

# **Chemistry Lab Report**

## **Experiment Title**

To determine the affect of Temperature on the Rate constant for the reaction between Potassium Hydroxide and Ethyl Ethanoate

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**Session:** May 2014

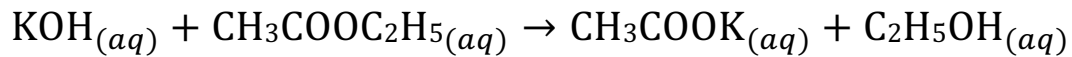
**School:** Gandhi Memorial International School

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# INTRODUCTION

The reaction that will be used in this experiment, to determine the effect of temperature on the heat constant is the reaction. This is shown through the equation –



The hydroxide ion is a highly nucleophilic anion that attacks polar bonds in both, organic and inorganic products. This reaction is commonly known as Saponification reactions.

In this experiment, it is important to know the path the reaction takes as the reaction progresses. In other words, it is important to know the reaction rate as the reaction progresses, and not just the initial reaction rate.

The path that the reaction takes can be measured by the conductivity of the reaction mixture. Since potassium hydroxide is a very strong base, it will dissociate into ions in the reaction mixture. This will lead to an increase in ions, and hence an increase in conductivity. However, once the reaction begins, the potassium hydroxide ions are used up to form other products. Though the product  $\text{CH}_3\text{COOK}_{(aq)}$  still dissociates slightly to form ethanoate and potassium ion, this is very slight and does not affect the result because of the great difference between its dissociation and that of potassium hydroxide.

Hence, the rate of the reaction can be traced by continuously measuring the conductivity of the reaction mixture.

The rate constant, however, needs to be found in order to convert rate of reaction to a rate constant, which is what is ultimately compared. However, the exact rate expression does not have to be found. Instead, concentrations will be kept to a constant of  $1 \text{ mol/dm}^3$ . Hence, the exact coefficients and order of reaction for reactant will not have to be found (process explained in detail when processing data).

# **DESIGN**

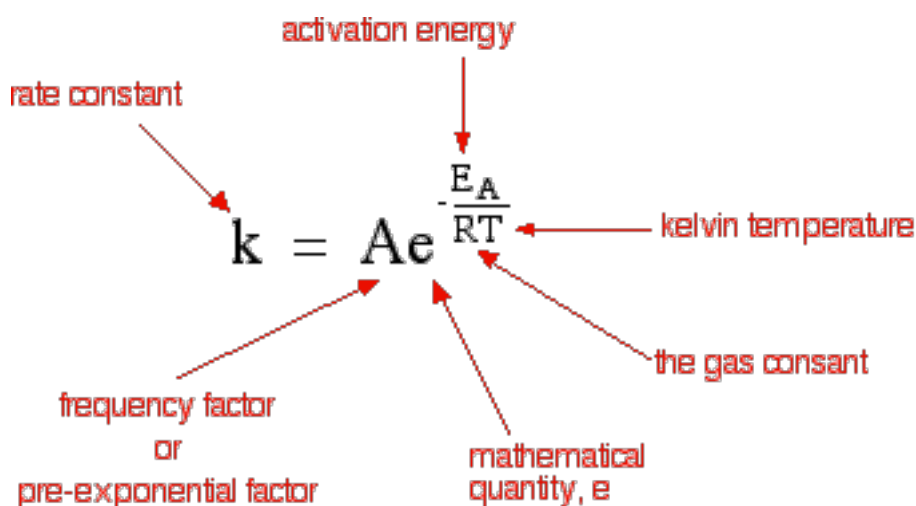
# ASPECT 1: *DEFINING THE PROBLEM*

## RESEARCH QUESTION

How does the change in temperature affect the rate constant of the reaction between Potassium Hydroxide and Ethyl Acetate, while concentration is kept constant?

## HYPOTHESIS

This theoretical mathematical hypothesis is based on the Arrhenius equation. This equation states that the rate constant and temperature are related by the following –

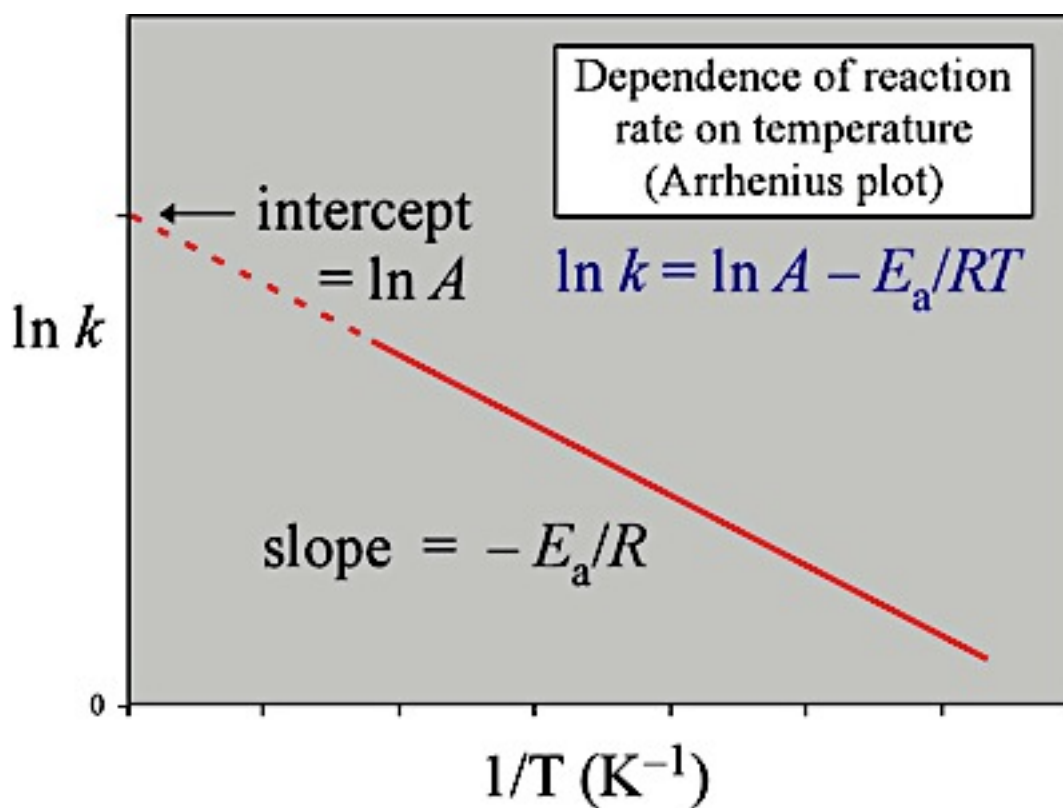


On taking natural log on both sides and conducting a series of math simplifications the calculation follows –

$$\begin{aligned}\ln k &= \ln Ae^{-\frac{E_A}{RT}} \\ \ln k &= \ln A + \ln e^{-\frac{E_A}{RT}} \\ \ln k &= \ln A + \frac{-E_A}{RT} \ln e \\ \ln k &= \frac{-E_A}{R} \cdot \frac{1}{T} + \ln A\end{aligned}$$

This equation is similar to  $y = m \cdot x + C$  where  $y = \ln k$ ,  $m = \frac{-E_A}{R}$ ,  $x = \frac{1}{T}$ ,  $C = \ln A$ . Hence, this formula shows that if the

natural log of the rate constant is plotted against the inverse of temperature, it will result in a straight-line graph.



This graph represents the mathematical theoretical hypothesis that is expected from this investigation.

We also infer from this graph that as temperature increases, the rate constant also increases, by an exponential and not linear factor.

This relationship will be investigated and evaluated in this experiment and any limitations including factors not taken into account will also be evaluated. Since this hypothesis is strictly mathematical, real-time factors could and would lead to a significant difference, especially at high temperatures.

I also hypothesize that readings will be less accurate and less precise at high temperatures as high temperatures are difficult to maintain for long durations of time.

# ASPECT 2: *CONTROLLING VARIABLES*

## STATEMENT and CONTROL OF VARIABLES

### Independent Variable -

**1. Temperature at which reaction is occurring** - The independent variable is the variable that I will change in the experiment. Since the purpose of my experiment is to determine the affects of temperature on the rate constant/rate of reaction, I will be changing the temperature at which the reaction occurs. Temperature will be measured using a normal thermometer (1 decimal point precision).

I will increase the temperature from room temperature and take readings every 5°C until the reaction occurs too rapidly to be measured by the technique used above. The temperature is also very hard to control as the reaction is likely to take some time to reach completion and the temperature has to be kept constant through out this reaction. Hence insulation will be used generously, and the Bunsen burner will be kept on constantly, a distance away from the container such that it maintains constant temperature.

The temperature will be changed by use of a water bath on both reactants and finally mixing the reactants in a third reaction container (Polystyrene Cup) with the conductivity probe attached.

