## I. Aim:

To determine the activation energy of the reaction between bromide ion and bromate(V) ion in acid solution.

$$5Br^-(aq) + BrO_3^-(aq) + 6H^+(aq) \longrightarrow 3Br_2(aq) + 3H_2O(l)$$

## II. Theory:

The progress of the reaction may be followed by adding a fixed amount of phenol together with some methyl red indicator. The bromine produced during the reaction reacts very rapidly with phenol. Once all the phenol is consumed, any further bromine bleaches the indicator immediately. So , the time for the reaction to proceed to a given point may be determined. Measuring the time, *t*, for the reaction to proceed to the same (small) extent at different temperatures. Then, a graph of ln $\frac{1}{t}$ against $\frac{1}{T}$ should be a straight line of gradient $-\frac{Ea}{R}$ (using the Arrhenius equation). Therefore, we can determine he activation energy of the reaction between bromide ion and bromate(V) ion in acid solution.

Equation for the reaction between phenol and bromine:

$$\mathbf{C_6H_5OH\ (aq) + 3Br_2\ (aq) \longrightarrow C_6H_2(OH)Br_3\ (aq) + 3\ HBr\ (aq)}$$

(phenol) (2,4,6-tribromophenol)

## III. Chemicals:

| | **Quantity** |
|---|---|
| Solution A (0.083M with respect to KBr and 0.017M with respect to KBrO3) | 60 $cm^3$ |
| 0.5 M $H_2SO_4$ | 30 $cm^3$ |
| 0.01 M phenol solution | 60 $cm^3$ |
| Methyl red indicator | Several drops |

## IV. Apparatus:

| | Quantity |
|---|---|
| Beaker | 1 |
| Boiling tube | 2 |
| Stop watch | 1 |
| -10°-110°C thermometer | 1 |
| Burette | 3 |

## V. Procedure:

1. Place 10.00 $cm^3$ of 0.01 M phenol solution, 10.00 $cm^3$ solution A and 10 drops of methyl red indicator into a boiling tube.
2. Place 5.00 $cm^3$ of 0.5 M $H_2SO_4$ in the second boiling tube.
3. Place both boiling tubes into a large beaker of water which is maintained between 49°C - 51°C by careful warming. Allow the contents of the tubes to reach the temperature of the water bath (± 1°C) and wait until the temperature remains to be constant.
4. Pour the entire 5.00 $cm^3$ $H_2SO_4$ into the clamped boiling tube, and swirl gently. .
5. Keep the first boiling in the water bath throughout the experiment. Record the time (t) taken, to the nearest second, for the complete disappearance of red colour.
6. Record also the temperature (T), to the nearest degree, of the reaction mixture at the end of the experiment.
7. Repeat step (1) to (6), maintain the reaction temperature at about 35°C, 40°C, 45°C, and 50°C. Record your result in the table below.
8. Record your result in the table.

## VI. Results and Calculation:

| Experiment | Time t / s | $\ln \frac{1}{t}$ | Temperature | | $\frac{1}{T}$ / $10^{-3}K^{-1}$ |
|---|---|---|---|---|---|
| | | | T/ °C | T/K | |
| 1 | 309.266 | -5.734 | 26.0 | 299.0 | 3.344 |
| 2 | 155.187 | -5.045 | 34.8 | 307.8 | 3.249 |
| 3 | 110.212 | -4.702 | 39.8 | 312.8 | 3.197 |
| 4 | 75.806 | -4.328 | 44.8 | 317.8 | 3.147 |
| 5 | 52.966 | -3.970 | 54.5 | 327.5 | 3.053 |
| 6 | 29.646 | -3.389 | 57.6 | 330.6 | 30.25 |

Let the rate equation be: Rate = $k[Br^-]^a[BrO_3^-]^b$

From Arrhenius equation, we have $k = Ae^{-E_a/RT}$, where A is Arrhenius constant.

