CHEMISTRY 12

FACTORS THAT AFFECT REACTION RATES

INTRODUCTION

The purpose of this experiment is to investigate how different factors affect the rate of a chemical reaction.

There are six parts to this study: examining the effect of temperature changes, concentration changes, changes in reactants, changes in surface area, addition of a catalyst and addition of an inhibitor.

PROCEDURE

Part I: The Effect of Temperature Changes

The reaction being studied is $2\ HCl(aq) + Na_2S_2O_3(aq) \longrightarrow S(s) + SO_2(g) + 2\ NaCl(aq) + H_2O(l)$.

1. Use a graduated cylinder to measure out 5.0 mL of 0.100 M $Na_2S_2O_3$ into each of four test tubes (18x-150 mm). Thoroughly rinse the graduated cylinder and use it to measure 5.0 mL of 0.100 M HCl into a different set of four test tubes (18 x 150 mm).

2. Juggle the following four tasks so that you can carry out the reaction quickly at four different temperatures, one after another. **IMPORTANT**: You may have to readjust the temperature from time to time if you don't use the baths right away.

   (a) Use ice chips to cool a 400 mL beaker $^2/_3$ full of tap water to a temperature of 10° 2°C.

   (b) Use hot and cold water from the tap to get a 400 mL beaker $^2/_3$ full of tap water at 30° 2°C.

   (c) Use hot and cold water from the tap to get a 400 mL beaker $^2/_3$ full of tap water at 50° 2°C.

   (d) Use a bunsen burner to heat a 400 mL beaker $^2/_3$ full of water to 70° 2°C.

3. Place one $Na_2S_2O_3$ tube and one HCl tube into each of the 10°C, 30°C, 50°C and 70°C bath for 5-minutes, to establish thermal equilibrium.

4. In each of the four reactions below, use a stop watch to measure the time passing between the instant a tube of $Na_2S_2O_3$ and a tube of HCl are mixed and the instant the mixed solution turns cloudy due to the production of solid sulphur.

   (a) One partner should quickly mix the HCl and $Na_2S_2O_3$ solutions in the 10°C bath, immediately stopper the solution and shake for a few seconds before putting the solution back into its ice bath. The other partner should start the stop watch at the instant the two solutions touch each other and stop timing when the solution turns cloudy. As soon as the reaction is finished, take the temperature of the test tube contents; this temperature is the reaction temperature.

   (b) Similarly, react and time the HCl and $Na_2S_2O_3$ solutions in the 30°C, 50°C and 70°C baths. (Don't forget to put the mixture back in its bath while you are timing the reaction.)

Part II: The Effect of Concentration Changes

The reaction being studied is $2\ HCl(aq) + Mg(s) \longrightarrow H_2(g) + MgCl_2(aq)$.

6. Into 4 separate 100 mL beakers measure 10 mL of each of 1.50 M, 2.50 M, 3.50 M and 4.50 M HCl. Weigh 4 strips of 25 mm long Mg ribbon to the nearest 0.001 g, using the high precision balance.

7. Add one of the weighed strips of Mg ribbon to the most dilute acid and immediately start timing the reaction, while constantly swirling the beaker. Stop the timing when the last trace of Mg disappears. Similarly, time the reaction of the other Mg strips with the other acid concentrations.

Part III: The Nature of the Reactants

The reaction being studied is the reaction between an acid and a metal:

$$2\ H^+(aq) + Metal(s) \longrightarrow H_2(g) + Metal^{2+}(aq)\ .$$

8. Add 10 mL of 3 M H_2SO_4 , 6 M HCl, 6 M HNO_3 and 6 M H_3PO_4 into 4 separate 100 mL beakers. In a fume hood, add a 25 mm piece of Mg to the HNO_3, swirl the beaker constantly, and record the time for the metal to completely react. Similarly, add a strip of Mg to each of the other acids, in turn. **NOTE:** If there is no reaction, write "no reaction"; if a reaction occurs but takes over 2 min, write "> 2 min".

9. Add 10 mL of 6 M HCl to three different 100 mL beakers. CARE! Do not confuse the three metals in this part: Cu is red–brown, Mg is a narrow silvery strip and Zn is a wider strip with a grey appearance. Place a 25 mm piece of Mg into the 1st beaker, swirl the beaker constantly, and record the time required for the metal to completely react. Similarly, add a 25 mm piece of Cu and Zn into the other two beakers. **NOTE:** If there is no visible reaction, write "no reaction"; if a reaction takes over 2 min, write "> 2 min".

