CHEMICAL EQUILIBRIUM

Theory Questions (GCE & iGCSE)

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(b) Ammonia is manufactured by the Haber Process. The economics of this process require that as much ammonia as possible is made as quickly as possible.
Explain how this can be done using the following information.

The conditions for the following reversible reaction are:

- 450 °C
- 200 atmospheres pressure
- iron catalyst

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ the reaction is exothermic

.....

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.....

..... [5]

0620/s13/qp31

(c) Vanadium(V) oxide is used to catalyse the exothermic reaction between sulfur dioxide and oxygen in the Contact Process.

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

The rate of this reaction can be increased either by using a catalyst or by increasing the temperature. Explain why a catalyst is used and not a higher temperature.

.....

.....

..... [2]

0620/s12/qp31

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6 **(a)** Methanol can be made from a mixture of carbon monoxide and hydrogen.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

The forward reaction is exothermic.

(i) Explain why the concentration of methanol at equilibrium does not change.

.....

..... [2]

(ii) Suggest conditions, in terms of temperature and pressure, which would give a high yield of methanol.

.....

..... [2]

(iii) How would the conditions used in practice compare with those given in **(ii)**? Give an explanation of any differences.

.....

.....

..... [2]

0620/s11/qp32

(b) Sulfur dioxide is used to make sulfur trioxide in the Contact Process.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

The forward reaction is exothermic. The conditions used are:

temperature: 450 °C
pressure: 2 atmospheres
catalyst: vanadium(V) oxide

Explain, mentioning both position of equilibrium and rate, why these conditions give the most economic yield.

.....

.....

.....

..... [4]

0620/s11/qp31

(b) At most temperatures, samples of nitrogen dioxide are equilibrium mixtures.

$$\underset{\text{dark brown}}{2NO_2(g)} \rightleftharpoons \underset{\text{pale yellow}}{N_2O_4(g)}$$

(i) At 25 °C, the mixture contains 20 % of nitrogen dioxide. At 100 °C this has risen to 90 %. Is the forward reaction exothermic or endothermic?
Give a reason for your choice.

.....

.....

..... [2]

(ii) Explain why the colour of the equilibrium mixture becomes lighter when the pressure on the mixture is increased.

.....

.....

..... [2]

0620/s10/qp32

6 Ammonia is manufactured by the Haber process.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ the forward reaction is exothermic

(a) (i) Name the raw materials from which nitrogen and hydrogen are obtained.

nitrogen from ..... [1]

hydrogen from ..... [1]

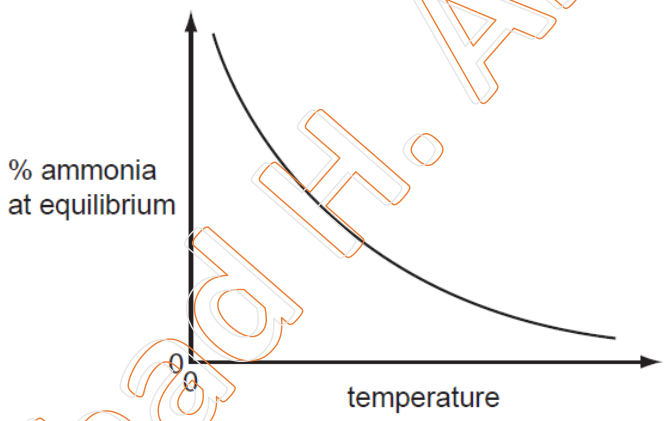
(ii) Name the catalyst used in this process.

..... [1]

(iii) What is the most important use of ammonia?

..... [1]

(b) The following graph shows how the percentage of ammonia in the equilibrium mixture changes with temperature.



(i) Explain the term *equilibrium*.

.....

.....

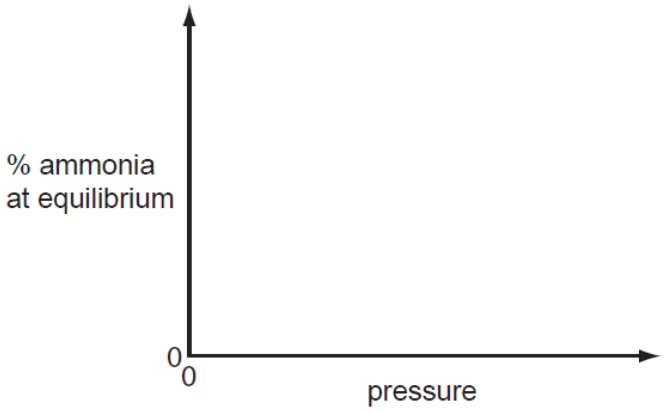
.....

..... [2]

(ii) How does the percentage of ammonia vary with temperature?

..... [1]

(c) **(i)** Sketch a graph which shows how the percentage of ammonia in the equilibrium mixture varies with pressure.



[1]

(ii) Explain why the graph has the shape shown.

.....

.....

