Learn Chemistry

Problem Based Practical Activities

Problem 7: Iodination inquiry

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This resource was produced as part of the National HE STEM Programme

National HE STEM Programme

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Registered Charity Number 207890

Problem 7:
Iodination inquiry

Curriculum links;
rate equations, rate determining step

Practical skills;
clock reactions, accuracy

A teacher asks the students to design a clock reaction to determine which is the rate-determining step in the iodination of propanone.

Problem 7: Iodination inquiry

Pre-Lab questions

(Remember to give full references for any information beyond A-level that you find out)

1. Consider the reaction: $2\,A + B \rightarrow C + D$

a) Sketch a graph to show how the reaction rate (taken here as the change in [C] per unit time) would vary with [A] if the reaction was;

i. zero order with respect to A

ii. first order with respect to A

iii. second order with respect to A

b) A detailed study of the kinetics of the reaction revealed that the mechanism involved the formation of an intermediate E;

Step one: $A + A \rightarrow C + E$ *slow*

Step two: $E + B \rightarrow D$ *fast*

Which step is the rate determining step in the reaction?

2. The rate of a reaction can be determined experimentally using an initial rate method. This involves measuring the time it takes for some easily recognisable event to occur very early on in a reaction (usually when less than 10% of the reaction has occurred).

a) For each of the following reactions identify a visual change that you could measure the time taken to occur and hence use to determine the initial rate of the reaction;

i. $Mg + 2\,HCl \rightarrow MgCl_2 + H_2$

ii. $Na_2S_2O_3 + 2\,HCl \rightarrow 2\,NaCl + S + SO_2 + H_2O$

iii. $CH_3CH_2Cl + OH^- \rightarrow CH_3CH_2OH + Cl^-$

b) In each of these reactions, the reaction time for the observed change is measured. Define the term "*reaction rate*" and hence explain how the reaction time can be converted into a reaction rate in any one of the reactions above.

3. The reaction **Q** + **R** $\rightarrow$ **P** was studied using the method of initial rates. The initial rate of formation of P was measured in three different experiments. The data are provided below.

Experiment	**[Q] / mol dm^{-3}**	**[R] / mol dm^{-3}**	**Initial Rate / mol dm^{-3} s^{-1}**
1	0.300	0.300	5.24×10^{-3}
2	0.600	0.300	2.10×10^{-2}
3	0.300	1.000	1.75×10^{-2}

a) Use the data above to determine the rate equation for the reaction.

b) What is the value of the rate constant, *k* ?

Problem 7: Iodination inquiry

Introduction

John Mountford Academy

A performing arts college

Dear scientist,

Help me please! I am a new teacher in a sixth form college in Newcastle and I am being observed by senior management in a couple of weeks time. They want to assess my ability to run a sixth form practical.

I would like the students to complete a practical to determine the rate equation for the iodination of propanone and use this information to identify the rate-determining step. The equation for the reaction is;

$$CH_3COCH_3 + I_2 \xrightarrow[\text{conditions}]{\text{acidic}} ICH_2COCH_3 + H^+ + I^-$$

A diagram showing the four steps involved in the mechanism is attached to this letter.

I have carried out some research on the internet and understand that the order of the reaction with respect to propanone, acid and iodine can be determined using a simple initial rate method. For this reaction, if much higher concentrations of propanone and acid are used, the initial rate of the reaction can be determined by the time needed for the iodine to be used up. A suitable starting mixture would be 5 cm^3 of a 2.0 M solution of propanone, 5 cm^3 of 1.0 M HCl and 2 cm^3 of 0.005 M of I_2 solution made up to 25 cm^3 total volume by the addition of water.

Please can you help me out by trialling some different combinations of initial concentrations of reactants which will help the students determine which of the four steps is the rate-determining step. Based on your trials, please provide a detailed experimental Student Worksheet for the students to follow for the experiment and the associated analysis of results, together with a set of model results including identification of the rate determining step and a full rate equation for the reaction. Please provide these in a separate document headed “Teacher Answers”. I would like to extend the “A” grade students by asking them to calculate a value for the rate constant, *k*. Please add these calculations to your Teacher Answers. I do not have time to do the reaction myself so will be fully reliant on you!

Finally, I will need to provide a differentiated set of learning objectives for the lesson which will show the progress the students are making. Can you please include these on the top of your Student Worksheet.

