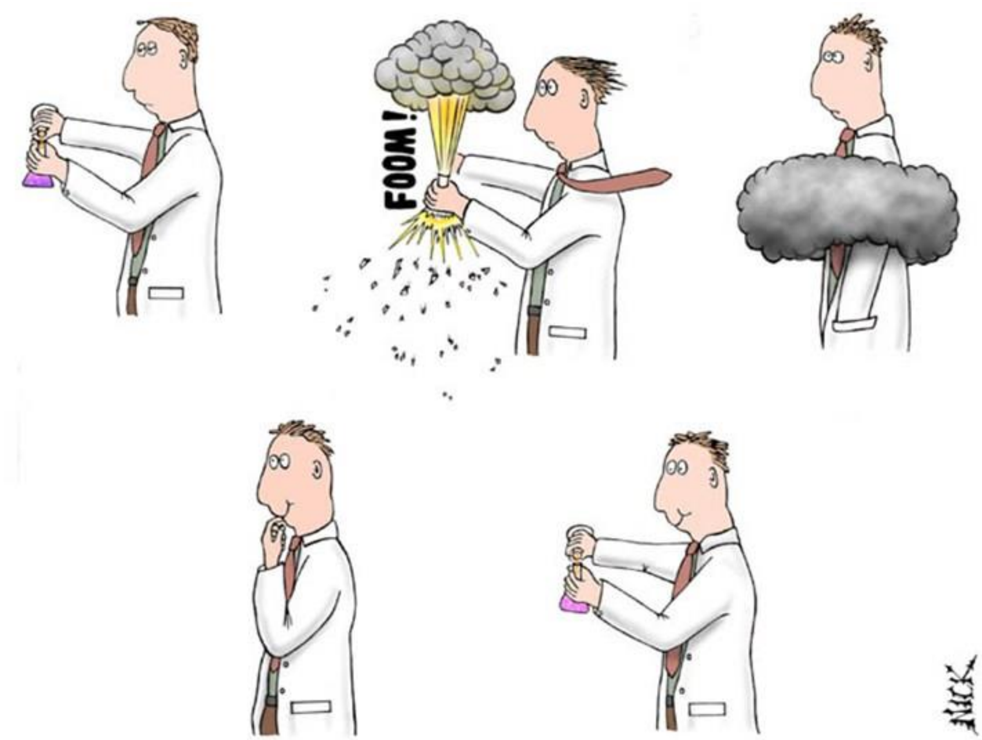
CHEMISTRY 40S

The Alchemist's Cookbook

UNIT 2 – RATES OF REACTION



NAME:____________________________________

It is expected that the activities in this book are completed as they are performed in class. This book will be collected at the end of the unit and a mark will be given.

LET'S GET STARTED!

By the end of this unit, you should be able to:

- ✓ Define rate of reaction as a change in quantity per unit of time. In chemistry, the standard unit of rate is molarity/second (mol/L.s)
- ✓ Calculate the rate of appearance of products and disappearance of reactants in mol/L.s from data obtained from experiment.
- ✓ Calculate the rate at which a product is formed from the rate at which a reactant is used up using stoichiometric ratios.
- ✓ Plot molarity vs. time on a grid and use the resulting graph to determine the average rate and instantaneous rate of reaction from the slope of the lines.
- ✓ Identify 4 variables that influence the rate of a reaction and explain why they do using collision theory.
- ✓ Draw and analyze a potential energy diagram of an exothermic and an endothermic reaction.
- ✓ Formulate a rate law for a reaction from rate data obtained in the lab.
- ✓ Explain the concept of a reaction mechanism and evaluate possible mechanisms for a given reaction.

This unit will take approximately 13 lessons to complete and will comprise 10% of your mark in this class.

ACTIVITY #1 – LAB: LET'S GET GASSY!

Background:

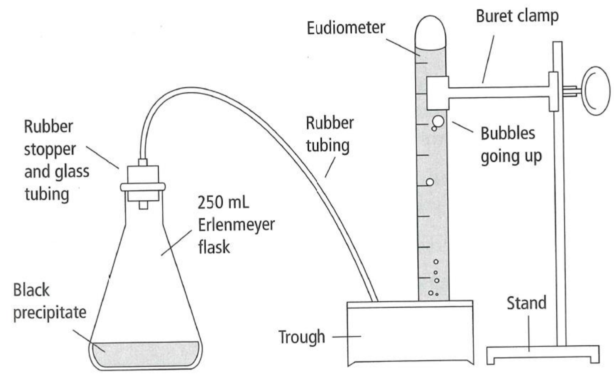
Chemists frequently need to know the rate at which a chemical reaction is creating product and the rate at which it is using up reactant in order to monitor how the reaction is proceeding. This information can be obtained in a variety of ways. For instance, if a gas is produced in a closed container, then continuous monitoring of gas pressure indicates the rate. If a colour is produced or used up, monitoring of the colour intensity with a device called a spectrophotometer indicates the rate. If a gas is produced and allowed to escape the system, the decrease in mass over time indicates the rate. In this lab, we will use yet another method of monitoring the rate of a reaction involving gases is to measure the volume of gas produced by the displacement of water in a eudiometer (gas measuring tube).

Household bleach is an aqueous solution of sodium hypochlorite (NaClO). Under normal conditions the hypochlorite ion (ClO^-) slowly breaks down into chloride ions (Cl^-) and oxygen gas (O_2) according to the following reaction:

$$2ClO^-(aq) \rightarrow 2Cl^-(aq) + O_2(g)$$

The reaction can be speeded up with the addition of something called a catalyst (we will learn more about this later in the unit). In this activity, we will use a catalyst (cobalt(III) oxide) to speed up the reaction above and measure the volume of oxygen gas produced. We will then use this information to calculate the average rate of the reaction.

Procedure:



1. Refer to the diagram to set up your gas collection apparatus.

2. Fill the eudiometer with water and invert it into the trough. Hold it in the vertical position with a clamp and ring stand.

