# A-Level Chemistry

## Rate Equations

### Question Paper

**Time available: 49 minutes**
**Marks available: 48 marks**

**1.** The mechanisms of some reactions can be deduced from kinetic data.

The table shows the results of five experiments involving the reaction between benzaldehyde ($C_6H_5CHO$) and potassium hydroxide solution.

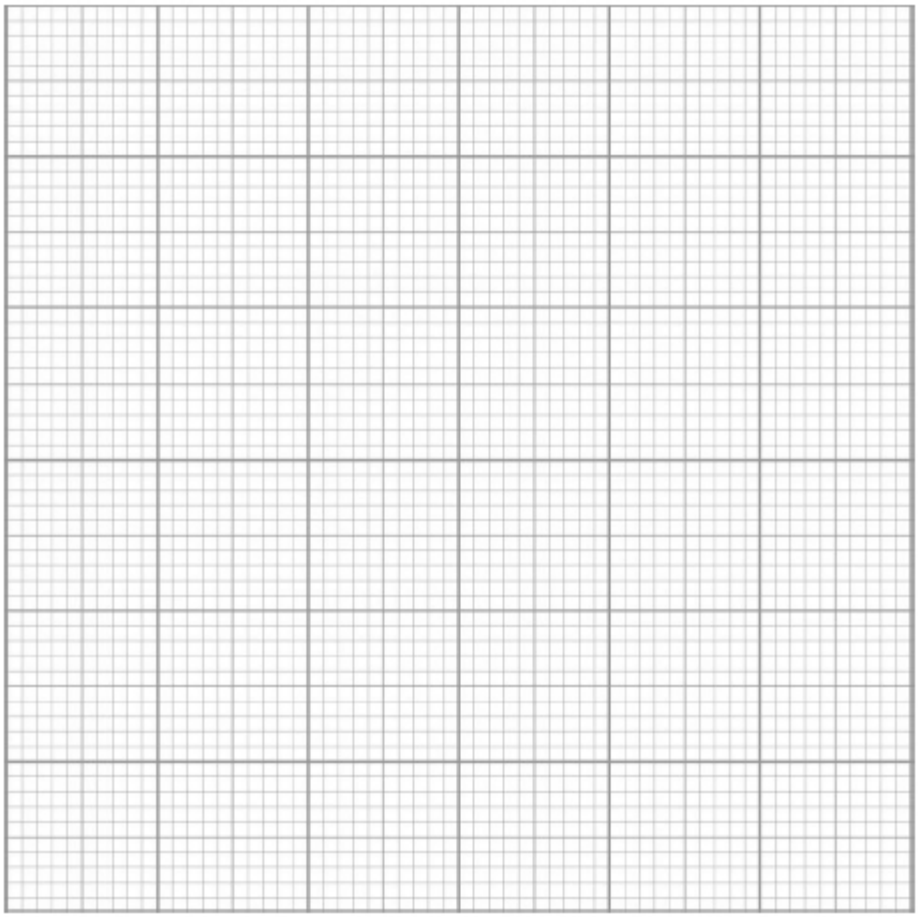
| **Experiment** | **Initial rate /mol dm$^{-3}$ s$^{-1}$** | **[$C_6H_5CHO$] /mol dm$^{-3}$** | **$C_6H_5CHO]^2$** | **[KOH] /mol dm$^{-3}$** |
|---|---|---|---|---|
| **1** | 0 | 0 | | 0 |
| **2** | $2.90 \times 10^{-6}$ | 0.25 | | 0.25 |
| **3** | $1.16 \times 10^{-5}$ | 0.50 | | 0.25 |
| **4** | $2.61 \times 10^{-5}$ | 0.75 | | 0.25 |
| **5** | $4.65 \times 10^{-5}$ | 1.00 | | 0.25 |

(a) Calculate the value of $[C_6H_5CHO]^2$ for each experiment.

Write your answers in the table above.