..... [2]

[Total: 10]

0620/s09/qp31

5 Carbonyl chloride, $COCl_2$, is a colourless gas. It is made by the following reaction.

$$CO(g) + Cl_2(g) \underset{\text{heat}}{\overset{\text{cool}}{\rightleftharpoons}} COCl_2(g)$$

(a) When the pressure on the equilibrium mixture is decreased, the position of equilibrium moves to left.

(i) How does the concentration of each of the three chemicals change?

.....

..... [2]

(ii) Explain why the position of equilibrium moves to left.

.....

..... [2]

(b) Using the information given with the equation, is the forward reaction exothermic or endothermic? Give a reason for your choice.

.....

..... [2]

5 Sulphuric acid is made by the Contact process in the following sequence of reactions.

sulphur → sulphur dioxide → sulphur trioxide → sulphuric acid

(a) (i) How is sulphur dioxide made from sulphur?

.....

[1]

(ii) Sulphur dioxide has other uses.
Why is it used in the manufacture of paper?

.....

[1]

(iii) How does it preserve food?

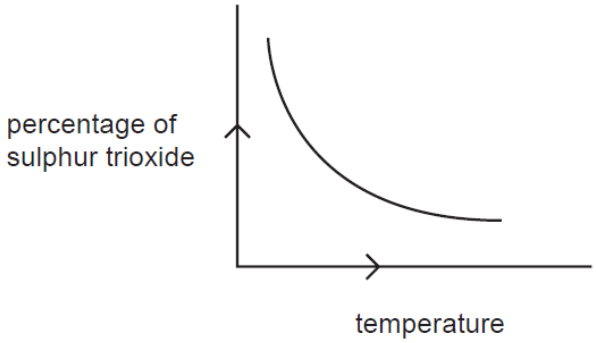
.....

[1]

(b) The equation for a stage of the Contact process is

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

The percentage of sulphur trioxide in the equilibrium mixture varies with temperature.



(i) How does the percentage of sulphur trioxide in the equilibrium mixture vary as the temperature increases? Circle the correct answer.

increases **stays the same** **decreases**

[1]

(ii) Is the forward reaction in the equilibrium $2SO_2 + O_2 \rightleftharpoons 2SO_3$ exothermic or endothermic? Give a reason for your choice.

.....

.....

[2]

(iii) Explain, mentioning both rate and percentage yield, why the temperature used in the Contact process is 450°C.

.....

..... [2]

(iv) Describe how the sulphur trioxide is changed into concentrated sulphuric acid.

.....

..... [2]

0620/s06/qp3

(c) Sulphuric acid is manufactured by the Contact Process. Sulphur dioxide is oxidised to sulphur trioxide by oxygen.

$$2SO_2 + O_2 \rightarrow 2SO_3$$

(i) Name the catalyst used in this reaction.

..... [1]

(ii) What temperature is used for this reaction?

..... [1]

(iii) Describe how sulphur trioxide is changed into sulphuric acid.

.....

..... [2]

0620/s05/qp3

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2 Sulphur is used to make sulphuric acid. In the UK, the annual production of the acid is about 2.5 million tonnes.

(a) The reactions in the manufacture of sulphuric acid by the Contact Process are shown below.

Sulphur	⟶	Sulphur dioxide
S	**reaction 1**	SO_2
Sulphur dioxide + oxygen	⟶	Sulphur trioxide
$2SO_2 + O_2$	**reaction 2**	$2SO_3$
Sulphur trioxide	⟶	Oleum
SO_3	**reaction 3**	$H_2S_2O_7$
Oleum + water	⟶	Sulphuric acid
$H_2S_2O_7$	**reaction 4**	H_2SO_4

(i) Give a large scale source of the element sulphur.

.....[1]

(ii) State another use of sulphur dioxide.

.....[1]

(iii) How is sulphur changed into sulphur dioxide?

.....[1]

(iv) Name the catalyst used in reaction **2**.

.....[1]

(v) Reaction **2** is exothermic. Why is a catalyst, rather than a higher temperature, used to increase the rate of this reversible reaction?

.....

.....[2]

(vi) Write a word equation for reaction **3**.

.....[1]

(vii) Write a symbol equation for reaction **4**.

.....[1]

5 Ammonia is manufactured by the Haber Process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$
200 atmospheres
450°C

The forward reaction is exothermic.

(a) (i) What is the catalyst for this reaction?

..... [1]

(ii) Newer catalysts have been discovered for this process. Using these catalysts, the operating temperature is lowered from 450°C to 400°C. What is the advantage of using a lower temperature?
Explain your answer.

advantage .....

explanation .....

..... [2]

(b) After passing over the catalyst, the mixture contains 15% of ammonia. It is cooled and the ammonia liquefies and is separated from the unreacted nitrogen and hydrogen. They are recycled.

(i) How are the gases recycled?

..... [1]

(ii) Only ammonia gas liquefies. Suggest an explanation for this.