### Dependent Variable -

**1. Conductivity of mixture respect to time (rate of reaction)** - The dependent variable is the variable I expect to change due to changing the independent variable. This is also the variable I will be measuring. For the experiments, I will mainly be measuring the rate at which the conductivity decreases with respect to time.

The conductivity change as the reaction progress under each temperature will be measured using a conductivity probe. However, this reading will simply provide us with rate of change of conductivity. Under processing, this conductivity will first be converted to rate of reaction (rate of change of concentration with time). Then finally, this rate reaction will be inserted into the rate expression to compute rate constant values, which will be he final goal of the experiment. The conductivity is measured in terms of  $\mu S/cm$  in two decimal places precision.

## Controlled Variables -

**1. Size of Solid Particles** - The size of the particles will directly affect the rate of the reaction. These sizes of particles include any catalyst or competitor that might be used in the reaction. If the size of the particle is smaller for some trials, the particles provide a greater surface area for the reaction to occur. This would mean that greater number of reactant molecules could react or decompose to form the product. The solid particles will be crushed to the extent that it can pass through a constant sieve, which ensures credibility.

If some reactions are slower and others faster, they will directly affect the rate of reaction calculated. This will further affect the rate constant value when calculations are conducted. Hence, since the affect of size of particles is not being measured, this would be a hindrance for the experiment.

**2. Concentration of Liquid Reagents** - I will also be keeping the concentration of liquid reagents constant. This is most important since the increase in concentration will directly affect the rate of the reaction. Since, analogous to the size of particles, the concentration of liquid reagents is not the factor being investigated, it will unfairly affect the rate constant. This will also be a hindrance to the investigation because the affect of temperature and the affect of concentration would not be isolated. Hence, liquid reagents will be made in the start of the investigation in a large quantity, and the same will be used for all trials and experiments at different temperatures.

**3. Pressure of Surroundings** - The pressure of the surroundings will be kept constant because it can cause a change in the rate of the reaction. A change in surrounding pressure will change the rate of the reaction, since the products are in part gasses. Hence if the gasses are not allowed to escape the container, instead of the reaction going to completion, equilibrium will be created which will largely alter both the rate of the reaction and the rate constant.

**4. Presence and Concentration of Catalyst** - The presence and concentration of competitors and catalysts will also greatly affect the rate calculated. Catalysts directly affect the rate constant, so this will affect the investigation. For the experiment, the catalyst for the decomposition of hydrogen peroxide was used limitedly and the concentration was kept constant across all trials

**5. Presence and Concentration of Competitors** - The presence of competitors will skew the rate of reaction, since the hydrogen peroxide will not only decompose directly, but side reactions between the hydrogen peroxide and the competitor will lead to a greater proportion of the hydrogen peroxide



reacting. Hence, the test tubes and other apparatus will be cleaned with acid before, to remove any competitors.

**6. Equipment Used for Each Trial** - Finally, I will conduct all the experiments in the same surrounding on the same day. I will use all the same apparatus (cleaned between trials and experiments) in order to keep uncertainty and other factors constant. Using the same equipment is important so that uncertainty in values don't change between trials.

**7. Insulation** - Insulation is very important in this experiment, because the reaction container has to maintain the same temperature until the reaction reaches completion. Hence, insulation will be kept constant and also used generously, to reduce uncertainty in temperature fluctuations.

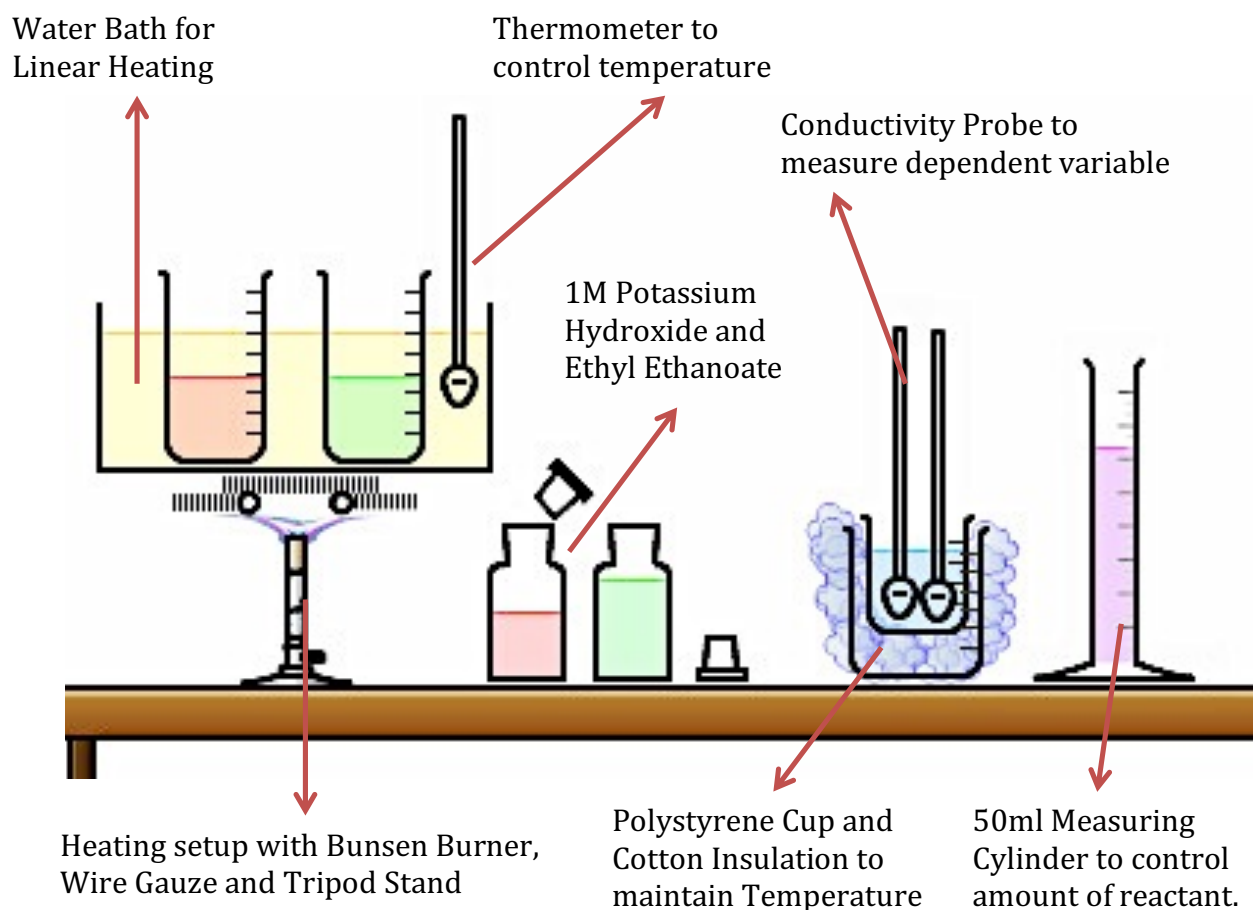
**8. Physical State of Reactants** - The physical state of the reactants and products makes a huge and monumental difference to the rate of the reaction. This is not as hard to control for this reaction as reactants and products mostly only occur naturally in the one state and hence cannot be variable.

# ASPECT 3: *DEVELOPING A METHOD FOR COLLECTION OF DATA*

## APPARATUS

1. Conductivity Probe  $\pm 0.01 \mu S/cm$
2. LabQuest Vernier Device and Software
3. Polystyrene Cup (as the experiment container) so heat loss is minimum.
4. 2, 1000ml Beaker where the 100ml Beaker Cup will be kept
5. 2, 100ml Beaker
6. Cotton as Insulation
7. 10ml and 50ml Measuring Cylinders  $\pm 0.5 ml$
8. Distilled Water
9. 1M Potassium Hydroxide
10. 1M Ethyl Ethanoate
11. Mercury Thermometer  $\pm 0.5 ^\circ C$

## DIAGRAM OF SETUP



## PROCEDURE

1. First, the solutions have to be prepared. Both solutions required, potassium hydroxide and ethyl ethanoate have to be at 1M concentration so that there is no need of a rate expression. In this case, 1M solutions were readily available. Else, 11.2g of Potassium Hydroxide solid dissolved and made up to 200ml with distilled water will lead to a 1M solution. Additionally, Ethyl Ethanoate can be diluted using distilled water similarly.
2. Since both solutions were available at require concentration, it did not have to be prepared. Hence, the uncertainties involved with changing the concentration of a liquid reagent, were avoided (uncertainties of volume measurements)
3. Once I made the solutions I set up the apparatus. For all experiments, I used 20ml of each solution, just enough so that the probe is submerged into the solution. Hence, this constant volume was noted. However, as precise as other measurements were, the least precise measurement was that of volume, since a measuring cylinder was used.
4. Then I poured 20ml of the two solutions into two separate Beakers and fitted them into two separate water baths. I put on my safety goggles while heating.
5. Then the Bunsen burner is brought up, and the temperature of the water bath is recorded. Once the temperature of the water bath reaches the required temperature, the two beakers are removed and the contents poured into a polystyrene cup. This is then promptly kept inside another 1000ml Beaker that is lined with cotton insulation.
6. The maximum temperature that could be safely reached with the water bath was about 55 degrees Celcius. Hence, for sufficient data, instead of trying to reach higher values to no avail, increments of 5 degrees, rather than 10 were taken.
7. Then, the two solutions are finally mixed in the one polystyrene cup with the conductivity probe fitted accurately inside. This was the most important step and temperature probe was also inserted to make sure that there were no changes in temperature, while one trial was taking place.
8. For 200 seconds, with 5 seconds increments, the conductivity probe measured the conductivity of the solution to determine the rate of progression of the reaction.
9. This was then repeated for 5 trials and temperatures ranging from 25°C to 55°C, from step 3 to step 6. The relevant data collected was the rate of

change of conductivity with progression in time. Conducting 5 trials allowed for the collection of varied and sufficient data to analyze and hence, form conclusions.

