**Q1.**          (a)     The following data were obtained in a series of experiments on the rate of the reaction between compounds **A** and **B** at a constant temperature.

|  |  |  |  |
| --- | --- | --- | --- |
| Experiment | Initial concentration of **A**/mol dm–3 | Initial concentration of **B**/mol dm–3 | Initialrate/mol dm–3 s–1 |
| 1 | 0.15 | 0.24 | 0.45 × 10–5 |
| 2 | 0.30 | 0.24 | 0.90 × 10–5 |
| 3 | 0.60 | 0.48 | 7.20 × 10–5 |

(i)      Show how the data in the table can be used to deduce that the reaction is first-order with respect to **A**.

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(ii)     Deduce the order with respect to **B**.

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**(2)**

(b)     The following data were obtained in a second series of experiments on the rate of the reaction between compounds **C** and **D** at a constant temperature.

|  |  |  |  |
| --- | --- | --- | --- |
| Experiment | Initial concentration of **A**/mol dm–3 | Initial concentration of **B**/mol dm–3 | Initialrate/mol dm–3 s–1 |
| 4 | 0.75 | 1.50 | 9.30 × 10–5 |
| 5 | 0.20 | 0.10 | To be calculated |

The rate equation for this reaction is

rate = *k*[**C**]2[**D**]

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

*Value for k* ...........................................................................................

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*Units of k* .............................................................................................

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(ii)     Calculate the value of the initial rate in Experiment 5.

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**(4)**

**(Total 6 marks)**

**Q2.**          Iodine and propanone react in acid solution according to the equation

I2   +   CH3COCH3   →   CH3COCH2I   +   HI

The rate equation for the reaction is found to be

rate = *k* [CH3COCH3][H+]

(a)     Deduce the order of reaction with respect to iodine and the overall order of reaction.

*Order with respect to iodine .*........................................................................

*Overall order* ................................................................................................

**(2)**

(b)     At the start of the experiment, the rate of reaction was found to be 2.00 × 10–5 mol dm–3 s–1 when the concentrations of the reactants were as shown below.

|  |  |
| --- | --- |
| Reactant | Concentration / mol dm–3 |
| CH3COCH3 | 1.50 |
| I2 | 2.00 × 10–2 |
| H+ | 3.00 × 10–2 |

Use these data to calculate a value for the rate constant and deduce its units.

*Rate constant* ...............................................................................................

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*Units* .............................................................................................................

**(3)**

(c)     How can you tell that H+ acts as a catalyst in this reaction?

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**(2)**

(d)     Calculate the initial rate of reaction if the experiment were to be repeated at the same temperature and with the same concentrations of iodine and propanone as in part (b) but at a pH of 1.25

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**(3)**

**(Total 10 marks)**

**Q3.**          (a)     The initial rate of the reaction between substances **P** and **Q** was measured in a series of experiments and the following rate equation was deduced.

rate = *k*[**P**]2[**Q**]

(i)      Complete the table of data below for the reaction between **P** and **Q**.

|  |  |  |  |
| --- | --- | --- | --- |
| Experiment | Initial [**P**] **/** mol dm–3 | Initial [**Q**] / mol dm–3 | Initial rate / mol dm–3 s–1 |
| 1 | 0.20 | 0.30 | 4.8 × 10–3 |
| 2 | 0.10 | 0.10 |   |
| 3 | 0.40 |   | 9.6 × 10–3 |
| 4 |   | 0.60 | 19.2 × 10–3 |

(ii)     Using the data from experiment 1, calculate a value for the rate constant, *k*, and deduce its units.

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**(6)**

(b)     What change in the reaction conditions would cause the value of the rate constant to change?

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**(1)**

**(Total 7 marks)**

**Q4.**          The rate of the reaction between substance **A** and substance **B** was studied in a series of experiments carried out at the same temperature. In each experiment the initial rate was measured using different concentrations of **A** and **B**. These results were used to deduce the order of reaction with respect to **A** and the order of reaction with respect to **B**.

(a)     What is meant by the term *order of reaction* with respect to **A**?

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**(1)**

(b)     When the concentrations of **A** and **B** were both doubled, the initial rate increased by a factor of 4. Deduce the **overall** order of the reaction.

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**(1)**

(c)     In another experiment, the concentration of **A** was increased by a factor of three and the concentration of **B** was halved. This caused the initial rate to increase by a factor of nine.

(i)      Deduce the order of reaction with respect to **A** and the order with respect to **B**.

