F325: Equilibria, Energetics and Elements
5.1.1 How Fast?

1. One cause of low-level smog is the reaction of ozone, O_3, with ethene, C_2H_4. The smog contains methanal, HCHO(g).

The equation for methanal production is shown below.

$$O_3(g) + C_2H_4(g) \rightarrow 2HCHO(g) + ½\ O_2(g)$$

The rate of the reaction was investigated, using a series of different concentrations of either $C_2H_4(g)$ or $O_3(g)$, by measuring the initial rate of formation of HCHO(g).

The results are shown below.

experiment	**$[O_3(g)]$ / 10^{-7} mol dm^{-3}**	**$[C_2H_4(g)]$ / 10^{-8} mol dm^{-3}**	**initial rate / 10^{-12} mol dm^{-3} s^{-1}**
1	0.5	1.0	1.0
2	2.0	1.0	4.0
3	4.0	2.0	16.0

(i) Analyse and interpret the results to deduce the order of reaction of each reactant and the rate equation.

Explain your reasoning.

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[5]

(ii) Calculate the value of the rate constant and state the units.

rate constant =..... units…….

[3]

(iii) Using the equation above, deduce the initial rate of **formation** of $O_2(g)$ in experiment 1.

Explain your reasoning.

answer = ... mol dm^{-3} s^{-1}

[1]

(iv) The experiment was repeated at a higher temperature.

How would the new conditions affect the rate of the reaction and the value of the rate constant?

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[1]

[Total 10 marks]

2. Nitrogen monoxide, NO, is involved in formation of ozone at low levels.

Nitrogen monoxide is produced by combustion in car engines. Ozone is then formed following the series of reactions shown below.

$$NO(g) + ½O_2(g) \rightarrow NO_2(g)$$

$$NO_2(g) \rightarrow NO(g) + O(g)$$

$$O_2(g) + O(g) \rightarrow O_3(g)$$

Write the overall equation for this reaction sequence.

Identify the catalyst and justify your answer.

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[Total 3 marks]

3. Nitrogen monoxide reacts with hydrogen at 500 °C as in the equation below.

$$2NO(g) + 2H_2(g) \rightarrow N_2(g) + 2H_2O(g)$$

A series of experiments was carried out to investigate the kinetics of this reaction. The results are shown in the table below.

experiment	[NO] / mol dm^{-3}	[H_2] / mol dm^{-3}	initial rate / mol dm^{-3} s^{-1}
1	0.10	0.20	2.6
2	0.10	0.50	6.5
3	0.30	0.50	58.5

In this question, one mark is available for the quality of spelling, punctuation and grammar.

(i) For each reactant, deduce the order of reaction. Show your reasoning.

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[4]

Quality of Written Communication [1]

(ii) Deduce the rate equation for this reaction.

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[1]

(iii) Calculate the rate constant, *k*, for this reaction. State the units for *k*.

k = ... units .....

[3]

[Total 9 marks]

4. Nitrogen monoxide, NO, is involved in formation of ozone at low levels and the breakdown of ozone at high levels.

(i) In the lower atmosphere, NO is produced by combustion in car engines. Ozone is then formed following the series of reactions shown below.

$$NO(g) + 1/2O_2(g) \rightarrow NO_2(g)$$

$$NO_2(g) \rightarrow NO(g) + O(g)$$

$$O_2(g) + O(g) \rightarrow O_3(g)$$

Write the overall equation for this reaction sequence.

Identify the catalyst and justify your answer.

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[3]

(ii) In the upper atmosphere, NO removes O_3 by the following reaction mechanism.

$NO(g) + O_3(g) \rightarrow NO_2(g) + O_2(g)$ slow

$O(g) + NO_2(g) \rightarrow NO(g) + O_2(g)$ fast

Suggest the rate equation for this process. Explain your reasoning.

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[2]

[Total 5 marks]