Plot a graph of initial rate against $[C_6H_5CHO]^2$ on the grid below.

Label the axes with units.



**(4)**

(b) Deduce the order of the reaction with respect to $C_6H_5CHO$ from the graph.

Explain your answer.

Order _____

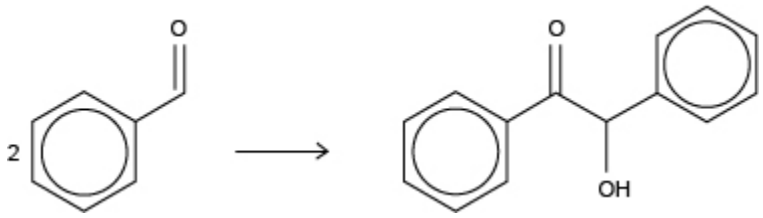
Explanation _____

_____

_____

**(2)**

(c) Benzaldehyde ($C_6H_5CHO$) undergoes a dimerisation reaction as shown:




The rate equation for the reaction is

$$rate = k\,[C_6H_5CHO]\,[CN^-]$$

Suggest the role of the cyanide ion in the reaction.

Explain your answer.

Role of $CN^-$ _____

Explanation _____

_____

_____

**(2)**

**(Total 8 marks)**

**2.** This question involves the use of kinetic data to deduce the order of a reaction and calculate a value for a rate constant.

The data in **Table 1** were obtained in a series of experiments on the rate of the reaction between compounds **A** and **B** at a constant temperature.

**Table 1**

| **Experiment** | **Initial concentration of A / mol dm$^{-3}$** | **Initial concentration of B / mol dm$^{-3}$** | **Initial rate / mol dm$^{-3}$ s$^{-1}$** |
|---|---|---|---|
| 1 | 0.12 | 0.26 | $2.10 \times 10^{-4}$ |
| 2 | 0.36 | 0.26 | $1.89 \times 10^{-3}$ |
| 3 | 0.72 | 0.13 | $3.78 \times 10^{-3}$ |

(a) Show how these data can be used to deduce the rate expression for the reaction between **A** and **B**.

**(3)**

The data in **Table 2** were obtained in two experiments on the rate of the reaction between compounds **C** and **D** at a constant temperature.

**Table 2**

| **Experiment** | **Initial concentration of C / mol dm$^{-3}$** | **Initial concentration of D / mol dm$^{-3}$** | **Initial rate / mol dm$^{-3}$ s$^{-1}$** |
|---|---|---|---|
| 4 | $1.9 \times 10^{-2}$ | $3.5 \times 10^{-2}$ | $7.2 \times 10^{-4}$ |
| 5 | $3.6 \times 10^{-2}$ | $5.4 \times 10^{-2}$ | To be calculated |

The rate equation for this reaction is

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

(b) Use the data from experiment **4** to calculate a value for the rate constant, *k*, at this temperature. Deduce the units of *k*.

*k* = _____ Units = _____

**(3)**

(c) Calculate a value for the initial rate in experiment **5**.

Initial rate = _____ mol $dm^{-3}$ $s^{-1}$

**(1)**

(d) The rate equation for a reaction is

$$rate = k[\mathbf{E}]$$

Explain qualitatively why doubling the temperature has a much greater effect on the rate of the reaction than doubling the concentration of **E**.

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**(3)**

(e) A slow reaction has a rate constant $k = 6.51 \times 10^{-3}$ mol$^{-1}$ dm$^3$ at 300 K.

Use the equation $\ln k = \ln A - E_a / RT$ to calculate a value, in kJ mol$^{-1}$, for the activation energy of this reaction.

The constant $A = 2.57 \times 10^{10}$ mol$^{-1}$ dm$^3$.
The gas constant $R = 8.31$ J K$^{-1}$ mol$^{-1}$.

