



**Topic Test: OxfordAQA**  
**International A level Chemistry**  
A2 Physical Chemistry: Unit 4 content

Name: \_\_\_\_\_

Class: \_\_\_\_\_

Date: \_\_\_\_\_

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Time: **78 minutes**

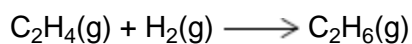
Marks: **75 marks**

Comments:

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**1**

The rate equation for the hydrogenation of ethene



is  $\text{Rate} = k[\text{C}_2\text{H}_4][\text{H}_2]$

At a fixed temperature, the reaction mixture is compressed to triple the original pressure.

What is the factor by which the rate of reaction changes?

**A** 6

**B** 9

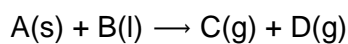
**C** 12

**D** 27

(Total 1 mark)

**2**

The equation for a reaction is



The rate of this reaction could be studied by following the

**A** decrease in partial pressure of A

**B** increase in concentration of B

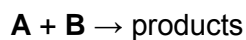
**C** decrease in concentration of C

**D** increase in partial pressure of D

(Total 1 mark)

**3**

The rate of reaction between solutions of **A** and **B** is investigated.



Three experiments are completed at a given temperature. The results of these experiments are shown in the table.

	Initial concentration of A / mol dm <sup>-3</sup>	Initial concentration of B / mol dm <sup>-3</sup>	Initial rate / mol dm <sup>-3</sup> s <sup>-1</sup>
<b>Experiment 1</b>	2.40 × 10 <sup>-3</sup>	2.80 × 10 <sup>-3</sup>	1.60 × 10 <sup>-4</sup>
<b>Experiment 2</b>	3.60 × 10 <sup>-3</sup>	4.20 × 10 <sup>-3</sup>	3.60 × 10 <sup>-4</sup>
<b>Experiment 3</b>	5.40 × 10 <sup>-3</sup>	4.20 × 10 <sup>-3</sup>	8.10 × 10 <sup>-4</sup>

- (a) Use the data in the table to deduce the order of reaction with respect to **A** and the order of reaction with respect to **B**.

Place **one** tick (✓) in the box which shows the order with respect to **A** and the order with respect to **B**.

Order with respect to **A**

Zero

First

Second

Order with respect to **B**

Zero

First

Second

(2)

- (b) The reaction between compounds **C** and **D** is studied at a given temperature. The rate equation for the reaction is found to be

$$\text{rate} = k [\text{C}]^2[\text{D}]$$

When the initial concentration of **C** is  $8.55 \times 10^{-2} \text{ mol dm}^{-3}$  and the initial concentration of **D** is  $2.80 \times 10^{-2} \text{ mol dm}^{-3}$ , the initial rate of reaction is  $9.43 \times 10^{-4} \text{ mol dm}^{-3} \text{ s}^{-1}$

Calculate the value of the rate constant at this temperature and deduce its units.

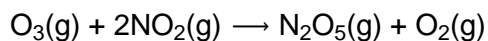
Rate constant \_\_\_\_\_ Units \_\_\_\_\_

(3)

(Total 5 marks)

4

Ozone reacts with nitrogen dioxide



The rate equation for the reaction is

$$\text{rate} = k[\text{O}_3][\text{NO}_2]$$

The rate of the reaction was investigated.

The data from one experiment are shown in **Table 1**.

**Table 1**

Initial $[\text{O}_3]$ / $\text{mol dm}^{-3}$	Initial $[\text{NO}_2]$ / $\text{mol dm}^{-3}$	Initial rate / $\text{mol dm}^{-3} \text{ s}^{-1}$
$3.0 \times 10^{-4}$	$2.0 \times 10^{-3}$	$4.0 \times 10^{-9}$

- (a) Suggest why it is **not** possible to confirm the rate equation for this reaction using the data shown in the table above.

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(1)

- (b) Suggest **two** additional experiments in this investigation needed to confirm the rate equation.

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(1)

- (c) Suggest a two-step mechanism for the reaction of ozone with nitrogen dioxide in which the first step is the rate determining step.

First step \_\_\_\_\_

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Second step \_\_\_\_\_

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(2)

The effect of temperature on the value of the rate constant for a different reaction was investigated. The data obtained are shown in **Table 2**.

**Table 2**

Experiment	Temperature, $T / K$	Rate constant, $k / \text{mol}^{-2} \text{dm}^6 \text{s}^{-1}$	$1 / T / K^{-1}$	$\ln k$
1	293	$1.00 \times 10^{-6}$	$3.41 \times 10^{-3}$	-13.8
2	313	$4.40 \times 10^{-6}$	$3.19 \times 10^{-3}$	-12.3
3	335	$1.92 \times 10^{-5}$	$2.99 \times 10^{-3}$	-10.9
4	350	$6.20 \times 10^{-5}$	$2.86 \times 10^{-3}$	-9.69
5	370	$2.20 \times 10^{-4}$	$2.70 \times 10^{-3}$	-8.42

(d) Use the units of the rate constant in **Table 2** to deduce the overall order of this reaction.

