EXPERIMENT E4(I)

Introduction to Kinetics: Factors that Affect the Rate of Reaction

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(Modified version of Chad Eller and University of Michigan General Chemistry Laboratory Manual)

I. OBJECTIVES

- Be able to list and rationalize the factors that affect the rates of reaction such as that shown in Figure 1.
- Explain various scenarios using the factors that affect reaction kinetics.
- Learn how team works to balance theory with practice

Figure 1. Eggshells reacting with HCl

II. INTRODUCTION

Throughout nature, chemical reactions occur at different rates. Some reactions such as the rusting of iron are relatively slow while others such as the combustion of gasoline occur very quickly. Scientists, however, have figured out ways to make various reactions run faster or slower. Becoming familiar with the factors that affect the rate of a reaction gives us insight into how reactions work. The field of chemistry that concerned with the rate at which reaction occurs is called chemical kinetics.

A rough analog can be made to the speed with which a computer completes a specific task. All computers are not created equal. If you try to run the newest 3-D game in high resolution on an old machine you will be lucky to get it to work at all. Each component of a computer has a definite and predictable effect on its performance. Too little RAM, slow bus speed, fragmented hard drive, inefficient operating system or application, multitasking, network congestion – they all work to slow down our computing experience. But for each problem there is a solution. It just takes a little knowledge (theory) and a few tries at improvement (experiments).

Chemists and computer engineers are not the only people concerned with the rates of processes. Consider these examples:

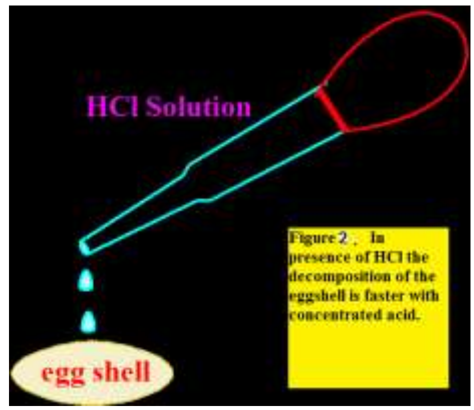
Career	Application
Biologist	Preservation or decomposition of specimens
Chemical Engineer	Speed of production effecting cost
Civil Engineer	Concrete and asphalt curing
Doctor	Medication or poison effecting the body
Museum Curator	Dating, restoration, preservation of artifacts
Restaurant Owner	Food spoilage and safety

BACKGROUND

In order to understand each factor that affect each the rate of a chemical reaction we can use the simple model of atoms as very small spheres in constant motion. Molecules are groups of these spheres that are bonded together and are constantly bouncing off each other. Picture just a few molecules at a time and consider what happens to them in different circumstances. Think of this model as we study the effects of concentration, surface area (for solids), temperature, and catalysts.

A. Effect of Changing the Concentration of Reactants

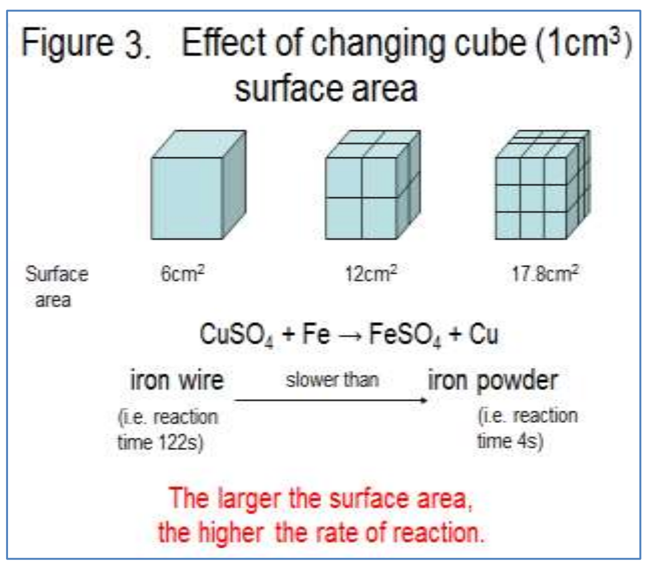
Chemical reactions involve breaking chemical bonds, rearranging the reactant atoms, and making new chemical bonds. In order for this to occur, molecules must collide with each other. If there are only a few molecules of each reactant in a given volume, the number of collision between them will be relatively low. By increasing the concentration of the reactants, we increase the number of reactants molecules in the same amount of space (Figure 2). This means there are more opportunities for a collision to occur.