..... [1]

7 In 1909, Haber discovered that nitrogen and hydrogen would react to form ammonia. The yield of ammonia was 8%.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$ the forward reaction is exothermic

catalyst platinum
temperature 600 °C
pressure 200 atm

(a) Describe how hydrogen is obtained for the modern process.

.....

..... [2]

(b) **(i)** What is the catalyst in the modern process?

..... [1]

(ii) Explain why the modern process, which uses a lower temperature, has a higher yield of 15%.

.....

..... [2]

0620/w05/qp3

3 Reversible reactions can come to equilibrium. They have both a forward and a backward reaction.

(a) When water is added to an acidic solution of bismuth(III) chloride, a white precipitate forms and the mixture slowly goes cloudy.

$$\underset{\text{colourless}}{BiCl_3(aq)} + H_2O(l) \underset{\text{backward}}{\overset{\text{forward}}{\rightleftharpoons}} \underset{\text{white}}{BiOCl(s)} + 2HCl(aq)$$

(i) Explain why the rate of the forward reaction decreases with time.

.....

..... [2]

(ii) Why does the rate of the backward reaction increase with time?

.....

..... [1]

(iii) After some time why does the appearance of the mixture remain unchanged?

.....

..... [2]

(iv) When a few drops of concentrated hydrochloric acid are added to the cloudy mixture, it changes to a colourless solution. Suggest an explanation.

.....

..... [2]

(b) Both of the following reactions are reversible.

reaction 1 $N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$

reaction 2 $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$

(i) Suggest a reason why an increase in pressure does not affect the position of equilibrium for reaction 1.

.....

[1]

(ii) What effect would an increase in pressure have on the position of equilibrium for reaction 2? Give a reason for your answer.

.....

.....

[2]

3 The simplest alcohol is methanol.

(a) It is manufactured by the following reversible reaction.

$$CO\ (g) + 2H_2\ (g) \rightleftharpoons CH_3OH\ (g)$$
$$300\,^{\circ}C$$
$$30 atm$$

(i) Reversible reactions can come to equilibrium. Explain the term *equilibrium*.

[1]

(ii) At 400 °C, the percentage of methanol in the equilibrium mixture is lower than at 300 °C. Suggest an explanation.

[2]

(iii) Suggest two advantages of using high pressure for this reaction.
Give a reason for each advantage.

advantage	
reason	

advantage	
reason	

[5]

5 Sulphur dioxide, SO_2, and sulphur trioxide, SO_3, are the two oxides of sulphur.

(a) Sulphur dioxide can kill bacteria and has bleaching properties. Give a use of sulphur dioxide that depends on each of these properties.

(i) ability to kill bacteria .....[1]

(ii) bleaching properties .....[1]

(b) Sulphur trioxide can be made from sulphur dioxide.

(i) Why is this reaction important industrially?

.....[1]

(ii) Complete the word equation.

sulphur dioxide + ... → sulphur trioxide [1]

(iii) What are the conditions for this reaction?

.....

.....[2]

1 Ammonia contains the elements nitrogen and hydrogen. It is manufactured from these elements in the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

The forward reaction is exothermic.

(a) **(i)** Nitrogen is obtained from liquid air by fractional distillation. Why does this technique separate liquid oxygen and nitrogen?

.....

.....

(ii) Name **two** raw materials from which hydrogen is manufactured.

.....[3]

(b) The table shows how the percentage of ammonia in the equilibrium mixture varies with pressure at 600 °C.

percentage ammonia	8	12	15	20
pressure/atm	200	300	400	500

(i) Explain why the percentage of ammonia increases as the pressure increases.

.....

.....[2]

(ii) How would the percentage of ammonia change if the measurements had been made at a lower temperature?
Explain your answer.

.....

.....

.....[2]

(iii) State **two** of the reaction conditions used in the Haber Process.

.....

.....[2]

1 **(a)** Sulphuric acid is made by the Contact Process.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \text{forward reaction is exothermic}$$

(i) What are the reaction conditions for the Contact Process?

.....

.....[3]

(ii) Would the yield of sulphur trioxide increase, decrease or stay the same when the temperature is increased? Explain your answer.

.....

.....

.....[2]

(iii) Describe how sulphur trioxide is changed into concentrated sulphuric acid.

.....

.....[2]

6 Iodine reacts with chlorine to form dark brown iodine monochloride.

$$I_2 + Cl_2 \rightarrow 2ICl$$

This reacts with more chlorine to give yellow iodine trichloride.
There is an equilibrium between these iodine chlorides.

$$\underset{\text{dark brown}}{ICl(l)} + Cl_2(g) \rightleftharpoons \underset{\text{yellow}}{ICl_3(s)}$$

(a) Explain what is meant by *equilibrium*.

.....

.....

..... [2]

(b) When the equilibrium mixture is heated it becomes a darker brown colour.
Is the reverse reaction endothermic or exothermic? Give a reason for your choice.

.....

.....

..... [2]

(c) The pressure on the equilibrium mixture is decreased.

