

IB Chemistry Group 4 Project

The Spectrophotometer and Reaction Rates

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Problem Statement

How do factors such as concentration, surface area, and mass affect the rate of a reaction in terms of color intensity?

Aim

The aim of this experiment is to understand the working of a spectrophotometer and to measure the rate of a reaction using the spectrophotometer. Changes will be imposed on the reactants' temperature, concentration and surface area, and variations in the rate will be observed.

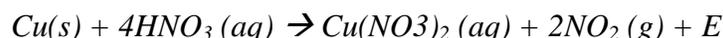
Theoretical Introduction

Background

In Chemistry, knowing the rate of a reaction can prove useful in several different applications of that reaction. There are several methods for measuring reaction rates:

- i) Temperature Change
- ii) Pressure Change
- iii) Mass Change
- iv) Concentration Change
- v) Colour Change

In this lab, we will be measuring the rate of a reaction in terms of change in colour intensity. The following exothermic reaction will be considered:



Cu is a reddish-brown solid, while $\text{HNO}_3(aq)$ is colourless. One of the products $\text{Cu}(\text{NO}_3)_2(aq)$ has a characteristic blue colour. The intensity of the blue colour can be measured with a photo-electric detector.

Hypothesis

Initially, the Cu + HNO_3 solution in the test tube will have a mild, brownish colour. As the reaction proceeds, the production of $\text{Cu}(\text{NO}_3)_2$ will increase and more of this will be produced. $\text{Cu}(\text{NO}_3)_2$ has a characteristic blue colour due to the arrangement of its atoms and electrons. This will have an effect on the intensity of light hitting the photo-electric cell. As the reaction proceeds, the $\text{Cu}(\text{NO}_3)_2$ will absorb all colours but blue, as $\text{Cu}(\text{NO}_3)_2$ is blue. This change in the intensity of light being reflected will produce a different ampere of current as time passes, and this change can be observed on the ammeter. The rate of the reaction can then be given by:

$$\text{Rate} = \frac{\Delta I}{\Delta t}$$

Investigation Methodology

The $\text{Cu}(\text{NO}_3)_2(aq)$ has a characteristic blue colour. The intensity of the blue colour can be measured with a spectrophotometer.

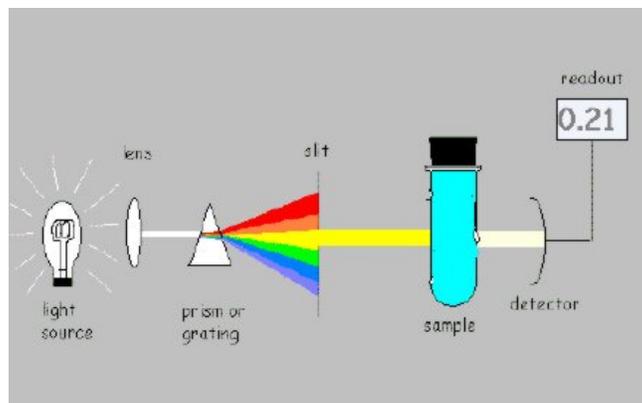


Figure 1: A simple spectrophotometer

Light from a light source will be passed through a test tube within which the reaction is occurring. The amount of light absorbed by the sample is directly proportional to the concentration of the light-absorbing chemical. After the light passes through this chemical, it is allowed to hit a photo-electric cell, which in-turn conducts electricity depending on the intensity of light hitting it. The magnitude of electricity conducted can be measured with an ammeter. Changes in the amount of light hitting the photocell allow measurement of changes in the concentration of *dissolved* chemicals.¹

Another point worth noting is that as the reaction proceeds, bubbles would be produced within the test tube. The rate of bubble production is also proportional to the rate at which the reaction proceeds. This gives us another variable to work with. If the reaction is speeded up by increasing the concentrations of the reactions, more number of bubbles would be produced in a given time, and these bubbles would affect the amount of light allowed to hit the photo-electric cell.

In the above reaction, the blue colour of the $\text{Cu}(\text{NO}_3)_2(\text{aq})$ would be appropriate to measure. As the reaction proceeds, the intensity of the blue colour will increase. Plotting a graph of current versus time allows the slope of the graph to be found. This slope is nothing but the rate of production of $\text{Cu}(\text{NO}_3)_2$, or in other words, the rate of the reaction.

$$\text{Rate} = \frac{\Delta \text{colour intensity}}{\Delta \text{time}}$$

Variables

1. When no change is imposed:
 - a. Independent: None
 - b. Dependent: Rate of the reaction
 - c. Controlled: Temperature, concentration, mass of Cu, and surface area.
2. When the concentration is changed

¹ Undissolved solids must not block the beam of light.

