Teacher's Preparatory Guide

Lab 2: Nanocatalysts Clean Your Car Emissions

Purpose: This lab is part 2 of a 2- (optional 3-) part series of inquiry-driven labs that are designed to help students understand reactions and research involved in a catalytic converter. This inquiry-based lab must be used *after* Lesson 1, for it uses the alginate structures students make in lesson 1. In this lab, students will design experiments to see how the surface area, type, and/or concentration of a catalyst affect the rate of a reaction. Students will relate the size of the alginate-MnO_2 catalytic spheres to nanoparticles used in catalytic converters in order to understand the reactions involved in a catalytic converter.

Level High School (Environmental Science, Chemistry)

Time required One or two 45-minute class periods, or one 90-minute block period

Materials for each group of 2–4 students

- 100 ml 3% H_2O_2
- 0.5 g per 30 ml of alginate/glass mixture manganese dioxide (see *Advance Preparation* section)
- 30 ml alginate/glass powder mixture
- 20 ml 5% $CaCl_2$ solution
- 30 ml medicine cup or other small plastic container
- glass stirring rod
- 300 ml plastic bottles or 250 ml Erlenmeyer flask
- plastic syringe (1 ml, 5 ml or 10 ml)
- 3 in. square household plastic screen or cheesecloth
- 1 ml plastic dropping pipette
- balance to be shared by several groups
- one piece weighing paper
- 10–25 ml graduated cylinder
- plastic shoe box filled with water
- ring stand
- clamp to hold graduated cylinder (and another possibly for the reaction bottle)
- 18 in. of Tygon® tubing
- one hole rubber stopper with 5 mm diameter glass tubing that fits the stoppers
- file for cutting glass tubing into pieces
- *optional:* fermentation bubblers with #2 one hole stoppers
- cork borer to make holes in #3 stoppers larger
- Vernier calipers (for measuring alginate structures)

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Safety Information: Do not breathe the glass powder. Note: Students do not directly work with the glass powder; rather, the glass powder is mixed with the alginate and manganese dioxide first, before given to students. Manganese dioxide is a strong oxidant and is moderately toxic by ingestion. Hydrogen peroxide 3% solution is a topical antiseptic and should not be splashed into the eyes or applied over large areas of the body. Calcium chloride solution (5%) can dry skin, so flush any spills on the skin with water. Material Safety Data Sheets (MSDS) for all of these chemicals should be available in the lab.

Advance Preparation

- PREPARATION OF ALGINATE/MnO_2/GLASS POWDER SOLUTION
  To prepare 300 ml of 2% alginate solution, add 6 grams of alginate to 300 ml of water. Mix in a blender for 30 seconds (or until all of the powder is dissolved), and heat in the microwave for 1 to 2 minutes until the mixture starts to boil. The alginate may be stored in the refrigerator if made the day before the lab; otherwise, be sure the mixture is cool before adding 5 grams of MnO_2 and 90 grams of glass powder. The mixture should be stirred with a glass rod. Alternate methods for preparing the alginate solution may be found in the *Teachers Guide* to the Microbial Lava Lamp Classroom Activity at http://www.csun.edu/~hcbio029.

Teacher Background Please refer to *Lab 1: Nanocatalysts Clean Your Car Emissions*.

Instructional Procedure: Lab 2

Time	Instruction	Reasoning
10 min	Groups decide which variable they will test and write a procedure.	Students use inquiry-driven and critical thinking skills.
10 min	Students set up equipment for monitoring the rate of the reaction.	Variations can be shape and size of the spheres/cylinders. Others could be tested as an extension activity—concentration of hydrogen peroxide, amount of manganese dioxide in the alginate mixture.
15 min	Students collect and record data.	Students will quantify the reaction rate.
10 min	Students share and discuss the data.	Students will see the effect that different sizes and shapes of the catalyst structure have on the rate of the reaction.

