

GCSE Chemistry (9 – 1)

Equilibrium

Name:

Group:



Instructions

- Read each question carefully before you begin to answer it.
- Use black ink or black ball-point pen for your answers.
- Fill in the boxes at the top of this page with your name and group.
- Attempt to answer every question in the booklet.
- Answer the questions in the spaces provided – there may be more space than you need in some answer spaces.
- Calculators may be used for this booklet.
- For any calculations, you **must** show all your working.
- Any and all drawings or graphs should be completed in pencil.

For markers use	
Question	Mark
1	/7
2	/7
3	/13
4	/15
5	/6
6	/11
Total	/59
%	
Grade	

Information

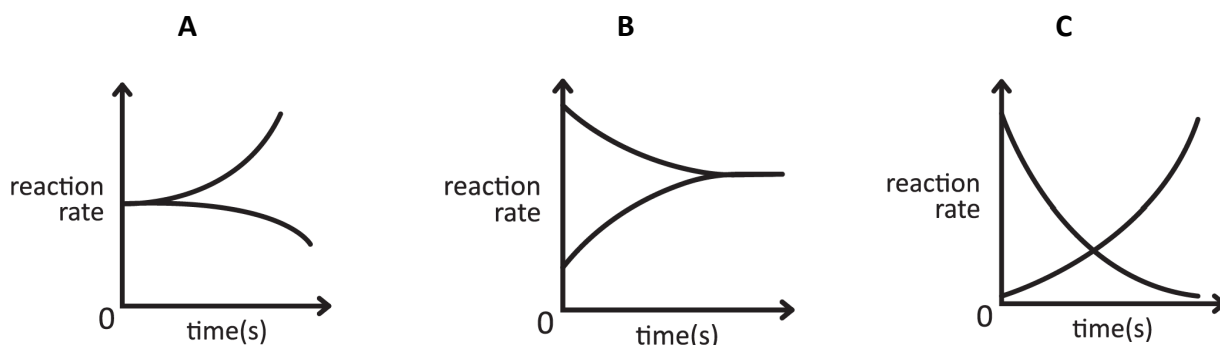
- The maximum mark for this paper is 59 marks.
- The marks for each question are shown in brackets.
- Please be aware that good English and clear presentation are required in your answers.



1. Equilibrium is the dynamic balance achieved in a reversible reaction when the reactants and products are changing into each other at exactly the same speed.

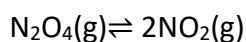
Circle the letter of the correct answer for each of the following questions.

- a. A reversible reaction is allowed to reach equilibrium. Which graph shows a dynamic equilibrium?



(1 mark)

- b. A chemical engineer is trying to produce the largest amount of nitrogen dioxide (NO_2) using the reversible reaction shown below.

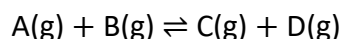


The forward reaction is endothermic. To get the highest yield of nitrogen dioxide, should the engineer use a high or low temperature, and a high or low pressure?

	Pressure in atmospheres	Temperature
A	4	Low
B	80	High
C	4	High
D	80	Low

(1 mark)

- c. Consider the reversible reaction below, which is at equilibrium in a sealed container at a constant temperature.



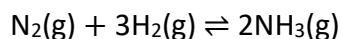
More of substance C is then introduced into the container.

After the system establishes a new equilibrium, which of the other substances will have a higher concentration than at the original equilibrium?

- A A, B, and D
- B A and B only
- C D only
- D B and D only

(1 mark)

- d. The Haber process synthesizes ammonia (NH₃) from nitrogen and hydrogen.
The forward reaction is exothermic.



The reaction is at equilibrium at a temperature of 400 °C.

What is the effect on the reaction rate **and** yield of ammonia if the temperature decreased to 300 °C?

- A The rate of reaction increases and the yield of ammonia increases.
- B The rate of reaction decreases and the yield of ammonia increases.
- C The rate of reaction decreases and the yield of ammonia decreases.
- D The rate of reaction increases and the yield of ammonia decreases.

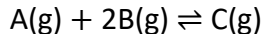
(1 mark)

- e. Which statement best describes a chemical system at dynamic equilibrium?

- A The concentrations of the reactants and products are equal.
- B The forward and reverse reactions have both stopped.
- C The rate of the forward reaction is equal to the rate of the reverse reaction.
- D The reaction can only occur in an open system.