*Order with respect to* ***A*** .......................................................................

*Order with respect to* ***B*** ........................................................................

(ii)     Using your answers from part (c)(i), write a rate equation for the reaction and suggest suitable units for the rate constant.

*Rate equation* .....................................................................................

*Units for the rate constant* ...................................................................

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**(4)**

**(Total 6 marks)**

**Q5.**          (a)     The following data were obtained in a series of experiments on the rate of the reaction between compounds **A** and **B** at a constant temperature.

|  |  |  |  |
| --- | --- | --- | --- |
| Experiment | Initial concentrationof **A**/mol dm–3 | Initial concentrationof **B**/mol dm–3 | Initial rate/mol dm–3 s–1 |
| 1 | 0.12 | 0.15 | 0.32 × 10–3 |
| 2 | 0.36 | 0.15 | 2.88 × 10–3 |
| 3 | 0.72 | 0.30 | 11.52 × 10–3 |

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

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

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**(2)**

(b)     The following data were obtained in a series of experiments on the rate of the reaction between NO and O2 at a constant temperature.

|  |  |  |  |
| --- | --- | --- | --- |
| Experiment | Initial concentrationof NO/mol dm–3 | Initial concentrationof O2/mol dm–3 | Initial rate/mol dm–3 s–1 |
| 4 | 5.0 × 10–2 | 2.0 × 10–2 | 6.5 × 10–4 |
| 5 | 6.5 × 10–2 | 3.4 × 10–2 | To be calculated |

The rate equation for this reaction is

*rate* = *k*[NO]2[O2]

(i)      Use the data from experiment 4 to calculate a value for the rate constant, *k*, at this temperature, and state its units.

*Value of k* ............................................................................................

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*Units of k* .............................................................................................

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

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**(4)**

**(Total 6 marks)**

**Q6.**          (a)     The initial rate of the reaction between compounds **A** and **B** was measured in a series of experiments at a fixed temperature. The following rate equation was deduced.

rate = *k*[**A**][**B**]2

(i)      Complete the table of data below for the reaction between **A** and **B**.

|  |  |  |  |
| --- | --- | --- | --- |
| Expt | Initial [**A**]/mol dm–3 | Initial [**B**]/mol dm–3 | Initial rate/mol dm–3 s–1 |
| 1 | 4.80 × 10–2 | 6.60 × 10–2 | 10.4 × 10–3 |
| 2 | 4.80 × 10–2 | 3.30 × 10–2 |   |
| 3 |   | 13.2 × 10–2 | 5.20 × 10–3 |
| 4 | 1.60 × 10–2 |   | 10.4 × 10–3 |

(ii)     Using the data for experiment 1, calculate a value for the rate constant, *k*, and state its units.

*Calculation* ..........................................................................................

.............................................................................................................

*Units* ....................................................................................................

**(6)**

(b)     State how the value of the rate constant, *k*, would change, if at all, if the concentration of **A** were increased in a series of experiments.

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**(1)**

**(Total 7 marks)**

**Q7.**          (a)     The following table shows the results of three experiments carried out at the same temperature to investigate the rate of the reaction between compounds **P** and **Q**.

|  |  |  |  |
| --- | --- | --- | --- |
|   | Experiment 1 | Experiment 2  | Experiment 3 |
| Initial concentration of **P**/mol dm–3 | 0.50 | 0.25 | 0.25 |
| Initial concentration of **Q**/mol dm–3 | 0.36 | 0.36 | 0.72 |
| Initial rate/mol dm–3 s–1 | 7.6 × 10–3 | 1.9 × 10–3 | 3.8 × 10–3 |

Use the data in the table to deduce the order with respect to **P** and the order with respect to **Q**.

*Order with respect to* ***P*** ................................................................................

*Order with respect to* ***Q*** ................................................................................

**(2)**

(b)     In a reaction between **R** and **S**, the order of reaction with respect to **R** is one, the order of reaction with respect to **S** is two and the rate constant at temperature *T*1 has a value of 4.2 × 10–4 mol–2 dm6 s–1.

(i)      Write a rate equation for the reaction. Calculate a value for the initial rate of reaction when the initial concentration of **R** is 0.16 mol dm–3 and that of **S** is
0.84 mol dm–3.

*Rate equation .*...................…..............................................................

*Calculation* ..........................................................................................

