Core practical 14: Determine the activation energy for the reaction between bromide ions and bromate(V) ions

Objective

- To use the Arrhenius equation to determine the activation energy of a reaction

Safety

- Wear a lab coat and gloves, and use eye protection.
- Phenol is corrosive and toxic.
- Sulfuric acid solution is an irritant.
- Potassium bromate(V) is oxidising.

Specification links

- Practical techniques 1, 2, 4, 11
- CPAC 1a, 2a, 2b, 3a, 4a, 4b

Procedure

1. Pipette 10 cm^3 of phenol solution and 10 cm^3 of bromide/bromate solution into one boiling tube.
2. Add four drops of methyl red indicator to the mixture.
3. Pipette 5 cm^3 of sulfuric acid solution into another boiling tube.
4. Use a kettle and a beaker to prepare a water bath with a temperature of 75 °C (±1 °C). Stand the two boiling tubes in the water bath.
5. When the contents of the boiling tubes have reached the water temperature, mix the contents of the two tubes by pouring rapidly from one tube into the other and then pouring the mixture back into the empty test tube. Start the stop clock at the same time.
6. Leave the boiling tube containing the reaction mixture in the water and time until the methyl red indicator disappears.
7. Copy the results table below and use the first two columns to record all your results.
8. Repeat the whole experiment at 65 °C, 55 °C, 45 °C, 35 °C, 25 °C and 15 °C. Use ice to achieve the lowest temperature.

Temp/°C	Time/s	T/K	$\frac{1}{T}$ K^{-1}	ln t

Notes on procedure

- Ensure that students are able to use the ln function on their calculators.
- Students may find it useful to discuss how to process their results.

Answers to questions

1. $C_6H_5OH + 3Br_2 \rightarrow C_6H_2Br_3OH + 3HBr$
2. When all the phenol has reacted, the bromine continuously produced in the first reaction will then react with the methyl red indicator, bleaching its colour.
3. Depends on students' data but using the sample data the answer should be approximately 6816.
4. E_a = 56 668 to 56 676 J mol^{-1} approximately

Sample data

Temp/°C	Time/s	T/K	$\frac{1}{T}$ K^{-1}	ln t
15	440	288	0.00347	6.1
25	221	298	0.00336	5.4
35	90	308	0.00325	4.5
45	45	318	0.00314	3.8
55	20	328	0.00305	3.0
65	8	338	0.00296	2.1
75	4	348	0.00278	1.4

Gradient of the graph = 6816

E_a = gradient $\times$ R = 56 676 J mol^{-1}

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All the maths you need

- Use a calculator to work out and use exponential and logarithmic functions.
- Substitute numerical values into algebraic equations using appropriate units for physical quantities.
- Plot two variables from experimental or other data.

Equipment

- 70 cm^3 of 0.01 mol dm^{-3} aqueous phenol solution
- 70 cm^3 bromide/bromate solution
- 50 cm^3 of 0.5 mol dm^{-3} sulfuric acid
- methyl red indicator
- three 100 cm^3 beakers
- 2 boiling tubes
- 10 cm^3 pipette
- thermometer (0–110 °C)
- stop clock
- 500 cm^3 beaker
- access to a kettle

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Temp/°C	Time/s	T/K	$\frac{1}{T}$ K^{-1}	ln t

Analysis of results

1. Calculate temperatures in Kelvin, K, and fill in the third column of the table (0°C = 273 K).
2. Fill in the fourth column of the table by dividing each of the temperatures into 1.
3. Fill in the fifth column by taking natural logs of the times.
4. Plot a graph of ln t (y-axis) against $\frac{1}{T}$ (x-axis).

Learning tips

- The Arrhenius equation is an exponential relationship between the rate constant, k, and temperature, T.

  $k = A e^{-\frac{Ea}{RT}}$

  where R = gas constant = 8.314 J mol^{-1} K^{-1} (T = temperature in Kelvin) and

  E_a = activation energy of the reaction.

  $k \propto$ reaction rate $\propto \frac{1}{t}$ so we can say that:

  $k = \frac{\text{a constant } c}{\text{time taken for methyl red to bleach}} = \frac{c}{t}$

- The Arrhenius equation can also be expressed as a logarithmic relationship:

  $\ln k = -\frac{E_a}{RT} + \ln A$ or $\ln(\frac{c}{t}) = -\frac{E_a}{RT} + \ln A$

  Rearranging: $\ln t = \ln c - \ln A + \frac{E_a}{RT}$

  Because ln c and ln A are constants, a graph of ln t against $\frac{1}{T}$ has a gradient of $\frac{E_a}{R}$.

Questions

1. Write an equation for the reaction between bromine and phenol.
2. What function does the methyl red have in this experiment?
3. Measure the gradient of your graph.
4. Calculate the activation energy of the reaction, E_a.

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Safety

- Wear a lab coat and gloves, and use eye protection.
- Solid phenol is toxic and corrosive. Avoid skin contact and wear protective gloves when preparing the solution.
- Consult CLEAPSS Hazcards® 70, 95A, 98A. Perform a risk assessment using up-to-date information before this practical is carried out.

Equipment per student/group	Notes on equipment
70 cm^3 of 0.01 mol dm^{-3} aqueous phenol solution	Solid phenol is toxic and corrosive. Avoid skin contact and wear protective gloves when preparing the solution.
70 cm^3 bromide/bromate solution	0.1 mol dm^{-3} w.r.t. potassium bromide solution 0.02 mol dm^{-3} w.r.t. potassium bromate(V) solution (equivalent to 11.90 g KBr and 3.34 g $KBrO_3$ in 1 dm^{-3} of solution) $KBrO_3$ is an oxidising solid.
50 cm^3 of 0.5 mol dm^{-3} sulfuric acid	Irritant
methyl red indicator	
three 100 cm^3 beakers	
2 boiling tubes	
10 cm^3 pipette	
thermometer (0–110 °C) × 1 °C	
stop clock	
500 cm^3 beaker	
access to a kettle	

Notes