- a. Independent: Concentration
 - b. Dependent: Rate of the reaction
 - c. Controlled: Temperature, Mass of Cu, and surface area.
3. When Cu is more finely grained
- a. Independent: Surface Area of reactant
 - b. Dependent: Rate of the reaction
 - c. Controlled: Temperature, concentration, mass of Cu, and surface area.

Materials Required

1. Spectrophotometer Lab Set containing the following:
 - a) Light source with filament
 - b) Converging Lens
 - c) Prism or diffraction grater
 - d) Slit Plate with slit mask
 - e) Test tube with stopper
 - f) Photo-electric detector
 - g) Voltmeter
2. Thermometer
3. 250-ml Graduated Cylinder
4. 150-ml beaker
5. Electronic Balance
6. Stopwatch
7. Test tube holder
8. Pure Cu (500g) [preferably in chunks]
9. Solid Nitric Acid (500g)

Procedure

1. Prepare the materials used and set them up as shown in the figure on this poster.
2. Make sure that the connection between the ammeter and the photoelectric detector is secure.
3. Record the initial intensity of this light as shown by the ammeter.
4. Prepare a 0.5 M solution of HNO_3 .
5. Dissolve a known mass of Cu with the HNO_3 , and quickly stopper the test tube and shake and swirl vigorously for approximately 4 seconds. The reaction begins.
6. Place the test tube between the spectrophotometer and the slit mask (so right into the light beam) as soon as possible, and start the timer.
7. Take the initial reading of the ammeter, and do it again every time there is a significant change.
8. Dump the contents of the test tube after the reaction has come to a near equilibrium, i.e. the characteristic blue colour of the $Cu(NO_3)_2$ can be observed.

9. Repeat the above experiment with different concentrations of HNO_3 , and different masses of Copper.
10. Grind the Cu into a fine powder and repeat the reaction measuring the rate.
11. Use granules of Copper and repeat the reaction measuring the rate.

Data Collection

No Change		No Change		Inc. SA		Dec. SA		Inc. Conc.		Dec. Conc.		Inc. Cu		Dec. Cu	
T	I														
0	24	649	12.3	0	38.2	0	37.7	0	37.8	0	46.5	0	38.6	0	37.7
108	7.8	655	11.8	29	37.3	108	26.4	17	11	29	30.7	37	30.5	18	17.5
145	7.2	665	11.4	32	37.1	124	23.5	23	9.3	37	30.5	41	30	23	16.5
178	6.5	670	11.0	38	36.8	130	23	32	8.5	45	30.1	46	29.3	27	15.2
197	6.4	681	10.5	128	36.1	136	22.2	40	8	60	28.1	49	27.5	30	14.5
272	6.3	687	10.2	163	35.4	152	22	44	7.9	66	26.9	54	26.8	33	13.9
924	8.2	692	9.7	171	35	166	21.6	65	7.7	70	26.1	64	26.3	37	13.2
		705	9.1	178	34.7	272	20.3			74	25.6	85	25.4	42	12.4
		715	8.8	205	34.4	280	19.8			82	25	97	24.5	48	11.8
		734	8.3	235	34.2					87	24.4	104	23.7	53	11.3
		738	8.0	299	33					99	23.5	112	23.1	57	11.0
		756	7.9	326	32.5					102	23.1	121	22.4	63	10.6
		775	7.6	335	32.2					109	22.7	127	21.7	70	10.3
		788	7.5	356	31.8					117	22.1	155	20	82	10.0
		818	7.2	396	31.3					127	21.6	176	19.8	90	9.6
		853	6.8	410	30.8					133	21	193	18.6	107	9.5
		1009	7.2	443	29.7					140	20.6	204	17.8	124	9.4
		1024	7.4	452	29.4					145	20.2	216	17.3		
		1032	7.3	480	28.7					151	19.6	223	16.8		
		1058	7.2	542	28.2					163	19.3	236	16		
		1066	7.3	551	27.8					168	19	262	15.4		
				591	26.3					180	18.5	286	14.6		
				621	25.3					192	18				
				645	24.7					205	17.7				
				677	23.6					236	16.3				
				707	22.9					246	15.9				
				755	21.3					256	15.7				
				768	21					265	15.4				
				808	20.4					274	15.1				
				914	20					288	14.7				
				995	19.4					295	14.5				
				1398	17					305	14.3				
				1534	16.4					322	15.9				
				2060	15.4					342	13.5				
				3212	13.6					367	13.2				
										392	12.8				
										444	12.3				