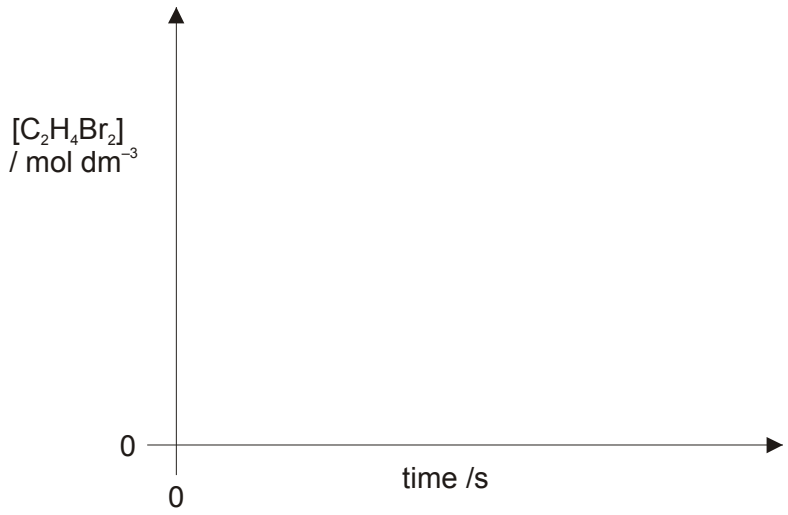
5. 1, 2-Dibromoethane, $C_2H_4Br_2$, reacts with potassium iodide as shown in the equation below.

$$C_2H_4Br_2 + 3KI \rightarrow C_2H_4 + 2KBr + KI_3$$

A series of experiments was carried out to investigate the kinetics of this reaction.

(a) In a first experiment the concentration of $C_2H_4Br_2$ was measured during the course of the reaction and a concentration-time graph was plotted. The reaction was shown to be first order with respect to $C_2H_4Br_2$.

(i) On the axes below, sketch a graph to show how $[C_2H_4Br_2]$ changed during the course of the reaction.



[2]

(ii) Show on the graph how you would measure the **initial** rate of the reaction.

[1]

(iii) How would you use the graph to show that the reaction is first order with respect to $C_2H_4Br_2$?

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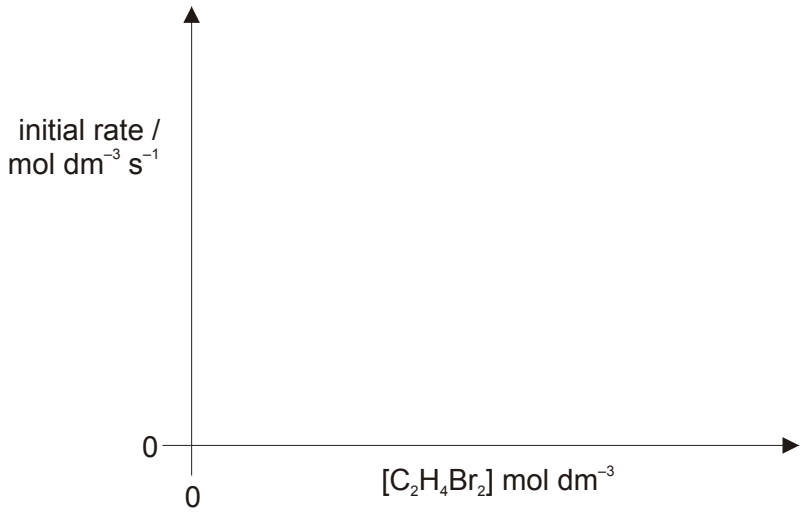
[1]

(iv) The experiment was repeated using different initial concentrations of $C_2H_4Br_2$.

Using the axes below, sketch a graph to show how the initial rate of the reaction changes with different concentrations of $C_2H_4Br_2$.



[1]

(b) In a second experiment, the initial concentration of KI was varied and the initial rate was measured. The results are shown in the table below.

experiment	[$C_2H_4Br_2$] /mol dm^{-3}	[KI] /mol dm^{-3}	initial rate /mol dm^{-3}s^{-1}
1	0.50	0.18	0.027
2	0.50	0.72	0.108

Deduce the order of reaction with respect to KI. Show your reasoning.

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[2]

(c) (i) Construct the rate equation for the reaction.

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[1]

(ii) Calculate the rate constant, *k,* for this reaction. State the units for *k.*

k = ... units .....

[3]

[Total 11 marks]

