Chemistry

Big Pieces or Small Piece: Which React Faster?

(from http://www.sciencebuddies.com)

Objective

The goal of this project is to measure the effect of reactant particle size on the rate of a chemical reaction.

Introduction

You may have seen a television commercial for Alka-Seltzer tablets, or heard one of their advertising slogans: "Plop, plop, fizz, fizz, oh what a relief it is!®" When you drop the tablets in water, they make a lot of bubbles, like an extra-fizzy soda. And like a soda, the bubbles are carbon dioxide gas (CO_2). However, with Alka-Seltzer®, the CO_2 is produced by a chemical reaction that occurs when the tablets dissolve in water. The main ingredients of Alka-Seltzer tablets are aspirin, citric acid, and sodium bicarbonate ($NaHCO_3$). When sodium bicarbonate dissolves in water, it dissociates (splits apart) into sodium (Na^+) and bicarbonate (HCO_3^-) ions. The bicarbonate reacts with hydrogen ions (H^+) from the citric acid to form carbon dioxide and water. The reaction is described by the following chemical equation:

$$3HCO_3^- + 3H^+ \rightarrow 3H_2O + 3CO_2$$

So how does particle size come into this? In order for the reaction shown above to take place, the ingredients in the tablet first have to dissolve. The table has a large surface area, so this step should be pretty fast, right? What effect do *you* think particle size will have on the speed of the bicarbonate reaction? You can find out for yourself by plopping prepared Alka-Seltzer® tablets (whole tablets, halved tablets, quartered tablets, and powdered tablets) into water at the same temperature, and timing how long it takes for the chemical reaction to go to completion.

Terms, Concepts and Questions to Start Background Research

To do this project, you should do research that enables you to understand the following terms and concepts:

- Molecules
- Temperature
- Reactants
- Products

- Reaction rate

Questions

- Do you think changing the particle size will have a measurable effect on the chemical reaction rate?
- Will smaller particles speed up or slow down the reaction?

Bibliography

- Bayer HealthCare, 2005. "Effect of Particle Size and Rate of Reaction," Bayer HealthCare, LLC http://www.alkaseltzer.com/as/student_experiment2.html.

Materials and Equipment

To do this experiment you will need the following materials and equipment:

- At least 12 Alka-Seltzer® tablets (if you plan to do additional variations to the project, you'll want to get a larger box)
- Sheet of blank paper
- Hammer
- Piece of scrap wood
- Thermometer (good range would be -10°C to 110°C
  - E.g. catalog # WW6332000 from Science Kit & Boreal Lab or catalog #15V1460 from Wards Natural Science)
  - Standard kitchen candy thermometer will also work fine
- Clear 12 ounce (355 mL) drinking glass (or larger)
  - **Note:** Use Pyrex glass when working with water heated on the stove or in the microwave)
- Measuring cup
- Masking tape
- Something to stir with (a teaspoon or a chopstick, for example)
- Tap water
- Stop watch (you can also use a clock or watch with a second hand)
- A helper
- Lab notebook
- Pencil

Experimental Procedure

1. Do your background research and make sure that you are familiar with the terms, concepts, and questions, above.

2. In this experiment, you will be measuring the time it takes for one Alka-Seltzer® tablet to react completely in water. You will investigate how the reaction time changes as you vary the particle size of the reactants.
3. You'll use the same glass for repeated trials, so it is convenient to mark the desired water level.
    a. Use the measuring cup to add 8 ounces (236 mL) of water to the glass. (If you're using metric volume units, rounding up to 250 mL is fine.)
    b. Use a piece of masking tape on the outside of the glass to mark the water level. Place the tape with its top edge even with the water level in the glass.
    c. Now you can use the masking tape to fill the glass to the right level for each trial.
4. For observing the reaction, you will use the same volume of water at the same starting temperature. The only variable that you should change is the particle size of the tablets. You will use four different particle sizes for the Alka-Seltzer® tablets:
    a. A whole tablet
    b. A tablet broken in half
    c. A tablet broken in quarters
    d. A tablet ground into powder. To do this, fold a single tablet to be ground inside a clean piece of paper. Place the folded paper on a piece of scrap wood, and use the hammer to firmly pound the tablet about ten times. Stop immediately if the paper shows signs of tearing: you don't want to lose any of the powder.
5. Here is how to measure the reaction time:
    a. Fill the glass with water to the level of the masking tape.
    b. Measure the temperature of the water, and record it in your lab notebook. Each trial should be carried out at the same temperature, so adjust the water temperature (by adding warm or cold water) as necessary.
    c. Remove the thermometer. (It's not a good idea to use the thermometer as a stirring rod. It might break.)
    d. Have your helper get ready with the stop watch, while you get ready with an Alka-Seltzer®. Have your helper count one–two–three. On three, the helper starts the stop watch and you drop the tablet (or tablet pieces) into the water.
    e. You'll immediately see bubbles of CO_2 streaming out from the tablet.
    f. Stir the water gently and steadily. Use the same stirring method and speed for all of your experimental trials. The tablet will gradually disintegrate. Watch for all of the solid white material from the tablet to disappear.
    g. When the solid material has completely disappeared and the bubbles have stopped forming, say "Stop!" to have your helper stop the stopwatch.
    h. Record the reaction time in your lab notebook.

    i. Tip: be careful when opening the packets and handling the Alka-Seltzer® tablets. The tablets are thin and brittle, so they break easily. You need to have four whole tablets for this experiment.

6. For each of the four particle sizes, you should repeat the experiment three times, for a total of 12 trials. You can organize your data in a table like the one below.