(ii)     In a second experiment performed at a different temperature, *T*2, the initial rate of reaction is 8.1 × 10–5 mol dm–3s–1 when the initial concentration of **R** is 0.76 mol dm–3 and that of **S** is 0.98 mol dm–3. Calculate the value of the rate constant at temperature *T*2.

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(iii)     Deduce which of *T*1 and *T*2 is the higher temperature.

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**(6)**

**(Total 8 marks)**

**Q8.**          (a)     Compound **A**, HCOOCH2CH2CH3, is an ester. Name this ester and write an equation for its reaction with aqueous sodium hydroxide.

*Name ……….................................................................................................*

*Equation .......................................................................................................*

**(2)**

(b)     The initial rate of reaction between ester **A** and aqueous sodium hydroxide was measured in a series of experiments at a constant temperature. The data obtained are shown below.

|  |  |  |  |
| --- | --- | --- | --- |
| Experiment | Initial concentration of NaOH / mol dm–3 | Initial concentration of **A** / mol dm–3 | Initial rate/ mol dm–3 s–1 |
| 1 | 0.040 | 0.030 | 4.0 × 10–4 |
| 2 | 0.040 | 0.045 | 6.0 × 10–4 |
| 3 | 0.060 | 0.045 | 9.0 × 10–4 |
| 4 | 0.120 | 0.060 | to be calculated |

Use the data in the table to deduce the order of reaction with respect to **A** and the order of reaction with respect to NaOH. Hence calculate the initial rate of reaction in Experiment 4.

*Order with respect to* ***A*** ................................................................................

*Order with respect to NaOH* .........................................................................

*Initial rate in Experiment 4 .*...........................................................................

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**(3)**

(c)     In a further experiment at a different temperature, the initial rate of reaction was found to be 9.0 × 10–3 mol dm–3 s–1 when the initial concentration of **A** was 0.020 mol dm–3 and the initial concentration of NaOH was 2.00 mol dm–3.
Under these new conditions with the much higher concentration of sodium hydroxide, the reaction is first order with respect to **A** and appears to be zero order with respect to sodium hydroxide.

(i)      Write a rate equation for the reaction under these new conditions.

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(ii)     Calculate a value for the rate constant under these new conditions and state its units.

*Calculation .........................................................................................*.

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Units ....................................................................................................

(iii)     Suggest why the order of reaction with respect to sodium hydroxide appears to be zero under these new conditions.

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**(6)**

(d)     A naturally-occurring triester, shown below, was heated under reflux with an excess of aqueous sodium hydroxide and the mixture produced was then distilled. One of the products distilled off and the other was left in the distillation flask.



(i)      Draw the structure of the product distilled off and give its name.

*Structure*

*Name* ..................................................................................................

(ii)     Give the formula of the product left in the distillation flask and give a use for it.

*Formula* ...............................................................................................

*Use .*.....................................................................................................

**(4)**

**(Total 15 marks)**

**Q9.**          The initial rate of the reaction between the gases NO and H2 was measured in a series of experiments at a constant temperature and the following rate equation was determined.

rate = *k*[NO]2[H2]

(a)     Complete the table of data below for the reaction between NO and H2

|  |  |  |  |
| --- | --- | --- | --- |
| Experiment  | Initial [NO] / mol dm–3 | Initial [H2] / mol dm–3 | Initial rate / mol dm–3 s–1  |
| 1  | 3.0 × 10–3  | 1.0 × 10–3 | 1.8 × 10–5  |
| 2  | 3.0 × 10–3 |   | 7.2 × 10–5 |
| 3  | 1.5 × 10–3 | 1.0 × 10–3  |   |
| 4  |   | 0.50 × 10–3  | 8.1 × 10–5 |

**(3)**

(b)     Using the data from experiment 1, calculate a value for the rate constant, *k*, and state its units.

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**(3)**

**(Total 6 marks)**

**Q10.**          The hydrolysis of methyl propanoate was studied in acidic conditions at 25°C and the rate equation was found to be

rate = *k*[CH3CH2COOCH3][H+]

(a)     Use the data below to calculate the value of the rate constant, *k*, at this temperature.
Deduce its units.

|  |  |  |
| --- | --- | --- |
| Initial rate of reaction / mol dm–3 s–1 | Initial concentration of methyl propanoate / mol dm–3 | Initial concentration of hydrochloric acid / mol dm–3 |
| 1.15 × 10–4 | 0.150 | 0.555 |

*Rate constant* ...............................................................................................

......................................................................................................................

......................................................................................................................

*Units* .............................................................................................................