3. Place the hose from the gas collection tube and stopper into the neck of the eudiometer.

4. Measure 15 mL of bleach solution into a 25 mL graduated cylinder and pour it into your Erlenmeyer flask.

5. Measure 5 mL of 0.10 mol/L cobalt(III) nitrate solution into a 10 mL graduated cylinder.

6. Pour the cobalt nitrate solution into the Erlenmeyer flask and IMMEDIATELY place the stopper and tube in the mouth of the flask. Start your stopwatch. **Swirl the flask gently, continually, and at a consistent rate.**

7. Record the total volume of oxygen gas collected every 30 seconds until a volume of 50 mL has been obtained. Also record the total time it took to obtain 50 mL of oxygen.

Experimental Results:

Time (s)	Volume of $O_2(g)$	Time (s)	Volume of $O_2(g)$
30		210	
60		240	
90		270	
120		300	
150		330	
180		360	
Total Time to Collect 50 mL of $O_2(g)$:			

Analysis of Results

1. Plot a graph of your results on the sheet of graph paper on the following page. Plot volume of oxygen produced vs time elapsed.

2. Calculate the overall rate of production of oxygen by dividing the total volume of gas produced by the total time take to produce that amount. Identify and use the correct units for your rates.

3. Bleach is made by the action of chlorine gas on sodium hydroxide:

   $$Cl_2(g) + OH^-(aq) \rightarrow Cl^-(aq) + ClO^-(aq) + H_2O(l)$$

   However, if an acid is added to the bleach, the process is reversed:

   $$Cl^-(aq) + ClO^-(aq) + 2H^+(aq) \rightarrow Cl_2(g) + H_2O(l)$$

   Why should you never mix bleach with any cleaner or household product that is acidic?

ACTIVITY #2 – CALCULATING RATES FROM DATA

At 40°C, hydrogen chloride gas, HCl(g), will form from the reaction of gaseous hydrogen and chlorine according to the following balanced chemical equation:

$$H_2(g) + Cl_2(g) \rightarrow 2\ HCl(g)$$

The following table contains measurements made by a chemist during this reaction.

	Concentration of Chemicals (mol/L)		
Time (s)	$H_2(g)$	$Cl_2(g)$	HCl(g)
0	1.000	1.000	0.000
2.16	0.500	0.500	1.000
4.32	0.250	0.250	1.500

Calculate the following average rate changes for each reactant and product in mol/L·s. <u>Use the formula for calculating rate to determine the first column. Use mole ratios to determine the other two columns.</u>

Time (s)	Rate of H_2 Disappearance (mol/L·s)	Rate of Cl_2 Disappearance (mol/L·s)	Rate of HCl Appearance (mol/L·s)
0-2.16			
2.16 – 4.32			

1. What do you notice happens to the average rate disappearance/appearance of each of the substances over time? Why do you think this happens?

2. What relationship do you notice between the rate of disappearance of the reactants at any one time, and the rate of appearance of the product during that same time?

ACTIVITY #3 – CALCULATING RATES FROM GRAPHS

A chemist measured the concentration of two gases at various time intervals during the chemical reaction $2NO_2(g) \rightarrow N_2O_4(g)$. Her data is contained in the table below.

Rate Data for the Reaction $2NO_2(g) \rightarrow N_2O_4(g)$		
Time (s)	$[NO_2]$	$[N_2O_4]$
0	1.0	0
50	0.79	0.11
100	0.65	0.18
150	0.55	0.23
200	0.48	0.26
250	0.43	0.29
300	0.38	0.31
350	0.34	0.33
400	0.31	0.35

1. Construct a graph to represent this data. Plot gas concentration in mol/L on the y-axis and time in seconds on the x- axis (square brackets in chemistry refer to the molarity of that solution in mol/L). Use your graph to answer the rest of the questions.

2. Determine the <u>instantaneous reaction rate</u> in *mol/L·s* for each gas at 50 s. Show your tangent lines on the graph.

3. Determine the <u>instantaneous reaction rate</u> in *mol/L·s* for each gas at 200 s. Show your tangent lines on the graph.

4. Using your answers from the previous questions, complete the following statements:

“As the reactants get used up, the rate of the reaction ___________________ because

____

____

____

____

____.”

“The rate at which the reactants are consumed in this reaction are _______________________ the rate at which products are produced. This is because

____

____

____

____

____.”

ACTIVITY #4 – POTENTIAL ENERGY DIAGRAMS

1. Draw the energy diagram showing the energy changes that occur during a successful collision of the exothermic reaction:

$$H_2 + I_2 \rightarrow 2\,HI + 250\,KJ$$

The energy of the reactants = 400 KJ
The activation energy of the forward reaction = 200 KJ

2. Draw the energy diagram showing the energy changes that occur during a successful collision of the endothermic reaction:

$$A + B + 200\,KJ \rightarrow C$$

The energy of the reactants = 200 KJ
The activation energy in the forward direction = 250 KJ

3. Write the following reaction in <u>ΔH notation</u>.

a) A + B + 200 kJ → C

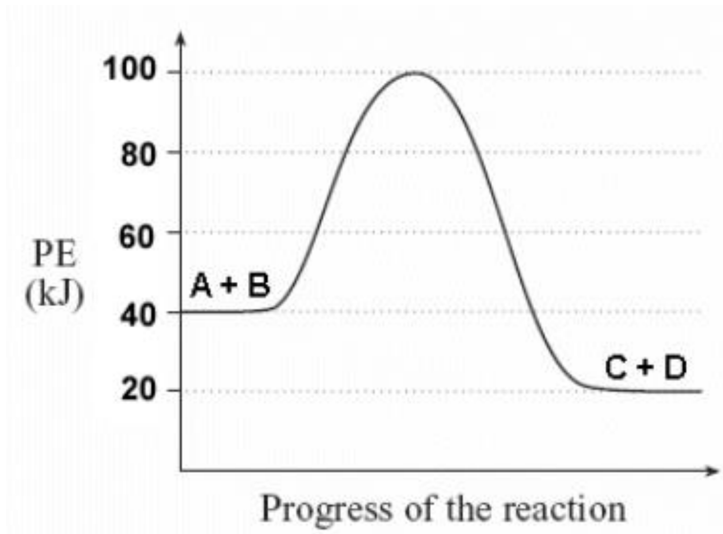
b) $2AlBr_3$ + $3BaF_2$ → $2AlF_3$ + $3BaBr_2$ + 276 kJ

4. Write the following reaction in <u>Standard Notation</u>.

a) H_2 + I_2 → 2 HI   ΔH = -250 kJ

b) $2NI_3$ + $3BaCl_2$ → $2NCl_3$ + $3BaI_2$ ΔH = 175 kJ

Use the following energy diagram to answer the rest of this page:



5. How much potential energy is stored in the bonds of the reactant molecules?

6. How much activation energy is required to allow the reactant molecules to collide effectively?

7. How much potential energy is stored in the bonds of the product molecules?

8. Does the potential energy stored in the bonds of the chemical molecules involved in this reaction increase or decrease as the reaction progresses?