Particle Size	Temperature (°C)	Reaction Time (s)			Average Reaction Time (s)
		Trial #1	Trial #2	Trial #3	
Whole Tablet					
Tablet Broken in Half					
Tablet Broken in Quarters					
Powdered Tablet					

7. Calculate the average reaction time for each of the four particle sizes.
8. Make a bar graph showing the average reaction time, in seconds, (y-axis) vs. particle size (x-axis).
9. How does reaction time change with particle size?

Variations

- More advanced students should also calculate the standard deviation of the reaction times for each temperature. http://www.sciencebuddies.org/mentoring/project_data_analysis_variance_std_deviation.shtml.
    - Use the standard deviation to add error bars to your graph.
    - For example, say that the average reaction time for one particle size was 45 seconds, and the standard deviation was 5.2 seconds (these are made-up numbers). You would graph the bar for the data point at 45 seconds, and then draw short vertical bars above and below the top of the bar. Each vertical bar would have a length equivalent to 5.2 seconds.
    - Error bars give your audience a measure of the variance in your data.

How Fast Does an Alka Seltzer® Tablet Make Gas?

(from http://www.sciencebuddies.com)

Objective

The goal of this project is to measure the effect of temperature on the rate of a chemical reaction.

Introduction

You may have seen a television commercial for Alka-Seltzer tablets, or heard one of their advertising slogans: "Plop, plop, fizz, fizz, oh what a relief it is!®" When you drop the tablets in water, they make a lot of bubbles, like an extra-fizzy soda. And like a soda, the bubbles are carbon dioxide gas (CO_2). However, with Alka-Seltzer®, the CO_2 is produced by a chemical reaction that occurs when the tablets dissolve in water.
The main ingredients of Alka-Seltzer tablets are aspirin, citric acid, and sodium bicarbonate ($NaHCO_3$). When sodium bicarbonate dissolves in water, it dissociates (splits apart) into sodium (Na^+) and bicarbonate (HCO_3^-) ions. The bicarbonate reacts with hydrogen ions (H^+) from the citric acid to form carbon dioxide and water. The reaction is described by the following chemical equation:

$$3HCO_3^- + 3H^+ \rightarrow 3H_2O + 3CO_2$$

The compounds on the left-hand side of the equation (bicarbonate ions and hydrogen ions) are called the *reactants*, and the compounds on the right-hand side of the reaction (water and carbon dioxide) are called the *products*.

So how does temperature come into this? In order for the reaction shown above to occur, the bicarbonate ions have to come into contact with the hydrogen ions. Molecules in a solution are in constant motion, and are constantly colliding with one another. The hydrogen and bicarbonate ions must collide at the right angle and with enough energy for the reaction to occur. The temperature of a solution is a measure of the average motion (kinetic energy) of the molecules in the solution. The higher the temperature, the faster the molecules are moving.
What effect do *you* think temperature will have on the speed of the bicarbonate reaction? In this project you can find out for yourself. You'll build a simple apparatus to

collect the carbon dioxide gas produced by the chemical reaction. Then you'll plop Alka-Seltzer® tablets into water at different temperatures, and measure the volume of carbon dioxide gas collected at different time points.

Terms, Concepts and Questions to Start Background Research

To do this project, you should do research that enables you to understand the following terms and concepts:

- Molecules
- Temperature
- Reactants
- Products
- Reaction rate
- Sodium bicarbonate ($NaHCO_3$)
- Citric acid ($C_6H_8O_7$)

Bibliography

- Brown, W.P., 2007. "GCSE notes on the Rates of Chemical Reactions," Doc Brown's Chemistry Clinic [accessed May 8, 2007] http://www.docbrown.info/page03/3_31rates.htm.
- Clark, J., 2002. "Understanding Chemistry: Rates of Reaction Menu," Chemguide [accessed May 11, 2007] http://www.chemguide.co.uk/physical/basicratesmenu.html.
- Helmenstine, A.M., 2007. "How To Create an Endothermic Chemical Reaction (Safe)," About: Chemistry [accessed May 8, 2007] http://chemistry.about.com/cs/howtos/ht/endothermic.htm.

Materials and Equipment

To do this experiment you will need the following materials and equipment:

- Safety goggles or safety glasses
- At least 12 Alka-Seltzer® tablets (if you plan to do additional variations to the project, you'll want to get a larger box)
- Thermometer (good range would be -10°C to 110°C
  - E.g. catalog #WW6332000 from Science Kit & Boreal Lab or catalog #15V1460 from Wards Natural Science.)
  - Standard kitchen candy thermometer will also work fine

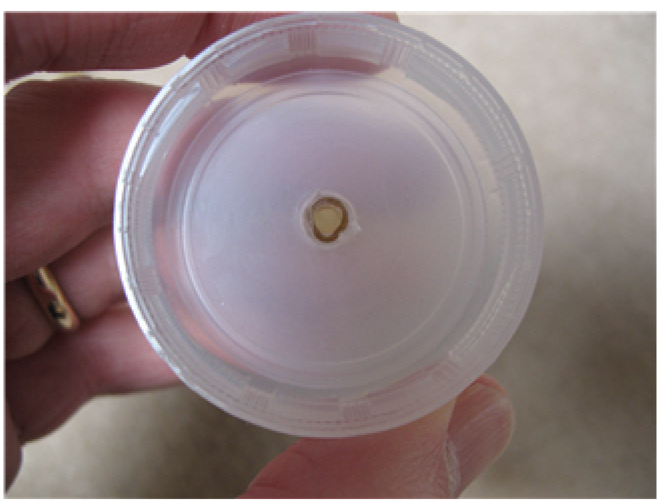
- Means for capturing the gas and measuring the volume (choose **one** of the following two methods):
    - 60 mL syringe and plastic tubing:
        - Pros: accurate gas volume measurement, fairly easy to set up
        - Cons: the smallest package contains 30 syringes, which is way more than you need, so this option is more expensive (unless you can find a source for single syringes or share your package with others)
        - Sources: Science Kit & Boreal Lab catalog #WW6312360 or Wards Natural Science catalog #14V1620.
    - 100 mL graduated cylinder + plastic dishpan or bucket of water:
        - Pros: accurate gas volume measurement, less expensive
        - Cons: the set-up is a bit more complicated
        - Sources: Science Kit & Boreal Lab catalog #WW6136608 or Wards Natural Science catalog #18V1743.
- Clear, wide-mouth plastic bottle with cap (12 ounces or larger, e.g., a small Gatorade® bottle)
- Aquarium tubing
    - Outer diameter: 5.6 mm (0.22 in)
    - Inner diamter: 4.7 mm (0.19 in)
    - 50 cm (about 2 feet) is good for use with syringe, 100 cm (about 3 feet) is good for use with graduated cylinder
    - Available at tropical fish stores, pet stores
- Drill
- 5.56 mm (7/32 in) drill bit (should be slightly smaller than the outer diameter of aquarium tubing to assure an air-tight fit)
- Center punch (or hammer and sharp nail)
- Measuring cup
- Masking tape
- Hot and cold tap water
- Ice
- Clock or watch with a second hand
- A helper
- Lab notebook
- Pencil

