Miina Härma Gymnasium

Chemistry

Reaction speed of hydrochloric acid to iron and zinc at normal body temperature and the reaction's effect on human metabolism

Martti Tarro

Extended Essay

Word count: 3,589

Advisor: Erkki Tempel

Tartu 2012

Abstract

The purpose of this study is to investigate the speed of reaction of hydrochloric acid reacting with iron and zinc. The investigation also focuses on the biological aspect of hydrochloric acid, specifically in the human stomach. Choice for the metals depended on their reactivity with acids, the availability of the metals for the school, and the abundance of the metals in the world. The investigation's research question turned out to be:

How fast does hydrochloric acid react with iron and zinc at normal body temperature and would that affect the human metabolism?

The concentrations of the acids are varied for pH values of 1 to 2, which are within the normal limits of a human stomach pH. The metals were taken in powder form. Measuring the final concentration of the solution was done using two methods. The first method tried was collecting the hydrogen gas to find out how much of the hydrochloric acid had reacted with the metals by the method of using an inversed burette. The second method was titrating the hydrochloric acid that was left over from the reaction.

To acquire information as to the reaction speed, experiments had to be carried out. The reaction rate could be found out using the formula:

$r = 0.5 \times \Delta c\ (HCl) / \Delta t$

Finding the rate of reaction, it could be calculated, with relation to human metabolism, how much of the metals would react with the hydrochloric acid in the human stomach.

The research showed that the reaction rates found from the measurements are fast enough to severely affect human metabolism. The reaction took place in a linear fashion, meaning the spped of the reaction was constant. Depending on the concentration of HCl, the mass of iron or zinc reacted in the stomach could be up to 30 grams.

Word count: 300

Table of Contents

Introduction

The topic choice

Choosing a research question was quite difficult for me. I wanted to research something that connected to my life yet would be important for the scientific community. The initial idea was making different strong acids react with different surfaces. This included dealing with reaction speeds, which was a difficult subject to comprehend for me, so I wanted more research into it to understand it better. To make the subject narrower, I thought to choose 2 strong acids (e.g. hydrochloric acid and sulphuric acid) and perhaps 3 or 4 surfaces typically found in a kitchen. This subject, being too broad, was scrapped to some extent. The subject then turned to hydrochloric acid reacting with different metals, and the definition of this reaction speed. And my physics teacher gave me an idea to connect the subject to a social aspect. As the hydrochloric acid also resides in the stomach, the idea was that if the metals are ingested, what would happen to them. That reminded me of a young relative of mine who always plays with toys and at times, tries to eat one. And so, the research question formed: **How fast does hydrochloric acid react with iron and zinc at normal body temperature and would that affect the human metabolism?**

Approach

My research intends to investigate the effects that would take place in a digestive system of a human in the case of ingestion of metals, and the reaction speed of those metals. This is determined by experiments with hydrochloric acid, the main component of the acid in the stomach that breaks down the food ingested, of different concentrations that are possible in the stomach. Choice for the metals for this investigation depended on their reactivity with acids, the availability of the metals for the school, and the abundance of the metals in the world. The final choice was zinc and iron. Another choice of mine would have been magnesium, but it reacted too quickly to be of any use for the research.

I also used hydrochloric acid of different concentrations that would be possible in the human stomach. The pH of the acid used ranged from 1 to 1.7. Higher pH values were not used due to the slow reaction produced.

Investigation

Background information

The term “reaction speed” usually refers to the rate of the reaction. The rates of reactions can be found out by knowing the concentrations of the initial and final solutions. Reaction speed is influenced by many factors. As collision theory **(Pilling, Seakins, 1995, 59-63)** suggests, higher concentration of atoms means more collisions, and more collisions means faster reactions. Higher temperature usually suggests higher rate of reaction **(Pilling, Seakins, 1995, 21-23)** (although, as in the case of anti-Arrhenius reactions, temperature might also decrease the rate of reaction). The molecules have higher energy, so they are faster and collide more often, leading, yet again, to faster reactions. The surface area and particle size also affect reactions. The smaller the particle size, the better can the molecules react with other molecules.

The chemical reactions for these reactions are:

$Fe + 2HCl \rightarrow FeCl_2 + H_2\uparrow$

$Zn + 2HCl \rightarrow ZnCl_2 + H_2\uparrow$

As the hydrochloric acid reacts in 2 moles per 1 mole of metal, the reaction rate could be calculated by the formula:

$r = 0.5 \times \Delta c(HCl) / \Delta t$

(http://www.chm.davidson.edu/vce/kinetics/RateOfReaction.html, 24.10.2012)

Iron, being the most abundant heavy metal (4.7% of the Earth’s crust **(Zumdahl, Steven, Zumdahl, Susan, 2003, 996-997)**) is one of the most important metals to our civilization. Iron is, in its initial form, silvery-white and easily processible. It is moderately active, positioned in the middle of the reactivity series. At room temperature, iron slowly oxidizes. When reacting with acids, in the case of my experiment, hydrochloric acid, the resulting solution contains iron (II) chloride ($FeCl_2$), and hydrogen gas is also formed in the reaction. The chemical equation for this reaction is: $Fe + 2HCl \rightarrow FeCl_2 + H_2\uparrow$ Iron is necessary for the human body to function, for transportation of oxygen and transportation of electrons in redox processes. The daily requirement of iron for an adult is considered to be 10-20 mg, whereas it becomes lethal at dosages of 200-500 mg. Iron containers used to be very popular. When food was cooked in them, compounds of iron were formed and ingested by the people. **(Karik, Truus, 2003, 226, 230-232, 241, 244)**

Zinc is also an important metal, being widely dispersed in the earth's crust. It's an excellent reducing agent, very active and it tarnishes rapidly. With the oxidation number of +2, zinc forms salts that are colourless. **(Karik, Truus, 2003, 319-324)** Zinc chloride solutes in water very easily (432 grams of $ZnCl_2$ in 100 grams of water at 25°C). If the zinc chloride is with crystallized water, the reaction with cations (e.g. K^+) forms complex chlorides. Zinc is used mostly as corrosion protection, but also in colour pigments. Zinc as a compact metal is just a bit toxic, but if food is held in zinc containers, it might damage a human's metabolism. Dissolving zinc salts particularly damage the liver (but the compounds, which don't dissolve in water, are also dangerous, dissolving with the effect of hydrochloric acid in the stomach). **(Karik, Truus, 2003, 319-324)**

