The Effects of Hydrochloric Acid Concentration on the Rate of Reaction Between Hydrochloric Acid and Magnesium

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Abstract

The purpose of this experiment was to determine the effects of hydrochloric acid concentration on the reaction between hydrochloric acid (HCl) and magnesium. We measured the amount of hydrogen gas produced as differing concentrations of HCl reacted with magnesium. Our independent variable was concentration, and we used 1.0M, 0.8M, 0.6M HCl during our experimental trials. Using a water basin and eudiometer apparatus we measured the quantity of hydrogen gas production with the different concentrations of HCl. Our results indicate that there is clearly a positive relationship between the concentration of HCl and the rate of reaction between HCl and magnesium.

Background Research

During the preliminary research that led up to this experiment, our group needed to consider that certain factors that affect rate of reaction – such as concentration, particle size, temperature and the presence of a catalyst – can have a significant impact on the results of an experiment. In order for a reaction to occur, particles must collide with sufficient force and correct spatial orientation to react with one another. Taking these factors into consideration, we decided upon concentration, or the quantity of a particular substance in a defined space, as our independent variable, because it seemed to be an easily manipulated variable that could cause noticeable changes in the rate at which our two substances reacted with each other. In our experiment, we would measure the rate of reaction based on the change in the volume of hydrogen gas produced as HCl and magnesium react with each other. .

Reaction rate formula = change in volume of hydrogen gas produced / change in time

- Chemical formula: $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

- Molarity Calculations for HCl:
  With 30 mL of HCl and 0 mL of water = 1.0 M
  With 24 mL of HCl and 6 mL of water = 0.8 M
  With 18 mL of HCl and 12 mL of water = 0.6 M

- Stoichiometry Calculations:

(100 mL H_2) x (1 mol H_2 / 22.4 L H_2) x (L / 1000L) x (1 mol Mg / 1 mol H_2) x (24.305 g Mg) / 1 mol Mg) = 0.11 g (110 mg) of Magnesium is required for this experiment.

*Originally, we did not account for the displaced air in the eudiometer (which turned out to be 30 mL) so the ideal amount of magnesium we needed was actually 76 mg, according to the very slightly modified calculations below. However, we realized this after the experiment, so we still experimented with 110 mg of magnesium.

(70 mL H2) x (1 mol H2 / 22.4 L H2) x (L / 1000L) x (1 mol Mg / 1 mol H2) x (24.305 g Mg) / 1 mol Mg) = 0.076 g of Magnesium (the amount of Magnesium that was actually required).

Investigation Question

How will the rate of reaction be affected by changes in the concentrations of hydrochloric acid?

Hypothesis

Hypothesis:

If we increase the concentration of hydrochloric acid which reacts with magnesium, then the rate of reaction will increase. If we decrease the concentration of hydrochloric acid in the same situation, then the rate of reaction will decrease.

Variables:

- Independent Variable: Concentration of the hydrochloric acid - at 1.0M, 0.8M, and 0.6M
  Dependent Variable: Rate of reaction - calculated from measurement of gas production (volume of gas produced in mL) over time (in seconds)
- Control Variables: Same apparatus, same volume of hydrochloric acid and same mass of magnesium for the reaction, equal temperature.