9. If potential energy is gained in a reaction, where does it come from? If potential energy is lost in a reaction, where does it go?

10. What is the change in enthalpy (H) of this reaction?

11. Will the surroundings become hotter or colder as this reaction progresses? Why?

12. Is this reaction endothermic or exothermic?

13. Draw the energy diagram that represents the following set of criteria:

Potential energy reactants = 250 kJ	Potential energy activated complex = 350 kJ	Potential energy products = 300 kJ

a) What happens to the amount of energy stored in the chemical bonds (chemical potential energy) of the molecules as the reaction progresses?

b) What happens to the amount of heat associated with this reaction (kinetic energy) as the reaction progresses?

c) Is the reaction exothermic or endothermic? How do you know?

d) Will the surroundings become hotter or colder as this reaction progresses? Why?

e) What is the value of ΔH?

14. Draw the energy diagram that represents the following set of criteria:

Potential energy reactants = 350 kJ	Activation Energy = 100 kJ	Potential energy products = 250 kJ

a) What happens to the amount of energy stored in the chemical bonds (chemical potential energy) of the molecules as the reaction progresses?

b) What happens to the amount of heat associated with this reaction (kinetic energy) as the reaction progresses?

c) Is the reaction exothermic or endothermic? How do you know?

d) Will the surroundings become hotter or colder as this reaction progresses? Why?

e) What is the value of ΔH?

15. Draw the energy diagram that represents the following set of criteria:

Potential energy reactants = 200 kJ	Potential energy activated complex = 400 kJ	Potential energy products = 150 kJ

a) What happens to the amount of energy stored in the chemical bonds (chemical potential energy) of the molecules as the reaction progresses?

b) What happens to the amount of heat associated with this reaction (kinetic energy) as the reaction progresses?

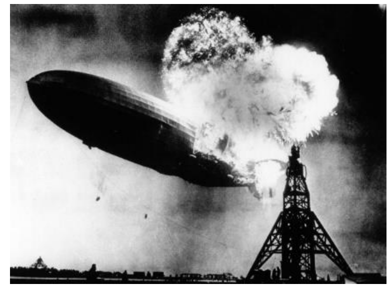
c) Is the reaction exothermic or endothermic? How do you know?

d) Will the surroundings become hotter or colder as this reaction progresses? Why?

e) What is the value of ΔH?

ACTIVITY #5 – LAB: MINI-HINDENBURGS

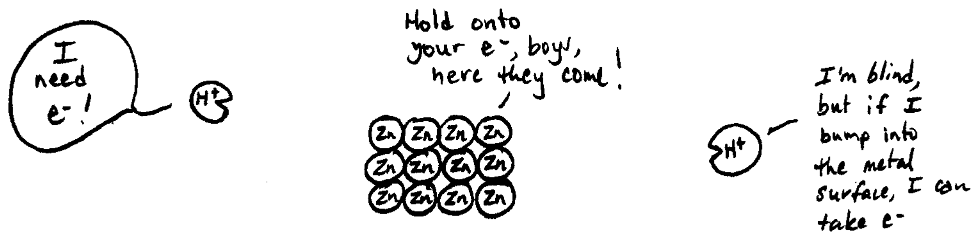
Overview:



In this lab, you will react a sample of zinc with hydrochloric acid to generate hydrogen gas. You will use a balloon to capture the hydrogen that is generated. At the end of class, we will ignite these balloons to create some nice explosions. The central concept you will be investigating in this lab is: ***What factors determine the SPEED of a reaction (the reaction rate)?***

Pre-Lab:

Use the amazing cartoon below to think about the chemistry that is going to occur in your reactions. Use this to guide the decisions you make and the conclusions you draw from your results.



1. Balance the equations below for the reactions you will perform. In each of these reactions, use oxidation numbers to identify the **substance being oxidized, the substance being reduced,** and the **spectator** ions.

$$\_\_\_\ Zn(s) + \_\_\_\ HCl(aq) \rightarrow \_\_\_\ ZnCl_2(aq) + \_\_\_\ H_2(g)$$

2. The concepts listed below all affect the rate at which the reaction depicted above will occur. For each concept, jot down an idea for how/why this factor will affect the rate of the reaction. Remember collision theory…number of effective collisions determines rate. Effective collisions rely on collision orientation and activation energy.

   a. The speed at which H^+(aq) swim through the aqueous medium.

   b. The number of Zn(s) atoms exposed to the acid

   c. The number of H^+(aq) available to react within the aqueous solution.

Procedure: (Put on eye protection and gloves immediately!)

1. Obtain metals. Weigh out appropriate mass zinc metal from the designated supply beakers on the buffet table.

   Mass of Zn = **______________** (should be between 1.80 g and 3.10 g)

2. Take a beaker of acid from the buffet table and pour **20.0 mL** of **6-molar** HCl into your two Erlenmeyer reaction flasks.
3. Drop your metal sample into the flask and **immediately** place a balloon atop the flask to capture the gas produced.
4. Using your pre-lab as a guide, INVENT AN EXPERIMENT with your partner for how to increase the zinc's initial reaction rate. When you think you have a good idea on how to speed up the zinc's reaction, CONSULT WITH MR. WIEBE who will provide you with an **instruction card** to help you run your experiment **with proper scientific controls**. **Perform your chosen experiment**.
5. As your reactions run, answer the questions below.
6. 15 minutes before the end of the class period, VISUALLY ESTIMATE THE VOLUME of hydrogen collected in each reaction by comparing the size of the balloons to objects of known volume, such as a 400 mL beaker, a 1-liter cube, etc. Write these estimates in the proper spaces on question D.
7. TERMINATE your reactions by REMOVING THE BALLOONS AND TYING THEM SHUT (don't lose your hydrogen gas when you do this!!!). Do this even if the reactions are not completed.
8. Dump your leftover acid solutions into the waste beaker on the buffet table. Shake leftover bits of metal into the trash (not in the sink!!!).
9. At the end of the hour, your hydrogen-filled balloons will be ignited in a designated spot (Mr. Wiebe **MUST SUPERVISE** the explosions). To ignite the balloons, you will need to hold your balloon with **TONGS** and bring the balloon into the flame of a Bunsen burner. **EVERYONE MUST WEAR SAFETY GLASSES DURING THESE EXPLOSIONS**!
10. Help Mr. Wiebe CLEAN UP the mess made from the exploding balloons.