Experimental Procedure

Note: In this experiment you will collect the carbon dioxide gas produced when a single Alka-Seltzer® tablet is placed in water. Choose *either* the syringe method *or* the graduated cylinder method for collecting the carbon dioxide gas.

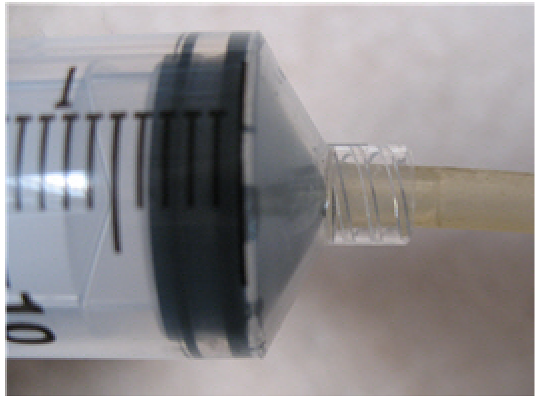
Experimental Setup Using Syringe

1. Drill a hole for the aquarium tubing in the center of the cap of the wide-mouth bottle.
    a. Wear safety goggles for this step.
    b. The hole should be slightly smaller than the outer diameter of the aquarium tubing to assure an air-tight fit.
    c. Mark the location for the hole in the center of the bottle cap. Use a center punch or tap a nail with a hammer to make a small depression at the center location so the drill bit won't slip.
    d. Carefully drill the hole in the bottle cap. It is easiest to do this with the cap screwed in place on the empty bottle. Have your helper hold the bottle straight.
2. Squeeze one end of the tubing and press it into the hole. Push the tubing through to the other side of the cap (see illustration below). This should make an airtight seal.



Aquarium tubing press-fit into drilled hole in bottle cap.

3. Press the other end of the tubing onto the end of the syringe. Tip: rotate the syringe so that the volume markings are easy to read when you set the syringe down.



Aquarium tubing pressed on to end of syringe.

4. Here is a picture of the completed plastic bottle/syringe gas collection apparatus.

Experimental Setup Using Graduated Cylinder

⊙Drill a hole for the aquarium tubing in the center of the cap of the wide-mouth bottle.

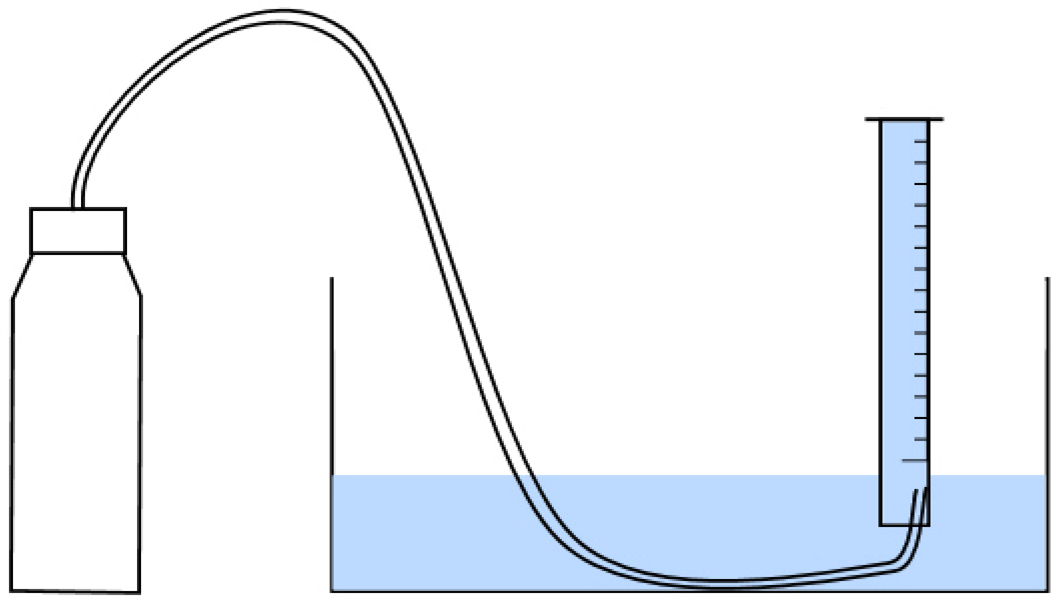
a. Wear safety goggles for this step.
b. The hole should be slightly smaller than the outer diameter of the aquarium tubing to assure an air-tight fit.
c. Mark the location for the hole in the center of the bottle cap. Use a center punch or tap a nail with a hammer to make a small depression at the center location so the drill bit won't slip.
d. Carefully drill the hole in the bottle cap. It is easiest to do this with the cap screwed in place on the empty bottle. Have your helper hold the bottle straight.