Part IV: The Effect of Surface Area Changes

The reaction being studied is $2\ HCl(aq) + CaCO_3(s) \longrightarrow CO_2(g) + CaCl_2(aq) + H_2O(l)$.

10. Add 15 mL of 3 M HCl into each of two different 100 mL beakers. Weigh and record the mass of one of the small pieces of solid chalk provided; it should be in the range 0.8–1.2 g. Use a weighing boat to weigh out 1.0'' 0.2 g of powdered calcium carbonate ($CaCO_3$, "chalk"). Record this latter mass.

11. Dump the powdered $CaCO_3$ into the first 100 mL beaker, swirl the beaker continuously, and record the time required for the solid to finish reacting (that is, to finish bubbling). Similarly, add the piece of solid chalk to the other 100 mL beaker, swirl the beaker while the reaction occurs, and record the time required for the solid to finish reacting (that is, to finish bubbling). **NOTE:** If there is no visible reaction (bubbles), just write "no reaction"; if a reaction takes over two minutes, just write "> 2 min".

Part V: The Effect of Adding a Catalyst

The reaction being studied is

$$2\ KMnO_4(aq) + 8\ H_2SO_4(aq) + 5\ K_2C_2O_4(aq) \longrightarrow 2\ MnSO_4(aq) + 10\ CO_2(g) + 8\ H_2O(l) + 6\ K_2SO_4(aq)\ .$$

12. Add 3 mL of 0.1 M $K_2C_2O_4$ and 1 mL of 1 M H_2SO_4 to each of 3 clean, "flicked dry" 13 x 100 mm test tubes. Mark one tube as #1. To the second tube add 1 drop of 0.1 M $MnSO_4$ catalyst (mark this as tube #2) and to the third tube add 3 drops of 0.1 M $MnSO_4$ catalyst (mark this as tube #3).

13. Put 5 drops of 0.02 M $KMnO_4$ into each of 3 clean and "flicked dry 13 x 100 mm test tubes. Use a clean dropper to suck up the 5 drops of $KMnO_4$ in one of the tubes, "squirt" the $KMnO_4$ into tube #1 prepared in step 12 and IMMEDIATELY start timing as you stopper and shake the tube. Record the time for the colour of the purple $KMnO_4$ solution to become a different colour. If the colour remains purple for more than 4 minutes, write the time as ">4 min" and go on to the next reaction.

14. Suck up the 5 drops of $KMnO_4$ in the 2nd tube, "squirt" the $KMnO_4$ into tube #2 prepared in step 12 and IMMEDIATELY start timing as you stopper and shake the tube. Record the time for the colour of the purple $KMnO_4$ solution to become a different colour. If the colour remains purple for more than 5 minutes, write the time as ">5 min" and go on to the next reaction; however, do not discard this reaction for at least 15 minutes (keep an eye on it from time to time. Repeat the reaction for tube #3.

Part VI: The Effect of Adding an Inhibitor: A TEACHER DEMONSTRATION

The reaction being studied is $2\ H_2O_2(aq) \longrightarrow 2\ H_2O(l) + O_2(g)$. **Think!** What evidence will you expect to **SEE** when this reaction occurs?

15. CAUTION: WEAR GLOVES – 30% hydrogen peroxide can give painful burns! Add 20 mL of 30% hydrogen peroxide, H_2O_2 , into a clean 250 mL erlenmeyer flask placed on a protective plastic sheet. Add 1 mL of 10% KI to the flask and swirl constantly for 30 s. Record what happens in the next minute. Repeat the procedure with a clean flask, but after swirling for 30 s add 3 mL of 0.5 M AgNO3 and continue swirling the flask for another 10 s. Again, record your observations. Clean up any liquid splashed on the demonstration table to avoid accidental contact with any remaining hydrogen peroxide.

ANALYSIS

1. (a) Construct a graph of time of reaction versus temperature, with time on the vertical axis, using the data collected in steps 1 to 4.
   (b) Based on your data, what can you conclude about the effect of temperature on the rate of a reaction? (Express your answer in the form: "As temperature increases, the reaction rate ...")
   (c) Use your graph to estimate the time required for the reaction at 40°C. Indicate on your graph how you arrived at the time for 40°C.