## EQUATIONS USED AND DATA PRESENTED

The rate constant is the final result that should be outputted for each temperature at the end of this experiment. Hence, the relationship between rate constant and temperature can be concluded. So first, the rate constant has to be calculated using the equation -

$$Rate = k [A] \cdot [B]$$

Where A and B are the reactants of this experiment. This rate expression will only work if the concentrations of all reactants are 1M (explained later, since the power on each A and B are omitted)

However, this experiment does not automatically output the rate of the reaction in rate of change of concentration. Instead, the rate of change of conductivity has to be changed to concentration. This is done by the equation -

$$k = \frac{\text{Initial Conductivity}}{\text{Gradient (Rate of Change of Cond.)}}$$

Hence, finally by the use of these equations, we will be left with the temperatures and the corresponding rate constants of this reaction at those temperatures. Finally, by plotting these directly on a graph, and in a way that the hypothesis suggests, relationships of the rate constant with temperature can be formed. This is the final representation of data.

# **DATA COLLECTION PROCESSING**

# ASPECT 1: RECORDING RAW DATA

Concentration of Potassium Hydroxide =  $1\text{M} \pm 0.01$  ( $1\text{mol} \cdot \text{dm}^{-3}$ )

Concentration of Ethyl Acetate =  $1\text{M} \pm 0.01$  ( $1\text{mol} \cdot \text{dm}^{-3}$ )

The conductivity was measured for 200 seconds, every 5 seconds, for the reaction occurring. Hence, the values are represented below are the conductivity values at different temperatures, as the reaction progresses.

## Qualitative Data

<b>Before the Experiment</b>	Both liquids are colourless with Ethyl Ethanoate having a characteristic sweet smell of Esters. Surprisingly, the combination of the polystyrene cup and cotton insulation prevented temperature from varying greatly. However, the water bath consumed a lot of extra time.
<b>During the Experiment</b>	It was important that both the liquids are miscible and hence, are completely mixed. There is no problem resulting from the partial mixture of reactants. Additionally, conductive probe seems to provide accurate data.
<b>After the Experiment</b>	Slight precipitate formed which is as the reaction suggests the salt which did not dissolve in the water (and hence lead to a change in conductivity in the first place)

## Temperature: 25°C (Rate of Change of Conductivity)

Time (Seconds) $\pm 1\text{s}$	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$	Time (Seconds) $\pm 1\text{s}$	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$	Time (Seconds) $\pm 1\text{s}$	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$
0	3961.20	75	3749.14	150	3685.24
5	3959.40	80	3742.83	155	3691.06
10	3958.04	85	3731.58	160	3691.51
15	3959.11	90	3723.54	165	3693.90
20	3955.36	95	3720.14	170	3691.50
25	3946.95	100	3715.69	175	3688.23
30	3941.74	105	3710.84	180	3690.56
35	3933.23	110	3706.84	185	3689.43
40	3911.79	115	3700.01	190	3687.34
45	3895.99	120	3695.04	195	3686.23
50	3873.80	125	3692.45	200	3688.23
55	3846.50	130	3698.43		
60	3829.02	135	3690.26		
65	3805.57	140	3696.12		
70	3772.32	145	3690.55		

## Temperature: 30°C

Time (Seconds) $\pm 1s$	Conductivity ( $\mu S/cm$ ) $\pm 0.01\mu S/cm$	Time (Seconds) $\pm 1s$	Conductivity ( $\mu S/cm$ ) $\pm 0.01\mu S/cm$	Time (Seconds) $\pm 1s$	Conductivity ( $\mu S/cm$ ) $\pm 0.01\mu S/cm$
0	3734.91	75	3373.71	150	3416.29
5	3733.12	80	3392.63	155	3407.67
10	3691.80	85	3392.09	160	3406.23
15	3617.73	90	3400.63	165	3426.27
20	3618.08	95	3380.15	170	3438.57
25	3544.66	100	3377.85	175	3445.75
30	3504.61	105	3386.57	180	3440.71
35	3491.42	110	3391.57	185	3428.12
40	3488.54	115	3417.06	190	3432.00
45	3485.10	120	3406.92	195	3432.79
50	3450.95	125	3421.88	200	3431.43
55	3435.77	130	3422.18		
60	3422.96	135	3411.97		
65	3412.66	140	3425.40		
70	3394.27	145	3406.38		

## Temperature: 35°C

Time (Seconds) $\pm 1s$	Conductivity ( $\mu S/cm$ ) $\pm 0.01\mu S/cm$	Time (Seconds) $\pm 1s$	Conductivity ( $\mu S/cm$ ) $\pm 0.01\mu S/cm$	Time (Seconds) $\pm 1s$	Conductivity ( $\mu S/cm$ ) $\pm 0.01\mu S/cm$
0	3408.18	75	3073.10	150	3084.62
5	3372.79	80	3073.84	155	3088.04
10	3290.67	85	3080.29	160	3102.86
15	3295.89	90	3060.96	165	3111.70
20	3222.51	95	3058.78	170	3123.23
25	3187.98	100	3068.10	175	3122.63
30	3169.46	105	3069.68	180	3111.42
35	3161.83	110	3092.20	185	3116.53
40	3168.39	115	3086.91	190	3125.87
45	3130.06	120	3098.95	195	3128.12
50	3117.61	125	3100.70	200	3131.93
55	3099.42	130	3094.79		
60	3091.26	135	3101.43		
65	3073.65	140	3091.95		
70	3050.95	145	3092.56		

## Temperature: 40°C

Time (Seconds) ±1s	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$	Time (Seconds) ±1s	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$	Time (Seconds) ±1s	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$
0	4268.93	75	3143.20	150	3100.89
5	4252.44	80	3120.22	155	3099.75
10	4195.39	85	3136.00	160	3103.53
15	4123.09	90	3123.50	165	3125.33
20	3690.84	95	3115.31	170	3120.92
25	3352.49	100	3090.74	175	3123.76
30	3266.47	105	3091.28	180	3126.39
35	3212.55	110	3090.39	185	3134.72
40	3196.97	115	3072.40	190	3135.11
45	3201.18	120	3088.44	195	3140.43
50	3199.88	125	3085.10	200	3153.16
55	3193.22	130	3073.37		
60	3175.94	135	3080.84		
65	3158.62	140	3089.00		
70	3161.39	145	3081.23		

## Temperature: 45°C

Time (Seconds) ±1s	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$	Time (Seconds) ±1s	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$	Time (Seconds) ±1s	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$
0	3940.01	75	2815.21	150	2780.14
5	3874.68	80	2815.36	155	2791.02
10	3813.56	85	2798.67	160	2799.74
15	3376.76	90	2795.06	165	2810.05
20	3035.57	95	2786.80	170	2813.58
25	2951.11	100	2775.50	175	2815.02
30	2888.29	105	2770.63	180	2825.50
35	2885.02	110	2767.26	185	2823.83
40	2886.24	115	2766.20	190	2832.57
45	2881.31	120	2763.86	195	2837.13
50	2873.65	125	2759.34	200	2841.36
55	2862.71	130	2763.77		
60	2852.13	135	2767.28		
65	2836.41	140	2764.61		
70	2819.66	145	2780.35		