\_\_\_\_\_

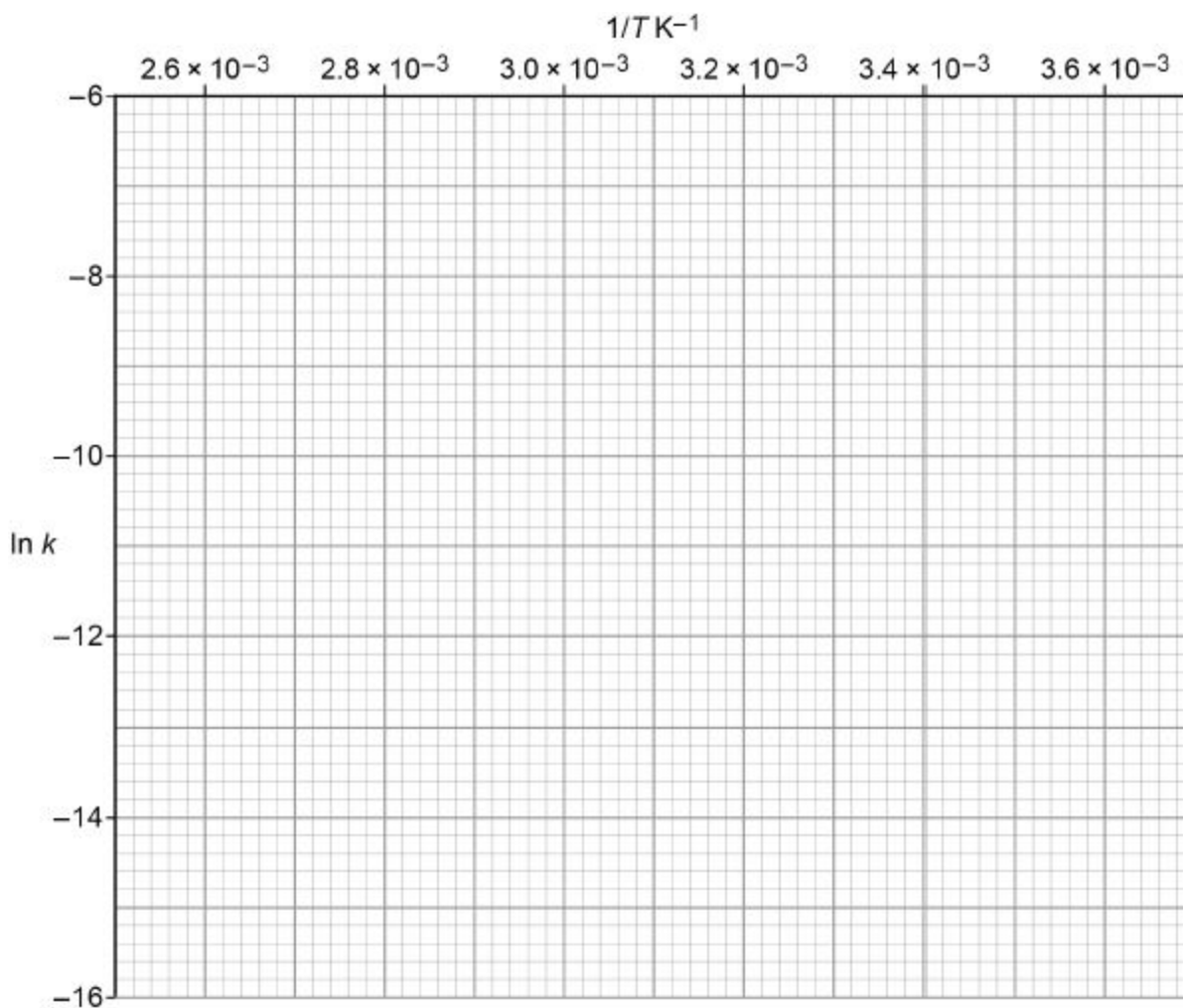
\_\_\_\_\_

overall order \_\_\_\_\_

(1)

(e) Plot a graph of  $\ln k$  against  $1/T$  using the axes provided.

Draw a line of best fit and determine its gradient.



Gradient = \_\_\_\_\_ K

(3)

(f) The rate constant,  $k$ , is related to the temperature,  $T$ , as shown in the equation

$$\ln k = \frac{-E_a}{RT} + \ln A$$

Use the equation and the gradient of your graph in part (e) to calculate the value in  $\text{kJ mol}^{-1}$  for the activation energy,  $E_a$ , of the reaction.

The value of the gas constant,  $R$ , is  $8.31 \text{ J K}^{-1} \text{ mol}^{-1}$

(If you were unable to answer part (e) you should use the value  $-4500 \text{ kJ mol}^{-1}$   
This is **not** the correct answer.)

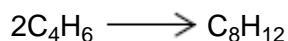
Activation energy \_\_\_\_\_  $\text{kJ mol}^{-1}$

(2)

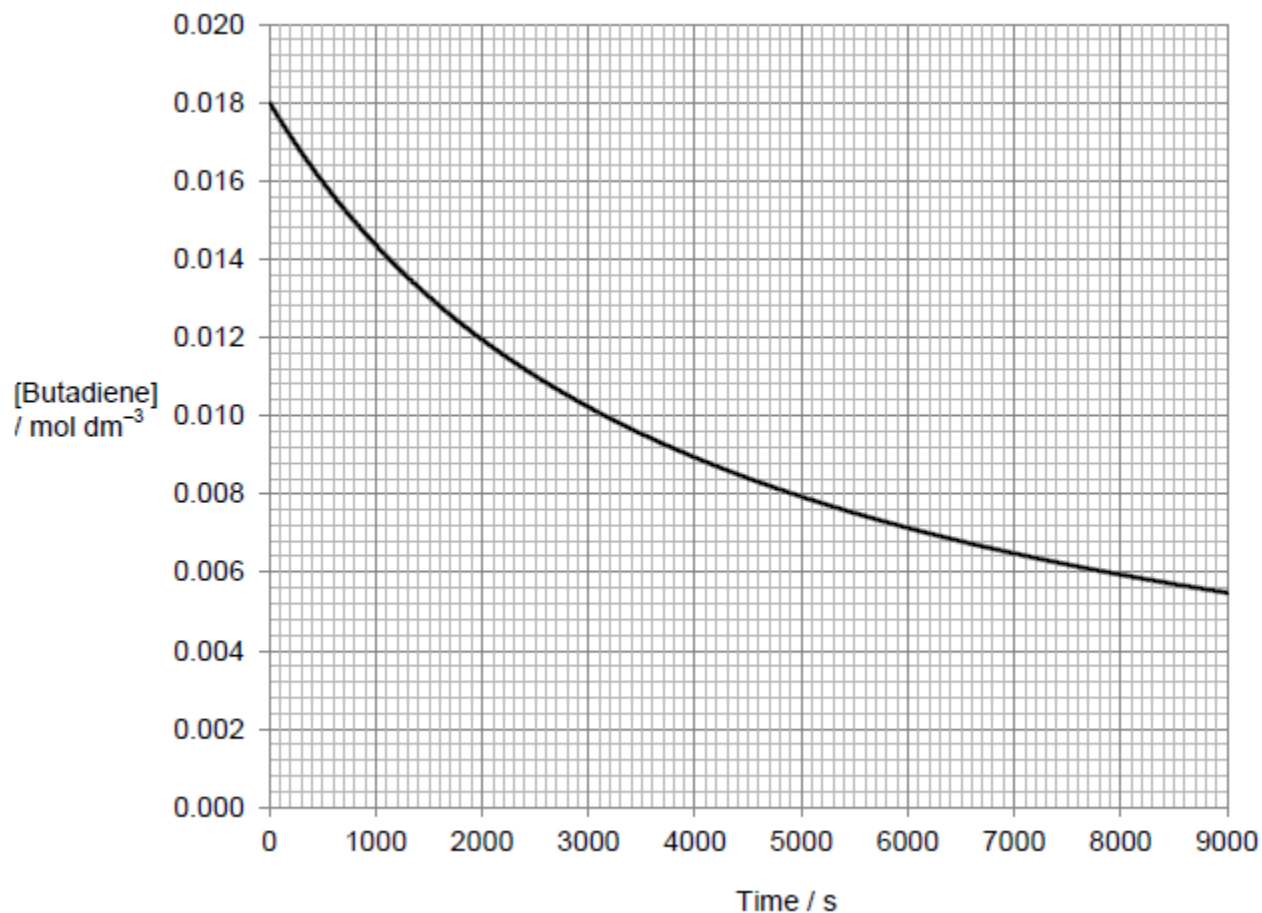
(Total 10 marks)