2. (a) Calculate the moles of HCl used in each of the four HCl solutions in step 6, using the formula:

$$\text{Molarity (c)} = \frac{\text{moles (n)}}{\text{volume (V)}}$$, where V is expressed in **litres.**

   (b) Using the mass of Mg found in step 6 and the molar mass of Mg, calculate the moles of Mg used in each reaction in steps 6 and 7.
   (c) Calculate the value of the ratio (moles HCl/moles Mg) for each of the 4 reactions; this ratio allows you to make allowance for slightly differing masses of Mg reacting and tells you how many times more HCl there was than Mg.
   (d) Construct a graph of time of reaction versus (moles HCl/moles Mg), with time on the vertical axis, using the data collected in steps 6 and 7.
   (e) Use the data you took in steps 6 and 7 to complete the following statement: "When the concentration of a reactant increases, the reaction rate ..... and the time of reaction ....".
   (f) i) Calculate the average mass of Mg used in Part II.
      ii) Calculate the moles of Mg corresponding to the above average mass.
      iii) Calculate the moles of HCl present in 10.0 mL of 3.0 M HCl.
      iv) Calculate the value of the ratio $\frac{\text{moles of HCl in 10.0 mL of 3.0 M HCl}}{\text{average moles of Mg}}$.
      v) Use your graph to estimate the time required for the reaction when 3.0 M HCl reacts with a strip of Mg having a mass equal to the average mass of Mg used in step 6. Indicate on your graph how you arrived at the time for 3.0 M HCl.

3. What happens to the concentration of the REACTANTS as a reaction proceeds? Therefore, what should happen to the rate of a reaction as the reaction proceeds?

4. (a) Using the data collected in step 8, list the four acids in increasing order of reaction rate with Mg. The HCl, HNO_3 and H_3PO_4 each contribute one H^+ into solution per mole of acid. The H_2SO_4 contributes 2 mol of H^+ per mole of acid.
   (b) Discuss whether you agree or disagree with the following statement and what evidence you have to support your belief: "All acids react equally well with magnesium metal".

5. (a) Using the data collected in step 9, list the three metals in increasing order of reaction rate with 6-MHCl.

(b) Discuss whether you agree or disagree with the following statement and what evidence you have to support your belief: "Hydrochloric acid reacts equally well with all metals".

6. Using the data collected in steps 10 and 11, state how the surface area of the reactants affects the rate of a reactant. How do you use the effect of surface area on the reaction rate when starting a campfire?

7. (a) i) Is the reaction of $KMnO_4$ with H_2SO_4 and $K_2C_2O_4$ fast or slow if $MnSO_4$ is not added?
   ii) What effect does the presence of $MnSO_4$ have on the rate of the reaction?
   iii) What happens to the rate of the reaction as the [$MnSO_4$] increases?
   iv) Discuss whether you agree or disagree with the following statement and what evidence you have to support your belief: "Unlike other reactants, the concentration of a catalyst has no effect on a reaction rate. There simply has to be some catalyst present".

   (b) Examine the reaction equation in Part V, including both reactants and products. This reaction is said to be "self–catalyzed" or "autocatalytic". Why is this statement true? What should happen to the [$MnSO_4$] as the reaction proceeds?

   (c) In question 3 you were asked "what should happen to the rate of a reaction as the reaction proceeds?" Is your answer to this part of question 3 true for a self–catalyzed reaction? Why?

8. (a) Hydrogen peroxide does not decompose into water and oxygen at a noticeable rate at room temperature; that is, it is said to be stable. What experimental observation shows that $Fe(NO_3)_3$ causes H_2O_2 to decompose at an accelerated rate?

   (b) Sodium phosphate, Na_3PO_4, is said to be an inhibitor for the catalyzed decomposition of H_2O_2 by Fe^{3+}. (An "inhibitor" slows down the rate of a reaction.) What experimental observation shows that Na_3PO_4 does or does not inhibit the rate at which $Fe(NO_3)_3$ decomposes H_2O_2?

   (c) When $Fe(NO_3)_3$ is added to water, the following dissociation reaction occurs:

$$Fe(NO_3)_3 \longrightarrow Fe^{3+} + 3\ NO_3^-.$$

   The Fe^{3+} is able to move freely through the H_2O_2 solution and catalyze the decomposition reaction. Similarly, when Na_3PO_4 is added to water the following dissociation reaction occurs:

$$Na_3PO_4 \longrightarrow 3\ Na^+ + PO_4^{3-}.$$

   When Fe^{3+} is combined with PO_4^{3-}, an insoluble precipitate of $FePO_4(s)$ forms:

$$Fe^{3+} + PO_4^{3-} \longrightarrow FePO_4(s).$$

   Why is Na_3PO_4 expected to act as an inhibitor for the catalyzed decomposition of H_2O_2 by Fe^{3+}?