IB SL 7 EQ Paper 2 Section A & Section B 16w to 99s 231 marks

Before 2016 paper 2 was included 4 section B questions, of which you had to chose 2. After 2016 all questions became compulsory on Paper 2.

**SL PAPER 1**
Percentage of all marks awarded for each topic from w2012 to w2014, TZ 0, 1 & 2 (red crosses) and for P1 just in 2016 s, w and SP (Green)

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**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>
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All topics ranked according to their impact on your final grade using exam papers from 1999 to 2016

<table>
<thead>
<tr>
<th>TOPICS and IA</th>
<th>IA</th>
<th>10</th>
<th>Option</th>
<th>N.ofSci</th>
<th>4</th>
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<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
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</tbody>
</table>

Essentially, Nature of Science (NoS) is almost half of the paper, sections after 6, so 7, 8 9 & 10 are only found in HL.
This is older data and will be updated in late 2019 (I stopped teaching IB in 2016, teaching A levels instead and started again in the second half of 2019).
Standard and Higher Level components compared

Essentially, IA has the exact same weight, the Option in HL is almost 50% more important than in SL but Topic 10 is more important in SL than HL. All other topics contribute almost equally to a SL and HL grade.
The dark blue bars are where your final IB grade will be from:

1. Your IA is the single most important part of your IB SL, more important than even the Option. Imagine how much time in class, at home and in revision you have or will give to topics 9, 10 and 11. Your IA, on average, will be worth more to your final grade than all those combined.
2. The Option is the most important topic for your IB grade compared to the everything else
3. Topic 10, Organic Chemistry, is by far the most important topic for papers 1 and 2.

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

2. One of the main constituents of acid deposition is sulfuric acid, $\text{H}_2\text{SO}_4$. This acid is formed from the sulfur dioxide pollutant, $\text{SO}_2$.

A mechanism proposed for its formation is:

$$\text{HOO}^\cdot(\text{g}) + \text{SO}_2(\text{g}) \rightarrow \text{HOSO}_2(\text{g})$$

$$\text{HOSO}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{HOO}^\cdot(\text{g}) + \text{SO}_3(\text{g})$$

$$\text{SO}_3(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{SO}_4(\text{aq})$$
(v) Consider the following equilibrium between the two oxides of sulfur, sulfur dioxide and sulfur trioxide:

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

Predict, with a reason, in which direction the position of equilibrium will shift for each of the changes listed below. \[3\]

<table>
<thead>
<tr>
<th>Change</th>
<th>Shift</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in temperature</td>
<td></td>
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<tr>
<td>Increase in pressure</td>
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<tr>
<td>Addition of a catalyst to the mixture</td>
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</tbody>
</table>

Q# 2/-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:

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

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

(ii) State the effect of an increase in the total pressure on the equilibrium constant, \(K_c\). \[1\]
(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. [2]
(ii) Increase in pressure. [2]

(iii) Addition of a catalyst. [2]

Q# 4/ IB Chem/2012/wTZ0/Paper 2 Section A/Standard Level/

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]
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>
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<tr>
<td>Addition of a catalyst</td>
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</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.  

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

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(ii) State and explain the effect of increasing the pressure on the position of equilibrium.  

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(c) (i) Deduce the equilibrium constant expression, $K_c$, for the equilibrium in (a).

(ii) State the effect of increasing $[H_3]$ on the value of $K_c$.

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

$$\text{Br}_2(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{HOBr(aq)} + \text{HBr(aq)}$$

(iii) Estimate the magnitude of $K_c$ for this reaction. Choose your value from the following options:

$$K_c = 0 \quad K_c < 1 \quad K_c = 1 \quad K_c > 1$$

(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.

Q# 7/IB Chem/2011/s/TZ1/Paper 2 Section A/Standard Level/

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.

(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.
(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]

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Q# 8/IB Chem/2010/w/tz0/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]

(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]

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.

$$
\begin{align*}
\text{H} & \quad \text{O} \\
\text{H} - \text{C} & \quad \text{O} - \text{C} & \quad \text{H} \\
\text{H} - \text{C} & \quad \text{O} - \text{C} - \text{R} & \quad \text{H} \\
\text{H} & \quad \text{C} - \text{O} - \text{C} - \text{R} \quad \text{(I)} & \quad + & \quad 3 \text{CH}_2\text{OH} \quad \text{(I)} & \quad \overset{\text{NaOH (s)}}{\rightleftharpoons} & \quad \text{H} & \quad \text{C} & \quad \text{O} \\
\text{H} & \quad \text{H} & \quad \text{H} \\
\text{vegetable oil} & \quad \text{methanol} & \quad \text{glycerol} & \quad \text{biodiesel}
\end{align*}
$$