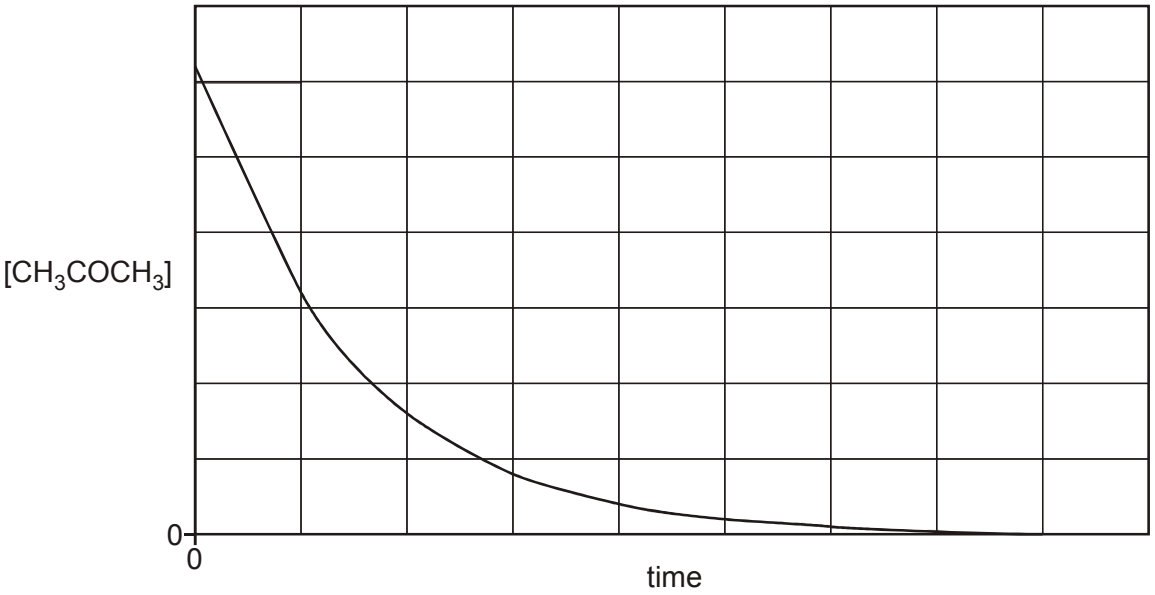
6. In this question, one mark is available for the quality of use and organisation of scientific terms.

Propanone reacts with iodine in the presence of dilute hydrochloric acid.

A student carried out an investigation into the kinetics of this reaction.

He measured how the concentration of propanone changes with time. He also investigated how different concentrations of iodine and hydrochloric acid affect the initial rate of the reaction.

The graph and results are shown below.



$[CH_3COCH_3]$ / mol dm^{-3}	$[I_2]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}	initial rate / mol dm^{-3} s^{-1}
1.5×10^{-3}	0.0300	0.0200	2.1×10^{-9}
1.5×10^{-3}	0.0300	0.0400	4.2×10^{-9}
1.5×10^{-3}	0.0600	0.0400	4.2×10^{-9}

The overall equation for the reaction is given below.

$$CH_3COCH_3 + I_2 \rightarrow CH_3COCH_2I + HI$$

This is a multi-step reaction.

- What conclusions can be drawn about the kinetics of this reaction from the student's investigation? Justify your reasoning.
- Calculate the rate constant for this reaction, including units.
- Suggest the equations for a possible two-step mechanism for this reaction. Label the rate-determining step and explain your reasoning.

Quality of Written Communication [1]

[Total 14 marks]

7. Nitrogen dioxide reacts with carbon monoxide emitted from car exhausts in the following reaction.

$$NO_2 + CO \rightarrow NO + CO_2$$

The rate equation for this reaction is $rate = k[NO_2]^2$.

This is a multi-step reaction. The first step is the rate-determining step.

(i) What is meant by the *rate-determining step*?

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[1]

(ii) Suggest a two-step reaction mechanism for this reaction that is consistent with the kinetic data and the overall reaction.

[2]

[Total 3 marks]

8. An excess of magnesium was added to 100 cm^3 of 0.0450 mol dm^{-3} hydrochloric acid. The same mass of magnesium was added to 100 cm^3 of 0.0450 mol dm^{-3} ethanoic acid.

Both reactions produced 54 cm^3 of hydrogen gas, measured at room temperature and pressure, but the reaction with ethanoic acid took much longer to produce this gas volume.

Explain why the reactions produced the same volume of a gas but at different rates.

Use equations in your answer.

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[Total 4 marks]

9. The decomposition of dinitrogen pentoxide, N_2O_5, at 45 °C was investigated. The reaction that takes place is shown below.

$$2N_2O_5 \rightarrow 4NO_2 + O_2$$

In an experiment, N_2O_5 with a concentration of 0.60 mol dm^{-3} was decomposed at 45 °C.

At this temperature, the reaction has a constant half-life of 1200 s.

(i) How can you tell that this reaction is first order with respect to N_2O_5?

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[1]

(ii) Write down an expression for the rate equation of this decomposition.

