3\text{H}_2\text{O}(l) \rightarrow 2\text{H}_3\text{PO}_4(aq)\).*

Q# 8 / IB Chem/2011/s/tz1/Paper 2 Section B/Standard Level/q8

7. (a) **Group**: number of outer shell/valence electrons;

**Period**: number of occupied (electron) shells; **[2]**

(b) C: 2 and Si: 3; **[1]**
Q# 9/ IB Chem/2011/s/tz1/Paper 2 Section B/Standard Level/

5. (a) (i) the amount of energy required to remove one (mole of) electron(s);
from (one mole of) an atom(s) in the gaseous state;

(ii) greater positive charge on nucleus / greater number of protons / greater core
charge;
greater attraction by Mg nucleus for electrons (in the same shell) / smaller
atomic radius;

(b) (i) calcium ionic charge is twice/greater than the potassium ionic charge / calcium
has more delocalized electrons than potassium;
greater attraction of delocalized electrons and Ca^{2+} / less attraction between the
delocalized electrons and K^+;

Do not accept calcium ion has a Z^- without comparison to K^+.

(ii) Na^+O ionic/stronger electrostatic) attractions between Na^+ and O^{2-};
SO_3 has (weak) intermolecular/van der Waals'/London/dispersion/dipole-
dipole attractions;
intermolecular/van der Waals'/London/dispersion/dipole-dipole forces are weaker/more easily broken than (strong) ionic bonds / ionic bonds are
stronger/harder to break than intermolecular bond/van der Waals'/London/dispersion/dipole-dipole forces;

Q# 10/ IB Chem/2010/s/tz1/Paper 2 Section B/Standard Level/q4

e) 2Na(s) + 2H_2O(l) → 2NaOH(aq) + H_2(g) / Na(s) + H_2O(l) → NaOH(aq) + ½ H_2(g)  

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.

(f) (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.
Allow [1 max] for electron arrangements of Na (e.g. 2,8,1) and Rb if second mark is
not scored.

(g) (i) solution becomes yellow/orange/brown/darker;
chlorine is more reactive than iodine (and displaces it from solution) / OWTTE;
Allow correct equation (2KI + Cl_2 → 2KCl + I_2) for second mark or stating
that iodine/I_2 is formed.

(ii) no colour change/nothing happens as fluorine is more reactive than chlorine / 

OWTTE;

(h) Down group 1:
metallic bonding gets weaker;
radii/atoms get bigger / delocalized electrons shielded/screened from nucleus by
filled shells;

Down group 7:
increased M_r of halogen molecules / OWTTE;
intermolecular/van der Waals/London/dispersion forces increase;
Q# 11/ IB Chem/2009/s/tz1/Paper 2 Section B/Standard Level/q5

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

(ii) \(2.8.8/\text{sp version;}

\emph{Accept any two of the following;}
the outer energy level/shell is full;
the increased charge on the nucleus;
great(est) attraction for electrons; \[3 \text{ max} \]

(iii) \(17 \text{ p in Cl nucleus attract the outer level more than 11 p in Na nucleus} / \text{greater nuclear charge attracts outer level more;}

\emph{Allow converse for Na.}
\emph{Do not accept larger nucleus.} \[1\]

(iv) \(S^2-\) has one proton less / \emph{smaller nuclear charge so outer level held less strongly} / \emph{OWTTE;}

\emph{Allow converse for chloride.}
\emph{Do not accept larger nucleus.} \[1\]

(v) the radii of the metal atoms increase (from Li \rightarrow Cs) (so the forces of attraction are less between them) / \emph{OWTTE;}
the forces of attraction between halogen molecules are van der Waals;
forces increase with increasing mass/number of electrons; \[3\]

Q# 12/ IB Chem/2008/s/tz1/Paper 2 Section B/Standard Level/q6

(c) \((\text{MgO}) \text{ basic and (P}_4\text{O}_6 / P_2\text{O}_5 \) \text{ acidic;}
\((\text{Al}_2\text{O}_3) \text{ neutral;}

\emph{Formulas not required but it must be clear which oxide is being referred to}

\[
\begin{align*}
\text{MgO} + \text{H}_2\text{O} & \rightarrow \text{Mg(OH)}_2; \\
\text{P}_4\text{O}_{10} + 6\text{H}_2\text{O} & \rightarrow 4\text{H}_3\text{PO}_4;
\end{align*}
\][4]

\emph{Accept suitable equation with P}_4\text{O}_6 / P_2\text{O}_5 / P_2\text{O}_3.

Q# 13/ IB Chem/2007/s/TZ1/Paper 2 Section A/Standard Level/

2. (a) the ability of an element/atom/nucleus to attract a \emph{bonding} pair of electrons; \[1\]

(b) electronegativity increases (along period 3 from Na to Cl); number of protons increases / nuclear charge increases / core charge increases / size of atoms decreases;
\emph{Do not accept greater nuclear attraction.} \[2\]

(c) \(Cl_2\) is a stronger oxidizing agent / Chlorine’s outer shell closer to nucleus; \(Cl_2\) has greater attraction for electrons / has a higher electron affinity;
\emph{Accept converse argument for Br}_2. \[2\]
Topic 4
Chem 4 Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q4

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

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

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).

(d) The Lewis (electron dot) structure of the ethanedioate ion is shown below.

\[
\begin{array}{c}
\text{C} \\
\text{O} \\
\end{array}
\begin{array}{c}
\text{C} \\
\text{O} \\
\end{array}
\text{O}^{2-}
\]

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]

Chem 4 Q# 3/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q1

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.

\[2\text{CO(g)} + 3\text{H}_2(g) \rightleftharpoons \text{HOCH}_2\text{CH}_2\text{OH(g)}\]

Ethene has the structural formula of CH₂CH₂

(c) Explain why the boiling point of ethane-1,2-diol is significantly greater than that of ethene. [2]
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:

\[
\begin{align*}
\text{HO}^\bullet(g) + \text{SO}_2(g) &\rightarrow \text{HOSO}_2(g) \\
\text{HOSO}_2(g) + \text{O}_2(g) &\rightarrow \text{HOOC}^\bullet(g) + \text{SO}_3(g) \\
\text{SO}_3(g) + \text{H}_2\text{O}(l) &\rightarrow \text{H}_2\text{SO}_4(aq)
\end{align*}
\]

(a) (ii) Draw one valid Lewis (electron dot) structure for each molecule below. [2]

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Lewis (electron dot) structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂</td>
<td></td>
</tr>
<tr>
<td>H₂O</td>
<td></td>
</tr>
</tbody>
</table>

(iii) Deduce the name of the electron domain geometry and the molecular geometry for each molecule. [2]

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Electron domain geometry</th>
<th>Molecular geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>H₂O</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

(iv) Deduce the bond angles in SO₂ and H₂O. [1]

SO₂:

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

H₂O:

..........................................................
1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula PH₃.

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

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

(iii) Explain why the phosphine molecule is not planar. [2]

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

\[ P_4(s) + 3\text{OH}^- (aq) + 3\text{H}_2\text{O} (l) \rightarrow \text{PH}_3 (g) + 3\text{H}_2\text{PO}_2^- (aq) \]

(i) Identify one other element that has allotropes and list two of its allotropes.

<table>
<thead>
<tr>
<th>Element:</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlIotrope 1:</td>
</tr>
<tr>
<td>AlIotrope 2:</td>
</tr>
</tbody>
</table>

(ii) The first reagent is written as \( P_4 \), not \( 4P \). Describe the difference between \( P_4 \) and \( 4P \).

Chem 4 Q# 6/ IB Chem/2012wQ1

(b) Although the molar masses of ICl and Br\(_2\) are very similar, the boiling point of ICl is 97.4 °C and that of Br\(_2\) is 58.8 °C. Explain the difference in these boiling points in terms of the intermolecular forces present in each liquid.
Chem 4 Q# 7/ IB Chem/2012/w/tz0/Paper 2 Section B/Standard Level/q5b

(ii) The Lewis (electron dot) structure of nitrous acid is given below.

\[
\text{H} \quad \text{O} \quad \overset{\cdot}{} \quad \text{N} \quad \overset{\cdot}{\cdot}
\]

Identify which nitrogen-oxygen bond is the shorter.

[1]

(iii) Deduce the approximate value of the hydrogen-oxygen-nitrogen bond angle in nitrous acid and explain your answer.

[2]

(v) Ammonia, \( \text{NH}_3 \), is a weak base. Deduce the Lewis (electron dot) structure of \( \text{NH}_3 \). State the name of the shape of the molecule and explain why \( \text{NH}_3 \) is a polar molecule.

[3]
(c) (i) Explain why metals are good conductors of electricity and why they are malleable. \[2\]

(ii) Iron is described as a transition metal. Identify the two most common ions of iron. \[1\]

(iii) Deduce the chemical formulas of lithium oxide and iron(II) oxide. \[1\]

Lithium oxide:

Iron(II) oxide:
5. Ethane, \(\text{C}_2\text{H}_6\), and disilane, \(\text{Si}_2\text{H}_6\), are both hydrides of group 4 elements with similar structures but with different chemical properties.

(a) (i) Deduce the Lewis (electron dot) structure for \(\text{Si}_2\text{H}_6\) showing all valence electrons. \([1]\)

(ii) State and explain the \(\text{H-Si-H}\) bond angle in \(\text{Si}_2\text{H}_6\). \([2]\)

(iii) State which of the bonds, \(\text{Si-H}\) or \(\text{C-H}\), is more polar. Explain your choice. \([2]\)
(iv) Predict, with an explanation, the polarity of the two molecules.

(v) Explain why disilane has a higher boiling point than ethane.

(ii) Compare the structure and bonding in carbon dioxide and silicon dioxide.
Phosphorus tribromide (PBr₃) is used to manufacture alprazolam, a drug used to treat anxiety disorders. Methanal (HCHO) is used as a disinfectant.

(i) For each of the species PBr₃ and HCHO:
   - deduce the Lewis structure.
   - predict the shape and bond angle.

<table>
<thead>
<tr>
<th>PBr₃</th>
<th>HCHO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lewis structure:</td>
<td>Lewis structure:</td>
</tr>
<tr>
<td>Shape:</td>
<td>Shape:</td>
</tr>
<tr>
<td>Bond angle:</td>
<td>Bond angle:</td>
</tr>
</tbody>
</table>

(ii) Explain why PBr₃ is a polar molecule.
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.likelairbag.net](image)

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]
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. [1]

(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. [2]
(c) Describe and compare three features of the structure and bonding in the three allotropes of carbon: diamond, graphite and C₆₀ fullerene.
(d) Both silicon and carbon form oxides.

(i) Draw the Lewis structure of CO$_2$ and predict its shape and bond angle.  

(ii) Describe the structure and bonding in SiO$_2$.  

(iii) 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. [2]

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Chem 4 Q# 14/ IB Chem/2010/Q3

(d) Describe the bonding in iron and explain the electrical conductivity and malleability of the metal. [4]

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Chem 4 Q# 15/ IB Chem/2010/Q3

(ii) Predict the value of the H–N–H bond angle in N$_2$H$_6^{2-}$. [1]

Chem 4 Q# 16/ IB Chem/2010/Q3

4. Ethene, C$_2$H$_4$, and hydrazine, N$_2$H$_4$, are hydrides of adjacent elements in the periodic table.

(a) (i) Draw Lewis (electron dot) structures for C$_2$H$_4$ and N$_2$H$_4$ showing all valence electrons. [2]


(b) The polarity of a molecule can be explained in terms of electronegativity.

(i) Define the term electronegativity. [2]

(ii) Compare the relative polarities of the C–H bond in ethene and the N–H bond in hydrazine. [1]

(iii) Hydrazine is a polar molecule and ethene is non-polar. Explain why ethene is non-polar. [1]

(c) 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]
2. \( \text{PF}_3, \text{SF}_2 \) and \( \text{SiF}_4 \) have different shapes. Draw their Lewis structures and use the VSEPR theory to predict the name of the shape of each molecule.

<table>
<thead>
<tr>
<th></th>
<th>( \text{PF}_3 )</th>
<th>( \text{SF}_2 )</th>
<th>( \text{SiF}_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lewis structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name of shape</td>
<td>..................</td>
<td>..................</td>
<td>..................</td>
</tr>
</tbody>
</table>

6. (a) (i) Draw the Lewis structures for carbon monoxide, \( \text{CO} \), carbon dioxide, \( \text{CO}_2 \) and methanol, \( \text{CH}_3\text{OH} \).

(ii) List, with an explanation, the three compounds in order of increasing carbon to oxygen bond length (shortest first).

(b) Predict the shape and bond angles for the following species:

(i) \( \text{CO}_2 \)

(ii) \( \text{CO}_3^{2-} \)

(iii) \( \text{BF}_4^{-} \)

3. Sodium oxide, \( \text{Na}_2\text{O} \), is a white solid with a high melting point.

(a) Explain why solid sodium oxide is a non-conductor of electricity.

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

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

.................................................................
3. (a) Three types of covalent bond (single, double and triple) are present in the molecules in the following equation.

\[ 2\text{C}_2\text{H}_2(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 4\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \]

(i) Identify one bond in these molecules that is correctly described by the following. \([4]\)

- A polar single bond
- A polar double bond
- A non-polar double bond
- A non-polar triple bond

(ii) Identify the shortest bond in these molecules. \([1]\)

(c) Complete the table to show the Lewis structure of each ion and the name of the shape of each ion.

<table>
<thead>
<tr>
<th>Lewis structure</th>
<th>NH$_4^+$</th>
<th>H$_3$O$^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of shape</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Topic 4 Mark Scheme

#### Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q4

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4.</td>
<td>f</td>
<td>3-Diplanar regularly repeating arrangement «of ions» OR lattice «of ions» ✓</td>
<td>Electrostatic attraction between oppositely charged ions OR electrostatic attraction between Mg²⁺ and O²⁻ ions ✓</td>
<td>Accept “diplanar” but “lattice” not stated. Do not accept “ionic” without description.</td>
<td>2</td>
</tr>
</tbody>
</table>

#### Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q2

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. d</td>
<td>electrons delocalized “across the O–O–O system” OR resonance occurs ✓</td>
<td>Accept delocalized π-bond(s). Accept any answer in the range 123 pm to 142 pm. Accept “bond intermediate between single and double bond” or “bond order 1.5”</td>
<td>2</td>
</tr>
</tbody>
</table>

#### Q# 3/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q1

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. c</td>
<td>ethane-1,2-diol can hydrogen bond to other molecules «and ethene cannot» OR ethane-1,2-diol has «significantly» greater van der Waals forces ✓</td>
<td>Accept converse arguments. Award 0 if answer implies covalent bonds are broken</td>
<td>2</td>
</tr>
</tbody>
</table>

#### Q# 4/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q2

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>i</td>
<td>SO₂</td>
<td>Lewis (electron dot) structure</td>
<td>Linear, x’s or dots may be used to represent electron pairs.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H₂O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>ii</td>
<td>Molecule</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SO₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>H₂O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a</td>
<td>iii</td>
<td></td>
<td>Electron domain geometry</td>
<td>Molecular geometry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SO₂</td>
<td>trigonal/triangular planar</td>
<td>bent/«shaped/angular» ✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H₂O</td>
<td>tetrahedral</td>
<td>bent/«shaped/angular» ✓</td>
</tr>
<tr>
<td>a</td>
<td>iv</td>
<td>SO₂</td>
<td>Accept any angle in the range greater than 115° but less than 120°.</td>
<td>Experimental value is 119°</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H₂O</td>
<td>104.5° ✓</td>
<td></td>
</tr>
</tbody>
</table>

---

Patrick Brannac  
Q# 5/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q1

<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>![Bond Structure]</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>non-polar AND P and H have the same electronegativity</td>
<td>Accept “similar electronegativities” Accept “polar” if there is a small difference in electronegativity and apply ECF in 1 a (iv).</td>
<td>1</td>
</tr>
<tr>
<td>1. a iii</td>
<td>4 electron domains/pairs/negative charge centres around the central atom OR a lone/non-bonding pair and three bonding pairs around the central atom OR repulsion between electron domains/pairs/negative charge centres produces non-planar shapes OR repulsion causes tetrahedral orientation/pyramidal shape</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>1. a iv</td>
<td>PH₃ has London dispersion forces</td>
<td>Accept van der Waals forces, dispersion forces and instantaneous dipoles – induced dipole forces, Accept “dipole–dipole forces” 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. Accept “dipole–dipole forces are weaker”.</td>
<td>2 max</td>
</tr>
</tbody>
</table>

Q# 6/ IB Chem/2012/wQ1

1. b i | Element carbon/C OR oxygen/O₂ | Allotropes 
- diamond 
- graphite 
- graphene 
- C₆₀ / buckminsterfullerene | Accept two correctly named allotropes of any other named element (S, Se, Sn, As, etc.). | 2 |
| 1. b ii | P₄ is a molecule comprising 4P atoms AND 4P is four/separate e⁻ atoms OR P₄ represents 4e⁻ atoms bonded together AND 4P represents e⁻ separate/non-bonded e⁻ atoms | | 1 |

(b) Br₂ 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 Br₂ 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.

Q# 7/ IB Chem/2012/w/tz0/Paper 2 Section B/Standard Level/q5b

(iii) accept any value in range 102 – 105°; Actual value is 102°.

lone/non-bonding pairs on oxygen occupy more space/repel more than bonding pairs hence decreasing the H–O–N bond angle (from 109.5°) / OWITE.
(v) \[
\begin{array}{c}
\text{H} \\
\text{N} \\
\text{H}
\end{array}
\]

Accept any combination of lines, dots or crosses to represent electron pairs.

trigonal/triangular pyramidal;
Accept pyramidal \(\text{since SL}\).
Do not allow tetrahedral.

net dipole moment present in molecule / NH bond polarities do not cancel each other out / unsymmetrical distribution of charge /OWTTE;
\[3\]
Do not accept molecule has no symmetry hence polar.

Q# 8/IB Chem/2012/w/tz0/Paper 2 Section B/Standard Level/q4

(c) (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;
Do not accept nuclei for \(M2\).
\[2\]

(ii) \(\text{Fe}^{2+} \) and \(\text{Fe}^{3+}\);
\[1\]

(iii) \text{Lithium oxide: } \text{Li}_2\text{O} \text{ and Iron(II) oxide: } \text{FeO};
\[1\]

Q# 9/IB Chem/2012/s/tz1/Paper 2 Section B/Standard Level/

5. (a) (i)
\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{Si} \\
\text{Si} \\
\text{H}
\end{array}
\]

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) C–H;
larger difference in electronegativity (for C–H bond) / smaller difference in electronegativity (for Si–H bond) / \(\Delta EN\) (CH) = 0.4 and \(\Delta EN\) (SiH) = 0.3;
\[2\]

(iv) both (molecules) non-polar;
both (molecules) symmetrical / polar bond effects cancel out / OWTTE;
\[2\]

(v) stronger/larger/greater \(\text{van der Waals/London/dispersion forces}\);
Do not accept stronger/larger/greater intermolecular forces.

more electrons / stronger instantaneous dipole;
Do not accept larger mass.
\[2\]
(b) (i) \((-1560 \times 2 =) -3120 \text{ (kJ)}\); 

(ii) Structure:
CO\(_2\) molecular and SiO\(_2\) three-dimensional network/giant lattice/giant covalent/macromolecular/repeating tetrahedral units;
CO\(_2\) linear and SiO\(_2\) tetrahedral;

Intramolecular Bonding:
covalent bonds in CO\(_2\) and SiO\(_2\);
double bonds in CO\(_2\) and single bonds in SiO\(_2\);
Accept diagrams showing bonding types (double and single) within the structures. 

[3 max]

Q# 10/ IB Chem/2011/w/TZ0/Paper 2 Section B/Standard Level/q5

(c) (i) 

<table>
<thead>
<tr>
<th>( \text{PBr}_3 )</th>
<th>( \text{HCOH} )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lewis structure:</strong></td>
<td><strong>Lewis structure:</strong></td>
</tr>
<tr>
<td>( :\text{Br}--\text{P}--\text{Br} : )</td>
<td>( :\text{O}--\text{C}--\text{H} : )</td>
</tr>
<tr>
<td>Allow x's, dots or lines to represent electrons.</td>
<td>Allow x's, dots or lines to represent electrons.</td>
</tr>
<tr>
<td>Penalize missing lone pairs on terminal atoms once only for the two Lewis structures.</td>
<td>Penalize missing lone pairs on terminal atoms once only for the two Lewis structures.</td>
</tr>
<tr>
<td><strong>Shape:</strong></td>
<td><strong>Shape:</strong></td>
</tr>
<tr>
<td>trigonal/triangular pyramidal; Allow pyramidal.</td>
<td>trigonal/triangular planar;</td>
</tr>
<tr>
<td><strong>Bond angle:</strong></td>
<td><strong>Bond angle:</strong></td>
</tr>
<tr>
<td>less than 109.5(^\circ); Allow any angle less than 109.5 but greater than or equal to 100 (experimental value is 101(^\circ)).</td>
<td>120(^\circ);</td>
</tr>
</tbody>
</table>

Do not allow ECF in this question from incorrect Lewis structure.

[6]

(ii) Br more electronegative than P / P–Br bond polar;
bond dipoles do not cancel / there is a net dipole / asymmetric distribution of electron cloud;

\[ \text{Br} \quad \text{Br} \quad \text{Br} \]

Allow polar bonds do not cancel or that it is an asymmetric molecule.
Award [2] for diagram showing net dipole moment as shown.

Q# 11/ IB Chem/2011/w/TZ0/Paper 2 Section A/Standard 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 / OWTTE.

[2]
Q# 12/ IB Chem/2011/wTZ0/Paper 2 Section A/Standard Level/

(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.  

Bonding:  

(giant/network/3D) covalent;  

Q# 13/ IB Chem/2011/s/tz1/Paper 2 Section B/Standard Level/q7

(c) Award [2 max] for three of the following features:

Bonding

Graphite and C_{60} fullerene: covalent bonds and van der Waals/London/dispersion forces;  

Diamond: covalent bonds (and van der Waals/London/dispersion forces);  

Delocalized electrons

Graphite and C_{60} fullerene: delocalized electrons;  

Diamond: no delocalized electrons;

Structure

Diamond: network/giant structure / macromolecular / three-dimensional structure and Graphite: layered structure / two-dimensional structure / planar;  

C_{60} fullerene: consists of molecules / spheres made of atoms arranged in hexagons/pentagons;  

Bond angles

Graphite: 120° and Diamond: 109°;  

C_{60} fullerene: bond angles between 109–120°;  

Allow Graphite: sp^2 and Diamond: sp^3;  

Allow C_{60} fullerene: sp^2 and sp^3.

Number of atoms each carbon is bonded to

Graphite and C_{60} fullerene: each C atom attached to 3 others;  

Diamond: each C atom attached to 4 atoms / tetrahedral arrangement of C (atoms).  

[6 max]
(d) (i) \[ \text{O} = \text{C} = \text{O} \] ;
linear and 180°.
Accept crosses, lines or dots as electron pairs. \[2\]

(ii) network/giant structure / macromolecular;
each Si atom 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.

(iii) Silicon dioxide: strong/covalent bonds in network/giant structure/macromolecule;
Carbon dioxide: weak/van der Waals’/dispersion/London forces between molecules; \[2\]

(e) triple (covalent) bond;
one electron pair donated by oxygen to carbon atom / dative (covalent)/coordinate (covalent) bond;
Award [1 max] for representation of \( \text{C}=\text{O} \);
Award [2] if CO shown with dative covalent bond.

Q# 14/ IB Chem/2010wQ3
(d) metallic (bonding):
positive ions/cations and delocalized/sea of electrons;
electrostatic attraction between the two;
Award [2 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# 15/ IB Chem/2010/w tz0/Paper 2 Section B/Standard Level/q4f
(ii) 109°/109.5°; \[1\]

Q# 16/ IB Chem/2010/w tz0/Paper 2 Section B/Standard Level/
4. (a) (i) \[ \begin{array}{c}
\text{H} \\
\text{C} \\
\text{H} \\
\text{H} \\
\end{array} \]
\[ \begin{array}{c}
\text{N} \\
\text{H} \\
\end{array} \]
Accept x’s, dots or lines for electron pairs.

(ii) \( \text{H}\text{―C―H}: \)
any angle between 118° and 122°;
due to three negative charge centres/electron domains/electron pairs;
\( \text{H}\text{―N―H}: \)
any angle between 104° and 108°;
due to four negative charge centres/electron domains/electron pairs;
extra repulsion due to lone electron pairs;
\textit{Do not allow ECF for wrong Lewis structures.}  

(b) (i) (relative) measure of an atoms attraction for electrons;
in a covalent bond / shared pair;

(ii) \( \text{C―H} \text{ is less polar as C is less electronegative / N―H bond is more polar as N is more electronegative / difference in electronegativity is greater for N-H than C-H;} \)

(iii) bond polarities cancel in \( \text{C}_2\text{H}_4 \text{ / OWTTE; } \)

(c) weaker van der Waals’/London/dispersion/intermolecular forces in ethene;
stronger (intermolecular) hydrogen bonding in hydrazine;
\textit{If no comparison between strengths then \{1 max}.}

Q# 17/ IB Chem/2009/w/TZ0/Paper 2 Section A/Standard Level/

2.