Analysis:

1. What did you change in your experiment? Why did you choose this change? Explain in terms of collision theory.

2. What results did you observe? What conclusions can be drawn from your experiment??

ACTIVITY #6 – RATE LAW CALCULATIONS

Determine the rate law and rate constant for each of the following.

1. $H_2O_2(g) + 2HI(g) \rightarrow 2H_2O(g) + I_2(g)$

Trial	$[H_2O_2]$ (M)	[HI] (M)	Rate (M/s)
1	0.10 M	0.10 M	0.0076
2	0.10 M	0.20 M	0.0152
3	0.20 M	0.10 M	0.0152

2. $2NO(g) + Br_2(g) \rightarrow 2NOBr(g)$

Trial	[NO] (M)	$[Br_2]$ (M)	Rate (M/h)
1	1.0	1.0	1.30×10^{-3}
2	2.0	1.0	5.20×10^{-3}
3	1.0	2.0	4.16×10^{-2}

3. $ClO^{3-}(aq) + 9I^-(aq) + 6H^+(aq) \rightarrow 3I^{3-}(aq) + Cl^-(aq) + 2H_2O(l)$

Trial	$[ClO^{3-}]$ (M)	$[I^-]$ (M)	$[H^+]$ (M)	Rate (M/s)
1	0.10	0.10	0.10	0.5
2	0.10	0.20	0.10	1.0
3	0.20	0.20	0.10	2.0
4	0.20	0.20	0.20	8.0

4. The rate law of a reaction between gases Y and Z is found to be

$$rate = k[Y]^2[Z]$$

Change in Concentration:	**Change in Rate:**
Y is doubled	
Y is tripled	
Z is quadrupled	
Y is quadrupled while the concentration of Z is doubled	
Y is cut in half while the concentration of Z is doubled.	
Y and Z are both tripled	

6. Consider the reaction: $2\ NO(g)\ +\ O_2(g)\ \rightarrow\ 2\ NO_2(g)$

The following data were obtained from three experiments using the method of initial rates:

	Initial [NO] (mol/L)	Initial [O_2] (mol/L)	Initial rate NO (mol/L)
Experiment 1	0.010	0.010	2.5×10^{-5}
Experiment 2	0.020	0.010	1.0×10^{-4}
Experiment 3	0.010	0.020	5.0×10^{-5}

a. Determine the order of the reaction for each reactant.

b. Write the rate equation for the reaction.

c. Calculate the rate constant.

d. Calculate the rate (in mol/L·s) at the instant when [NO] = 0.015 mol/L and [O_2] = 0.0050 mol/L

6. The reaction $2\ NO(g) + 2\ H_2(g) \rightarrow N_2(g) + 2\ H_2O(g)$ was studied at 904 °C, and the data in the table were collected.

	Initial [NO] (mol/L)	Initial [H_2] (mol/L)	Initial rate N_2 (mol/L)
Experiment 1	0.420	0.122	0.136
Experiment 2	0.210	0.122	0.0339
Experiment 3	0.210	0.244	0.0678
Experiment 4	0.105	0.488	0.0339

a. Determine the order of the reaction for each reactant.

b. Write the rate equation for the reaction.

c. Calculate the rate constant at 904 °C.

d. Find the rate of appearance of N_2 at the instant when [NO] = 0.350 M and [H_2] = 0.205 M.

7. The reaction of [t]butyl-bromide $(CH_3)_3CBr$ with water is represented by the equation:

$$(CH_3)_3CBr + H_2O \rightarrow (CH_3)_3COH + HBr$$

The following data were obtained from three experiments using the method of initial rates:

	Initial $[(CH_3)_3CBr]$ (mol/L)	Initial $[H_2O]$ (mol/L)	Initial rate (mol/L)
Experiment 1	5.0×10^{-2}	2.0×10^{-2}	2.0×10^{-6}
Experiment 2	5.0×10^{-2}	4.0×10^{-2}	2.0×10^{-6}
Experiment 3	1.0×10^{-1}	4.0×10^{-2}	4.0×10^{-6}

a. What is the order with respect to $(CH_3)_3CBr$ and H_2O?

c. What is the overall order of the reaction?

d. Write the rate equation.

e. Calculate the rate constant, k, for the reaction.

ACTIVITY #7 – LAB: THE AMAZING IODINE CLOCK REACTION

We know from past activities that changing the concentration of a reactant changes the initial rate of the reaction. We also know that there is a direct relationship between these two variables, as communicated by the rate law of that reaction. In this experiment, a special reaction – called a clock reaction – will be used to measure changes in rate and concentration and determine the order of the reactants.

The balanced net ionic equation for this reaction is:

$$3\ IO_3^-(aq) + 8\ HSO_3^-(aq) \rightarrow I_3^-(s) + 8\ SO_4^{2-}(aq) + 6\ H^+(aq) + H_2O(l)$$

Long story short, this reaction will continue until the $HSO_3^-(aq)$ gets used up. When you see a blue-black colour appear, that signals that all the $HSO_3^-(aq)$ has been consumed. You will measure the time it takes for the reaction to reach completion by timing the reaction from the first mixing to the appearance of the blue colour.