(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]

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]
7. (a) The equation for the exothermic reaction in the Contact process is given below:  

\[ 2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g) \]

(i) Write the equilibrium constant expression for the reaction. [1]

(ii) State and explain qualitatively the pressure and temperature conditions that will give the highest yield of sulfur trioxide. [4]

(iii) In practice, conditions used commercially in the Contact process are 450°C and 2 atmospheres of pressure. Explain why these conditions are used rather than those that give the highest yield. [3]

(iv) Name a catalyst used in the Contact process. State and explain its effect on the value of the equilibrium constant. [3]

4. Ammonia is produced by the Haber process according to the following reaction.

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

(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 \( K \) when the temperature is increased. [2]

(d) Explain why a catalyst has no effect on the position of equilibrium. [1]
4. Ammonia is produced by the Haber process according to the following reaction.

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

(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. \[ [1] \]

6. Information about some reactions used in industry is shown in the following table:

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Equation</th>
<th>( \Delta H^\circ / \text{kJ} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>( \text{H}_3(g) + \text{Cl}_2(g) \rightarrow 2\text{HCl}(g) )</td>
<td>(-184 )</td>
</tr>
<tr>
<td>B</td>
<td>( \text{CH}_4(g) + \text{H}_2\text{O}(g) \rightleftharpoons 3\text{H}_2(g) + \text{CO}(g) )</td>
<td>(+210 )</td>
</tr>
<tr>
<td>C</td>
<td>( \text{CO}(g) + \text{H}_2\text{O}(g) \rightleftharpoons \text{H}_2(g) + \text{CO}_2(g) )</td>
<td>(-42 )</td>
</tr>
<tr>
<td>D</td>
<td>( \text{CaCO}_3(s) \rightleftharpoons \text{CaO}(s) + \text{CO}_2(g) )</td>
<td>(+180 )</td>
</tr>
<tr>
<td>E</td>
<td>( n\text{C}_2\text{H}_4(g) \rightarrow (-\text{C}-\text{C}-)_n(s) )</td>
<td>(-92 )</td>
</tr>
</tbody>
</table>

(a) Identify, with a reason, which of the reactions A to E is/are

(i) the two in which an increase in temperature shifts the position of equilibrium to the right. \[ [2] \]

(ii) the two in which an increase in pressure shifts the position of equilibrium to the left. \[ [2] \]
(b) Many reversible reactions in industry use a catalyst. State and explain the effect of a catalyst on the position of equilibrium and on the value of $K_c$. \([4]\]

6. Consider the following reaction in the Contact process for the production of sulfuric acid for parts (a) to (f) in this question.

$$2\text{SO}_2 + \text{O}_2 \rightleftharpoons 2\text{SO}_3$$

(a) Write the equilibrium constant expression for the reaction. \([1]\]

(b) (i) State the catalyst used in this reaction of the Contact process. \([1]\]

(ii) State and explain the effect of the catalyst on the value of the equilibrium constant and on the rate of the reaction. \([4]\]

(c) Use the collision theory to explain why increasing the temperature increases the rate of the reaction between sulfur dioxide and oxygen. \([2]\]

(d) Using Le Chatelier’s principle state and explain the effect on the position of equilibrium of

   (i) increasing the pressure at constant temperature. \([2]\]

   (ii) removing of sulfur trioxide. \([2]\]

   (iii) using a catalyst. \([2]\]

(e) Using the following data, explain whether the above reaction is exothermic or endothermic. \([2]\]

<table>
<thead>
<tr>
<th>Temperature / K</th>
<th>Equilibrium constant $K_c$ / dm$^3$ mol$^{-2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>298</td>
<td>$9.77 \times 10^{25}$</td>
</tr>
<tr>
<td>500</td>
<td>$8.61 \times 10^{11}$</td>
</tr>
<tr>
<td>700</td>
<td>$1.75 \times 10^6$</td>
</tr>
</tbody>
</table>
6. **(a)** The equation for one reversible reaction involving oxides of nitrogen is shown below:

\[ \text{N}_2\text{O}_4 (g) \rightleftharpoons 2\text{NO}_2 (g) \quad \Delta H^\circ = +58 \text{ kJ} \]

Experimental data for this reaction can be represented on the following graph:

(i) Write an expression for the equilibrium constant, \( K_c \), for the reaction. Explain the significance of the horizontal parts of the lines on the graph. State what can be deduced about the magnitude of \( K_c \) for the reaction, giving a reason. \([4]\)