⊙Squeeze one end of the tubing and press it into the hole. Push the tubing through to the other side of the cap (see illustration below). This should make an airtight seal.

Aquarium tubing press-fit into drilled hole in bottle cap.

⊙ You will be collecting carbon dioxide from the Alka-Seltzer® chemical reaction by displacing water trapped in an inverted graduated cylinder. Here's how to set it up:

a. Fill your plastic dishpan (or bucket) about one-third full with water.
b. Fill the graduated cylinder with water.
    i. If your dishpan is deep enough, fill the graduated cylinder by tipping it on its side inside the dishpan. Allow any bubbles to escape by tilting the cylinder up slightly, while keeping it under water. Keeping the opening of the cylinder under water, turn it upside down and attach it to the side of the dishpan with masking tape (or have your helper hold it in place).
    ii. If your dishpan is not deep enough, fill the graduated cylinder completely using the faucet and cover the top tightly with plastic wrap. Quickly invert the cylinder and place the opening in the dishpan, beneath the surface of the water. Remove the plastic wrap. Attach the cylinder to the side of the tub with packing tape (or have your helper hold it in place).
c. The graduated cylinder should now be upside down, full of water and with its opening under the surface of the water in the dishpan. Place the free end of the tubing from the plastic bottle inside the graduated cylinder. Your apparatus is now ready to trap carbon dioxide from the Alka-Seltzer® chemical reaction (see illustration below).



Schematic diagram of inverted graduated cylinder gas collection apparatus.

d. You can test your gas collection apparatus by blowing gently into the tube. The bubbles you create should be captured inside the cylinder. (You'll need to re-fill the cylinder before starting your experiment.)

Running the Experiment

1. In this experiment, you will be measuring the reaction rate for the production of carbon dioxide gas from a single Alka-Seltzer® tablet.
    a. You will measure the volume of gas produced at 10-second time intervals after the reaction begins.
    b. You will investigate how the reaction rate changes with water temperature.
2. You'll use the same plastic bottle for repeated trials, so it is convenient to mark the desired water level.
    a. The actual volume of water used is not critical, as long as it is at least 240 ml (8 oz.).
    b. The smaller the air space in the bottle, the sooner you will be able to start collecting carbon dioxide gas.
    c. You do want to use the same amount of water for each trial. Use a piece of masking tape on the outside of the bottle to mark the water level. Place the tape with its top edge even with the water level in the bottle.
3. For measuring the reaction rate, you will use the same volume of water at three different starting temperatures: hot tap water, cold tap water, and ice water.
    - For the hot and cold tap water, run the water until the temperature stabilizes. Fill the bottle with water to the level of the masking tape.

- For ice water, fill the bottle about half full with ice cubes, then add cold tap water to the level of the masking tape. Stir for a minute or two so that the temperature equilibrates.

4. Here is how to measure the reaction rate:
   . Fill the glass bottle water to the level of the masking tape.
   a. Measure the temperature of the water, and record it in your lab notebook.
   b. Remove the thermometer.
   c. Have your helper get ready with the stop watch, while you get ready with an Alka-Seltzer® tablet. Hold the tablet in one hand and the bottle cap ((with tubing attached) in the other hand.
   d. Have your helper count one–two–three. On three, the helper starts timing and you drop the tablet into the water.
   e. Quickly cap the bottle tightly. You'll immediately see bubbles of CO_2 streaming out from the tablet.
   f. Using the hand that you *don't* use for writing, swirl the bottle gently, keeping the bottom of the bottle flat on the table top.
   g. Every ten seconds, your helper should call out "Time!" You should immediately read the carbon dioxide volume (in the syringe or graduated cylinder) and write it down in your lab notebook. Prepare a table like the one below to keep your data organized.

Water temp. (°C)	Trial #	Volume of CO_2 after reaction begins (times in seconds)											
		10	20	30	40	50	60	70	80	90	100	110	120

   h. Continue recording the volume of gas at ten-second intervals until the volume is no longer changing. At this point, the reaction is complete.
   i. Tip: be careful when opening the packets and handling the Alka-Seltzer® tablets. The tablets are thin and brittle, so they break easily. If some of the tablets are whole, and some are broken into many pieces, the separate trials will not be a fair test.

5. For each of the three temperatures, you should repeat the experiment four times, for a total of 12 trials.

Analyzing Your Data

1. For each water temperature, calculate the average volume of gas at each time point for the four trials (see the table below)

Water temp. (°C)	Trial #	Volume of CO_2 after reaction begins (times in seconds)											
		10	20	30	40	50	60	70	80	90	100	110	120
17°C	1												
17°C	2												
17°C	3												
17°C	4												
Average	—												

2. Make a graph of the volume of CO_2, in mL, (y-axis) vs. time after the reaction begins, in seconds (x-axis).
    a. You can include the data from all three temperatures on one graph.
    b. Use a different symbol and color for each temperature.
    c. Remember to include a legend that identifies the temperature associated with each symbol.
3. More advanced students should also calculate the standard deviation of the reaction times for each temperature. http://www.sciencebuddies.org/mentoring/project_data_analysis_variance_std_deviation.shtml
    a. Use the standard deviation to add error bars to your graph.
    b. For example, say that the average volume for 17°C water 30 seconds after the reaction began was 45 mL, and the standard deviation was 5.2 mL (these are made-up numbers). You would graph the symbol for the data point at 45 mL, and then draw short vertical bars above and below the symbol. Each vertical bar would have a length equivalent to 5.2 mL.
    c. Error bars give your audience a measure of the variance in your data.
4. How does reaction rate change with temperature?