5

Butadiene dimerises according to the equation



The kinetics of the dimerisation are studied and the graph of the concentration of a sample of butadiene is plotted against time. The graph is shown below.



(a) Draw a tangent to the curve when the concentration of butadiene is  $0.0120 \text{ mol dm}^{-3}$ .

(1)

(b) The initial rate of reaction in this experiment has the value  $4.57 \times 10^{-6} \text{ mol dm}^{-3} \text{ s}^{-1}$ .

Use this value, together with a rate obtained from your tangent, to justify that the order of the reaction is 2 with respect to butadiene.

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(5)

(Total 6 marks)

6

The rate of hydrolysis of an ester **X** ( $\text{HCOOCH}_2\text{CH}_2\text{CH}_3$ ) was studied in alkaline conditions at a given temperature. The rate was found to be first order with respect to the ester and first order with respect to hydroxide ions.

(a) (i) Name ester **X**.

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(1)

(ii) Using **X** to represent the ester, write a rate equation for this hydrolysis reaction.

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(1)

- (iii) When the initial concentration of **X** was  $0.024 \text{ mol dm}^{-3}$  and the initial concentration of hydroxide ions was  $0.035 \text{ mol dm}^{-3}$ , the initial rate of the reaction was  $8.5 \times 10^{-5} \text{ mol dm}^{-3} \text{ s}^{-1}$ .

Calculate a value for the rate constant at this temperature and give its units.

Calculation \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Units \_\_\_\_\_

\_\_\_\_\_

**(3)**

- (iv) In a second experiment at the same temperature, water was added to the original reaction mixture so that the total volume was doubled.  
Calculate the initial rate of reaction in this second experiment.

\_\_\_\_\_

\_\_\_\_\_

**(1)**

- (v) In a third experiment at the same temperature, the concentration of **X** was half that used in the experiment in part (a) (iii) and the concentration of hydroxide ions was three times the original value.  
Calculate the initial rate of reaction in this third experiment.

\_\_\_\_\_

\_\_\_\_\_

**(1)**

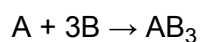
- (vi) State the effect, if any, on the value of the rate constant  $k$  when the temperature is lowered but all other conditions are kept constant. Explain your answer.

Effect \_\_\_\_\_

Explanation \_\_\_\_\_

**(2)**

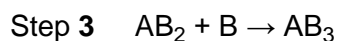
(b) Compound **A** reacts with compound **B** as shown by the overall equation



The rate equation for the reaction is

$$\text{rate} = k[A][B]^2$$

A suggested mechanism for the reaction is



Deduce which one of the three steps is the rate-determining step.

Explain your answer.

Rate-determining step \_\_\_\_\_

Explanation \_\_\_\_\_

\_\_\_\_\_

(2)

(Total 11 marks)

7

(a) The data in the following table were obtained in two experiments about the rate of the reaction between substances **B** and **C** at a constant temperature.

Experiment	Initial concentration of <b>B</b> / mol dm <sup>-3</sup>	Initial concentration of <b>C</b> / mol dm <sup>-3</sup>	Initial rate / mol dm <sup>-3</sup> s <sup>-1</sup>
1	$4.2 \times 10^{-2}$	$2.6 \times 10^{-2}$	$8.4 \times 10^{-5}$
2	$6.3 \times 10^{-2}$	$7.8 \times 10^{-2}$	To be calculated

The rate equation for this reaction is known to be

$$\text{rate} = k[\mathbf{B}]^2[\mathbf{C}]$$

- (i) Use the data from Experiment 1 to calculate a value for the rate constant  $k$  at this temperature and deduce its units.

Calculation \_\_\_\_\_

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Units \_\_\_\_\_

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(3)

- (ii) Calculate a value for the initial rate in Experiment 2.

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(1)

- (b) The data in the following table were obtained in a series of experiments about the rate of the reaction between substances **D** and **E** at a constant temperature.