The chemical equations for the two reactions I conducted were:

$\underline{Fe + 2HCl \rightarrow FeCl_2 + H_2\uparrow}$ and

$\underline{Zn + 2HCl \rightarrow ZnCl_2 + H_2\uparrow}$

In reality, less hydrogen is formed than the equation shows, because during the reaction, protium (H) atoms are formed, which are transformed in 2 ways: 1) most of the protium atoms form dihydrogen (H_2), 2) 20-40% of the protium atoms react with the oxygen dissolved in the water, producing water, with the chemical equation $4H^+ + O_2 \rightarrow 2H_2O$, due to which the amount of hydrogen formed in the reaction is less than the equation shows. **(Karik, Truus, 2003, 230-232)** The pieces of food are chemically broken down in the stomach by the gastric juice to produce chyme. The gastric juice contains protein-digesting enzymes (pepsinogen), hydrochloric acid and mucus or mucin. **(Leonhardt, H., 1992, 212, 216)** Hydrochloric acid (HCl) in the stomach forms hydrogen (H^+) ions and chloride (Cl^-) ions. As hydrochloric acid is a relatively strong acid, it releases hydrogen and chloride ions of the same concentration as the acid itself, meaning that the concentration of the acid is almost equal to the concentration of the hydrogen ions. The process of digestion by hydrochloric acid is now explained.

The stomach works as a storage and mixing chamber for ingested food. Upon entering the stomach, the food is mixed with the stomach secretions to become chyme. (Stomach secretions from the gastric glands include mucus, hydrochloric acid, pepsinogen, and regulatory molecules such as intrinsic factor and gastrin. Hydrochloric acid produces a low pH in the stomach, which acts as an antimicrobial agent that kills microorganisms **(Leonhardt, H., 1992, 212, 216)** Pepsinogen, a protein secreted by chief cells, is converted by hydrochloric acid to the active enzyme pepsin. Pepsin is an enzyme that breaks proteins into smaller peptide chains. Pepsin exhibits optimum enzymatic activity at a pH of 3 or below, the pH produced in the stomach by the presence of hydrochloric acid. **(Seeley, Stephens, Tate, 2005, 420, 426)** The duodenum is usually protected by sodium bicarbonate (secreted mainly by the pancreas), which neutralizes the chyme. When large amounts of acid enter the duodenum, however, the sodium bicarbonate is not adequate to neutralize the acid. **(Seeley, Stephens, Tate, 2005, 448)** (The mucus membrane of the stomach produces the protein-splitting enzyme called pepsinogen, which is activated by the hydrochloric acid (HCl) of the stomach at a pH of 1.2 to 2 into pepsin. The parietal cells produce the gastric acid. They are large and relatively strongly acidophile, showing how rich they are in membranes and mitochondria, which make up about 40% of the cell volume. Using up large amounts of energy, pariental cells release H^+ ions (and also Cl^- ions) apically to produce gastric acids. At the same time the gastric acids give basic bicarbonate ions. **(Leonhardt, H, 1992, 216)** (Normal body temperature is a range like any other homeostatically controlled condition in the body. The average normal temperature is usually considered to be 37°C when it is measured orally and 37.6°C when it is measured rectally. Rectal temperature comes closer to the true core body temperature, but an oral temperature is more easily obtained in older children and adults, and therefore is the preferred measure. **(Seeley, Stephens, Tate, 2005, 448)**

Methods for data collection

My research concentrated on finding the rate of reaction between hydrochloric acid and zinc and iron. To find this, the final concentration of the solutions had to be determined, or in other words, the amount of hydrochloric acid or metal reacted had to be found. The hydrochloric acid used was initially a 31.5% (concentration 10.4 M) solution, so it had to be diluted to get the needed concentration. Although the concentration of the solution might have decreased over time (as it appears to be an old solution of HCl), this was not considered until the end of the experiment due to my misconceptions.

The initial method considered for the data collection was collecting the hydrogen gas in an inverted burette. That would have shown exactly how much of the hydrochloric acid had reacted and how much hydrogen gas produced. The reaction was to be completed in a Florence flask, with a stopper attached to the top. A rubber tube was attached in the stopper, which led to an inverted burette, which was filled with water. The bottom tip of the burette was in a flask of water, to stop the burette from emptying of water. When the reaction would happen, the hydrogen gas would be produced and would move up through the tube into the burette, pushing the air in the upper part of the burette to push the water down.

Test 1

The first experiments were done with too little ground work and an indefinite research question. The temperature of the reaction was measured only initially, which was room temperature (24.2 °C) instead of a human body temperature (37 °C). In addition, the concentration of the acid was too strong, as it would have shown the pH to be -0.3. The reaction was done with zinc pellets of mass of about 5 grams and 8 grams of 0.5M solution of hydrochloric acid. It was closely observed and the volume of the hydrogen gas noted after every 2-3 minutes. This experiment was conducted for 47 minutes. By that time, the water in the burette was decreasing rapidly (based on the current speed, the amount of water seemed to run out in the next few minutes) and the burette was emptying up, so the experiment had to be stopped. In the end, about 10 cm^3 of hydrogen gas had been produced in the reaction.

Test 2

The second experiment was also conducted with zinc pellets, in this case about 15 grams of 0.5M HCl and 0.16 grams of zinc. The temperature of the solutions was about 22 °C. Three sets of data were collected simultaneously with three sets of apparatus. The duration of the experiments was taken to be three and a half hours. The results turned out to be very varying; hence a large systematic error was concluded. I have three hypothesises for the mistakes. Firstly, the hydrogen gas could have leaked from somewhere between the screw of the burette and the burette itself. Also, it was possible that the rubber tubes used were leaking. The tubes were probably very old and might have been cracked in some places. The choice for the tubes was not very wide, so these tubes were the best ones. And another possibility is that some of the hydrogen had dissolved in the water **(Karik, Truus, 2003, 230-232)**. As the results varied too much and the temperature was still about 295 K instead of 310 K of a human body, these results could not have been used either.