In Which Temperature Do Crystals Grow Best?

(Project found at http://www.all-science-fair-projects.com/)

Purpose

Determine the temperature which crystals will grow the best.

Materials

- ☑ Crystal growing kit
- ☑ Six crystals
- ☑ Six glass dishes
- ☑ Six crystal solutions
- ☑ Heat lamp
- ☑ Triple-beam balance
- ☑ Thermometer
- ☑ Three rocks

Procedures

1. Following directions, mix crystal solution. Repeat eight more times.

2. Place each dish with crystal solution in a box. Repeat eight times.

3. Take temperature of the refrigerator, heat lamp, and the temperature of the room. Record the temperatures in your science journal.

4. Place three dishes of crystal solutions in the refrigerator; three dishes of crystal solution on top of a cupboard; three dishes under the heat lamp.

5. Observe and record growth of crystals for four days.

6. On fourth day, dump solution from dishes.

7. Record the growth of the crystals in your science journal.

8. Let the crystals dry. Remove them from the dish. Weigh the crystals from each trial and find out which is heaviest. Record your results in your science journal.

Plop, Plop, Fizz Fast: The Effect of Temperature on Reaction Time

(from http://www.sciencebuddies.com)

Objective

The goal of this project is to measure the effect of temperature on the rate of a chemical reaction.

Introduction

You may have seen a television commercial for Alka-Seltzer tablets, or heard one of their advertising slogans: "Plop, plop, fizz, fizz, oh what a relief it is!®" When you drop the tablets in water, they make a lot of bubbles, like an extra-fizzy soda. And like a soda, the bubbles are carbon dioxide gas (CO_2). However, with Alka-Seltzer®, the CO_2 is produced by a chemical reaction that occurs when the tablets dissolve in water.
The main ingredients of Alka-Seltzer tablets are aspirin, citric acid, and sodium bicarbonate ($NaHCO_3$). When sodium bicarbonate dissolves in water, it dissociates (splits apart) into sodium (Na^+) and bicarbonate (HCO_3^-) ions. The bicarbonate reacts with hydrogen ions (H^+) from the citric acid to form carbon dioxide and water. The reaction is described by the following chemical equation:

$$3HCO_3^- + 3H^+ \rightarrow 3H_2O + 3CO_2$$

So how does temperature come into this? In order for the reaction shown above to occur, the bicarbonate ions have to come into contact with the hydrogen ions. Molecules in a solution are in constant motion, and are constantly colliding with one another. The hydrogen and bicarbonate ions must collide at the right angle and with enough energy for the reaction to occur. The temperature of a solution is a measure of the average motion (kinetic energy) of the molecules in the solution. The higher the temperature, the faster the molecules are moving. What effect do *you* think temperature will have on the speed of the bicarbonate reaction? You can find out for yourself by plopping Alka-Seltzer® tablets into water at different temperatures, and timing how long it takes for the chemical reaction to go to completion.

Terms, Concepts and Questions to Start Background Research

To do this project, you should do research that enables you to understand the following terms and concepts:

- Molecules
- Temperature
- Reactants
- Products
- Reaction rate

Questions

- Keeping in mind that an increase in temperature reflects an increase in the average molecular motion, how will increased temperature affect the reaction rate?
- What temperature change is required to increase the reaction time by a factor of 2?
- What temperature change is required to decrease the reaction time by a factor of 2?

Bibliography

- Bayer HealthCare, 2005. "Temperature and Rate of Reaction," Bayer HealthCare, LLC [accessed May 8, 2007] http://www.alkaseltzer.com/as/student_experiment1.html.

Materials and Equipment

To do this experiment you will need the following materials and equipment:

- At least 12 Alka-Seltzer® tablets (if you plan to do additional variations to the project, you'll want to get a larger box)
- Thermometer (good range would be -10°C to 110°C
  - E.g. catalog # WW6332000 from Science Kit & Boreal Lab or catalog #15V1460 from Wards Natural Science
  - Standard kitchen candy thermometer will also work fine
- Clear 12 ounce (355 mL) drinking glass (or larger)
  - **note:** Use Pyrex glass when working with water heated on the stove or in the microwave)
- Measuring cup

- Masking tape
- Something to stir with (a teaspoon or a chopstick, for example)
- Hot and cold tap water
- Ice
- Stop watch (you can also use a clock or watch with a second hand)
- A helper
- Lab notebook
- Pencil

Experimental Procedure

1. Do your background research and make sure that you are familiar with the terms, concepts, and questions, above.
2. In this experiment, you will be measuring the time it takes for one Alka-Seltzer® tablet to react completely in water. You will investigate how the reaction time changes with water temperature.
3. You'll use the same glass for repeated trials, so it is convenient to mark the desired water level.
    a. Use the measuring cup to add 8 ounces (236 mL) of water to the glass. (If you're using metric volume units, rounding up to 250 mL is fine.)
    b. Use a piece of masking tape on the outside of the glass to mark the water level. Place the tape with its top edge even with the water level in the glass.
    c. Now you can use the masking tape to fill the glass to the right level for each trial.
4. For observing the reaction, you will use the same volume of water at three different starting temperatures: hot tap water, cold tap water, and ice water.
    a. For the hot and cold tap water, run the water until the temperature stabilizes. Fill the glass with water to the level of the masking tape.
    b. For ice water, fill the glass about half full with ice cubes, then add cold tap water to the level of the masking tape. Stir for a minute or two so that the temperature equilibrates.
5. Here is how to measure the reaction time:
    a. Fill the glass with water to the level of the masking tape.
    b. Measure the temperature of the water, and record it in your lab notebook.
    c. Remove the thermometer. (It's not a good idea to use the thermometer as a stirring rod. It might break.)
    d. Have your helper get ready with the stop watch, while you get ready with an Alka-Seltzer® tablet. Have your helper count one–two–three. On three, the helper starts the stop watch and you drop the tablet into the water.
    e. You'll immediately see bubbles of CO_2 streaming out from the tablet.

