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.

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.

<table>
<thead>
<tr>
<th>Temp/°C</th>
<th>Time/s</th>
<th>T/K</th>
<th>1/T K$^{-1}$</th>
<th>ln t</th>
</tr>
</thead>
<tbody>
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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.

Specification links

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

1.  \( 
\text{C}_6\text{H}_5\text{OH} + 3\text{Br}_2 \rightarrow \text{C}_6\text{H}_2\text{Br}_3\text{OH} + 3\text{HBr} 
\)

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.  \( \text{E}_a = 56668 \text{ to } 56676 \text{ J mol}^{-1} \) approximately

Sample data

<table>
<thead>
<tr>
<th>Temp/°C</th>
<th>Time/s</th>
<th>( T )/K</th>
<th>( \frac{1}{T} ) K(^{-1} )</th>
<th>( \ln t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>440</td>
<td>288</td>
<td>0.00347</td>
<td>6.1</td>
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<tr>
<td>25</td>
<td>221</td>
<td>298</td>
<td>0.00336</td>
<td>5.4</td>
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<tr>
<td>35</td>
<td>90</td>
<td>308</td>
<td>0.00325</td>
<td>4.5</td>
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<tr>
<td>45</td>
<td>45</td>
<td>318</td>
<td>0.00314</td>
<td>3.8</td>
</tr>
<tr>
<td>55</td>
<td>20</td>
<td>328</td>
<td>0.00305</td>
<td>3.0</td>
</tr>
<tr>
<td>65</td>
<td>8</td>
<td>338</td>
<td>0.00296</td>
<td>2.1</td>
</tr>
<tr>
<td>75</td>
<td>4</td>
<td>348</td>
<td>0.00278</td>
<td>1.4</td>
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Gradient of the graph = 6816

\( \text{E}_a = \text{gradient} \times R = 56676 \text{ J mol}^{-1} \)
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- Phenol is corrosive and toxic.
- Sulfuric acid solution is an irritant.
- Potassium bromate(V) is oxidising.

**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 cm³ of 0.01 mol dm⁻³ aqueous phenol solution
- 70 cm³ bromide/bromate solution
- 50 cm³ of 0.5 mol dm⁻³ sulfuric acid
- methyl red indicator
- three 100 cm³ beakers
- 2 boiling tubes
- 10 cm³ pipette
- thermometer (0–110 °C)
- stop clock
- 500 cm³ beaker
- access to a kettle

**Procedure**
1. Pipette 10 cm³ of phenol solution and 10 cm³ of bromide/bromate solution into one boiling tube.
2. Add four drops of methyl red indicator to the mixture.
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<table>
<thead>
<tr>
<th>Temp/°C</th>
<th>Time/s</th>
<th>T/K</th>
<th>(\frac{1}{T} \text{K}^{-1})</th>
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Practical activities have been safety checked but not trialled by CLEAPSS.
Users may need to adapt the risk assessment information to local circumstances. This document may have been altered from the original.
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, \( T \).
  
\[
k = A e^{\frac{-E_a}{RT}}
\]

where \( R \) = gas constant = 8.314 J mol\(^{-1}\) K\(^{-1}\) (\( T \) = temperature in Kelvin) and \( E_a \) = activation energy of the reaction.

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

\[
k = \text{a constant} \times \frac{c}{t}
\]

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

\[
\ln k = -\frac{E_a}{RT} + \ln A \text{ or } \ln \left( \frac{C}{t} \right) = -\frac{E_a}{RT} + \ln A
\]

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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**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.
- 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**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Notes on equipment</th>
</tr>
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<tbody>
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<td>Solid phenol is toxic and corrosive. Avoid skin contact and wear protective gloves when preparing the solution.</td>
</tr>
<tr>
<td>70 cm³ bromide/bromate solution</td>
<td>0.1 mol dm⁻³ w.r.t. potassium bromide solution</td>
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<tr>
<td></td>
<td>0.02 mol dm⁻³ w.r.t. potassium bromate(V) solution</td>
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<td>(equivalent to 11.90 g KBr and 3.34 g KBrO₃ in 1 dm⁻³ of solution)</td>
</tr>
<tr>
<td>50 cm³ of 0.5 mol dm⁻³ sulfuric acid</td>
<td>Irritant</td>
</tr>
<tr>
<td>methyl red indicator</td>
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</tr>
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<td>three 100 cm³ beakers</td>
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<tr>
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**Notes**