By taking natural logarithm of above equation, we have $\ln k = \ln A - E_a \div (RT)$ [1]

∵ All concentration terms have been kept constant
∴ Rate only varies as k (rate constant)
∵ Rate is directly proportional to 1/t & varies as k in the rate equation
∴ We can substitute k by 1/t in **[1]**:

$\ln (1/t) = \ln A - E_a \div (RT)$, which is the equation of the previous graph

From the graph, the slope is -6.7659
∴ $-E_a = (-6.7659)(R)$
$E_a = (-6.7659)(8.3)$
$= 56.16\ Jmol^{-1}$

## VII. <u>Discussion:</u>

1. <u>Why does the reaction not start until the contents of the boiling tubes are mixed ?</u>
   There are three reactants in the reaction, i.e. $Br^-(aq)$, $BrO_3^-(aq)$ and $H^+(aq)$ ions. The three reactants are put separately in the two boiling tubes. If the contents of the boiling tube s are not mixed, the three reactants are not mixed and the reaction will not start.
2. <u>What is the function of phenol in this experiment</u>?
   The reason for adding a small amount of phenol at the start is that it will react with the bromine formed early in the reaction. Once all the phenol has reacted the bromine now formed will bleach the methyl red so there is a rapid colour change from red to colourless and the time taken to reach this point can be recorded. If no phenol was added the reaction would be too fast with time, the phenol allows a ‘breathing space’ which is the same for every run of the experiment.
3. <u>What is the use of methyl red in the experiment?</u>
   The methyl red here is a substance rapidly bleached by bromine, not a normal acid-base indicator.

4. Based on the results, is it advisable to perform the experiment at high temperature such as 80 °C?

The reaction is very fast at a high temperature, and the reaction time is too short (say, about 1 second or even less) to be measured. This will cause a great error in time reading

5. Why is it not necessary to know how far the reaction has proceeded at the point where the methyl red is decolorised?

Because the volume of bromine produed in every experiments are the same,so it cannot find out how far the reaction has proceeded by the number of mole.

6. The Arrhenius equation is can be represented as: $k = Ae^{-\frac{Ea}{RT}}$.

Derive an equation to relate ln k and 1/T.

ln k = ln A

$$k = Ae^{-\frac{Ea}{RT}}$$

$$-\frac{Ea}{RT}$$

ln k = $-\frac{Ea}{R}\frac{1}{T}$ + ln A

7. Explain why the reaction rate can be affected by temperature.

By the Arrhenius equation, $k = Ae^{-\frac{\Delta E}{RT}}$

where k is the rate constant of the reaction,

A is the constant which is independent of temperature,

e is the base of natural logarithm,

$E_a$ is the activation energy of the reaction in J mol$^{-1}$,

R is the ideal gas constant (i.e. 8.3J K$^{-1}$ mol$^{-1}$),

T is the temperature in Kelvin

obviously, raising T makes $\frac{Ea}{RT}$ smaller, then k will increase and the reaction will proceed faster. Conversely, lowering T makes $\frac{Ea}{RT}$ larger, then k will decrease and the reaction proceed slower. Similarly, if $E_a$ is low, $\frac{Ea}{RT}$ will be small. Then, k will be large and the reaction w ill be fast. If $E_a$ is high, $\frac{Ea}{RT}$ will be large. Then, k will be smal l and the reaction will be slow.

8. <u>Explain the fact that the reaction with low activation energy proceeds faster.</u>

If the activation energy is low, more collisions between reactant particles would have collision energies higher than activation energy (the minimum energy for the reaction occurs). In other words, there are more collisions between reactant particles are effective.

9. <u>Errors</u>

-Temperature is recorded when the solution bleaches. However, the reaction temperature would vary throughout the reaction period, especially if the reaction starts before the temperatures of the solutions become steady. Therefore, if the temperature is lower, we should put the boiling tube in the water bath; if the temperature is higher, we should get out the boiling tube from the water bath.

-If the reaction may not be stirred well, the reaction mixture may not be homogenous, and this will lead to a greater time reading.

## VIII. Conclusion:

The activation energy of the reaction between bromide ion and bromate(V) ion in acid solution is 56.16 $Jmol^{-1}$