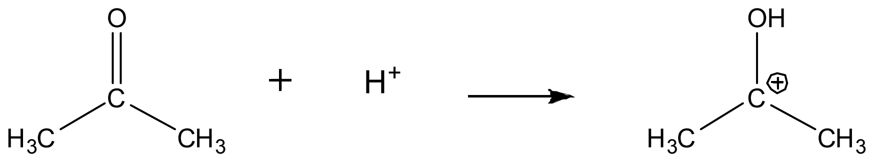
Many thanks for your help,

Sarah Tressed

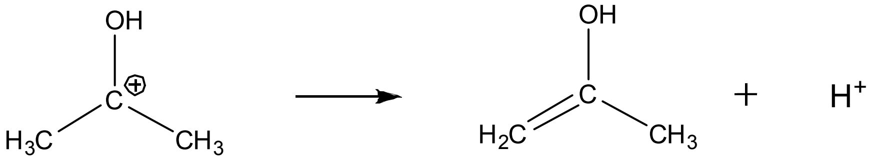
Sarah Tressed

Proposed mechanism for the iodination of propanone

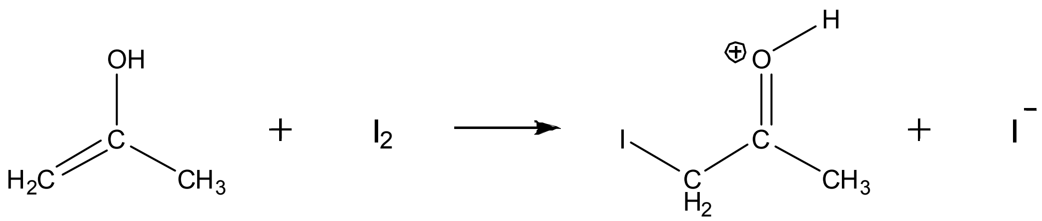
Step 1



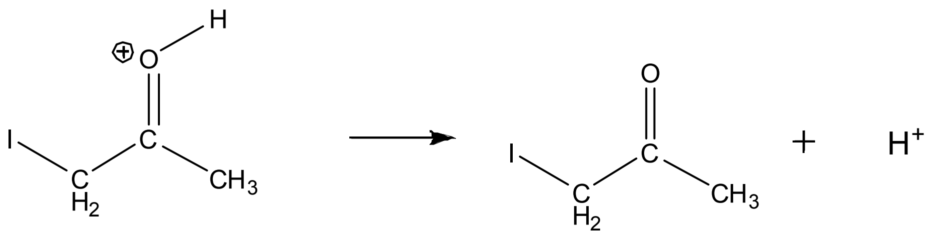
Step 2



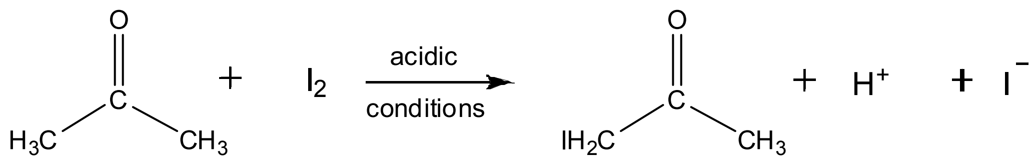
Step 3



Step 4



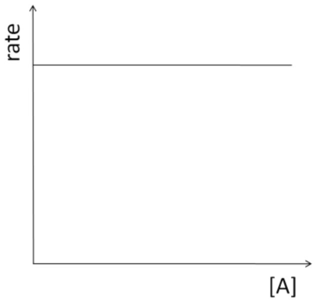
Overall reaction

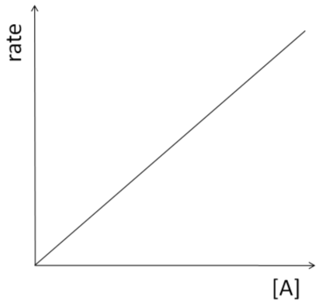


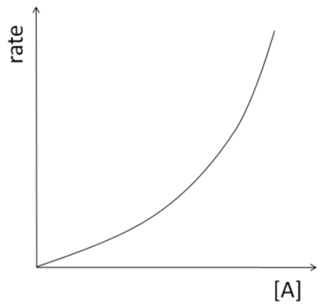
Teacher and Technician Pack

Pre-Lab answers

1. a) i. **zero order** wrt A; ii. **first order** wrt A; iii. **second order** wrt A







b) **Step one**, the slow step is the rate-determining step

2. a) i. $Mg + 2\,HCl \rightarrow MgCl_2 + H_2$
Measure the time taken to produce a certain amount of H_2 gas

ii. $Na_2S_2O_3 + 2\,HCl \rightarrow 2\,NaCl + S + SO_2 + H_2O$
Measure the time taken for the solution to turn sufficiently cloudy as a result of the colloidal suspension of sulphur that forms that you cannot see through the flask

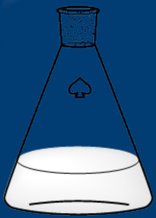
iii. $CH_3CH_2Cl + OH^- \rightarrow CH_3CH_2OH + Cl^-$
Add a certain amount of silver nitrate solution to the reaction and measure the time taken for a white precipitate (of AgCl) to form

Alternatively, the rate of each of the reactions above could be measured using a pH meter to determine the change in concentration of H^+ with unit time.

b) The **reaction rate** is defined as *the change in concentration of reactants or products per unit time*. Therefore to convert the reaction time into a reaction rate you would need to determine the change in concentration of the reactant / product at the point when you stopped the clock and divide this concentration (mol dm^{-3}) by the time (s) it took for this change to occur.