Experiment	Initial concentration of <b>D</b> / mol dm <sup>-3</sup>	Initial concentration of <b>E</b> / mol dm <sup>-3</sup>	Initial rate / mol dm <sup>-3</sup> s <sup>-1</sup>
<b>3</b>	0.13	0.23	$0.26 \times 10^{-3}$
<b>4</b>	0.39	0.23	$2.34 \times 10^{-3}$
<b>5</b>	0.78	0.46	$9.36 \times 10^{-3}$

- (i) Deduce the order of reaction with respect to **D**.

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(1)

(ii) Deduce the order of reaction with respect to **E**.

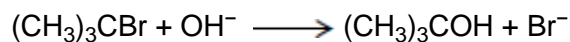
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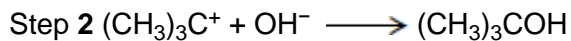
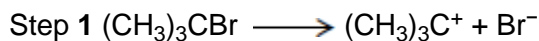
(1)

(c) The compound  $(\text{CH}_3)_3\text{CBr}$  reacts with aqueous sodium hydroxide as shown in the following equation.



This reaction was found to be first order with respect to  $(\text{CH}_3)_3\text{CBr}$  but zero order with respect to hydroxide ions.

The following two-step process was suggested.



(i) Deduce the rate-determining step in this two-step process.

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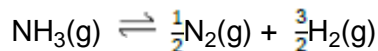
(1)

(ii) Outline a mechanism for this step using a curly arrow.

(1)

(Total 8 marks)

- 8** When one mole of ammonia is heated to a given temperature, 50% of the compound dissociates and the following equilibrium is established.



What is the total number of moles of gas present in this equilibrium mixture?

- A** 1.5
- B** 2.0
- C** 2.5
- D** 3.0

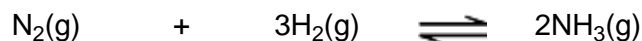
(Total 1 mark)

- 9** What does compromise temperature mean when referring to a reversible reaction used in an industrial process?

- A** A high temperature in an endothermic process to increase the yield.
- B** A low temperature in an exothermic process to increase the yield.
- C** A temperature that achieves a reasonable rate at a reasonable pressure.
- D** A temperature that achieves a reasonable rate and a reasonable yield.

(Total 1 mark)

- 10** Ammonia is manufactured by the Haber process in which the following equilibrium is established.



(a) Give **two** features of a reaction at equilibrium.

Feature 1 \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Feature 2 \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

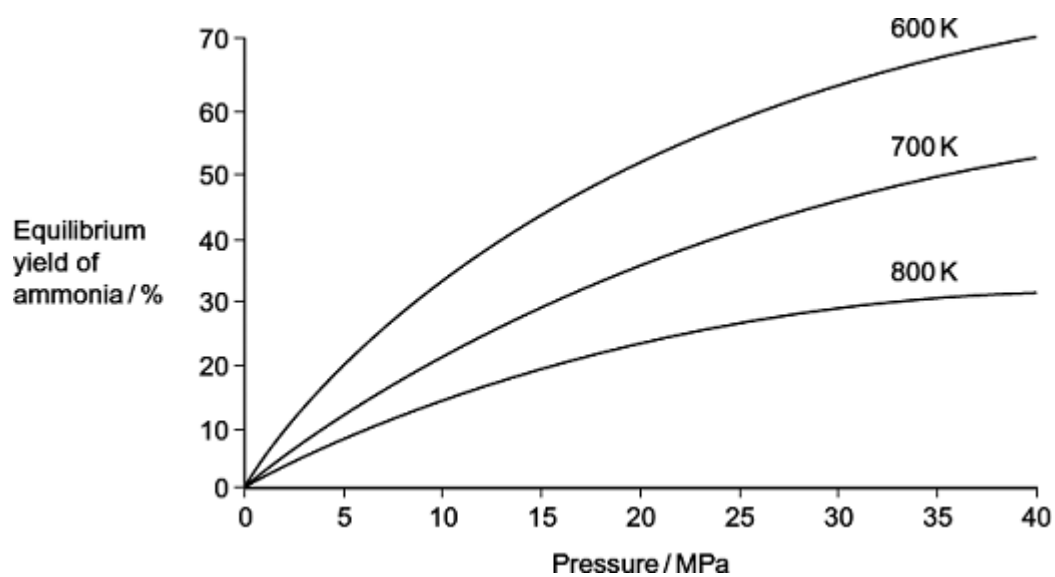
(2)

(b) Explain why a catalyst has no effect on the position of an equilibrium.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

(2)

(c) The diagram shows how the equilibrium yield of ammonia varies with changes in pressure and temperature.



- (i) Use the diagram to state the effect of an **increase** in pressure at constant temperature on the yield of ammonia. Use Le Chatelier's principle to explain this effect.

Effect on yield \_\_\_\_\_

Explanation \_\_\_\_\_

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**(3)**

- (ii) Use the diagram to state the effect of an **increase** in temperature at constant pressure on the yield of ammonia. Use Le Chatelier's principle to explain this effect.

Effect on yield \_\_\_\_\_

Explanation \_\_\_\_\_

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**(3)**

- (d) At equilibrium, with a pressure of 35 MPa and a temperature of 600 K, the yield of ammonia is 65%.

- (i) State why industry uses a temperature higher than 600 K.

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**(1)**

- (ii) State why industry uses a pressure lower than 35 MPa. Do **not** include references to safety.