Materials and Apparatus

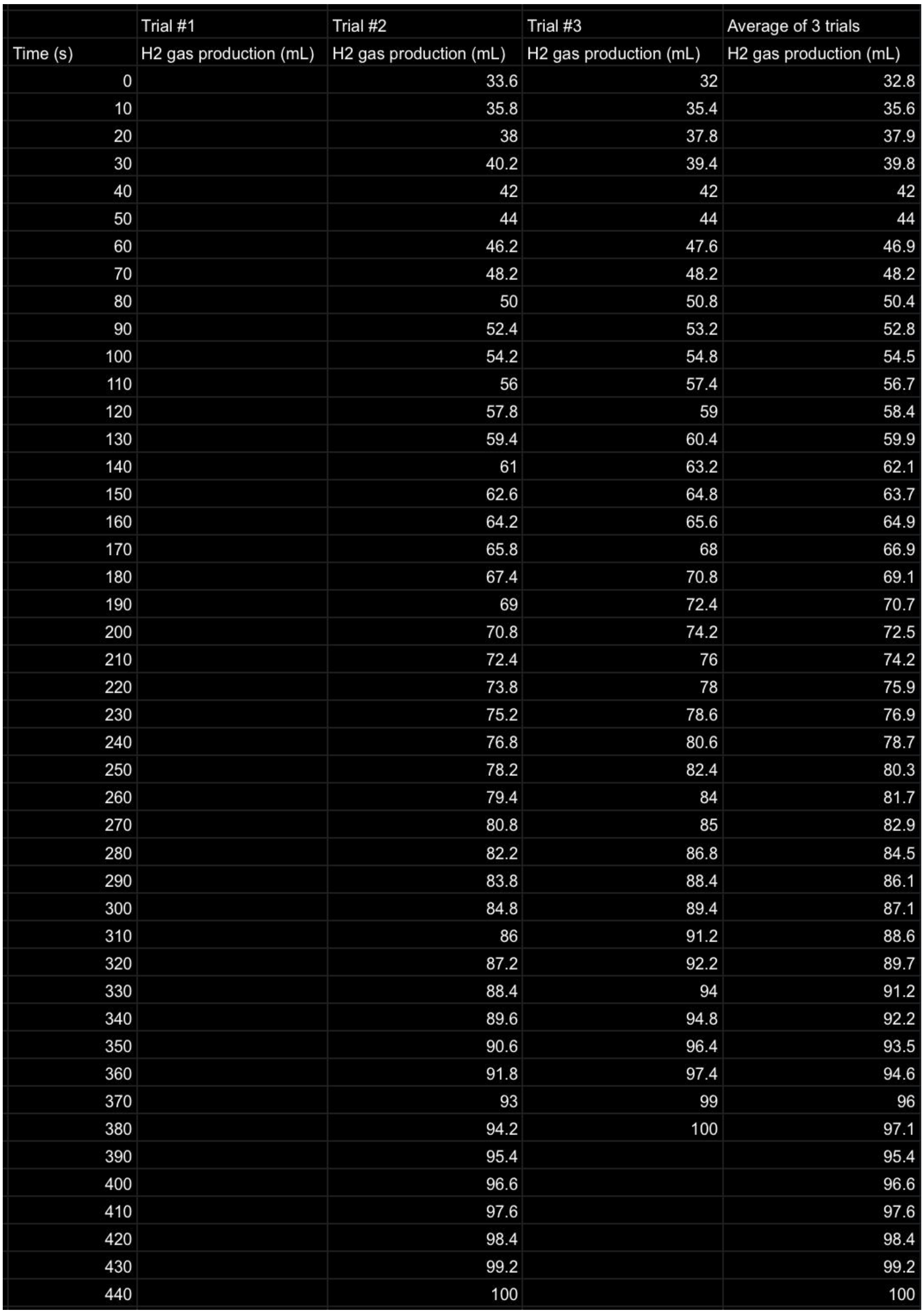
- ☐ 10 mL plunging syringe
- ☐ Tub with water
- ☐ Syringes
- ☐ Magnesium pellets
- ☐ Hydrochloric acid (1.0M)
- ☐ Delivery tube
- ☐ Two-holed rubber stopper
- ☐ Eudiometer (burette)
- ☐ Clamp stand
- ☐ Burette clamp
- ☐ Water basin
- ☐ Timer
- ☐ Erlenmeyer Flask
- ☐ Device with a camera
- ☐ Waste beaker

☐ Weigh boat(s)
☐ Electronic balance
☐ Safety glasses
☐ Gloves

Procedure / Method

1) Set up the eudiometer in the water basin, and then begin filling the eudiometer (or burette) with water.
2) Place the eudiometer upside down within the burette clamp, with the opening of the eudiometer submerged inside the water basin.
3) Place the weighboat onto the electronic balance and click tare to reset the balance's display to zero. By doing so, you can ensure that the weight of the weightboat is not accounted for.
4) Drop some Magnesium into the weightboat, and adjust until you measure approximately 110 mg of Magnesium.
5) Prepare an empty Erlenmeyer flask, and add the 110 mg of magnesium to it
6) Insert a rubber stopper into the top of the Erlenmeyer flask, and ensure that there is no gapping or space for CO_2 to escape. .
7) Insert one end of a delivery tube into the rubber stopper, and the other end into the eudiometer.
8) Fill a syringe with 30mL of 1.0M hydrochloric acid, making sure to remove as much air as possible by flicking it. Insert the syringe into the rubber stopper.
9) Set up the syringe, place it into the other opening of the stopper.
10) Push down the plunger of the syringe to push all of its contents into the Erlenmeyer flask.
11) Using a timer, record the time it takes for H_2 to fill up the entire eudiometer as HCl and Magnesium react with each other. Record this with a device (such as a smartphone) and later rewatch the recording to determine values (in mL) every 10 seconds.
12) Make sure to record the amount of displaced air in the eudiometer as the baseline volume of gas which could be attributed to the natural displacement of matter within the flask when the hydrochloric acid was added. This would later be subtracted from the final volume of H_2.
13) Repeat steps 1-12 with 30mL of 0.8 M HCl (24 mL HCl, 6 mL H_2O)
14) Repeat steps 1-12 with 30mL of 0.6M hydrochloric acid (18mL HCl, 12mL H_2O).
15) Repeat steps 1-14 twice more (for a total of three trials).