3. a) By comparing **exp 1** and **2**, the reaction is second order wrt [Q]
By comparing **exp 1** and **exp 3**, the reaction is first order wrt [R]
Therefore the rate equation for the reaction is **rate =** $\boldsymbol{k[Q]^2[R]}$

b) 5.24×10^{-3} mol dm^{-3} s^{-1} = $k \times 0.300^2$ mol^2 dm^{-6} $\times$ 0.300 mol dm^{-3}
Hence, k = 0.194 mol^{-2} dm^6 s^{-1}



Students trial the initial combination of reagents given

5 cm^3 2 M propanone **[Highly flammable, irritant]**
5 cm^3 1 M HCl **[Low hazard]**
2 cm^3 0.005 M I_2 **[Low hazard]**
13 cm^3 water

By trialling the reaction, the students identify that the easily recognisable event in this case is the disappearance of the last trace of colour from the reactant iodine.†

2.0 M propanone / cm^3	1.0 M HCl / cm^3	0.005 M I_2 / cm^3	H_2O / cm^3	Time / s
5	5	2	13	279

† The clock is started on addition of the iodine solution

WARNING! The product from the reaction, iodopropanone is a **lachrymator** (strongly irritant to the eyes). The reaction mixture should be poured down a fume cupboard sink with plenty of running water immediately once each measurement is complete.

Students decide on suitable combinations of reagents to determine the order of the reaction wrt propanone, I_2 and H^+

Three runs of each experiment are completed and an average time taken

2.0 M propanone / cm^3	1.0 M HCl / cm^3	0.005 M I_2 / cm^3	H_2O / cm^3	Time / s
5	5	2	13	279
10	5	2	8	145
5	10	2	8	141
5	5	1*	14	143

* If the students opt to change [I_2] they must also take into account that they are changing the amount of the reaction they are measuring the time of.

Analysis of the results reveal the rate equation to be;

rate = $k[CH_3COCH_3][H^+]$

∴ step 1 is the rds

$k = 1.8 \times 10^{-5}$ mol^{-1} dm^3 s^{-1}

Using the initial experimental run, calculating the initial concentrations:

$[I_2] = \dfrac{\text{no. of moles of } I_2}{0.025\ dm^3} = \dfrac{0.005\ mol\ dm^{-3} \times 0.002\ dm^3}{0.025\ dm^3} = 4 \times 10^{-4}\ mol\ dm^{-3}$

$[CH_3COCH_3] = \dfrac{\text{no. of moles of } CH_3COCH_3}{0.025\ dm^3} = \dfrac{2.0\ mol\ dm^{-3} \times 0.005\ dm^3}{0.025\ dm^3} = 0.4\ mol\ dm^{-3}$

$[H^+] = \dfrac{\text{no. of moles of } H^+}{0.025\ dm^3} = \dfrac{1.0\ mol\ dm^{-3} \times 0.005\ dm^3}{0.025\ dm^3} = 0.2\ mol\ dm^{-3}$

$\text{Rate} = \dfrac{\text{change in } [I_2]}{\text{time taken}} = \dfrac{4 \times 10^{-4}\ mol\ dm^{-3} - 0}{279\ s} = 1.43 \times 10^{-6}\ mol\ dm^{-3}\ s^{-1}$ (assuming $[I_2]$ went to zero)

$\therefore k = \dfrac{\text{rate}}{[\text{propanone}][H^+]} = \dfrac{1.43 \times 10^{-6}\ mol\ dm^{-3}\ s^{-1}}{0.4\ mol\ dm^{-3} \times 0.2\ mol\ dm^{-3}} = 1.8 \times 10^{-5}\ mol^{-1}\ dm^3\ s^{-1}$

NOTE The choice of the observed change in [I_2] as a method for measuring the initial rate of this reaction only works because the reaction is zero order with respect to iodine. Therefore the concentration of iodine does not affect the reaction rate and hence we can study the rate by making iodine the limiting reagent present in a large excess of propanone and acid. If iodine was involved in the rate determining step, as its concentration decreased the reaction would become slower and slower and the results would be skewed. You may wish to discuss this point with your more able students.

Teacher and Technician Pack

Equipment list

See the **Health and safety guidance** section in the **Introduction** for more general information on risk assessments and a key to the health and safety symbols used.

Each group will need;

100 cm^3 of 2.0 M propanone solution **[Highly flammable; Irritant]**

100 cm^3 of 1.0 M HCl solution **[Low hazard]**

30 cm^3 of 0.005 M Iodine solution in aqueous potassium iodide **[Low hazard]**

Distilled water

4 × burettes, burette stands and clamps and funnels (1 for each solution and water) (these can be shared between groups if needed)

2 × 100 cm^3 conical flask

Test tubes (for storage of acid and iodine solutions before addition)

Stopwatch

2 × white tile or white paper

Health and safety note

The product of the reaction, iodopropanone, is a lachrymator (strongly irritant to eyes). The reaction mixture must therefore be disposed of as soon as measurements have been taken by flushing down a fume cupboard sink with lots of running water.