Test 3

The third experiment was conducted using a different methodology. The solutions of hydrochloric acid were prepared to be of pH values of 1 to 1.7, hence in the acceptable range of a human's gastric acid's pH. The amount of hydrochloric acid taken for the experiment was about 20 grams, and the amount of metals was about 0.20 grams. The concentrations of hydrochloric acid were 0.020 M, 0.060 M, and 0.100 M. The metals were both in powdered form. Then the reactions were conducted in a simple beaker, measuring the temperature of the acid throughout the experiment. The temperature was controlled, tried to keep between 36 °C and 38 °C, as is shown by the graphs in Appendix VII. Although (as the graphs show) the temperature was between the range of 36 °C and 38 °C only about half the time, the fluctuation in temperature didn't affect the rate of reaction by much. The temperature was raised by heating the beaker over an ethanol burner for some time. The temperature was maintained by conducting the experiment in a calorimeter. The temperature was measured the whole time throughout the experiment. When the temperature started dropping below 36 °C, the beaker was heated again. This experiment was conducted for 30 minutes, and then a 10 gram sample of the final solution was taken into a different beaker. As the zinc or iron was not present in the sample, the reaction was stopped. Then the amount of hydrochloric acid in the resulting solution was found by the technique of back titration.

Back titration is a method, where a measured amount of the titrant is added to a sample, so there is a bit of an excess. After the reaction with the analyte is completed, the amount of unreacted titrant may be determined by titration with another standard solution. By knowing the amount of titrant taken and the amount remaining unreacted, we can find out the amount of sample that reacted with the titrant. **(Christian, G., 2003, 170)** Back titration might be necessary when the rate of reaction between the analyte and titrant is too slow or when the standard solution lacks stability.

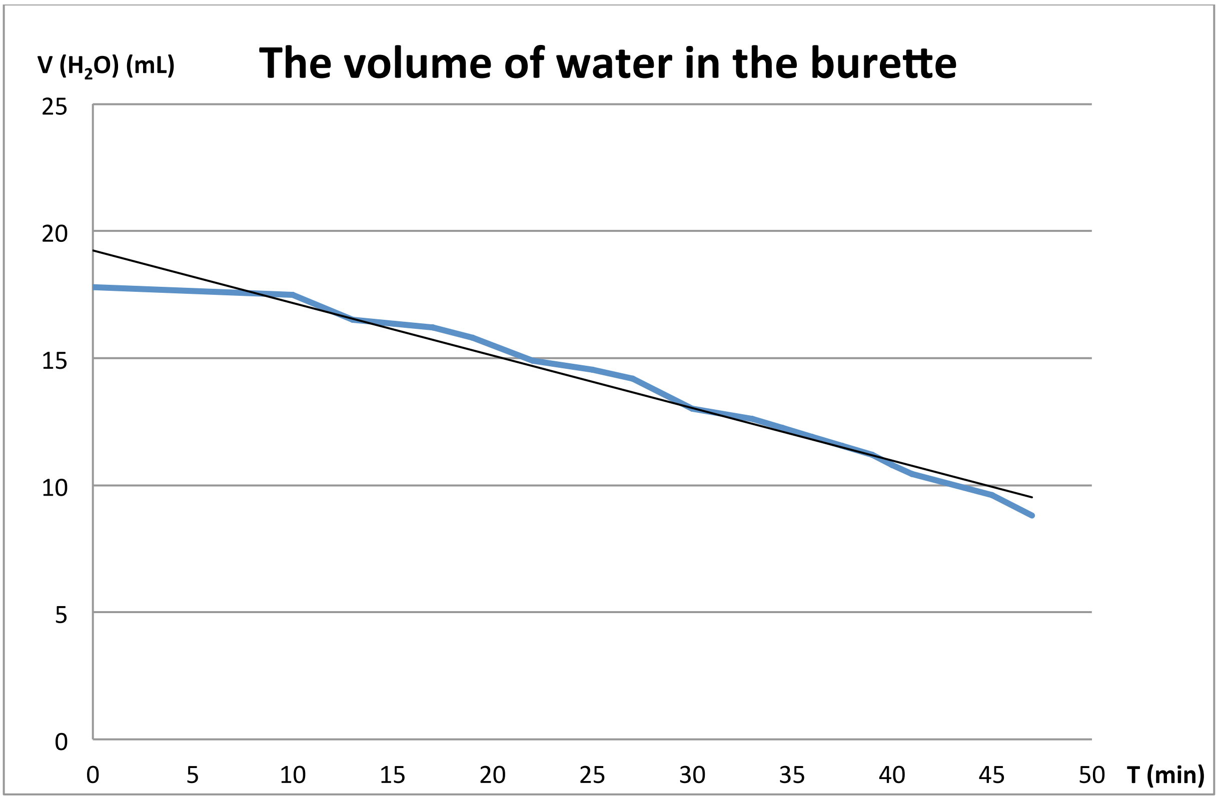
In the case of my back-titration, the sample of either zinc chloride and HCl or iron (II) chloride and HCl was titrated, with the titrant being potassium hydroxide (KOH). A sample of 10 grams of the solution was taken and titrated against a known concentration of KOH (c = 0.05 M). As the solution still contained hydrochloric acid that hadn't yet reacted with the metals, it reacted with the base, forming potassium chloride (KCl). In the case of HCl reacting with iron, the iron salt ($FeCl_2$) formed dissolved in the water, but with the addition of potassium hydroxide, it crystallized, forming a dark greenish tetrahydrate. When HCl reacted with zinc, the resulting salt ($ZnCl_2$) also dissolved in water, and only crystallized with the addition of KOH, showing a white salt. As the resulting solution is neutral, an indicator (phenolphthalein) was added to the solution. The point where all the hydrochloric acid had reacted is the equivalence point of this reaction.

The equivalence point in a titration is a theoretical point reached when the amount of titrant added is chemically equivalent to the amount of analyte in the sample. **(Skoog, West, Holler, Crouch, 2004)** The equivalence point cannot be determined experimentally, but rather estimated by observing some kind of physical change in accordance with the condition of equivalence, which is called the end point of titration. Even though much effort is made to determine that the difference between the end point and the equivalence point is small, there is still an experimental error due to the physical changes in the solution and the ability to perceive them. In the case of my experiment, the theoretical (equivalence) point could not have been calculated due to the unknown reaction speed, as it was to be calculated with the titration itself.