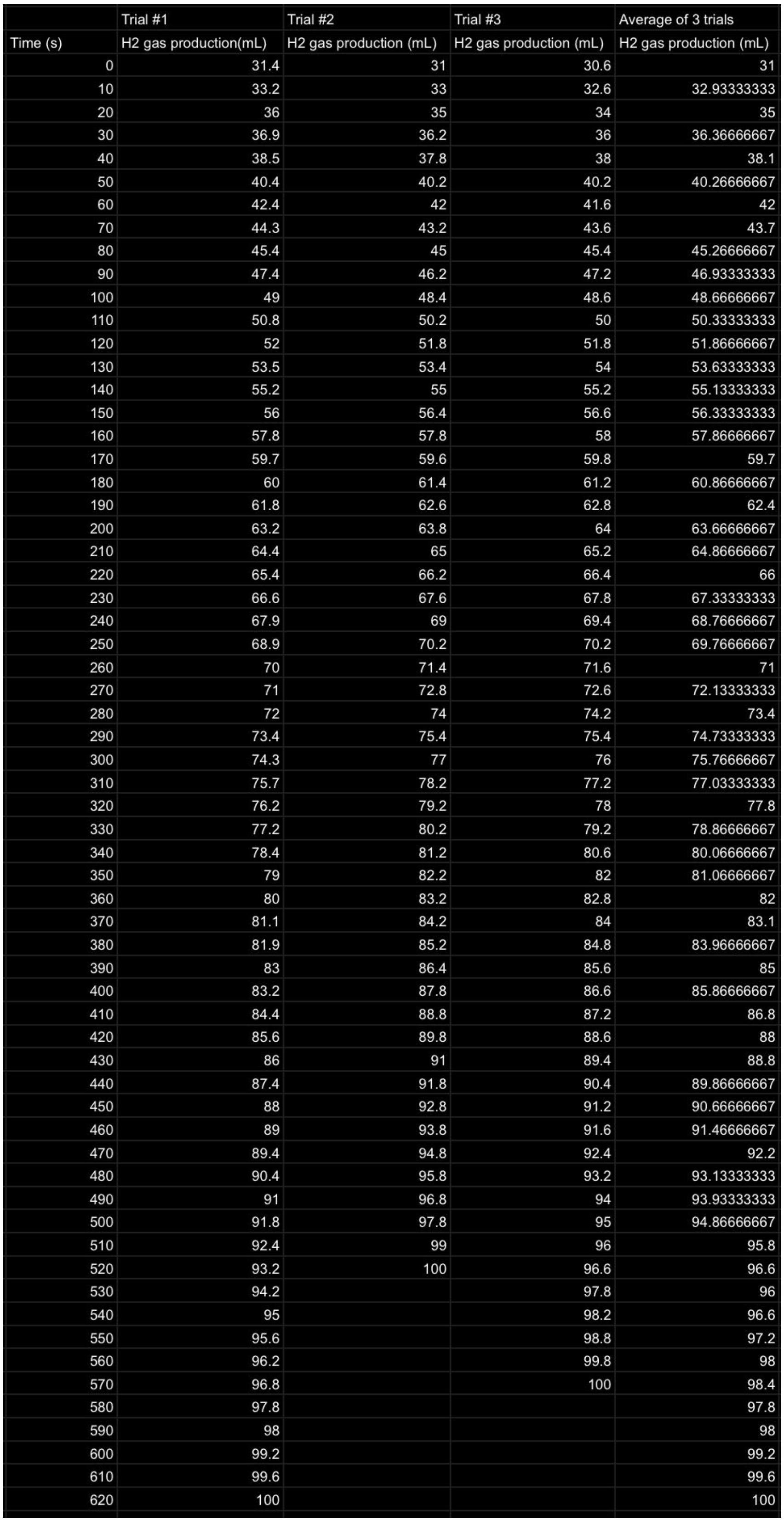
Data collection (tables)