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**(1)**

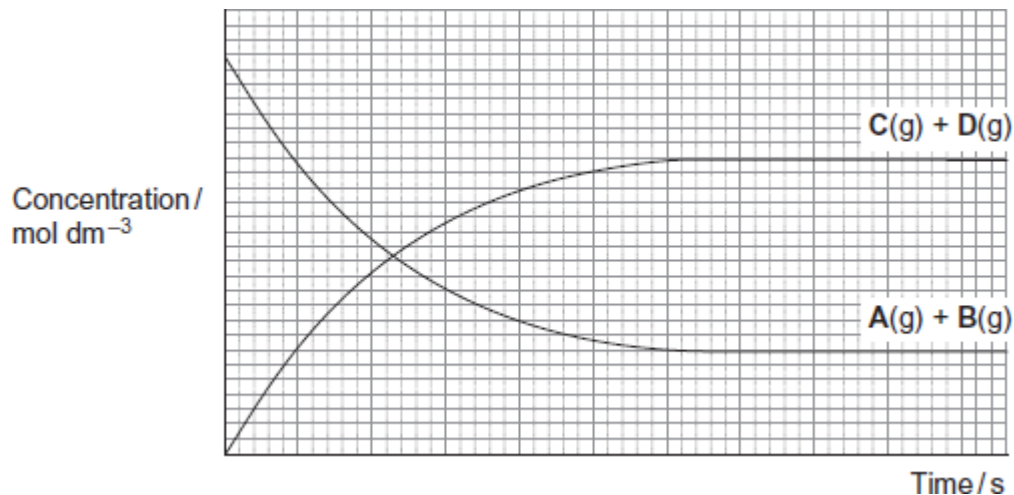
**(Total 12 marks)**

11

A dynamic equilibrium is established when gas **A** is mixed with gas **B** at a given temperature.



The figure below shows how the concentrations of reactants and products change with time.



(a) (i) On the appropriate axis of the figure, place an **X** to show the time when equilibrium is first established.

(1)

(ii) State how the rate of the forward reaction and the rate of the reverse reaction are related to each other at equilibrium.

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(1)

(b) Give the meaning of the term **dynamic** in the context of a dynamic equilibrium.

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(1)

(c) The total pressure on the system is increased at constant temperature.

(i) State and explain the effect, if any, of this change on the position of this equilibrium.

Effect \_\_\_\_\_

Explanation \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

(2)

(ii) State and explain the effect, if any, of this change on the time taken to reach this equilibrium.

Effect \_\_\_\_\_

Explanation \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

(3)

(Total 8 marks)

12

The equation for the reaction between gaseous hydrogen and iodine is



An equilibrium mixture of gaseous hydrogen, iodine and hydrogen iodide was prepared at 500 K

The pressure and temperature of the equilibrium mixture were both increased.

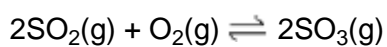
Which statements describe the effects of these changes on the value of  $K_p$ ?

	Effect of increase in pressure	Effect of increase in temperature	
A	$K_p$ increases	$K_p$ increases	<input type="checkbox"/>
B	$K_p$ increases	$K_p$ decreases	<input type="checkbox"/>
C	$K_p$ unchanged	$K_p$ increases	<input type="checkbox"/>
D	$K_p$ unchanged	$K_p$ decreases	<input type="checkbox"/>

(Total 1 mark)

13

Which change would alter the value of the equilibrium constant ( $K_p$ ) for this reaction?

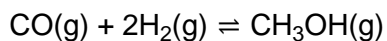


- A Increasing the total pressure of the system.
- B Increasing the concentration of sulfur trioxide.
- C Increasing the concentration of sulfur dioxide.
- D Increasing the temperature.

(Total 1 mark)

14

Methanol can be made by reacting carbon monoxide with hydrogen.



- (a) Write an expression for  $K_p$  for the manufacture of methanol from carbon monoxide and hydrogen.

$K_p$

(1)

(b) What are the units of  $K_p$  for this equilibrium?

Tick (✓) **one** box.

kPa<sup>2</sup>

kPa<sup>-2</sup>

mol<sup>2</sup> dm<sup>-6</sup>

mol<sup>-2</sup> dm<sup>6</sup>

(1)

(c) Explain why the value of  $K_p$  for this reaction decreases when the temperature is increased.

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(2)

A mixture of 10.0 mol of each of CO, H<sub>2</sub> and CH<sub>3</sub>OH is placed in a flask of volume 2.50 dm<sup>3</sup> and left to reach equilibrium at a given temperature.

At equilibrium, the flask contains 6.0 mol of CO

The total pressure in the flask is 5000 kPa

(d) Calculate the amount, in mol, of H<sub>2</sub> and of CH<sub>3</sub>OH in the flask at equilibrium.

Amount of H<sub>2</sub> \_\_\_\_\_ mol

Amount of CH<sub>3</sub>OH \_\_\_\_\_ mol

(2)

- (e) Calculate the value of  $K_p$  under these conditions. You do **not** need to give units for your answer in this part of the question.

(If you were unable to answer question (d) you should use 8.0 mol as the amount of  $H_2$  and 8.0 mol as the amount of  $CH_3OH$ . These are **not** the correct values.)

$K_p$  \_\_\_\_\_

**(3)**

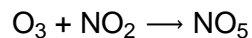
**(Total 9 marks)**

## Mark schemes

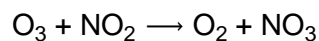
- 1** B [1]
- 2** D [1]
- 3** (a) Order with respect to A: 2<sup>nd</sup>/second/2 1  
Order with respect to B: 0/zero 1
- (b)  $k = \text{rate} / [\text{C}]^2[\text{D}]$  1  
*M1 rearranged rate equation or numbers in rearranged equation*
- $k = 9.43 \times 10^{-4} / (8.55 \times 10^{-2})^2 (2.80 \times 10^{-2})$
- $k = 4.61$
- $k = 4.607$   
*2 sf or more needed* 1
- Units =  $\text{mol}^{-2} \text{dm}^6 \text{s}^{-1}$   
*units must all be on one line* 1
- 4** (a) has not changed any concentration [5]  
*allow only one experiment has been completed* 1
- (b) Experiment with  $[\text{O}_3]$  changed (but not  $[\text{NO}_2]$ )  
Experiment with  $[\text{NO}_2]$  changed (but not  $[\text{O}_3]$ ) 1

(c) (first step)

*Allow any equation with 1 O<sub>3</sub> and 1 NO<sub>2</sub> on left and balances*



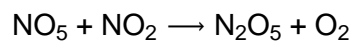
**OR**



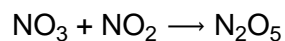
*If first mark not awarded then CE = 0*

1

(second step)