The indicator phenolphthalein ($C_{20}H_{14}O_4$) works so that in strongly acidic solutions (pH of less than 0), the colour is orange-red. In acidic solutions, with pH of 0 to 8 or 9 (different values for various sources), the indicator is colourless, and in the case of basic solutions, it turns pink. **(http://digipac.ca/chemical/equilibrium/phenolpthalein.htm, 25.10.2012)** As in the case of titration, if the reaction between KOH and HCl would have happened, potassium hydroxide would be in excess, and the solution would turn pink. When phenolphthalein was added to the solutions, they turned cloudy white. That is due to the high local concentration of the solid phenolphthalein, exceeding the solubility of the sample. **(Skoog, West, Holler, Crouch, 2004)**

Processed data

Test 1



This is the graph of the volume of water in the inverted burette against time, where the time duration was taken to be from 10 to 47 minutes. As this was the first test, some criteria for the research were not met. The concentration of the hydrochloric acid was too high to be suitable for the human stomach, and the temperature was only 297.2 K. Nevertheless, this graph shows us that the reaction takes place linearly, meaning the volume of hydrogen produced stays the same over time. Despite that, initially, the reaction was slower (in the first 10 minutes, only 0.3 mL of hydrogen had been produced), but speeded up towards the end of the measurements (between minutes 30 and 40, 2.2 mL of hydrogen was produced). This might be due to the protective layer of zinc oxide (ZnO) on the surface of the zinc pellet.

Test 2

The masses of zinc were taken to be 0.16 ±0.01 g.

	t (min)	T (°C)	m (HCl) (g)	V (initial) (mL)	V (final) (mL)	ΔV (mL)
	(±1 min)	(±0.2 °C)	(±0.01 g)	(±0.2 mL)	(±0.2 mL)	(±0.4 mL)

1st set of data	206	22.3	14.90	49.8	45.5	4.3
2nd set of data	206	21.9	15.03	49.7	49.7	0.0
3rd set of data	206	21.9	14.99	36.9	37.1	-0.2

The calculations for the data are done in Appendix V.

In this case, the data doesn't match the theoretical results at all. Even though all the concentrations of HCl, masses of both hydrochloric acid and zinc, and the time duration for the experiment were the same, the resulting volume of hydrogen varied from -0.2 mL to 4.3 mL. The difference is probably due to the different rubber tubes used.

<u>Test 3</u>

The calculations for the concentrations of the solutions are done in Appendix VI.

Metal	c (initial) (mol/dm^3)	c (final) (mol/dm^3)	Δc (mol/dm^3)
	($\pm 0.002\ mol/dm^3$)	($\pm 0.002\ mol/dm^3$)	($\pm 0.004\ mol/dm^3$)
Fe	0.020	0.009	0.011
Fe	0.060	0.019	0.041
Fe	0.100	0.080	0.020
Zn	0.020	0.013	0.007
Zn	0.060	0.034	0.026
Zn	0.100	0.044	0.056

Metal	r ($mol/(dm^3 \times s)$)
	($\pm 2.00\times10^{-6}\ mol/(dm^3\times s)$)
Fe	3.06×10^{-6}
Fe	1.14×10^{-5}
Fe	5.56×10^{-6}
Zn	1.94×10^{-6}

Zn	7.22×10^{-6}
Zn	1.56×10^{-5}

In this experiment, the rates of reactions could be calculated by

These results show the number of moles of metals that could react in a cubic decimetre of a hydrochloric acid solution in one second. The results were collected in the period of 30 minutes, so if the time duration is taken to be more than that, then the reaction rate might be different.

The human stomach is of volume about 4 litres, but normally holds fluids of about 1.5 litres. **(http://www.dimensionsinfo.com/stomach-volume/, 22.10.2012)**

The duration of human digestion varies. It cannot be states with absolute accuracy, and it depends on the type of item ingested, In some persons, even in health, stomach digestion may be uniformly an hour or more slower than it is in others. The quality, composition, and quantity of the food all affect the rate of gastric digestion. Digestion may last from 2 to 15 hours. Taking an average of 7 hours (25200 seconds), and the volume of hydrochloric acid to be 1.5 dm^3, the amount of metals reacted could be:

Metal	r (mol/($dm^3\times$s)	n (mol)	m (g)
	($\pm2.00\times10^{-6}$ mol/($dm^3\times$s))	($\pm$0.005 mol)	($\pm$0.5 g)

Fe	3.06×10^{-6}	0.116	6.5
Fe	1.14×10^{-5}	0.431	24.0
Fe	5.56×10^{-6}	0.210	12.0
Zn	1.94×10^{-6}	0.073	4.8
Zn	7.22×10^{-6}	0.273	18.0
Zn	1.56×10^{-5}	0.590	39.0

Conclusion and Evaluation

The experiments conducted showed that the metals react with the hydrochloric acid in a non-linear fashion, with the initial rate of reaction being slower than the rate of reaction after 30-40 minutes. In the 3rd test, which was the final and most accurate experiment, one of the data points didn't match the general trend. In the case of 0.100 M hydrochloric acid reacting with iron, the amount of potassium hydroxide required for the hydrogen to react in the titration was too much, so the reaction rate turned out slower than the reaction rate of 0.060 M hydrochloric acid and iron. This, however, is not possible, as (in the case of this reaction) a higher concentration of acid gives a faster rate of reaction, as was shown by the other results.

The results collected in the 3rd experiment show that the rates of reactions are increasing with increased concentrations, and are relatively higher for iron than for zinc, meaning that iron reacts quicker with hydrochloric acid than zinc. That might be due to the zinc particles in the powder being of different size, leading to different measurement results.

Further investigation could be made into finding the activation energy of the reaction between iron or zinc and hydrochloric acid.

The results could have been improved by measuring the pH in the solution of HCl and the metal salt. That could have led to the more accurate results in the titration process.