	Trial #1	Trial #2	Trial #3	Average of 3 trials
Time (s)	H2 gas production (mL)	H2 gas production (mL)	H2 gas production (mL)	H2 gas production (mL)
0		33.6	32	32.8
10		35.8	35.4	35.6
20		38	37.8	37.9
30		40.2	39.4	39.8
40		42	42	42
50		44	44	44
60		46.2	47.6	46.9
70		48.2	48.2	48.2
80		50	50.8	50.4
90		52.4	53.2	52.8
100		54.2	54.8	54.5
110		56	57.4	56.7
120		57.8	59	58.4
130		59.4	60.4	59.9
140		61	63.2	62.1
150		62.6	64.8	63.7
160		64.2	65.6	64.9
170		65.8	68	66.9
180		67.4	70.8	69.1
190		69	72.4	70.7
200		70.8	74.2	72.5
210		72.4	76	74.2
220		73.8	78	75.9
230		75.2	78.6	76.9
240		76.8	80.6	78.7
250		78.2	82.4	80.3
260		79.4	84	81.7
270		80.8	85	82.9
280		82.2	86.8	84.5
290		83.8	88.4	86.1
300		84.8	89.4	87.1
310		86	91.2	88.6
320		87.2	92.2	89.7
330		88.4	94	91.2
340		89.6	94.8	92.2
350		90.6	96.4	93.5
360		91.8	97.4	94.6
370		93	99	96
380		94.2	100	97.1
390		95.4		95.4
400		96.6		96.6
410		97.6		97.6
420		98.4		98.4
430		99.2		99.2
440		100		100

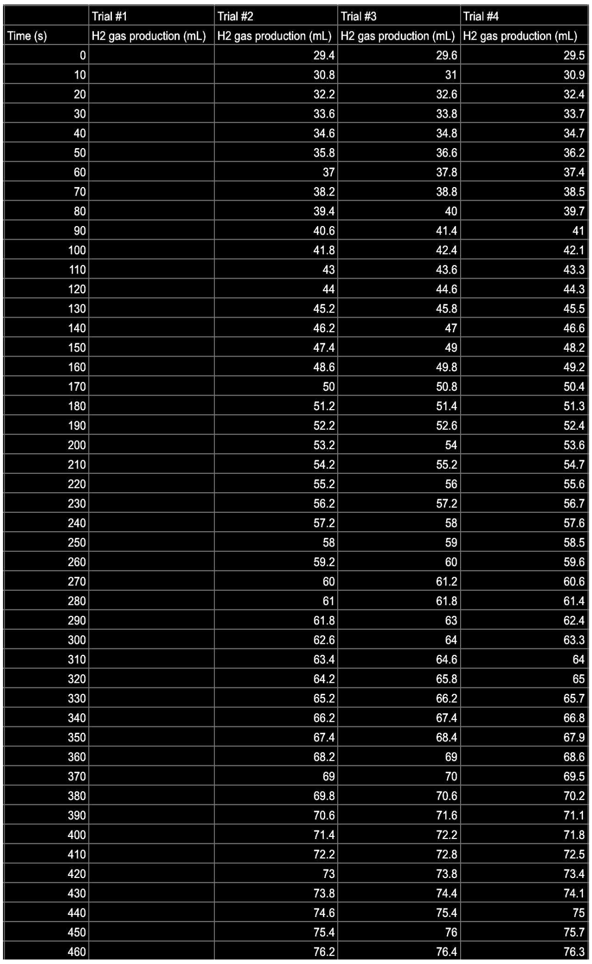
<u>Table 1.0</u>: H2 gas production (in mL) measured at 10 second intervals for 1.0 M HCl across three trials.

*Note: Trial 1 for 1.0 M HCl took much longer than the other two trials for the H2 gas to be produced. This could have led to inconsistencies in our data, which is why it was ultimately omitted.