f. Stir the water gently and steadily. Use the same stirring method and speed for all of your experimental trials. The tablet will gradually disintegrate. Watch for all of the solid white material from the tablet to disappear.
g. When the solid material has completely disappeared, and the bubbles have stopped forming, say "Stop!" to have your helper stop the stopwatch.
h. Record the reaction time in your lab notebook.
i. Tip: be careful when opening the packets and handling the Alka-Seltzer® tablets. The tablets are thin and brittle, so they break easily. If some of the tablets are whole, and some are broken into many pieces, the separate trials will not be a fair test.

6. For each of the three temperatures, you should repeat the experiment four times, for a total of 12 trials. You can organize your data in a table like the one below.

Condition	Temperature (°C)	Reaction Time (s)				Average Reaction Time (s)
		Trial #1	Trial #2	Trial #3	Trial #4	
Hot Tap Water						
Cold Tap Water						
Ice Water						

7. Calculate the average reaction time for each of the three water temperatures.
8. Make a graph of the average reaction time, in seconds, (y-axis) vs. water temperature, in degrees Celsius (x-axis).
9. How does reaction time change with temperature?

Variations

- More advanced students should also calculate the standard deviation of the reaction times for each temperature. http://www.sciencebuddies.org/mentoring/project_data_analysis_variance_std_deviation.shtml.
  - Use the standard deviation to add error bars to your graph.
  - For example, say that the average reaction time for one temperature was 45 seconds, and the standard deviation was 5.2 seconds (these are made-up numbers). You would graph the symbol for the data point at 45 seconds,

and then draw short vertical bars above and below the symbol. Each vertical bar would have a length equivalent to 5.2 seconds.

  - Error bars give your audience a measure of the variance in your data.

- **Adult supervision required.** Is reaction rate predictable over a larger temperature range? Water remains liquid above 0°C and below 100°C. Repeat the experiment at one or more additional high temperatures to find out. Use Pyrex glass for containing heated water, and use appropriate care (e.g. wear hot mitts and safety goggles) when handling hot water.

The Chemistry of Hair Highlights

(from http://www.sciencebuddies.com)

Objective

The goal of this project is to investigate how hydrogen-peroxide based hair treatments change the color of human hair.

Introduction

Bleaching, lightening, or de-coloring (removing pigment) hair can be achieved by using natural sunlight or chemicals designed specifically for this purpose. Using sunlight alone, the results achieved will depend on the natural color of the hair. Visible results can take several weeks or months. If the natural hair color is darker than a medium blonde, the most successful way to lighten the hair is using hydrogen peroxide and an ammonia-based hair lightener.

In order to understand how the process of chemically lightening hair works, it is important to understand the structure of a shaft of human hair. Figure 1, below (from a scientific article on the biochemistry of human skin by Desmond Tobin, Ph.D.), illustrates the microscopic structure of a human hair. The left-hand panel of the illustration (Figure 1a), is a cartoon of a human hair shaft with a cut-away view to show the inner structure. Each strand of hair has an outer layer of flattened cuticle cells (Cu), which surround the fibrous cortical cells (Co). The medulla (Md) is a central core of cells in the hair shaft. Also shown is a microfibril (MF) within a cortical cell. The middle panel (Figure 1b), shows an actual hair shaft under the microscope. You can see how the flattened cuticle cells (Cu) have a scale-like appearance when magnified. The dark central medulla (Md) is also visible. The right-hand panel (Figure 1c), shows a cross-section of a fine human hair. Here you can see that the cuticle cells (Cu) are highly flattened, and wrap around the cortical cells (Co) in many layers. The cortical cells contain the dark pigment granules that give each hair strand its natural color (Tobin, 2006).