(i) How would this affect the position of equilibrium and why?

It would move to the ..... [1]

reason .....

..... [1]

(ii) Describe what you would observe.

.....

..... [1]

[Total: 7]

0620/s10/qp31

7 Titanium is a transition element. It is isolated by the following reactions.

$$\text{titanium ore} \rightarrow \underset{TiO_2}{\text{titanium(IV) oxide}} \rightarrow \underset{TiCl_4}{\text{titanium(IV) chloride}} \rightarrow \underset{Ti}{\text{titanium}}$$

(a) Why is it usually necessary to include a number in the name of the compounds of transition elements?

..... [1]

(b) Titanium(IV) chloride is made by heating the oxide with coke and chlorine.

$$TiO_2 + 2Cl_2 \rightleftharpoons TiCl_4 + O_2$$

$$2C + O_2 \rightleftharpoons 2CO$$

Explain why the presence of coke ensures the maximum yield of the metal chloride.

.....

.....

..... [2]

5 Ammonia is made by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

The forward reaction is exothermic.
The conditions in the reaction chamber are:

- a pressure of 200 atmospheres,
- a catalyst of finely divided iron,
- a temperature of 400 to 450 °C.

(a) What are the **two** advantages of using a high pressure? Give a reason for both.

advantage 1 .....

reason .....

.....

advantage 2 .....

reason .....

.....

[4]

(b) A higher temperature would give a faster reaction rate.
Why is a higher temperature **not** used?

.....

.....

..... [3]

(c) **(i)** Why is the iron catalyst used as a fine powder?

.....

..... [1]

(ii) Give **two** reasons why a catalyst is used.

.....

.....

.....

..... [2]

(d) The equilibrium mixture leaving the reaction chamber contains 15% ammonia. Suggest how the ammonia could be separated from the mixture.

	boiling point / °C
hydrogen	–253
nitrogen	–196
ammonia	–33

.....

..... [2]

0620/s14/qp33

5 Carbonyl chloride is made from carbon monoxide and chlorine.

$$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$$

(a) Two methods of preparing carbon monoxide are from methane and oxygen, and from methane and steam.

(i) The reaction between methane and oxygen can also form carbon dioxide. How can carbon monoxide be made instead of carbon dioxide?

..... [1]

(ii) The following reaction is used to make carbon monoxide and hydrogen.
The reaction is carried out at 1100 °C and normal pressure.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$$

The reaction is reversible and comes to equilibrium. Suggest why a high temperature is used.

.....

.....

..... [2]

(iii) What is the disadvantage of using a high pressure for the reaction given in **(a)(ii)**?

.....

..... [2]

(b) Chlorine is made by the electrolysis of concentrated aqueous sodium chloride.
Describe this electrolysis. Write ionic equations for the reactions at the electrodes and name the sodium compound formed.

.....

.....

.....

.....

.....

..... [5]

0620/s14/qp32

3 Plant growth is improved by the availability of essential elements, such as nitrogen, and by the soil having a suitable pH.

(a) Nitrogen-based fertilisers are made from ammonia. Ammonia is manufactured by the Haber process.

(i) Describe the Haber process giving reaction conditions and a balanced equation.
(Do not discuss reaction rate and yield.)

.....

.....

.....

.....

..... [5]

0620/s14/qp32

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4 At present the most important method of manufacturing hydrogen is steam reforming of methane.

(a) In the first stage of the process, methane reacts with steam at 800 °C.

$$CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g)$$

In the second stage of the process, carbon monoxide reacts with steam at 200 °C.

$$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$$

(i) Explain why the position of equilibrium in the first reaction is affected by pressure but the position of equilibrium in the second reaction is not.

.....

.....

..... [2]

(ii) Suggest why a high temperature is needed in the first reaction to get a high yield of products but in the second reaction a high yield is obtained at a low temperature.

.....

..... [2]

0620/s13/qp32

(b) Almost all samples of nitrogen dioxide are an equilibrium mixture of nitrogen dioxide, NO_2, and dinitrogen tetroxide, N_2O_4.

$$2NO_2(g) \underset{\text{reverse reaction}}{\overset{\text{forward reaction}}{\rightleftharpoons}} N_2O_4(g)$$

dark brown — colourless

In the forward reaction, a bond forms between the two nitrogen dioxide molecules.

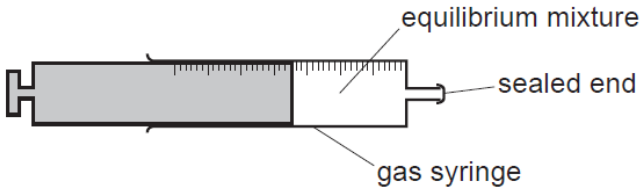
$$NO_2 + NO_2 \rightarrow O_2N-NO_2$$

(i) Explain the term *equilibrium mixture*.

.....

..... [1]

(ii) The syringe contains a sample of the equilibrium mixture. The plunger was pulled back reducing the pressure.
How would the colour of the gas inside the syringe change? Give an explanation for your answer.