(ii) Use Le Chatelier’s principle to predict and explain the effect of increasing the temperature on the position of equilibrium. \([2]\)

(iii) Use Le Chatelier’s principle to predict and explain the effect of increasing the pressure on the position of equilibrium. \([2]\)

(iv) State and explain the effects of a catalyst on the forward and reverse reactions, on the position of equilibrium and on the value of \( K_c \). \([6]\)

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**Q# 19/IB Chem/2004/w/tz0/Paper 2 Section B/Standard Level/**

(d) Carbon dioxide gas in the atmosphere reacts slightly with rainwater as shown below.

\[ \text{CO}_2 (g) + \text{H}_2\text{O(l)} \rightleftharpoons \text{H}^+(aq) + \text{HCO}_3^-(aq) \]

(i) State the meaning of the \( \rightleftharpoons \) sign. \([1]\)

(ii) Predict the effect, if any, of the presence of a catalyst on the acidity of rainwater. Give a reason for your answer. \([2]\)

(iii) Use Le Chatelier’s principle to predict the effect of the addition of a small quantity of an alkali on the acidity of rainwater. Explain what effect, if any, this would have on the equilibrium constant, \( K_c \). \([3]\)
4. Consider the following equilibrium reaction.

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

Using Le Chatelier’s Principle, state and explain what will happen to the position of equilibrium if (a) the temperature increases. [2]

(b) the pressure increases. [2]

Q# 21/IB Chem/2003/w/tz0/Paper 2 Section B/Standard Level/

(b) The following equilibrium is established at 1700 °C.

\[ \text{CO}_2 (g) + \text{H}_2 (g) \rightleftharpoons \text{H}_2\text{O} (g) + \text{CO} (g) \]

If only carbon dioxide gas and hydrogen gas are present initially, sketch on a graph a line representing rate against time for (i) the forward reaction and (ii) the reverse reaction until shortly after equilibrium is established. Explain the shape of each line. [7]

(c) \( K_c \) for the equilibrium reaction is determined at two different temperatures. At 850 °C, \( K_c = 1.1 \) whereas at 1700 °C, \( K_c = 4.9 \).

On the basis of these \( K_c \) values explain whether the reaction is exothermic or endothermic. [3]

Q# 22/IB Chem/2003/s/TZ1/Paper 2 Section A/Standard Level/

(c) In practice, typical conditions used in the Haber process are a temperature of 500 °C and a pressure of 200 atmospheres. Explain why these conditions are used rather than those that give the highest yield. [2]

(d) Write the equilibrium constant expression, \( K_c \), for the production of ammonia. [1]
3. The table below gives information about the percentage yield of ammonia obtained in the Haber Process under different conditions.

<table>
<thead>
<tr>
<th>Temperature / °C</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>50.7</td>
<td>14.7</td>
<td>3.9</td>
<td>1.2</td>
</tr>
<tr>
<td>100</td>
<td>81.7</td>
<td>52.5</td>
<td>25.2</td>
<td>10.6</td>
</tr>
<tr>
<td>200</td>
<td>89.1</td>
<td>66.7</td>
<td>38.8</td>
<td>18.3</td>
</tr>
<tr>
<td>300</td>
<td>89.9</td>
<td>71.1</td>
<td>47.1</td>
<td>24.4</td>
</tr>
<tr>
<td>400</td>
<td>94.6</td>
<td>79.7</td>
<td>55.4</td>
<td>31.9</td>
</tr>
<tr>
<td>600</td>
<td>95.4</td>
<td>84.2</td>
<td>65.2</td>
<td>42.3</td>
</tr>
</tbody>
</table>

(a) Deduce which combination of temperature and pressure gives the highest yield of ammonia. [1]

(b) The equation for the main reaction in the Haber Process is shown below.

\[ \text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) \quad \Delta H = -92 \text{ kJ} \]

Use this information to state and explain, using Le Chatelier’s Principle, the effect on the equilibrium yield of ammonia of

(i) an increase in pressure. [2]

(ii) an increase in temperature. [2]

(c) In practice, the conditions used are typically 500 °C and 200 atm. Explain why the conditions that give the highest yield are not used. [2]
5. Ammonia is made on a large scale by the Haber process. The main reaction occurring is

\[ \text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) \quad \Delta H = -92 \text{ kJ mol}^{-1}. \]

(a) State two characteristics of a reversible reaction at equilibrium.

(b) This reaction is described as \textit{homogeneous}. State what is meant by the term \textit{homogeneous}.

(c) Write the equilibrium constant expression for the reaction.

(d) When nitrogen and hydrogen are mixed together at room temperature and atmospheric pressure the reaction is very slow. In industry, typical values of pressure and temperature used are 250 atmospheres and 450 °C.