......................................................................................................................

**(3)**

(b)     The reaction in part (a) was repeated at the same temperature, but water was added so that the volume of the reaction mixture was doubled. Calculate the initial rate of reaction under these conditions.

......................................................................................................................

......................................................................................................................

**(1)**

(c)     A third experiment was carried out at a different temperature. Some data from this experiment are shown in the table below.

|  |  |  |
| --- | --- | --- |
| Initial rate of reaction / mol dm–3 s–1 | Value of rate constant at this different temperature | Initial methyl propanoate / mol dm–3 |
| 4.56 × 10–5 | 8.94 × 10–4 | 0.123 |

Calculate the initial pH of the reaction mixture. Give your answer to two decimal places.

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**(3)**

**(Total 7 marks)**

**Q11.**          Propanone and iodine react in acidic conditions according to the following equation.

CH3COCH3 + I2 → ICH2COCH3 + HI

A student studied the kinetics of this reaction using hydrochloric acid and a solution containing propanone and iodine. From the results the following rate equation was deduced.

rate = *k*[CH3COCH3][H+]

(a)     Give the overall order for this reaction.

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**(1)**

(b)     When the initial concentrations of the reactants were as shown in the table below, the initial rate of reaction was found to be 1.24 × 10–4 mol dm–3 s–1.

|  |  |
| --- | --- |
|   | initial concentration / mol dm–3 |
| CH3COCH3 | 4.40 |
| I2 | 5.00 × 10–3 |
| H+ | 0.820 |

Use these data to calculate a value for the rate constant, *k*, for the reaction and give its units.

Calculation ...................................................................................................

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Units .............................................................................................................

**(3)**

(c)     Deduce how the initial rate of reaction changes when the concentration of iodine is doubled but the concentrations of propanone and of hydrochloric acid are unchanged.

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**(1)**

(d)     The following mechanism for the overall reaction has been proposed.



Use the rate equation to suggest which of the four steps could be the rate-determining step. Explain your answer.

Rate-determining step .................................................................................

Explanation ..................................................................................................

......................................................................................................................

**(2)**

(e)     Use your understanding of reaction mechanisms to predict a mechanism for Step **2** by adding one or more curly arrows as necessary to the structure of the carbocation below.



**(1)**

**(Total 8 marks)**

**Q12.**          A reaction mechanism is a series of steps by which an overall reaction may proceed.
The reactions occurring in these steps may be deduced from a study of reaction rates.
Experimental evidence about initial rates leads to a rate equation. A mechanism is then proposed which agrees with this rate equation.
Ethanal dimerises in dilute alkaline solution to form compound **X** as shown in the following equation.

2CH3CHO → CH3CH(OH)CH2CHO

**X**

A chemist studied the kinetics of the reaction at 298 K and then proposed the following rate equation.

Rate = *k* [CH3CHO][OH–]

(a)Give the IUPAC name of compound **X**.

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**(1)**

(b)     The initial rate of the reaction at 298K was found to be 2.2 × 10–3 mol dm–3 s–1 when the initial concentration of ethanal was 0.10 mol dm–3 and the initial concentration of sodium hydroxide was 0.020 mol dm–3.
Calculate a value for the rate constant at this temperature and give its units.

Calculation ...................................................................................................

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Units .............................................................................................................

**(3)**

(c)The sample of **X** produced consists of a racemic mixture (racemate). Explain how this racemic mixture is formed.

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**(2)**

(d)     A three-step mechanism has been proposed for this reaction according to the following equations.

|  |  |
| --- | --- |
| Step **1** |  |
| Step **2** |  |
| Step **3** |  |

(i)      Using the rate equation, predict which of the three steps is the rate-determining step. Explain your answer.

Rate-determining step ........................................................................

Explanation .........................................................................................

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**(2)**

(ii)     Deduce the role of ethanal in Step **1**.

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**(1)**

(iii)Use your knowledge of reaction mechanisms to deduce the type of reaction occurring in Step **2**.

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**(1)**

(iv)    In the space below draw out the mechanism of Step **2** showing the relevant curly arrows.

**(2)**

(e)In a similar three-step mechanism, one molecule of **X** reacts further with one molecule of ethanal. The product is a trimer containing six carbon atoms.

Deduce the structure of this trimer.

**(1)**

**(Total 13 marks)**

**Q13.**          Synthesis gas is a mixture of carbon monoxide and hydrogen. Methanol can be manufactured from synthesis gas in a reversible reaction as shown by the following equation.