**OR**



*The second step, when added to the first step must give the correct overall equation*

1

(d) third/3

1

(e) all five points plotted correctly

1

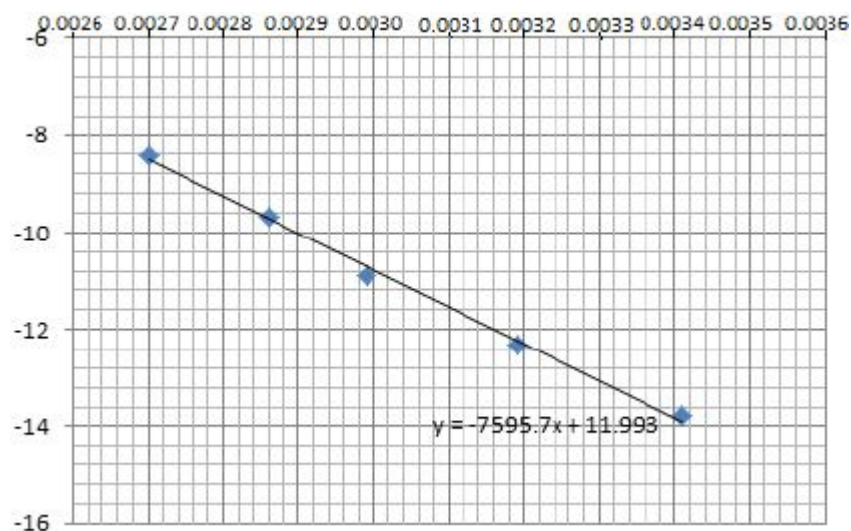
straight line of best fit drawn

1

gradient of line drawn calculated correctly – this must have a negative sign.

*correct gradient is -7596.*

1



(f) gradient  $\times (-8.31/1000)$

If  $-4500$  is used answer =  $(+)37(.395) \text{ kJ mol}^{-1}$

1

correct evaluation to nearest whole number or better

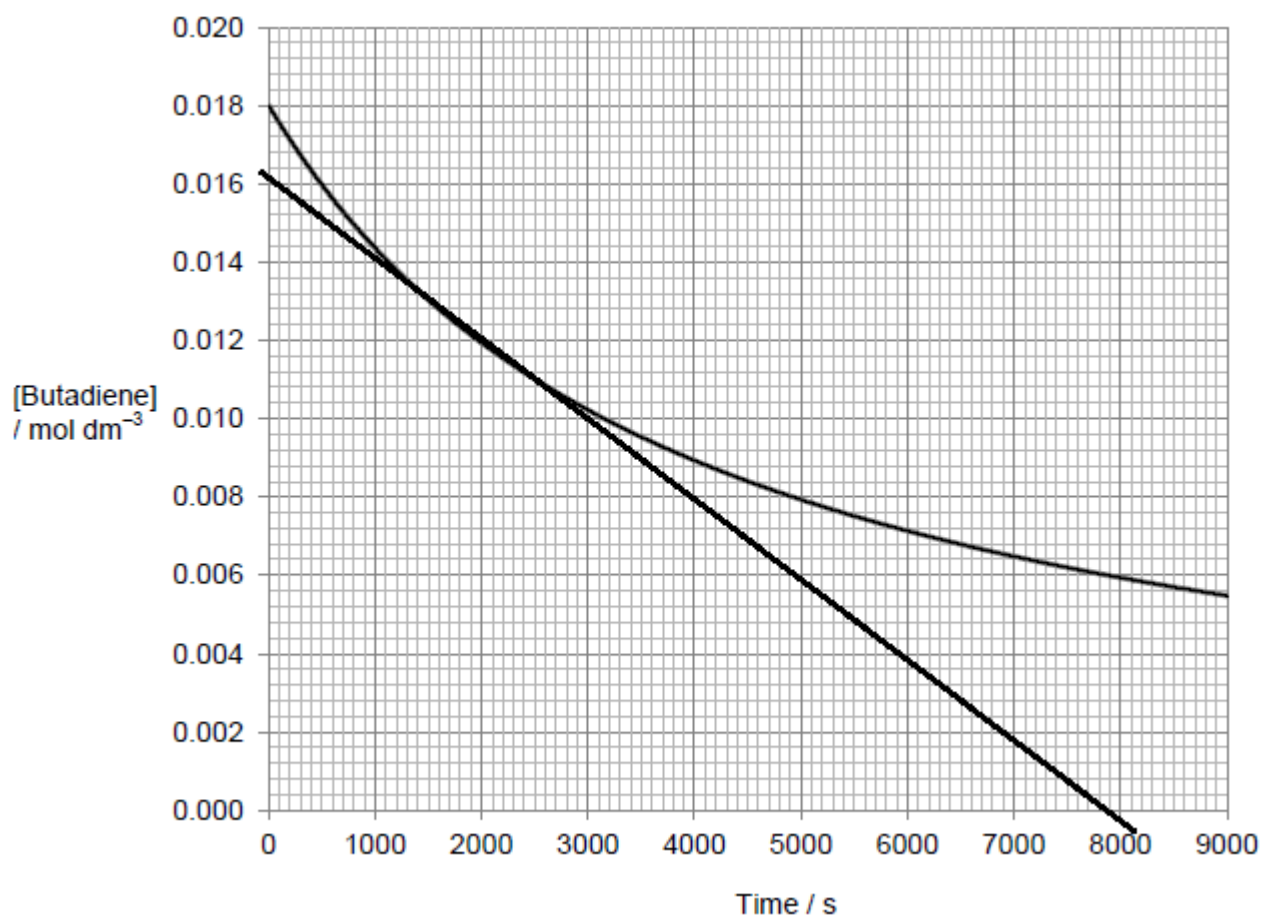
1

gradient of  $-7596$  gives  $63(.12) \text{ (kJ mol}^{-1}\text{)}$

[10]

5

(a) Gradient drawn on graph



Line must touch the curve at 0.012 but must not cross the curve.