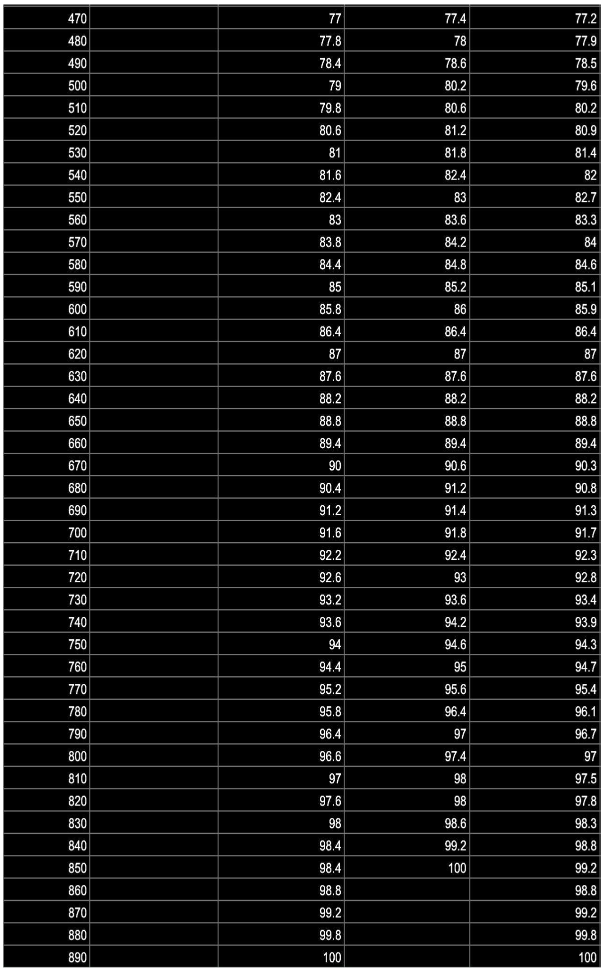
	Trial #1	Trial #2	Trial #3	Average of 3 trials
Time (s)	H2 gas production(mL)	H2 gas production (mL)	H2 gas production (mL)	H2 gas production (mL)
0	31.4	31	30.6	31
10	33.2	33	32.6	32.93333333
20	36	35	34	35
30	36.9	36.2	36	36.36666667
40	38.5	37.8	38	38.1
50	40.4	40.2	40.2	40.26666667
60	42.4	42	41.6	42
70	44.3	43.2	43.6	43.7
80	45.4	45	45.4	45.26666667
90	47.4	46.2	47.2	46.93333333
100	49	48.4	48.6	48.66666667
110	50.8	50.2	50	50.33333333
120	52	51.8	51.8	51.86666667
130	53.5	53.4	54	53.63333333
140	55.2	55	55.2	55.13333333
150	56	56.4	56.6	56.33333333
160	57.8	57.8	58	57.86666667
170	59.7	59.6	59.8	59.7
180	60	61.4	61.2	60.86666667
190	61.8	62.6	62.8	62.4
200	63.2	63.8	64	63.66666667
210	64.4	65	65.2	64.86666667
220	65.4	66.2	66.4	66
230	66.6	67.6	67.8	67.33333333
240	67.9	69	69.4	68.76666667
250	68.9	70.2	70.2	69.76666667
260	70	71.4	71.6	71
270	71	72.8	72.6	72.13333333
280	72	74	74.2	73.4
290	73.4	75.4	75.4	74.73333333
300	74.3	77	76	75.76666667
310	75.7	78.2	77.2	77.03333333
320	76.2	79.2	78	77.8
330	77.2	80.2	79.2	78.86666667
340	78.4	81.2	80.6	80.06666667
350	79	82.2	82	81.06666667
360	80	83.2	82.8	82
370	81.1	84.2	84	83.1
380	81.9	85.2	84.8	83.96666667
390	83	86.4	85.6	85
400	83.2	87.8	86.6	85.86666667
410	84.4	88.8	87.2	86.8
420	85.6	89.8	88.6	88
430	86	91	89.4	88.8
440	87.4	91.8	90.4	89.86666667
450	88	92.8	91.2	90.66666667
460	89	93.8	91.6	91.46666667
470	89.4	94.8	92.4	92.2
480	90.4	95.8	93.2	93.13333333
490	91	96.8	94	93.93333333
500	91.8	97.8	95	94.86666667
510	92.4	99	96	95.8
520	93.2	100	96.6	96.6
530	94.2		97.8	96
540	95		98.2	96.6
550	95.6		98.8	97.2
560	96.2		99.8	98
570	96.8		100	98.4
580	97.8			97.8
590	98			98
600	99.2			99.2
610	99.6			99.6
620	100			100

Table 2.0: H2 gas production (in mL) measured at 10 second intervals for 0.8 M HCl across three trials.