.....

.....

..... [3]

(iii) A sealed tube containing an equilibrium mixture of nitrogen dioxide and dinitrogen tetroxide was placed in a beaker of ice cold water.
The colour of the mixture changed from brown to pale yellow.

Is the forward reaction exothermic or endothermic? Give an explanation for your choice.

.....

..... [2]

(iv) What other piece of information given in the equation supports your answer to **(iii)**?

$$NO_2 + NO_2 \rightarrow O_2N-NO_2$$

..... [1]

0620/s13/qp33

(b) Nickel ores are converted into nickel(II) oxide. This can be reduced to impure nickel by heating with carbon. The nickel is purified by the following reversible reaction.

$$Ni(s) + 4CO(g) \rightleftharpoons Ni(CO)_4(g)$$

nickel carbonyl

(i) Impure nickel is heated at 60 °C. The forward reaction occurs.

$$Ni(s) + 4CO(g) \rightarrow Ni(CO)_4(g)$$

impure

The nickel carbonyl, a gas, moves into a hotter chamber at 200 °C. The backward reaction occurs and the nickel carbonyl decomposes.

$$Ni(CO)_4(g) \rightarrow Ni(s) + 4CO(g)$$

pure

Is the forward reaction exothermic or endothermic? Give a reason for your answer.

.....

.....

..... [2]

(ii) Explain why the forward reaction is favoured by an increase in pressure.

.....

..... [2]

(iii) Suggest what happens to the impurities.

..... [1]

(iv) Suggest another method of refining nickel. Give a brief description of the method which you have suggested. A labelled diagram is acceptable.

[4]

(b) Many fertilisers are manufactured from ammonia. Describe how ammonia is made in the Haber process. Give the essential conditions and an equation for the process.

.....

.....

.....

..... [4]

0620/w11/qp33

(c) When antimony chloride is added to water, a faint white precipitate forms and the mixture slowly goes cloudy.

$$\underset{\text{colourless}}{SbCl_3(aq)} + \underset{}{H_2O(l)} \underset{\text{backward}}{\overset{\text{forward}}{\rightleftharpoons}} \underset{}{2HCl(aq)} + \underset{\text{white}}{SbOCl(s)}$$

(i) Explain why after some time the appearance of the mixture remains unchanged.

.....

..... [2]

(ii) When a few drops of concentrated hydrochloric acid are added to the mixture, it changes to a colourless solution. Suggest an explanation.

.....

..... [1]

(iii) Suggest how you could make the colourless solution go cloudy.

..... [1]

0620/w11/qp32

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2 Sulfur is needed for the production of sulfuric acid. Two of the major sources of sulfur are

- underground deposits of the element sulfur,
- sulfur compounds from natural gas and petroleum.

(a) Explain why sulfur and its compounds are removed from these fuels before they are burned.

.....

..... [2]

(b) Sulfur dioxide is made by spraying molten sulfur into air. The sulfur ignites and sulfur dioxide is formed.

(i) Suggest why molten sulfur is used in the form of a fine spray.

.....

..... [2]

(ii) Explain why traces of sulfur dioxide act as a preservative in fruit juices.

..... [1]

(iii) State another use of sulfur dioxide.

..... [1]

(c) Describe how sulfur dioxide is changed into sulfur trioxide. Give the reaction conditions and an equation.

.....

.....

.....

..... [4]

(d) Complete the following equations for the formation of sulfuric acid from sulfur trioxide.

SO_3 + ... → $H_2S_2O_7$

$H_2S_2O_7$ + ... → .....H_2SO_4 [2]

[Total: 12]

0620/w11/qp32

4 Reversible reactions can come to equilibrium. The following are three examples of types of gaseous equilibria.

$A_2(g) + B_2(g) \rightleftharpoons 2AB(g)$ **reaction 1**

$A_2(g) + 3B_2(g) \rightleftharpoons 2AB_3(g)$ **reaction 2**

$2AB_2(g) \rightleftharpoons 2AB(g) + B_2(g)$ **reaction 3**

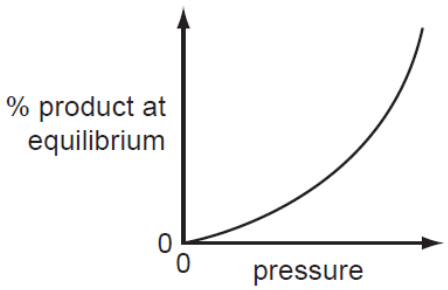
(a) Explain the term *equilibrium*.

.....

..... [2]

(b) The following graphs show how the percentage of products of a reversible reaction at equilibrium could vary with pressure.
For each graph, decide whether the percentage of products decreases, increases or stays the same when the pressure is **increased**, then match each graph to one of the above reactions and give a reason for your choice.