(1 mark)

- f. Consider the following reversible reaction:

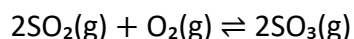


A catalyst is added to the system while it is at equilibrium. What is the effect of adding the catalyst?

- A The yield of product C increases and the rate of reaction increases.
- B The yield of product C is unchanged and the rate of reaction increases.
- C The yield of product C decreases and the rate of reaction increases.
- D The yield of product C is unchanged and the rate of reaction is unchanged.

(1 mark)

- g. The Contact process is used to produce sulfur trioxide. The reversible reaction is shown below:



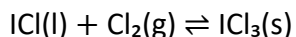
The reaction is carried out in a sealed reaction vessel at equilibrium. What is the effect on the position of equilibrium and the yield of sulfur trioxide if the pressure is increased?

- A The equilibrium shifts to the right and the yield of sulfur trioxide increases.
- B The equilibrium shifts to the left and the yield of sulfur trioxide decreases.
- C There is no change in the position of equilibrium or the yield.
- D The equilibrium shifts to the left and the yield of sulfur trioxide increases.

(1 mark)

(Total for Question 1 is 7 marks)

2. Iodine monochloride reacts reversibly with chlorine gas in a sealed container to form solid, yellow iodine trichloride. The equilibrium is shown below.



ICl(l) (Iodine monochloride) is a liquid that has a dark brown colour.

ICl₃(s) (Iodine trichloride) is a solid that has a yellow colour.

- a. Describe what is meant by the term dynamic equilibrium in the context of a reversible reaction.

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(2 marks)

- b. The forward reaction is exothermic.

Predict what would be observed if the equilibrium mixture is cooled. Explain your answer.

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(2 marks)

- c. The pressure of the system is increased.

- i. State and explain the effect this has on the position of the equilibrium.

It would move to the:

Reason:

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(2 marks)

- ii. Describe the change in appearance of the mixture.

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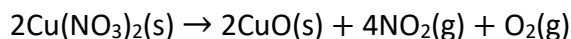
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(1 mark)

(Total for Question 2 is 7 marks)

3. Nitrogen dioxide, a brown gas, can be produced by the thermal decomposition of copper(II) nitrate. The equilibrium is shown below.



- a. Other metals can also be used in this decomposition.

- i. Lead is another metal whose nitrate decomposes in the same way as copper(II) nitrate.

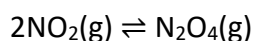
Name a different metal whose nitrate also decomposes to give the metal oxide, nitrogen dioxide and oxygen.

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(1 mark)

- ii. Complete the word equation for the decomposition of potassium nitrate, which follows a different pattern.

potassium nitrate $\rightarrow$ + oxygen (1 mark)

- b. Nitrogen dioxide exists in a dynamic equilibrium with dinitrogen tetroxide.



$\text{NO}_2(\text{g})$ (nitrogen dioxide) is a gas that has a dark brown colour.

$\text{N}_2\text{O}_4(\text{g})$ (dinitrogen tetroxide) is a gas that has a pale yellow colour.

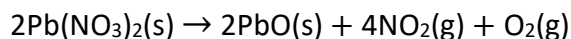
- i. The forward reaction is exothermic. An equilibrium mixture at 50 °C contains 40% of nitrogen dioxide. Predict whether the percentage of nitrogen dioxide will be higher or lower if the mixture is cooled to 10 °C. Give a reason for your choice.

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(2 marks)

- ii. Explain why the colour of the equilibrium mixture becomes darker when the pressure on the mixture is decreased.

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(2 marks)

- c. A 10.0 g sample of impure lead(II) nitrate was heated until decomposition was complete. The impurities did not decompose. The volume of oxygen gas formed was 0.24 dm³ measured at r.t.p. Calculate the percentage of lead(II) nitrate in the sample.



Mass of one mole of $\text{Pb}(\text{NO}_3)_2 = 331 \text{ g}$

The volume of one mole of any gas at r.t.p. is 24 dm³

Number of moles of O_2 formed = ...

Number of moles of $\text{Pb}(\text{NO}_3)_2$ in the sample = ...

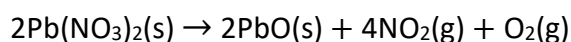
Mass of lead(II) nitrate in the sample = ... g

Percentage of lead(II) nitrate in sample = ... %

(4 marks)

- d. Calculate the atom economy for the production of oxygen (O_2) in this reaction. Give your answer to one decimal place.