Fishing can be used as an analogue for the effect of concentration. If you are fishing in a well–stocked pond with thousands of fish (a high concentration) you have a better chance of catching a fish than if the same pond only had 2 or 3 fish (a lower concentration).

B. Effect of Changing the Surface Area

In the case where one of the reactants is a solid, the majority of the atoms are trapped beneath the surface. Only the atoms on the surface are available to collide with the other reactant. When a sample cube is cut into smaller pieces (Figure 3), the amount of surface area increases, even though the volume does not change. Grinding a solid into a powder vastly increases the surface area, making a large portion of the atoms available to collide with the other reactant. In your daily experience, you may have seen that fine salt crystals dissolve in water faster than course rock salt.



C. Effects of Changing the Temperature

The average molecular kinetic energy of a sample is constant at a given temperature. However, the random nature of molecular motion means that some molecules will be moving faster than others. At any given temperature a few molecules have enough energy to react. This minimum required energy is called the activation energy, E_a. As the temperature of the system is increased, the kinetic energy available during collisions goes up and the proportion of collisions exceeding E_a increases (Figure 4). This allows the reaction to take place faster at a higher temperature.

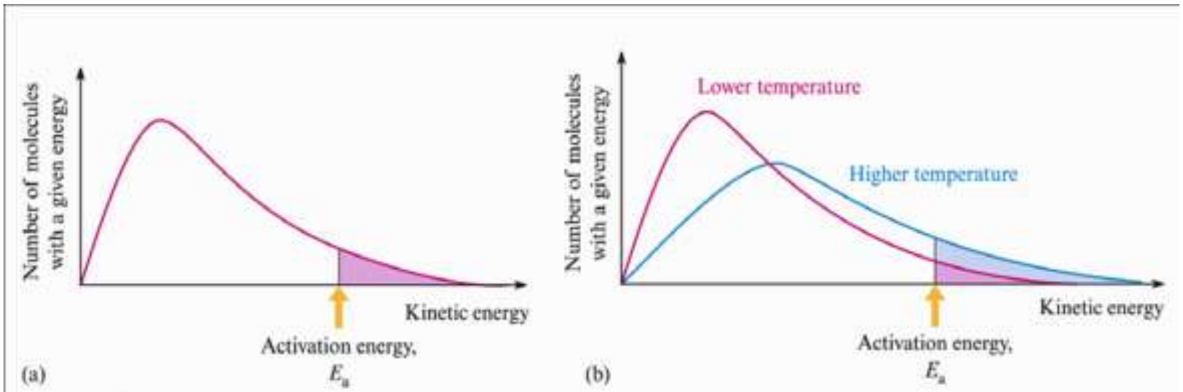


Figure 4 . The relationship between temperature and the fraction of collisions with enough energy to react.

Think of rolling a ball up an inclined driveway into a garage. If you roll the ball slowly, it comes right back to you. When you roll it fast enough, however, the ball makes it into the garage. The amount of the energy needed to get the ball into the garage is analogous to activation energy of a reaction. Only when a molecule can acquire at least that much energy does a reaction take place.

Just as some driveways are steeper than others, chemical reactions differ in the amount of energy needed to make them occur. Why don't all reactions have the same E_a? Sometimes the bond to be broken is very strong. In other reactions there is an unstable intermediate molecule that requires a lot of energy to make (Figure 5).

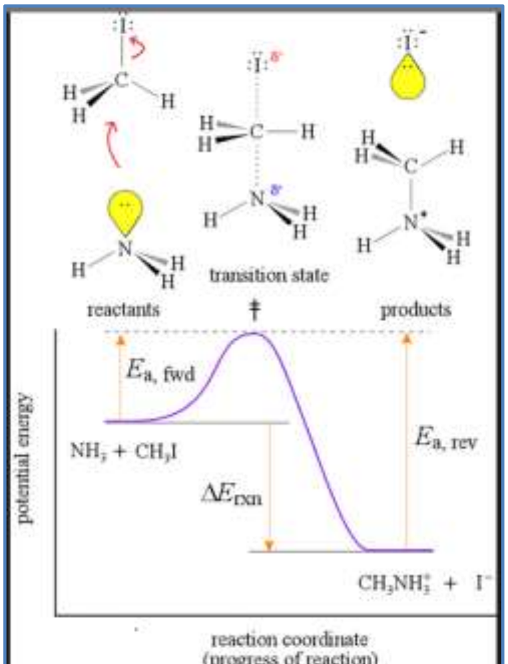


Figure 5 Activation energy and transition state for a reaction between NH_3 and CH_3I