CO(g) + 2H2(g) CH3OH(g)          Δ*H*~~ο~~ = –91 kJ mol–1

(a)     A sample of synthesis gas containing 0.240 mol of carbon monoxide and 0.380 mol of hydrogen was sealed together with a catalyst in a container of volume 1.50 dm3.
When equilibrium was established at temperature *T*1 the equilibrium mixture contained 0.170 mol of carbon monoxide.

Calculate the amount, in moles, of methanol and the amount, in moles, of hydrogen in the equilibrium mixture.

Methanol .....................................................................................................

Hydrogen .....................................................................................................

**(2)**

(b)     A different sample of synthesis gas was allowed to reach equilibrium in a similar container of volume 1.50 dm3 at temperature *T*1

At equilibrium, the mixture contained 0.210 mol of carbon monoxide, 0.275 mol of hydrogen and 0.0820 mol of methanol.

(i)      Write an expression for the equilibrium constant *K*c for this reaction.

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**(1)**

(ii)     Calculate a value for *K*c for the reaction at temperature *T*1 and state its units.

Calculation ….......................................................................................

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Units ....................................................................................................

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**(4)**

(iii)     State the effect, if any, on the value of *K*c of adding more hydrogen to the equilibrium mixture.

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**(1)**

(c)     The temperature of the mixture in part (b) was changed to *T*2 and the mixture was left to reach a new equilibrium position. At this new temperature the equilibrium concentration of methanol had increased.

Deduce which of *T*1 or *T*2 is the higher temperature and explain your answer.

Higher temperature ......................................................................................

Explanation ..................................................................................................

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**(3)**

(d)     The following reaction has been suggested as an alternative method for the production of methanol.

CO2(g) + 3H2(g) CH3OH(g) + H2O(g)

The hydrogen used in this method is obtained from the electrolysis of water.

Suggest **one** possible environmental disadvantage of the production of hydrogen by electrolysis.

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**(1)**

(e)     One industrial use of methanol is in the production of biodiesel from vegetable oils such as



Give the formula of **one** compound in biodiesel that is formed by the reaction of methanol with the vegetable oil shown above.

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**(1)**

**(Total 13 marks)**

**Q14.**          The rate of hydrolysis of an ester **X** (HCOOCH2CH2CH3) 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 mol dm–3 and the initial concentration of hydroxide ions was 0.035 mol dm–3, the initial rate of the reaction was
8.5 × 10–5 mol dm–3 s–1.
Calculate a value for the rate constant at this temperature and give its units.

Calculation ..........................................................................................

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Units ....................................................................................................

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**(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.

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**(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.

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**(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

A + 3B → AB3

The rate equation for the reaction is

rate = *k*[A][B]2

A suggested mechanism for the reaction is

Step **1**     A    + B → AB

Step **2**     AB  + B → AB2

Step **3**     AB2 + B → AB3

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

Explain your answer.

Rate-determining step .................................................................................

Explanation ..................................................................................................

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**(2)**

**(Total 11 marks)**

**Q15.**(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** / mol dm−3 | Initial concentration of **C** / mol dm−3 | Initial rate / mol dm−3 s−1 |
|   | **1** | 4.2 × 10−2 | 2.6 × 10−2 | 8.4 × 10−5 |
|   | **2** | 6.3 × 10−2 | 7.8 × 10−2 | To be calculated |

The rate equation for this reaction is known to be

rate = *k*[**B**]2[**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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*(Extra space)* ........................................................................................

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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 **D** / mol dm−3 | Initial concentration of **E** / mol dm−3 | Initial rate /mol dm−3 s−1 |
|   | **3** | 0.13 | 0.23 | 0.26 × 10−3 |
|   | **4** | 0.39 | 0.23 | 2.34 × 10−3 |
|   | **5** | 0.78 | 0.46 | 9.36 × 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 (CH3)3CBr reacts with aqueous sodium hydroxide as shown in the folfollowing equation.

(CH3)3CBr + OH−   (CH3)3COH + Br−

This reaction was found to be first order with respect to (CH3)3CBr but zero order with respect to hydroxide ions.

The following two-step process was suggested.

Step **1** (CH3)3CBr   (CH3)3C+ + Br−

Step **2** (CH3)3C+ + OH−   (CH3)3COH

(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)**

**Q16.**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 × 10−3 |
|   | **2** | 0.45 | 0.24 | 3.78 × 10−3 |
|   | **3** | 0.90 | 0.12 | 7.56 × 10−3 |

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

...............................................................................................................