(Relative atomic masses: N = 14, O = 16, Pb = 207)

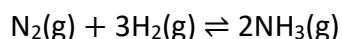


Atom economy = ...

(3 marks)

(Total for Question 3 is 13 marks)

4. Ammonia is manufactured from nitrogen and hydrogen in the Haber process.
The reaction is reversible and can reach a dynamic equilibrium.



- a. State **two** features of a reaction that is in a state of dynamic equilibrium.

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(2 marks)

- b. The Haber process is typically carried out at a temperature of 450 °C and a pressure of 200 atmospheres, using an iron catalyst. These are known as compromise conditions.

- i. The forward reaction is exothermic.

Explain why a relatively high temperature of 450 °C is used, even though this decreases the equilibrium yield of ammonia.

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(2 marks)

- ii. Explain, in terms of reacting particles, why using a higher pressure increases the rate of reaction.

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(2 marks)

- iii. State the purpose of the iron catalyst and explain why it does **not** affect the position of the equilibrium.

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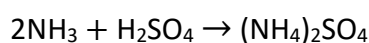
(2 marks)

c. To run the Haber process efficiently and profitably, chemists must calculate the exact quantities of substances involved.

- i. Calculate the volume of nitrogen that would be needed to react completely with 600 dm³ of hydrogen. (All gas volumes are measured at the same temperature and pressure).

volume of nitrogen = ... dm³
(1 mark)

- ii. The ammonia produced can be reacted with sulfuric acid to make ammonium sulfate, a fertiliser.



Calculate the mass of ammonium sulfate produced when 8.5 g of ammonia reacts completely with sulfuric acid. (Relative atomic masses H = 1.0, N = 14, O = 16, S = 32)

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mass of ammonium sulfate = ... g
(3 marks)

- d. In an industrial batch, the reaction described in part (c)(ii) was carried out starting with 8.5 g of ammonia. The actual mass of ammonium sulfate produced was 28.05 g.

Calculate the percentage yield for this reaction.

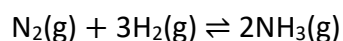
You should use your answer from part (c)(ii) as the theoretical yield.

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percentage yield = ... %
(3 marks)

(Total for Question 4 is 15 marks)

5. The synthesis of ammonia in the Haber process is a reversible, exothermic reaction.



To achieve a high equilibrium yield of ammonia, a low temperature is favoured. However, the industrial process is carried out at a relatively high temperature of 450 °C and uses an iron catalyst.

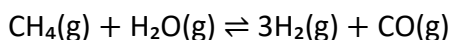
Explain why these industrial conditions are used, rather than a lower temperature without a catalyst. In your answer, you should discuss the effects of temperature and the catalyst on **both** the rate of reaction and the equilibrium yield.

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(6 marks)

(Total for Question 5 is 6 marks)

6. Hydrogen is a vital feedstock for the chemical industry, often produced by the steam reforming of methane. The hydrogen can then be used to produce ammonia, which is the starting material for manufacturing nitric acid.
- a. The first stage of steam reforming is a reversible reaction where methane and steam are converted into hydrogen and carbon monoxide.



This reaction is endothermic.

State and explain the effect of increasing the temperature on the equilibrium yield of hydrogen.

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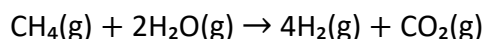
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(2 marks)

- b. The overall equation for the steam reforming process is:



Calculate the maximum volume of hydrogen gas (in dm^3), measured at room temperature and pressure (r.t.p.), that could be produced from 8.0 g of methane (CH_4).

(Relative formula mass, M_r , of CH_4 = 16. The volume of 1 mole of any gas at r.t.p. is 24 dm^3)

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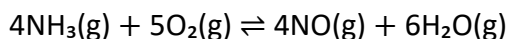
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maximum volume of hydrogen = ... dm^3

(3 marks)

- c. The ammonia produced from hydrogen is converted into nitric oxide in the first stage of the Ostwald process. This is a reversible reaction.



The forward reaction is exothermic.

The industrial conditions used are a compromise to ensure a high rate of production and a reasonable yield. These conditions include:

- A temperature of around 900°C
- A pressure of between 5-10 atmospheres
- The use of a platinum-rhodium catalyst

In your answer, you should refer to the effects of the conditions on the reaction rate, the position of equilibrium, and any economic considerations.

(6 marks)

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