<table>
<thead>
<tr>
<th></th>
<th>PF₃</th>
<th>SF₂</th>
<th>SiF₄</th>
</tr>
</thead>
</table>
| Lewis structure | \[ \begin{array}{c}
\text{F} \\
\downarrow \text{H} \\
\text{F} \\
\end{array} \] \text{1 lone pair on P required for the mark} | \[ \begin{array}{c}
\text{F} \\
\downarrow \text{H} \\
\text{F} \\
\end{array} \] \text{2 lone pairs on S required for the mark} | \[ \begin{array}{c}
\text{F} \\
\downarrow \text{H} \\
\text{Si} \\
\text{F} \\
\end{array} \] |
| Name of shape | trigonal/trigonal pyramidal; | bent/ angular/ \text{V} \text{ shaped; } | tetrahedral/tetrahedron; |

\textit{Penalise missing lone pairs on fluorine atoms once in correct structures only.}
\textit{For Lewis structures candidates are not expected to draw exact shapes of molecules.}
\textit{Do not allow ECF for wrong Lewis structures.}
\textit{Accept dots or crosses instead of lines.}

Q# 18/ IB Chem/2009/s/tz1/Paper 2 Section B/Standard Level/
6. (a) (i) 
\[ \text{\( \text{C}=\text{O} \); } \quad \text{\( \text{O}^2-\)} \]
\[ \text{\( \text{O} \)); } \quad \text{\( \text{O}^2-\)} \]
\[ \text{H} - \text{C} - \text{O} \quad \text{H} - \text{C} - \text{O} - \text{H} \]
\[ \text{H}^+ \text{C}^+ \text{O}^- \quad \text{H}^+ \text{C}^+ \text{O}^- \text{H}^- \]

All outer electron pairs must be shown for mark in each case. Accept electrons shown as all \( x \) rather than \( \bullet \) and \( \cdot \).

(ii) CO < CO\(_2\) < CH\(_3\)OH:
triple bonds are shorter than double bonds which are shorter than single bonds / the more pairs of electrons that are shared the stronger the attracting so the shorter the bond / OWTTE.
The order must be correct to gain the second marking point unless ECF from (a).

(b) (i) (CO\(_2\)) linear: 
180°;

(ii) (CO\(_3^{2-}\)) trigonal planar / triangular planar;
120°;

(iii) (BF\(_4^-\)) tetrahedral;
109.5° / 109° / 109° 28’;

Q# 19/ IB Chem/2009/s/TZ1/Paper 2 Section A/Standard Level/

3. (a) in the solid state ions are in fixed positions / there are no moveable ions / OWTTE; 
Do not accept answer that refers to atoms or molecules.

Q# 20/ IB Chem/2008/w/TZ0/Paper 2 Section A/Standard Level/

3. (a) (i) polar single
O–H;
Accept C–H, H\(_2\)O

polar double
C=O;
Accept CO\(_2\)

non-polar double
O=O;
Accept O=O

non-polar triple
C≡C/triple carbon bond / O–H;

(ii) C≡C/triple carbon bond;
Q# 21/ IB Chem/2008/s/tz1/Paper 2 Section B/Standard Level/

6. (a) (i) 

\[
\begin{align*}
 & \text{BF}_3 \\
 & \quad \text{trigonal planar;}
\end{align*}
\]

\[
\begin{align*}
 & \text{Cl}_3 \\
 & \quad \text{(trigonal) pyramidal;}
\end{align*}
\]

BF\textsubscript{3} non-polar and PCl\textsubscript{3} polar;  

(ii) 

\[
\begin{align*}
 & \text{SO}_2 \\
 & \quad \text{linear;}
\end{align*}
\]

\[
\begin{align*}
 & \text{CO}_2 \\
 & \quad \text{non-polar;}
\end{align*}
\]

Do not allow ECF from wrong Lewis structures. 
Penalize missing lone pairs on fluorine, oxygen and chlorine once only. 
Penalize missing or extra lone pairs on central atom every time.

(b) (i) K more reactive / Na less reactive; 
easier to remove electron from K / lower IE; 

(ii) I\textsuperscript{-} more easily oxidised / Br\textsuperscript{2-} less easily oxidized; 
easier to remove electron from I\textsuperscript{-}; 

(iii) Mg conductor / S non-conductor; 
Mg’s sea of delocalised electrons free to move, whereas S’s electrons are covalently bonded/not free to move:
Topic 5
Chem 5 Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q1

1. Ethane-1,2-diol, HOCH$_2$CH$_2$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.

   \[ 2\text{CO}(g) + 3\text{H}_2(g) \rightleftharpoons \text{HOCH}_2\text{CH}_2\text{OH}(g) \]

   (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 kJ mol$^{-1}$.

   \[ \text{[3]} \]

   (iv) The enthalpy change, \( \Delta H^\circ \), for the following similar reaction is $-233.8$ kJ.

   \[ 2\text{CO} (g) + 3\text{H}_2(g) \rightleftharpoons \text{HOCH}_2\text{CH}_2\text{OH}(l) \]

   Deduce why this value differs from your answer to (a)(iii).

   \[ \text{[1]} \]
3. 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 be produced from the reaction of coke with steam:

\[ \text{C}(s) + 2\text{H}_2\text{O}(g) \rightarrow 2\text{H}_2(g) + \text{CO}_2(g) \]

Using information from section 12 of the data booklet, calculate the change in enthalpy, \(\Delta H\), in kJ mol\(^{-1}\), for this reaction.

2. Impurities cause phosphine to ignite spontaneously in air to form an oxide of phosphorus and water.

(a) (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.

Standard enthalpy of combustion of phosphine, \(\Delta H^\circ_f = -750 \text{ kJ mol}^{-1}\)
Specific heat capacity of air = 1.00 \(\text{J g}^{-1} \text{K}^{-1} = 1.00 \text{kJ kg}^{-1} \text{K}^{-1}\)
7. 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. [4]

(ii) Using the theoretical value in Table 12 of the Data Booklet, discuss the experimental results, including one improvement that could be made. [3]
(b) Methanol can be produced according to the following equation.

\[ \text{CO}(g) + 2\text{H}_2(g) \rightarrow \text{CH}_3\text{OH}(l) \]

Calculate the standard enthalpy change of this reaction using the following data:

I: \[ 2\text{CH}_3\text{OH}(l) + 3\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 4\text{H}_2\text{O}(l) \quad \Delta H^\circ = -1452 \text{ kJ mol}^{-1} \]

II: \[ 2\text{CO}(g) + \text{O}_2(g) \rightarrow 2\text{CO}_2(g) \quad \Delta H^\circ = -566 \text{ kJ mol}^{-1} \]

III: \[ 2\text{H}_2(g) + \text{O}_2(g) \rightarrow 2\text{H}_2\text{O}(l) \quad \Delta H^\circ = -572 \text{ kJ mol}^{-1} \]

(iv) Using a digital thermometer, the students discovered that the reaction was exothermic. State the sign of the enthalpy change of the reaction, \( \Delta H \).

\[ \text{[3]} \]

Chem 5 Q# 5/ IB Chem/2012wQ1a

Chem 5 Q# 6/ IB Chem/2012/w/TZ0/Paper 2 Section A/Standard Level/
2. (a) Define the term *average bond enthalpy*.

(b) The following equation represents a combustion reaction of propane, \( C_3H_8(g) \) when the oxygen supply is limited.

\[
C_3H_8(g) + 3\frac{1}{2}O_2(g) \rightarrow 3CO(g) + 4H_2O(g)
\]

(i) Determine \( \Delta H \), the enthalpy change of the reaction, in kJ mol\(^{-1} \), using average bond enthalpy data from Table 10 of the Data Booklet. The bond enthalpy for the carbon-oxygen bond in carbon monoxide, CO, is 1072 kJ mol\(^{-1} \).

(ii) The CO molecule has dative covalent bonding. Identify a nitrogen-containing positive ion which also has this type of bonding.
(b) Disilane undergoes complete oxidation to form silicon dioxide and water.

\[ 2\text{Si}_2\text{H}_6(\text{g}) + 7\text{O}_2(\text{g}) \rightarrow 4\text{SiO}_2(\text{s}) + 6\text{H}_2\text{O}(\text{l}) \]

The standard enthalpy change for this reaction, \( \Delta H^\circ = -5520 \text{ kJ} \).

(i) Calculate the standard enthalpy change, in kJ, for the corresponding combustion reaction of 2 moles of ethane, using Table 12 of the Data Booklet. \([1]\)

The different properties of the hydrides can be accounted for by the different bond enthalpies of the covalent bonds formed by silicon and carbon.

(i) Define the term average bond enthalpy. \([2]\)
(ii) 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. \[3\]

---

(d) (i) Define the term **endothermic reaction.** \[1\]

---

(f) Iron, used as the catalyst in the Haber process, has a specific heat capacity of 0.4490 J g⁻¹ K⁻¹. If 245.0 kJ of heat is supplied to 8.500 kg of iron, initially at a temperature of 15.25 °C, determine its final temperature in K. \[3\]
Chem 5 Q# 9/ IB Chem/2011/w/TZ0/Paper 2 Section A/Standard Level/

4. (a) Define the term average bond enthalpy.

Chem 5 Q# 10/ IB Chem/2011/s/TZ1/Paper 2 Section A/Standard Level/

4. Ethanol is used as a component in fuel for some vehicles. One fuel mixture contains 10% by mass of ethanol in unleaded petrol (gasoline). This mixture is often referred to as Gasohol E10.

(a) Assume that the other 90% by mass of Gasohol E10 is octane. 1.00 kg of this fuel mixture was burned.

\[
\text{CH}_3\text{CH}_2\text{OH}(l) + 3\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 3\text{H}_2\text{O}(l) \quad \Delta H^\circ = -1367 \text{ kJ mol}^{-1}
\]

\[
\text{C}_8\text{H}_{18}(l) + 12\frac{1}{2}\text{O}_2(g) \rightarrow 8\text{CO}_2(g) + 9\text{H}_2\text{O}(l) \quad \Delta H^\circ = -5470 \text{ kJ mol}^{-1}
\]

(i) Calculate the mass, in g, of ethanol and octane in 1.00 kg of the fuel mixture.

(ii) Calculate the amount, in mol, of ethanol and octane in 1.00 kg of the fuel mixture.

(iii) Calculate the total amount of energy, in kJ, released when 1.00 kg of the fuel mixture is completely burned.
(b) If the fuel blend was vaporized before combustion, predict whether the amount of energy released would be greater, less or the same. Explain your answer. [2]

Chem 5 Q# 11/ IB Chem/2011/s/TZ1/Paper 2 Section A/Standard Level/
TABLE 10

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.

\[ \text{CH}_3\text{OH}(l) + 1\frac{1}{2}\text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(g) \]

(a) Using the information from Table 10 of the Data Booklet, determine the theoretical enthalpy of combustion of methanol. [3]
(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 experimental 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.

(iii) Determine the enthalpy change, in kJ mol\(^{-1}\), for the combustion of 1 mole of methanol.
(c) The Data Booklet value for the enthalpy of combustion of methanol is \(-726 \text{ kJ mol}^{-1}\). Suggest why this value differs from the values calculated in parts (a) and (b).

(i) Part (a) 

(ii) Part (b) 

(d) Hydrazine is a valuable rocket fuel.

The equation for the reaction between hydrazine and oxygen is given below.

\[
\text{N}_2\text{H}_4(g) + \text{O}_2(g) \rightarrow \text{N}_2(g) + 2\text{H}_2\text{O}(g)
\]

Use the bond enthalpy values from Table 10 of the Data Booklet to determine the enthalpy change for this reaction.
1. The data below are from an experiment to measure the enthalpy change for the reaction of aqueous copper(II) sulfate, CuSO₄(aq) and zinc, Zn(s).

\[ \text{Cu}^{2+}(aq) + \text{Zn}(s) \rightarrow \text{Cu}(s) + \text{Zn}^{2+}(aq) \]

50.0 cm³ of 1.00 mol dm⁻³ copper(II) sulfate solution was placed in a polystyrene cup and zinc powder was added after 100 seconds. The temperature-time data was taken from a data-logging software program. The table shows the initial 23 readings.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>time / s</td>
<td>Temperature / °C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>24.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>24.8</td>
<td></td>
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</tr>
<tr>
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<td></td>
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<td>8</td>
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<td>7.0</td>
<td>24.8</td>
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<tr>
<td>10</td>
<td>8.0</td>
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<tr>
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<tr>
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<tr>
<td>14</td>
<td>12.0</td>
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</table>

A straight line has been drawn through some of the data points. The equation for this line is given by the data logging software as

\[ T = -0.050t + 78.0 \]

where \( T \) is the Temperature at time \( t \).
(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.

(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.

(ii) State the assumption made in part (b) (i).

(iii) Calculate the heat, in kJ, produced during the reaction using the expression given in part (a).

(c) The colour of the solution changed from blue to colourless. Deduce the amount, in moles, of zinc which reacted in the polystyrene cup.

(d) Calculate the enthalpy change, in kJ mol\(^{-1}\), for this reaction.
(e) An experiment was designed to investigate how the enthalpy change for a displacement reaction relates to the reactivities of the metals involved. The following metals in order of decreasing reactivity were available.

Magnesium: most reactive
Uranium
Zinc
Iron
Copper
Silver: least reactive

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 of the reaction and the reactivity of the metal. \[1\]

(ii) Sketch a graph on the diagram below to illustrate your hypothesis. \[1\]
6. (a) In an experiment to measure the enthalpy change of combustion of ethanol, a student heated a copper calorimeter containing 100 cm$^3$ of water with a spirit lamp and collected the following data.

- Initial temperature of water: 20.0°C
- Final temperature of water: 55.0°C
- Mass of ethanol burned: 1.78 g
- Density of water: 1.00 g cm$^{-3}$

(i) Use the data to calculate the heat evolved when the ethanol was combusted. [2]

(ii) Calculate the enthalpy change of combustion per mole of ethanol. [2]

(iii) Suggest two reasons why the result is not the same as the value in the Data Booklet. [2]

Chem 5 Q# 15/ IB Chem/2009/w/TZ0/Paper 2 Section A/Standard Level/

3. The standard enthalpy change of three combustion reactions is given below in kJ.

\[
2\text{C}_2\text{H}_6(g) + 7\text{O}_2(g) \rightarrow 4\text{CO}_2(g) + 6\text{H}_2\text{O}(l) \quad \Delta H^\circ = -3120 \\
2\text{H}_2(g) + \text{O}_2(g) \rightarrow 2\text{H}_2\text{O}(l) \quad \Delta H^\circ = -572 \\
\text{C}_2\text{H}_4(g) + 3\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 2\text{H}_2\text{O}(l) \quad \Delta H^\circ = -1411
\]

Based on the above information, calculate the standard change in enthalpy, $\Delta H^\circ$, for the following reaction.

\[
\text{C}_2\text{H}_6(g) \rightarrow \text{C}_2\text{H}_4(g) + \text{H}_2(g) \quad [4]
\]
2. 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.

\[ \text{C}_2\text{H}_4(\text{g}) + \text{H}_2(\text{g}) \rightarrow \text{C}_2\text{H}_6(\text{g}) \]

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) Marit arranged the values she found in Table 12 into an energy cycle.

\[
\begin{align*}
\text{C}_2\text{H}_4(\text{g}) \quad &+ \quad \text{H}_2(\text{g}) \quad \xrightarrow{\Delta H^\circ \text{ (hydrogenation)}} \quad \text{C}_2\text{H}_6(\text{g}) \\
3\text{O}_2 \quad &\xrightarrow{-1411 \text{ kJ mol}^{-1}} \quad 2\text{CO}_2(\text{g}) \quad + \quad 3\text{H}_2\text{O(1)} \\
\quad &\xrightarrow{-286 \text{ kJ mol}^{-1}} \quad \text{O}_2
\end{align*}
\]

Calculate the value for the enthalpy of hydrogenation of ethene from the energy cycle. [1]

(c) Suggest one reason why John’s answer is slightly less accurate than Marit’s answer. [1]
(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]

4. (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]

(iii) The equation for an important reaction of ethene is given below.

\[ CH_2=CH_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2C=CH_2(g) \]

Use information from Table 10 in the Data Booklet to calculate the enthalpy change for this reaction. [3]

(iv) Draw a labelled enthalpy level diagram to represent the reaction in part (a) (iii). [2]
(b) The standard enthalpy changes for the following reactions can be found in Table 13 of the Data Booklet.

\[ C(s) + O_2(g) \rightarrow CO_2(g) \]
\[ H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l) \]
\[ C_8H_{18}(l) + 12\frac{1}{2}O_2(g) \rightarrow 8CO_2(g) + 9H_2O(l) \]

(i) Use this information to determine the standard enthalpy change for the formation of octane from its elements.

\[ 8C(s) + 9H_2(g) \rightarrow C_8H_{18}(l) \quad [4] \]

(ii) Predict which of the following reactions has the most negative enthalpy change, and explain your choice.

I \[ H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(g) \]
II \[ H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l) \quad [2] \]

Chem 5 Q# 18/ IB Chem/2008/s/TZ1/Paper 2 Section A/Standard Level/

3. (a) The standard enthalpy changes of three combustion reactions at 298 K are given below in kJ mol\(^{-1}\).

\[ C(s) + O_2(g) \rightarrow CO_2(g) \quad \Delta H^\circ = -394 \]
\[ H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l) \quad \Delta H^\circ = -286 \]
\[ CH_3COOH(l) + 2O_2(g) \rightarrow 2CO_2(g) + 2H_2O(l) \quad \Delta H^\circ = -876 \]

Use the data above to calculate the standard enthalpy change for the following reaction.

\[ 2C(s) + 2H_2(g) + O_2(g) \rightarrow CH_3COOH(l) \quad \Delta H^\circ =? \quad [4] \]
3. (a) Define the term *average bond enthalpy.*

(b) Use the information from Table 10 in the Data Booklet to calculate the enthalpy change for the complete combustion of but-1-ene according to the following equation.

\[
C_4H_8(g) + 6O_2(g) \rightarrow 4CO_2(g) + 4H_2O(g)
\]

(c) Predict, giving a reason, how the enthalpy change for the complete combustion of but-2-ene would compare with that of but-1-ene based on average bond enthalpies.

(e) The enthalpy level diagram for a certain reaction is shown below.

State and explain the relative stabilities of the reactants and products.
### Topic 5

#### Mark Scheme

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<tr>
<th>Question</th>
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<th>Notes</th>
<th>Total</th>
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<tbody>
<tr>
<td>1. a</td>
<td>Bonds broken: $2\text{C}_2\text{O}_4^2- + 3(\text{H}_2\text{O}) \rightarrow 2(\text{CO}_2) + 3(\text{H}_2\text{O}) + (3436 \text{kJ mol}^{-1}) + (3462 \text{kJ mol}^{-1})$</td>
<td>Award [3] for correct final answer. Award [2 max] for $\Delta H = 3462$ kJ mol$^{-1}$.</td>
<td>3</td>
</tr>
<tr>
<td>1. a</td>
<td>Bonds formed: $2(\text{C} - \text{O}) + 2(\text{C} - \text{H}) + 4(\text{C} - \text{H}) + (\text{C} - \text{C}) / 2(358 \text{kJ mol}^{-1}) + (4\times(141 \text{kJ mol}^{-1})) + (345 \text{kJ mol}^{-1}) / 3644 \text{kJ mol}^{-1}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. a</td>
<td>Accept product is known as a liquid. Accept answers referring to bond enthalpies being mean/averages.</td>
<td>1</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Question</th>
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<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. a</td>
<td>Only water is produced (no non-polluting)</td>
<td>Award [2] for correct final answer.</td>
<td>1</td>
</tr>
<tr>
<td>3. b</td>
<td>$\Delta H = [(-393.5) - (-241.5)] + 90.1 \text{ kJ}$</td>
<td>Do not accept $-3730$.</td>
<td>2</td>
</tr>
</tbody>
</table>

<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>Temperature rise $\Delta T = \frac{750 \times 10^2}{2000 \times 1 \times 0.05023 \text{ kg}}$</td>
<td>Do not accept $-3730$.</td>
<td>1</td>
</tr>
<tr>
<td>3. b</td>
<td>$\Delta H = \frac{4.45}{7.18 \times 10^{-4} \text{ mol}}$; Accept integer values of molar mass. Final answer must have negative sign and correct units. Award [4] for correct final answer with correct units.</td>
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</table>

#### Question 7

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. (a) i</td>
<td>$(q = mc\Delta T) = 0.0500 \times 4.18 \times 213 = 4.45$ (kJ); $\Delta H = \frac{4.45}{7.18 \times 10^{-4} \text{ mol}}$; Do not accept $m = 0.05023 \text{ kg}$.</td>
<td></td>
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<tr>
<td>7. (a) i</td>
<td>$(\text{in methanol}) = \frac{0.230}{32.05} = 7.18 \times 10^{-3} \text{ (mol)}$;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. (a) i</td>
<td>$\Delta H = \frac{4.45}{7.18 \times 10^{-4} \text{ mol}^{-1}}$; Accept integer values of molar mass. Final answer must have negative sign and correct units. Award [4] for correct final answer with correct units.</td>
<td></td>
<td>[4]</td>
</tr>
<tr>
<td>7. (a) i</td>
<td>less heat is liberated than theoretically $\sim 726$ 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.</td>
<td>If the value calculated in (a) (i) is more exothermic than theoretically, allow ECF for M1 and for improvement if consistent.</td>
<td>[3]</td>
</tr>
<tr>
<td>7. (b)</td>
<td>$\Delta H = \frac{1}{2}$ II + III $- \frac{1}{2}$ I/ correct diagram/energy cycle:</td>
<td>Award [3] for correct final answer.</td>
<td>[3]</td>
</tr>
<tr>
<td>7. (b)</td>
<td>$-283 - 572 = (-726)$; $-129 \text{ (kJ mol}^{-1})$;</td>
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<tr>
<td>7. (b)</td>
<td>Allow answers in the range of 82.5 to 84.5%.</td>
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<td>[4]</td>
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</table>

### Question 5

#### IB Chem 2012wQ1a

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
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<tbody>
<tr>
<td>3. (i)</td>
<td>$\left( \frac{8.60}{10.3} \right) = 83.5%$;</td>
<td>Allow answers in the range of 82.5 to 84.5%.</td>
<td>[I]</td>
</tr>
</tbody>
</table>
2. (a) energy needed to break (1 mol of) a bond in a gaseous molecule/state/phase; average calculated from a range of similar compounds / OWTTE; 

\[2\]

Do not accept similar bonds instead of similar compounds. 

**M2 can be scored independently.**

(b) (i) Bonds breaking: 
\[2 \times (C-C) + 8 \times (C-H) + 3.5 \times (O-O)\]
\[- (2)(347) + (8)(413) + (3.5)(498)\]
\[- 5741 \text{ (kJ mol}^{-1}\text{)};\]

Bonds forming: 
\[3 \times (C-O) + 8 \times (O-H)\]
\[= (3)(1072) + (8)(464) = 6928 \text{ (kJ mol}^{-1}\text{)};\]

**Enthalpy change:** 
\[5741 - 6928 = -1187 \text{ (kJ mol}^{-1}\text{)};\]

Award [3] for correct final answer.

(ii) \(\text{NH}_4^+/\text{ammonium} / \text{N}_2\text{H}_5^+/\text{hydrazinium} / \text{CH}_3\text{NH}_3^+/\text{methylammonium} / \text{H}_2\text{NO}_3^+/\text{nitraoxonium};\)

[1]

Q# 7/ IB Chem/2012/s/tz1/Paper 2 Section B/Standard Level/q5

(b) (i) \((-1560 \times 2) = -3120 \text{ (kJ)};\)

[1]

(c) (i) energy needed to break (one mol of) a bond in a gaseous molecule; averaged over similar compounds; 

Do not allow averaged over several compounds.

(ii) Bonds broken: 
\(6\text{Si–H, Si–Si, H–H} / (+)2570 \text{ (kJ)};\)

Bonds formed: 
\(8\text{Si–H} / (-)2544 \text{ (kJ)};\)
\[+26 \text{ (kJ)};\]

**OR**

Bonds broken: 
\(\text{Si–Si, H–H} / (+)662 \text{ (kJ)};\)

Bonds formed: 
\(2\text{Si–H} / (-)636 \text{ (kJ)};\)
\[+26 \text{ (kJ)};\]

[3]

Q# 8/ IB Chem/2011/w/tz0/Paper 2 Section B/Standard Level/q6

(d) (i) (system) absorbs/takes in heat from surroundings / OWTTE; 

Allow standard enthalpy change / \(\Delta H^\circ\) positive. 

Allow bond breaking more energetic than bond formation / OWTTE. 

Absorbs/takes in heat alone not sufficient for mark.

(f) \(q = mc\Delta T = 2.450 \times 10^3 \times (8.500 \times 10^3)(0.4490)(T_f - 15.25);\)
\[T_f = 79.44 \text{ °C} / \Delta T = 64.19 \text{ (°C / K)};\]
\[T_f = (79.44 + 273) = 352 \text{ (K)};\]

Award [3] for correct final answer. 

Accept the use of 273.15 K instead of 273 K giving final value of 352.59 K. 

For M1 and M2 award [1 max] for use of \(q = mc\Delta T\) if incorrect units of \(m\) and \(c\) are used.
4. (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]

Q# 10/ IB Chem/2011/s/TZ1/Paper 2 Section A/Standard Level/

4. (a) (i) (10% 1000 g =) 100 g ethanol and (90% 1000 g =) 900 g octane; [1]

(ii) \( n(\text{ethanol}) = 2.17 \text{ mol and } n(\text{octane}) = 7.88 \text{ mol}; [1]

(iii) \( E_{\text{released from ethanol}} = (2.17 \times 1367) = 2966 \text{ (kJ)}; \)

\( E_{\text{released from octane}} = (7.88 \times 5470) = 43104 \text{ (kJ)}; \)

\( \text{total energy released } = (2966 + 43104) = 4.61 \times 10^4 \text{ (kJ)}; [3] \)

Award [3] for correct final answer.

Accept answers using whole numbers for molar masses and rounding.

(b) greater;

fewer intermolecular bonds/forces to break / vaporization is endothermic / gaseous fuel has greater enthalpy than liquid fuel / OWTTE; [2]

M2 cannot be scored if M1 is incorrect.