(i) State the effects on both the rate of reaction and the value of the equilibrium constant of increasing the temperature.

(ii) State the effects on both the rate of reaction and the value of the equilibrium constant of increasing the pressure.

(iii) Suggest why a pressure of 1000 atmospheres is not used.

(e) Name the catalyst used in the Haber process. State and explain its effect on the value of the equilibrium constant.

(g) A mixture of nitrogen and hydrogen is left at 450 °C and 250 atmospheres until equilibrium is reached. Use Le Chatelier’s principle to state and explain what will happen to the position of equilibrium when

(i) some of the ammonia is removed;

(ii) the pressure is increased.

1. Hydrogen and iodine are placed in a closed container and allowed to react at 750 °C and one atmosphere pressure. The following equilibrium is reached:

\[ \text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI}(g) \quad \Delta H = -10 \text{ kJ mol}^{-1} \]

(a) State the qualitative effect of an increase in pressure on the rate of the forward reaction and on the equilibrium position. Explain your answer in each case.
(b) After equilibrium has been established, some \( \text{H}_3 \) is added to the system. Describe the changes in the concentrations of \( \text{I}_2 \) and \( \text{HI} \) until a new equilibrium is established. [2]

(b) (i) State Le Chatelier’s Principle. [1]

(ii) State the factors which affect the position of equilibrium in a reaction. Explain the influence of one of these factors using Le Chatelier’s Principle. [3]

(iv) State the factors which affect the time taken to reach equilibrium and explain briefly the influence of one of these factors. [3]

(c) Write an equation, including state symbols, for the synthesis of ammonia by the Haber process. Explain the use of high pressure and moderately-high temperatures in the production of ammonia. [4]

Q# 27/IB Chem/2000/w/TZ0/Paper 2 Section A/Standard Level/

3. For the reversible reaction:

\[ \text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g}) \quad \Delta H > 0 \]

the equilibrium constant \( K_c = 60 \) at a particular temperature.

(a) Give the equilibrium expression and explain why the equilibrium constant has no units. [2]

(b) For this reaction, what information does the value of \( K_c \) provide about the relative concentrations of the product and reactants at equilibrium? [1]

(c) What effect, if any, will an increase in pressure have on the equilibrium position? [1]

(d) Explain why an increase in temperature increases the value of the equilibrium constant for the above reaction. [1]
1. Ammonia, NH₃, is manufactured by the Haber process according to the following equilibrium reaction:

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

The following data gives approximate values for the yield of ammonia at various temperatures and pressures.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Pressure (atm)</th>
<th>Molar % of NH₃ at equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>200</td>
<td>40</td>
</tr>
<tr>
<td>400</td>
<td>300</td>
<td>50</td>
</tr>
<tr>
<td>400</td>
<td>400</td>
<td>57</td>
</tr>
<tr>
<td>450</td>
<td>200</td>
<td>25</td>
</tr>
<tr>
<td>500</td>
<td>200</td>
<td>18</td>
</tr>
</tbody>
</table>

Use the data to deduce:

(a) (i) the effect of pressure on the yield of ammonia. Explain your answer. [2]

(ii) whether the synthesis of ammonia is endothermic or exothermic. Explain your answer. [2]

(b) State what combination of pressure (i.e. high or low) and temperature (i.e. high or low) would give the highest % of ammonia. [1]

(c) Write the equilibrium constant expression, \( K_c \), for the formation of ammonia. [2]

(d) State and explain what happens to the value of \( K_c \) if the temperature is increased. [2]

(e) How does the catalyst affect:

(i) the rate of formation of ammonia; [1]

(ii) the position of equilibrium? [1]
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>a</td>
<td>v</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Change</td>
<td>Shift</td>
<td>Reason</td>
</tr>
<tr>
<td></td>
<td>Increase in temperature</td>
<td>LHS</td>
<td>since (forward) exothermic reaction/ $\Delta H &lt; 0$</td>
</tr>
<tr>
<td></td>
<td>Increase in pressure</td>
<td>RHS</td>
<td>since fewer (gaseous) molecules on RHS</td>
</tr>
<tr>
<td></td>
<td>Addition of a catalyst to the mixture</td>
<td>No change</td>
<td>since affects rate of forward and reverse reactions equally</td>
</tr>
</tbody>
</table>

Q# 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>$\Delta_r G_m \rightarrow [-\text{COCl}_2]^+ [\text{CO}]_2[\text{Cl}_2]^{-}$</td>
<td>1</td>
</tr>
<tr>
<td>3.</td>
<td>a ii</td>
<td>no effect</td>
<td>1</td>
</tr>
</tbody>
</table>

(c) (i) rate of forward reaction equals rate of backward reaction; concentrations of reactants and products do not change / constant macroscopic properties;  

(ii) $K_c = \frac{[\text{CH}_3\text{OH}]}{[\text{CO}][\text{H}_2]^2}$;  

Do not award mark if incorrect brackets are used or brackets omitted.  