Word count: 3,589

Bibliography

Gary D. Christian, 2004, “Analytical Chemistry”, 6th edition

Steven S. Zumdahl, Susan A. Zumdahl, 2003, “Chemistry”, 6th edition, pp. 996-997

Helmut Leonhardt, 1992, M.D. “Color Atlas and Textbook of Human Anatomy, Vol. 2: Internal Organs”, 4th edition, pp. 212, 216

Hergi Karik, Kalle Truus, 2003, “Elementide Keemia”, pp. 226, 230-232, 241, 244, 319-324

Rod R. Seeley, Ph. D., Trent D. Stephens, Ph.D., Philip Tate, D.A., 2005, “Essentials of Anatomy and Physiology”

Douglas A. Skoog, Donald M. West, F. James Holler, Stanley R Crouch, 2004, “Fundamentals of Analytical Chemistry”, 8th edition

Catrin Brown, Mike Ford, 2009, “Higher Level Chemistry”

Michael J. Pilling, Paul W. Seakins, 1995, “Reaction Kinetics”, pp. 21-23, 59-63

http://www.chm.davidson.edu/vce/kinetics/RateOfReaction.html

http://digipac.ca/chemical/equilibrium/phenolpthalein.htm

http://www.dimensionsinfo.com/stomach-volume/

http://www.science.uwaterloo.ca/~cchieh/cact/c123/stacids.html

http://www.sigmaaldrich.com/catalog/product/FLUKA/318957?lang=en&region=EE

http://www.sigmaaldrich.com/catalog/product/riedel/07115?lang=en&region=EE

Appendices

Appendix I

Variables

Independent:

- The concentrations of hydrochloric acid

Dependent:

- The amount of potassium hydroxide produced
- the amount of hydrogen produced
- Temperature

Controlled:

- the masses of metals used, which were weighed for each experiment
- the masses of the samples of hydrochloric acid that had reacted with the metals
- the masses of the initial hydrochloric acid
- Particle size for the metals

Appendix II

Apparatus used

- Burette (25.0 mL, ±0.2mL)
- Florence flask (100 mL, 250mL)
- Ring stand (and a utility clamp)
- Rubber stopper
- Rubber tube
- Ethanol burner
- Lighter
- Calorimeter
- Narrow stem micropipette
- Beaker (100 mL, 50 mL)
- Wash bottle with distilled water
- Vernier LabQuest interface
- Vernier stainless steel temperature probe (±0.5 °C)
- Vernier thermocouple (±2.2 °C)
- Weighing scale (±0.01 g)
- Spatula

Appendix III

Initial hydrochloric acid

% (initial HCl) = 31.5%

ρ = 1.2 g/mL

M = 36.46 g/mol

The density and the molar mass of the 31.5% hydrochloric acid were found from the homepage of Sigma-Aldrich, which is the producer of the acid I used. (http://www.sigmaaldrich.com/catalog/product/riedel/07115?lang=en&region=EE)

Taking the volume to be V, the mass of the solution would be:

$m = \rho \times V$

$m\ (HCl) = \rho \times V \times (31.5 / 100)$

$n\ (HCl) = \rho \times V \times (31.5 / 100) / M$

$c = \rho \times V \times (31.5 / 100) / (M \times V) = \rho \times (31.5 / 100) / M = 1.2 \times (31.5 / 100) / 36.46 = 0.0104$ mol/mL = 10.4 mol/dm^3

Appendix IV

Raw data and calculations for test 1

The needed concentration for the hydrochloric acid was 0.5 M.

ρ (0.5M HCl) = 1.01 g/cm^3

The density of the 0.5M hydrochloric acid was found from the homepage of Sigma-Aldrich, which was the producer of the acid I used. (http://www.sigmaaldrich.com/catalog/product/FLUKA/318957?lang=en&region=EE)

m (0.5M HCl) = 8.02 g

V (HCl) = 8.02 / 1.01 = 7.94 cm^3

n (HCl) = c × V = 0.5 × 0.00794 = 0.00397 mol

m (Zn) = 5.03 g

n (Zn) = 5.03 / 65.5 = 0.0798 mol

T = 297.2 K

V (mL)	t (min)
(±0.20 mL)	(±0.2 min)
17.80	0.0
17.50	10.0
16.50	13.0
16.20	17.0
15.80	19.0
14.90	22.0
14.55	25.0
14.20	27.0
13.00	30.0
12.60	33.0
12.25	34.5

11.90	36.0
11.55	37.5
11.20	39.0
10.80	40.0
10.45	41.0
9.60	45.0
8.80	47.0

- t = 0.0 -10.0 s

$\Delta t = 10.0 - 0.0 = 10.0$ s

$\Delta V = 17.80 - 17.50 = 0.30$ mL

- t = 30.0 – 40.0 s

$\Delta t = 40.0 - 30.0 = 10.0$ s

$\Delta V = 13.00 - 10.80 = 2.20$ mL

Appendix V

Raw data and calculations for test 2

1st set of data

c (HCl) = 0.5 M

m (0.5M HCl) = 14.90 g

ρ (0.5M HCl) = 1.01 g/cm^3

V (HCl) = 14.90 / 1.01 = 14.75 cm^3

n (HCl) = 0.5 × 0.01475 = 0.0074 mol

n (Zn) = 0.16 / 65.5 = 0.0025 mol

ΔV = 49.8 – 45.5 = 4.3 mL

2nd set of data

c (HCl) = 0.5 M

m (0.5M HCl) = 15.03 g

V (HCl) = 15.03 / 1.01 = 14.88 cm^3

n (HCl) = 0.5 × 0.01488 = 0.0074 mol

n (Zn) = 0.16 / 65.5 = 0.0025 mol

ΔV = 49.7 – 49.7 = 0.0 mL

3rd set of data

c (HCl) = 0.5 M

m (0.5M HCl) = 14.99 g

V (HCl) = 14.99 / 1.01 = 14.84 cm^3

n (HCl) = 0.5 × 0.01484 = 0.0074 mol

n (Zn) = 0.16 / 65.5 = 0.0025 mol

ΔV = 36.9 – 37.1 = -0.2 mL

Appendix VI

Raw data and calculations for test 3

c (HCl) (mol/dm^3)	m (HCl) (g)	Metal	m (metal) (g)	m (sample) (g)	V (in.) (mL)	V (final) (mL)
(±0.002	(±0.01 g)		(±0.01 g)	(±0.01 g)	(±0.2 mL)	(±0.2 mL)

mol/dm^3)						
0.020	20.01	Fe	0.21	10.02	11.5	15.0
0.020	20.02	Zn	0.21	10.01	6.5	11.5
0.060	20.01	Fe	0.20	10.00	0.0	7.6
0.060	20.00	Zn	0.22	10.02	2.3	13.6
0.100	20.01	Fe	0.21	10.01	1.5	33.5
0.100	20.02	Zn	0.21	10.01	9.5	27.0

c (mol/dm^3)	Metal	V (in.) (mL)	V (final) (mL)	ΔV (mL)
(±0.002 mol/dm^3)		(±0.2 mL)	(±0.2 mL)	(±0.4 mL)
0.020	Fe	11.5	15.0	3.5
0.020	Zn	6.5	11.5	5.0
0.060	Fe	0.0	7.6	7.6
0.060	Zn	2.3	13.6	11.3
0.100	Fe	1.5	33.5	32.0
0.100	Zn	9.5	27.0	17.5

It should be noted that in this case, the volumes are the volumes of KOH when titrated.