## Temperature: 50°C

Time (Seconds) ±1s	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$	Time (Seconds) ±1s	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$	Time (Seconds) ±1s	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$
0	3730.03	75	2741.09	150	2797.29
5	3738.02	80	2749.10	155	2799.93
10	3667.73	85	2742.27	160	2816.91
15	3585.90	90	2747.29	165	2827.45
20	3286.55	95	2752.71	170	2835.19
25	3030.53	100	2752.78	175	2846.51
30	2970.04	105	2765.13	180	2864.21
35	2912.59	110	2773.71	185	2887.72
40	2858.05	115	2778.32	190	2885.14
45	2805.09	120	2776.13	195	2917.03
50	2774.94	125	2786.21	200	2906.43
55	2760.96	130	2793.67		
60	2754.57	135	2789.04		
65	2739.16	140	2795.41		
70	2735.46	145	2794.71		

## Temperature: 55°C

Time (Seconds) ±1s	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$	Time (Seconds) ±1s	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$	Time (Seconds) ±1s	Conductivity ( $\mu\text{S}/\text{cm}$ ) $\pm 0.01\mu\text{S}/\text{cm}$
0	3595.99	75	2605.52	150	2661.22
5	3528.00	80	2610.28	155	2675.33
10	3447.76	85	2604.97	160	2690.65
15	3144.83	90	2612.91	165	2699.72
20	2898.27	95	2615.00	170	2709.19
25	2829.85	100	2625.65	175	2722.10
30	2768.28	105	2633.56	180	2748.34
35	2719.48	110	2635.08	185	2747.49
40	2665.64	115	2640.17	190	2775.22
45	2631.86	120	2643.42	195	2773.66
50	2624.84	125	2653.50	200	2807.58
55	2609.96	130	2650.92		
60	2602.71	135	2651.62		
65	2598.57	140	2650.97		
70	2602.26	145	2652.87		

## ASPECT 2 & 3: *PROCESSING and PRESENTING RAW DATA*

From the data collected above, the rate of the reaction can be calculated, by the formula -

$$\text{Rate} = k [A]^x \cdot [B]^y$$

Where A and B are the concentrations of reactants that feature on the rate expression, and  $x$  and  $y$  are their orders of reaction. In order to circumvent the the process of finding the rate expression, because the rate expression does not actually have to be found, concentrations were taken at 1M.

Hence, since the power on 1 doesn't matter (since it will still remain 1),  $x$  and  $y$  can be eliminated.

Hence, the Rate expression becomes -

$$\text{Rate} = k [A] \cdot [B]$$

Finally,

$$k = \frac{\text{Rate}}{1}$$

However, another conversion is necessary in order for this process to be reliable. From the graphs below, the change in conductivity with time for the reaction can be calculated by the gradients drawn appropriately, from the start until the apparent end of the reaction. However, this is not the same as the rate of reaction above. The rate above is in terms of rate of change of concentration, not conductivity. Hence, the rate of change of conductivity has to be converted to in terms of concentration.

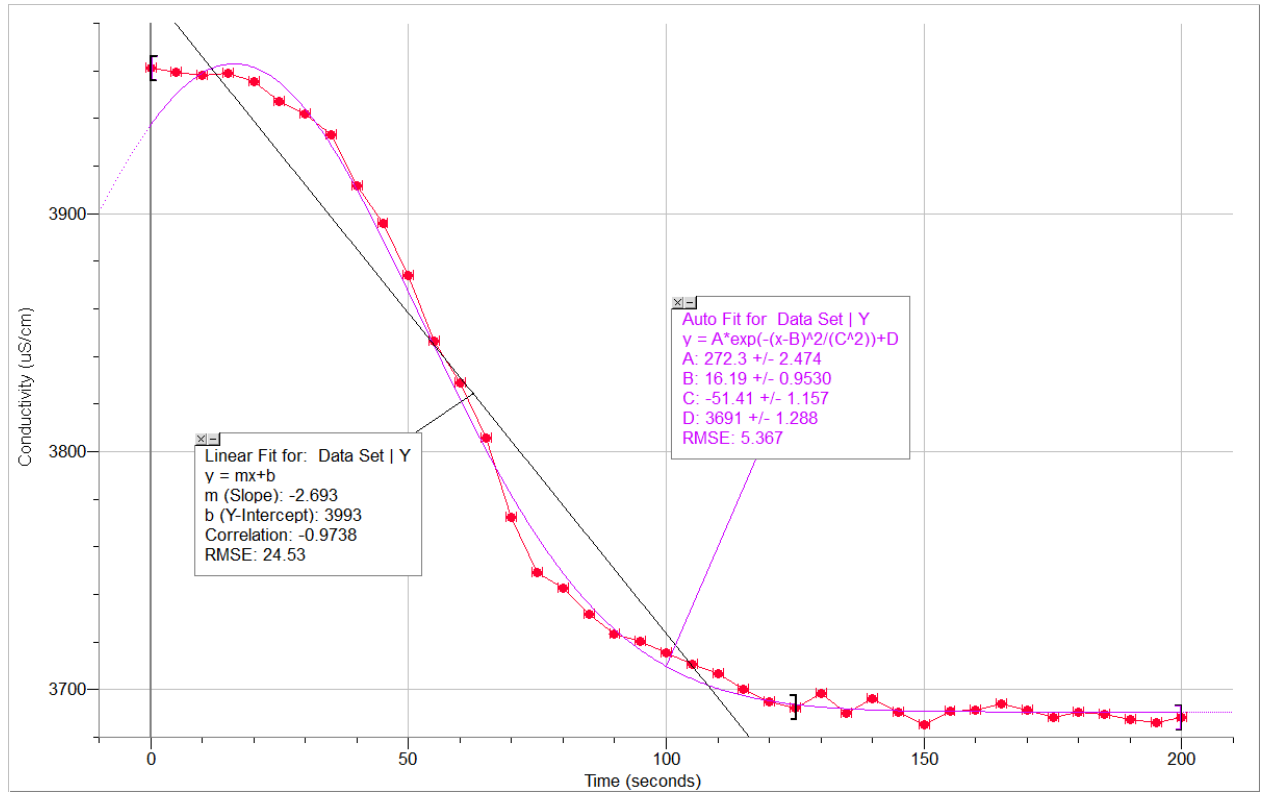
$$\text{Rate}_{\text{conc.}} = \frac{\Delta L (\text{conductivity})}{\Delta T} \cdot \left( \frac{\text{Molar Concentration of Reactant}}{\text{Molar Cond.}} \right)$$

$$\text{Rate}_{\text{conc.}} = \frac{\text{Rate}_{\text{cond.}}}{\text{Molar Conductivity}}$$

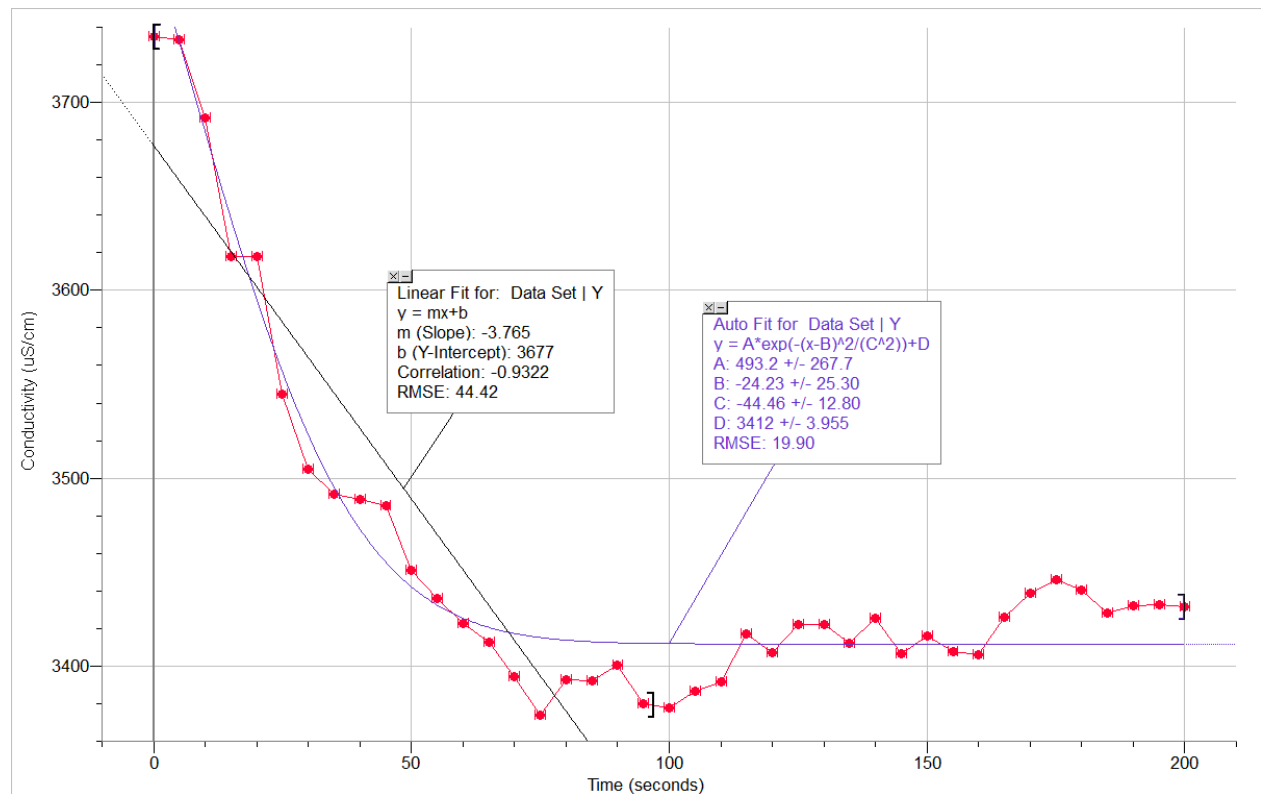
Finally,

$$k = \frac{\text{Initial Conductivity}}{\text{Gradient (Rate of Change of Cond.)}}$$