(i)



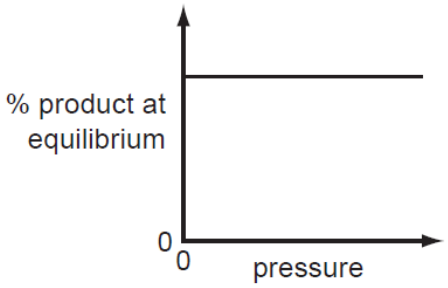
effect on percentage of products .....

reaction .....

reason .....

..... [3]

(ii)



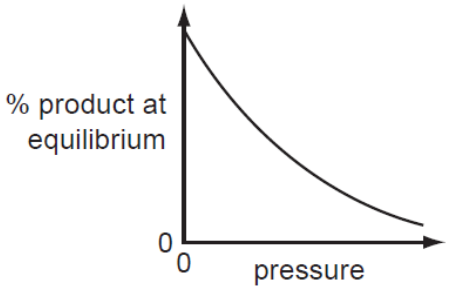
effect on percentage of products .....

reaction .....

reason .....

..... [3]

(iii)



effect on percentage of products .....

reaction .....

reason .....

..... [3]

[Total: 11]

0620/w11/qp31

(b) Ammonia is made by the Haber Process.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ forward reaction is exothermic

The percentage of ammonia in the equilibrium mixture varies with conditions.

pressure / atmospheres	100	200	300	400
% ammonia at 300 °C	45	65	72	78
% ammonia at 500 °C	9	18	25	31

The conditions actually used are 200 atmospheres, 450 °C and an iron catalyst.

(i) The original catalyst was platinum. Suggest a reason why it was changed to iron.

..... [1]

(ii) Explain why the highest pressure gives the highest percentage of ammonia in the equilibrium mixture.

.....

..... [2]

(iii) What happens to the unreacted nitrogen and hydrogen?

.....

..... [1]

(iv) State **one** advantage and **one** disadvantage of using a lower temperature.

advantage .....

..... [1]

disadvantage .....

..... [1]

[Total: 9]

0620/w10/qp31

7 The major use of sulfur dioxide is to manufacture sulfuric acid.

(a) (i) Another use of sulfur dioxide is as the food additive E220.
How does it preserve food?

.....

..... [1]

(ii) Why is sulfur dioxide used in the manufacture of wood pulp?

..... [1]

(iii) How is sulfur dioxide manufactured?

..... [1]

(b) Complete the following description of the manufacture of sulfuric acid.

Sulfur dioxide reacts with ..... to form sulfur trioxide.

The above reaction is catalysed by ..... .

The optimum temperature for this reaction is ..... °C.

Sulfur trioxide needs to react with ..... to form sulfuric acid. [4]

6 **(a)** Sulfuric acid is made by the Contact process.

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

This is carried out in the presence of a catalyst at 450 °C and 2 atmospheres pressure.

(i) How is the sulfur dioxide made?

.....

..... [1]

(ii) Give another use of sulfur dioxide.

..... [1]

(iii) Name the catalyst used.

..... [1]

(iv) If the temperature is decreased to 300 °C, the yield of sulfur trioxide increases. Explain why this lower temperature is not used.

.....

..... [1]

(v) Sulfur trioxide is dissolved in concentrated sulfuric acid. This is added to water to make more sulfuric acid. Why is sulfur trioxide not added directly to water?

.....

..... [1]

(b) Sulfuric acid was first made in the Middle East by heating the mineral, green vitriol, $FeSO_4.7H_2O$. The gases formed were cooled.

$FeSO_4.7H_2O(s) \rightarrow FeSO_4(s) + 7H_2O(g)$
green crystals — yellow powder

$2FeSO_4(s) \rightarrow Fe_2O_3(s) + SO_2(g) + SO_3(g)$

On cooling

$SO_3 + H_2O \rightarrow H_2SO_4$ sulfuric acid
$SO_2 + H_2O \rightarrow H_2SO_3$ sulfurous acid

(i) How could you show that the first reaction is reversible?

.....

..... [2]

4 The distinctive smell of the seaside was thought to be caused by ozone, O_3.
Ozone is a form of the element oxygen.

(a) A mixture of oxygen and ozone is formed by passing electric sparks through oxygen.

$$3O_2 \rightleftharpoons 2O_3$$

Suggest a technique that might separate this mixture. Explain why this method separates the two forms of oxygen.

technique .....

explanation .....

.....

.....

..... [2]

(b) Ozone is an oxidant. It can oxidise an iodide to iodine.

$$2I^- + O_3 + 2H^+ \rightarrow I_2 + O_2 + H_2O$$

(i) What would you see when ozone is bubbled through aqueous acidified potassium iodide?

.....

.....

.....

..... [2]

6 Sulfuric acid is an important acid, both in the laboratory and in industry.
Sulfuric acid is manufactured in the Contact Process. Originally, it was made by heating metal sulfates and by burning a mixture of sulfur and potassium nitrate.

(a) Give a major use of sulfuric acid.

