

The Decomposition of Hydrogen Peroxide

This experiment will look at the decomposition of hydrogen peroxide and the rate of reaction of that process.

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Factors Influencing the Reaction Rate

There are several factors which influence the reaction rate. First of all, it's the nature of reaction, what type of species are being formed as the reaction proceeds, concentration of the reactants, the temperature of the reactant, and the presence of or lack of a catalyst in the solution.

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Reaction Rate

The rate of a reaction is the change in concentration of a product, or one of the products as a function of the change in time. So if we look at the example shown below, where we have $A+B$ yields C as our product, we can see that rate equals the change in concentration of C over the change in time.

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General Rate Law

From our experimental data we can form a general rate law. Rate equals ' k ' times the concentration of ' A ' to the ' m ' power times the concentration of ' B ' to the ' n ' power where ' k ' is our rate constant. This will be constant for a reaction under the same temperature conditions. M and N are the order of the reaction with respect to each reactant. So ' m ' is the order of the reaction with respect to ' A ' and ' n ' is the order of the reaction with respect to ' B '. M and N are not coefficients from the balanced chemical equation. These numbers are determined by looking at experimental data. M and N are always integers, such as 0, 1, 2, and 3. Again, these are determined from experimental data.

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Determining Order of the Reaction

We can determine the order of the reaction with respect to each reactant based on experimental data. We can then find the overall order of the reaction by summing the individual orders together. For our previous example, the overall order of the reaction will be equal to $m+n$.

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Decomposition of Hydrogen Peroxide

In this experiment we're going to be looking at the decomposition of hydrogen peroxide. Over time, hydrogen peroxide will decompose to form water and oxygen. The presence of potassium iodide in the solution will make this process go much faster. The next time you use hydrogen peroxide out of the bottle in your home medicine cabinet, make sure you check the date. While this process is slow, it does happen. You do need to pay attention to the expiration date so you know what you're getting in the bottle is actually peroxide and not just a bottle of water. Because this forms a gaseous product in oxygen, we are going to measure the pressure change over time to determine the rate of the reaction.

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Experimental Setup

The image here shows the experimental setup. We'll have a test tube immersed in a beaker of water so that the temperature remains constant. We'll use a temperature probe to monitor that temperature so that we can accurately record the value. Before you start, make sure you check the units on the pressure sensor. The reading should be in kilo Pascals. If you need help fixing this, check with you TA for assistance.

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Data

Now, you're going to be collecting some data on this experiment and we also have some other information that you collected before you actually started the reaction when we measured out our solutions. There's a lot of information here, and the goal is that we're going to build a table much like the table that you saw on rate problems when you did them in chemistry 107. So you can look at the examples in Chang, and that's what we're shooting for. It's going to take us a couple more steps to get there. Nobody is just going to tell us the concentration and tell us the rate, we have to do a few calculations, but the table in the end should look very similar to that one. So the first thing we're going to look at is the temperature. This is the easy part because we measure the temperature of the water bath that the test tube is in. That will be the temperature of our reaction. We know that one. The next thing we need to look at is the concentration of H_2O_2 after mixing and the concentration of KI after mixing. This mixing happens when we first mix these two solutions together. Imagine we mix the solution and freeze them so that no reaction has occurred. That will be our concentration after mixing. We're going to figure out what those concentrations are BEFORE the decomposition process actually started. As soon as those two solutions are combined, the decomposition process is going to move very quickly. We're going to figure out what the concentration WOULD HAVE BEEN if the decomposition didn't start immediately.

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Mass Percent and Molarity

Now there's a couple things we're going to need to do that. First of all, the hydrogen peroxide is given in mass percent. Mass percent and molarity are related because they're both concentrations. However, their definitions are somewhat different. Molarity is moles of solute over liters of solution. Mass percent is mass of the solute divided by the total mass of the solution times one hundred. You will need to convert from mass percent of hydrogen peroxide to molarity of hydrogen peroxide. An example of this is worked out in your lab manual. If you need help, check with your TA, go to the learning center or see the lab supervisor.

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Dilution

To determine the concentrations of both the hydrogen peroxide and the KI solution, you will also need to do a dilution calculation. It has the formula $M_1V_1 = M_2V_2$. M_1 and M_2 are your concentrations and V_1 and V_2 are your volumes. Don't forget for V_2 you need to use the total volume of the solution. Let's set up an example here. What is the NaCl concentration when I combine 5mL of 1M NaCl solution with 10mL of 1M KBr solution? We're worried about the NaCl concentration. I'm going to look at that information to determine my M_1 and my V_1 . If I look at the example, I see that M_1 is going to be 1.0M. V_1 will be 5.0mL equals M_2 - that's the value we don't know times the V_2 and that in this case we need to add up both of these because the total volume after we combine these two solutions together will be 5+10 or 15mL. Remember to add up the total volume in order to determine the concentration of the diluted solution. When we work out the math, we find that $M_2 = 0.33\text{M NaCl}$. We can do something similar with KI only we'd start with the volume 1 of 10mL but our total volume because we're combining these two solutions, would still be 15mL.