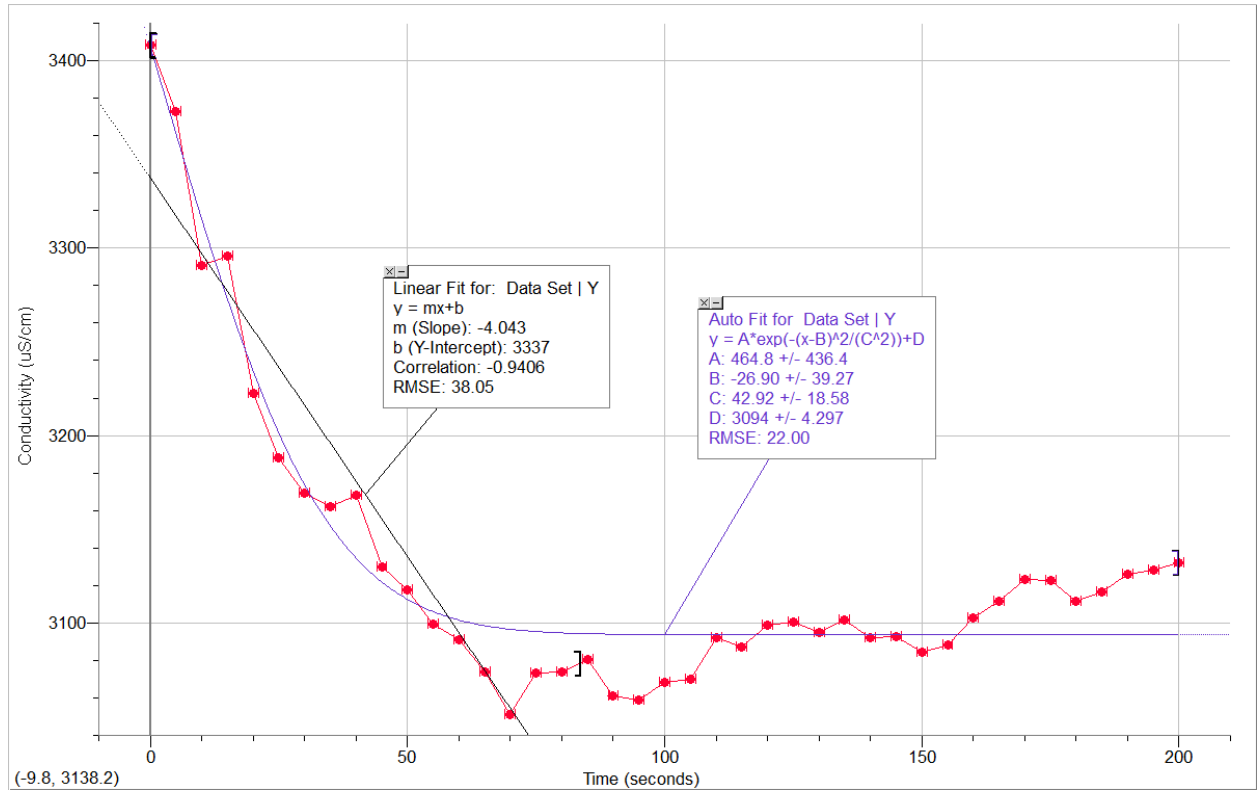
## Temperature: 25°C



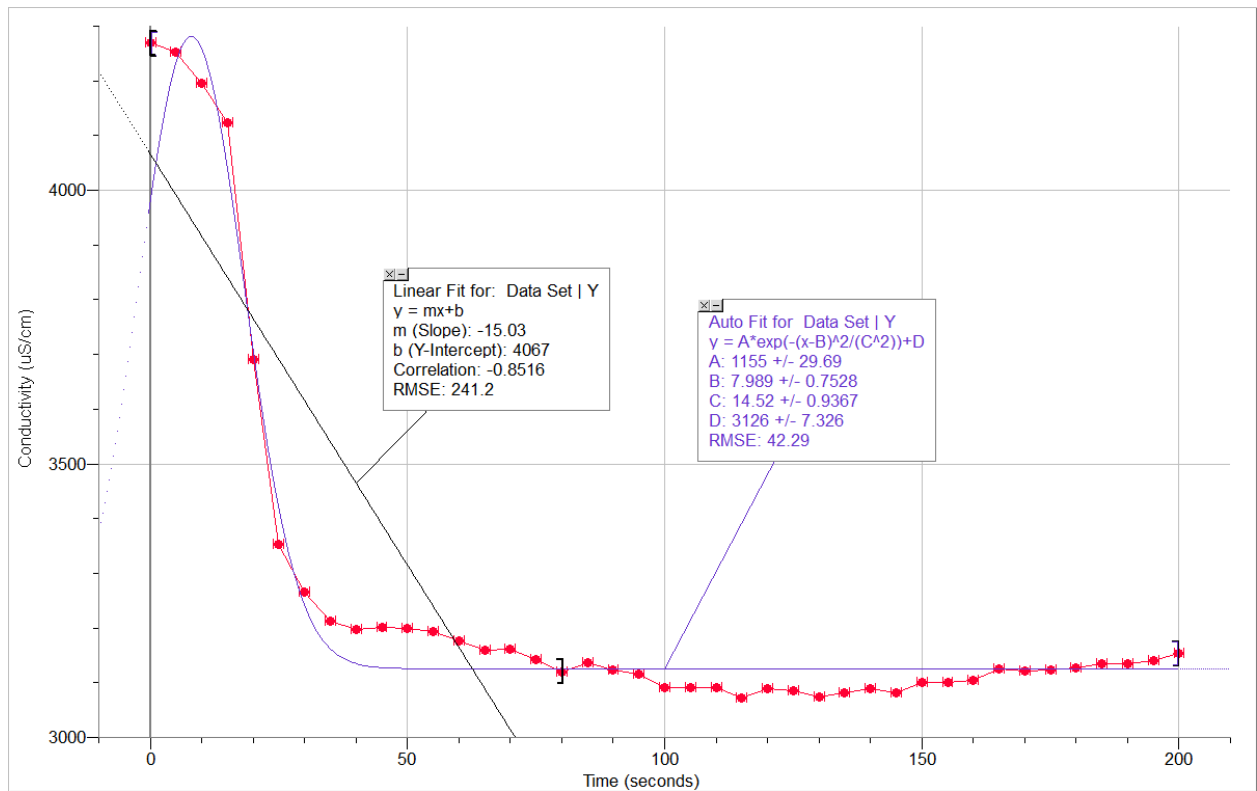
## Temperature: 30°C



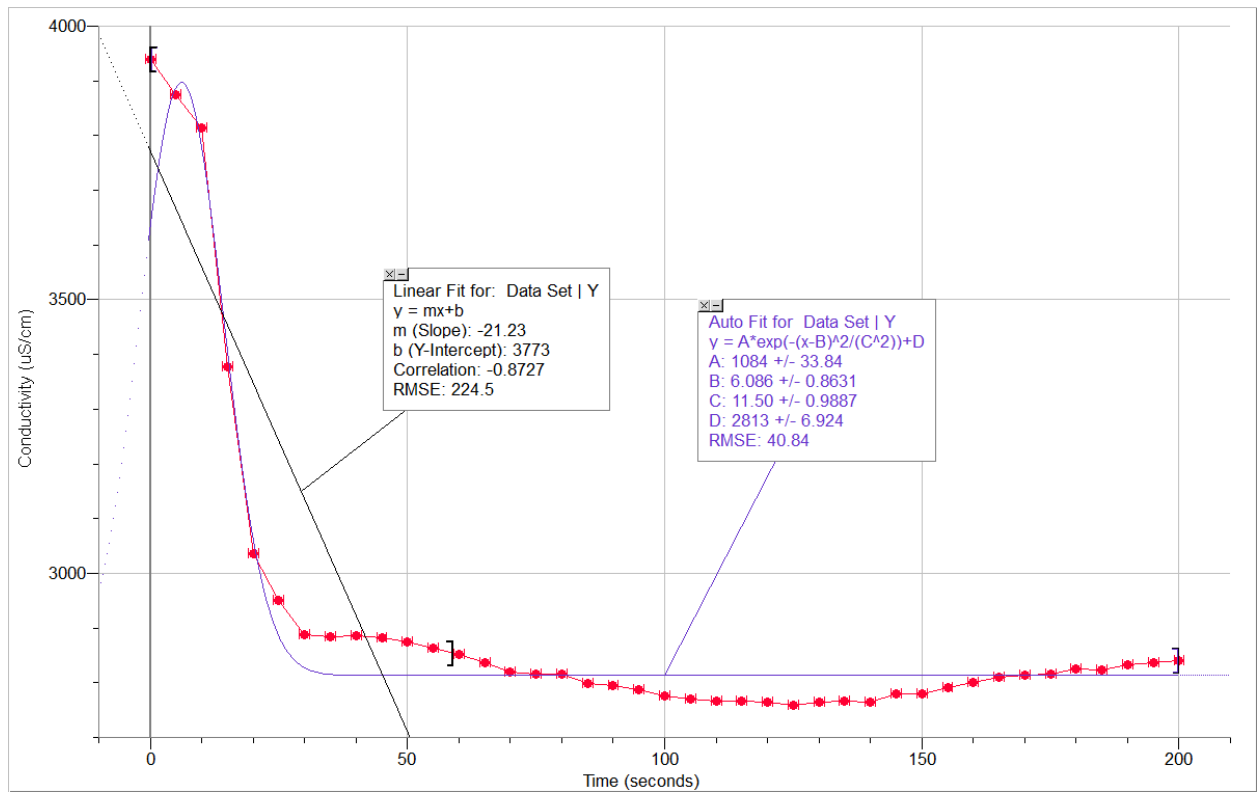
## Temperature: 35°C



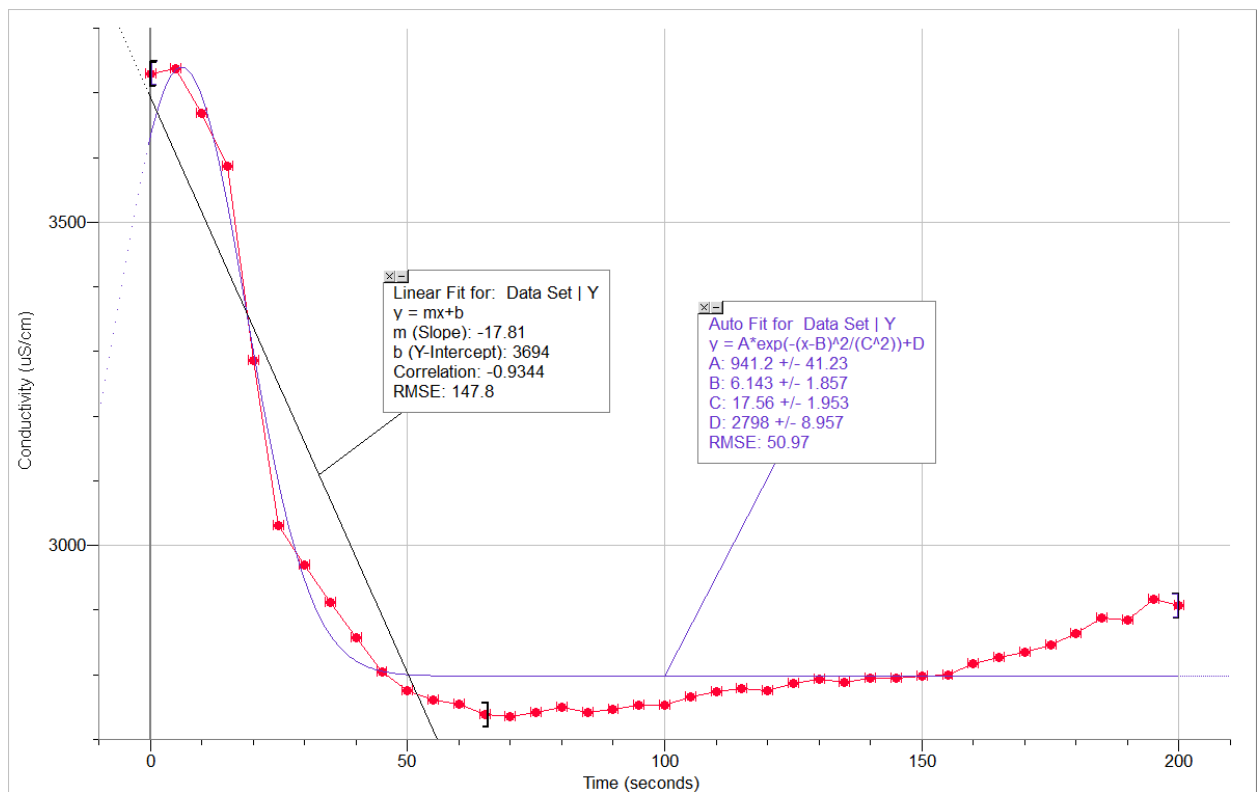
## Temperature: 40°C



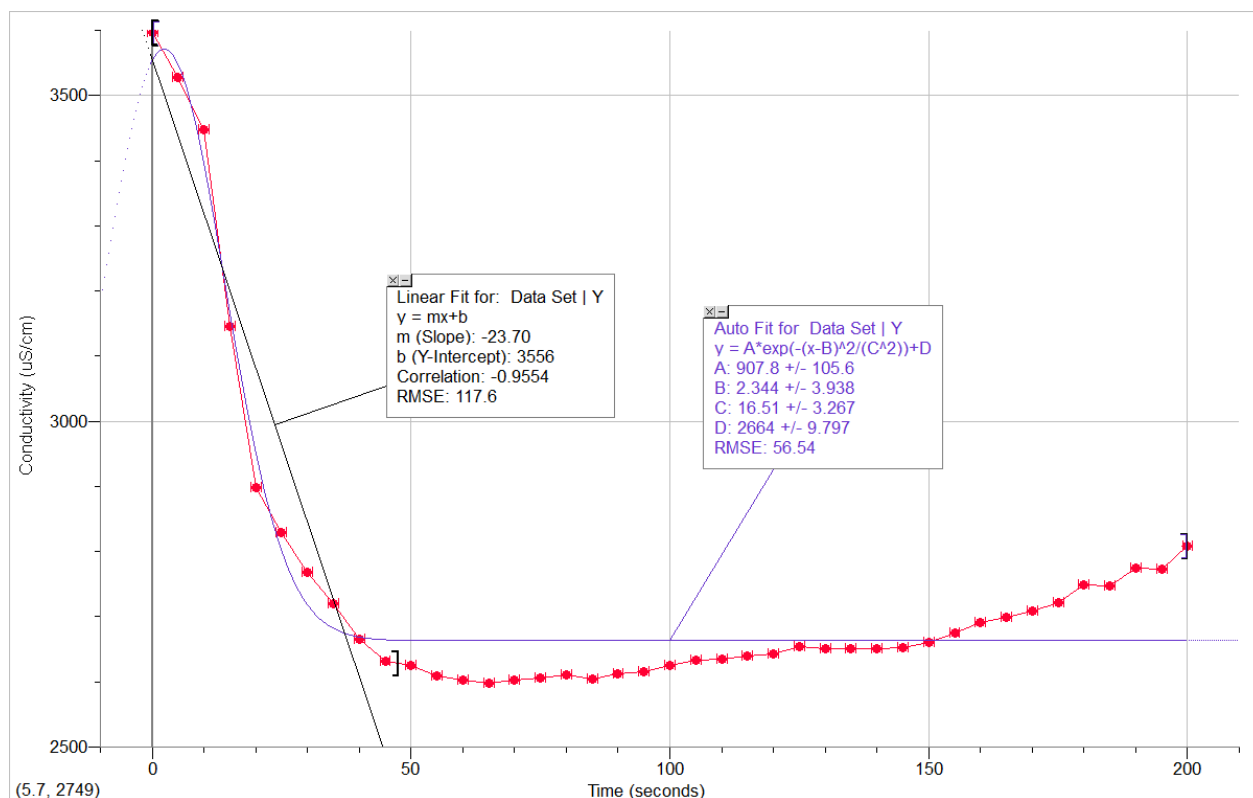
## Temperature: 45°C



## Temperature: 50°C



## Temperature: 55°C



The data that is needed for the Rate Constant ( $K$ ) is the initial conductivity and the rate of change of conductivity of the reaction occurring due to the reaction (which is shown by the gradient of the linear lines created from the start to the end of the reaction) and the initial conductivity (also obtained from the first point on the graph)