	Trial #1	Trial #2	Trial #3	Trial #4
Time (s)	H2 gas production (mL)	H2 gas production (mL)	H2 gas production (mL)	H2 gas production (mL)
0		29.4	29.6	29.5
10		30.8	31	30.9
20		32.2	32.6	32.4
30		33.6	33.8	33.7
40		34.6	34.8	34.7
50		35.8	36.6	36.2
60		37	37.8	37.4
70		38.2	38.8	38.5
80		39.4	40	39.7
90		40.6	41.4	41
100		41.8	42.4	42.1
110		43	43.6	43.3
120		44	44.6	44.3
130		45.2	45.8	45.5
140		46.2	47	46.6
150		47.4	49	48.2
160		48.6	49.8	49.2
170		50	50.8	50.4
180		51.2	51.4	51.3
190		52.2	52.6	52.4
200		53.2	54	53.6
210		54.2	55.2	54.7
220		55.2	56	55.6
230		56.2	57.2	56.7
240		57.2	58	57.6
250		58	59	58.5
260		59.2	60	59.6
270		60	61.2	60.6
280		61	61.8	61.4
290		61.8	63	62.4
300		62.6	64	63.3
310		63.4	64.6	64
320		64.2	65.8	65
330		65.2	66.2	65.7
340		66.2	67.4	66.8
350		67.4	68.4	67.9
360		68.2	69	68.6
370		69	70	69.5
380		69.8	70.6	70.2
390		70.6	71.6	71.1
400		71.4	72.2	71.8
410		72.2	72.8	72.5
420		73	73.8	73.4
430		73.8	74.4	74.1
440		74.6	75.4	75
450		75.4	76	75.7
460		76.2	76.4	76.3

Table 3.0: H2 gas production (in mL) measured at 10 second intervals for 0.6 M HCl across three trials.