Remember that average rate of a reaction can be determined by the following:

$$Average\ Rate = \frac{\Delta[Reactant]}{\Delta time}$$

For this reaction specifically, the average rate can be determined as follows:

$$Average\ Rate = \frac{1}{8}\frac{\Delta[HSO_3]}{\Delta time} = \frac{1}{3}\frac{\Delta[IO_3]}{\Delta time}$$

Since the $HSO_3^-(aq)$ gets completely used up each trial and reaches 0 mol/L, the $\Delta[HSO_3^-] = [HSO_3^-]$ initial. As such, to calculate the average rate of the reaction in each flask, we can use the following equation:

$$Average\ Rate = \frac{1}{8}\frac{[HSO_3]initial}{\Delta time}$$

The initial $[HSO_3^-]$ needs to be calculated for each trial of the experiment because when solutions are mixed the bisulfite concentration is diluted initially. You can calculate the initial concentration using your formula for dilution.

$$M_1V_1 = M_2V_2$$

where M = molarity, V = volume, 1 = initial, and 2 = final

Materials:

Solution A: 0.020 M K**<u>IO₃</u>**

Solution B: 0.0080 M Na**<u>HSO₃</u>** in a solution containing starch and sulfuric acid

Observations:

Part 1: The Effect of Diluting HSO_3^- on the Reaction Rate

Flask	Volume of 0.020 M KIO_3	Volume of Water	Volume of 0.0080 M $NaHSO_3$	Time to React (s)
1	50.0 mL	-	50.0 mL	
2	50.0 mL	10.0 mL	40.0 mL	
3	50.0 mL	20.0 mL	30.0 mL	
4	50.0 mL	30.0 mL	20.0 mL	
5	50.0 mL	40.0 mL	10.0 mL	

Part 2: The Effect of Diluting IO_3^- on the Reaction Rate

Flask	Volume of 0.020 M KIO_3	Volume of Water	Volume of 0.0080 M $NaHSO_3$	Average Time to React (s)
1	50.0 mL	-	50.0 mL	
2	40.0 mL	10.0 mL	50.0 mL	
3	30.0 mL	20.0 mL	50.0 mL	
4	20.0 mL	30.0 mL	50.0 mL	
5	10.0 mL	40.0 mL	50.0 mL	

Analysis

PART 1:

Flask	Initial $[HSO_3^-]$, M	Initial $[IO_3^-]$, M	Average Rate of Reaction (mol/L·s)
1			
2			
3			
4			
5			

PART 2:

Flask	Initial $[HSO_3^-]$, M	Initial $[IO_3^-]$, M	Average Rate of Reaction (mol/L·s)
1			
2			
3			
4			
5			

1. Calculate the initial concentrations of IO_3^-(aq) and HSO_3^-(aq) for each flask in both parts of the lab and record these values on the charts above. Remember, the final volume of the dilution will be the combined volume of BOTH solutions after they are mixed. SHOW HERE your calculation of $[HSO_3^-]$ in Flask #2 in Part 1 of the lab.

2. Calculate the reaction rate for each trial using the formula for average rate given earlier in the handout and record these values in the charts above. SHOW HERE your calculation of average rate in Flask #2 in Part 1 of the lab.

3. Using the information in the chart for Part 1, calculate the order for $HSO_3^-(aq)$.

4. Using the information in the chart for Part 2, calculate the order for $IO_3^-(aq)$.

5. Using Part 1 Trial 1, calculate the k value for this reaction. Repeat this using Part 2 Trial 1. How do your answers compare?

6. Write the complete rate late for this clock reaction.

7. Use your completed rate law to determine the rate of this reaction if you started with 0.050M HSO3- and 0.0250M IO3-.

8. Use collision theory to briefly explain how and why increasing concentration of reactants affects rate of reaction. Do your results in this experiment agree with collision theory?

ACTIVITY #8 – REACTION MECHANISMS

1. Use the following mechanism to answer this question:

Step 1:	$OCl^- + H_2O$	→	$HOCl + OH^-$
Step 2:	$HOCl + I^-$	→	$HOI + Cl^-$
Step 3:	$HOI + OH^-$	→	$H_2O + OI^-$

a) The net chemical equation is:

b) The reaction intermediates are:

c) The catalyst is:

2. Use the following mechanism to answer this question:

Step 1:	Br_2	→	$2Br$	slow
Step 2:	$Br + OCl_2$	→	$BrOCl + Cl$	fast
Step 3:	$Br + Cl$	→	$BrCl$	fast

a) The net chemical equation is:

b) The reaction intermediates are:

c) The catalyst is:

d) The rate determining step is:

e) The rate law is:

f) If the concentration of Br_2 is increased will the rate of the reaction increase? Explain your answer.

g) If the concentration of OCl_2 is increased will the rate of the reaction increase? Explain your answer.

3. Nitrogen monoxide reacts with hydrogen gas to produce nitrogen gas and water vapour. The mechanism is believed to be:

Step 1:	2 NO	$\rightarrow N_2O_2$
Step 2:	$N_2O_2 + H_2$	$\rightarrow N_2O + H_2O$
Step 3:	$N_2O + H_2$	$\rightarrow N_2 + H_2O$

a) Determine the overall net equation

b) Identify any reaction intermediates

c) Can you determine the rate law from this information? Why or why not?

5. A proposed mechanism for a reaction is as followed:

Step 1: $O_3(g) \rightarrow O_2(g) + O(g)$ Slow
Step 2: $O_3(g) + O(g) \rightarrow 2O_2(g)$ Fast

a) Write the rate law equation expected for this mechanism.

b) What is the overall net chemical equation for this mechanism?

c) What is the intermediate in the mechanism?

6. The steps of a proposed reaction mechanism for a reaction are:

Step 1: $NO(g) + NO(g) \rightarrow N_2O_2(g)$
Step 2: $N_2O_2(g) + O_2(g) \rightarrow 2NO_2(g)$

a) What is the overall net chemical equation for this mechanism?

b) What is/are the intermediate(s) in the proposed reaction mechanism?

c) The rate law for this proposed mechanism was experimentally determined to be rate = $k[NO]^2[O_2]$. Based on this, which step in the mechanism is the rate determining step and why?