Activation energy = _____

**(2)**

**(Total 12 marks)**

**3.** The initial rate of the reaction between gases **D** and **E** was measured in a series of experiments at a constant temperature. The results are shown in the table.

| **Expt** | **Initial [D] / mol dm$^{-3}$** | **Initial [E] / mol dm$^{-3}$** | **Initial rate / mol dm$^{-3}$ s$^{-1}$** |
|---|---|---|---|
| 1 | $1.25 \times 10^{-2}$ | $5.81 \times 10^{-1}$ | $1.16 \times 10^{-2}$ |
| 2 | $1.88 \times 10^{-2}$ | $8.73 \times 10^{-1}$ | $3.92 \times 10^{-2}$ |
| 3 | $1.88 \times 10^{-2}$ | 1.75 | $1.57 \times 10^{-1}$ |

(a) Deduce the order of reaction with respect to **D** and the order with respect to **E**.

Order with respect to **D** _____

Order with respect to **E** _____

Space for working _____

_____

_____

_____

**(2)**

(b) Suggest why initial rates of reaction are used to determine these orders rather than rates of reaction at other times during the experiments.

_____

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_____

**(1)**

(c) State how the initial rate is obtained from a graph of the concentration of the product against time.

_____

_____

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**(2)**

**(Total 5 marks)**

**4.** The reaction between propanone and iodine in the presence of hydrochloric acid was studied at a constant temperature.

$$CH_3COCH_3 + I_2 \longrightarrow CH_3COCH_2I + HI$$

The following rate equation was deduced.

$$\text{rate} = k\,[CH_3COCH_3][H^+]$$

(a) Suggest why the order with respect to iodine is zero.

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**(1)**

(b) In an experiment the initial concentrations of propanone, iodine and hydrochloric acid were as shown in the table. The initial rate of reaction in this experiment was $8.64 \times 10^{-7}$ mol $dm^{-3}$ $s^{-1}$.

| | **Initial concentration / mol $dm^{-3}$** |
|---|---|
| $CH_3COCH_3$ | $5.82 \times 10^{-2}$ |
| $I_2$ | $1.78 \times 10^{-3}$ |
| $H^+$ | $4.76 \times 10^{-1}$ |

Use the data in the table and the rate equation to calculate a value for the rate constant at this temperature.
Give units with your answer.

**(2)**

(c) A series of experiments was carried out using concentrations of propanone approximately 100 times the concentrations of iodine and hydrochloric acid.

Suggest the rate equation under these conditions.
Explain your answer.

**(2)**

**(Total 5 marks)**

**5.** Gases **A** and **B** react as shown in the following equation.

$$2\mathbf{A}(g) + \mathbf{B}(g) \longrightarrow \mathbf{C}(g) + \mathbf{D}(g)$$

The initial rate of the reaction was measured in a series of experiments at a constant temperature. The following rate equation was determined.

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

An incomplete table of data for the reaction between **A** and **B** is shown in the table.

| Experiment | Initial [A] / mol dm$^{-3}$ | Initial [B] / mol dm$^{-3}$ | Initial rate / mol dm$^{-3}$ s$^{-1}$ |
|---|---|---|---|
| **1** | $4.2 \times 10^{-3}$ | $2.8 \times 10^{-3}$ | $3.3 \times 10^{-5}$ |
| **2** | $7.9 \times 10^{-3}$ | $2.8 \times 10^{-3}$ | |
| **3** | | $5.6 \times 10^{-3}$ | $1.8 \times 10^{-4}$ |

(a) Use the data from Experiment **1** to calculate a value for the rate constant, *k*, at this temperature.
Deduce the units of *k*.

Calculation _____

_____

_____

_____

_____

Units _____

_____

**(3)**

(b) Use your value of *k* from (a) to complete the table for the reaction between **A** and **B**.
(If you have been unable to calculate an answer for (a), you may assume a value of 2.3. This is **not** the correct answer.)

**(2)**

(c) The reaction is zero order with respect to **B**.

State the significance of this zero order for the mechanism of the reaction.