Also, the time duration for all the measurements was 1800 seconds (30 minutes).

All the graphs of the temperature over time for these experiments are given in Appendix VII.

c (HCl) = 0.020 M, Fe

$\Delta V = 3.5\ cm^3$

c (KOH) = 0.05 M

n (KOH) = 0.05 × 0.0035 = 1.75 × 10^{-4} mol

n (KOH) = n (HCl)

V (sample) = V (0.020M HCl) ≈ 20.01 / 1.00 = 20.0 cm^3

c (HCl) (final) = 1.75 × 10^{-4} / 0.0200 = 0.00875 M

c (HCl) (initial) = 0.020 M

Δc = 0.020 – 0.00875 = 0.01125 M

<u>c (HCl) = 0.060 M, Fe</u>

ΔV = 7.6 cm^3

c (KOH) = 0.05 M

n (KOH) = 0.05 × 0.0076 = 3.8 × 10^{-4} mol

n (KOH) = n (HCl)

V (sample) = V (0.060M HCl) ≈ 20.01 / 1.00 = 20.0 cm^3

c (HCl) (final) = 3.8 × 10^{-4} / 0.0200 = 0.019 M

Δc = 0.060 – 0.019 = 0.041 M

<u>c (HCl) = 0.100 M, Fe</u>

ΔV = 32.0 cm^3

c (KOH) = 0.05 M

n (KOH) = 0.05 × 0.0320 = 0.0016 mol

n (KOH) = n (HCl)

V (sample) = V (0.060M HCl) ≈ 20.01 / 1.00 = 20.0 cm^3

c (HCl) (final) = 0.0016 / 0.0200 = 0.08 M

$\Delta c = 0.100 – 0.08 = 0.02$ M

<u>c (HCl) = 0.020 M, Zn</u>

$\Delta V = 5.0\ cm^3$

c (KOH) = 0.05 M

n (KOH) = $0.05 \times 0.0050 = 2.5 \times 10^{-4}$ mol

n (KOH) = n (HCl)

V (sample) = V (0.060M HCl) $\approx 20.02 / 1.00 = 20.0\ cm^3$

c (HCl) (final) = $2.5 \times 10^{-4} / 0.0200 = 0.0125$ M

$\Delta c = 0.020 – 0.0125 = 0.0075$ M

<u>c (HCl) = 0.060 M, Zn</u>

$\Delta V = 13.6\ cm^3$

c (KOH) = 0.05 M

n (KOH) = $0.05 \times 0.0136 = 6.8 \times 10^{-4}$ mol

n (KOH) = n (HCl)

V (sample) = V (0.060M HCl) $\approx 20.00 / 1.00 = 20.0\ cm^3$

c (HCl) (final) = $6.8 \times 10^{-4} / 0.0200 = 0.034$ M

$\Delta c = 0.060 – 0.034 = 0.026$ M

<u>c (HCl) = 0.100 M, Zn</u>

$\Delta V = 17.5\ cm^3$

c (KOH) = 0.05 M

n (KOH) = 0.05 × 0.0175 = 8.75 × 10^{-4} mol

n (KOH) = n (HCl)