Q# 11/ IB Chem/2011/s/TZ1/Paper 2 Section A/Standard Level/

1. (a) amount of energy required to break bonds of reactants 

\( 3 \times 413 + 358 + 464 + 1.5 \times 498 \text{ (kJ mol}^{-1} \text{) / 2808 \text{ (kJ mol}^{-1} \text{)}}; \)

amount of energy released during bond formation of products 

\( 4 \times 464 + 2 \times 746 \text{ (kJ mol}^{-1} \text{) / 3348 \text{ (kJ mol}^{-1} \text{)}}; \)

\( \Delta H = -540 \text{ (kJ mol}^{-1} \text{)}; [3] \)

Award [3] for correct final answer.

Award [2] for (+)540.

If old Data Booklet is used accept answer: -535 (kJ mol\(^{-1}\)) or award [2] for (+)535.

(b) (i) \( m(\text{methanol}) = (80.557 - 80.034) = 0.523 \text{ (g)}; \)

\( n(\text{methanol}) = \left( \frac{0.523 \text{ g}}{32.05 \text{ g mol}^{-1}} \right) = 0.0163 \text{ (mol)}; [2] \)

Award [2] for correct final answer.

(ii) \( \Delta T = (26.4 - 21.5) = 4.9 \text{ (K)}; \)

\( q = (mc\Delta T) = 20.000 \times 4.18 \times 4.9 \text{ (J) / 20.000} \times 4.18 \times 4.9 \times 10^{-3} \text{ (kJ)}; \)

0.41\( \text{ (kJ)}; [3] \)

Award [3] for correct final answer.

(iii) \( \Delta H_f^\circ = \frac{-0.41 \text{ (kJ)}}{0.0163 \text{ (mol)}} / -25153 \text{ (kJ mol}^{-1} \text{)}; \)

\( = -25 \text{ (kJ mol}^{-1} \text{)}; [2] \)

Award [2] for correct final answer.

Award [1] for (+)25 (kJ mol\(^{-1}\)).

(c) (i) bond enthalpies are average values/differ (slightly) from one compound to another (depending on the neighbouring atoms) / methanol is liquid not gas in the reaction; [1]

(ii) not all heat produced transferred to water / heat lost to surroundings/environment / OWTTE / incomplete combustion (of methanol) / water forms as H\(_2\)O(l) instead of H\(_2\)O(g); [1]

Do not allow just “heat lost”.
Q# 12/ IB Chem/2010/w/TZ0/Paper 2 Section B/Standard Level/q4

(d) bonds broken: \( 4 \text{ N–H, N–N, O=O} / +2220 \text{(kJ mol}^{-1} \text{)} \); 
bonds formed: \( \text{N≡N, 4 O–H} / -2801 \text{(kJ mol}^{-1} \text{)} \); 
\[ -581 \text{(kJ mol}^{-1} \text{)} \] 
Award [3] for correct final answer.

Q# 13/ IB Chem/2010/w/TZ0/Paper 2 Section A/Standard 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) \( T_{\text{calc}} = 73.0 \text{ (°C)} \); 
Allow in the range 72 to 74 (°C).
\[ \Delta T = 48.2 \text{ (°C)} ; \] 
Allow in the range 47 to 49 (°C).
Award [2] for correct final answer 
Allow ECF if \( T_{\text{final}} \) or \( T_{\text{initial}} \) correct.
(ii) temperature decreases at uniform rate (when above room temperature) / OWTTE; 
[1]
(iii) 10.1 (kJ); 
Allow in the range 9.9 to 10.2 (kJ).
[1]
(c) \( n_{\text{Zn}} = n_{\text{CuSO}} = \frac{1.00 \times 50.0}{1000} = 0.0500 \text{(mol)} ; \)
[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.

(e) (i) the more reactive the metal the more negative the enthalpy change/the more 
exothermic the reaction / OWTTE; 
Do not accept greater enthalpy change.
[1]
(ii) any curve with positive gradient which passes through \( \Delta H = 0 \) at Cu; 
Allow point graph or histogram. 
Accept either positive or zero enthalpy change for Ag.
Q# 14/ IB Chem/2010/s/tz1/Paper 2 Section B/Standard Level/

6. (a) (i) \[ 100 \times 4.18 \times 35.0 \];
14630 J / 14600 J / 14.6 kJ, [2]
Award [2] for correct final answer.
No ECF here if incorrect mass used.

(ii) \[ \frac{1.78}{46.08} = 0.0386 \text{ mol}; \]
\[ \frac{14.6}{0.0386} = (-)378 \text{ kJ mol}^{-1}; \] [2]
Accept (-)377 and (-)379 kJ mol$^{-1}$.
Award [2] for correct final answer.

(iii) heat loss:
incomplete combustion;
heat absorbed by calorimeter not included; [2 max]
Accept other sensible suggestions.

Q# 15/ IB Chem/2009/w/TZ0/Paper 2 Section A/Standard Level/

3. \((C_2H_6(g) + \frac{3}{2}O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l))\) \[ \Delta H^\circ = -1560; \]
\((H_2O(l) \rightarrow H_2(g) + \frac{1}{2}O_2(g))\) \[ \Delta H^\circ = +286; \]
\((2CO_2(g) + 2H_2O(l) \rightarrow C_2H_4(g) + 3O_2(g))\) \[ \Delta H^\circ = +1411; \]
\((C_2H_4(g) \rightarrow C_2H_6(g) + H_2(g))\) \[ \Delta H^\circ = +137 (kJ); \] [4]
Allow other correct methods.
Award [2] for -137.
Allow ECF for the final marking point.

Q# 16/ IB Chem/2009/s/TZ1/Paper 2 Section A/Standard Level/

2. (a) energy required = C=C + H-H/612 + 436 and
ergy released = C=C + 2(C-H)/347 + 2(413) /
energy required = C=C + H-H + 4(C-H)/612 + 436 + 4(413) and
ergy released = C=C + 6(C-H)/347 + 6(413);
\[ \Delta H = \frac{(1048-1173)}{(2700-2825)} = -125 \text{ kJ mol}^{-1}; \] [2]

(b) \[ \Delta H = -1411 + (-286) - (-1560) = -137 \text{ kJ mol}^{-1}; \] [1]

(c) the actual values for the specific bonds may be different to the average values / the
combustion values referred to the specific compounds / OWTTE; [1]

(d) (i) -125 kJ mol$^{-1}$; [1]

(ii) average bond enthalpies do not apply to the liquid state / OWTTE;
the enthalpy of vaporization/condensation of cyclohexene and cyclohexane / OWTTE; [2]
4. (i) energy change to break/make (one mole) of bonds (in molecule) in gaseous state; averaged over similar compounds; [2]

(ii) H–H bond is only present in one molecule/OWTTE; [1]

(iii) bonds broken: C=C and \( \frac{1}{2} \) O=O / 612 + 248 / 860;
bonds formed: C–C and 2 C–O / 348 + 720 / 1068;
\( \Delta H = (860 - 1068) = -208 \text{ kJ/kJ mol}^{-1} \); [3]
Correct final answer award [3] marks. 208 kJ/kJ mol\(^{-1}\) or +208 kJ/kJ mol\(^{-1}\) award [2] marks. ECF from bonds broken and formed.
No penalty for including 4 C–H bonds in both bonds broken and formed.

(iv) diagram showing
vertical axis labelled enthalpy/energy;
Do not accept enthalpy change.
reactants line above products line and \( \Delta H \); [2]
ECF from sign in (iii).
Ignore connecting lines, intermediates, activated complexes.
Enthalpy change value not needed, but if in wrong place, then deduct [1] mark.

(v) negative;
decrease in gas moles/molecules/volume/decrease in disorder/increase in order; [2]

3. (a) \( 2\text{C(s) + 2O}_2(g) \rightarrow 2\text{CO}_2(g) \quad \Delta H^\circ = -788 \text{ kJ} \);
\( 2\text{H}_2(g) + \text{O}_2(g) \rightarrow 2\text{H}_2\text{O}(l) \quad \Delta H^\circ = -572 \text{ kJ} \);
\( 2\text{CO}_2(g) + 2\text{H}_2\text{O}(l) \rightarrow \text{CH}_3\text{COOH}(l) + 2\text{O}_2(g) \) \( \Delta H^\circ = +876 \text{ kJ} \);

\( 2\text{C(s) + 2H}_2(g) + \text{O}_2(g) \rightarrow \text{CH}_3\text{COOH}(l) \quad \Delta H^\circ = -484 \text{ (kJ)} \);
Award [4] for correct final answer.
Q# 19/ IB Chem/2007/s/TZ1/Paper 2 Section A/Standard Level/

3. (a) amount of energy needed to **break one mole** of (covalent) bonds, in the gaseous state; average calculated from a range of compounds; **[2 max]**
   
   Award [1] each for any two points above.

   (b) bonds broken: \(612 + 2 \times 348 + 8 \times 412 + 6 \times 496 \div 7580 \text{ kJ mol}^{-1}\);
   bonds made: \(8 \times 743 + 8 \times 463 + 9648 \text{ kJ mol}^{-1}\);
   
   \((\text{bonds broken} - \text{bonds made} =) \Delta H = -2068 \text{ (kJ mol}^{-1}\)) **[3]**
   
   Award [3] for the correct answer.
   Allow full ECF – 1 mistake equals 1 penalty.
   Allow kJ but not other wrong units.

   (c) same/equal, because the same bonds are being broken and formed; **[1]**

   (e) products more stable than reactants;
   bonds are stronger in products than reactants \(H_p < H_r\) / enthalpy / stored energy of products less than reactants; **[2]**
3. Sodium thiosulfate solution reacts with dilute hydrochloric acid to form a precipitate of sulfur at room temperature.

\[ \text{Na}_2\text{S}_2\text{O}_3(\text{aq}) + 2\text{HCl}(\text{aq}) \rightarrow \text{S(s)} + \text{SO}_2(\text{g}) + 2\text{NaCl}(\text{aq}) + X \]

The precipitate of sulfur makes the mixture cloudy, so a mark underneath the reaction mixture becomes invisible with time.

10.0 cm\(^3\) of 2.00 mol dm\(^{-3}\) hydrochloric acid was added to a 50.0 cm\(^3\) solution of sodium thiosulfate at temperature, \(T_1\). 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>([\text{Na}_2\text{S}_2\text{O}_3(\text{aq})]/\text{mol dm}^{-3})</th>
<th>Time, (t), for mark to disappear / s ± 1 s</th>
<th>(\frac{1}{t}/10^{-3}) 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/]
(d) Draw the best fit line of \( \frac{1}{t} \) against concentration of sodium thiosulfate on the axes provided.

(e) 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.
(f) 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]

(g) Suggest one reason why the values of rates of reactions obtained at higher temperatures may be less accurate. [1]
Chem 6 Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q1

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]

Chem 6 Q# 3/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q2(a)

(v) Consider the following equilibrium between the two oxides of sulfur, sulfur dioxide and sulfur trioxide:

\[ 2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g) \quad \Delta H = -198 \text{kJ} \]
(vi) Sketch the potential energy profile for the forward reaction in part (v) to show the effect of a catalyst on the activation energy, $E_{\text{act}}$. [2]

![Potential energy profile diagram]

Chem 6 Q# 4/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q3

3. Phosgene, COCl₂, is usually produced by the reaction between carbon monoxide and chlorine according to the equation:

$$\text{CO} (g) + \text{Cl}_2 (g) \rightleftharpoons \text{COCl}_2 (g) \quad \Delta H = -108 \, \text{kJ}$$

(b) (i) Sketch the potential energy profile for the synthesis of phosgene, using the axes given, indicating both the enthalpy of reaction and activation energy. [2]

![Potential energy profile diagram]

(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]
(iii) Sketch and label a second Maxwell–Boltzmann energy distribution curve representing the same system but at a higher temperature, $T_{\text{higher}}$.

(iv) Explain why an increase in temperature increases the rate of this reaction.

(c) Vanadium(V) oxide, $\text{V}_2\text{O}_5$, is a catalyst that can be used in the Contact process. It provides an alternative pathway for the reaction, lowering the activation energy, $E_a$.

(i) Define the term activation energy, $E_a$. 

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

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

.................................
(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. \[3\]

1. Propanone reacts with bromine in acidic solution according to the following equation.

\[
\text{CH}_3\text{COCH}_3\text{(aq)} + \text{Br}_2\text{(aq)} + \text{H}^+\text{(aq)} \rightarrow \text{BrCH}_2\text{COCH}_3\text{(aq)} + \text{HBr}\text{(aq)}
\]

A student investigated the kinetics of this reaction using data logging equipment. Her data are shown below.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Experiment</td>
<td>([\text{CH}_3\text{COCH}_3] = 0.001)</td>
<td>([\text{Br}_2]\ ± 0.0001)</td>
<td>([\text{H}^+]\ ± 0.0001)</td>
<td>Time for colour to fade / s ± 1</td>
<td>Rate of reaction / mol dm(^{-3}) s(^{-1})</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0.200</td>
<td>0.0100</td>
<td>0.0500</td>
<td>250</td>
<td>4.00 \times 10^{-5}</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>0.400</td>
<td>0.0100</td>
<td>0.0500</td>
<td>125</td>
<td>8.00 \times 10^{-2}</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>0.200</td>
<td>0.0200</td>
<td>0.0500</td>
<td>500</td>
<td>4.00 \times 10^{-5}</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>0.200</td>
<td>0.0100</td>
<td>0.1000</td>
<td>125</td>
<td>8.00 \times 10^{-5}</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>0.400</td>
<td>0.0050</td>
<td>0.0500</td>
<td>63</td>
<td>X</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a) (i) Identify the reagent the student used to monitor the rate of reaction. \[1\]
(ii) Calculate the rate of reaction for Experiment 5 and comment on the precision of your result. [2]

(iii) Determine the percentage uncertainty in the calculated rate for Experiment 4. [2]

(b) (i) Describe how the rate of reaction changes when the concentration of CH₃COCH₃ is doubled and explain this change on a molecular level. [2]

(ii) The student suggested that H⁺ acts as a catalyst in the reaction. Describe the effect of a catalyst on a chemical reaction. [1]
Chem 6 Q# 7/ IB Chem/2011/wQ NOT WITH Q1b
The volume of nitrogen formed for this question was 34.1 dm³

(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.

(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.

Chem 6 Q# 8/ IB Chem/2011/w/tz0/Paper 2 Section B/Standard Level/q6

(b) Define the term activation energy, $E_a$. 
(c) Nitrogen monoxide, NO, is involved in the decomposition of ozone according to the following mechanism.

\[ O_3 \rightarrow O_2 + O^\bullet \]
\[ O_3 + NO \rightarrow NO_2 + O_2 \]
\[ NO_2 + O^\bullet \rightarrow NO + O_2 \]

Overall: \( 2O_2 \rightarrow 3O_2 \)

State and explain whether or not NO is acting as a catalyst. \( [2] \)

(ii) Sketch the Maxwell-Boltzmann energy distribution curve for a reaction with and without a catalyst, and label both axes. \( [3] \)

(i) Define the term rate of reaction. \( [1] \)
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.

\[
\text{CH}_3\text{COCH}_3(\text{aq}) + \text{I}_2(\text{aq}) + \text{H}^+(\text{aq}) \rightarrow \text{CH}_2\text{ICOCH}_3(\text{aq}) + \text{HI(} \text{aq)}
\]

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. Their results are shown graphically below.

(a) Discuss whether either Alex’s or Hannah’s hypothesis is correct. [2]

(b) Explain why the reaction rate will increase with increasing temperature. [2]
(c) (i) This reaction uses a catalyst. Sketch and annotate the Maxwell-Boltzmann energy distribution curve for a reaction with and without a catalyst on labelled axes below.  

(ii) Describe how a catalyst works.  

(b) Graphing is an important method in the study of the rates of chemical reaction. Sketch a graph to show how the reactant concentration changes with time in a typical chemical reaction taking place in solution. Show how the rate of the reaction at a particular time can be determined.  

(c) A solution of hydrogen peroxide, \( \text{H}_2\text{O}_2 \), is added to a solution of sodium iodide, \( \text{NaI} \), acidified with hydrochloric acid, \( \text{HCl} \). The yellow colour of the iodine, \( \text{I}_2 \), can be used to determine the rate of reaction.

\[
\text{H}_2\text{O}_2(\text{aq}) + 2\text{NaI}(\text{aq}) + 2\text{HCl}(\text{aq}) \rightarrow 2\text{NaCl}(\text{aq}) + \text{I}_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l})
\]

The experiment is repeated with some changes to the reaction conditions. For each of the changes that follow, predict, stating a reason, its effect on the rate of reaction.

(i) The concentration of \( \text{H}_2\text{O}_2 \) is increased at constant temperature.  

(ii) The solution of \( \text{NaI} \) is prepared from a fine powder instead of large crystals.  

(d) Explain why the rate of a reaction increases when the temperature of the system increases.
1. The diagram shows the apparatus used to study the rate of reaction between calcium carbonate and hydrochloric acid.

\[ \text{CaCO}_3(s) + 2\text{HCl}(aq) \rightarrow \text{CaCl}_2(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \]

(a) 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 \(1.00 \text{ mol dm}^{-3}\) \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 1.

![Graph showing mass vs. time](image_url)
(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 CaCO$_3$(s)/g</th>
<th>Volume of 1.00 mol$\text{dm}^{-3}$ HCl(aq)/cm$^3$</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>

(b) Further experiments were carried out using the reaction in part (a), making only one change to Experiment 1. In Experiment 4, the mass of small pieces of calcium carbonate used was 5.00 g. In Experiment 5, the temperature of the mixture was increased by 30°C. In both cases, the reaction was faster than in Experiment 1.

(i) Use the collision theory to explain the main reason why Experiment 4 was faster than Experiment 1.

(ii) Use the collision theory to explain the main reason why Experiment 5 was faster than Experiment 1.

(d) When 2.0 g of calcium carbonate pieces, CaCO$_3$ react with 50 cm$^3$ of 2.0 mol$\text{dm}^{-3}$ hydrochloric acid, HCl(aq), at 25°C, carbon dioxide gas is evolved. Describe the effect of the following changes on the rate of reaction between CaCO$_3$ and HCl and explain your answer in terms of the collision theory.

(i) The same mass of CaCO$_3$ pieces react with 50 cm$^3$ of 1.0 mol$\text{dm}^{-3}$ HCl(aq) at 25°C.

(ii) The same mass of CaCO$_3$ pieces react with 100 cm$^3$ of 2.0 mol$\text{dm}^{-3}$ HCl(aq) at 25°C.
(iii) The same mass of CaCO₃ powder reacts with 50 cm³ of 2.0 mol dm⁻³ HCl(aq) at 25°C. [2]

(iv) The same mass of CaCO₃ pieces reacts with 50 cm³ of 2.0 mol dm⁻³ HCl(aq) at 35°C. [3]

(e) State why the addition of a catalyst increases the rate of a reaction. [1]

Chem 6 Q# 13/ IB Chem/2007/s/TZ1/Paper 2 Section A/Standard Level/

1. Excess 0.100 mol dm⁻³ nitric acid is added to a certain mass of powdered calcium carbonate at 20°C. The rate of reaction is monitored by measuring the change in mass over time due to the loss of carbon dioxide.

\[ 2\text{HNO}_3(aq) + \text{CaCO}_3(s) \rightarrow \text{Ca(NO}_3)_2(aq) + \text{H}_2\text{O(l)} + \text{CO}_2(g) \]

![Graph showing mass loss over time]

(a) Define the term rate of reaction. [1]

(b) Explain why the mass loss remains constant after a certain time. [1]

(c) Draw a line on the graph above, to show what the graph would look like if the same mass of calcium carbonate in larger pieces were reacted with excess 0.100 mol dm⁻³ nitric acid. [1]
(d) Explain in terms of the collision theory what would happen to the rate if the reaction was conducted at 50 °C.

(c) Determine the rate of formation of carbon dioxide when the nitric acid reacts at a rate of $2.00 \times 10^{-3}$ mol cm$^{-3}$ s$^{-1}$.

(f) Calculate the volume of carbon dioxide produced at 1.01×10$^5$ Pa and 20.0°C when 0.350 g of calcium carbonate reacts with excess 0.100 mol dm$^{-3}$ nitric acid.
### Topic 6 Mark Scheme

**Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q3**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
</table>
| 3. d     | ![Graph](image) | five points plotted correctly ✓  
best fit line drawn with ruler, going through the origin ✓ | 2 |

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
</table>
| 3. e     | ![Graph](image) | 22.5 \( \times 10^{-3} \text{ s}^{-1} \) ✓  
\( \text{Time} = \frac{1}{22.5 \times 10^{-3}} \approx 44.4 \text{ s} \) ✓ | Award [2] for correct final answer.  
Accept value based on candidate's graph. | 2 |

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
</table>
| 3. i i   | ![Graph](image) | correctly labelled axes ✓  
peak of \( T_1 \) curve lower AND to the right of \( T_2 \) curve ✓ | 2 |
<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. f ii</td>
<td>greater proportion of molecules have $E \geq E_a$ or $E &gt; E_a$ OR greater area under curve to the right of the $E_a$ ✓</td>
<td>Accept more molecules have energy greater than $E_a$ Do not accept just “particles have greater kinetic energy”. Accept “rate/...” OR “rate/chance/probability/likelihood” instead of “frequency”. Accept suitably shaded/annotated diagram. Do not accept just “more collisions”.</td>
<td>2</td>
</tr>
<tr>
<td>3. g</td>
<td>shorter reaction time so larger «%» error in timing/reading when mark disappears ✓</td>
<td>Accept cooling of reaction mixture during course of reaction.</td>
<td>1</td>
</tr>
</tbody>
</table>

### Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q1

<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>$K_c = \frac{[HOCH_2CH,OCH_2]}{[CO_2]^2 \times [H_2]^3}$ ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. a ii</td>
<td>Position of equilibrium: moves to right OR favours product ✓</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>$K_c$: no change OR is a constant at constant temperature ✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Q# 3/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q2

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>a vi</td>
<td>Potential energy Reactants Products Progress of reaction correct positions of reactants and products ✓ correct profile with labels showing activation energy with and without a catalyst ✓</td>
<td></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. a i</td>
<td>$K_i = \frac{[COCl_2]}{[CO][Cl_2]}$ ✔</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>3. a ii</td>
<td>no effect ✔</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>3. b i</td>
<td><img src="Image1.png" alt="Diagram" /></td>
<td>products lower than reactants and enthalpy of reaction correctly marked and labelled with name or value ✔</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>activation energy correctly marked and labelled with name or value ✔</td>
<td></td>
</tr>
<tr>
<td>3. b ii</td>
<td><img src="Image2.png" alt="Diagram" /></td>
<td>lower dotted curve, between same reactants and product levels, labelled &quot;Catalysed&quot; ✔</td>
<td>1</td>
</tr>
<tr>
<td>3. b iii</td>
<td><img src="Image3.png" alt="Diagram" /></td>
<td>second curve at a higher temperature is correctly drawn (maximum lower and to right of original) ✔</td>
<td>1</td>
</tr>
<tr>
<td>3. b iv</td>
<td><img src="Image4.png" alt="Diagram" /></td>
<td>greater proportion of molecules have $E \geq E_a$ or $E &gt; E_a$ ✔</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>greater area under curve to the right of the $E_a$ ✔</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>greater frequency of collisions between molecules or more collisions per unit time/second ✔</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Accept other clear ways of indicating energy/enthalpy changes.
- Do not accept just particles have greater kinetic energy.
- Do not accept just "more collisions".
Q# 5/ IB Chem/2012wQ3

(c)  

(i) **minimum/least/smallest** energy needed (by reactants/colliding particles) to react/start/initiate a reaction;  
**Allow energy difference between reactants and transition state.**  

(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.**
Q# 6/ IB Chem/2012/s/TZ1/Paper 2 Section A/Standard Level/

1. (a) (i) bromine/Br₂; 
   \[ \text{Do not allow Br or bromide/Br}^- \].
   [1]

   (ii) \[ 7.9 \times 10^{-5} \text{ (mol dm}^{-3} \text{ s}^{-1}) \]; 
   The number of significant figures must be correct. 
   Allow \[ 8.0 \times 10^{-5} \text{ (mol dm}^{-3} \text{ s}^{-1}) \].
   (only 2 significant figures) because of precision of time/[Br₂] measurements:
   Allow answers based on rate laws or orders of reaction.
   M2 can only be scored if M1 correct.
   [2]

   (iii) \([\text{Br}_2] \): 1% and \( \text{Time:} \) 0.8%; 
   \(\text{Percentage Uncertainty:} \) 1.8%; 
   Accept Percentage Uncertainty: 2%. 
   Do not allow answers based on rate laws or orders of reaction.
   [2]

(b) (i) rate doubles; 
   \(\text{Do not allow rate increases.}\)
   increased frequency of collisions / more collisions per unit time; 
   Do not accept “more collisions”.
   [2]

   (ii) catalyst increases rate of reaction without chemically changing/being consumed / OWTTE; 
   Do not award mark for stating catalyst increases rate of forward and reverse reactions (equally).
   catalyst lowers activation energy / offers an alternative reaction pathway; 
   [1 max]

   (iii) (valid hypothesis) as rate increases as \([\text{H}^+]\) increases/comparing data in Experiments 1 and 4; 
   \(\text{H}^+ \) is not in equation/does not chemically change / OWTTE; 
   No marks awarded if invalid hypothesis stated.
   [2]

Q# 7/ IB Chem/2011wQ1

(d) (i) \( \frac{34.1}{0.0400} = 853 \text{ dm}^3 \text{ s}^{-1} / \left( \frac{1.50}{0.0400} \right) = 37.5 \text{ mol s}^{-1} \); 
   Accept 851 dm³ s⁻¹. 
   Units required for mark.
   [1]

   (ii) more energetic collisions / more species have energy \( \geq E_r \); 
   Allow more frequent collisions / species collide more often.
   [1]
(b) minimum energy needed (by reactants/colliding particles) to react/start/initiate a reaction;  
Allow energy difference between reactants and transition state.  