1

(b) Stage 1: Rate of reaction when concentration =  $0.0120 \text{ mol dm}^{-3}$

From the tangent

Change in [butadiene] =  $-0.0160 - 0$  and change in time =  $7800 - 0$

*Extended response*

1

Gradient =  $-(0.0160 - 0) / (7800 - 0) = -2.05 \times 10^{-6}$

Rate =  $2.05 \times 10^{-6} \text{ (mol dm}^{-3} \text{ s}^{-1}\text{)}$

1

Stage 2: Comparison of rates and concentrations

$$\text{Initial rate / rate at } 0.0120 = (4.57 \times 10^{-6}) / (2.05 \times 10^{-6}) = 2.23$$

*Marking points in stage 2 can be in either order*

1

$$\text{Initial concentration / concentration at point where tangent drawn} = 0.018 / 0.012 = 1.5$$

1

Stage 3: Deduction of order

If order is 2, rate should increase by factor of  $(1.5)^2 = 2.25$  this is approximately equal to 2.23 therefore order is 2nd with respect to butadiene

1

[6]

6

(a) (i) propyl methanoate

*must be correct spelling*

1

(ii) rate =  $k[X][OH^-]$

*allow HCOOCH<sub>2</sub>CH<sub>2</sub>CH<sub>3</sub> (or close) for X*

*allow ( ) but penalise missing minus*

1

(iii)  $k = \frac{8.5 \times 10^{-5}}{(0.024)(0.035)}$

*In (a)(iii), if wrong orders allow*

*mark is for insertion of numbers in correct expression for k*

*If expression for k is upside down, only score units conseq to their expression*

1

$$= 0.10(12) \quad \text{2sf minimum}$$

*1 for conseq answer*

1

$$\text{mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$$

*1 for conseq units*

*any order*

1

(iv)  $2.1(3) \times 10^{-5}$

*or  $2.1(2) \times 10^{-5}$  ignore units*

*allow 2 sf*

**NB If wrong check the orders in part (a)(iii) and allow (a)(iv) if conseq to wrong k**

**See \* below**

1

(v)  $1.3 \times 10^{-4}$  ( $1.28 \times 10^{-4}$ )

allow ( $1.26 \times 10^{-4}$ ) to ( $1.3 \times 10^{-4}$ ) ignore units

allow 2 sf

**NB If wrong check the orders in part (a)(iii) and allow (a)(iv) if conseq to wrong k**

**See \*\* below**

1

**For example, if orders given are 1st in X and second in OH<sup>-</sup>**

[The mark in a(ii) and also first mark in a(iii) have already been lost]

So allow mark \* in (iv) for rate = their k  $\times$  (0.012)(0.0175)<sup>2</sup> = their k  $\times$  ( $3.7 \times 10^{-6}$ )  
(allow answer to 2sf)

\*\* in (v) for rate = their k  $\times$  (0.012)(0.105)<sup>2</sup> = their k  $\times$  ( $1.32 \times 10^{-4}$ )  
(allow answer to 2sf)

**The numbers will of course vary for different orders.**

(vi) Lowered

*if wrong, no further mark*

1

fewer particles/collisions have energy  $> E_a$

**OR**

fewer have sufficient (activation) energy (to react)

*not just fewer successful collisions*

1

(b) Step 2

1

(this step with previous) involves one mol/molecule/particle  
A and two Bs

or 1:2 ratio or same amounts (of reactants) as in rate equation

*if wrong, no further mark*

1

[11]

7

(a) (i)  $k = \frac{8.4 \times 10^{-5}}{(4.2 \times 10^{-2})^2 \times 2.6 \times 10^{-2}}$  OR  $\frac{8.4 \times 10^{-5}}{(1.76 \times 10^{-3}) \times 2.6 \times 10^{-2}}$

*Mark is for insertion of numbers into a correctly rearranged rate equation, k = etc.*

*If upside down, score only units mark from their k*

*AE (-1) for copying numbers wrongly or swapping two numbers*

1

= 1.8(3)

1

$$\text{mol}^{-2} \text{ dm}^6 \text{ s}^{-1}$$

Any order

If  $k$  calculation wrong, allow units consequential to their

$k = \text{expression}$

1

(ii)  $5.67 \times 10^{-4} \text{ (mol dm}^{-3} \text{ s}^{-1})$  **OR** their  $k \times 3.1 \times 10^{-4}$

Allow  $5.57 \times 10^{-4}$  to  $5.7 \times 10^{-4}$

1

(b) (i) 2 or second or  $[D]^2$

1

(ii) 0 or zero or  $[E]^0$

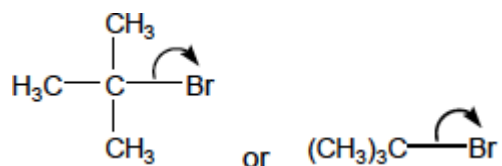
1

(c) (i) Step 1 or equation as shown

Penalise Step 2 but mark on

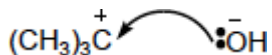
1

(ii)



Ignore correct partial charges, penalise full / incorrect partial charges

If Step 2 given above, can score the mark here for



allow:  $\text{OH}^-$  (must show lp)

If  $\text{S}_{\text{N}}2$  mechanism shown then no mark (penalise involvement of  $\text{:OH}^-$  in step 1)

Ignore anything after correct step 1

1

[8]

8

A

[1]

9

D

[1]

(a) **In either order**

*For M1 accept [ ] for concentration*

**M1** Concentrations (of reactants and products) remain or stay constant / the same

*NOT “equal concentrations” and NOT “concentration(s) is / are the same”*

**M2** Forward rate = Reverse / backward rate

*NOT “amount”*

*Ignore “dynamic” and ignore “speed”*

*Ignore “closed system”*

*It is possible to score both marks under the heading of a single feature*

2

(b) **M1** Catalysts increase rate of / speed up both forward and reverse / backward reactions