Data Table

Now we know how to find H_2O_2 after mixing and the KI after mixing. Next, we need to look at finding the initial rate. Notice that we have written here kPa per second because that's the way we're going to collect the information in the lab.

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Determination of Initial Rate

This is a sample graph of data for this experiment. If u look on the Y-axis, you see pressure and kPa and on the X-axis you see time in seconds. If we determine what the slope of this line is, remember: change in 'y' over change in 'x' is the slope. If we look at the units of that, we're going to have kPa over seconds. That's exactly what we need in the table. If we take the slope of our best fit line, which in this case is 0.0954, that is going to be our initial rate in kPa per second.

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Data Table

Now we need to find the initial rate in molarity per second. We have the rate in kPa per second. This is just going to be a conversion to get from one set of units to the other set of units.

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Unit Conversion: kPa/s to M/s

We've got kPa/s on one side and we've got M/s on the other side. The reason we're changing the units is because M/s is typically the way the initial rates are reported when you do sample problems. In this case we formed a gas, oxygen and we have a unit of pressure. Anytime I have that, ideal gas law will be involved: $PV=nRT$. We know that molarity equals moles over liters. When we look at the units of the ideal gas law, that's going to be the same as n/V . We're not going to worry about the seconds right now. We're just going to worry about molarity. Let's rearrange the ideal gas law so that we get n/V on one side by itself. $P/RT = n/V$. We can now rewrite that to say $P/RT = M$ (molarity). Now we've got pressure over RT equals molarity. If we look at our one set of units on the left, we have a pressure unit and on the right we have molarity. Now all we need to do is divide both sides by seconds. If we rewrite this, we're going to end up with pressure over seconds divided by RT equals molarity over seconds. The fraction on the left looks a little odd but I wanted to write it so that it matches up with the information that we have from the problem. We have pressure over seconds- we got that from the slope of our graph. Divide that number by RT . What we'll end up with is our value in the units of molarity per second.

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Data Table

That tells us how to get the initial rate in molarity per second. Now all we have left is the rate constant 'k'. The units of this are going to vary depending on the order of the reaction. We're going to find this information by setting up our general rate law using the experimental data and then solving for 'k'.

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Rate Law & Rate Constant

Now let's compare our table to a problem in Chang. We're beginning to see that we've got these lists of concentrations, we have some initial rates and that's the information we need to determine our general rate law. We compare how the concentrations change with how the rate changes to determine the order of the reaction with respect to both the H_2O_2 and the KI . Once we set up our general rate law, we can calculate the rate constant. When we do examples in class or in lecture, we get nice round

numbers...1, 2, 3. When we're looking at experimental data, particularly for students in their first year of chemistry, we don't always get such nice numbers. You may need to round generously to get whole numbers for your orders of the reaction.

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Data Table

Now we've found everything we need to complete our data table. We have a lot of information there.

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Arrhenius Equation

We're going to do one more thing after this. We're going to use something called the Arrhenius equation to determine what the activation energy of the reaction is. In order to do this, we need to determine the rate constant at two different temperatures, but the concentrations of the reactants must be the same. That way everything is the same, except for the temperature. When we plug our values in, k_2 as our rate constant at temperature 2, k_1 as our rate constant at temperature 1, E_a as our activation energy, R is the gas constant, T_1 is our temperature at conditions 1, and T_2 is our second temperature. Make sure you get your numbers inserted into the formula correctly. This may look a little bit different than the formula listed in your Chang book. Sometimes these values, the T_1 and T_2 value, will be flipped. When that happens, it will be a minus sign in front of it. It doesn't matter which one you use, they're both mathematically equivalent. Just make sure you're consistent with the formulas so that you don't mix things up.

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General Tips for Experiment

A few general tips for this experiment:

Make sure you record the exact volumes used of each solution. The amounts given in the lab manual are a general guideline, but it's important that you have the exact volume used in your particular experimental setup. Remember, when using volumetric glassware, you can always estimate one decimal place beyond the markings on the glassware. The fitting between the sensor and the tubing needs to be snug so there are no leaks. Please don't over tighten them as you can easily break the fittings. As soon as you mix your solutions, you should immediately insert the stopper and press 'collect' on Logger Pro. The reaction begins as soon as the reagents are mixed, therefore oxygen is being formed. You will get a much better data set if you get the data as close to the start of the reaction as possible. Use a clamp and

a ring stand to immerse the test tube in water. It's not sufficient for the test tube to be floating on top of the water. It needs to be in the water so the solution temperature is constant.

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General Tips for Experiment

Students are encouraged to do a trial one to make sure they have all the equipment set up correctly and they know how to start the experiment on Logger Pro. Then, you can repeat trial one and collect the data that you will actually use on your data analysis and then your lab report. Please use caution as hot plates are hot. They will melt plastic such as the tubing on the gas pressure sensor and the cord on the temperature probe. If you should accidentally melt one of those, please notify your TA so that it can be replaced or repaired. Again, record the EXACT volume used. It's much more important that you have the exact volumes used in your experiment rather than just writing down the volumes listed in the lab manual. You can estimate one decimal place beyond the markings on any volumetric glassware. As with all experiments, if you have questions, see your TA, go to the learning center, or talk to the lab supervisor.