(c) catalyst;  
regenerated at end of reaction / OWTTE;  

(d) (i) (system) absorbs/takes in heat from surroundings / OWTTE.  
Allow standard enthalpy change $\Delta H^\circ$ positive.  
Allow bond breaking more energetic than bond formation / 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.  

Award [2 max] if a second curve is drawn, but at a higher temperature, M2 will not be scored here.  

(e) (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.
Q# 9/ IB Chem/2010/s/TZ1/Paper 2 Section A/Standard Level/

2.  (a) \([I_2]\) does not affect rate / OWTTE;
    neither correct/both partially correct with explanation as to how; \([2]\)

(b) more particles/molecules have sufficient energy to overcome activation energy / OWTTE;
    more frequent collisions; \([2]\)

(c) (i)

\[
\begin{array}{c}
\text{axes correctly labelled } x = \text{energy/velocity/speed, } y = \text{number/}\%	ext{ of} \\
\text{molecules/particles/probability; graph showing correct curve for} \\
\text{Maxwell-Boltzmann distribution; If two curves are drawn, first and} \\
\text{second mark can still be scored, but not third. Curve(s) must begin} \\
\text{at origin and not go up at high energy.}
\end{array}
\]

\[\text{two activation energies shown with } E_{\text{act}} \text{ shown lower.}
\]
\[\text{Award the mark for the final point if shown on an enthalpy level diagram.} \]

(ii) catalyst provides an alternative pathway of lower energy / OWTTE;
    Accept catalyst lowers activation energy (of reaction). \([1]\)

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(b)

\[
\begin{array}{c}
\text{labelled axes (including appropriate units);}
\text{correctly drawn curve,}
\text{correctly drawn tangent;}
\end{array}
\]

rate equal to slope/gradient of tangent (at given time) / rate \[= \frac{y}{x} \] at time \(t\); \([4]\)

[3 max] for straight line graph or graph showing product formation.
(c)  
(i) increases rate of reaction;  
molecules (of $\text{H}_2\text{O}_2\text{.}$) collide more frequently / more collisions per unit time;  
No ECF here. \[2\]

(ii) no effect / (solution) remains unchanged;  
solid NaI is not reacting / aqueous solution of NaI is reacting / surface area of NaI  
is not relevant in preparing the solution / OWTTE. \[2\]

(d) kinetic energy/speed of reacting molecules increases;  
frequency of collisions increases per unit time;  
greater proportion of molecules have energy greater than activation energy/$E_a$; \[3 \text{ max}\]  
Accept more energetic collisions.

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(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 max].

(b)  
(i) greater surface area (of CaCO$_3$);  
more frequent collisions (between reactant particles) / OWTTE;  
Accept ions, but not atoms or molecules, instead of particles.  
Do not accept just more collisions without reference to time. \[2\]

(ii) particles move faster / have more energy;  
Accept ions, but not atoms or molecules, instead of particles, unless already  
penalized in (b)(i).  
more particles have $E > E_a$;  
more successful collisions; \[2 \text{ max}\]

If no points scored, award [1] for “more frequent collisions”.

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(d)  
(i) rate of reaction decreases;  
less frequent collisions between reactants; \[2\]

(ii) no effect;  
no change in concentration of HCl; \[2\]

(iii) rate of reaction increases;  
increase in surface area increases frequency of collisions; \[2\]

(iv) rate of reaction increases;  
kinetic energy of reacting particles increases, more frequent collisions;  
greater proportion of particles have energy $\geq E_a$; \[3\]  
(i) – (iv) second mark dependent on correct first mark

(c) activation energy is lowered; \[1\]
1. (a) change of concentration/mass/amount/volume of a reactant/product with time;  
   Do not accept “substance”.  
   [1]
(b) all the \( \text{CaCO}_3(s) \) has been consumed / no further \( \text{CO}_2(g) \) is produced / reaction is complete;  
   Do not accept reaction has stopped or all reactants used up.  
   [1]
(c) line on graph should be initially less steep / a smaller gradient and should plateau at the same mass loss;  
   [1]
(d) there are more particles with KE greater than or equal to \( E_a \);  
   collisions more frequent / more collisions per unit time / more successful forceful collisions per unit time;  
   the rate increases;  
   [3]
(e) \( 1.00 \times 10^{-3} \) (mol cm\(^{-2}\) s\(^{-1}\));  
   Ignore units even if wrong.  
   Apply \(-1\) (sf).  
   [1]
(f) \( n(\text{CO}_2) = n(\text{CaCO}_3) = \frac{0.350}{100.09 \text{ g mol}^{-1}}; \)  
   \[ V = \frac{nRT}{P} / V(\text{CO}_2) = \frac{n(\text{CO}_2) \times 293 \times 8.31}{1.01 \times 10^5}; \]  
   \[ = 8.43 \times 10^{-3} \text{ m}^3 / 84.3 \text{ cm}^3 / 0.0843 \text{ dm}^3; \]  
   [3]  
   Units required for mark.  
   Apply \(-1\) (SF).  
   Award [3] for correct final answer.  
   Allow for ECF from \( n(\text{CaCO}_3) \) up to [2 max].
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:

\[ \text{HO}^*(g) + \text{SO}_2(g) \rightarrow \text{HOSO}_2(g) \]
\[ \text{HOSO}_2(g) + \text{O}_2(g) \rightarrow \text{HOO}^*(g) + \text{SO}_3(g) \]
\[ \text{SO}_3(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_4(aq) \]

(v) Consider the following equilibrium between the two oxides of sulfur, sulfur dioxide and sulfur trioxide:

\[ 2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g) \quad \Delta H = -198 \text{ kJ} \]

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 to the mixture</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Phosgene, COCl₂, is usually produced by the reaction between carbon monoxide and chlorine according to the equation:

\[ \text{CO}(g) + \text{Cl}_2(g) \rightleftharpoons \text{COCl}_2(g) \quad \Delta H = -108 \text{ kJ} \]

(a) (i) Deduce the equilibrium constant expression, \( K_c \), for this reaction.

(ii) State the effect of an increase in the total pressure on the equilibrium constant, \( K_c \).
(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) Identify one other important industrial synthesis that is an equilibrium reaction. \[1\]
(d) State and explain the effect of the following changes on the equilibrium position of the reaction in part (c).

(i) Increase in temperature.  

(ii) Increase in pressure.  

(iii) Addition of a catalyst.
3. Chemical equilibrium and kinetics are important concepts in chemistry.

(a) A glass container is half-filled with liquid bromine and then sealed. The system eventually reaches a dynamic equilibrium. State one characteristic of a system in equilibrium. [1]

(b) The oxidation of sulfur dioxide is an important reaction in the Contact process used to manufacture sulfuric acid.

\[ 2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g) \quad \Delta H = -198.2 \text{ kJ} \]

(i) Deduce the equilibrium constant expression, \(K_c\). [1]

(ii) Predict how each of the following changes affects the position of equilibrium and the value of \(K_c\). [3]

<table>
<thead>
<tr>
<th>Position of equilibrium</th>
<th>Value of (K_c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decrease in temperature</td>
<td></td>
</tr>
<tr>
<td>Increase in pressure</td>
<td></td>
</tr>
<tr>
<td>Addition of a catalyst</td>
<td></td>
</tr>
</tbody>
</table>
6. Consider the equilibrium system involving bromine and its hydride.

(a) State an equation to represent the equilibrium with $\text{H}_2(\text{g})$ and $\text{Br}_2(\text{g})$ as reactants. \([1]\)

(b) (i) Predict what happens to the position of equilibrium if a small amount of hydrogen is introduced. \([1]\)

(ii) State and explain the effect of increasing the pressure on the position of equilibrium. \([2]\)
(c) (i) Deduce the equilibrium constant expression, $K_c$, for the equilibrium in (a).

(ii) State the effect of increasing [H$_2$] on the value of $K_c$.

(iii) When bromine dissolves in water, 1% of the original bromine molecules react according to the following equation.

\[ \text{Br}_2 \text{(aq)} + \text{H}_2\text{O (l)} \rightleftharpoons \text{HOB}_\text{r (aq)} + \text{HBr (aq)} \]

(iv) State and explain what happens to the equilibrium, in (e), when aqueous sodium hydroxide is added to the reaction solution at equilibrium.
6. (a) Consider the following equilibrium:

\[ 4\text{NH}_3(g) + 5\text{O}_2(g) \rightleftharpoons 4\text{NO}(g) + 6\text{H}_2\text{O}(g) \quad \Delta H^\circ = -909 \text{ kJ} \]

(i) Deduce the equilibrium constant expression, \( K_c \), for the reaction. \([1]\)

(ii) Predict the direction in which the equilibrium will shift when the following changes occur. \([4]\)

- The volume increases.
- The temperature decreases.
- \(\text{H}_2\text{O}(g)\) is removed from the system.
- A catalyst is added to the reaction mixture.

(e) Nitrogen reacts with hydrogen to form ammonia in the Haber process, according to the following equilibrium.

\[ \text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) \quad \Delta H^\circ = -92.6 \text{ kJ} \]
(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.
3. 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, \( K_c \), 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. [2]

(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. [1]

Chem 7 Q# 8/ IB Chem/2010/wtz0/Paper 2 Section B/Standard Level/

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.

\[ \text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) \]

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) Explain the effect of increasing the temperature on the rate of reaction. [2]
Chem 7 Q# 9/ IB Chem/2010/s/tz1/Paper 2 Section B/Standard Level/

(d) (i) A state of equilibrium can exist when a piece of copper metal is placed in a solution of copper(II) sulfate. Outline the characteristics of a chemical system in dynamic equilibrium. [2]

(ii) For an exothermic reaction state how an increase in temperature would affect both $K_c$ and the position of equilibrium. [2]

Chem 7 Q# 10/ IB Chem/2009sQ1

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:

$$
\text{H}_2\text{C}=\text{O} \text{O}_\text{R} + 3 \text{CH}_3\text{OH} (l) \xrightleftharpoons[\text{NaOH}(s)]{\text{H}_2\text{O}} \text{H}_2\text{C}=\text{O} \text{H} + 3 \text{CH}_3\text{O} - \text{C} - \text{R} (l)
$$

where 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]
5. (a) Consider the following reaction taking place at 375 °C in a 1.00 dm³ closed container.

\[ \text{Cl}_2(g) + \text{SO}_2(g) \rightleftharpoons \text{SO}_2\text{Cl}_2(g) \quad \Delta H^\circ = -84.5 \text{ kJ} \]

(i) Deduce the equilibrium constant expression, \( K_c \), for the reaction. [1]

(ii) 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]

(iii) If the volume of the container is changed to 1.50 dm³, 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]

(iv) 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]

Chem 7 Q# 12/ IB Chem/2008/s/tz1/Paper 2 Section B/Standard Level/

7. (a) 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, giving 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]

(b) Deduce the equilibrium constant expression, \( K_c \), including units for the forward reaction in part (a). [2]

(c) Identify which of the changes in part (a) will affect the value of \( K_c \) and predict whether the value of \( K_c \) will increase or decrease. [2]
4. Ammonia is produced by the Haber process according to the following reaction.

\[ \text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g}) \quad \Delta H \text{ is negative} \]

(a) State the equilibrium constant expression for the above reaction. [1]

(b) Predict, giving a reason, the effect on the position of equilibrium when the pressure in the reaction vessel is increased. [2]

(c) State and explain the effect on the value of \( K_c \) when the temperature is increased. [2]

(d) Explain why a catalyst has no effect on the position of equilibrium. [1]
## Topic 7 Mark Scheme

### Q# 1/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q2

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>[Image: Change][Shift][Reason]</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>a</td>
<td>v</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase in temperature</td>
<td>LHS</td>
<td>since forward exothermic reaction ( \Delta H &lt; 0 ) ✓</td>
<td></td>
</tr>
<tr>
<td>Increase in pressure</td>
<td>RHS</td>
<td>since fewer gaseous molecules on RHS ✓</td>
<td></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>
<td></td>
</tr>
</tbody>
</table>

### Q# 2/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q3

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>a i</td>
<td>( K_c \rightarrow [COCl_2] / [CO][Cl_2] ) ✓</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>a ii</td>
<td>no effect ✓</td>
<td>1</td>
</tr>
</tbody>
</table>

### Q# 3/ IB Chem/2013/s/tz1/Paper 2 Section B/Standard Level/q7

(c) (i) rate of forward reaction equals rate of backward reaction; concentrations of reactants and products do not change / constant macroscopic properties; [2]

(ii) \( K_c = \frac{[CH_3OH]}{[CO][H_2]} \); [1]

*Do not award mark if incorrect brackets are used or brackets omitted.*

(iii) Haber process/production of NH\(_3\) / contact process/production of H\(_2\)SO\(_4\); *Accept suitable equation.* [1]

(d) (i) shifts to left/reactants; to endothermic side / (forward) reaction is exothermic; [2]

(ii) shifts to the right/products; to the side with fewer gas molecules/moles of gas; [2]

(iii) no effect on equilibrium; rate of forward and backward reaction increase *equally* / activation energy of forward and backward reaction lowered *equally*; [2]
Q# 4/ IB Chem/2012/w/TZ0/Paper 2 Section A/Standard Level/

3. (a) rate of forward process/reaction = rate of backwards/reverse process/reaction / rate of vaporization/evaporation = rate of condensation; concentrations of reactants and products remain constant; no change in macroscopic properties / closed system / constant matter/energy / OWTTE;  
Do not accept concentration of reactants and products are equal. 
Accept constant colour of Br₂ vapour/liquid.  

(b) (i) \( K_c = \frac{[SO_2]^2}{[SO_2]^2[O_2]} \);  

(ii) | Position of equilibrium | Value of \( K_c \) |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Decrease in temperature</td>
<td>shifts to right/products</td>
</tr>
<tr>
<td>Increase in pressure</td>
<td>shifts to right/products</td>
</tr>
<tr>
<td>Addition of a catalyst</td>
<td>no effect</td>
</tr>
</tbody>
</table>


Q# 5/ IB Chem/2012/s/tz1/Paper 2 Section B/Standard Level/

6. (a) \( H_2(g) + Br_2(g) \rightarrow 2HBr(g) \);  

(b) (i) shifts to right/toward products/forward reaction favoured;  
Accept reverse statement if process written the other way around. Answer must match stated equation.  

(ii) no effect;  
same amounts/number of (gaseous) moles/molecules on both sides;  

(c) (i) \( K_c = \frac{[HBr]^2}{[H_2][Br_2]} \);  

(ii) no effect (only depends on the temperature);  

(e) (i) \( Br_2: 0 \)  
\( HBr: -1 \)  
\( HOBr: +1 \)  
Award [2] for three correct.  
Award [1] for any two correct.  

(ii) bromine is oxidized and reduced / disproportionation;  

(iii) \( K_c < 1 \);  

(iv) shifts to right/toward products/forward reaction favoured;  
to replace \( H^+ / HBr / HOBr \) / to remove \( H_2O \) formed from neutralization;
Q# 6/ IB Chem/2011/w/tz0/Paper 2 Section B/Standard Level/

6. (a) (i) \( K_v \) = \[ \frac{[NO]^n[H_2O]^m}{[NH_3]^n[O_2]^m} \] ; \[1\]

*No mark if square brackets are omitted or are incorrect.*

(ii) right;
right;
right;
no change; \[4\]

(e)

(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;

**Temperature:**
low temperature shifts equilibrium (even further) to right;

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 / OWTT;

Q# 7/ IB Chem/2011/s/TZ1/Paper 2 Section A/Standard Level/

3. (a) \( K_v = \frac{[CH_2OH]}{[CO][H_2]} \) ; \[1\]

*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 / OWTT; \[2\]

(ii) amount (of methanol)/product increases / more methanol;
3 gas molecules/mol → 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/Ea (of both the forward and reverse reaction equally) / provides alternative path with lower activation energy/Ea;

**Accept reactants adsorb onto the catalyst surface and bonds weaken resulting in a decrease in the activation energy.** \[1\]
Q# 8/ IB Chem/2010/w/tz0/Paper 2 Section B/Standard 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 max]

   (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) (rate increases because) increase in frequency (of collisions);
     increase in energy (of collisions);
     more colliding molecules with $E \geq E_a$;  [2 max]

Q# 9/ IB Chem/2010/s/tz1/Paper 2 Section B/Standard Level/

(d) (i) macroscopic properties remain constant / concentrations remain constant / no
     change to copper solution seen;
     rate of reverse/backwards reaction = rate of forward reaction;  [2]

   (ii) $K_c$ decreases;
     position of equilibrium shifts to left;  [2]

Q# 10/ IB Chem/2009/s/TZ1/Paper 2 Section A/Standard Level/

(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) $K_c = \frac{[\text{glycerol}] \times [\text{biodiesel}]^3}{[\text{vegetable oil}] \times [\text{methanol}]}$;  [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;
     * No ECF for explanation.  [2]
Q# 11/ IB Chem/2009/w/tz0/Paper 2 Section B/Standard Level/

5. (a)  \( K_c = \frac{[\text{SO}_2\text{Cl}_2]}{[\text{Cl}_2][\text{SO}_1]} \); \[1\]
   
   *Ignore state symbols.*  
   
   *Square brackets [*] required for the equilibrium expression.*  
   
   (ii) value of \( K_c \) increases;  
   
   \([\text{SO}_2\text{Cl}_2] \) increases;  
   
   *decrease in temperature favours (forward) reaction which is exothermic;*  
   
   *Do not allow ECF.*  
   
   (iii) no effect on the value of \( K_c \) depends only on temperature;  
   
   \([\text{SO}_2\text{Cl}_2] \) decreases;  
   
   *increase in volume favours the reverse reaction which has more gaseous moles;*  
   
   *Do not allow ECF.*  
   
   (iv) no effect;  
   
   *catalyst increases the rate of forward and reverse reactions (equally) / catalyst decreases activation energies (equally);*  
   
   Q# 12/ IB Chem/2008/s/tz1/Paper 2 Section B/Standard Level/

7. (a) (i) (equilibrium shifted to the left) equilibrium concentration of NO is reduced;  
   
   *more gas molecules on the right hand side than on the left;*  
   
   (ii) (equilibrium shifted to the left) equilibrium concentration of NO is reduced;  
   
   (forward) reaction is exothermic;  
   
   (iii) no effect on the equilibrium concentration of NO;  
   
   *catalyst increases the rate of forward and reverse reaction equally;*  
   
   (b) \[ K_c = \frac{[\text{NO}]^5[\text{H}_2\text{O}]^8}{[\text{NH}_4]^4[\text{O}_2]}; \]  
   
   mol dm\(^{-3}\);  
   
   (c) increase in temperature;  
   
   \( K_c \) decreases;  
   
   Q# 13/ IB Chem/2007/s/TZ1/Paper 2 Section A/Standard Level/

4. (a)  \( K_c = \frac{[\text{NH}_4]^5}{[\text{H}_2]^5[\text{N}_2]}; \) \[1\]
   
   *Do not allow round brackets unless \( K_p \) is used.*  
   
   (b) equilibrium shifts to the right / products;  
   
   4 mol \( \rightarrow \) 2 mol of gas / fewer moles of gas on the right/products;  
   
   (c) \( K_c \) decreases;  
   
   *equilibrium position shifts to the left/reactants / forward reaction is exothermic / reverse reaction is endothermic;*  
   
   (d) catalyst increases the rate of the forward and backward reactions equally / lowers the activation energy of both forward and backward reaction equally / lowers \( E_a \) so rate of forward and backward reactions increase;  
   
   [1]
3. Sodium thiosulfate solution reacts with dilute hydrochloric acid to form a precipitate of sulfur at room temperature.

\[ \text{Na}_2\text{S}_2\text{O}_3 (aq) + 2\text{HCl (aq)} \rightarrow \text{S (s)} + \text{SO}_2 (g) + 2\text{NaCl (aq)} + \text{X} \]

(a) Identify the formula and state symbol of X.

(b) Suggest why the experiment should be carried out in a fume hood or in a well-ventilated laboratory.

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.

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.
Chem 8 Q# 3/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q2(a)

(vii) Sulfuric acid, \( \text{H}_2\text{SO}_4 \), can be described as a Brönsted–Lowry acid. State what you understand by this description. [1]

(viii) The hydrogen sulfate ion, \( \text{HSO}_4^- \), is amphiprotic, so can act as an acid or a base. In the reaction of \( \text{HSO}_4^- \) with the hydronium cation, \( \text{H}_3\text{O}^+ \), identify the two species acting as bases.

\[ \text{HSO}_4^- (\text{aq}) + \text{H}_3\text{O}^+ (\text{aq}) \rightleftharpoons \text{H}_2\text{SO}_4 (\text{aq}) + \text{H}_2\text{O} (l) \] [1]

Chem 8 Q# 4/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q2

2. Impurities cause phosphine to ignite spontaneously in air to form an oxide of phosphorus and water. (b) Phosphorus Oxide reacts with water.

(ii) Predict how dissolving an oxide of phosphorus would affect the pH and electrical conductivity of water. [1]

\[ \text{pH}: \]

\[ \text{Electrical conductivity}: \]

(iii) Suggest why oxides of phosphorus are not major contributors to acid deposition. [1]
(iv) The levels of sulfur dioxide, 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:

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Chem 8 Q# 5/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q1

1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula PH₃.

(b)

(iii) The ion H₃PO₂⁻ is amphiprotic. Outline what is meant by amphiprotic, giving the formulas of both species it is converted to when it behaves in this manner.
(d) A solution of HA is a weak acid. Distinguish between a weak acid and a strong acid. [1]

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(e) Describe an experiment, other than measuring the pH, to distinguish HA from a strong acid of the same concentration and describe what would be observed. [2]

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(c) (i) Deduce the Lewis structures of NH$_3$ and BF$_3$.

\[
\begin{array}{cc}
\text{NH}_3 & \text{BF}_3 \\
\end{array}
\]

(ii) Describe how covalent bonds are formed.

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(iii) Compare the shapes of the two molecules and explain the difference using valence shell electron pair repulsion theory (VSEPR).

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(iv) Predict and explain whether the molecules NH₃ and BF₃ are polar molecules. [2]

(b) Nitric acid, HNO₃, is strong and nitrous acid, HNO₂, is weak.

(i) Define an acid according to the Brønsted–Lowry and Lewis theories. [2]

Brønsted–Lowry theory:

Lewis theory:

(iv) Distinguish between a strong acid and a weak acid in terms of their dissociation in aqueous solution. [1]
(vi) When lime was added to a sample of soil, the pH changed from 5 to 7. Calculate the factor by which the hydrogen ion concentration changes.

(vii) One common nitrogen-containing fertilizer is ammonium sulfate. State its chemical formula.

(d) 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.
Chem 8 Q# 11/ IB Chem/2012/s/tz1/Paper 2 Section B/Standard Level/q5b

(iii) Carbon dioxide and silicon dioxide can both be described as acidic oxides. Describe the pH changes that occur when each is added to separate samples of water. [2]

Chem 8 Q# 12/ IB Chem/2011/w/tz0/Paper 2 Section B/Standard Level/

(iii) Z is an example of a weak acid. State what is meant by the term weak acid. [1]

Chem 8 Q# 13/ IB Chem/2011/s/tz1/Paper 2 Section B/Standard Level/ q5

(c) (i) Define the terms acid and base according to the Brønsted-Lowry theory and state one example of a weak acid and one example of a strong base. [2]
(ii) Describe two different methods, one chemical and one physical, other than measuring the pH, that could be used to distinguish between ethanoic acid and hydrochloric acid solutions of the same concentration.

(iii) Black coffee has a pH of 5 and toothpaste has a pH of 8. Identify which is more acidic and deduce how many times the $[H^+]$ is greater in the more acidic product.

(d) Samples of sodium oxide and sulfur trioxide are added to separate beakers of water. Deduce the equation for each reaction and identify each oxide as acidic, basic or neutral.
Chem 8 Q# 14/ IB Chem/2010sQ3b
Ethanoic acid has the formula CH₃COOH

(iii) State an equation, including state symbols, for the reaction of ethanoic acid with water. Identify a Brønsted-Lowry acid in the equation and its conjugate base. [3]

Chem 8 Q# 15/ IB Chem/2010s/w/tz0/Paper 2 Section B/Standard Level/q6

(c) The nitrite ion is present in nitrous acid, HNO₂, which is a weak acid. The nitrate ion is present in nitric acid, HNO₃, which is a strong acid. Distinguish between the terms strong and weak acid and state the equations used to show the dissociation of each acid in aqueous solution. [3]

(d) A small piece of magnesium ribbon is added to solutions of nitric and nitrous acid of the same concentration at the same temperature. Describe two observations that would allow you to distinguish between the two acids. [2]

(e) 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 nitrous 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]
(f) The graph below shows how the conductivity of the two acids changes with concentration.

![Graph showing conductivity vs. concentration for Acid 1 and Acid 2.]

Identify **Acid 1** and explain your choice. [2]

Chem 8 Q# 16/ IB Chem/2010/w/tz0/Paper 2 Section B/Standard Level/q4

(f) The reaction between $\text{N}_2\text{H}_4(\text{aq})$ and $\text{HCl}(\text{aq})$ 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]

Chem 8 Q# 17/ IB Chem/2009sQ3

(c) (i) State the acid-base nature of sodium oxide. [1]

(ii) State the equation for the reaction of sodium oxide with water. [1]
6. (a) The equations of two acid-base reactions are given below.

Reaction A \[ \text{NH}_3(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq) \]

The reaction mixture in A consists mainly of reactants because the equilibrium lies to the left.

Reaction B \[ \text{NH}_2^- (aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NH}_3(aq) + \text{OH}^-(aq) \]

The reaction mixture in B consists mainly of products because the equilibrium lies to the right.