(iii) Haber process / production of NH$_3$ / contact process / production of H$_2$SO$_4$; Accept suitable equation.  

(d) (i) shifts to left/reactants; to endothermic side / (forward) reaction is exothermic;  

(ii) shifts to the right/products; to the side with fewer gas molecules/moles of gas;  

(iii) no effect on equilibrium; rate of forward and backward reaction increase equally / activation energy of forward and backward reaction lowered equally;  

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 / OWTE;  

Do not accept concentration of reactants and products are equal.  

Accept constant colour of Br$_2$ vapour/liquid.  

(b) (i) $(K_c) = \frac{[\text{SO}_3]^2}{[\text{SO}_2][\text{O}_2]}$;  

[1]
(b) (i) \( K_c = \frac{[SO_2]^2}{[SO_3][O_2]} \);

(ii) Position of equilibrium & Value of \( K_c \\
Decrease in temperature & shifts to right/products & increases \\
Increase in pressure & shifts to right/products & no effect \\
Addition of a catalyst & no effect & no effect \\


Q# 5/ IB Chem/2012/s/tz1/Paper 2 Section B/Standard Level/

6. (a) \( \text{H}_2(\text{g}) + \text{Br}_2(\text{g}) \rightleftharpoons 2\text{HBr}(\text{g}) \); [1]

(b) (i) shifts to right/toward products/forward reaction favoured; [1]

   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; [2]

(c) (i) \( K_c = \frac{[\text{HBr}]^2}{[\text{H}_2][\text{Br}_2]} \); [1]

(ii) no effect (only depends on the temperature); [1]

(e) (i) \( \begin{align*}
\text{Br}_2: & \ 0 \\
\text{HBr}: & \ -1 \\
\text{HOBr}: & \ +1
\end{align*} \)

Award [2] for three correct.

Award [1] for any two correct.

(ii) bromine is oxidized and reduced / disproportionation; [1]

(iii) \( K_c < 1 \); [1]

(iv) shifts to right/toward products/forward reaction favoured;

   to replace \( \text{H}^+ / \text{HBr} / \text{HOBr} \) / to remove \( \text{H}_2\text{O} \) formed from neutralization; [2]

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

6. (a) (i) \( K_c = \frac{[\text{NO}_2][\text{H}_2\text{O}]}{[\text{NH}_3][\text{O}_2]} \); [1]

   No mark if square brackets are omitted or are incorrect.

   (ii) right; right; right; no change; [4]
(ii) pressure is lower/moderate and temperature is higher in Haber process / 
− 200 atm (pressure) and − 700 K (temperature) used in Haber process;

*Pressure:*
high pressure shifts equilibrium to right;
high pressure (faster rate but) expensive/dangerous / greater capital and running costs;

*Temperature:*
low temperature shifts equilibrium (even further) to right;
low temperature gives slower rate (but high yield);

high pressure increases yield and lower temperature decreases rate;  
Accept converse argument.

(not possible to have high yield and fast rate simultaneously therefore) 
compromise needed / OWTTE;  

[4 max]

Q# 7/ IB Chem/2011/s/TZ1/Paper 2 Section A/Standard Level/

3. (a) \( K_c = \frac{[\text{CH}_3\text{OH}]}{[\text{CO}_2][\text{H}_2]} \);  

Do not award mark if incorrect brackets are used or brackets are missing.

(b) (i) amount (of methanol)/product decreases / less methanol;  
(forward reaction) exothermic / reverse reaction endothermic / OWTTE;  

(b) (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;  

(c) high pressure expensive / greater cost of operating at high pressure;  lower temperature − lower (reaction) rate;  

(d) increases rate of forward and reverse reactions (equally) / lowers activation energy/\( E_a \) (of both the forward and reverse reaction equally) / provides alternative path with lower activation energy/\( E_a \);  
Accept reactants adsorb onto the catalyst surface and bonds weaken resulting in a decrease in the activation energy.

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;  

(ii) yield increases / equilibrium moves to the right / more ammonia;  
increase in pressure favours the reaction which has fewer moles of gaseous products;  

(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;
rates 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) $K_c = \frac{[\text{glycerol}] \times [\text{biodiesel}]}{[\text{vegetable oil}] \times [\text{methanol}]}$; [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; [2]

No ECF for explanation.