*(Space for working)* ...............................................................................

...............................................................................................................

...............................................................................................................

...............................................................................................................

**(1)**

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

...............................................................................................................

*(Space for working)* ...............................................................................

...............................................................................................................

...............................................................................................................

...............................................................................................................

**(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 × 10−2 | 2.6 × 10−2 | 8.6 × 10−4 |
|   | **5** | 6.3 × 10−2 | 7.5 × 10−2 | To be calculated |

The rate equation for this reaction is

*rate* = **k**[**G**]2[**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**.

...............................................................................................................

...............................................................................................................

**(1)**

**(Total 6 marks)**

**M1.**          (a)     (i)      (Experiment 1 → 2) [A] doubled, ([B] constant,)
rate doubled **(1)**

*stated or shown numerically*

(ii)     2 **(1)**or shown as ... [B]2

**2**

(b)     (i)      k =  = 1.1(0) × 10–4

            **(1)                        (1)**

units of k: mol–2 dm6 s–1 **(1)**

(ii)     rate = (1.10 × 10–4) × (0.20)2 × (0.10)
       = 4.4(1) × 10–7 (mol dm–3 s–1)
                 **(1) for the answer**

*Ignore units
Conseq on (i)
Upside down expression for k scores zero in (i) for 9073
but rate = 9073 × (0.2)2 × (0.1) = 36(.3)
conseq scores (1) in (ii)*

**4**

**[6]**

**M2.**          (a)     *Order with respect to iodine*: 0 **(1)***Overall order:* 2 **(1)**

**2**

(b)     *Rate constant*: k =  = 4.4(4) × 10–4 **(1)**

*Units*: mol–1 dm3 s–1 **(1)**

**3**

(c)     Appears in rate equation **(1)**

*OR implied by mention of concentration or order*

          does not appear in (stoichiometric / overall) equation (1)

**2**

(d)     pH = –log10 [H+] **(1)**      =1.25
[H+] = 0.056(2) **(1)**

           rate = (4.44 × 10–4) × (1.50) × (0.0562)

 = 3.75 × 10–5 **(1)** (mol dm3 s–1)

(3.7 — 3.8)

*Can score all 3 conseq on k from part (b)*

**3**

**[10]**

**M3.**          (a)     (i)      Experiment 2: 0.4(0) × 10–3 **(1)**Experiment 3: 0.15 **(1)**Experiment 4: 0.28 **(1)**

(ii)     k =  = 0.4(0) mol–2 dm6 s–1

                        **(1)**                   **(1)**          **(1)**

**6**

(b)     (change in) temperature **(1)**

**1**

**[7]**

**M4.**          (a)     Power (or index or shown as *x* in [ ]x) of concentration term
(in rate equation) **(1)**

**1**

(b)     2 **(1)**

**1**

(c)     (i)      *Order with respect to* ***A****:*2 **(1)**

         *Order with respect to* ***B***: 0 **(1)**

(ii)     *Rate equation:* (rate =) k [A]2 **(1)**

*Allow conseq on c(i)*

         *Units for rate constant*: mol–1 dm3 s–1 **(1)**

*conseq on rate equation*

**4**

**[6]**

          Organic points

(1)     Curly arrows: must show movement of a pair of electrons,
i.e. from bond to atom or from lp to atom / space
e.g.



(2)     Structures

penalise sticks (i.e. ) once per paper



Penalise once per paper

          allow CH3– or –CH3 or  or CH3    or   H3C–

**M5.**          (a)     (i)      2 **(1)**

(ii)     0 **(1)**                                                                                                        2

(b)     (i)      *Value of k*: k =  =  = 13

*Units of k*: mol–2 dm6 s–1 **(1)**

(ii)     rate = 13 (6.5 × 10–2)2 (3.4 × 10–2)
       = 1.9 × 10–3        (mol dm–3 s–1) **(1)**

*If k wrong, the mark in (ii) may be gained conseq for their
k × 1.437 × 10–4*

**4**

**[6]**

**M6.**          (a)     (i)      Experiment 2     2.60 × 10–3

**1**

Experiment 3     0.60 × 10–2

**1**

Experiment 4     11.4 × 10–2

**1**

(ii)     k = 

**1**

         = 49.7

*(Allow 49.8 and 50)*

**1**

         mol–2 dm6 s–1

**1**

(b)     No change

**1**

**[7]**

**M7.**         (a)     order with respect to **P** is 2

**1**

order with respect to **Q** is 1

**1**

(b)     (i)      rate = *k***[R][S]**2

*(if wrong expression, no further marks)*

**1**

rate = (4.2 × 10–4) × 0.16 × 0.842

**1**

= 4.7 × 10–5 (mol dm–3 s–1)