D. Orientation of the Collisions

As every baseball player knows, hitting the ball does not guarantee a home run. Sometimes the ball hits the top of the bat and pops straight up, other times it hits the bottom of the bat, and the batter grounds out. Only when the swing is aligned with the ball you can hit a home run.

Likewise, in chemistry, every collision does not result in a chemical reaction (Figure 6). In order for bonds to form, atomic orbitals must overlap just right. Complex molecules can have shapes that make it unlikely for this overlapping of orbitals to happen in any particular collision. The likelihood of a correct spatial relationship is expressed in the constant 'A', which we will use later in a mathematical model of reaction rates.

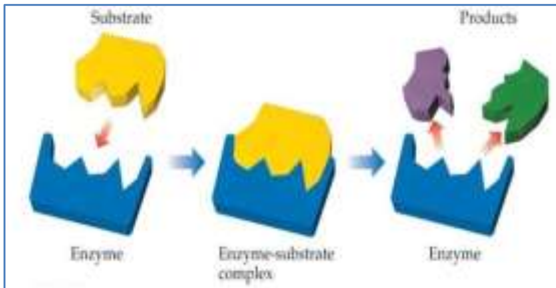


Figure 6. The imporance of correct collision orientation on the success of a chemical reaction (Enzyme catalysis example)

E. Effect of Adding a Catalyst

Although scientists are not able to directly control the activation energy of the orientation of a collision for a reaction, the use of catalyst often allow for the manipulation of these factors. A catalyst is a material that does not permanently change or get used up in a reaction, but helps the reaction run faster. The catalyst lets a reaction from the same product it normally would, but by following a different, less energy intensive route (Figure 7).

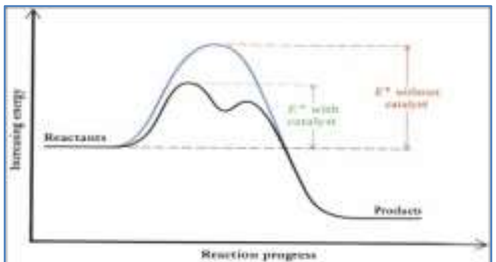


Figure7. The difference in activation energy between a catalyzed and uncatalyzed reaction.

You can think of a catalyst as bridges: they let you cross the river without having to walk miles and miles to find a shallow spot to wade across. Bridges are used, but not destroyed, and where you end up is the same. They just make the trip easier and faster. Catalysts work in many different and often complicated ways. Sometimes they temporarily donate or absorb electrons, hydrogen ions or hydroxide ions in order to provide the alternative, lower energy reaction mechanism.

III. OVERVIEW

Each factor that affects the rate of reaction will be demonstrated with a chemical reaction or model. Pay attention to which factor is affecting the rate in each case. A key to understanding kinetics is to consider how the changes we make will determine what the atoms are experiencing thereby leading to a change in the rate of reaction. Before proceeding with the experiment you must follow the safety rules and warning.

Results of experiment E4(I) are mostly qualitative & not quantitative, like observing color change, bubbles etc. So, no need to have precise microgram weights of solid powders of Fe, Zn, MnO_2, and KI. Save your accurate efforts to complete the next experiment E4(II), so simply compare your sample powder amount to standard sample amounts setting against the wall of the lab. Again, minimize waste and contamination.

Safety Warning: Safety rules & chemical waste disposal guidelines must be followed in order to prevent personal injury and to protect yourself, others & the environment. If you are unable to observe the rules then you are at risk of been dismissed from the lab.

Caution:

● Do not dump any of the reagents down the sink!

● Discard the waste in an appropriate waste container under the supervision of your instructor!