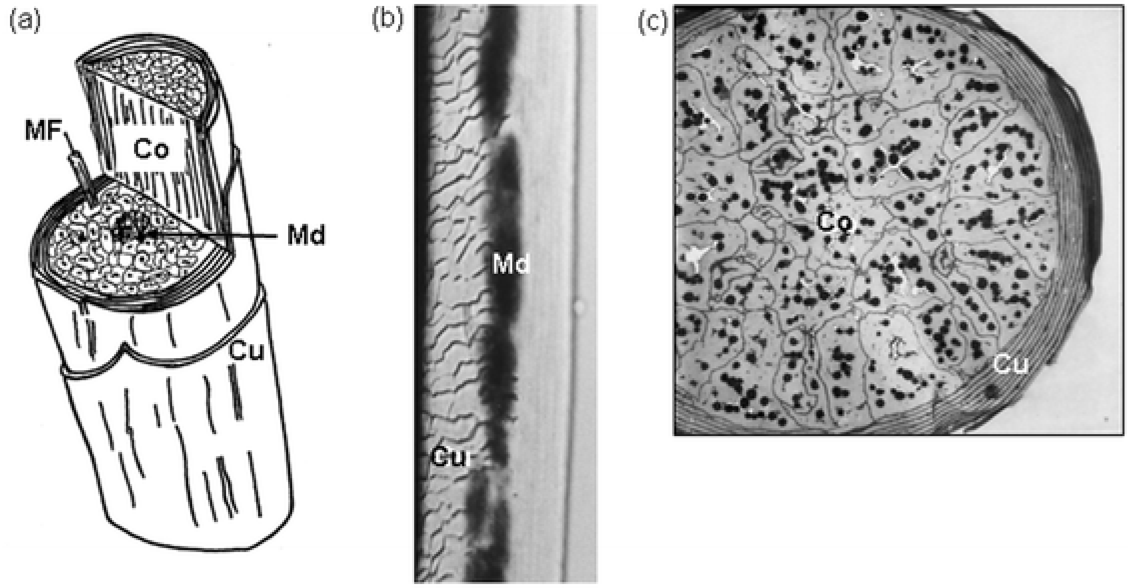


Figure 1. Microscopic structure of a human hair shaft. Part (a) shows a cutaway cartoon of a single hair shaft. The labels show cuticle cells (Cu), cortical cells (Co), the medulla (Md), and a microfibril (MF) within a cortical cell. Part (b) shows a transmitted light micrograph of a single hair strand. The scale-like layer of cuticle cells (Cu) is clearly visible, as is the central medulla (Md). Part (c) shows a cross-section of a fine hair strand. The flattened cuticle cells (Cu) wrap tightly around the cortical cells (Co), which contain many dark pigment granules (Tobin, 2006).

The predominant proteins in hair are from the family of *keratins*, the same family of proteins that make your fingernails. Protein molecules are built from amino acids. In a hair strand, the keratin molecules contain a large number of a particular amino acid called *cysteine*. Each cysteine in the keratin molecule is a potential attachment point, where the keratin molecule can be tightly connected to another cysteine, forming a chemical bond called a *cross-link*. The keratins in hair have many such cross-links, making a hair strand strong and flexible. If you are interested in finding out about how hair grows, you should do research on *hair follicles*, the specialized structure in the skin that produces each individual hair strand.

The cuticle cells also have a coating of specialized molecules that repel water. These molecules are called *lipids*. By repelling water, the lipid molecules help to protect the hair strand. In order for bleaching chemicals to reach the pigment molecules in the cortical cells, the cuticle layer (including its protective lipid coating) must first be opened up. In chemical lightening solutions, this opening is accomplished by making the solution basic. You should do background research on the pH scale, to learn about basic, neutral, and acidic solutions. See the Bibliography for resources to get started.
The hair pigment goes through different stages of changing color as it lightens. The amount of change depends on how much pigment the hair has and the length of time the

hair is exposed to the lightening chemicals. Lightening can be divided into roughly seven stages from the darkest to the lightest. A natural head of black hair will go from black to brown, to red, to red-gold, to gold, to yellow, and finally to pale yellow (almost white). The hair also becomes more porous (increasing the hair's capacity to absorb liquids) during the lightening treatment.

Hydrogen peroxide (H_2O_2) is an oxidizing chemical that bleaches the natural pigments in human hair. For hair treatment, the concentration of hydrogen peroxide is often expressed in *volumes*, referring to the total volume of oxygen (at standard temperature and pressure) that can be produced from the hydrogen peroxide. A "10 volume" solution is equivalent to 3% hydrogen peroxide in water (weight/volume, i.e., 3 grams of H_2O_2 plus enough water to make a total volume of 100 ml). A "20 volume" solution is equivalent to 6% hydrogen peroxide, etc. (Wikipedia contributors, 2006). The higher the concentration of peroxide used the greater the breakdown of melanin (tiny grains of pigment which create natural hair color) resulting in a lighter color.

Hair lighteners are available for use in liquid, cream, and powder form. By mixing a chosen concentration of hydrogen peroxide and a lightener, then applying the mixture to natural hair, we can achieve visible lightening of selected pieces of human hair. In this experiment, you will compare the results of lightening hair with a commercial product to untreated hair, and to hair treated with a "natural" hair lightener such as lemon juice or sunlight.

Terms, Concepts and Questions to Start Background Research

To do this project, you should do research that enables you to understand the following terms and concepts:

- human hair strand, structure, composition, how it grows:
    - cuticle,
    - cortex,
    - pigments: eumelanin, phaeomelanin.
    - keratin,
    - hair follicle.
- understanding the pH scale is helpful for this project,
- hydrogen peroxide (H_2O_2).

Questions

- How are "volumes" of hydrogen peroxide related to concentration of hydrogen peroxide expressed in percentage terms (weight/volume)?
- How does the pH of the bleaching solution affect its ability to lighten hair?
- How does sunlight lighten hair color?

Bibliography

- Most libraries should have copies of these books. (Note that each has multiple editions with different publication dates; the particular edition is not critical.)
  - Milady Publishing Company, 2000. *Milady's Standard Textbook of Cosmetology* Albany, NY: Milady Publishing Company, a division of Delmar Publishers, Inc.
  - Heavilin, S., ed., 2002. *Milady's Illustrated Cosmetology Dictionary* Albany, NY: Milady/Thomson Learning.
- These sites explain the pH scale:
  - Environment Canada, 2002. "Kids' Corner pH Scale," The Green Lane: Acid Rain, Environment Canada website [accessed March 14, 2006] http://www.ec.gc.ca/acidrain/kids.html.
  - Decelles, P., 2002. "The pH Scale," Virtually Biology Course, Basic Chemistry Concepts, Johnson County Community College [accessed March 14, 2006] http://staff.jccc.net/pdecell/chemistry/phscale.html.
- For a start on background information on hair lightening chemicals, try these references:
  - Helmenstine, A.M., Ph.D., 2007. "Hair Color Chemistry," About: Chemistry, About, Inc., a part of The New York Times Company [accessed January 10, 2007] http://chemistry.about.com/cs/howthingswork/a/aa101203a.htm.
  - Wikipedia contributors, 2007. "Peroxide," Wikipedia, The Free Encyclopedia [accessed January 10, 2007] http://en.wikipedia.org/w/index.php?title=Peroxide&oldid=99338248.
  - Field, Simon Quellen, 2003. *Ingredients: What's in the Stuff We Buy* Kinetic MicroScience Press, available online at [accessed January 10, 2007]: http://sci-toys.com/ingredients/bleach.html.
- The figures in the Introduction on human hair structure are from this (advanced!) article, which contains excellent illustrations of hair follicles and hair shafts: Tobin, D.J., 2006. "Biochemistry of Human Skin—Our Brain on the Outside," *Chem. Soc. Rev.* 35: 52–67, available online at [accessed January 10, 2007] http://www.rsc.org/delivery/_ArticleLinking/DisplayHTMLArticleforfree.cfm?JournalCode=CS&Year=2006&ManuscriptID=b505793k&Iss=1.