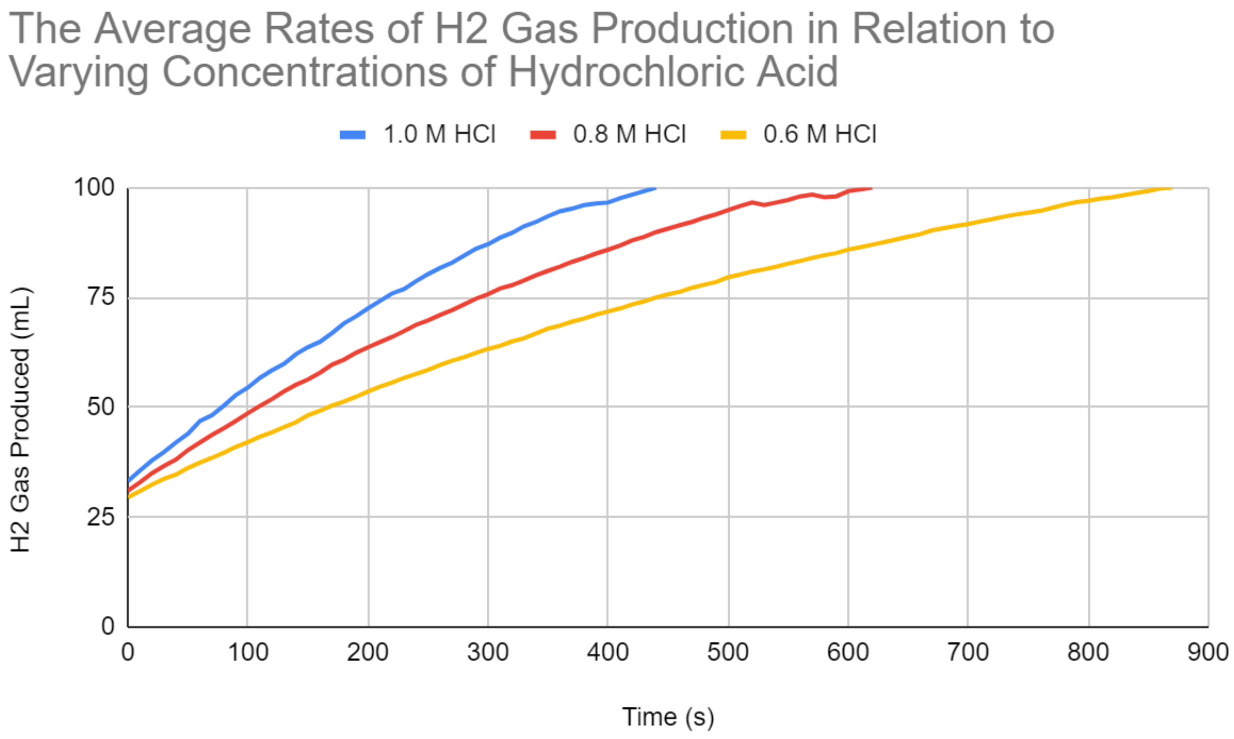


470		77	77.4	77.2
480		77.8	78	77.9
490		78.4	78.6	78.5
500		79	80.2	79.6
510		79.8	80.6	80.2
520		80.6	81.2	80.9
530		81	81.8	81.4
540		81.6	82.4	82
550		82.4	83	82.7
560		83	83.6	83.3
570		83.8	84.2	84
580		84.4	84.8	84.6
590		85	85.2	85.1
600		85.8	86	85.9
610		86.4	86.4	86.4
620		87	87	87
630		87.6	87.6	87.6
640		88.2	88.2	88.2
650		88.8	88.8	88.8
660		89.4	89.4	89.4
670		90	90.6	90.3
680		90.4	91.2	90.8
690		91.2	91.4	91.3
700		91.6	91.8	91.7
710		92.2	92.4	92.3
720		92.6	93	92.8
730		93.2	93.6	93.4
740		93.6	94.2	93.9
750		94	94.6	94.3
760		94.4	95	94.7
770		95.2	95.6	95.4
780		95.8	96.4	96.1
790		96.4	97	96.7
800		96.6	97.4	97
810		97	98	97.5
820		97.6	98	97.8
830		98	98.6	98.3
840		98.4	99.2	98.8
850		98.4	100	99.2
860		98.8		98.8
870		99.2		99.2
880		99.8		99.8
890		100		100

Table 3.1: Continuation of data from Table 3.0.

*Note: Similar to trial 1 for 1.0 M HCl, trial 1 for 0.6 M HCl took much longer than the other two trials for the H2 gas to be produced. This could have led to inconsistencies in our data, which is why it was also omitted.

Data Presentation (graph):



Data Processing/Calculations

To design my graph, I took the average H2 gas production values across three trials for each of 1.0 M, 0.8 M, and 0.6 M HCl. Then, I compiled all those average values from each of the three different concentrations of hydrochloric acid into one table and used that data to create my graph (as seen above). A sample of my calculations to find the averages can be seen below:

(61.8 mL + 62.6 mL + 62.8 mL) / 3 = 62.4 mL

In this example, 61.8 mL of hydrogen gas was produced at some point during trial 1 of the experiment for 0.8 M HCl, 62.6 mL of hydrogen gas was produced at the same point in trial 2, and 62.8 mL of hydrogen gas was produced at that point in trial 3. I took these values, added them up, and divided the total by 3 to acquire an average value of 62.4 mL.

<u>Average Rate of Reaction Calculations:</u>

General Formula: Final Volume of H2 gas - Initial Volume of H2 gas / Time Elapsed = Average Reaction Rate (mL/s)

- For 1.0 M HCl:

100 mL - 33.2 mL / 440 s = 0.152 mL / s

- For 0.8 M HCl:

100 mL - 31 mL / 620 s = 0.111 mL / s

- For 0.6 M HCl:

100 mL - 29.5 mL / 890 s = 0.079 mL / s

Initial Rate of Reaction Calculations:

For 1.0 M HCl: (100 mL - 33.2 mL) / (300 s - 0 s) = 65 mL / 300 s = 0.217 mL / s

For 0.8 M HCl: (100 mL - 31 mL) / (375 s - 0 s) = 69 mL / 375 = 0.184 mL / s

For 0.6 M HCl: (100 mL - 29.5 mL) / (490 s - 0s) = 70.5 mL / 490 s = 0.144 mL / s

Data Analysis

Trends

Based on the data displayed in the graphs above, the higher the concentration of hydrochloric acid, the steeper the curve, indicating a higher rate of reaction. The 1.0 M HCl took the least amount of time to produce 100 mL of H_2. At the same time, across all three trials, the data set with the lowest rate of reaction was the one with 0.6 M HCl, which had a more gradual incline, and which always took over 800 seconds to produce 100 mL of H_2. Based on the graphs, the second highest rate of reaction also corresponded with the second highest concentration of hydrochloric acid, the 0.8 M trial. All Generally, there is a clear trend that is common among all three graphs: the higher the HCl concentration, the less time it takes to produce 100 mL of hydrogen gas.