● Do not allow solutions to come in contact with your skin! Wear gloves & goggles!
(Silver ion, Ag^+, will color your skin. Some ions are TOXIC).

●Separate chemical waste of: Acetone, HCL, solutions of ($CuSO_4$, I_2, MnO_2), H_2O_2, & solids to recycle Fe & Zn.

● **Do not waste chemicals and repeat trials not required.**

This is a group experiment where each student shares data with his members of the group, each 2 students in a group must do first experiment E4(I) (Parts A, B, C & E, but once for each part, do not repeat trials). Be conservative on the use of chemicals and do not waste on no need trials. Each student must submit individual report the following week. Do not forget that the individual pre-lab exercises (PLE) due at start of each experiment and should reflect the changes in the procedures shown below.

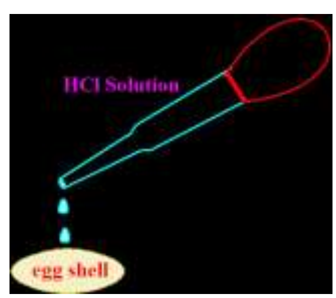
There are few minor changes to the lab manual instructions of the University of Michigan including skipping minor sections but they are shown by lighted or fading print (shown in case instructor may want you to conduct them).

IV. EXPERIMENTAL PROCEDURES

"Each 2 students complete the entire experiment E4(I). Take photos of your favorite lab work for use in your final PPT presentation assigned by your TA about one of the experiments E1-E5"

PART A. Effect of Changing the Concentration of Reactants

Chemicals Used	Materials Used
HCl, 1M and 6M in dropper bottles Eggshells	Watch glass (2)



Caution: 6M HCl is caustic. If any is spilled on your skin, immediately rinse with running water and inform your laboratory instructor. As always, you should wear your goggles at all times when working in the laboratory. Dispose of waste according to instructor's directions.

1. Bring with you to the lab some eggshells from boiled eggs.
2. Place small pieces of the eggshells in each of the two watch glasses.
3. Add 10 drops of 1M HCl to one sample of eggshells and 6M HCl on the other. Record your observations.

PART B. Effect of Changing the Surface Area

Chemicals Used	Materials Used
Coffee creamer (Skip this) $CuSO_4$, 0.2 M Iron wires & iron powder	Candle (tea light or votive candle) and lighter (Skip this) Spatula Disposable pipet 50 mL beakers (2) Hot plate and thermometer Glass stirring rods

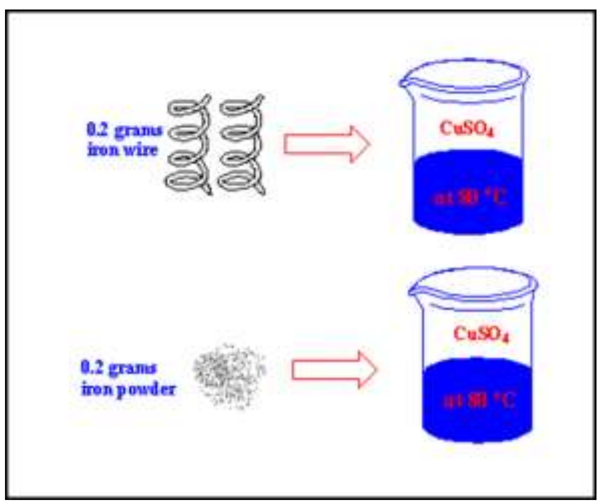
Caution: Clear flammable materials from lab bench and surrounding areas.

Case I: Flammability of coffee creamer (SKIP THIS CASE I & PROCEED TO CASE II):

After lighting the candle, use a spatula to hold a small amount of coffee creamer in the flame for 5 seconds. Record your observations. Next, draw a small amount of coffee creamer into a disposable pipet. While standing at arms length from the candle, aim a burst of coffee creamer at the flame. Again, record your observations. Clean your lab bench according to your instructor's directions.

Case II: Reaction between $CuSO_4$ and iron metal.

1. Add 5 mL of 0.2 M $CuSO_4$ to each of two 50-mL beakers and heat both in hot water bath to 80 ºC.
2. While solution is heating, prepare separately 1 piece of 0.2g iron wire (0.2g, about 8cm long) and 0.2g iron powder (0.2g, use spatula about 1cm wide of powder from tip). Simultaneously drop the iron samples one into the 1 beakers and the other to the other beaker, then stir.
3. Record any color changes and how long it takes before the changes occur. Dispose the waste according to your instructor's directions.