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**(1)**

**(Total 6 marks)**

**6.** (a) The table shows the results of three experiments to investigate the rate of reaction between compounds **A** and **B** dissolved in a given solvent.
All three experiments were carried out at the same temperature.

| | **Experiment 1** | **Experiment 2** | **Experiment 3** |
|---|---|---|---|
| **Initial concentration of A / mol dm$^{-3}$** | $1.60 \times 10^{-2}$ | $2.40 \times 10^{-2}$ | $3.60 \times 10^{-2}$ |
| **Initial concentration of B / mol dm$^{-3}$** | $4.20 \times 10^{-2}$ | $6.30 \times 10^{-2}$ | $6.30 \times 10^{-2}$ |
| **Initial rate /mol dm$^{-3}$ s$^{-1}$** | $8.00 \times 10^{-5}$ | $1.80 \times 10^{-4}$ | $4.05 \times 10^{-4}$ |

(i) Deduce the order of reaction with respect to **A**.
Tick (✓) **one** box.

| **Order of reaction with respect to A** | **Tick (✓)** |
|---|---|
| 0 | |
| 1 | |
| 2 | |

**(1)**

(ii) Deduce the order of reaction with respect to **B**.
Tick (✓) **one** box.

| **Order of reaction with respect to B** | **Tick (✓)** |
|---|---|
| 0 | |
| 1 | |
| 2 | |

**(1)**

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

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

(i) When the initial concentration of **C** is $4.55 \times 10^{-2}$ mol $dm^{-3}$ and the initial concentration of **D** is $1.70 \times 10^{-2}$ mol $dm^{-3}$, the initial rate of reaction is $6.64 \times 10^{-5}$ mol $dm^{-3}$ $s^{-1}$.

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

Calculation _____

_____

_____

_____

Units of rate constant _____

_____

**(3)**

(ii) The experiment in part (i) is repeated at the same temperature but after the addition of extra solvent so that the total volume of the mixture is doubled.

Deduce the new initial rate of reaction.

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**(1)**

**(Total 6 marks)**

**7.** This question involves the use of kinetic data to calculate the order of a reaction and also a value for a rate constant.

(a) The data in this table were obtained in a series of experiments on the rate of the reaction between compounds **E** and **F** at a constant temperature.

| Experiment | Initial concentration of **E** / mol $dm^{-3}$ | Initial concentration of **F** / mol $dm^{-3}$ | Initial rate of reaction / mol $dm^{-3}$ $s^{-1}$ |
|---|---|---|---|
| **1** | 0.15 | 0.24 | $0.42 \times 10^{-3}$ |
| **2** | 0.45 | 0.24 | $3.78 \times 10^{-3}$ |
| **3** | 0.90 | 0.12 | $7.56 \times 10^{-3}$ |

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

_____

**(1)**

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

_____

**(1)**

(b) The data in the following table were obtained in two experiments on the rate of the reaction between compounds **G** and **H** at a constant temperature.

| Experiment | Initial concentration of **G** / mol $dm^{-3}$ | Initial concentration of **H** / mol $dm^{-3}$ | Initial rate of reaction / mol $dm^{-3}$ $s^{-1}$ |
|---|---|---|---|
| **4** | $3.8 \times 10^{-2}$ | $2.6 \times 10^{-2}$ | $8.6 \times 10^{-4}$ |
| **5** | $6.3 \times 10^{-2}$ | $7.5 \times 10^{-2}$ | To be calculated |

The rate equation for this reaction is

$$rate = \mathbf{k}[\mathbf{G}]^2[\mathbf{H}]$$

(i) Use the data from Experiment **4** to calculate a value for the rate constant *k* at this temperature. Deduce the units of *k*.

Calculation _____

_____

_____

_____

Units _____

_____

**(3)**

(ii) Calculate a value for the initial rate of reaction in Experiment **5**.

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**(1)**

**(Total 6 marks)**