(i) For each of the reactions A and B, deduce whether water is acting as an acid or a base and explain your answer. \[2\]

(ii) In reaction B, identify the stronger base, \(\text{NH}_2^-\) or \(\text{OH}^-\) and explain your answer. \[2\]

(iii) In reactions A and B, identify the stronger acid, \(\text{NH}_4^+\) or \(\text{NH}_3\) (underlined) and explain your answer. \[2\]

(b) Describe two different experimental methods to distinguish between aqueous solutions of a strong base and a weak base. \[5\]

(c) Two acidic solutions, X and Y, of equal concentrations have pH values of 2 and 6 respectively.

(i) Calculate the hydrogen ion concentrations in the two solutions and identify the stronger acid. \[2\]

(ii) Determine the ratio of the hydrogen ion concentrations in the two solutions X and Y. \[1\]

(d) (i) Define a Lewis acid and state an example that is not a Brønsted-Lowry acid. \[2\]

(ii) Draw structural formulas to represent the reaction between the Lewis acid named in (d) (i) and a Lewis base and identify the nature of the bond formed in the product. \[4\]
(c)  
(i) Define a Brønsted-Lowry acid. \[1\]

(ii) Deduce the two acids and their conjugate bases in the following reaction:

\[ \text{H}_2\text{O}(l) + \text{NH}_3(\text{aq}) \rightleftharpoons \text{OH}^- (\text{aq}) + \text{NH}_4^+ (\text{aq}) \] \[2\]

(iii) Explain why the following reaction can also be described as an acid-base reaction:

\[ \text{F}^- (g) + \text{BF}_3(g) \rightleftharpoons \text{BF}_4^- (s) \] \[2\]

(d) Ethanoic acid, CH₃COOH, is a weak acid.

(i) Define the term weak acid and state the equation for the reaction of ethanoic acid with water. \[2\]

(ii) Vinegar, which contains ethanoic acid, can be used to clean deposits of calcium carbonate from the elements of electric kettles. State the equation for the reaction of ethanoic acid with calcium carbonate. \[2\]

Chem 8 Q# 20/ IB Chem/2008wQ3

(b) The equation for the reaction that occurs when ammonia gas dissolves in water is shown below.

\[ \text{NH}_3(g) + \text{H}_2\text{O} (l) \rightleftharpoons \text{NH}_4^+ (\text{aq}) + \text{OH}^- (\text{aq}) \]

(i) State how the equation indicates that ammonia is a base. \[1\]

(ii) State how the equation indicates that ammonia is a weak base. \[1\]

(iii) Identify which pH value is approximately correct for ammonia solution. \[1\]
3. (a) (i) A solution of hydrochloric acid has a concentration of 0.10 mol dm$^{-3}$ and a pH value of 1. The solution is diluted by a factor of 100. Determine the concentration of the acid and the pH value in the diluted solution. [2]

(ii) Explain why 0.10 mol dm$^{-3}$ ethanoic acid solution and the diluted solution in (a) (i) have similar [H$^+$] values. [3]

(b) Suggest one method, other than measuring pH, which could be used to distinguish between solutions of a strong acid and a weak acid of the same concentration. State the expected results. [2]
4. (a) Iodide ions, \( \text{I}^- (aq) \), react with iodate ions, \( \text{IO}_3^-(aq) \), in an acidic solution to form molecular iodine and water.

(i) Determine the oxidation number of iodine in each iodine-containing species in the reaction. \([2]\)

(ii) Identify, with a reason, the species that undergoes:

- oxidation \([2]\)
- reduction

(b) Describe how electrolysis is used to plate an object with copper. Write an equation for the reaction occurring at the negative electrode (cathode). \([4]\)
### Topic 8

**Mark Scheme**

#### Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q3

<table>
<thead>
<tr>
<th>3. a</th>
<th>H₂O AND (b) ✓</th>
<th>Do not accept H₂O(aq).</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>SO₂(g) is an irritant/causes breathing problems ⬤ OR SO₂(g) is poisonous/toxic ✓</td>
<td>Accept SO₂(g) is acidic, but do not accept &quot;causes acid rain&quot;. Accept SO₂(g) is harmful. Accept SO₂(g) has a foul/pungent smell.</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q2

<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>
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<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 linear scale/simple numbers ✓</td>
<td>Do not accept &quot;easy for calculations&quot;.</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Q# 3/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q2

<table>
<thead>
<tr>
<th>a</th>
<th>VII proton/H donor ✓</th>
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<tbody>
<tr>
<td>a</td>
<td>VIII HSO₄⁻(aq) and H₂O(l) ✓</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Q# 4/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q2

| 2. b | pH decreases AND electrical conductivity: increases. ✓ | 1 |
| 2. b | i) phosphorus not commonly found in fuels OR no common pathways for phosphorus oxides to enter the air OR amount of phosphorus-containing organic matter undergoing anaerobic decomposition is small ✓ | Accept "phosphorus oxides are solids so are not easily distributed in the atmosphere". Accept "low levels of phosphorus oxide in the air". Do not accept "H₃PO₃ is a weak acid". | 1 |
| 2. b | iv) Pre-combustion: remove sulfur/sulfur containing compounds ✓ Post-combustion: remove SO₂ by neutralization/reaction with alkali/base ✓ | Accept "time injection fluidised bed combustion" for either, but not both. | 2 |

#### Q# 5/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q1

| 1. b | iii) can act as both a Brønsted–Lowry acid and a Brønsted–Lowry base OR can accept and/or donate a hydrogen ion/proton/H⁺ ✓ | 2 |
|      | HPO₄⁻ AND H₂PO₄ ✓ | 1 |

#### Q# 6/ IB Chem/2013sQ1

1. (d) weak acids partially dissociated/ionized and strong acids completely dissociated/ionized (in solution/water) / OWTTE;

2. (e) measuring electrical conductivity; strong acids have greater electrical conductivity / weak acids have lower electrical conductivity;

   OR

   adding a reactive metal / carbonate / hydrogen carbonate;

   *Accept correct example.*

   stronger effervescence with strong acids / weaker with weak acids / OWTTE;

   OR

   adding a strong base;

   *Accept correct example.*

   strong acid would increase more in temperature / weak acids increase less in temperature;
Q# 7/ IB Chem/2013/s/tz1/Paper 2 Section B/Standard Level/q6

(d) (i) electron pair acceptor; [1]

(ii) \( \text{NH}_3 \): Lewis base;
\( \text{BF}_3 \): Lewis acid;
\( \text{NH}_3 \) has non-bonding/lone pair of electrons and \( \text{BF}_3 \) has only 3 pairs of electrons around B/incomplete octet;
Reference to outer electrons of N and B is needed for the mark. [3]

Q# 8/ IB Chem/2013/s/tz1/Paper 2 Section B/Standard Level/q6

(c) (i) \[
\begin{align*}
\text{NH}_3 & : & \text{BF}_3 \\
\begin{array}{c}
\text{H} \\
\text{N} \\
\text{H}
\end{array} & : & \begin{array}{c}
\text{F} \\
\text{B} \\
\text{F}
\end{array} \\
\text{H} & : & \text{F}
\end{align*}
\]
Accept any combination of lines, dots or crosses to represent electron pairs. [2]

(ii) sharing of electrons between atoms; [1]

(iii) \( \text{NH}_3 \): (trigonal/triangular) pyramidal;
\( \text{BF}_3 \): trigonal/triangular planar;
\( \text{NH}_3 \) has 4 negative charges/three bonding pairs and one lone pair and
\( \text{BF}_3 \) has 3 negative centres of charge/three bonding pairs / OWTTE;
(bond angles) \( 107^\circ \) in \( \text{NH}_3 \) and \( 120^\circ \) in \( \text{BF}_3 \);
Accept \( 107.5^\circ \) for \( \text{NH}_3 \). [4]

(iv) \( \text{BF}_3 \) not polar as no net dipole moment / BF bond polarities cancel each other out / symmetrical distribution of charge;
\( \text{NH}_3 \) polar as net dipole moment present / NH bond polarities do not cancel each other out / unsymmetrical distribution of charge;
Accept suitable diagram showing dipole moments.
Do not accept electronegativities cancel out. [2]

Q# 9/ IB Chem/2012/w/tz0/Paper 2 Section B/Standard Level/q5

(b) (i) **Brønsted Lowry theory**: proton/H\(^+\) donor;
**Lewis theory**: electron-pair acceptor; [2]

(iv) **Strong acid**: acid/electrolyte completely/100% dissociated/ionized in solution/water / OWTTE and **Weak acid**: acid/electrolyte partially dissociated/ionized in solution/water / OWTTE; [1]

(vi) changes by \( 10^2/100 \);
Allow changes from \( 10^{-5} \) to \( 10^{-7} \). [1]

(vii) \( \text{(NH}_4\text{)}_2\text{SO}_4 \); [1]

Q# 10/ IB Chem/2012/s/tz1/Paper 2 Section B/Standard Level/q6

(d) **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;
\( \text{HBr(aq)} \rightarrow \text{H}^+(\text{aq}) + \text{Br}^-(\text{aq}) \);
\( \text{HF(aq)} \leftrightarrow \text{H}^+(\text{aq}) + \text{F}^-(\text{aq}) \); [3]
Q# 11/ IB Chem/2012/s/tz1/Paper 2 Section B/Standard Level/q5b

(iii) \( \text{CO}_2 \):
\[ \text{pH (of resultant solution) weakly acidic} \ / \ \text{pH in range} \ 5.5-6.5 \ (\text{accept any value in this range}); \]
\[ \text{SiO}_2; \]
\[ \text{pH remains as 7;} \]

Q# 12/ IB Chem/2011/w/tz0/Paper 2 Section B/Standard Level/

(iii) acid partially dissociates/ions;

Q# 13/ IB Chem/2011q5

(c) (i) acid is a proton/\( H^+ \) donor and base is a proton/\( H^+ \) acceptor;
\( H_2\text{CO}_3/\text{CH}_3\text{COOH} \) and \( \text{NaOH/\text{KOH}/\text{Ba(OH)}_2} \);
Accept any suitable examples.

(ii) **Chemical [2 max]**
reaction with reactive metal/Mg/Zn/carbonate/hydrogen carbonate;
hydrochloric acid would react faster/more vigorously / ethanoic acid would react slower/less vigorously;

**OR**
react with alkali;
temperature change will be more for hydrochloric acid / temperature change will be less for ethanoic acid;

**Physical [2 max]**
conductivity;
hydrochloric acid will conduct more/higher / ethanoic acid will conduct less/lower;
Accept other suitable examples.

(iii) black coffee;
\( 10^3/1000 \) times;

(d) \( \text{Na}_2\text{O}(s) + \text{H}_2\text{O}(l) \rightarrow 2\text{NaOH}(aq) \); \( \text{SO}_2(l) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_4(aq) \);
Ignore state symbols.
Na\(_2\)O: basic and SO\(_3\): acidic;

Q# 14/ IB Chem/2010/s/TZ1/Paper 2 Section A/Standard Level/

(iii) \( \text{CH}_3\text{COOH (aq)} + \text{H}_2\text{O(aq)} \rightleftharpoons \text{CH}_3\text{COO}^-(aq) + \text{H}_3\text{O}^+(aq) \)

OR
\( \text{CH}_3\text{COOH (aq)} \rightleftharpoons \text{CH}_3\text{COO}^-(aq) + \text{H}_3\text{O}^+(aq) \)

OR
\( \text{CH}_3\text{COOH (aq)} \rightleftharpoons \text{CH}_3\text{COO}^-(aq) + \text{H}^+(aq) \)
correct equation;
state symbols and \( \rightleftharpoons \);
BL acid is CH\(_3\)COOH and cb is CH\(_3\)COO\(^-\)/BL acid is H\(_3\)O\(^+\) and cb is H\(_2\)O;
Q# 15/ IB Chem/2010/w/tz0/Paper 2 Section B/Standard Level/q6

(c) strong acid completely dissociated/ionized and weak acid partially dissociated/ionized;
\[ \text{HNO}_3(aq) \rightarrow \text{H}^+(aq) + \text{NO}_3^-(aq) \] \[ \text{HNO}_2(aq) \rightleftharpoons \text{H}^+(aq) + \text{NO}_2^-(aq) \] [3]
Allow only arrows as shown.
State symbols not needed.
Accept \( H_2O \) and \( H_3O^+ \).

(d) With \( \text{HNO}_3 \):
faster rate of bubble/gas/hydrogen production;
faster rate of magnesium dissolving;
higher temperature change; [2 max]
Accept opposite argument for \( \text{HNO}_2 \).
Award [1] if 2 observations given but acid is not identified.
Reference to specific observations needed.

(e) (i) (nitric acid) 7.5 cm\(^3\); [1]
(ii) not valid as nitrous acid reacts with same volume/7.5 cm\(^3\); [1]

(f) \( \text{HNO}_3 \);
(higher conductivity for solutions with same concentration as) there are more ions in solution; [2]

Q# 16/ IB Chem/2010/w/tz0/Paper 2 Section B/Standard Level/q4

(f) (i) acid-base/neutralization; [1]

Q# 17/ IB Chem/2009sQ3

(c) (i) basic;
Allow alkaline [1]

(ii) \( \text{Na}_2\text{O} + \text{H}_2\text{O} \rightarrow 2\text{NaOH} \) / \( \text{Na}_2\text{O} + \text{II}_2\text{O} \rightarrow 2\text{Na}^+ + 2\text{OII}^- \); [1]
Do not accept \( \rightleftharpoons \)
6. (a) (i) acid in both reactions; because it loses a proton/hydrogen ion/\(H^+\) / proton/hydrogen ion/\(H^+\) donor; Second mark can be scored if they do not identify it as an acid in both reactions. \([2]\)

(ii) \(\text{NH}_2^-\); more readily accepts a proton / equilibrium lies to the right / takes \(H^+\) from \(H_2O\); \(\text{If} \text{OH}^- \text{chosen award} [0]\)

(iii) \(\text{NH}_3\); donates a proton more readily than \(\text{NH}_3\) / equilibrium lies to the left; \(\text{If} \text{NH}_3 \text{chosen award} [0]\)

(b) solutions of the same concentration;

pH meter;
strong base has a higher pH / weak base has lower pH;
indicator paper/U I solution;
strong base has a higher pH/more purple / weak base has lower pH/blue not purple / \textit{OWTTE};
measuring conductivity (with conductivity meter);
strong base has a higher conductivity / weak base has lower conductivity;
comparing heat of neutralisation with acid;
strong base releases more heat / weak base releases less heat;
\textit{Award [4 max] for two correct methods with expected results.} \([5]\)

c. (i) \(X\);
\([X] = 10^{-2} \text{ (mol dm}^{-3}\text{)} \) and \([Y] = 10^{-5} \text{ (mol dm}^{-3}\text{)}\); \([2]\)

(ii) \(10000/10^4 : 1\); \([1]\)
\textit{Ratio should be in form above.}

d. (i) (Lewis acid) electron pair acceptor;
appropriate example (such as \(\text{AlCl}_3\), \(\text{BF}_3\) etc.); \([2]\)

(ii) structural formula of Lewis acid (e.g. \(\text{BF}_3\), \(\text{AlCl}_3\), Transition element etc);
structural formula of Lewis base (e.g. \(\text{NH}_3\), \(\text{H}_2\text{O}\) etc);
structural formula of product (e.g. \(\text{F}_3\text{BNH}_3\) etc);
dative covalent (bond)/coordinate (bond); \([4]\)

\[
\text{F} \quad \text{B} \quad \text{H} \quad + \quad \text{N} \quad \text{H} \quad \rightarrow \quad \text{F} \quad \text{B} \quad \text{N} \quad \text{H} \\
\text{F} \quad \text{H} \quad \text{F} \quad \text{H}
\]

Lewis acid \quad Lewis base \quad Product

\textit{Penalize missing structural formulas once.}
Q# 20/ IB Chem/2008wQ3

(b) (i) produces hydroxide/OH⁻ ions / accepts a proton/H⁺ / donates pair of electrons;  
(ii) ⇄ / reversible arrow / incomplete/partial dissociation;  
(iii) 11;

Q# 21/ IB Chem/2007/w/TZ0/Paper 2 Section A/Standard Level/

3. (a) (i) 0.0010 / 1.0×10⁻³ (mol dm⁻³);  
    pH = 3;  
(ii) HCl: strong acid / fully dissociated;  
    CH₃COOH: weak acid / partially dissociated; 
    HCl less concentrated / CH₃COOH more concentrated; 
    only one molecule in 100 dissociates in ethanoic acid so [H⁺] 1/100/ OWTTE [3 max]

(b) measure electrical conductivity;  
strong acids are good conductors / weak acids are poor conductors;  

OR

react with magnesium or a named active metal / (metal) carbonate;  
hydrogen carbonate/bicarbonate;  
strong acids have a faster reaction / more gas bubbles (per unit time) / more heat produced / weak acids have a slower reaction / less gas bubbles (per unit time) / less heat produced;  

Accept answers based on:  
titrination curves: namely strong acid and strong base will have an equivalence point pH of 7 and a weak acid and strong base will have an equivalence point pH of 7.  
OR

temperature change: on neutralization for temperature change: namely, neutralization (H⁺ + OH⁻) is exothermic, weak acid is partially dissociated so some energy used up in dissociation of weak acid – net result, weak acid would produce less energy / less temperature increase compared to neutralization of strong acid.
Q# 22/ IB Chem/2007/w/TZ0/Paper 2 Section A/Standard Level/

4. (a) (i) \[ I^- = -1/1^- \]
\[ IO_3^- = +5/5^+ \]
\[ I_2 = 0 \]  
Award [2] for all three correct, [1] for any two correct,
Signs must be included
Do not accept Roman numerals

(ii) oxidation
\[ I^- \text{ (to } I_2) \text{, increase in oxidation number / loss of electron(s);} \]
reduction
\[ IO_3^- \text{ (to } I^-) \text{, decrease in oxidation number / gain of electron(s);} \] [2]

(b) object to be plated is negative electrode/cathode;
pure copper is positive electrode/anode;
Accept inert electrode
(both electrodes in) solution/electrolyte of copper(II) sulfate/chloride/ CuSO_4 / CuCl_2 ;
Accept an annotated diagram showing all the information for the first [3] marks

\[ Cu^{2+} + 2e^- \rightarrow Cu ; \] [4]

Topic 9
Chem 9 Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q4

(g) Magnesium chloride can be electrolysed.

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 922 K and 987 K
respectively. [2]

<table>
<thead>
<tr>
<th>Anode (positive electrode):</th>
</tr>
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<tbody>
<tr>
<td></td>
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<tr>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Cathode (negative electrode):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Chem 9 Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q1

1. Ethane-1,2-diol, HOCH_2CH_2OH, 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.

\[ 2CO(g) + 3H_2(g) \rightleftharpoons HOCH_2CH_2OH(g) \]
(b) Determine the average oxidation state of carbon in ethene and in ethane-1,2-diol.

| Ethene:                                                                                           |
|                                                                                                   |
| Ethane-1,2-diol:                                                                                  |

Chem 9 Q# 3/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q1

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 cm\(^3\) of the bleach to a 250 cm\(^3\) volumetric flask. The solution was filled to the graduation mark with deionized water.

- 25.00 cm\(^3\) 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, Na\(_2\)S\(_2\)O\(_3\)(aq), using starch indicator.

\[
\text{I}_2 (aq) + 2\text{S}_2\text{O}_3^{2-} (aq) \rightarrow 2\text{I}^- (aq) + \text{S}_4\text{O}_6^{2-} (aq)
\]
(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. \[1\]

NaClO:

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

I\textsubscript{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 +2 on one atom and −2 on the other atom. Discuss this statement in terms of your understanding of oxidation state.

Lewis (electron dot) structure of thiosulfate

(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.

$$\text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$$

Valid:

Not valid:
1. Phosphine (IUPAC name phosphane) is a hydride of phosphorus, with the formula \( \text{PH}_3 \).

(b) 

(iv) State the oxidation state of phosphorus in \( \text{P}_4 \) and \( \text{H}_2\text{PO}_2^- \). 

\[
\begin{align*}
\text{P}_4: & \\
\text{H}_2\text{PO}_2^-:
\end{align*}
\]

(v) 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 \( \text{P}_4 \) to \( \text{H}_2\text{PO}_2^- \) and the way in which the use of oxidation numbers has resolved this.
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.  \([1]\)

(b) Calculate the change in oxidation numbers of carbon and manganese.  \([2]\)

Carbon:

Manganese:

(c) Identify the oxidizing and reducing agents.  \([1]\)

Oxidizing agent:

Reducing agent:
3. Both sodium and sodium chloride can conduct electricity.

(a) Compare how electric current passes through sodium and sodium chloride by completing the table below.

<table>
<thead>
<tr>
<th></th>
<th>Sodium</th>
<th>Sodium chloride</th>
</tr>
</thead>
<tbody>
<tr>
<td>State of matter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particles that conduct the current</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reaction occurring</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(b) Sodium can be obtained by electrolysis from molten sodium chloride. Describe, using a diagram, the essential components of this electrolytic cell.

(c) State one example that shows the economic importance of electrolysis.
5. 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:

NO₃⁻:

H₃AsO₃:

N₂O₃:

(iii) Distinguish between the terms oxidizing agent and reducing agent. [1]
(iv) In the removal of arsenic from contaminated groundwater, $\text{H}_3\text{AsO}_3$ 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.  

(c) 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.  

(ii) Explain the changes in the oxidation numbers of bromine.
(f) Fluorine reacts with water to produce oxygen.

\[ 2 \text{F}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow 4\text{HF}(\text{g}) + \text{O}_2(\text{g}) \]

(i) Identify the oxidizing agent in the reaction. \([1]\)

(ii) 100 cm\(^3\) of fluorine gas is added to water. Calculate the volume of oxygen produced at the same temperature and pressure. \([1]\)
4. Chemical energy can be converted to electrical energy in the voltaic cell below.

(a) (i) State the electron arrangement of a magnesium atom. [1]

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

(ii) State the half-equation which describes the change at the Mg electrode and deduce which metal is the positive electrode (cathode) of the cell. [2]

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

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

(b) Deduce the equation for the overall reaction occurring in the cell. [1]

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

..........................................................
5. (a) Deduce the balanced chemical equation for the reaction between sodium and sulfur. State the electron arrangements of the reactants and product, and explain whether sulfur is oxidized or reduced. [4]

\[
\text{Na}_2\text{S}(s) + \text{S}(s) \rightarrow \text{Na}_2\text{S}_2(s)
\]

(b) Consider the following reaction sequence:

\[
\text{Cr}_2\text{O}_7^{2-}(aq) \rightarrow \text{Na}_2\text{CrO}_4(aq) \rightarrow \text{Cr}_2\text{O}_7^{2-}(aq)
\]

\[
\begin{align*}
\text{A} & \rightarrow \text{B} & \rightarrow \text{C}
\end{align*}
\]

(i) State the name of A. [1]

(ii) Describe the redox behaviour of chromium with reference to oxidation numbers in the conversion of B to C. [1]

(iii) Define the term *oxidizing agent* and identify the oxidizing agent in the following reaction.

\[
\text{Cr}_2\text{O}_7^{2-}(aq) + \text{I}^-(aq) + 8\text{H}^+(aq) \rightarrow 2\text{Cr}^{3+}(aq) + \text{IO}_3^- (aq) + 4\text{H}_2\text{O}(l)
\] [2]
3. (a) Molten sodium chloride can be electrolysed using graphite electrodes.

(i) Draw the essential components of this electrolytic cell and identify the products that form at each electrode. 

Product formed at positive electrode (anode):

Product formed at negative electrode (cathode):

(ii) State the half-equations for the oxidation and reduction processes and deduce the overall cell reaction, including state symbols.

Oxidation half-equation:

Reduction half-equation:

Overall cell reaction:
(b) Explain why solid sodium chloride does not conduct electricity.

(c) Using another electrolysis reaction, aluminium can be extracted from its ore, bauxite, which contains Al₂O₃. State one reason why aluminium is often used instead of iron in many engineering applications.

(b) Fertilizers may cause health problems for babies because nitrates can change into nitrites in water used for drinking.

(i) Define oxidation in terms of oxidation numbers.

(ii) Deduce the oxidation states of nitrogen in the nitrate, NO₃⁻, and nitrite, NO₂⁻, ions.