					471	12		
					558	11.3		
					618	11.1		
					722	10.6		

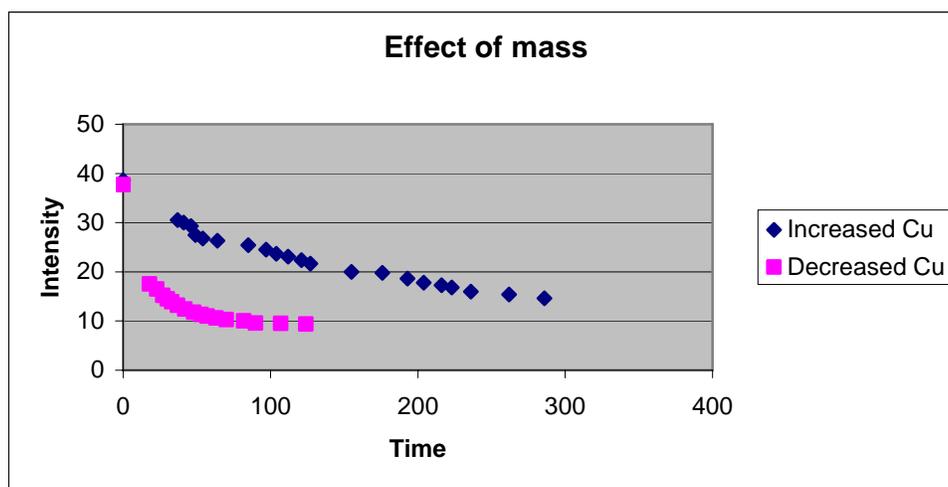
Data Analysis

Attached

Evaluation

Conclusion

By analyzing the graphs that show the relationship between the intensity of light detected by the ammeter and time, it is evident that changes on the reactant's concentration, mass and surface area *do* affect the rate of the reaction. Although this change is not conspicuous given the limitations of this experiment, the graphs indicate that changes alter at least the initial rates of the reaction. For example, the effect of mass can be seen clearly from the below graph.



If we were to compare the second differentials (the rate of change of change) of the two graphs, we would find that the rate of the first graph (increased Cu) drops more slowly than the second (decrease Cu), although the rate of the second graph becomes constant fairly quickly.

Similar analysis can be conducted with other graphs, and similar results are obtained.

There are a few reasons as to why it was difficult to deduce useful results from this experiment. Most importantly, we did not have enough data points to come to a valid conclusion. This makes it impossible to say with certainty whether the results form a random distribution or whether there really exists a mathematical pattern to it.

Limitations

There were a number of limitations that had to be overcome while trying to conduct this lab, both in terms of the materials used as well as the procedures followed. Certain variables, such as the amount of light in the room and the distance between our spectrophotometer peripherals, were neglected and this could have contributed to certain systematic errors.

Secondly, we did not impose any harsh changes on the reactants' properties while repeating the experiment. This could mean that the changes imposed were not significant enough to distinctly show variations in the measured rate. If for instance we had quadrupled the initial concentration of HNO_3 instead of just increasing it a slight bit, it may have been much clearer as how the rate of the reaction varies.

Another limitation of our experiment is that it is difficult to speak quantitatively about the results obtained. For example, it is impossible to say how much the initial rate of the reaction would change if say the mass of Cu was doubled or halved.

Experimental Refinements

If we were to redesign this lab from scratch, we would take into consideration the following points:

1. Use a reaction that is more sensitive to changes.
2. Control variables-to-be-controlled more tightly.
3. Eliminate random errors in measurement such as human parallax errors.
4. Take into consideration neglected variables such as outside lighting.
5. Impose more significant changes to reactants' properties
6. Take intensity readings more often and for a longer duration.

Technical Details

This lab was riddled with several unknown variables that interfered with our data. Also, the lack of appropriate equipment for depositing the copper into the solution made it difficult to add all of the copper at once. In a real chemical laboratory, there would be funnels with large enough necks to fit both into the test tube (or another container altogether) as well as allow all of the copper into the test tube. Additionally, our observations indicate that a majority of the copper strips seem to themselves block the incident light. Ideally, we would have had a larger container to allow the copper to settle at the very bottom. Another suggestion to chemists planning to repeat the same experiment would be to use something more predictable in their movement and easier to handle, instead of copper wire or copper granules. Furthermore, we had no way of getting rid of the spontaneous production of bubbles, but with proper equipment, there could be, at least theoretically, a straightforward way to drain off the bubbles before they reached the "testing window." As a result, only a change in color would affect the intensity of light passing through the test tube.