..... [1]

(b) A group of naturally occurring minerals have the formula of the type $FeSO_4.xH_2O$ where x is 1, 4, 5, 6 or 7. The most common of these minerals is iron(II) sulfate-7-water.

(i) When this mineral is heated gently it dehydrates.

$$\underset{\text{green}}{FeSO_4.7H_2O} \rightleftharpoons \underset{\text{pale yellow}}{FeSO_4} + 7H_2O$$

Describe how you could show that this reaction is reversible.

.....

.....

..... [2]

(ii) When the iron(II) sulfate is heated strongly, further decomposition occurs.

$$2FeSO_4(s) \rightarrow Fe_2O_3(s) + SO_2(g) + SO_3(g)$$

The gases formed in this reaction react with water and oxygen to form sulfuric acid.
Explain how the sulfuric acid is formed.

.....

..... [2]

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3 The main use of sulfur dioxide is the manufacture of sulfuric acid.

(a) State **two** other uses of sulfur dioxide.

.....

..... [2]

(b) One source of sulfur dioxide is burning sulfur in air.
Describe how sulfur dioxide can be made from the ore zinc sulfide.

.....

..... [2]

(c) The Contact process changes sulfur dioxide into sulfur trioxide.

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

the forward reaction is exothermic

temperature 400 to 450 °C

low pressure 1 to 10 atmospheres

catalyst vanadium(V) oxide

(i) What is the formula of vanadium(V) oxide?

..... [1]

(ii) Vanadium(V) oxide is an efficient catalyst at any temperature in the range 400 to 450 °C.
Scientists are looking for an alternative catalyst which is efficient at 300 °C.
What would be the advantage of using a lower temperature?

.....

.....

..... [2]

(iii) The process does not use a high pressure because of the extra expense.
Suggest **two** advantages of using a high pressure?
Explain your suggestions.

.....

.....

.....

.....

..... [4]

(d) Sulfuric acid is made by dissolving sulfur trioxide in concentrated sulfuric acid to form oleum. Water is reacted with oleum to form more sulfuric acid.
Why is sulfur trioxide not reacted directly with water?

..... [1]

[Total: 12]

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---

4 Sulfuric acid is a strong acid. Hexanesulfonic acid is also a strong acid. It has similar properties to sulfuric acid.

(a) Sulfonic acids are made from alkanes and oleum, $H_2S_2O_7$.

$$C_6H_{14} + H_2S_2O_7 \rightarrow C_6H_{13}SO_3H + H_2SO_4$$

(i) Describe how oleum is made from sulfur by the Contact process. Give equations and reaction conditions.

.....

.....

.....

.....

.....

.....

..... [6]

(ii) How is concentrated sulfuric acid made from oleum?

..... [1]

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---

3 **(a)** Nitric acid is now made by the oxidation of ammonia. It used to be made from air and water. This process used very large amounts of electricity.

Air was blown through an electric arc and heated to 3000 °C.

$$N_2(g) + O_2(g) \rightleftharpoons 2NO(g) \qquad \textbf{equilibrium 1}$$

nitric oxide

The equilibrium mixture leaving the arc contained 5 % of nitric oxide. This mixture was cooled rapidly. At lower temperatures, nitric oxide will react with oxygen to form nitrogen dioxide.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2 \qquad \textbf{equilibrium 2}$$

Nitrogen dioxide reacts with oxygen and water to form nitric acid.

(i) Suggest a reason why the yield of nitric oxide in **equilibrium 1** increases with temperature.

..... [1]

(ii) What effect, if any, would increasing the pressure have on the percentage of nitric oxide in **equilibrium 1**? Explain your answer.

.....

..... [2]

(iii) Deduce why **equilibrium 2** is only carried out at lower temperatures.

.....

..... [2]

(iv) Complete the equation for the reaction between nitrogen dioxide, water and oxygen to form nitric acid.

.....NO_2 + O_2 + ... → .....HNO_3 [2]

(v) Ammonia is more expensive than water and air. Suggest a reason why the ammonia-based process is preferred to the electric arc process.

..... [1]

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3 Ammonia is manufactured by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

The forward reaction is exothermic.

(a) Describe how the reactants are obtained.

(i) Nitrogen

.....

..... [2]

(ii) Hydrogen

.....

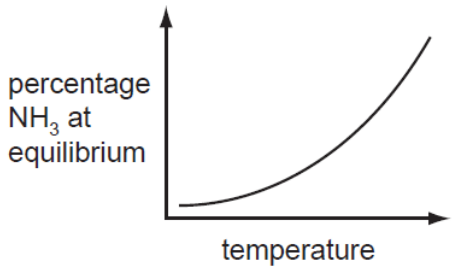
.....

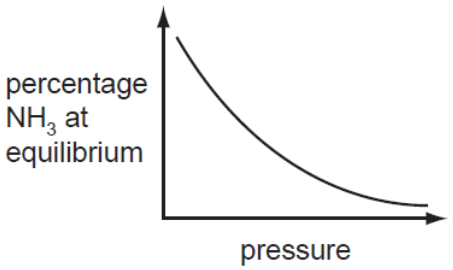
..... [3]

(b) The percentage of ammonia in the equilibrium mixture varies with temperature and pressure.