Conclusion and Evaluation

In our experiment, the independent variable is the concentration of hydrochloric acid and our dependent variable is the rate of the production of hydrogen gas over time. When we adjusted the concentration of HCl we observed noticeable changes in the rates of reaction between HCl and magnesium. We hypothesized that the rate of reaction would increase with an increase in HCl concentration and conversely that the decrease in concentration would reduce the rate of reaction. Based on the data that we collected from our experiment, both of our hypotheses were valid. Our graphs clearly show a directly proportional relationship between HCl concentration and the rate of the reaction. When we decreased the concentration of hydrochloric acid to 0.8 M and then to 0.6 M, it took progressively longer for hydrogen gas to fill up the entire eudiometer and the reduced incline of the graph indicates a decrease in the rate of reaction.When evaluating our data and method associated with the data, we found that one of our trials in particular – trial 1 – was a bit inconsistent. In the graph for trial 1 there is a very small gap in the rate of reaction difference between 1.0 M and 0.8 M but then a much larger one between 0.8 M and 0.6 M. This is most likely caused by experimental errors that we may have or may not have been aware of. Furthermore, according to our initial rate of reaction calculations, the rate of reaction for 1.0 M HCl was higher than that of 0.8 M HCl (0.217 M/s compared to 0.184 M/s), and the rate of reaction for 0.8 M was greater than that of 0.6 M HCl (0.184 M/s compared to 0.144 M/s). Some minor assumptions that were made would be that the room temperature and therefore the temperature of the water in the basin was constant throughout our experiment. We also assumed that all of the reactants reacted, although there was still a very small quantity of magnesium left at the bottom of the Erlenmeyer flask that went unaccounted for – this, however, should not have affected our results much. Generally speaking, we were satisfied with the results of our experiment and according to the data that we received, the relationship between our independent and dependent variables correlated very well with our hypothesis.

Applications & Improvements

Applications:

This experiment can be applied to a variety of situations in the real world, and has quite a few applications. To begin with, this experiment can be used as a prime example to illustrate the characteristic reaction of metals with acid – in this case the metal being magnesium and the acid being hydrochloric acid. Additionally, it can of course be used to produce hydrogen gas that, in large amounts, could be extremely useful – from powering vehicles to generating electricity cleanly. Furthermore, this research can be used to justify phenomena such as the changes in states of matter as hydrogen from HCl (an aqueous solution) separates from chlorine to form a gas (H_2) while the chlorine from HCl separates and combines with magnesium (a solid) to form a new aqueous solution ($MgCl_2$). These particular rearrangements of atoms can therefore offer insights into how new states of matter form without changes in factors such as temperature. Finally, the changes in the rate of reaction in accordance with the changes in the concentration of HCl provide valuable information on the association between reactant concentration and how quickly two substances react with each other.

Improvements:

To collect more accurate data and reduce the probability of experimental errors, there are certainly things that we could do to improve our experimental method. Primarily, if we had the luxury of more time, we could perform more trials to increase the consistency of our results and even determine whether our data was a fluke or if it represents a normal case. In our experiment, to save time, we didn't spend too much time trying to accurately measure 110 mg of magnesium, resulting in values that were slightly higher or lower than 110 mg (such as 112 mg, 108 mg, 109 mg, etc.). However, if we measured the weight of the magnesium more accurately and acquired our ideal value of 110 mg, we may have obtained more consistent "curves" in our graphs – particularly for trial 1. In addition to this, as mentioned previously, we did not account for the 30 mL of displaced air in the eudiometer at first. We instead assumed that 100 mL of hydrogen gas would be produced through the reaction (just enough to fill the eudiometer). This is why we calculated that we must use around 110 milligrams of magnesium in order to have enough of the metal to react with the hydrochloric acid. However, if we had taken into account the 30 mL of displaced air before doing the experiment when we were performing our calculations, we would have known that about 76 mg of magnesium would have been adequate. Since we had more magnesium than we needed, the reaction may have progressed more quickly as the surface area of the magnesium metal reacting with the HCl inside of the Erlenmeyer flask was greater. Hence, this could have definitely affected the true reaction rate of our experiment as well. The lesson for next time would be to always account for the displaced air before doing any stoichiometric calculations. Furthermore, we got a percent yield of 86% for 1.0 M HCl, 91% for 0.8 M HCl, and 83% for 0.6 M HCl. These inaccuracies could be addressed with more accurate weight measurements and greater precision when recording the amount of hydrogen gas produced in the eudiometer, as we did eyeball a few of the measurements. Higher precision when measuring H2 gas quantity inside the eudiometer could certainly yield higher percent yields.

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