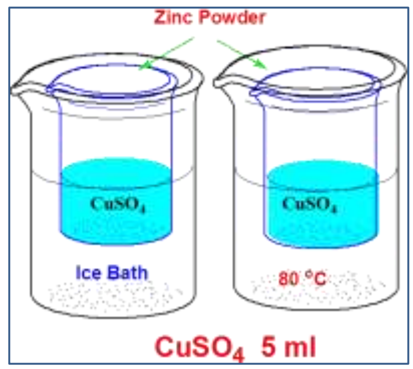
PART C. Effect of Changing the Temperature

Chemicals Used	Materials Used
Food coloring (dark) (Skip this) $CuSO_4$ (0.2 M) Ice Zinc metal (10 mesh, granular)	50-mL Glass beakers (2) Hot plate and thermometer Tongs or heat resistant gloves Spatula, graduated cylinder Clay, small lump

Case I: **Dispersal of dye in hot and cold water (SKIP THIS CASE I & PROCEED TO CASE II).**

Fill two 400-mL beakers each with 250 mL water. Heat one to 80 ºC. Without stirring, add one drop of food coloring to each container by touching the surface with the dropper. Record the time required for the color to disperse.

Case II: **Reaction between $CuSO_4$ and Zinc.**



Add in sequence 5 mL portions of 0.2 M $CuSO_4$ into available graduated cylinder then pour into each of two 50-mL beakers. Heat one solution to 80 ºC in the hot water bath, while cooling the other in an ice bath. Add a few pieces of granular zinc (about 0.05g, use spatula about 0.2cm full of powder from tip) to the cold container. Record any color changes and how long it took for the changes to occur. Repeat by adding a few pieces of zinc to the hot solution. Again, record your results. Dispose of waste according to instructor's direction..

Case III: **Modeling Activation Energy (SKIP THIS PART III).**

Roll a piece of modeling clay into a ball no bigger than Ping-Pong ball. Drop the clay on a clean area of floor from a height of 1 foot. Gently push the clay sideways to see if it rolls. Note any shape change upon impact. Drop the clay several more times each time about one foot higher. Roughly how high did you need to drop the clay for it to stick firmly to the floor?

PART D. Modeling the Significance of the Orientation of Collisions (SKIP THIS PART D & PROCEED TO PART E)

Materials Used
Styrofoam–Velcro balls (4, 2 each with one piece of Velcro and 2 each with 6 pieces of Velcro) Box or deep tray

Place two of the Styrofoam balls with 6 pieces of Velcro on them in a box or deep tray. Gently shake the container until the two balls stick. Repeat with the 2 balls that have only one Velcro square. Describe how readily the balls stick together in each case.

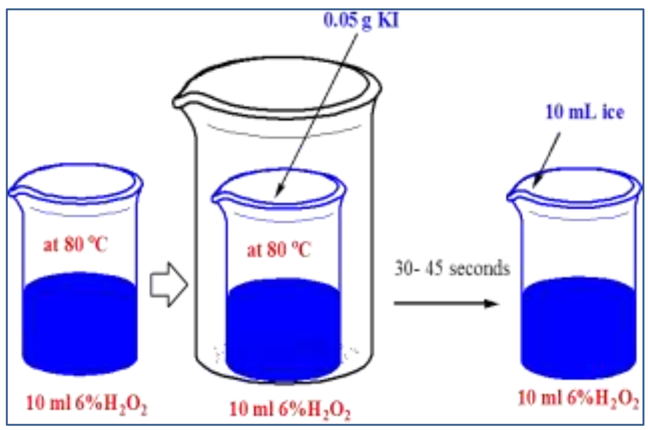
PART E. Effect of Adding a Catalyst. (Catalyst does not get consumed by the reaction but it donates or absorbs electrons, hydrogen ions or hydroxide ions)

Chemicals Used	Materials Used
Hydrogen peroxide (H_2O_2), 6% solution MnO_2 Ice 0.5% corn starch solution (Skip this) Iodine solution (saturated) in dropper bottles	100-mL beaker Hot plate and thermometer Tongs or heat resistance gloves 600-mL beaker Spatula 50-mL beaker Glass stirring rods

Caution: Avoid contact with hydrogen peroxide. If any is spilled on your skin, immediately rinse with running water and inform your laboratory instructor. As always, wear your goggles at all times when working in the laboratory. Dispose of peroxide waste according to instructor's directions. In general, peroxide waste is NOT compatible with other chemical waste. Carefully add MnO_2 powder H_2O_2 and avoid direct view of any liquid splashing.