(g) Nitric acid reacts with silver in a redox reaction.

\[ \_\text{Ag(s)} + \_\text{NO}_3^- (aq) + \_ \rightarrow \_\text{Ag}^+ (aq) + \_\text{NO(g)} + \_ \]

Using oxidation numbers, deduce the complete balanced equation for the reaction showing all the reactants and products.
5. (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]

(b) Consider the following three redox reactions.

\[
\text{Cd(s)} + \text{Ni}^{2+} (\text{aq}) \rightarrow \text{Cd}^{2+} (\text{aq}) + \text{Ni(s)}
\]

\[
\text{Ni(s)} + 2\text{Ag}^{+} (\text{aq}) \rightarrow \text{Ni}^{2+} (\text{aq}) + 2\text{Ag(s)}
\]

\[
\text{Zn(s)} + \text{Cd}^{2+} (\text{aq}) \rightarrow \text{Zn}^{2+} (\text{aq}) + \text{Cd(s)}
\]

(i) Deduce the order of reactivity of the four metals, cadmium, nickel, silver and zinc and list in order of decreasing reactivity. [2]

(ii) Identify the best oxidizing agent and the best reducing agent. [2]

(c) (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]
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) + 2NO₂(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 $S_2O_3^{2-}$ 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) With reference to its metallic structure, describe how brass conducts electricity. \[1\]

(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. \[1\]
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>

<table>
<thead>
<tr>
<th>Mass of iron ore / g</th>
<th>3.682×10$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration of KMnO$_4$ solution / mol dm$^{-3}$</td>
<td>2.152×10$^{-2}$</td>
</tr>
</tbody>
</table>

(a) Deduce the balanced redox equation for this reaction in acidic solution. [2]

(b) Identify the reducing agent in the reaction. [1]

(c) Calculate the amount, in moles, of MnO$_4^-$ used in the titration. [2]
(d) Calculate the amount, in moles, of Fe present in the $3.682 \times 10^{-3}$ g sample of iron ore. \[2\]

(e) Determine the percentage by mass of Fe present in the $3.682 \times 10^{-3}$ g sample of iron ore. \[2\]

Chem 9 Q# 17/ IB Chem/2009/s/TZ1/Paper 2 Section A/Standard Level/
4. (a) Define oxidation in terms of electron transfer. \[1\]

(b) Chlorine can be made by reacting concentrated hydrochloric acid with potassium manganate(VII), KMnO$_4$.

$$2\text{KMnO}_4(aq) + 16\text{HCl}(aq) \rightarrow 2\text{MnCl}_2(aq) + 2\text{KCl}(aq) + 5\text{Cl}_2(aq) + 8\text{H}_2\text{O}(aq)$$

(i) State the oxidation number of manganese in KMnO$_4$ and in MnCl$_2$.

$$\text{KMnO}_4$$ ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

$$\text{MnCl}_2$$ ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

(ii) Deduce which species has been oxidized in this reaction and state the change in oxidation number that it has undergone. \[2\]
5. (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

\[ 2\text{K}_2\text{Cr}_2\text{O}_7(aq) + 2\text{HCl}(aq) \rightarrow \text{K}_2\text{Cr}_3\text{O}_7(aq) + 2\text{KCl}(aq) + \text{H}_2\text{O}(l) \] [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(NO₃)₂</td>
<td>Z + W(NO₃)₂</td>
</tr>
<tr>
<td>2</td>
<td>X + YCl₂</td>
<td>no reaction</td>
</tr>
<tr>
<td>3</td>
<td>Y + ZSO₄</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]
(e) The diagram shows two half-cells connected together by a salt bridge. The metal in the left-hand cell is more reactive than the metal in the right-hand cell. The reading on the voltmeter is 1.6 V.

(i) Describe the purpose of the salt bridge and identify one substance that might be used in it. [2]

(ii) Identify compound P and metal Q. [2]

(iii) Deduce the half-equation for the reaction in the left-hand cell. [1]

(iv) The voltmeter is replaced by a battery with a voltage of 2.0 V so that the reaction in part (e) (iii) is reversed. Deduce the half-equation for the reaction in the right-hand cell when the battery is connected. [1]
8. (a) Consider the following reactions.

\[ \text{Ni(s)} + \text{Cu}^{2+} (aq) \rightarrow \text{Ni}^{2+} (aq) + \text{Cu} (s) \]
\[ \text{Mg(s)} + \text{Zn}^{2+} (aq) \rightarrow \text{Mg}^{2+} (aq) + \text{Zn} (s) \]
\[ \text{Zn(s)} + \text{Ni}^{2+} (aq) \rightarrow \text{Zn}^{2+} (aq) + \text{Ni(s)} \]

(i) List the four metals in order of decreasing reactivity. [2]

(ii) State and explain which is the strongest reducing agent in these reactions. [2]

(iii) State and explain which is the strongest oxidizing agent in these reactions. [2]

(b) Electrolysis of molten lead(II) bromide can be carried out using platinum electrodes.

(i) Explain why lead(II) bromide does not conduct electricity in the solid state but does in the molten state. [2]

(ii) State a half-equation for the reaction occurring at the positive electrode (anode) and identify whether the change is oxidation or reduction. [2]

(iii) State a half-equation for the reaction occurring at the negative electrode (cathode) and identify whether the change is oxidation or reduction. [2]
Q# 1/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q4

| 4. g | Anode (positive electrode): Cl₂(g) → 2Cl⁻(aq) + 2e⁻✓
      | Cathode (negative electrode): Mg²⁺ + 2e⁻ → Mg(s)✓
Penalize missing/incorrect state symbols at Cl₂ and Mg⁺ once only.
Award 1 max if equations are at wrong electrodes.
Accept Mg(s). |

Q# 2/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q1

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. b</td>
<td>Ethene → 2 ✓</td>
<td>Do not accept 2⁻, 1⁻ respectively.</td>
<td>2</td>
</tr>
</tbody>
</table>

Q# 3/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q1

| b       | a) Chlorine: +1 (for chlorine) and +1 (for iodine) ✓ |
|         | b) i) Chlorine since chlorine reduces gains electrons OR
|         | Chlorine since oxidation state of chlorine changes from +1 to −1 decreases OR
|         | Chlorine since it loses oxygen / causes iodide to be oxidized ✓ |
|         | b) ii) Produces chlorine from reaction with ClO⁻ which is toxic ✓ |
|         | b) iii) Oxidation states are not real OR
|         | Oxidation states are just used for electron book-keeping purposes ✓ |
|         | Average oxidation state of sulfur calculated to be +2 ✓ |
|         | but the two sulfur are bonded differently in different environments so have different oxidation states ✓ |
|         | 2 max |

Q# 4/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q1

| c       | 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 ✓ |
|         | Not valid: loss of electrons might suggest formation of ionic product but not valid since CO₂ is covalent OR
|         | Loss of electrons might suggest formation of ionic product but not valid since reaction only involves neutral molecules ✓ |
|         | OWTTB |

Q# 5/ IB Chem/2013/s/TZ1/Paper 2 Section A/Standard Level/

| 4. (a) | Loss of electrons; |
|        | (b) Carbon: III to IV / +3 to +4 / (+)1; |
|        | Manganese: VII to II / +7 to -2 / -5; |
|        | Accept correct names instead of formulas. Do not accept Mn and C. |

Q# 6/ IB Chem/2013/s/TZ1/Paper 2 Section A/Standard Level/

3. (a) | Sodium | Sodium chloride |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>State of matter</td>
<td>solid (and liquid)</td>
</tr>
<tr>
<td>Particles that conduct the current</td>
<td>electrons</td>
</tr>
<tr>
<td>Reaction occurring</td>
<td>no reaction occurs</td>
</tr>
</tbody>
</table>

Award [1] for each feature that is correct for both sodium and sodium chloride. Accept equation or half-equations for the reaction of sodium chloride in “reaction occurring”.

(b)

![Diagram showing electrolysis](image)

clear diagram containing all elements (power supply, connecting wires, electrodes, container and electrolyte);
labelled positive electrode/ anode and negative electrode/ cathode;
Accept positive and negative by correct symbols near power supply.
Accept power supply if shown as conventional long/short lines (as in diagram above) or clearly labelled DC power supply.

labelled electrolyte/NaCl(l);
State of NaCl not needed. [3]

(c) production of aluminium/chlorine/lithium/magnesium/hydrogen/sodium hydroxide /sodium chlorate / electroplating / purification of metals;
Do not allow production of sodium. [1]
Q# 7/ IB Chem/2012/w/tz0/Paper 2 Section B/Standard Level/

5. (a) (i) **Oxidation**: loss of electrons and **Reduction**: gain of electrons;  

(ii) \( \text{As}_2\text{O}_3^+; +3 \);  
\( \text{NO}_3^-; +5 \);  
\( \text{H}_3\text{AsO}_3^-; +3 \);  
\( \text{N}_2\text{O}_3^-; +5 \);  
Penalize incorrect notation e.g. III, V, 3+, 5+, 3, 5 once only.

(iii) **Oxidizing agent**: substance reduced / removes electrons from another substance / causes some other substance to be oxidized / **OWTTE** and **Reducing agent**: substance oxidized / gives electrons to another substance / causes some other substance to be reduced / **OWTTE**;  
Accept Oxidizing agent: electron/e\(^-\) acceptor / causes oxidation / oxidation number/state decreases and Reducing agent: electron/e\(^-\) donor / causes reduction / oxidation number/state increases.

(iv) \( \text{As}_2\text{O}_3 (s) + 2\text{NO}_3^- (aq) + 2\text{H}^+(aq) + 2\text{H}_2\text{O}(l) \rightarrow 2\text{H}_3\text{AsO}_4 (aq) + \text{N}_2\text{O}_3 (aq) \)

correct coefficients for \( \text{As}_2\text{O}_3 \), \( \text{H}_3\text{AsO}_4 \) and \( \text{NO}_3^- \), \( \text{N}_2\text{O}_3 \);  
correct balanced equation;  
Ignore state symbols.  
M1 must be correct to award M2.

**Oxidizing agent**: \( \text{NO}_3^- (aq) \)/nitrate and **Reducing agent**: \( \text{As}_2\text{O}_3 (s) \)/arsenic(III) oxide;  
Accept \( \text{HNO}_3 (aq) \)/nitric acid.  
Accept arsenic oxide.  
Species must be fully correct to score M3.  
Ignore state symbols.

Q# 8/ IB Chem/2012/s/tz1/Paper 2 Section B/Standard Level/q6

(e) (i) \( \text{Br}_2; 0 \)  
\( \text{HBr}; -1 \)  
\( \text{HOBr}; +1 \)  
Award [2] for three correct.  
Award [1] for any two correct.

(ii) **bromine** is oxidized and reduced / disproportionation;  

(f) (i) **F**/fluorine;  
**Do not allow F**.  
[1]

(ii) \( 50 \text{ cm}^3 / 0.050 \text{ dm}^3 \);  
[1]

Q# 9/ IB Chem/2012/s/TZ1/Paper 2 Section A/Standard Level/

4. (a) (i) \( 2,8,2; \)  
[1]

(ii) \( \text{Mg}(s) \rightarrow \text{Mg}^{2+}(aq) + 2e^-; \)  
**Fe**/**iron**;  
**Do not accept Fe/Fe\(^{2+}\) half-equation or Fe\(^{2+}\).**  
[2]

(b) \( \text{Mg}(s) + \text{Fe}^{2+}(aq) \rightarrow \text{Mg}^{2+}(aq) + \text{Fe}(s); \)  
[1]

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Q# 10/ IB Chem/2011/w/TZ0/Paper 2 Section B/Standard Level/

5. (a) $2Na(s) + S(s) \rightarrow Na_2S(s)$ / $2Na(s) + \frac{1}{2}S_2(g) \rightarrow Na_2S(s)$ / $16Na(s) + S_8(s) \rightarrow 8Na_2S(s)$;
   Ignore state symbols.

   Na: 2, 8, 1 and S: 2, 8, 6;
   Na$^+$: 2, 8 and S$^2-$: 2, 8, 8;
   reduced since it has gained electrons / reduced since oxidation number has decreased;
   *Do not award mark if incorrect oxidation numbers are given.*

(d) (i) chromium(III) oxide;
   *Do not award mark for chromium oxide.*

(ii) chromium is neither oxidized or reduced since there is no change in oxidation number / to +6;

(iii) substance reduced / causes other substance to be oxidized / increase oxidation number of another species / gains electrons / OWTTE;

   Oxidizing agent:
   Cr$_2$O$_7^{2-}$ / dichromate (ion);
   [2]

Q# 11/ IB Chem/2011/w/TZ0/Paper 2 Section A/Standard Level/

3. (a) (i) Cell showing:
   container, liquid, electrodes and power supply;
   *No labels are required, but do not award mark if incorrect labels are used (e.g. sodium chloride solution). A line must be drawn on the container to indicate the presence of a liquid. If power supply is a battery then do not penalise electrodes incorrectly assigned as + or −.*

   Positive electrode (anode):
   chlorine (gas) / Cl$_2$(g)

   and

   Negative electrode (cathode):
   sodium (liquid) / Na(l);
   *Ignore state symbols in (i) but do not award mark for Cl.*

(ii) Oxidation half-equation:
   $2Cl^- \rightarrow Cl_2 + 2e^-$ / Cl$^- \rightarrow \frac{1}{2}Cl_2 + e^-$

   and

   Reduction half-equation:
   $Na^+ + e^- \rightarrow Na$ / $2Na^+ + 2e^- \rightarrow 2Na$;
   *Allow e instead of e$^-$. 

   Overall cell reaction:
   $2NaCl(l) \rightarrow 2Na(l) + Cl_2(g)$ / NaCl(l) $\rightarrow$ Na(l) + $\frac{1}{2}$Cl$_2$(g);
   *Award [1] for oxidation and reduction half-equations, Award [1] for overall cell reaction, including correct state symbols. Accept Na$^+$ (l) + Cl$^-$ (l) instead of NaCl(l) as a reactant. Penalize equilibrium arrows once only.*

(b) ions not free to move when solid / ions in rigid lattice / OWTTE;
   [1]

(c) Al less dense (compared to Fe) / Al forms a protective (oxide) layer / Fe rusts / OWTTE;
   *Do not accept Al is lighter.*
   [1]
Q# 12/ IB Chem/2010/w/tz0/Paper 2 Section B/Standard Level/q6

(b) (i) increase in the oxidation number; [1]

(ii) $\text{(NO}_3\text{)}^- + 5$ and $\text{(NO}_2\text{)}^- + 3$;
Accept V and III.
Do not penalize missing charges on numbers. [1]

(g) change in oxidation numbers: Ag from 0 to +1 and N from +5 to +2;
Do not penalize missing charges on numbers.

balanced equation: $3\text{Ag} + \text{NO}_3^- + 4\text{H}^+ \rightarrow 3\text{Ag}^+ + \text{NO} + 2\text{H}_2\text{O}$ [3]
Award [1] for correct reactants and product;
Award [3] for correct balanced equation.
Ignore state symbols.

Q# 13/ IB Chem/2010/s/tz1/Paper 2 Section B/Standard Level/

5. (a) (i)

![Diagram of an electrochemical cell with Mg(s) and Ag(s) electrodes, Mg$^{2+}$(aq) and Ag$^+(aq)$ solutions, and a salt bridge]

correctly labelled electrodes and solutions;
labelling salt bridge;
voltmeter.
Allow bulb or ammeter.
direction of electron flow: [4]

(ii) Oxidation:
$\text{Mg(s)} \rightarrow \text{Mg}^{2+} (\text{aq}) + 2\text{e}^-$

Reduction:
$\text{Ag}^+ (\text{aq}) + \text{e}^- \rightarrow \text{Ag(s)}$ [2]

Ignore state symbols.
Award [1 max] if equations not labelled reduction or oxidation or labelled the wrong way round.
Allow $e^-$ instead of $\text{Ag}^+$.
Penalize equilibrium sign or reversible arrows once only in parts (a) (ii) and (c) (ii).

(b) (i) Zn > Cd > Ni > Ag
Zn most reactive;
rest of order correct; [2]

(ii) Best oxidizing agent:
Ag$^+$.
Do not accept Ag.

Best reducing agent:
Zn;
Do not accept Zn$^{2+}$. [2]
Q# 14/ IB Chem/2010/s TZ1/Paper 2 Section A/Standard Level/

1. (a) 

(i) **Copper:**

0 to +2 / increases by 2 / +2 / 2+;

Allow zero/hought for 0.

(ii) **Nitrogen:**

+5 to +4 / decreases by 1 / -1 / 1-;

Penalize missing + sign or incorrect notation such as 2+, 2− or II, once only.

(b) 

(i) $0.100 \times 0.0285 = 2.85 \times 10^{-3} \text{ (mol)}$;

Award 2 for correct final answer.

(ii) $2.85 \times 10^{-3} \text{ (mol)}$; 

(iii) $(63.55 \times 2.85 \times 10^{-3}) = 0.181 \text{ g}$;

Allow 0.035.

(iv) $\left(\frac{0.181}{0.456} \times 100 = \right) 39.7\%$;

(i) [1]

(v) $\left(\frac{44.2 - 39.7}{44.2} \times 100 = \right) 10/10.2\%$;

Allow 11.3% i.e. percentage obtained in (iv) is used to divide instead of 44.2%.

(c) **Brass has:**

delocalized electrons / sea of mobile electrons / sea of electrons free to move;

No mark for just “mobile electrons”.
Q# 15/ IB Chem/2009/sQ3

(b) \( 20^{3-} \rightarrow O_2 + 4e^- / O_3^2- \rightarrow \frac{1}{2}O_2 + 2e^- ; \) 
Accept e instead of e\(^-\).  \[1\]

Q# 16/ IB Chem/2009/w/TZ0/Paper 2 Section A/Standard Level/

1. (a) \( \text{MnO}_4^- (aq) + 5\text{Fe}^{2+} (aq) + 8\text{H}^+ (aq) \rightarrow \text{Mn}^{2+} (aq) + 5\text{Fe}^{3+} (aq) + 4\text{H}_2\text{O} (l) \)  
Award [2] if correctly balanced.  
Award [1] for correctly placing \( \text{H}^+ \) and \( \text{H}_2\text{O} \).  
Award [1 max] for correct balanced equation but with electrons shown.  
Ignore state symbols.  \[2\]

(b) \( \text{Fe}^{2+} / \text{iron(II)}; \) 
Do not accept iron.  \[1\]

(c) \( n = 2.152 \times 10^{-3} \times 2.250 \times 10^{-2} ; \) 
\( 4.842 \times 10^{-4} \) (mol);  \[2\]
Award [1] for correct volume  
Award [1] for correct calculation.

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

(e) \( 2.421 \times 10^{-3} \times 55.85 = 0.1352 \) (g);  
\( \frac{0.1352}{0.3682} = 36.72\% ; \)  \[2\]  
Allow ECF from part (d).

Q# 17/ IB Chem/2009/s/TZ1/Paper 2 Section A/Standard Level/

4. (a) Loss of (one or more) electrons;  \[1\]

(b) (i) \( \text{KMnO}_4 + 7; \) 
\( \text{MnCl}_2 + 2; \)  
Must have + sign for mark.  
\[1 \text{ max} \] if roman numerals or 7+ or 2+ used or if + signs are missing.

(ii) \( \text{Cl}^- / \text{chloride} / \text{chlorine} / \text{Cl (has been oxidized)} / \text{HCl} ; \) 
oxidation number from \(-1\) to \(0\) / has increased by one;  \[2\]  
If HCl is given for first mark, it must be clear that it is the Cl that has the change of oxidation number.
Q# 18/ IB Chem/2008/w/tz0/Paper 2 Section B/Standard Level/

5. (a) (oxidation is) loss of electron(s); 
   Br⁻ / bromide; [2]

(b) Ti   +4 and +4;  
   Cl    0 and −1;  
   C     0 and +4;  
   Penalize 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. [3]

(c) (i) Cr oxidation number +6/same on both sides/does not change; 
   neither oxidation nor reduction occur; 
   No ECF. [2]

(ii) Cl oxidation number 0 on left and −1 and +1 on right; 
   both oxidation and reduction occur / disproportionation; 
   No ECF. [2]

(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 Z 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 OWTTE in this part. 
   Any three of last four score [1] each. 

(ii) 2V + 3XO → V₂O₅ + 3X; [1]

(e) (i) allows ions to flow through it / to complete the circuit/balances charge; 
   potassium chloride/KCl / potassium nitrate/KNO₃; [2] 
   Accept any other unreactive soluble salt including sulfates. 

(ii) P is magnesium sulfate/MgSO₄; 
   Accept magnesium chloride MgCl₂ or magnesium nitrate Mg(NO₃)₂. 
   Q is zinc/Zn; [2]

(iii) Mg → Mg²⁺ + 2e⁻; [1] 
   Accept e instead of e⁻. 
   Accept −2e⁻ on left. 
   Ignore state symbols. 

(iv) Zn → Zn²⁺ + 2e⁻; [1] 
   Accept e instead of e⁻. 
   Accept −2e⁻ on left. 
   Ignore state symbols.
Q# 19/ IB Chem/2008/s/tz1/Paper 2 Section B/Standard Level/

8.  (a)  
   (i)  \[ \text{Mg} > \text{Zn} > \text{Ni} > \text{Cu} \]  
   \text{Four metals in correct order; award [2], first and last metal order correct award [1].}  
   \[2\]
   
   (ii) \text{Mg; Mg can reduce all other species; has a greater tendency to donate electrons;}  
   \[2\]
   
   (iii) \text{Cu}^{2+}; \text{Cu}^{2+} \text{ can oxidise other species; has a greater tendency to accept electrons; Do not accept Cu}  
   \[2\]

(b)  
   (i)  \text{(solid state) ions in fixed position; (molten state) ions are free to move;}  
   \[2\]
   
   (ii) \text{2Br}^- \rightarrow \text{Br}_2 + 2e^- / \text{Br}^- \rightarrow \frac{1}{2} \text{Br}_2 + e^- \text{; } \text{Accept } e^- \text{ instead of } e^- \text{; oxidation;}  
   \[2\]
   
   (iii) \text{Pb}^{2+} + 2e^- \rightarrow \text{Pb}; \text{ Accept } e^- \text{ instead of } e^- \text{; reduction;}  
   \[2\]

\text{Award [1] for two correct equations with wrong electrodes.}
5. Propane and propene are members of different homologous series.

(a) Draw the full structural formulas of propane and propene. [1]

Propane:

Propene:

(b) 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. [2]

(ii) State an equation for the reaction of 1 mol of propene with 1 mol of bromine. [1]
(iii) State the type of each reaction with bromine.

Propane:

Propene:

Chem 10 Q# 94/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q1
(d) Ethane-1,2-diol can be oxidized first to ethanedioic acid, (COOH)₂, and then to carbon dioxide and water. Suggest the reagents to oxidize ethane-1,2-diol.

Chem 10 Q# 95/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q4 NOT with (b)(i & ii)

4. 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.

Identify the four functional groups, I, II, III and IV.
(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.

Bute has molecular formula of

$$\text{C}_{19}\text{H}_{20}\text{N}_2\text{O}_2$$

(iii) Deduce the degree of unsaturation (index of hydrogen deficiency – IHD) of bute. $[1]$ 

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

$X$ is this molecule:

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

(iii) $Y$ is an isomer of $X$ containing a different functional group. State the condensed structural formula of $Y$. $[1]$ 

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

(vi) X reacts with acidified potassium dichromate(VI) solution to form Q and with ethanoic acid to form W. Deduce the condensed structural formula of Q and W.

Q:

W:

(vii) Apply IUPAC rules to state the name of compound Q.
Chem 10 Q# 96/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q2
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:

\[
\text{HO}^\bullet(g) + \text{SO}_2(g) \rightarrow \text{HOSO}_2(g)
\]
\[
\text{HOSO}_2(g) + \text{O}_2(g) \rightarrow \text{HOO}^\bullet(g) + \text{SO}_3(g)
\]
\[
\text{SO}_3(g) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{SO}_4(aq)
\]

(a) (i) State what the symbol (\(\bullet\)) represents in the species shown in this mechanism. [1]

---

Chem 10 Q# 97/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q4
4. Aikenes are widely used in the production of polymers. The compound A, shown below, is used in the manufacture of synthetic rubber.

![Chemical structure of compound A](image)

(a) (i) State the name, applying IUPAC rules, of compound A. [1]

---

(ii) Draw a section, showing three repeating units, of the polymer that can be formed from compound A. [1]

---

(iii) Compound A is flammable. Formulate the equation for its complete combustion. [1]
(b) Compound B is related to compound 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]

(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:
8. Ethene belongs to the homologous series of the alkenes.

(a) (i) Outline three features of a homologous series. [3]

(ii) Describe a test to distinguish ethene from ethane, including what is observed in each case. [2]

(iii) Bromoethane can be produced either from ethene or from ethane. State an equation for each reaction. [2]
(b) A bromoalkane, $\text{C}_4\text{H}_9\text{Br}$, reacts with a warm, aqueous sodium hydroxide solution, $\text{NaOH}$.

(i) State the equation for the reaction of $\text{C}_4\text{H}_9\text{Br}$ with $\text{NaOH}$.  

(ii) Suggest what would happen to the pH of the solution as the reaction proceeds.  

(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>$[\text{C}_4\text{H}_9\text{Br}] / 10^{-2}\text{mol dm}^{-3}$</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 effect of the concentration of $\text{C}_4\text{H}_9\text{Br}$ and $\text{NaOH}$ on the rate of reaction.  

$\text{C}_4\text{H}_9\text{Br}$:  

$\text{NaOH}$:
(ii) Suggest why warm sodium hydroxide solution is used. [1]

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

(iii) Deduce whether C₄H₉Br is a primary or tertiary halogenoalkane. [2]

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

(iv) Determine the structural formula of C₄H₉Br. [1]

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

(v) Describe, using an equation, how C₄H₉Br can be converted into C₄H₉Br₂. [1]

.................................................................................................
.................................................................................................
.................................................................................................
.................................................................................................
.................................................................................................
.................................................................................................
5. The following diagram shows the three-dimensional structure of a molecule.

(a) Apply IUPAC rules to state the name of this molecule. [1]

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

(b) Deduce the structural formula of two isomers of the molecule above with the same functional group. [2]

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

(c) Describe, using an equation, the oxidation by acidified potassium dichromate(VI) of the substance shown in the diagram. Use the symbol [O] to represent the oxidizing agent. [1]

.................................................................................................................................
(b) The combustion of unleaded gasoline still produces pollution with both local and global consequences. Identify one exhaust gas which causes local pollution and one exhaust gas which causes global pollution. [2]

Local pollutant:

Global pollutant:

6. Alkenes, alcohols and esters are three families of organic compounds with many commercial uses.

(a) (i) State two industrial uses of ethene. [2]

(ii) State the meaning of the term structural isomers. [1]
(iii) X is an isomer of C₄H₈ and has the structural formula shown below.

Apply IUPAC rules to name this isomer. Deduce the structural formulas of two other isomers of C₄H₈.

(iv) State the balanced chemical equation for the reaction of X with HBr to form Y.

(v) Y reacts with aqueous sodium hydroxide, NaOH (aq), to form an alcohol, Z. Identify whether Z is a primary, secondary or tertiary alcohol.
(vii) Deduce the structural formula of the organic product formed when \( Z \) is oxidized by heating under reflux with acidified potassium dichromate(VI) and state the name of the functional group of this organic product. [2]

(b) Esters are often used in perfumes. Analysis of a compound containing the ester functional group only, gives a percentage composition by mass of C: 62.0\% and H: 10.4\%.