V (sample) = V (0.060M HCl) ≈ 20.02 / 1.00 = 20.0 cm^3

c (HCl) (final) = 8.75 × 10^{-4} / 0.0200 = 0.044 M

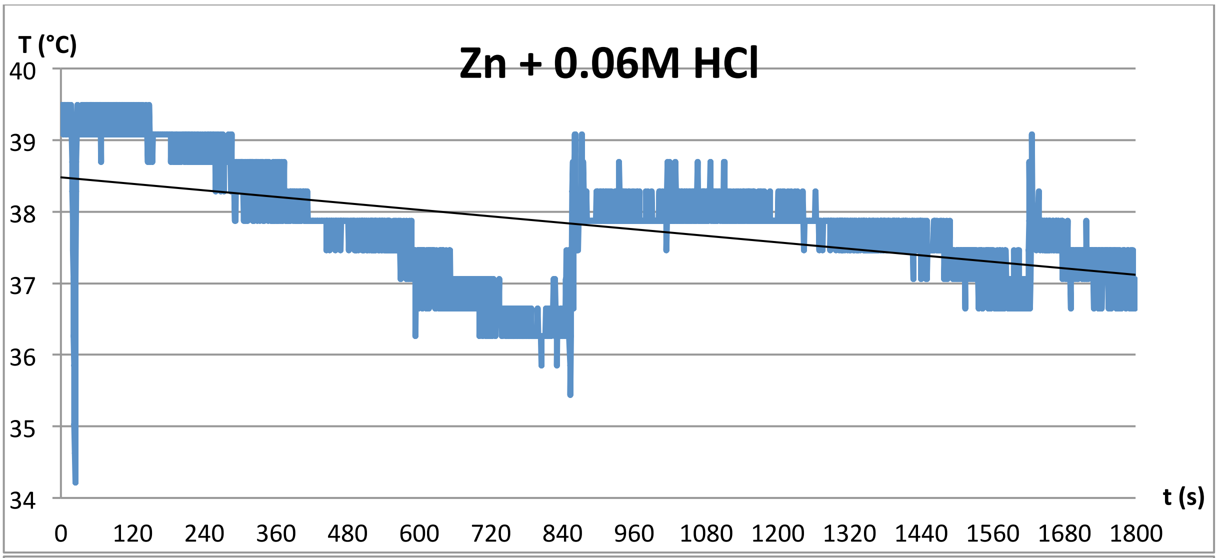
Δc = 0.100 – 0.044 = 0.056 M

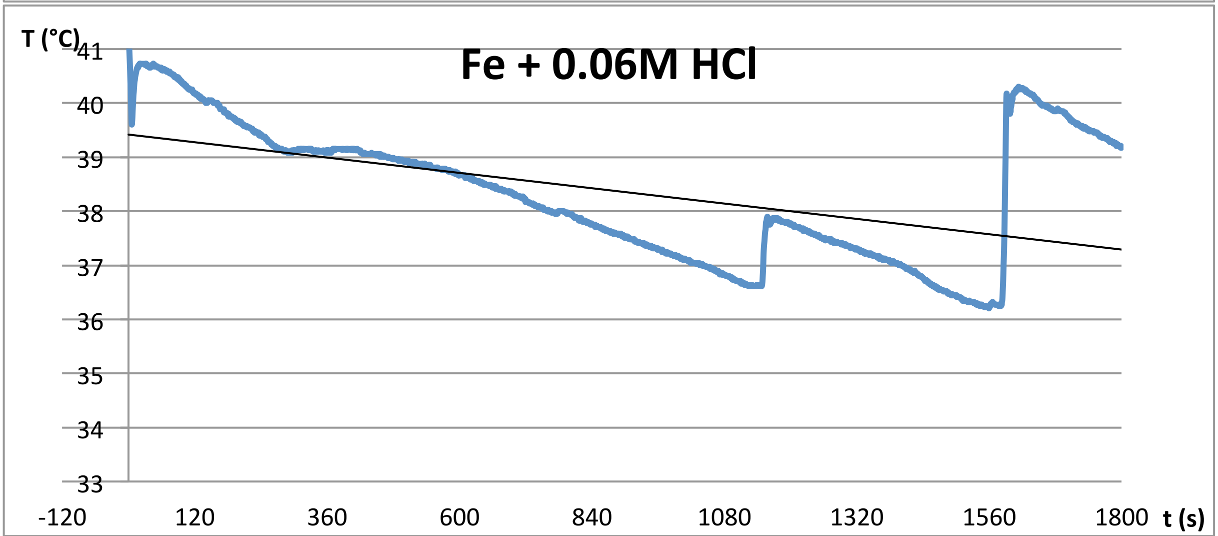
Rate of reaction is calculated r = 0.5 × Δc(HCl) / Δt

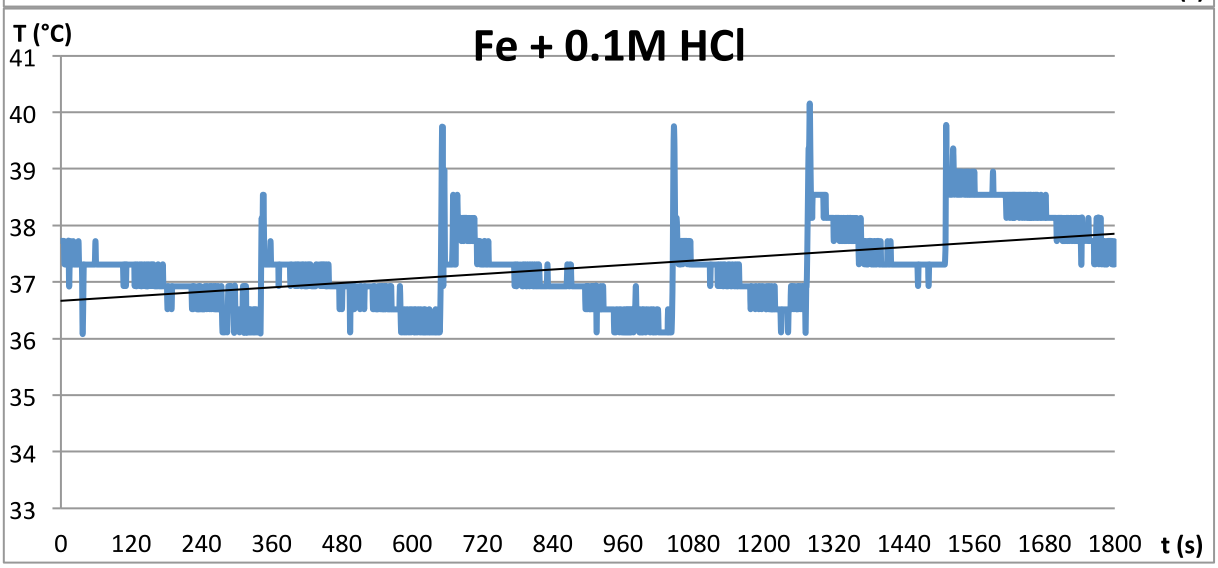
Metal	Δc (mol/dm^3)	r (mol/(dm^3×s))
	(±0.004 mol/dm^3)	(±2.00×10^{-6} mol/(dm^3×s))
Fe	0.011	3.06×10^{-6}
Fe	0.041	1.14×10^{-5}
Fe	0.020	5.56×10^{-6}
Zn	0.007	1.94×10^{-6}
Zn	0.026	7.22×10^{-6}
Zn	0.056	1.56×10^{-5}