### Summary of Data from Graph:

Temperature $\pm 0.5^\circ\text{C}$	Initial Conductivity $\pm 0.01 \mu\text{S/cm}$	Rate of Change of Conductivity $\pm 0.02 \mu\text{S/cm}$
25	4661.2	2.69
30	4734.91	3.77
35	3408.18	4.04
40	6268.93	15.03
45	5940.01	21.23
50	4730.03	17.81
55	4595.99	23.70

# Annotated Calculations and Uncertainty

## Step 1: Simplifying the Rate Expression and Adding Uncertainties

As stated, Rate =  $k$  [KOH] · [CH<sub>3</sub>COOC<sub>2</sub>H<sub>5</sub>]

Concentration of KOH =  $1.00 \pm 0.01$ M

Concentration of CH<sub>3</sub>COOC<sub>2</sub>H<sub>5</sub> =  $1.00 \pm 0.01$ M

Hence, Rate =  $k \pm 2\%$

Therefore, when an expression was derived for the rate constant, the uncertainty already present was

$$k = \frac{\text{Rate}_{\text{cond.}}}{\text{Molar Conductivity}} \pm 2\%$$

Temperature $\pm 0.5^\circ\text{C}$	Init. Cond. $\pm 0.01 \mu\text{S/cm}$	% unc.	$\Delta$ Cond. $\pm 0.02 \mu\text{S/cm}$	%unc.
25	4661.2	$2.15 \cdot 10^{-4}$	2.69	$7.43 \cdot 10^{-1}$
30	4734.91	$2.11 \cdot 10^{-4}$	3.77	$5.31 \cdot 10^{-1}$
35	3408.18	$2.93 \cdot 10^{-4}$	4.04	$4.95 \cdot 10^{-1}$
40	6268.93	$1.60 \cdot 10^{-4}$	15.03	$1.33 \cdot 10^{-1}$
45	5940.01	$1.68 \cdot 10^{-4}$	21.23	$9.42 \cdot 10^{-2}$
50	4730.03	$2.11 \cdot 10^{-4}$	17.81	$1.12 \cdot 10^{-1}$
55	4595.99	$2.18 \cdot 10^{-4}$	23.70	$8.44 \cdot 10^{-2}$

## Step 2: Calculating the Rate Constant as opposed to Temperature

$$k = \frac{\text{Rate}_{\text{cond.}}}{\text{Molar Conductivity}} \pm 2\%$$

Since Rate Constant is the division of the change in conductivity with initial conductivity, the percentage uncertainties previously found are added, along with the 2% uncertainty already present.

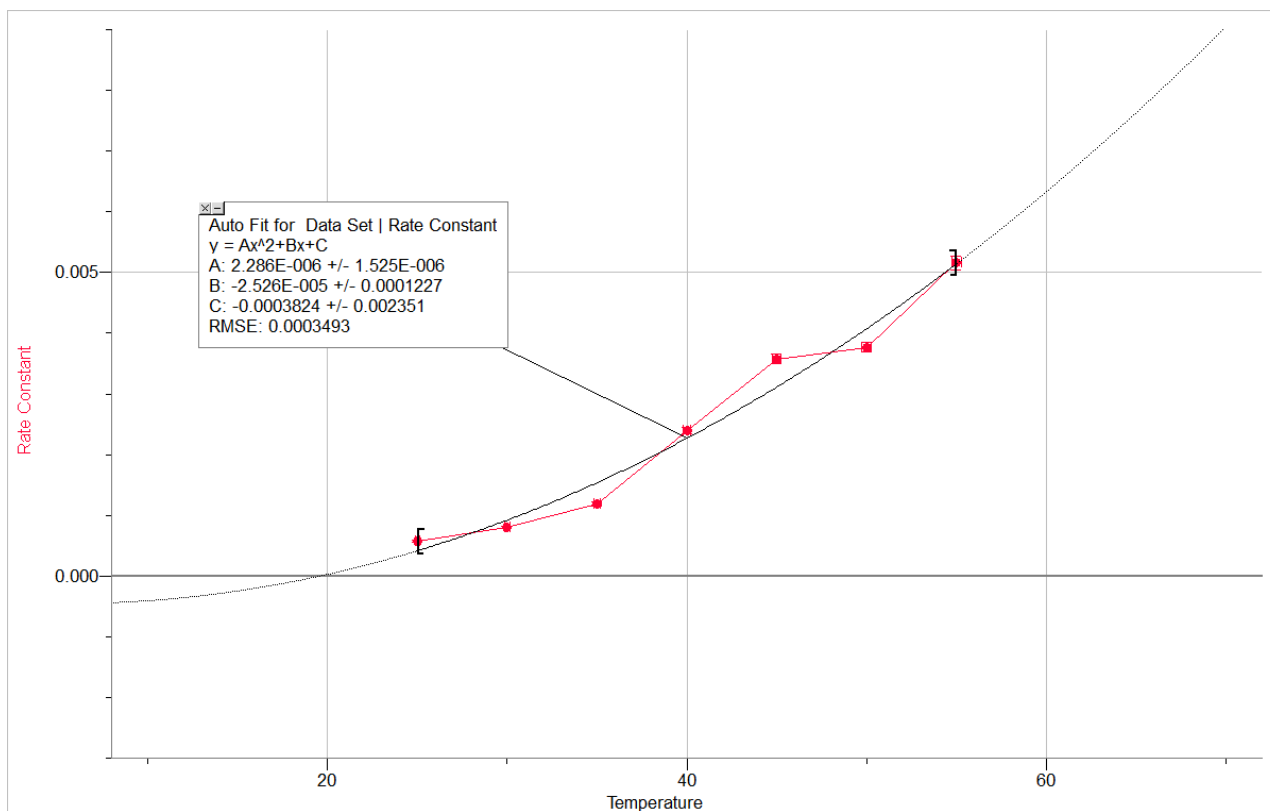
Temperature $\pm 0.5^\circ\text{C}$	Initial Conductivity $\pm 0.01 \mu\text{S/cm}$	Rate of Change of Conductivity $\pm 0.02 \mu\text{S/cm}$	Rate Constant	Percentage Uncertainty
25	4661.2	2.69	$5.77 \cdot 10^{-4}$	2.7
30	4734.91	3.77	$7.96 \cdot 10^{-4}$	2.5
35	3408.18	4.04	$1.19 \cdot 10^{-3}$	2.5
40	6268.93	15.03	$2.40 \cdot 10^{-3}$	2.1
45	5940.01	21.23	$3.57 \cdot 10^{-3}$	2.1
50	4730.03	17.81	$3.77 \cdot 10^{-3}$	2.1
55	4595.99	23.70	$5.16 \cdot 10^{-3}$	2.1

Therefore, the relationship between Rate Constant and Temperature in summarized by -

Temperature $\pm 0.5^\circ\text{C}$	Rate Constant $\text{mol}^{-1} \cdot \text{dm}^3 \cdot \text{s}^{-1}$
25	$5.77 \cdot 10^{-4} \pm 2.74\%$
30	$7.96 \cdot 10^{-4} \pm 2.53\%$
35	$1.19 \cdot 10^{-3} \pm 2.50\%$
40	$2.40 \cdot 10^{-3} \pm 2.13\%$
45	$3.57 \cdot 10^{-3} \pm 2.09\%$
50	$3.77 \cdot 10^{-3} \pm 2.11\%$
55	$5.16 \cdot 10^{-3} \pm 2.08\%$



Graph: The Rate constant plotted directly against the temperatures at which those rate constants occurred.



The rate constant is graphed against the temperature for all temperatures tested in this experiment. By inputting into a graphing software and curve fitting the data values, the output is a square curve. Hence, from this graph, we can conclude using the curve that since –