7. A proposed mechanism for a reaction is as follows:

Step 1: $C_4H_9Br(aq) \rightarrow C_4H_9^+(aq) + Br^-(aq)$ slow
Step 2: $C_4H_9^+(aq) + H_2O(l) \rightarrow C_4H_9OH_2^+(aq)$ fast
Step 3: $C_4H_9OH_2^+(aq) + H_2O(l) \rightarrow C_4H_9OH(aq) + H_3O^+(aq)$ fast

a) Write the rate law expected for this reaction mechanism.

b) What is the overall net chemical reaction for this mechanism?

c) What are the intermediates in the proposed mechanism?

8. A proposed mechanism for a reaction is as follows:

Step 1: $NH_4^+(aq) \rightarrow NH_3(aq) + H^+(aq)$ slow
Step 2: $H^+(aq) + HNO_2(aq) \rightarrow H_2O(l) + NO^+(aq)$ fast
Step 3: $NH_3(aq) + NO^+(aq) \rightarrow NH_3NO^+(aq)$ fast
Step 4: $NH_3NO^+(aq) \rightarrow N_2(g) + H_2O(l) + H^+(aq)$ fast

a) What is the overall net chemical equation for this reaction mechanism?

b) What are the intermediates for this mechanism?

c) The rate law for this reaction was experimentally determined to be rate = $k[HNO_2(aq)][NH_4^+(aq)]$. Is this reaction mechanism plausible? Support your answer.

ACTIVITY #9 – UNIT TEST REVIEW

105.5 g of calcium reacts with 21.0 g of oxygen to produce calcium oxide, according to the following reaction:

$$2Ca(s) + O_2(g) \rightarrow 2CaO(s)$$

1. The reaction takes 3 minutes and 35 seconds to reach completion. 52.9 g of calcium was left in the container at the end. What was the average rate at which the calcium was used up? Provide your answer in **g/s** and **mol/min**.

2. List 4 things that could be done to speed up the rate of this reaction.

Use the following data table to answer the next 3 questions

Concentrations of Reactant and Products Over Time for the Reaction $2NO_2(g) \rightarrow 2NO(g) + O_2(g)$			
	Concentration (mol/L)		
Time (s)	NO_2	NO	O_2
0	0.0100	0	0
50	0.0079	0.0021	0.0011
100	0.0065	0.0035	0.0018
150	0.0055	0.0045	0.0023
200	0.0048	0.0052	0.0026

4. Calculate the average rate of disappearance of NO_2 from 100 to 200 seconds

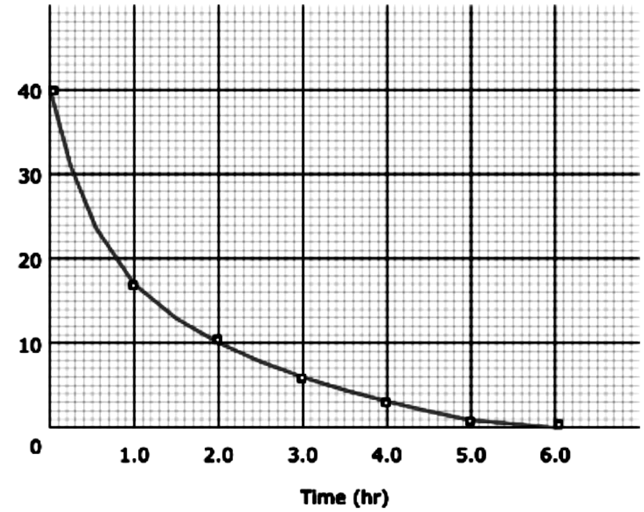
5. Calculate the average rate of appearance of O_2 from 100 to 200 seconds

6. Use Collision Theory and the balanced chemical equation for this reaction to explain why your answers to 4 & 5 are not the same.

7. Use the tangent line method to calculate the instantaneous rate of reaction in mol/L·h at both of the following points:

a) 30 mol/L

b) 10 mol/L



8. Use Collision Theory to explain why the instantaneous rates at both points in time in question 7 are not the same.

9. Consider the combustion of propane, $C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(g)$. If the rate of disappearance of $O_2(g)$ during a period is 6.4 mol/L·s, determine the rates of the following during the same period.

   a. What is the rate of disappearance of $C_3H_8(g)$?

   b. What is the rate of appearance of $CO_2(g)$?

   c. What is the rate of appearance of $H_2O(g)$?

10. Use Kinetic Molecular Theory and Collision Theory to explain why and how the following changes causes the rate of a reaction to increase.

Increasing Concentration

Increasing Temperature

Adding a Catalyst

Increasing Surface Area

The following is information about a chemical reaction. Use it to answer the following questions.

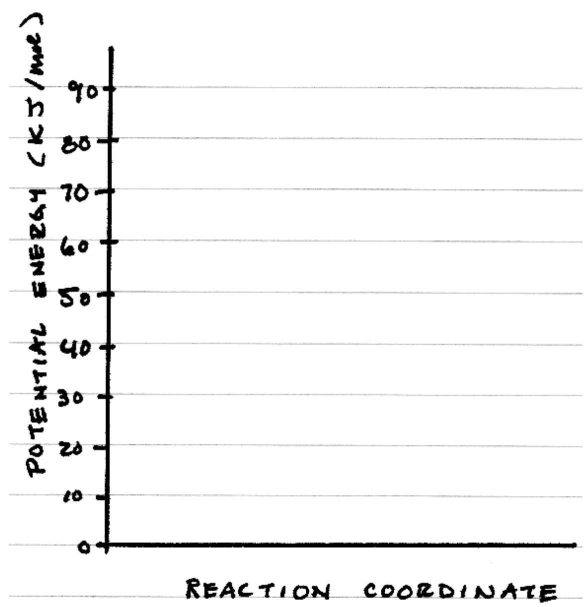
Potential Energy of Reactant Molecules	30 kJ/mol
Change in Potential Energy (Enthalpy)	-20 kJ/mol
Activation Energy	40 kJ/mol

11. Draw the PE curve on the grid provided.

12. The potential energy stored in the molecules of the **products** is ___________________

13. The **activation energy** to make the reaction occur in **reverse** is _________________

14. Use a dotted line (- - - - - - -) to sketch the diagram of a catalyzed version of the same reaction on the same grid.