*If M1 is given as “no effect” / “no change” then CE= 0 for clip*

**M2** increase in rate / affect on rate / speed is equal / the same

*Ignore references to “decrease in rate”*

2

(c) (i) **M1** (The yield) increases / goes up / gets more

*If M1 is given as “decreases” / “no effect” / “no change” then CE= 0 for clip, but mark on from a blank.*

**M2** There are more moles / molecules (of gas) on the left / of reactants

*Ignore “volumes”, “articles” “atoms” and “species” for M2*

**OR** fewer moles / molecules (of gas) on the right / products

**OR** there are 4 moles / molecules (of gas) on the left and 2 moles / molecules on the right.

**OR** (equilibrium) shifts / moves to the side with less moles / molecules

**M3 Can only score M3 if M2 is correct**

The equilibrium shifts / moves (from left to right) to oppose the increase in pressure

*For M3, not simply “to oppose the change”*

*For M3 credit the equilibrium shifts / moves to lower / decrease the pressure*

*(There must be a specific reference to the change that is opposed)*

3

(ii) **M1** The yield decreases / goes down / gets less  
*If M1 is given as "increase" / "no effect" / "no change" then CE= 0 for clip, but mark on from a blank.*

**M2** (Forward) reaction is exothermic **OR** gives out / releases heat

**OR**

reverse reaction is endothermic **OR** takes in / absorbs heat

**Can only score M3 if M2 is correct**

The equilibrium shifts / moves (from right to left) to oppose the increase in temperature

*For M3, not simply "to oppose the change"*

*For M3 credit the equilibrium shifts / moves*

*to absorb the heat OR*

*to cool the reaction OR*

*to lower the temperature*

*(There must be a specific reference to the change that is opposed)*

3

(d) (i) Must be comparative

*Credit correct reference to rate being too (s)low / (s)lower at temperatures less than 600 K*

Higher rate of reaction

**OR** increase / speed up the rate (of reaction)

*Ignore statements about the "yield of ammonia"*

**OR** Gets to equilibrium faster/ quicker

**OR** faster or quicker rate / speed of attainment of equilibrium

1

(ii) Less electrical pumping cost

*Not just "less expensive" alone*

**OR**

*Not just "less energy or saves energy" alone*

Use lower pressure equipment / valves / gaskets / piping etc.

*Credit correct qualified references to higher pressures*

**OR**

Uses less expensive equipment

*Ignore references to safety*

1

[12]

11

- (a) (i) Award mark for **X on the time axis** at the point where the lines just become **horizontal**

*Allow this mark if X is above the letters "sh" in the word "show" in part(ii) - in the range of lines 31 to 33.*

1

- (ii) They are equal / the same

**OR**

Forward (rate) = Reverse / backward (rate)

*Allow the word 'speed' in this context.*

*Ignore reference to concentration.*

1

- (b) Both **OR** forward and reverse reactions occur at the same time

**OR** both are occurring at once

**OR** both occur all of the time

**OR** both are ongoing

**OR** both never stop

*Ignore 'at equal rates'.*

*Ignore reference to concentration or equilibrium.*

*The idea that both reactions occur simultaneously is essential.*

*The simple idea of 'both reactions occurring' is insufficient for the mark.*

1

- (c) (i) **M1** No effect / no change / none / stays the same

**M2** requires correct **M1**

*In **M2**, ignore reference to particles or atoms.*

**M2** Equal (number of) moles / molecules on both sides

2

- (ii) **M1** Less time or it decreases or (equilibrium) reached faster (ie **M1** is a reference to time taken)

*If **M1** is 'more time / it increases' or 'no effect', then **CE=0** for the clip.*

*Reference to faster / increased rate / increased speed alone penalises **M1**, but mark on **M2** and **M3**.*

**M2** More particles / molecules in a given volume / space

**OR** the particles / molecules are closer together

*If **M1** is blank, then look for all three marks in the text.*

**M3** More successful / productive collisions in a given time

**OR** more collisions with  $E > E_{Act}$  in a given time

**OR** more frequent successful / productive collisions

**OR** increased / greater successful / productive collision frequency / rate

*Ignore reference to reactants / products.*

*Penalise **M3** if an increase / decrease in the value of  $E_{Act}$  is stated.*

3

[8]

12

D

[1]

13

D

[1]

14

(a) 
$$K_p = \frac{p_{CH_3OH}}{p_{CO} \times (p_{H_2})^2}$$

*ignore curved brackets, do not accept [ ]*

*allow  $p^2 H_2$  etc.*

1

- (b)  $\text{kPa}^{-2}$  (second box)

1

- (c) **M1** (forward) reaction is exothermic

*allow equilibrium moves in endothermic direction*

1

**M2** Equilibrium moves left to give out heat **OR** position of equilibrium moves left to reduce the temperature/oppose the increase in temperature

*Not just 'oppose the change'*

1

(d) moles hydrogen = 2(.0)

1

moles CH<sub>3</sub>OH = 14(.0)

1

(e) **M1** mole fractions of all three gases

CO = 0.2727...; H<sub>2</sub> = 0.0909....; CH<sub>3</sub>OH = 0.6363....

*fall back values give:*

**M1** mole fractions of all three gases

CO = 0.2727...; H<sub>2</sub> = 0.363636 CH<sub>3</sub>OH = 0.363636

1

**M2** partial pressures of all three gases

CO = 1363.63...kPa H<sub>2</sub> = 454.545... kPa CH<sub>3</sub>OH = 3181.81.... kPa

*fall back values give:*

**M2** partial pressures of all three gases

CO = 1363(.63 .kPa H<sub>2</sub> = 1818(.18) kPa

CH<sub>3</sub>OH = 1818(.18) kPa

1

**M3**  $K_p = 1.13 \times 10^{-5}$

*fall back values give:*

**M3**  $K_p = 4.03 \times 10^{-7}$

1

[9]