Case I: **Decomposing H_2O_2**

In a 100-mL beaker, heat 10 mL of 6% H_2O_2 to 80ºC. Using tongs or heat resistant gloves remove the beaker from the hot plate and place the whole beaker inside a large 600-mL beaker. Using spatula, add roughly 0.05g of MnO_2 (a pinky nail sized granular) to the H_2O_2. Record your observations within 30-45 seconds. Do not view from above, as minor splashing may occur. After 30 – 45 seconds, add 10 mL of ice to the solution. Again, record your observations.



Case II: **Hydrolysis of Starch. (SKIP THIS CASE II)**

Using 50-mL beakers, warm two 10-mL samples of 0.5% corn starch solution to 40ºC. Add 10 drops of iodine to each sample and record your observations. Collect 2 mL of saliva from yourself and lab partner. Thoroughly mix the saliva into one of the corn starch/iodine solutions. Record the time required for the solution to become light lavender or clear. Add a few more drops of iodine. Note the color of drops as they enter solution, and the color after mixing. Dispose of waste according to your instructor's directions.

E4(I): Introduction to Kinetics: Factors That Affect the Rate of Reaction

Name:	Lab instructor:
Date:	Lab section:

V. PRE-LABORATORY EXERCISES (PLE)

1. Name four factors that are under the control of scientist when he or she wants to increase the rate of a reaction.

2. As scientists, we often talk about wanting to speed reactions up. Can you think, however, of any reactions that you might rather slow down than speed up? Can you imagine any way to use the factors from previous question to help you control the specific reaction you want to slow down?

3. You have an important project due tomorrow and you are trying to use every free second to put on the fishing touches. Whenever possible, you also rush through your typical daily tasks and responsibilities. Which of the following has associated with it a time constraint that is under your control and can be adjusted safely: showering, driving to school, math class, eating lunch, Doctor’s appointment and grocery shopping. Briefly explain your answers.

4. A living cell must accomplish many complicated chemical tasks. Our bodies contain countless enzymes that are used to speed up otherwise slow reactions. Knowing that enzymes are a type of catalyst, which of the following factors is effected by the presence of an enzyme: the energy of the reactants, the energy of the products, the energy of the transition state, the likelihood of a collision with the correct orientation, or the temperature of the reaction. Briefly explain your answer (s).

E4(I): Introduction to Kinetics: Factors That Affect the Rate of Reaction

Name:	Lab instructor:
Date:	Lab section:

Important note: Students of each group must record their experimental raw data on one datasheet of page 13, then copy it (photocopies ok) and include it with this PLQ. In addition, students must complete all the sections on this PLQ.

VI. RESULTS AND POST-LABORATORY QUESTIONS (PLQ)

Part A. Effect of Changing the Concentration of Reactants

In what ways was the reaction between the eggshells and the 1 M HCl similar to the reaction between the eggshells and the 6 M HCl? In what ways were the reactions different?

Part B. Effect of changing the surface area

Case I: <u>Flammability of coffee creamer (SKIP CASE I & PROCEED TO CASE II)</u>

What was the effect of spraying g the coffee creamer at the flame rather than holding a spatula full in the flame? Explain your observations in terms of surface area.

Case II: Reaction between $CuSO_4$ and iron metal.

Describe the appearance of the solution before addition of the iron metal.

Describe the appearance of the solution and the iron wire after the reaction.

Describe the appearance of the solution and the iron powder after the reaction.

In which case did the reaction occur first? Explain why.

Part C. Effect of Changing the Temperature

Case I: **Dispersal of dye in hot and cold water (SKIP THIS CASE I AND PROCEED TO CASE II)**

Time required to disperse dye in room temperature water:
Time required to disperse dye in hot water:
Explain your observations in terms of the kinetic energy of the water molecules.