Q# 11/ IB Chem/2009/w/tz0/Paper 2 Section B/Standard Level/

5. (a) $K_c = \frac{[\text{SO}_2\text{Cl}_2 \text{]} \times [\text{SO}_2 \text{]}}{[\text{Cl}_2 \text{][SO}_2 \text{]}}$; [1]

Ignore state symbols.
Square brackets [ ] required for the equilibrium expression.

(ii) value of $K_c$ increases;
$[\text{SO}_2\text{Cl}_2 \text{]}$ increases;
decrease in temperature favours (forward) reaction which is exothermic;

Do not allow ECF; [3]

(iii) no effect on the value of $K_c$ / depends only on temperature;
$[\text{SO}_2\text{Cl}_2 \text{]}$ decreases;
increase in volume favours the reverse reaction which has more gaseous moles;

Do not allow ECF; [3]

(iv) no effect;
catalyst increases the rate of forward and reverse reactions (equally) / catalyst decreases activation energies (equally); [2]
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; [2]

(ii) (equilibrium shifted to the left) equilibrium concentration of NO is reduced; (forward) reaction is exothermic; [2]

(iii) no effect on the equilibrium concentration of NO; catalyst increases the rate of forward and reverse reaction equally; [2]

(b) \( K_c = \frac{[\text{NO}]^4[\text{H}_2\text{O}]}{[\text{NH}_3]^8[\text{O}_2]} \); mol dm\(^{-3}\); [2]

(c) increase in temperature; \( K_c \) decreases; [2]

---

Q# 13/ IB Chem/2007/w/tz0/Paper 2 Section B/Standard Level/

7. (a) (i) \( K_c = \frac{[\text{SO}_2]^2}{[\text{SO}_3]^2[\text{O}_2]} \); [1]

(ii) pressure high pressure (will allow system to occupy smaller volume); \( V_{\text{product}} < V_{\text{reactant}} \) / equilibrium moves to the right to reduce pressure / reaction proceeds to lower/lowest number of gaseous molecules / OWTTE;

(iii) temperature low temperature; (exothermic reaction) forward reaction favoured to replace some of the heat removed / equilibrium moves to the right to produce heat / OWTTE; [4]

No mark for just saying “due to Le Chatelier’s principle”

(iv) rate is faster at 450 °C (than at low temperatures); >95% / 90—99% yield / (very) high conversion takes place; unnecessary to use expensive high pressure equipment / (to achieve) high pressure is very expensive; [3]

(iv) vanadium pentoxide / vanadium(V) oxide / \( \text{V}_2\text{O}_5 \) / finely divided platinum / Pt; no effect on \( K_c \); forward and reverse rates speeded up (equally); [3]

---

Q# 14/ IB Chem/2007/s/TZ1/Paper 2 Section A/Standard Level/

4. (a) \( K_c = \frac{[\text{N}_2]^{\text{r}}}{[\text{H}_2][\text{N}_2]} \); [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; [2]

(c) \( K_c \) decreases; equilibrium position shifts to the left/reactants / forward reaction is exothermic / reverse reaction is endothermic; [2]

(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]
4. (a) \( \frac{[\text{NH}_3]^+}{[\text{H}_2]\text{F}^-[\text{N}_2]} \) \[1\]

*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; \[2\]

(c) \( K_c \) decreases;
equilibrium position shifts to the left / reactants / forward reaction is exothermic / reverse reaction is endothermic; \[2\]

(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; \[1\]

6. (a) (i) B and D;
(reactions are) endothermic / have positive \( \Delta H^\circ \) values; \[2\]

(ii) B and D;
fewer gas volumes / moles on left / more gas volumes on right; \[2\]

(b) no effect on position of equilibrium;
forward and reverse reactions speeded up equally / effects the rate of reaction but not the extent of the reaction;
no effect on value \( K_c \) of;
no change in concentrations of reactants or products / \( K_c \) only changes if temperature alters; \[4\]

6. (a) \( K / K_c = [\text{SO}_3]^+ + [\text{SO}_2]^2+ [\text{O}_2] \) \[1\]

*Accept correct \( K_p \) expression.*

(b) (i) vanadium(V) oxide / (di)vanadium pentaoxide / V_2O_5; \[1\]

*Allow just vanadium oxide but not correct formula.*

(ii) catalyst does not affect the value of \( K_c \);
forward and reverse rates increase equally / by the same factor;
catalyst increases the rate of the reaction;
(by providing an alternative path for the reaction with) lower activation energy; \[4\]

(c) more energetic collisions / more molecules have energy greater than activation energy;
more frequent collisions;
*Do not accept more collisions without reference to time.* \[2\]

(d) (i) shifts equilibrium position to the products / right;
to the side with fewer gas molecules or moles / lower volume of gas; \[2\]

(ii) shifts equilibrium position to the products / right;
to compensate for loss of \( \text{SO}_3 \) / produce more \( \text{SO}_3 \); \[2\]

(iii) no effect;
forward and backward rates increased equally / by the same factor; \[2\]
(e) exothermic:
\[ K_c \text{ decreases with increasing temperature} / \text{back reaction favoured} / \text{heat used up} / \]
OWTTE.