$$y = 2.3 \cdot 10^{-6}x^2 - 2.5 \cdot 10^{-5}x - 3.8 \cdot 10^{-4}$$

where  $y$  = Rate Constant and  $x$  = Temperature

Therefore,

$$k(T) = 2.3 \cdot 10^{-6}T^2 - 2.5 \cdot 10^{-5}T - 3.8 \cdot 10^{-4}$$

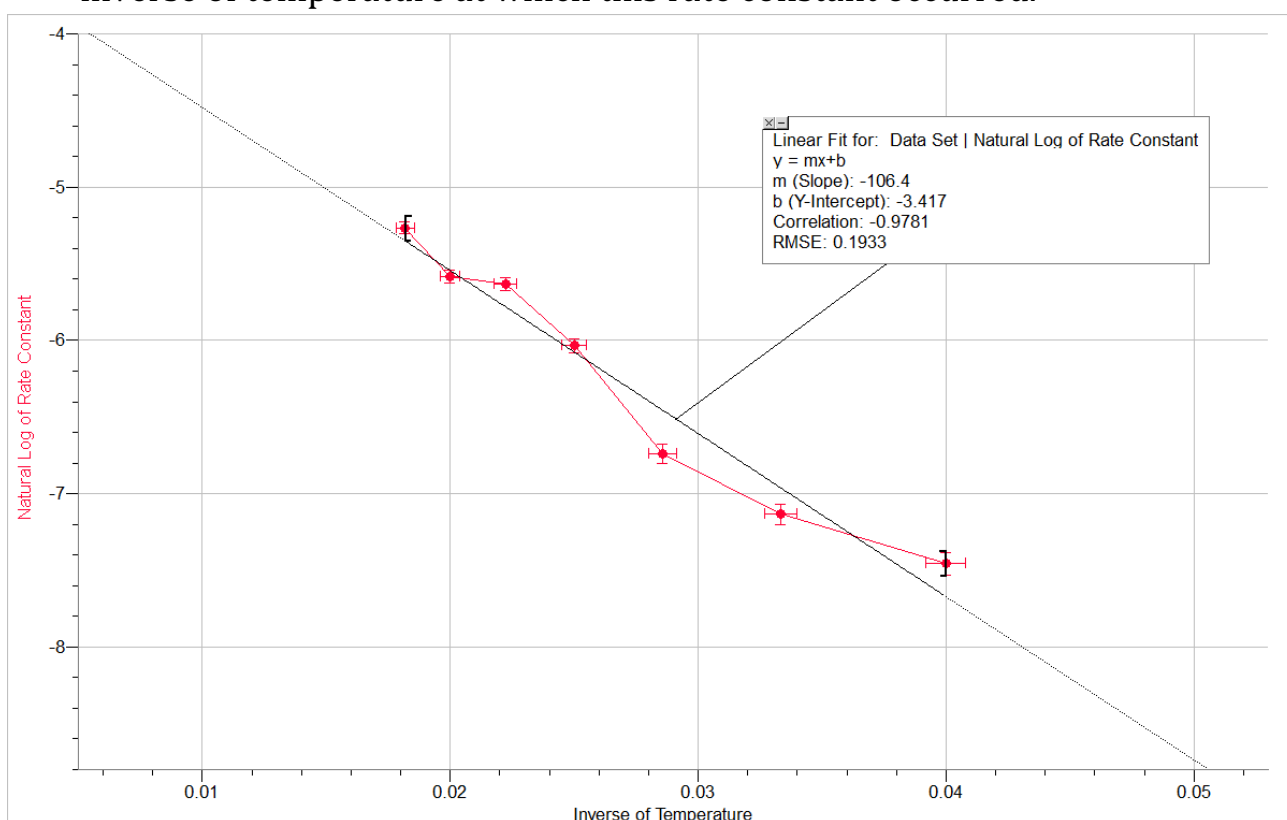
This is a very important conclusion and equation, because with input temperatures across a range, the rate constant can be estimated and predicted using this equation. Hence, for example, the rate constant can be estimated at 46 degrees Celsius and 84 degrees Celsius. However, at much higher or lower temperatures, this relation will get skewed and hence will not provide accurate estimations.

### Step 3: Forming a relationship of the natural log of rate constant vs. the inverse of temperature

As the hypothesis suggests, a graph of the natural log of rate constant vs. inverse of temperature should lead to a straight line graph

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

Graph: The natural log of rate constant found plotted against the inverse of temperature at which this rate constant occurred.



When the natural log of rate constant is plotted against the inverse of temperature, the resulting data points do indeed form an approximate line with Gradient =  $-106.4$  and Y intercept =  $-3.417$ .

According to the equation above, a graph plotted as such would have a gradient of  $\frac{-E_A}{R}$  and a y intercept of  $\ln A$ .

Hence, the hypothesis is proved correct within experimental error, which satisfies the equation -

$$\ln k = -\frac{106.4}{T} - 3.417$$

# **CONCLUSION AND EVALUATION**

## **ASPECT 1: CONCLUDING**

There was a clear pattern between the rate constant and the temperature that was observed. After all the calculations the rate constant was calculated for each temperature. When these rate constants were plotted on a graph, the points were curved to a square curve. By conclusion, it was found that the curve was modeled by –

$$k(T) = 2.3 \cdot 10^{-6}T^2 - 2.5 \cdot 10^{-5}T - 3.8 \cdot 10^{-4}$$

This equation is perhaps one of the most important because if temperature values are plugged in then the rate constant values are automatically output. Temperature values have to be in degrees Celsius. This is a direct relationship between temperature and rate constant, and for the temperatures for which this experiment was conducted; the above square curve seems to plot the points to a great accuracy.

This was further supported when the graph proposed by the Arrhenius Equation was created by graphing the natural log of the rate constant against the inverse of temperature. As proposed by the equation, this led to a straight-line graph with a negative gradient and a certain y intercept.

This graphed proved not only that the Arrhenius Equation was apt to this experiment but also provided some credibility to the results that I got from the experiment. This Arrhenius Equation is modeled by the curve with equation –

$$\ln k = -\frac{106.4}{T} - 3.417$$

This is just as important as the curve above, as it is more accurate and will also output rate constant values for input of temperature values. Hence, the hypothesis was proved as it seems to follow the mathematical relationship that was proposed.

However, these specific equations are only for this particular reaction. A more general relationship could be that rate constant values and temperatures seem to be modeled to some accuracy using the Arrhenius Equation. It also raises the possibility that most or many reactions within these conditions will follow a direct square relationship.

## **ASPECT 2: *EVALUATING PROCEDURES***

1. The water bath was a good idea when it came to heating the solutions. Though it took a lot of extra time and was very monotonous as it required great amounts of waiting time, to both heat and cool, it led to linear heating which was key to this experiment. Additionally, since both liquids were heated in the same water bath, it ensured that both the liquids that were later mixed in the polystyrene cup were the same temperature. So the error was limited.
2. By using a polystyrene cup, and additional cotton, the temperature did not vary significantly during the 200 seconds when the conductivity was being measured as the reaction was occurring. However, at high temperatures, the temperature indeed did change towards the end of the 200 seconds. But even in that case it wasn't very significant and did not have much effect on the result because the reaction was already over by then.
3. The conductivity probe had to be calibrated first. By using two-point calibration in liquids with known conductivity, the probe was calibrated. However, any uncertainty in those solutions, any mistakes, would cause an error and uncertainty in calibration of the instrument and could potentially lead to a great skew in data. This however, cannot be known and calculated.
4. Additionally, the most accurate instruments were tried to be used, including a temperature probe instead of a thermometer at one time. However, the least certain instrument/the instrument with the greatest uncertainty were volume measurements. The most accurate instrument that I could find was a measuring cylinder which had quite a great uncertainty. Fortunately, only the amount of the two solutions was calculated in volume. Those solutions did not have to be made from more concentrated solutions and hence dodged those errors and uncertainties.
5. Random errors could have occurred when the reaction is concerned. A reaction does not occur at the same rate at any time, or even in congruent trials. A reaction depends on the effective collisions which, when averaged should be the same amongst other trials, but independently are completely random and do not follow a certain structure or rate. Hence, these could have led to random errors.
6. A wide range of temperatures were used which allowed the relationship to be reliably concluded and led to a reliable conclusion, one which can not be reasonably and easily doubted.

## ***ASPECT 3: IMPROVEMENTS***

1. Various improvements could have been made to the procedure. The first is to make sure that no errors were committed in the calibration of instruments. This could have been prevented or at least minimized by first conducting the calibration using the two point values known and then checking the values that the conductivity probe produces with other solutions. The difference in the meter reading and actual value would be the offset, and would either be added or subtracted to all measured values for more accurate readings.
2. Temperature improvements could also be made, so that there would be no deviation until the end of the reaction. This could have been done by conducting the reaction itself in a water bath using an immersion heater. An immersion heater can be set to a constant value of power. At each temperature, the power should be set to a value, where the same amount of heat evolved by the heater is equivalent to the heat lost by the water. This will ensure in absolutely no change in temperature. Under these conditions, there would be no change and it would be conducted in a reliable manner.
3. The only other error that was caused in experiment, was the uncertainty in volume. The laboratory's most accurate measure of volume is measuring cylinder, however, the electronic balance present is very accurate up to two decimal places in grams. Hence, volume could have been measured in terms of mass of liquid, which would have been immensely accurate and further reduced the error in the experiment.
4. More trials conducted for a wider range of temperatures would have been better for a conclusion, since the conclusion and the mathematical equations found as relationships would apply to a wider range of temperatures and would be more proven and hence reliable.
5. Finally, this exact experiment should be conducted for more reactions, not just one with potassium hydroxide and ethyl ethanoate. More reactions that prove the same general mathematical hypothesis would be conclusive and even more interesting. Additionally, differences in nuances between the reactions could further be analyzed to explain any differences and similarities. Hence, this is the most important improvement for further experiments and investigations.

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