(i) Draw the ester functional group. [1]

(ii) Determine the empirical formula of the ester, showing your working. [4]
(iii) The molar mass of the ester is 116.18 g mol⁻¹. Determine its molecular formula. 

\[
\text{Chemistry Problem 7:}
\]

A student prepared hex-1-ene, \( \text{C}_6\text{H}_{12} \), from hexan-1-ol, \( \text{C}_6\text{H}_{12}\text{OH} \), by a dehydration reaction.

\[
\text{C}_6\text{H}_{12}\text{OH}(l) \rightarrow \text{C}_6\text{H}_{12}(l) + \text{H}_2\text{O}(l)
\]

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.
(ii) Calculate the percentage yield of hex-1-ene produced.

(iii) Another student repeated the experiment and reported a yield of 5.24 g of organic product. Comment on this result.

(b) Hex-1-ene can be converted to hexane in a single step.

(i) State the reagent and conditions needed and draw the structural formula of the product.
(ii) Deduce the names of three isomers of hexane. [3]

(iii) Identify the compound with the molecular formula \( \text{C}_6\text{H}_{14} \) which has the highest boiling point and explain your choice. [3]

(iv) The conversion of carbon-carbon double bonds to carbon-carbon single bonds is an important stage in the synthesis of a commercial product. Identify this commercial product. [1]
(c)  

(i) 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.

<table>
<thead>
<tr>
<th>Initiation:</th>
</tr>
</thead>
<tbody>
<tr>
<td>......................</td>
</tr>
<tr>
<td>Essential condition:</td>
</tr>
<tr>
<td>......................</td>
</tr>
<tr>
<td>Propagation:</td>
</tr>
<tr>
<td>......................</td>
</tr>
<tr>
<td>Termination:</td>
</tr>
<tr>
<td>......................</td>
</tr>
</tbody>
</table>

(ii) Deduce the number of straight-chain structural isomers produced with the molecular formula $C_5H_{13}Cl$.  

| .................................................. |
| .................................................. |
3. Compound X (shown below) is produced by bacteria living in human armpits and is thought to be partly responsible for unpleasant body smells.

(a) Bromine water can be used to test for the presence of one of the functional groups in X. Identify this functional group and describe the colour change observed. [2]

(b) The other functional group changes when X is refluxed with acidified excess potassium dichromate(VI) to produce a compound Y.

(i) Identify the functional group present in Y but not in X. [1]

(ii) State the type of reaction that X undergoes to form Y. [1]
(c) A different compound is produced if excess $X$ is heated with acidified potassium dichromate(VI) and the product $Z$ is distilled off as it forms.

(i) Identify the functional group present in $Z$ but not in $X$.

(ii) Predict the order of increasing boiling point of the compounds $X$, $Y$ and $Z$ and explain your answer.

(d) Based on the types of intermolecular force present, explain why butan-1-ol has a higher boiling point than butanal.
7. (a) One example of a homologous series is the alcohols. Describe two features of a homologous series.

(b) Consider the following reactions.

\[(\text{CH}_3)_2\text{CH(CH}_2\text{)}_3\text{OH} \rightarrow (\text{CH}_3)_2\text{CH(CHOH)}_2\text{CH}_2\text{CH}_2\text{CHO}\]

\[X \rightarrow Y \rightarrow Z\]

(i) The IUPAC name of X is 4-methylnpent-1-ol. State the IUPAC names of Y and Z.

Y: .......................................................... 
Z: ..........................................................

(ii) State the reagents and reaction conditions used to convert X to Y and X to Z.

X to Y: ..........................................................
X to Z: ..........................................................
(iv) Discuss the volatility of Y compared to Z.

6. Alkenes are important starting materials for a variety of products.

(a) State and explain the trend of the boiling points of the first five members of the alkene homologous series.

(b) Describe two features of a homologous series.
(c) Below is a schematic diagram representing some reactions of ethene. The letters A–D represent the organic compounds formed from the reactants and catalysts shown.

\[ \text{A} \quad \text{H}_2\text{O} / \text{H}_2\text{SO}_4 \quad \text{H}_2\text{C} = \text{CH}_3 \quad \text{H}_2 / \text{Ni} \quad \text{D} \]

\[ \text{B} \quad \text{H}_2\text{C} = \text{CH}_3 \quad \text{Cl}_2 \quad \text{C} \]

Deduce the structural formulas of compounds A, B, C, and D and state the IUPAC name of compound C. [5]

A:

B:

C:

IUPAC name: .................................................................

D:
(d) Describe a chemical test that could be used to distinguish between pent-1-ene and pentane. [2]
(e) State and explain whether the following molecules are primary, secondary or tertiary halogenoalkanes.

\[ E: \]
\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{C} \quad \text{C} \\
\text{C} \quad \text{C} \\
\text{C} \quad \text{Cl} \\
\text{H} \\
\text{H} \\
\text{H} \\
\end{array}
\]

\[ F: \]
\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{C} \quad \text{C} \\
\text{C} \quad \text{C} \\
\text{C} \quad \text{Cl} \\
\text{H} \\
\text{H} \\
\text{C} \\
\text{H} \\
\text{H} \\
\end{array}
\]

\[ G: \]
\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{C} \quad \text{C} \\
\text{C} \quad \text{C} \\
\text{C} \quad \text{C} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{H} \\
\text{C} \\
\text{C} \\
\text{H} \\
\text{Cl} \\
\end{array}
\]
(f) Explain, using equations, the following steps in the free-radical mechanism of the reaction of methane with chlorine.

- Initiation
- Propagation
- Termination

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(e) State the name of the product and identify the type of reaction which occurs between ethene and hydrogen chloride.

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5. Consider the following sequence of reactions.

\[
\begin{align*}
\text{RCH}_3 & \xrightarrow{\text{reaction 1}} \text{RCH}_2\text{Br} \xrightarrow{\text{reaction 2}} \text{RCH}_2\text{OH} \xrightarrow{\text{reaction 3}} \text{RCOOH}
\end{align*}
\]

RCH₃ is an unknown alkane in which R represents an alkyl group.

(a) The alkane contains 81.7% by mass of carbon. Determine its empirical formula, showing your working.

(b) Equal volumes of carbon dioxide and the unknown alkane are found to have the same mass, measured to an accuracy of two significant figures, at the same temperature and pressure. Deduce the molecular formula of the alkane.

(c) (i) State the reagent and conditions needed for reaction 1.

(ii) State the reagent(s) and conditions needed for reaction 3.

(d) Reaction 1 involves a free-radical mechanism. Describe the stepwise mechanism, by giving equations to represent the initiation, propagation and termination steps.
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2. The alkenes are an example of a homologous series.

(a) State the name of the alkene shown. [1]

(b) Bromine water, \( \text{Br}_2(\text{aq}) \), can be used to distinguish between the alkanes and the alkenes.

(i) Describe the colour change observed when the alkene shown in part (a) is added to bromine water. [1]

(ii) Draw the structural formula and state the name of the product formed. [2]
(c) 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. [2]

(ii) State the type of polymerization reaction shown by the alkene in part (a). [1]

(iii) Deduce the structure of the resulting polymer showing three repeating units. [1]

(iv) Explain why monomers are often gases or volatile liquids, but polymers are solids. [2]

(b) Ethanol is part of the homologous series of alcohols. Describe two features of a homologous series. [2]
(c) (i) Below are four structural isomers of alcohols with molecular formula \( \text{C}_4\text{H}_{10}\text{O} \). State the name of each of the isomers A, B, C and D. 

(ii) Determine the isomer that cannot be oxidized by acidified potassium dichromate(VI), \( \text{K}_2\text{Cr}_2\text{O}_7 \). 

(iii) Determine the isomer which can be oxidized to butanal. 

(iv) Determine the isomer which can be oxidized to butanone. 

(v) Suggest the structural formula of another isomer of \( \text{C}_4\text{H}_{10}\text{O} \).
3. (a) Chloroethene, \( \text{C}_2\text{H}_3\text{Cl} \), is an important organic compound used to manufacture the polymer poly(chloroethene).

(i) Draw the Lewis structure for chloroethene and predict the \( \text{H} - \text{C} - \text{Cl} \) bond angle. \([2]\)

(ii) Draw a section of poly(chloroethene) containing six carbon atoms. \([1]\)

(iii) Outline why the polymerization of alkenes is of economic importance and why the disposal of plastics is a problem. \([2]\)

(b) (i) Chloroethene can be converted to ethanol in two steps. For each step deduce an overall equation for the reaction taking place. \([2]\)

Step 1:

Step 2:
(ii) State the reagents and conditions necessary to prepare ethanoic acid from ethanol in the laboratory. [2]

7. (a) Halogenoalkanes can undergo substitution reactions with potassium hydroxide solution.

(i) State an equation for the reaction of \( \text{C}_4\text{H}_9\text{Cl} \) with KOH. [1]

(b) (i) Draw four structural isomers of molecular formula \( \text{C}_4\text{H}_{10}\text{O} \) which contain the \(-\text{OH}\) group. [4]

(ii) On reaction with acidified potassium dichromate(VII), two of the isomers are oxidised in two steps to produce different products. Draw the structural formula of the two products formed from one of the isomers. [2]

(iii) A third isomer is oxidised in one step. Draw the structural formula of the organic product formed. [1]

(iv) State the colour change that takes place in these oxidation reactions. [1]

(v) Identify the isomer which resists oxidation by acidified potassium dichromate(VI). [1]
4.  (a) The boiling points of the isomers of pentane, C₅H₁₂, 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>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling point</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(ii) State the IUPAC names of isomers B and C. [2]

B: ..............................................................

C: ..............................................................

(b) Both C₅H₁₀ and C₅H₁₁OH 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]
(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]

7. (a) Three compounds with similar relative molecular masses are butane, propanal and propan-1-ol.

(i) List the three compounds in order of increasing boiling point (lowest first) and explain the differences in their boiling points. [4]

(ii) Predict, with an explanation, which of the three compounds is least soluble or miscible in water. [2]

(iii) When propan-1-ol is oxidized using a warm acidified solution of potassium dichromate(VI) two different organic products can be obtained. Deduce the name and structural formula for each of these two products. [3]

(iv) Propan-2-ol is an isomer of propan-1-ol. Draw the structure of propan-2-ol. [1]

(v) Identify the class of alcohols that propan-2-ol belongs to and state the name of the organic product formed when it is oxidized by an acidified solution of potassium dichromate(VI). [2]

(b) Ethanol can be formed from ethene in a two step reaction:

\[
\text{H} \quad \text{C} = \text{C} \quad \text{H} \quad \text{g} \quad \text{step 1} \quad \text{H} \quad \text{C} - \text{H} \quad \text{Be} \quad \text{H} \quad \text{H} \quad \text{g} \quad \text{step 2} \quad \text{H} \quad \text{C} = \text{C} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{OH}
\]

(i) State the name of the reagent used for step 1. [1]

(ii) State the name of the reagent and the conditions used for step 2. [2]
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.

\[
\begin{align*}
\text{Vegetable Oil} & \quad \text{Methanol} & & \text{Glycerol} & & \text{Biodiesel} \\
\text{H} & - & \text{C} & - & \text{O} & - & \text{C} & - & \text{R} & (I) & + & 3 \text{CH}_3\text{OH} (l) & \xrightarrow{\text{NaOH} (s)} & \text{H} & - & \text{C} & - & \text{OH} (l) & + & 3 \text{CH}_3\text{-O-CH}_2\text{R} (l)
\end{align*}
\]

(a) Identify the organic functional group present in both vegetable oil and biodiesel.

(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=C_{17}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.

(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.
(c) Calculate the percentage yield of biodiesel obtained in this process. [2]

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

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

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

(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. [1]

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

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

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

6. Several **straight-chain** organic compounds have the molecular formula C₆H₁₂O₂. Compound A is acidic but compounds B, C and D are neutral liquids with characteristic smells. None of the compounds contain C=C bonds.

(a) (i) Deduce the empirical formula for these compounds. [1]

(ii) Deduce the structural formula and name of compound A. [2]

(b) (i) Compound A can be prepared by the oxidation of butan-1-ol. Identify the reagents used for the oxidation. Predict the name of the organic compound that can be formed when butan-1-ol is partially oxidized. Suggest how the reaction can be controlled to give a low yield of this compound formed by partial oxidation and a high yield of compound A. [4]

(iii) Draw the structural formulas of compounds C and D. [2]

(iv) Predict, with reference to the intermolecular forces in each case, which of the compounds A and B has the higher boiling point. [2]
(c) The sequence shows some reactions of organic compounds.

\[
\begin{align*}
A & \xrightarrow{\text{K}_2\text{Cr}_2\text{O}_7/\text{H}^+} B & B & \xrightarrow{\text{K}_2\text{Cr}_2\text{O}_7/\text{H}^+} C \\
\text{C}_3\text{H}_6\text{O} & \rightarrow \text{C}_3\text{H}_6\text{O} & \rightarrow \text{C}_3\text{H}_6\text{O}_2
\end{align*}
\]

(i) Describe the colour change that occurs when K₂Cr₂O₇ acts as an oxidizing agent. [1]

(ii) Deduce the names of compounds A, B and C. [3]

(iii) Compound A reacts with ethanoic acid to form compound D with molecular formula C₄H₄O₂. State the type of reaction occurring and deduce the name of compound D. [2]

(iv) Explain, with reference to the intermolecular forces present, why compound A has a higher boiling point than compound B. [2]

5. (a) The compound C₂H₆ reacts with bromine. Write an equation and state an observation for this reaction. [2]

\[
\text{C}_2\text{H}_6 + \text{Br}_2 \rightarrow \text{C}_2\text{H}_5\text{Br} + \text{HBr}
\]

(b) Suggest the type of polymerization reaction that C₂H₆ undergoes and draw the structure of a section of the polymer chain formed from three monomer molecules. [2]

Type of polymerization: ________________________________

[Diagram of polymerization structure]
### Topic 10 Mark Scheme

#### Q# 93/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/QS

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
</table>
| 5. a     | Propane: \[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{C} \\
\text{H}_3 \\
\end{array}
\]
AND Propene: \[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{C} \\
\text{H}_3 \\
\text{H} \\
\end{array}
\] | 1 |

5. b i) \[\text{C}_3\text{H}_6 + \text{Br}_2 \rightarrow \text{C}_3\text{H}_5\text{Br} + \text{HBr} \checkmark\]
   OR high temperature
   Do not accept “reflux” for M2. 2

5. b ii) \[\text{C}_3\text{H}_6 + \text{Br}_2 \rightarrow \text{C}_3\text{H}_5\text{Br}_2 \checkmark\] 1

5. b iii) Propane: “free radical” substitution / S₅ AND Propene: “electrophilic” addition / S₅, \checkmark
   Award mark even if incorrect type of substitution/addition given. 1

#### Q# 94/ IB Chem/2016/w/TZ0/Paper 2 Section A/Standard Level/Q1

1. d) Accelerated potassium dichromate(VI) / H⁺ and \( \text{K}_2\text{Cr}_2\text{O}_7 / \text{H}^+ \) AND
   OR
   Accelerated potassium manganate(VII) / H⁺ \( \text{KMnO}_4 / \text{H}^+ \)
   Accept H₂SO₄ or H₂PO₄ for H⁺.
   Accept “permanganate” for “manganate(VII)”. 1

#### Q# 95/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q4

4. a) I. carbonylic \checkmark
    II. phenyl \checkmark
    III. carboxyl / carboxy \checkmark
    IV. hydroxyl \checkmark
   Award [1] for all four correct, [1] for two or three correct.
   Do not allow benzene.
   Do not allow carboxylic/alkanoid acid.
   Do not allow alcohol or hydroxide. 2 max

b iii) \[(0.5)(40-20-2) \checkmark\] 1

b iv) A: C=H and B: C=O 1

b v) O-H and N-H \checkmark
   Frequencies/stretches due to O-H and N-H occur above 3200 cm⁻¹ which are not present in IR of base \checkmark 2

e i) 1:1:6 \checkmark 1

c ii) \[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{C} \\
\text{H} \\
\text{H} \\
\end{array}
\] 1

c iii) \[
\begin{array}{c}
\text{H} \\
\text{O} \\
\text{H} \\
\text{C}_3\text{H}_2\text{O}_2\text{CH}_2 \\
\end{array}
\] 1

c iv) Similarity:
   both have fragment corresponding to \( M_i - 15 \) / both have \( m/z = 45 \) \checkmark
   Difference:
   X has fragment corresponding to \( M_i - 17 \) / X has \( m/z = 43 \)
   OR X has fragment corresponding to \( M_i - 43 \) / X has \( m/z = 17 \)
   OR Y has fragment corresponding to \( M_i - 31 \) / Y has \( m/z = 29 \)
   OR Y has fragment corresponding to \( M_i - 29 \) / Y has \( m/z = 31 \)
   Allow both have same molecular ion peak \( M_i \) / both have \( m/z = 60 \). However, in practice the molecular ion peak is of low abundance and difficult to observe for propan-2-ol. 2
Q# 96/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q2

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. 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>
<tr>
<td></td>
<td>X:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CH₃</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CH₃</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>OR</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>CH₃</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H—C—O — — — — O — — — — H</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CH₃</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Y:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H₃C — O — CH₂CH₃</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e vi</td>
<td>CH₃COCH₂ ✓</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>e vii</td>
<td>CH₃COOCH(CH₃)₂ ✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q# 97/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q4

<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>methylpropane ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. a ii</td>
<td>CH₃ — C(CH₃)₂ — CH₂ — C(CH₃)₂ — CH₃ ✓</td>
<td>Must have continuation bonds at both ends. Accept any orientation of the monomers, which could give methyl side-chains on neighbouring atoms etc.</td>
<td>1</td>
</tr>
<tr>
<td>4. a iii</td>
<td>C₆H₆(g) + 5O₂(g) → 4CO₂(g) + 6H₂O(l) ✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. b</td>
<td>Test: Extract with bromine/Br₂ in the dark OR Extract with bromine water/Br₂(aq) in the dark ✓</td>
<td>Accept other correct reagents, such as manganese(VII) or iodine solutions, and descriptions of the corresponding changes observed. Accept “decolourised” for A and “not decolourised/unchanged” for B. Do not accept “clear/transparent” instead of “colourless”.</td>
<td>2</td>
</tr>
<tr>
<td>A: from yellow/orange/brown to colourless AND B: colour remains/slowly decolourized ✓</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8. (a) (i) same functional group / same general formula;
difference between successive members is CH₂;
similar chemical properties;
Do not accept “same” chemical properties.

gradually changing physical properties; [3 max]

(ii) adding bromine (water);
ethene: brown/orange to colourless / decolourizes bromine water and
ethane: does not change colour; [2]

OR

adding acidified potassium permanganate solution/KMnO₄(aq);
ethene: purple to colourless/brown and
ethane: does not change colour;

OR

adding Baeyer’s reagent;
ethene: purple/pink to brown and
ethane: does not change colour;

Do not accept “clear” or “transparent” for “colourless”.

(iii) \[ \text{C}_2\text{H}_4 + \text{HBr} \rightarrow \text{C}_2\text{H}_3\text{Br} ; \]
\[ \text{C}_2\text{H}_4 + \text{Br}_2 \rightarrow \text{C}_2\text{H}_3\text{Br} + \text{HBr} ; \]
Accept structural formulas.
Penalise missing H atoms or incorrect bonds (such as C–HO, C–H₂C) in structural formulas only once in the paper.

(b) (i) \[ \text{C}_2\text{H}_3\text{Br} + \text{OH}^- \rightarrow \text{C}_2\text{H}_3\text{OH} + \text{Br}^- ; \]
Accept NaOH in the equation.
[1]

(ii) decreases; [1]

(c) (i) \[ \text{C}_4\text{H}_8\text{Br} : \]
\[ [\text{C}_4\text{H}_8\text{Br}] \text{ doubles and time halves/rate doubles / rate proportional to } [\text{C}_4\text{H}_8\text{Br}] ; \]
Do not accept rate increases when [C₄H₈Br] increases.

NaOH:
[NaOH] doubles and time/rate does not change / rate independent of [NaOH]; [2]

(ii) increases rate;
Accept increases number of collisions.
[1]

(iii) rate depends on [C₄H₈Br] only / rate does not depend on [OH⁻] / S_n1 reaction / first order reaction / if it was primary, reaction would be S_n2;
tertiary;
Accept ECF.
[2]

(iv) (CH₃)₂CBr;
Allow both condensed and full structural formula.
Accept ECF.
[1]

(v) \[ \text{C}_4\text{H}_8\text{Br} + \text{Br}_2 \rightarrow \text{C}_4\text{H}_8\text{Br}_2 + \text{HBr} ; \]
[1]
Q# 98/ IB Chem/2013/sTZ1/Paper 2 Section A/Standard Level/
5. (a) butan-2-ol/2-butanol;  

(b) \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \); \( (\text{CH}_3)_2\text{CH}_2\text{OH} \); \( (\text{CH}_3)_2\text{COH} \);  
Accept condensed or full structural formulas. 
Penalise missing H atoms or incorrect bonds (such as C–HO, C–H_2C) only once in the whole paper. 

(c) \( \text{C}_2\text{H}_5\text{CHOHCH}_3 + [\text{O}] \rightarrow \text{C}_2\text{H}_5\text{COCH}_3 + \text{H}_2\text{O} \);  
Accept condensed or full structural formulas. 
Accept [O] on top of the arrow. 
Do not accept equation without \( \text{H}_2\text{O} \). 
Do not accept equation with \( \text{H}^+ /\text{Cr}_2\text{O}_7^{2-} \).

Q# 99/ IB Chem/2012sQ2
(b) Local pollutant:  
carbon monoxide/CO / volatile organics/VOCs / nitrogen oxide/NO / (unburnt) hydrocarbons; 
Do not accept methane/\text{CH}_4, ethane/\text{C}_2\text{H}_6, propane/\text{C}_3\text{H}_8 or butane/\text{C}_4\text{H}_{10}.

Global pollutant:  
nitrogen oxide/NO / carbon dioxide/\text{CO}_2;  
Accept nitrogen dioxide/\text{NO}_2 / \text{NO}_x for both local or global pollutant.  
Accept other widely used names for NO such as nitric oxide/nitrogen monoxide/nitrogen(II) oxide or nitrogen(IV) oxide for \text{NO}_2.

Q# 173/ IB Chem/2012/w/tz0/Paper 2 Section B/Standard Level/
Penalize missing hydrogens or incorrect bonding (e.g. C–H_2C) once only in 6.
6. (a) (i) (hydration of ethane) to manufacture ethanol/\text{C}_2\text{H}_6 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH};  
synthesis of \( \text{CH}_3\text{COOH} \)/ethanoic acid;  
Allow acetic acid instead of ethanoic acid.  
synthesis of ethane-1,2-diol;  
Allow 1,2-ethanediol/1,2 ethanediol/ethylene glycol/glycol alcohol instead of ethane-1,2-diol. 
any appropriate polymerization of ethene;  
e.g. polyethene, polychloroethene/\text{PVC}, polyphenylethene/polystyrene/\text{PS} etc.  
Accept other industrial uses such as ripening of fruits. 
Do not accept manufacture of margarine/alcohol/plastics/polymers/fuel.

(ii) compounds with the same molecular formula but different arrangement of atoms/structural formula/structures;  
Do not allow similar instead of same.

(iii) (cis)-but-2-ene / (Z)but-2-ene / but-2-ene;  
Accept (cis)-2-butene / Z-2-butene.  
Ignore missing hyphens. 
\( \text{CH}_3\text{CH}_2\text{CH}==\text{CH}_2 \);  
\( \text{H}_2\text{C}==\text{C} (\text{CH}_3)_2 \);  
Accept either full or condensed structural formulas. 
Allow structural formula of trans-but-2-ene.

(iv) \( (\text{CH}_3)\text{CH}==\text{CH} (\text{CH}_3) + \text{HBr} \rightarrow \text{CH}_3\text{CHBrCH}_2\text{CH}_3 \);  
Allow \( \text{C}_3\text{H}_7 + \text{HBr} \rightarrow \text{C}_3\text{H}_7\text{Br} \).  

(v) secondary/2º;  

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(vii) \( \text{CH}_3\text{COCH}_2\text{CH}_3 \):
Full or condensed structural formula may be given.
For primary \( Z \) from (v), accept \( \text{CH}_3\text{CH}_2\text{CH}_2\text{COOH/CH}_3\text{H}_2\text{COOH} \) but not
\( \text{CH}_3\text{CH}_2\text{CH}_2\text{CHO} \).

ketone / alkanone; [2]

(b) (i) drawing of \( \text{RCOOR}' \) group / \( \text{R} \underset{\text{O}}{\text{C}} \underset{\text{O}}{\text{C}} \underset{\text{O}}{\text{R}' \text{ Allow } \text{C instead of } \text{R or } \text{R}' \text{.} \ [1]}

\( \text{allow } \underset{\text{O}}{\text{C}} \underset{\text{O}}{\text{C}} \), [1]

(ii) \((100 - 62.0 - 10.4 =) 27.6 \% O; \)
\( n_C : \left( \frac{62.0}{12.01} \right) = 5.162 \text{ (mol)} \) and \( n_H : \left( \frac{10.4}{1.01} \right) = 10.297 \text{ (mol)} \)
and \( n_O : \left( \frac{27.6}{16.00} \right) = 1.725 \text{ (mol)} \);

dividing 5.162 and 10.297 by 1.725 (to get values \( \text{C}_2\text{H}_5\text{COOH}_1 \));
(empirical formula = ) \( \text{C}_3\text{H}_6\text{O} \); [4]

Award [4] for correct final answer if alternative method used.
Allow integer values for atomic masses (i.e. 12, 1 and 16).