*ignore units even if wrong*

**1**

(ii)     

**1**

= 1.1 × 10–4

**1**

(iii)     *T*1

*\*If calculated value for k > 4.2 × 10–4, then answer to (iii) is T2*

**1**

**[8]**

**M8.**          (a)     propyl methanoate;

HCOOC3H7 + OH– → HCOO– + C3H7OH

**1**

OR

HCOOC3H7 + NaOH → HCOONa + C3H7OH;

**1**

(b)     order wrt A = 1;

**1**

order wrt NaOH = 1;

**1**

Initial rate in Exp 4 = 2.4 × 10–3;

**1**

(c)     (i)      r(ate) = k[A]

OR

r(ate) = k[A][NaOH]0;

*(penalise missing [ ] but mark on)
(penalise missing [ ] once per paper)
(if wrong order, allow only units mark conseq on their rate eqs)
(penalise ka or kw etc)*

**1**

(ii)     ;

**1**

= 0.45;

**1**

         s–1;

**l**

(iii)     (large) excess of OH– or [OH–] is large/high;

**1**

[OH–] is (effectively) constant

OR

[A] is the limiting factor                *(Q of L mark)*

**1**

(d)     (i)

          

**1**

          propan(e)-1,2,3-triol

          *OR*

          1,2,3-propan(e)triol

          *OR*

          Glycerol;

**1**

(ii)     CH3(CH2)16COONa  or  C17H35COONa or C18H35O2Na;

*(ignore 3 in front of formula but not if indicating trimer)*

**1**

(not just anion and penalise Na shown as covalently bonded) soap -
allow with detergent but not detergent alone;

**1**

**[15]**

**M9.**          (a)     exp2      4.0 × 10–3

**1**

exp3      0.45 × 10–5

**1**

exp4      9.0 × 10–3

**1**

(b)     

**1**

2000

**1**

mol–2 dm6 s–1

**1**

**[6]**

**M10.**          (a)     *k* = rate/[CH3CH2COOCH3][H+]

**1**

or

 = 

 = 1.38 × 10–3 to 1.4 × 10–3

**1**

mol–1 dm3 s–1

**1**

(b)     ans = rate constant × (½ × 0.150) × (½ × 0.555)

*ignore units*

      = rate constant × 0.0208

2.88 × 10–5 (1.38 × 10–3 gives 2.87 × 10–5)

*Allow 2.87 – 2.91 × 10–5 (1.4 × 10–3 gives 2.91 × 10–5)*

**1**

(c)     [H+] = rate/ k[CH3COOCH2CH3]

**1**

= 

= 0.415 (0.4146)

**1**

pH = 0.38 mark independently

*[H+] = 0.41 gives pH = 0.39*

**1**

**[7]**

**M11.**          (a)     2 or two or second

**1**

(b)     k = 

*mark is for insertion of numbers into a correctly rearranged rate equ, k = etc
if upside down, (or use of I2 data) score only units mark*

**1**

= 3.44 × 10–5 (min 3sfs)

**1**

mol–1 dm3 s–1

*any order*

**1**

(c)     no change or no effect or stays the same or 1.24 × 10–4

**1**

(d)     1 or 2 or 1 and 2

*if wrong no further mark but mark on from no answer*

**1**

rate equ doesn’t involve I2 or only step which includes 2
species in rate equ

**1**

(e)



*any second arrow loses the mark*

**1**

**[8]**

**M12.**          (a)     3-hydroxybutanal

*ignore number 1   i.e. allow 3-hydroxybutan-1-al*

*not hydroxyl*

**1**

(b)     

**1**

= 1.1

**1**

mol–1 dm3 s–1

**1**

(c)     planar or flat C=O or molecule

*allow planar molecule*

**1**

equal probability of attack from above or below

*must be equal; not attack of OH–*

**1**

(d)     (i)      Step 1 if wrong – no mark for explanation.