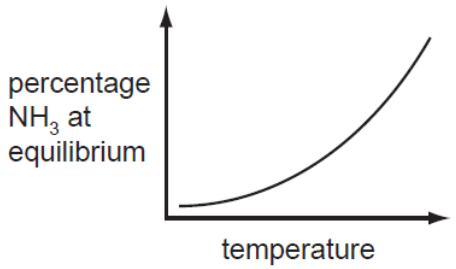
(i) Which pair of graphs, **A**, **B** or **C**, shows correctly how the percentage of ammonia at equilibrium varies with temperature and pressure?

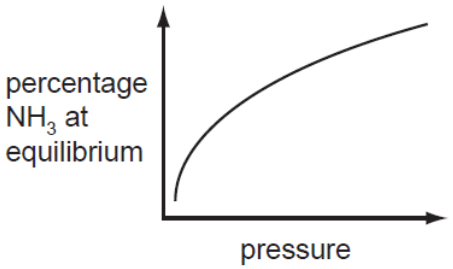
pair **A**



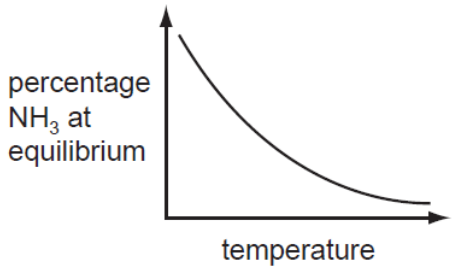


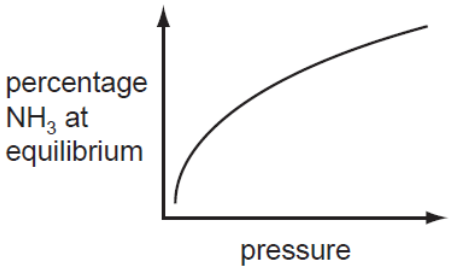
pair **B**





pair **C**





The pair with **both graphs correct** is ..... [1]

(ii) Give a full explanation of why the pair of graphs you have chosen in **(i)** is correct.

.....

.....

.....

.....

.....

.....

..... [6]

(iii) Catalysts do not alter the position of equilibrium. Explain why a catalyst is used in this process.

.....

.....

.....

..... [2]

[Total: 14]

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7 Ammonia is made by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

(a) State **one** major use of ammonia.

..... [1]

(b) Describe how hydrogen is obtained for the Haber process.

.....

.....

..... [3]

(c) This reaction is carried out at a high pressure, 200 atmospheres.
State, with an explanation for each, **two** advantages of using a high pressure.

.....

.....

.....

.....

..... [5]

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(b) Methanol is manufactured using the following method.

$$CH_4(g) + H_2O(g) \rightarrow CO(g) + 3H_2(g) \qquad \text{reaction 1}$$

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \text{reaction 2}$$

The conditions for reaction 2 are:

pressure	100 atmospheres
catalyst	a mixture of copper, zinc oxide and aluminium oxide
temperature	250 °C

The forward reaction is exothermic.

(i) Why is high pressure used in reaction 2?

.....

..... [2]

(ii) Explain why using a catalyst at 250 °C is preferred to using a higher temperature of 350 °C and no catalyst.

.....

.....

..... [3]

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5 The food additive E220 is sulfur dioxide. It is a preservative for a variety of foods and drinks.

(a) State **two** other uses of sulfur dioxide.

.....

..... [2]

(b) How is sulfur dioxide manufactured?

.....

..... [2]

(c) Sulfur dioxide is a reductant (reducing agent). Describe what you would see when aqueous sulfur dioxide is added to acidified potassium manganate(VII).

.....

..... [2]

0620/w12/qp32

5 Carbonyl chloride, $COCl_2$, is widely used in industry to make polymers, dyes and pharmaceuticals.

(a) Carbonyl chloride was first made in 1812 by exposing a mixture of carbon monoxide and chlorine to bright sunlight. This is a photochemical reaction.

$$CO(g) + Cl_2(g) \rightarrow COCl_2(g)$$

(i) Explain the phrase *photochemical reaction*.

.....

..... [2]

(ii) Give another example of a photochemical reaction and explain why it is important either to the environment or in industry.

.....

.....

..... [3]

(b) Carbonyl chloride is now made by the reversible reaction given below.

$$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$$

The forward reaction is exothermic.
The reaction is catalysed by carbon within a temperature range of 50 to 150 °C.

(i) Predict the effect on the yield of carbonyl chloride of increasing the pressure. Explain your answer.

.....

..... [2]

(ii) If the temperature is allowed to increase to above 200 °C, very little carbonyl chloride is formed. Explain why.

.....

..... [2]

(iii) Explain why a catalyst is used.

..... [1]