(iii) \( \text{C}_6\text{H}_{12}\text{O}_2 \); [1]
Q# 165/ IB Chem/2012/s/tz1/Paper 2 Section B/Standard Level/

7. (a) (i) molar mass = 102.20 (g mol\(^{-1}\));
    amount (\(\frac{5.00}{102.20}\)) = 0.0489 (mol); [2]

(ii) theoretical yield = \(84.18 \times 0.0489 = 4.12\) (g);
    percentage yield = \(\left(\frac{2.62}{4.12} \times 100\right)\) 63.6 %; [2]
    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; [2]
    Do not accept error in reading balance/weighing scale.

(b) (i) hydrogen and Ni/Pd/Pt catalyst:

```
      H       H       H       H       H       H
H ─ C ─ C ─ C ─ C ─ C ─ C ─ H
      H       H       H       H       H
```

Allow condensed structural formula \(\text{CH}_3(\text{CH}_3)_4\text{CH}_3\). [2]

(ii) 2-methylpentane;
    3-methylpentane;
    2,2-dimethylbutane;
    2,3-dimethylbutane; [3 max]

(iii) 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'; [3]
    Accept the opposite arguments.
    Do not accept stronger/larger/greater intermolecular forces.

(iv) margarine; [1]
(c) (i) \[ \text{Initiation:} \]
\[ \text{Cl}_2 \rightarrow 2\text{Cl}^*; \]

\[ \text{Essential condition:} \]
UV/sunlight/hfs/hv / heat;

\[ \text{Propagation:} \]
\[ \text{Cl}^* + \text{R} - \text{H} \rightarrow \text{HCl} + \text{R}^* / \text{R}^* + \text{Cl}_2 \rightarrow \text{RCl} + \text{Cl}^*; \]

\[ \text{Termination:} \]
\[ \text{Cl}^* + \text{Cl} \rightarrow \text{Cl}_2 / \text{Cl}^* + \text{R}^* \rightarrow \text{RCl} / \text{R}^* + \text{R}^* \rightarrow \text{R}_2; \]

\text{Allow more specific detail of } R \text{ based on hexane (e.g. } \text{CH}_3(\text{CH}_2)_4\text{CH}_2-\text{H}) \text{ in mechanistic steps.} \quad [4]

(ii) three/3;

\text{If all three isomers are represented correctly award mark.} \quad [1]

Q#101/ IB Chem/2011

3. (a) (carbon to carbon) double bond / alkene; 
\text{Accept if identified on diagram.} \quad [2]

orange brown/red/yellow to colourless / bromine is decolourized; 
\text{M2 can be only scored if M1 correct.}

(b) (i) COOH/CO_2H / carboxylic acid / alkanonic acid; 
\text{Do not allow carboxylic/alkanonic, carbonyl or carboxylate.} \quad [1]

(ii) redox / oxidation (of alcohol); \quad [1]

(c) (i) aldehyde / alkanal / CHO; 
\text{Accept C=O / carbonyl.} \quad [1]

(ii) \text{Z < X < Y;}
\text{Accept } Z, X, Y \text{ or } ZXY.

\text{no hydrogen bonding in } Z / \text{hydrogen bonding in } X \text{ and } Y; 
\text{Accept statements such as } Z \text{ has only van der Waals/London/dispersion forces and dipole-dipole forces.} \quad [3]

\text{Y most polar / more electrons / forms dimers / forms two hydrogen bonds /}
\text{greater molecular/molar mass;}
\text{Do not accept } Y \text{ has a larger mass.}

Q#101/ IB Chem/2011

(d) hydrogen bonding in butan-1-ol; 
\text{stronger than dipole-dipole attractions in butanal;}
\text{Accept converse argument.} \quad [2]
\text{Do not penalize dipole-dipole bonding instead of dipole-dipole attractions.}
7. (a) same functional group; 
successive/neighbouring members differ by CH₂; 
same general formula; 
similar chemical properties;  
gradation in physical properties. [2 max]

(b) (i) Y: 4-methylpentanal; 
Z: 4-methylpentanoic acid. [2] 
Award [1] if student has correct endings for both molecules but has used incorrect stem.

(ii) For both reactions reagents: 
named suitable acidified oxidizing agent; 
Suitable oxidizing agents are potassium dichromate(VI)/K₂Cr₂O₇ / sodium dichromate(VI)/Na₂Cr₂O₇ / dichromate/Cr₂O₇²⁻ / potassium permanganate(VII)/potassium permanganate/KMnO₄ / permanganate/manganate(VII)/MnO₄⁻. Accept H⁺/H₂SO₄ instead of sulfuric acid and acidified. 
Allow potassium dichromate or sodium dichromate (i.e. without (VI)) or potassium permanganate (i.e. without (VII)). Conditions: distillation for X to Y and reflux for X to Z. [2] 
Award [1] if correct reagents and conditions identified for one process only.

(iii) acid partially dissociates/ions; [1]

(iv) Y more volatile than Z; 
hydrogen bonding in carboxylic acid/Z; [2] 
Accept converse argument.
6. (a) boiling points increase (from the first member to the fifth member):
increasing size of molecule/area of contact/number of electrons (from the first to the
fifth member);
strength of intermolecular/van der Waals'/London/dispersion forces increase / more
energy required to break the intermolecular bonds (from first member to fifth member);

(b) same general formula;
successive members differ by CH₂;
same functional group / similar/same chemical properties;
gradual change in physical properties;
Accept specific physical property such as melting point, boiling point only once.

(c) A:

\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H}
\end{array}
\]

\[
\begin{array}{c}
\text{C} \\
\text{C} \\
\text{OH}
\end{array}
\]

\[
\begin{array}{c}
\text{H} \\
\text{H}
\end{array}
\]

B:

\[
\begin{array}{c}
\text{H} \\
\text{H}
\end{array}
\]

\[
\begin{array}{c}
\text{H} \\
\text{H}
\end{array}
\]

\[
\begin{array}{c}
\text{C} \\
\text{C} \\
\text{H}
\end{array}
\]

C:

\[
\begin{array}{c}
\text{H} \\
\text{H}
\end{array}
\]

\[
\begin{array}{c}
\text{Cl} \\
\text{C} \\
\text{C} \\
\text{Cl}
\end{array}
\]

\[
\begin{array}{c}
\text{H} \\
\text{H}
\end{array}
\]

1,2-dichloroethane;

D:

\[
\begin{array}{c}
\text{H} \\
\text{H}
\end{array}
\]

\[
\begin{array}{c}
\text{Cl} \\
\text{C} \\
\text{C} \\
\text{H}
\end{array}
\]

\[
\begin{array}{c}
\text{H} \\
\text{H}
\end{array}
\]

Accept condensed formulas. Penalize missing hydrogens only once.
(d) add bromine water/bromine; pentane no change/stays brown and pent-1-ene decolourizes bromine water/bromine; OR
add acidified KMnO₄; pentane no change/stays purple and pent-1-ene decolourizes acidified KMnO₄; [2 max]
Accept any correct colour change.
Do not accept ‘clear’ instead of ‘colourless’.

(e) E: primary and F: secondary;
G: primary;
G / E: only one alkyl group/2 H atoms attached to the carbon atom attached to the Cl / only one carbon atom attached to the carbon atom attached to the Cl;
F: two alkyl groups/1 H atom attached to the carbon atom attached to the Cl / two carbon atoms attached to the carbon atom attached to the Cl; [4]

(f) Initiation:
Cl₂ $\xrightarrow{UV/hv/heat}$ $2Cl^•$
Reference to UV/hv/heat must be included.

Propagation:
Cl^• + CH₄ $\rightarrow$ CH₃• + HCl;
CH₃• + Cl₂ $\rightarrow$ CH₂Cl + Cl•;

Termination:
Cl^• + Cl• $\rightarrow$ Cl₂ / CH₂• + Cl• $\rightarrow$ CH₃Cl / CH₂• + CH₂• $\rightarrow$ C₂H₆; [4]
Allow representation of radical without • (e.g. Cl, CH₃) if consistent throughout mechanism.
If representation of radical (i.e. •) is inconsistent, penalize once only.

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(e) chloroethane:
(electrophilic) addition;
Do not accept free radical/nucleophilic addition. [2]
5. (a) \( n_c = \frac{81.7}{12.01} = 6.80 \) and \( n_{HH} = \frac{18.3}{1.01} = 18.1 \):
   ratio of 1:2.67/1:2.7;
   \( \text{C}_3\text{H}_8 \);
   No penalty for using 12 and 1.  \[3\]

(b) \( \text{C}_3\text{H}_8 \);
   \[1\]

(c) (i) \( \text{Br}_2/\text{bromine} \);
   UV/ultraviolet light;
   Accept hf/hv/sunlight. \[2\]

(ii) \( \text{C}_2\text{O}_7^{2-}/\text{MnO}_4^- \) and acidified/\( \text{H}^+/\text{H}_2\text{O} \):
   Accept names.
   heat / reflux; \[2\]

(d) \textit{Initiation}:
   \( \text{B}_2 \rightarrow 2\text{Br}^* \);

\textit{Propagation}:
   \( \text{Br}^* + \text{RCH}_3 \rightarrow \text{HBr} + \text{RCH}_2^* \);
   \( \text{RCH}_3^* + \text{Br}_2 \rightarrow \text{RCH}_2\text{Br} + \text{Br}^* \);

\textit{Termination: [1 max]}
   \( \text{Br}^* + \text{Br}^* \rightarrow \text{Br}_2 \);
   \( \text{RCH}_3^* + \text{Br}^* \rightarrow \text{RCH}_3\text{Br} \);
   \( \text{RCH}_3^* + \text{RCH}_2^* \rightarrow \text{RCH}_2\text{CH}_3\text{R} \);
   [4 max]
   Award [1] for any termination step.
   Accept radical with or without * throughout.
   Do not penalise the use of an incorrect alkane in the mechanism.

(f) (i) \( \text{CH}_3\text{OCH}_2\text{CH}_3 \);
    \( \text{CH}_2\text{CHOHCH}_3 \);
    Allow more detailed structural formulas. \[2\]

(ii) \( \text{CH}_2\text{CHOHCH}_3 \) has higher boiling point due to hydrogen bonding;
    \( \text{CH}_3\text{OCH}_2\text{CH}_3 \) has lower boiling point due to Van der Waals/London/
    dispersion/dipole-dipole forces;
    hydrogen bonds in \( \text{CH}_3\text{CHOHCH}_3 \) are stronger;
    Allow if wrong structures suggested. \[2\text{max}\]
2. (a) methylpropene. 
   Accept 2-methylpropene. 

   (b) (i) brown/orange/yellow to colourless / bromine is decolorised;

   (ii) 1,2-dibromo-2-methylpropane / 1,2-dibromomethylpropane / 1-bromo-2-
       methylpropan-2-ol / 1-bromomethylpropan-2-ol;
   Do not penalize missing commas, hyphens or added spaces.

   \[
   \begin{align*}
   \text{Br} & \quad \text{Br} \\
   \text{H}_3\text{C} & \quad \text{C} \quad \text{C} \quad \text{H} \\
   \text{CH}_3 & \quad \text{H} & \quad \text{OH} \quad \text{Br} \\
   & \quad \text{H}_3\text{C} \quad \text{C} \quad \text{C} \quad \text{H} \\
   & \quad \text{CH}_3 \quad \text{H} 
   \end{align*}
   \]

   Award [1] if structure and correct name are given for 2-bromo-2-
   methylpropan-1-ol.

   (c) (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;
   Award [2 max]
   Award [2] for any two.

   (ii) addition;

   (iii) \[
   \begin{align*}
   \text{CH}_3 & \quad \text{H} \\
   \text{CH}_3 & \quad \text{H} \\
   \text{CH}_3 & \quad \text{H} \\
   \text{CH}_3 & \quad \text{H} \\
   \text{CH}_3 & \quad \text{H} \\
   \end{align*}
   \]
   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;
   Accept opposite argument for polymers.
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(b) same general formula:
same functional group:
successive members differ by CH₂:
Allow methylene for CH₂

similar chemical properties;
gradually changing physical properties: [2 max]

(c) (i) A: butan-1-ol;
      B: butan-2-ol;
      C: (2-)methylpropan-2-ol;
      D: (2-)methylpropan-1-ol; [4]
Accept answers in the form of 1-butanol and 2-methyl-2-propanol etc.
Penalize incorrect punctuation, e.g. commas for hyphens, only once.

(ii) C/(2-)methylpropan-2-ol; [1]

(iii) A/butan-1-ol; [1]

(iv) B/butan-2-ol; [1]

(v)

\[
\begin{align*}
\text{H} & \quad \text{C} & \quad \text{C} & \quad \text{O} & \quad \text{C} & \quad \text{C} & \quad \text{H} \\
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H}
\end{align*}
\]

/ CH₃CH₂OCH₂CH₃ /

\[
\begin{align*}
\text{H} & \quad \text{C} & \quad \text{O} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{H} \\
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H}
\end{align*}
\]

/ CH₃OCH₂CH₂CH₃ /

\[
\begin{align*}
\text{H} & \quad \text{C} & \quad \text{O} & \quad \text{C} & \quad \text{C} & \quad \text{H} \\
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H}
\end{align*}
\]

/ CH₃OCH(CH₃)₂; [1]
Q# 103/ IB Chem/2010/s/TZ1/Paper 2 Section A/Standard Level/

3. (a) (i) 

\[
\begin{array}{c}
\text{H} \\
\text{C} = \text{C} \\
\text{Cl} \\
\end{array}
\]

Accept lines, dots or crosses for electron pairs.
Lone pairs required on chlorine.

(approximately) 120°;

Accept any bond angle in the range 113 – 120°.

(ii) 

\[
\left( \begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{C} = \text{C} \\
\text{C} = \text{C} \\
\text{H} \\
\text{Cl} \\
\text{H} \\
\text{Cl} \\
\end{array} \right)
\]

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.

(iii) 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.

(b) (i) Step 1:

\[
\text{CH}_2\text{CHCl} + \text{H}_2 \rightarrow \text{CH}_3\text{CH}_2\text{Cl} ;
\]

Step 2:

\[
\text{CH}_2\text{CH}_2\text{Cl} + \text{OH}^- \rightarrow \text{CH}_3\text{CH}_2\text{OH} + \text{Cl}^- ;
\]

Allow NaOH or NaCl etc. instead of OH^- and Cl^-.
Allow abbreviated formulas C_2H_5Cl, C_2H_5OH, C_2H_5Cl.

(ii) \(\text{H}_2\text{SO}_4/\text{H}^+\text{/acidified and Cr}_2\text{O}_7^{2-}/\text{(potassium/sodium) dichromate;}
\)
Accept suitable oxidizing agents (e.g. \text{KMnO}_4 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# 131/ IB Chem/2009/w/tz0/Paper 2 Section B/Standard Level/

7. (a) (i) \(\text{C}_4\text{H}_8\text{Cl} + \text{KOH} \rightarrow \text{C}_4\text{H}_8\text{OH} + \text{KCl} ;\)
(b) (i) 
\[
\begin{align*}
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} \\
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \\
\text{H} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{OH} & \quad ; \\
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \\
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \\
\text{H} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{OH} & \quad ; \\
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \\
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \\
\text{H} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{OH} & \quad ; \\
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \\
\text{H} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{OH} & \quad ; \\
\text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \quad \text{H} & \\
\end{align*}
\]

*Penalise missing H atoms once only. Accept correct condensed structural formulas.*

(ii) \( \text{CH}_3-\text{CH}_2-\text{CH}_2-\text{CHO} / (\text{CH}_3)_2\text{CHCHO} ; \)  
\( \text{CH}_3-\text{CH}_2-\text{CH}_2-\text{COOH} / (\text{CH}_3)_2\text{CHCOOH} ; \)

(iii) \( \text{CH}_3-\text{CH}_2-\text{CO}-\text{CH}_3 ; \)

(iv) orange to green;

(v) \( \text{CH}_3 \)
\[
\begin{align*}
\text{CH}_3 & \quad \text{C} & \quad \text{CH}_3 & \quad / 2-\text{methylpropan-2-ol} ; \\
\text{OH} & \quad & \quad & \quad & \quad & \quad & \quad & \quad & \quad & \quad & \quad & \quad & \quad & \quad & [1] \\
\end{align*}
\]
4. (a) (i) | Isomer | A | B | C |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling point</td>
<td>36 °C</td>
<td>28 °C</td>
<td>10 °C</td>
</tr>
</tbody>
</table>

Award [2] 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; *[3]*

Accept the opposite arguments

(ii) B: 2-methylbutane/methylbutane;
C: 2,2-dimethyl propane/dimethyl propane; *[2]*

Do not penalize missing commas, hyphens or added spaces.

Do not accept 2-dimethylpropane, or 2,2-methylpropane.

(b) C₅H₁₂:

Accept any two of the following explanations.

C₅H₁₂OH has greater molar mass / produces less grams of CO₂ and H₂O per gram of the compound / suitable calculations to show this;
C₅H₁₂OH contains an O atom which contributes nothing to the energy released / partially oxidized / OWTE;

analogous compounds such as butane and butan-1-ol show a lower value for the alcohol per mole in the data book / OWTE;

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/hydrogen bonding / OWTE; *[3 max]*

(c) Improvements [2]

less/no particulates/C/CO/VOC’s produced with CNG;
less/no SO₂/SO₃ produced;

Reasons [1 max]

CO/SO₂ toxic/poisonous;
SO₂ causes acid rain;

CNG is likely to undergo complete/more combustion;

CNG has no/less sulfur impurities; *[3 max]*
7. (a) (i) butane < propanal < propan-1-ol;  
butane has van der Waals/London/dispersion forces;  
propanal has dipole-dipole attractive forces;  
propan-1-ol has hydrogen bonding;  
*imf marks are independent of the order.*  
*Treat references to bond breaking as contradictions if the imfs are correct.*  
(ii) butane is least soluble;  
it cannot form hydrogen bonds/attractive forces with water molecules;  
(iii) propanal and propanoic acid;  
\[
\begin{align*}
\text{CH}_3\text{CH}_2\text{CHO} & & \text{C}_2\text{H}_5\text{CHO} & & \text{H}_3\text{C} & & \text{C} & & \text{C} & & \text{H} & & \text{H} \\
\text{H} & & \text{H} & & \text{H} \\
\end{align*}
\]
\[
\begin{align*}
\text{CH}_3\text{CH}_2\text{COOH} & & \text{C}_2\text{H}_5\text{COOH} & & \text{H} & & \text{C} & & \text{C} & & \text{C} & & \text{OH} & & \text{H} & & \text{H} \\
\text{H} & & \text{H} & & \text{H} \\
\end{align*}
\]
(iv)  
\[
\begin{align*}
\text{H} & & \text{OH} & & \text{H} \\
\text{H} & & \text{H} & & \text{H} \\
\text{H} & & \text{H} & & \text{H} \\
\text{CH}_3\text{CH}(&\text{OH})\text{CH}_3 & ;
\end{align*}
\]
(v) secondary (alcohol);  
propanone / acetone;  
(b) (i) hydrogen bromide / hydrobromic acid:  
*Do not accept HBr, as name is asked for.*  
(ii) sodium hydroxide / hydroxide ions (name required);  
dilute and aqueous / dilute and warm / aqueous and warm;  

Q# 105/ IB Chem/2009/s/TZ1/Paper 2 Section A/Standard Level/  
1. (a) ester;  
(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 = \( 6.204 - (3 \times 1.144) = 2.808 \) mol;
(d) vegetable oil is mainly non-polar and methanol is polar. Stirring brings them into more contact with each other to increase the frequency of collisions. Do not allow simply mixing.

(e) The relative molecular mass of biodiesel, \( C_{18}H_{36}O_2 = 296.55 \)

- 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.

Q# 121/ IB Chem/2008/w/tz0/Paper 2 Section B/Standard Level/  
6. (a) (i) \( C_2H_2O \);  
(ii) \( CH_3CH_2CH_2COOH / CH_3CH_2CH_2CO_2H \); butanoic acid;  
(iii) ester;

(b) (i) Potassium dichromate / \( K_2Cr_2O_7 \) / \( Cr_2O_7^{2-} \) / \( KMnO_4 / MnO_4^- \); acidified / sulfuric acid / \( H_2SO_4 \); butanal; heat under reflux / use excess oxidising agent / heat for longer / use higher temperature;

(ii) \( CH_3COOH + C_2H_5OH \rightarrow CH_3COOC_2H_5 + H_2O \); 
Accept reversible arrow symbol and more detailed structures.
ethyl ethanoate;

(iii) \( HCOOCH_2CH_2CH_3 \);
\( CH_3CH_2COOCH_3 \);
Accept structures in reverse order.

(iv) A (is higher) because of (stronger) hydrogen bonding; B (is lower as it) has (weaker) dipole-dipole attractions;
Q# 118/ IB Chem/2008/s/tz1/Paper 2 Section B/Standard Level/

(c) (i) orange to green; [1]

(ii) A is propan-1-ol/1-propanol;  
Do not accept propanol
B is propanal;  
C is propanoic acid; [3]

(iii) esterification / condensation;  
propyl ethanoate; [2]

(iv) A has (stronger) hydrogen bonding;  
B has (weaker) dipole-dipole attractions;  
At least one of stronger or weaker needed to score both marks. [2]

Q# 106/ IB Chem/2008/s/TZ1/Paper 2 Section A/Standard Level/

5. (a) \( \text{C}_2\text{H}_4 + \text{Br}_2 \rightarrow \text{C}_2\text{H}_5\text{Br} / \text{CH}_3\text{CHBrCH}_2\text{Br} \); 
(orange/brown/red) colour (of bromine) disappears/is decolourized;  
Do not accept "goes clear". [2]

(b) \[
\begin{array}{c}
\text{H} \\
\text{H} \quad \text{H} \\
\text{H} \quad \text{H} \\
\text{H} \quad \text{H} \\
\end{array}
\]  
chiral carbon atom; [2]

(c) addition (polymerization);  
\[
\begin{array}{c}
\text{H} \\
\text{H} \quad \text{H} \\
\text{H} \quad \text{H} \\
\text{H} \quad \text{H} \\
\text{H} \quad \text{H} \\
\end{array}
\]  
\[
\begin{array}{c}
\text{H} \\
\text{CH}_3 \quad \text{H} \\
\text{CH}_3 \quad \text{H} \\
\text{CH}_3 \quad \text{H} \\
\text{CH}_3 \quad \text{H} \\
\end{array}
\]  
Allow CH\(_3\) groups alternately above and below the spine.  
Allow dotted/dashed lines at ends but not H-atoms. [2]
Bute has molecular formula of 
\[ \text{C}_{19}\text{H}_{20}\text{N}_{2}\text{O}_{2} \]

(iv) The infrared (IR) spectrum of bute is shown below.

[Source: SDBS web: www.sdbs.ristdb.sist.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.

\[ \text{A:} \] 
\[ \text{B:} \]
(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.

Bond containing oxygen not present in structure:

-----------------------------------------------------------------------------------------------

Bond containing nitrogen not present in structure:

-----------------------------------------------------------------------------------------------

Explanation:

-----------------------------------------------------------------------------------------------

(c) An alcohol, $X$, of molecular formula $C_3H_7O$, used as a disinfectant in hospitals, has the following $^1H$NMR spectrum.

![NMR Spectrum Image]

[Source: SDBS web: www.sdbs.iisd.aiist.go.jp (National Institute of Advanced Industrial Science and Technology, 2014)]

The three peaks in the $^1H$NMR 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.

-----------------------------------------------------------------------------------------------
Chem 11 Q# 2/ IB Chem/2016/s/T20/Paper 2 Section A/Standard Level/Q4

4. Alkenes are widely used in the production of polymers. The compound A, shown below, is used in the manufacture of synthetic rubber.

![Chemical structure of A](image1)

Compound B is related to compound A.

![Chemical structure of B](image2)
(iii) Spectroscopic methods could also be used to distinguish between compounds A and B.

Predict one difference in the IR spectra and one difference in the $^1$H NMR spectra of these compounds, using sections 26 and 27 of the data booklet. [2]

IR spectra:

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

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

$^1$H NMR spectra:

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

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

(c) A sample of compound A was prepared in which the $^{12}$C in the CH$_2$ group was replaced by $^{13}$C.

(i) State the main difference between the mass spectrum of this sample and that of normal compound A. [1]
**Topic 11 Mark Scheme**

**Q# 1/ IB Chem/2016/SP/TZ0/Paper 2 Section A/Standard Level/Q4**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>b iv</td>
<td>C–H and C=O</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>b v</td>
<td>O–H and N–H ✓</td>
<td>frequencies/stretches due to O–H and N–H occur above 3200 cm⁻¹ which are not present in IR of butane ✓</td>
<td>2</td>
</tr>
<tr>
<td>c i</td>
<td>1:1:6 ✓</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

**Q# 2/ IB Chem/2016/s/TZ0/Paper 2 Section A/Standard Level/Q4**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. b iii</td>
<td>A would absorb at 1620–1680 cm⁻¹ AND B would not ✓</td>
<td>'H NMR: A would have 2 signals AND B would have 1 signal OR A would have a signal at 4.5–6.0 ppm AND B would not OR A would have a signal at 0.9–1.0 ppm AND B would not OR B would have a signal at 1.3–1.4 ppm AND A would not ✓</td>
<td>2</td>
</tr>
</tbody>
</table>

**Notes:**
- Accept "peak" for "signal".
- Award [1 mark] if students have a correct assignment of a signal, but no comparison, for both IR and NMR.
- Accept "B would have a signal at 2.0ppm" as shown in its 'H NMR spectrum.

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Notes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. c i</td>
<td>molecular ion peak at m/z = 57 ✓, m/z 56</td>
<td>molecular ion peak at one m/z higher OR will not have a charge peak at 56 ✓</td>
<td>Accept a peak at m/z one greater than the 13C one for any likely fragment.</td>
</tr>
</tbody>
</table>