Case II: **Reaction between $CuSO_4$ and zinc**

Record any color changes & time to occur	**Cold solution**	**Hot solution**
Time for 1st color change in the….		
Time for 2nd color change in the ….		

What effect does increasing the temperature have on the rate of reaction? Explain why.

Case III: **Modeling Activation Energy (SKIP THIS CASE III)**

Why doesn't the clay always stick to the floor? Explain how this activity serves as an analogy for activation energy.

Part D. Modeling the Significance of the Orientation of Collisions (SKIP THIS PART D)

In which case (the ball with 1 Velcro or 6 Velcro pieces) was the required orientation for successful collision more restrictive? Explain.

Did this agree with your observations of how long it took for the balls to stick? Explain.

Part E. Effect of Adding a Catalyst

Case I: **<u>Decomposing H_2O_2</u>**

Observations after addition of KI:

Observations after addition of ice:

In Case I, which material is the catalyst?

Does the temperature affect the usefulness of a catalyst?

Case II: **Hydrolysis of Starch** **(SKIP THIS CASE II)**

Description of corn starch solution:

Observation after addition of Iodine:

Observation after addition of saliva (compare with control):

Observation after addition of more iodine:

1. Marble, like chalk is composed of $CaCO_3$. Explain why monitoring the acidity of rainfall would be important with regards to conserving historically and artistically important outdoor statues.
2. A chemical engineer is trying to increase output of a chemical plant. She is considering using an expensive catalyst or increasing the temperature of the large reaction vessel by 20ºC to accomplish the same task. Which route will be least expensive in the short term? Long term?
3. Is the blue chemical in the $CuSO_4$ solution a catalyst? How do you know?
4. As the reaction progresses and the reactants are consumed, will this tend to increase or decrease the rate of reaction? Explain.

E4(I) DATASHEET FOR A LAB SECTION

Print this datasheet and bring it with your ALR report, record your raw experimental data on it, then attach it to your individual PLQ.

	A	B	C	D	E	F	G	H	I	J	K
1		VC211 EXPERIMENT E4(I) DATASHEET: KINETICS FACTORS AFFECTING REACTION RATES									
2		SECTION: ________		TA: ____________				EACH 2 STUDENTS COMPLETE ENTIRE E4(I) EXPERIMENT			
3				GROUP EXPERIMENT BUT EACH TWO STUDENTS DO ENTIRE EXPERIMENT. SUBMIT INDIVIDUAL REPORT							
4		PROCEDURE PARTS →		A	A	B	B	C	C	E	E
5				CONCENTRATION EFFECT		SURFACE AREA EFFECT		TEMPERATURE EFFECT		ADDING CATALYST EFFECT	
6	GRP	NAME	ID	EGGSHELL RXNS		COLOR CHANGE $CuSO_4$ @ 80^0C		COLOR CHANGE $CuSO_4$ & 0.05g Zn		10mL 6% H_2O_2 & 0.05g MnO_2 POWDER	
7	#	Chinese		1M HCl	6M HCl	0.2g Fe Wire	0.2g Fe Powder	Ice Cold	Hot @ 80^0C	80^0C, in 30-40s	10mL ICE AFTER 30-40s
8–9		NOTES →		Add no more than 10 drops		Use available cylinder to measure 5.0 mL and the available hot water bath		Use available cylinder to measure 5.0 mL and the available hot water bath		To avoid back flash avoid direct view and place the sample small beaker inside larger beaker	
10	1										
11	1										
12	1										
13	1										
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26	5										
27	5										

IMPORTANT NOTES

- **Each two students will do entire E4(I)**
- **Clean all glassware and rinse with distilled water**
- **Use 5mL $CuSO_4$ & hold beaker down with hand while wearing cloth gloves**
- **Use hot water bath for heating to 80^0C**
- **Handle hot beakers with tong or cloth glove**
- **Work safely & dispose chemicals in waste container**
- **Must follow chemical disposal instructions: E4(I) waste in one large beaker (no rinse water), then remove solids into its own waste container, then drain solution into inorganic waste containers, while disposing E4(II) waste into another beaker then remove stirring rod and place on top of stirrer machine pan then dispose the solution in organic waste container**