**1**

involves ethanal and OH– or species/ “molecules”
in rate equation

**1**

(ii)     (B-L) acid or proton donor

*not Lewis acid*

**1**

(iii)     nucleophilic addition

*QOL*

**1**

(iv)



*not allow M2 before M1, but allow M1 attack on C+ after non-scoring carbonyl arrow*

*ignore error in product*

**2**

(e)



**1**

**[13]**

**M13.**          (a)     mol CH3OH = 0.07(0)

**1**

mol H2 = 0.24(0)

**1**

(b)     (i)       or 

*allow ( ) but expression using formulae must have brackets alternative expression using numbers must include volumes*

**1**

(ii)     **M1** divides by vol

*Mark independently from (b)(i)
any AE is –1
if volume missed, can score only M3 and M4*

**1**

**M2    **

*mark is for correct insertion of correct numbers in correct Kc expression in b(ii)
If Kc expression wrong, can only score M1 & M4
If numbers rounded, allow M2 but check range for M3*

**1**

**M3** 11.6 or 11.7

*mark for answer
above 11.7 up to 12.2 scores 2 for M1 and M2
if vol missed, can score M3 for 5.16 (allow range 4.88 to 5.21)*

**1**

**M4** mol–2 dm6

*Units conseq to their Kc in (b)(ii)*

**1**

(iii)     no effect or no change or none

**1**

(c)     **M1** T1

*if wrong - no further marks*

**1**

**M2** (forward) reaction is exothermic **OR** gives out heat

         backward reaction is endothermic

*only award M3 if M2 is correct*

**1**

**M3** shifts to RHS to replace lost heat

         ***OR*** to increase the temperature

         ***OR*** to oppose fall in temp

         backward reaction takes in heat

         ***OR*** to lower the temperature

*not just to oppose the change*

**1**

(d)     fossil fuels used
***OR***CO2 H2O produced/given off/formed which are greenhouse gases
***OR***SO2 produced/given off/formed which causes acid rain
***OR***Carbon produced/given off/formed causes global dimming

*not allow electricity is expensive
ignore just global warming
ignore energy or hazard discussion*

**1**

(e)     C17H35COOCH3 **or** C17H31COOCH3 or C17H29COOCH3

**OR**

CH3OOCC17H35 or CH3OOCC17H31 or CH3OOCC17H29

**1**

**[13]**

**M14.**          (a)     (i)      propyl methanoate

*must be correct spelling*

**1**

(ii)     rate = k[X][OH–]

*allow HCOOCH2CH2CH3 (or close) for X*

*allow ( ) but penalise missing minus*

**1**

(iii)     k = 

*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)      2sf minimum

*1 for conseq answer*

**1**

mol–1 dm3 s–1

*1 for conseq units*

*any order*

**1**

(iv)    2.1(3) × 10–5

*or 2.1(2) × 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 ×10–4 (1.28 ×10–4)

*allow (1.26 × 10–4) to (1.3 × 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–**[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 × (0.012)(0.0175)2 = their k ×(3.7 × 10–6)
                           (allow answer to 2sf)
**\*\*** in (v) for rate = their k × (0.012)(0.105)2 = their k ×(1.32 × 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 > Ea***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]**

**M15.**(a)     (i)  

*Mark is for insertion of numbers into a correctly rearranged rate equ , 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**

mol−2 dm+6 s−1

*Any order*

*If k calculation wrong, allow units consequential to their k = expression*

**1**

(ii)     5.67 × 10−4 (mol dm−3 s−1)   ***OR***    their *k* × 3.1 × 10−4

*Allow 5.57 × 10−4 to 5.7 × 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: OH− (must show lp)*

*If SN2 mechanism shown then no mark (penalise involvement of :OH− in step 1)*

*Ignore anything after correct step 1*

**1**

**[8]**

**M16.**(a)     (i)      2 or two or second or [E]2

**1**

(ii)     1 or one or first or [F]1 or [F]

**1**

(b)    (i)      *k* = 

*mark is for insertion of numbers into a correctly rearranged rate equ , k = etc.
AE (−1) for copying numbers wrongly or swapping two numbers.*

**1**

= 22.9 (Allow 22.9 − 24 after correct rounding)

**1**

mol−2dm+6 s&8722;1

*Any order.*

**1**

(ii)     6.8(2) × 10−3 (mol dm&8722;3s−1)
***OR*** if their k is wrong, award the mark consequentially
a quick check can be achieved by using
their answer = 2.9768 × 10−4 Allow 2.9 − 3.1 × 10−4 for the mark
    their *k*

*Allow 6.8 × 10−3 to 6.9 × 10−3Ignore units.*

**1**

**[6]**