18/ IB Chem/2005/w/tz0/Paper 2 Section B/Standard Level/

6. (a) (i) \( (K_c = \frac{[NO_2]^+}{[N_2O_4]} \) \\
(horizontal line) concentration of reactant and product remains constant / equilibrium reached; \\
(magnitude of) \( K_c \) greater than 1; \\
Accept 1.6; \\
product concentration greater than reactant concentration; 

(ii) increased temperature shifts equilibrium position to right; \\
(forward) reaction is endothermic / absorbs heat; 

(ii) increased pressure shifts equilibrium to left; \\
(fewer (gas) moles/molecules on left; 

(iv) both forward and reverse rates increased / increase in forward reverse rates are equal; \\
activation energy reduced; \\
position of equilibrium unchanged; \\
concentration/amount of reactants and products remain constant; \\
value of \( K_c \) unchanged; \\
\( K_c \) only affected by changes in temperature; 

Q# 19/ IB Chem/2004/w/tz0/Paper 2 Section B/Standard Level/

(d) (i) reversible reaction / reaction may proceed in either direction (depending on reaction conditions) equilibrium / dynamic equilibrium; 

(ii) no effect; \\
catalyst will speed up both forward and reverse reactions (equally) / \\
increase the rate at which equilibrium is achieved; 

(iii) acidity: no effect; \\
equilibrium shifts to the right; \\
\( K_c \): no change; 

Q# 20/ IB Chem/2004/s/TZ1/Paper 2 Section A/Standard Level/

4. (a) (position of) equilibrium shifts to the left / towards reactants; \\
(forward) reaction is exothermic / \( \Delta H \) is negative / the reverse reaction is endothermic / OWTTE; \\
Do not accept “Le Chatelier’s Principle” without some additional explanation. 

(b) (position of) equilibrium shifts to the right / towards products; \\
fewer gas molecules on the right hand side / volume decreases in forward reaction / OWTTE; \\
Do not accept “Le Chatelier’s Principle” without some additional explanation.
(b) two curves - one labeled "forward" starting up high up y-axis and one labeled "reverse" starting from zero; curves merge and become horizontal; No penalty for failing to label axes.

*forward reaction:* highest concentration, thus rate high to begin with; as reaction proceeds, concentrations decrease, so does rate;

*reverse reaction:* zero rate initially / at t = 0 (since no products present); rate increases as concentration of products increases;

*equilibrium established when rate of forward reaction = rate of reverse reaction;*

(c) reaction is) endothermic;
Kc increases with (increasing) temperature;
forward reaction favoured / heat used up / OWTTE;

Q# 22/ IB Chem/2003/s/TZ1/Paper 2 Section A/Standard Level/

1. (a) 200 °C  600 atm. (*both for [I], units not needed*);
   allow the “highest pressure and the lowest temperature”

(b) (i) yield increases / equilibrium moves to the right / more ammonia;
   4 (gas) molecules → 2 / decrease in volume / fewer molecules on right hand side;

   (ii) yield decreases / equilibrium moves to the left / less ammonia;
   exothermic reaction / OWTTE;

(c) high pressure expensive / greater cost of operating at high pressure / reinforced pipes etc. needed;
   lower temperature – greater yield, but lowers rate; *Do not award a mark just for the word “compromise”.*

(d) $K_c = \frac{[NH_3]^2}{[N_2][H_2]}$ (ignore units);
3. (a) 600 atm and 200 °C (units needed, do not accept just low temperature and high pressure); [1]

(b) (i) yield increases / more ammonia formed; (not just forward reaction favoured) equilibrium shifts to side with fewer gas moles / molecules / volumes / OWTTE; [2]

(ii) yield decreases / less ammonia formed; (not just reverse reaction favoured) equilibrium shifts in endothermic direction / to side which absorbs energy / OWTTE; [2]

(c) at 200 °C / low temperature reaction is (too) slow; at 600 atm / high pressure the cost / danger is (too) great; (Do not allow just high cost if no mention of pressure). [2]