15. Below is some initial rate data for the reaction, $A + B \rightarrow 2C$.

[A]	**[B]**	**Rate (mol/L·s)**
0.40	0.10	3.5×10^3
0.20	0.10	1.8×10^3
0.20	0.20	1.45×10^4

a) Determine the **orders** of reactants A _____ and B _____

b) Write the **rate law** for this reaction: ________________________________

c) Calculate the value of the **rate constant, k**. ______________________

d) Calculate the rate of the reaction if [A] = 0.50M and [B] = 0.65M.

16. Consider the following reaction:

$$2NO + 2H_2 + 100kJ \rightarrow 2H_2O + N_2 \qquad \text{Rate} = k[NO][H_2]$$

A proposed mechanism for the above reaction is:

Step 1: $NO + H_2 \rightarrow N + H_2O$
Step 2: ?
Step 3: $N_2O + H_2 \rightarrow N_2 + H_2O$

a) Write the equation for step 2 in the proposed mechanism.

b) Which step is the rate determining step? How can you tell?

c) Is this reaction endothermic or exothermic? How did you determine this?

17. Consider this reaction mechanism:

$$HCOOH + H_2SO_4 \rightarrow HCOOH_2^+ + HSO_4^-$$
$$HCOOH_2^+ \rightarrow COH^+ + H_2O$$
$$COH^+ + HSO_4^- \rightarrow CO + H_2SO_4$$

a) What is the overall reaction? ____

b) List any "intermediates." ____

c) List any catalysts. ____________________________________

d) If the first step is the slow step, what is the rate law? __________________________________

SOLUBILITY OF COMMON COMPOUNDS IN WATER

The term soluble here means > 0.1 mol/L at 25°C.

Negative Ions (Anions)	Positive Ions (Cations)	Solubility of Compounds
All	Alkali ions: Li^+, Na^+, K^+, Rb^+, Cs^+, Fr^+	Soluble
All	Hydrogen ion: H^+	Soluble
All	Ammonium ion: NH_4^+	Soluble
Nitrate, NO_3^-	All	Soluble
Chloride, Cl^- or Bromide, Br^- or Iodide, I^-	All others	Soluble
	Ag^+, Pb^{2+}, Cu^+	Low Solubility
Sulphate, SO_4^{2-}	All others	Soluble
	Ag^+, Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}	Low Solubility
Sulphide, S^{2-}	Alkali ions, H^+, NH_4^+, Be^{2+}, Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}	Soluble
	All others	Low Solubility
Hydroxide, OH^-	Alkali ions, H^+, NH_4^+, Sr^{2+}	Soluble
	All others	Low Solubility
Phosphate, PO_4^{3-} or Carbonate, CO_3^{2-} or Sulphite, SO_3^{2-}	Alkali ions, H^+, NH_4^+	Soluble
	All others	Low Solubility

Periodic Chart of Ions

Table of Polyatomic Ions

acetate	CH_3COO^-	dichromate	$Cr_2O_7^{2-}$	dihydrogen phosphate	$H_2PO_4^-$
ammonium	NH_4^+	cyanide	CN^-	silicate	SiO_3^{2-}
benzoate	$C_6H_5COO^-$	hydroxide	OH^-	sulphate	SO_4^{2-}
borate	BO_3^{3-}	iodate	IO_3^-	sulphite	SO_3^{2-}
carbonate	CO_3^{2-}	nitrate	NO_3^-	hydrogen sulphide	HS^-
hydrogen carbonate	HCO_3^-	nitrite	NO_2^-	hydrogen sulphate	HSO_4^-
chlorate	ClO_3^-	oxalate	$OOCCOO^{2-}$	hydrogen sulphite	HSO_3^-
hypochlorite	ClO^-	permanganate	MnO_4^-	thiocyanate	SCN^-
chromate	CrO_4^{2-}	phosphate	PO_4^{3-}	thiosulphate	$S_2O_3^{2-}$
		hydrogen phosphate	HPO_4^{2-}		

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 H^+ hydrogen																	2 He helium
3 Li^+ lithium	4 Be^{2+} Beryllium											5 B boron	6 C carbon	7 N^{3-} nitride	8 O^{2-} oxide	9 F^- fluoride	10 Ne neon
11 Na^+ sodium	12 Mg^{2+} magnesium											13 Al^{3+} aluminum	14 Si silicon	15 P^{3-} phosphide	16 S^{2-} sulfide	17 Cl^- chloride	18 Ar argon
19 K^+ potassium	20 Ca^{2+} calcium	21 Sc^{3+} scandium	22 Ti^{4+} titanium (IV) Ti^{3+} titanium (III)	23 V^{5+} vanadium (V) V^{4+} vanadium (IV)	24 Cr^{3+} chromium (III) Cr^{2+} chromium (II)	25 Mn^{2+} manganese (II) Mn^{4+} manganese (IV)	26 Fe^{3+} iron (III) Fe^{2+} iron (II)	27 Co^{2+} cobalt (II) Co^{3+} cobalt (III)	28 Ni^{2+} nickel (II) Ni^{3+} nickel (III)	29 Cu^{2+} copper (II) Cu^+ copper (I)	30 Zn^{2+} zinc	31 Ga^{3+} gallium	32 Ge^{4+} germanium	33 As^{3-} arsenide	34 Se^{2-} selenide	35 Br^- bromide	36 Kr krypton
37 Rb^+ rubidium	38 Sr^{2+} strontium	39 Y^{3+} yttrium	40 Zr^{4+} zirconium	41 Nb^{5+} niobium (V) Nb^{3+} niobium (III)	42 Mo^{6+} molybdenum	43 Tc^{7+} technetium	44 Ru^{3+} ruthenium (III) Ru^{4+} ruthenium (IV)	45 Rh^{3+} rhodium	46 Pd^{2+} paladium (II) Pd^{4+} paladium (IV)	47 Ag^+ silver	48 Cd^{2+} cadmium	49 In^{3+} indium	50 Sn^{4+} tin (IV) Sn^{2+} tin (II)	51 Sb^{3+} antimony (III) Sb^{5+} antimony (V)	52 Te^{2-} telluride	53 I^- iodide	54 Xe xenon
55 Cs^+ cesium	56 Ba^{2+} barium	57 La^{3+} lanthanum	72 Hf^{4+} hafnium	73 Ta^{5+} tantalum	74 W^{6+} tungsten	75 Re^{7+} rhenium	76 Os^{4+} osmium	77 Ir^{4+} iridium	78 Pt^{4+} platinum (IV) Pt^{2+} platinum (II)	79 Au^{3+} gold (III) Au^+ gold (I)	80 Hg^{2+} mercury (II) Hg^+ mercury (I)	81 Tl^+ thallium (I) Tl^{3+} thallium (III)	82 Pb^{2+} lead (II) Pb^{4+} lead (IV)	83 Bi^{3+} bismuth (III) Bi^{5+} bismuth (V)	84 Po^{2+} polonium (II) Po^{4+} polonium (IV)	85 At^- astatide	86 Rn radon
87 Fr^+ francium	88 Ra^{2+} radium	89 Ac^{3+} actinium															