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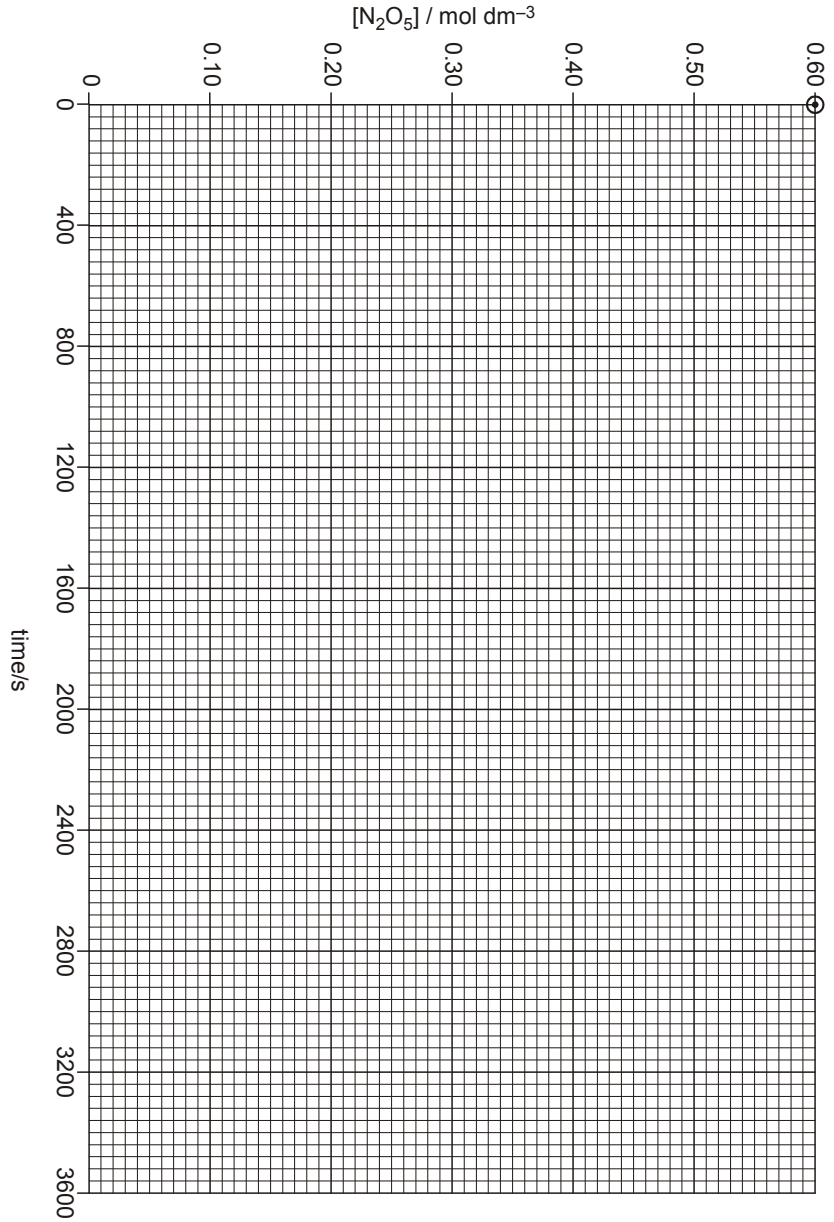
[1]

(iii) Complete the graph below to show how the $[N_2O_5]$ changes over the first 3600 s of the reaction.



[2]

(iv) The rate of this reaction can be determined from this graph.

Show on the graph how the rate can be measured after 1200 s.

[1]

(v) The rate can also be calculated from the rate equation. The rate constant for this reaction is 6.2×10^{-4} s^{-1}.

Calculate the initial rate of this reaction. State the units.

rate =…….…… units……..……..

[2]

[Total 7 marks]

10. A student investigated the hydration of 2-methylpropene, $(CH_3)_2C=CH_2$, with dilute aqueous acid to form 2-methylpropan-2-ol, $(CH_3)_3COH$.

The following mechanism has been proposed for this hydration.

step 1 $(CH_3)_2C=CH_2 + H^+(aq) \rightarrow (CH_3)_3C^+$ rate determining step

step 2 $(CH_3)_3C+ + H_2O \rightarrow (CH_3)_3COH + H^+(aq)$

(i) Step 1 is the rate-determining step for this hydration.

What is meant by the term *rate-determining step*?

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[1]

(ii) Write a balanced equation for the overall hydration reaction.

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[1]

(iii) Suggest the role of $H^+(aq)$ in this mechanism. Explain your reason.

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[2]

(iv) Use the mechanism above to suggest the rate equation for this hydration.

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[1]

[Total 5 marks]