5. (a) forward and reverse reactions still occurring / forward and reverse rates equal [1]; concentrations of reactants and products unchanged [1]. [2]

(b) Reactants and products in the same phase/state. [1]

(c) \[ K_c = \frac{[\text{NH}_3]^3}{[\text{N}_2][\text{H}_2]^3} \]

Accept correct expression for \( K_p \)
Use of [] and formulas in correct position [1]; powers correct [1]. [2]

(d) (i) rate increased [1];
      equilibrium constant decreased [1]. [2]

(ii) rate increased [1];
      equilibrium constant unchanged [1]. [2]

(iii) too expensive / greater cost of energy or pipes / more safety precautions / thicker pipes [1]

(e) iron / Fe [1];
    equilibrium constant unchanged [1];
    only temperature affects \( K_c \) / catalyst speeds up forward and reverse reactions equally / activation energy reduced by same amount for both forward and reverse reactions [1]. [3]

(f) (Award [1] for any three of the following:)

successful collisions need minimum/activation energy / correct geometry [1];
increasing temperature causes increase in energy of particles [1];
so increased proportion of successful collisions [1];
so increased frequency of collisions / more collisions per unit time [1];
Do not accept just “more collisions”. [3]

(g) (i) shifted to right [1];
     to replace the ammonia removed [1]; [2]

(ii) shifted to right [1];
     fewer gas moles on the right / OWTTE [1]. [2]
1. (a) Reaction rate is faster. Increase in pressure increases concentration of reactants / same amount in less volume, and the rate increases as the number of collisions per unit volume increases. [1]

Equilibrium position does not change. K is independent of concentration / depends on T only. [1]

(b) \([I_2]\): Decreases slightly, then becomes constant. [1]

\([HI]\): Increases slightly, then becomes constant. [1]

4. (a) Change of concentration of reactant/product with time [1]
Identify feasible reaction [1]
State what is to be measured [1]
Record time for specific event [1]
Plot graph of reciprocal time \(\left(\frac{1}{t}\right)\) [1] [5 max]

(N.B. we are timing [1] a specific process e.g. gas/precipitate appearing, etc. [1])

(b) (i) If a system at equilibrium is disturbed, the equilibrium moves in the direction which tends to reduce the disturbance (OWTTE). [1]

(ii) Temperature and pressure / concentration [1] (ignore others) For the factor chosen, [1] for effect/influence and [1] for explanation [3 max]

Temperature: effect depends on whether endothermic or exothermic [1], explanation [1]
Pressure: effect depends on number of moles of gaseous reactants and products [1], explanation [1]
Concentration: effect depends on whether change is to reactants or products [1], explanation [1]

(iii) Molecules must collide in order to react [1]
Not all collisions lead to a reaction [1]
Minimum energy needed/activation energy [1]
Appropriate collision geometry required [1] [4 max]

(iv) Temperature, concentration/pressure, catalyst, surface area [2]
(Award [2] for 3 or 4 factors and [1] for 2 factors)

(Award [1] for explanation, for example)

Temperature increase: increases frequency / number of collisions / more molecules have sufficient energy to react [1]

Conc./pressure increase: increase in the number / frequency of collisions [1]

Catalyst: reduces minimum energy needed to react / reduces \(E_g\) / provides alternative reaction pathway with lower energy [1]

Surface area: increases number of collisions [1] [3 max]
(c)  \( \text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g}) \)  (state symbols and \( \equiv \) required) [1]

- Low temperature, high yield [1]
- Low temperature, low rate [1]
- High pressure, high yield [1]
- High pressure, high rate [1] [3 max]

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3. (a)  \[ K_c = \frac{[\text{HI}]}{[\text{H}_2][\text{I}_2]} \] [1]

Units cancel for reactants and products / for numerator and denominator. [1]

(b) Concentration of product / HI greater (than \([\text{H}_2]\) and \([\text{I}_2]\)) [1]

(c) It will have no effect. [1]

(d) As the reaction is endothermic, increasing \( T \) will shift equilibrium position to the right. [1]

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1. (a) (i) Increases

the volume/number of moles decreases during the reaction, so increasing the pressure shifts equilibrium to the right. [1 mark]

(ii) Exothermic

because the yield decreases as the temperature increases

must have exothermic to score second mark [1 mark]

(b) Low temperature, high pressure

Do not award credit for specific numerical values [1 mark]

(c)  \[ K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3} \]  for powers [1 mark]

product (as numerator) [1 mark]

(d) Decreased

equilibrium moves (shifts) to left/less \( \text{NH}_3 \) produced [1 mark]

(e) (i) increased [1 mark]

(ii) unchanged [1 mark]