KEY

atomic number →	26	
	Fe^{3+}	← ion charge
	iron (III)	← stock name (IUPAC)
symbol →	Fe^{2+}	
	iron (II)	

58 Ce^{3+} cerium	59 Pr^{3+} praseodymium	60 Nd^{3+} neodymium	61 Pm^{3+} promethium	62 Sm^{3+} samarium (III) Sm^{2+} samium(II)	63 Eu^{3+} europium (III) Eu^{2+} europium(II)	64 Gd^{3+} gadolinium	65 Tb^{3+} terbium	66 Dy^{3+} dysprosium	67 Ho^{3+} holmium	68 Er^{3+} erbium	69 Tm^{3+} thulium	70 Yb^{3+} ytterbium (III) Yb^{2+} ytterbium (II)	71 Lu lutetium
90 Th^{4+} thorium	91 Pa^{5+} protactinium (V) Pa^{4+} protactinium(IV)	92 U^{6+} uranium (VI) U^{4+} uranium (IV)	93 Np^{5+} neptunium	94 Pu^{4+} plutonium (IV) Pu^{6+} plutonium (VI)	95 Am^{3+} americium (III) Am^{4+} americium (IV)	96 Cm^{3+} curium	97 Bk^{3+} berkelium (III) Bk^{4+} berkelium (IV)	98 Cf^{3+} californium	99 Es^{3+} einsteinium	100 Fm^{3+} fermium	101 Md^{2+} mendelevium(II) Md^{3+} mendelevium (III)	102 No^{2+} nobelium (II) No^{3+} nobelium (III)	103 Gd^{3+} lawrencium

Periodic Table of the Elements

Key:

14	Atomic Number
Si	Symbol
Silicon	Name
28.1	Atomic Mass

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** Hydrogen 1.0																	2 **He** Helium 4.0
3 **Li** Lithium 6.9	4 **Be** Beryllium 9.0											5 **B** Boron 10.8	6 **C** Carbon 12.0	7 **N** Nitrogen 14.0	8 **O** Oxygen 16.0	9 **F** Fluorine 19.0	10 **Ne** Neon 20.2
11 **Na** Sodium 23.0	12 **Mg** Magnesium 24.3											13 **Al** Aluminum 27.0	14 **Si** Silicon 28.1	15 **P** Phosphorus 31.0	16 **S** Sulphur 32.1	17 **Cl** Chlorine 35.5	18 **Ar** Argon 39.9
19 **K** Potassium 39.1	20 **Ca** Calcium 40.1	21 **Sc** Scandium 45.0	22 **Ti** Titanium 47.9	23 **V** Vanadium 50.9	24 **Cr** Chromium 52.0	25 **Mn** Manganese 54.9	26 **Fe** Iron 55.8	27 **Co** Cobalt 58.9	28 **Ni** Nickel 58.7	29 **Cu** Copper 63.5	30 **Zn** Zinc 65.4	31 **Ga** Gallium 69.7	32 **Ge** Germanium 72.6	33 **As** Arsenic 74.9	34 **Se** Selenium 79.0	35 **Br** Bromine 79.9	36 **Kr** Krypton 83.8
37 **Rb** Rubidium 85.5	38 **Sr** Strontium 87.6	39 **Y** Yttrium 88.9	40 **Zr** Zirconium 91.2	41 **Nb** Niobium 92.9	42 **Mo** Molybdenum 95.9	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.1	45 **Rh** Rhodium 102.9	46 **Pd** Palladium 106.4	47 **Ag** Silver 107.9	48 **Cd** Cadmium 112.4	49 **In** Indium 114.8	50 **Sn** Tin 118.7	51 **Sb** Antimony 121.8	52 **Te** Tellurium 127.6	53 **I** Iodine 126.9	54 **Xe** Xenon 131.3
55 **Cs** Cesium 132.9	56 **Ba** Barium 137.3	57 **La** Lanthanum 138.9	72 **Hf** Hafnium 178.5	73 **Ta** Tantalum 180.9	74 **W** Tungsten 183.8	75 **Re** Rhenium 186.2	76 **Os** Osmium 190.2	77 **Ir** Iridium 192.2	78 **Pt** Platinum 195.1	79 **Au** Gold 197.0	80 **Hg** Mercury 200.6	81 **Tl** Thallium 204.4	82 **Pb** Lead 207.2	83 **Bi** Bismuth 209.0	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (263)	107 **Bh** Bohrium (262)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (266)									

58 **Ce** Cerium 140.1	59 **Pr** Praseodymium 140.9	60 **Nd** Neodymium 144.2	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.4	63 **Eu** Europium 152.0	64 **Gd** Gadolinium 157.3	65 **Tb** Terbium 158.9	66 **Dy** Dysprosium 162.5	67 **Ho** Holmium 164.9	68 **Er** Erbium 167.3	69 **Tm** Thulium 168.9	70 **Yb** Ytterbium 173.0	71 **Lu** Lutetium 175.0
90 **Th** Thorium 232.0	91 **Pa** Protactinium 231.0	92 **U** Uranium 238.0	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)

Based on mass of C^{12} at 12.00.

Values in parentheses are the masses of the most stable or best known isotopes for elements which do not occur naturally.