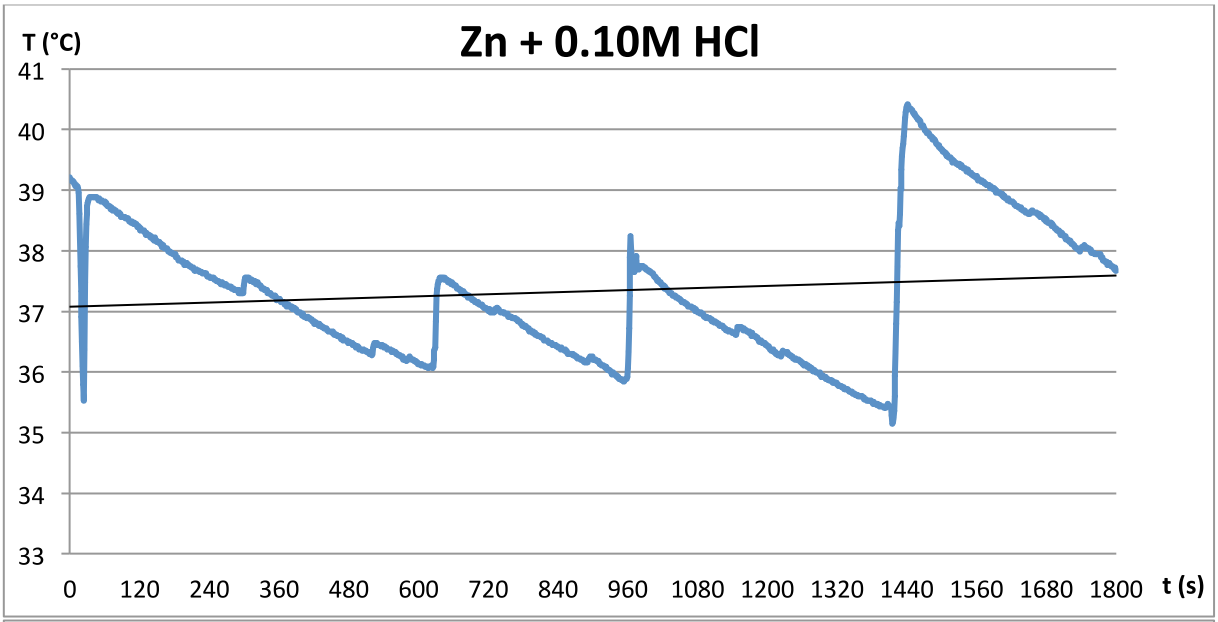
Appendix VII

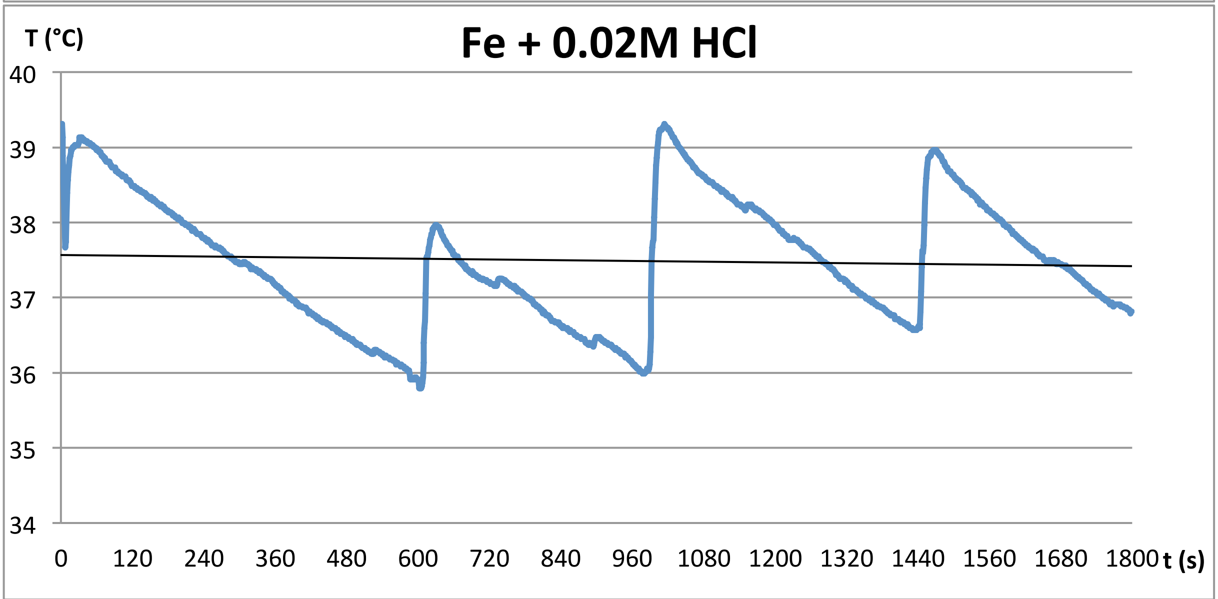
Temperature measurements for test 3

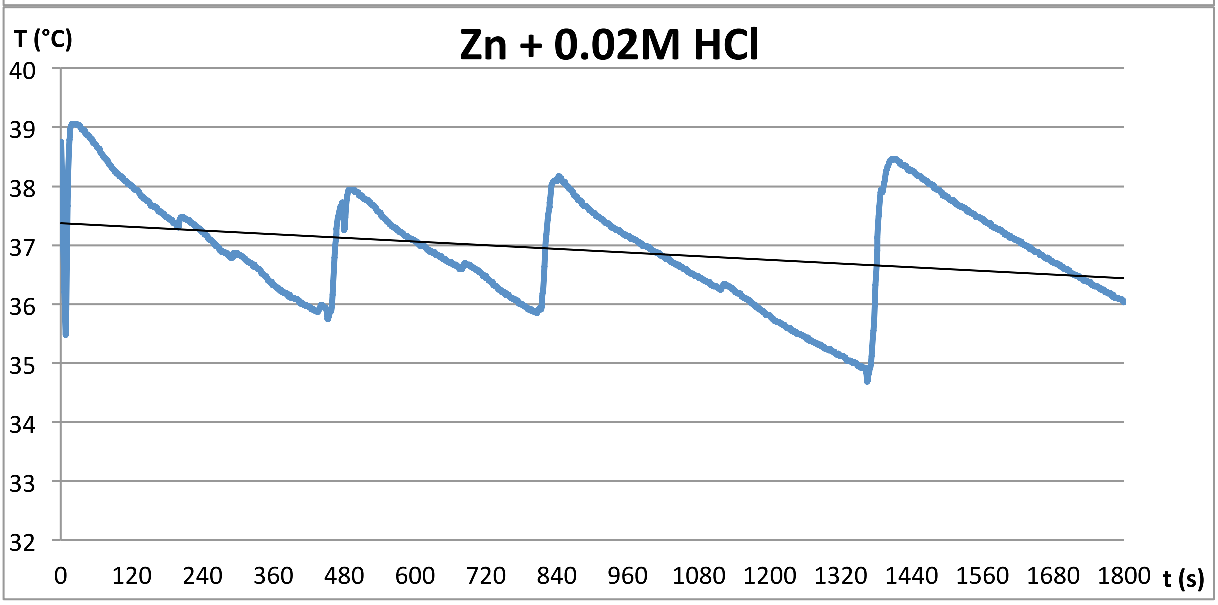

Zn + 0.06M HCl
T (°C)
40
39
38
37
36
35
34
t (s)
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800


Fe + 0.06M HCl
T (°C)
41
40
39
38
37
36
35
34
33
-120 120 360 600 840 1080 1320 1560 1800
t (s)


Fe + 0.1M HCl
T (°C)
41
40
39
38
37
36
35
34
33
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
t (s)


Zn + 0.10M HCl
T (°C)
41
40
39
38
37
36
35
34
33
0
120
240
360
480
600
720
840
960
1080
1200
1320
1440
1560
1680
1800
t (s)


Fe + 0.02M HCl
T (°C)
40
39
38
37
36
35
34
0
120
240
360
480
600
720
840
960
1080
1200
1320
1440
1560
1680
1800
t (s)


Zn + 0.02M HCl
T (°C)
40
39
38
37
36
35
34
33
32
0
120
240
360
480
600
720
840
960
1080
1200
1320
1440
1560
1680
1800
t (s)