Materials and Equipment

To do this experiment you will need the following materials and equipment:

- swatches of chemically untreated human hair:
  - approximately 1.5 cm wide × 10 cm long;
  - light brown or darker color;
  - 'chemically untreated' means no permanent waves, no hair color (or even beat up from styling with blow dryers and curling irons);
  - you should be able to obtain these from a beauty salon.
- at least 6 ounces hydrogen peroxide-based developer, in both "10 volume" (contains 3% hydrogen peroxide) and "20 volume" (contains 6% hydrogen peroxide) concentrations; notes:
  - These are the most commonly available volumes at beauty supply stores open to the public.
  - You will need a parent or guardian to purchase.
  - You could also ask at a beauty salon if the salon would be willing to help you with obtaining some.
  - If you can get "40 volume" developer (contains 12% hydrogen peroxide) this would expand the experiment.
  - Most hydrogen peroxide in hair lightening kits sold at superstores or drug stores would be "20 volume."
- hair lightener, powder or cream type; notes:
  - Available at beauty supply stores open to the public.
  - You will need a parent or guardian to purchase.
  - You could also purchase a hair lightener (highlighting) kit from a superstore or drugstore.
  - You could also ask a beauty salon if they would help you in obtaining these.
  - You will need at least enough for one application on a typical head (i.e., the amount from one kit).
- tint brush; notes:
  - Available at a beauty supply store open to the public, *or*
  - use a stiff brush approximately 4 cm wide.
- plastic or glass bowl (no metal),
- protective gloves (latex or vinyl),
- protective eyewear (e.g., goggles),
- aluminum foil,
- lemon juice or other natural lightener for comparison,
- sturdy tape or small elastic bands (for mounting swatches on board).

Experimental Procedure

Safety Note: Use caution with the hydrogen peroxide solutions in this project.

- ***Wear protective gloves and eyewear.***
- ***The solutions can bleach your clothing if they splatter, so it's a good idea to wear a lab coat or old clothes.***
- ***Avoid contact with skin and eyes. If contact occurs, immediately flush with lukewarm water.***
- ***Obtain medical assistance for eye contact.***

1. Do your background research so that you are knowledgeable about the terms, concepts and questions, above. It is especially important that you research and understand the terms and structure of the human hair strand.
2. For chemically lightening a swatch of hair, use the following procedure:
   a. Secure one end of each hair swatch with an elastic band or sturdy tape.
   b. Wear protective gloves when mixing and using the hair lightener solution.
   c. Mix the hair lightener in a bowl.
      - If you are using powder lightener, use approximately 2 tablespoons of powder. Add enough hydrogen peroxide to make a creamy paste about the consistency of honey.
      - If you are using a cream lightener, mix enough hydrogen peroxide to make a honey consistency.
      - For a fair comparison (for example, if you use different concentrations of hydrogen peroxide) use the same amount of hydrogen peroxide for each solution you make.
   d. Lay a hair swatch on a piece of aluminum foil.
   e. Apply the lightening mixture to the hair swatch with the stiff brush. Saturate the swatch with the mixture.
   f. Leave the mixture on the swatch for a set amount of time, for example, 10 minutes.
   g. Rinse the hair swatch with tap water.
   h. Dry the hair swatch.

    i. Remember to label each swatch and keep track of the treatment for each swatch (e.g., hydrogen peroxide concentration, lightener used, length of treatment time) in your lab notebook.
3. Keep one hair swatch completely untreated for comparison.
4. For comparison to peroxide treatment, try sunlight or another "natural" lightening treatment.
5. For sunlight bleaching you can try this method:
    a. Put a swatch of hair in a secure outdoor location that receives direct sun (preferably afternoon).
    b. Do this for at least 1 week.
    c. Compare to untreated and chemically treated swatches and note your results.
6. For "natural" chemical lightening, you can try this method:
    a. Put enough lemon juice (or other natural lightener, such as chamomile tea) on the hair to saturate the hair swatch.
    b. Place in the sun (will not work without sunlight) for several hours.
    c. Rinse hair with tap water.
    d. Dry hair.
    e. Compare to untreated and chemically treated swatches and note your results.
7. Note that you can use the hair swatches on your display board to show the actual results of your experiment.

Variations

- Try different concentrations of hydrogen peroxide. What are the results in lightening the hair using "10 volumes," "20 volumes," and "40 volumes" peroxide?
- Are the results different if the lightener is left on the hair a longer time?
- What happens if the natural lightener or the mixture dries out on the hair? Does drying out stop the process of lightening?
- Compare effects on different types of hair. What is the degree of lightening on hair that is very dark (i.e., dark brown or black)? What is the degree of lightening on hair that is light to begin with (i.e., medium to light blonde)?
- Does adding heat (heat lamp) make a difference in the time or lightening of the hair?
- What condition is the hair left in after the lightening? Dry, rough, dull, or possibly destroyed? Does the length of time that the hair is exposed to the lightener solution affect the condition of the hair? Does a different concentration of peroxide affect the condition of the hair? Design an experiment to find out.