Procedure

Students will be given opportunities to determine how to calculate the rate of the reaction that they are observing. Small groups will brainstorm ideas, then this will be open for a class discussion. Ideas for calculating the reaction rate include rate of bubbling in the bubbler or recording the time needed to collect a certain volume of oxygen by water displacement in an inverted graduated cylinder or a eudiometer tube.

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Flask with bubbler

Collecting gas by water displacement

Guided Dialogue Before beginning the lab, review the meaning of these terms:

Catalyst *A substance that is used to increase the reaction rate of a chemical reaction but does not become part of the end products. The catalyst provides a different pathway or mechanism that makes bond making, bond breaking or electron exchange occur more rapidly. It lowers the activation energy needed for the reaction to proceed (see "reaction energy diagram" in Wikipedia).*

Oxidation *Loss of electrons (in this reaction, oxygen in hydrogen peroxide is both oxidized* $H_2O_2 \rightarrow H_2O$ *and reduced* $H_2O_2 \rightarrow O_2$*).*

Reduction *Gain of electrons and reduced* $H_2O_2 \rightarrow O_2$ *in the overall reaction* $H_2O_2 \rightarrow H_20 + O_2$*.*

Directions for the Activity

Name:______________________________Date:______________Class:_______________

Student Worksheet
(with answers)

Catalytic Conversions: Guided Inquiry

Avoid splashing hydrogen peroxide into the eyes or onto other areas of the body. Any spills of calcium chloride on the skin should be immediately flushed with water.

Introduction

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Catalysts are in the news! The most valuable part of your car that thieves want to steal is your catalytic converter. To try to understand why, you will examine a common reaction that involves inorganic systems using a metallic oxide as a catalyst. Your job is to design an effective catalyst and quantify the rate at which the inorganic catalyst converts the reactants into products when one of the variables in the reaction is manipulated.

What variable will your group test? *Examples include: size and/or shape of alginate-MnO_2 structures, amount of MnO_2 in the alginate, or concentration of hydrogen peroxide*

How will your group measure the reaction rate? *The volume of a gas produced in a chemical reaction can be measured at regular time intervals and from that the reaction rate can easily be determined.*

Materials

- 30 ml alginate-glass MnO_2 mixture
- 100 ml 3% H_2O_2
- 250–300 ml container
- 5% $CaCl_2$ solution (20ml)
- one hole stopper with glass tubing
- Tygon® tubing (18 inches)
- 10-25ml graduated cylinder
- plastic shoe box filled with water
- small plastic container
- glass stirring rod
- plastic syringes or pipettes
- balance
- weighing paper
- clamps to hold graduated cylinder
- ring stand
- caliper
- fermentation bubbler

Question: How does size and shape of a catalyst affect the reaction rate?

Make a Prediction

If the surface area that exposes the catalyst to the substrate is larger, then the reaction rate will be quicker.

Procedure

1. Select the type of alginate/MnO_2 structures saved from the previous lab that you want to test. Remove them from the $CaCl_2$ solution using cheesecloth or a plastic screen.
2. Rinse the structures with tap water; blot gently with paper towel to remove excess water.
3. Mass four grams of these structures.
4. Add them to 100 ml of hydrogen peroxide that is in the flask.

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5. Place a rubber stopper on the flask.
6. Connect Tygon® tubing to the stopper.
7. Clamp an inverted graduated cylinder full of water over a plastic shoe box containing water.
8. Insert the tubing into the graduated cylinder.
9. Wait one minute for the system to equilibrate.
10. In the table below record the volume of gas collected every minute for the next 5 minutes.

Record Your Observations

Time (minutes)	Volume (milliliters)
1	*0.75 ml*
2	*1.5 ml*
3	*2.25 ml*
4	*3.0 ml*
5	*3.75 ml*

Record any other observations that you observed during the reaction time:

Example answer: The alginate/manganese dioxide structures quickly rise to the surface of the hydrogen peroxide solution in the flask. The bubbling gas released pushes the water out of the graduated cylinder and the volume of gas is easily observed by this water displacement method.

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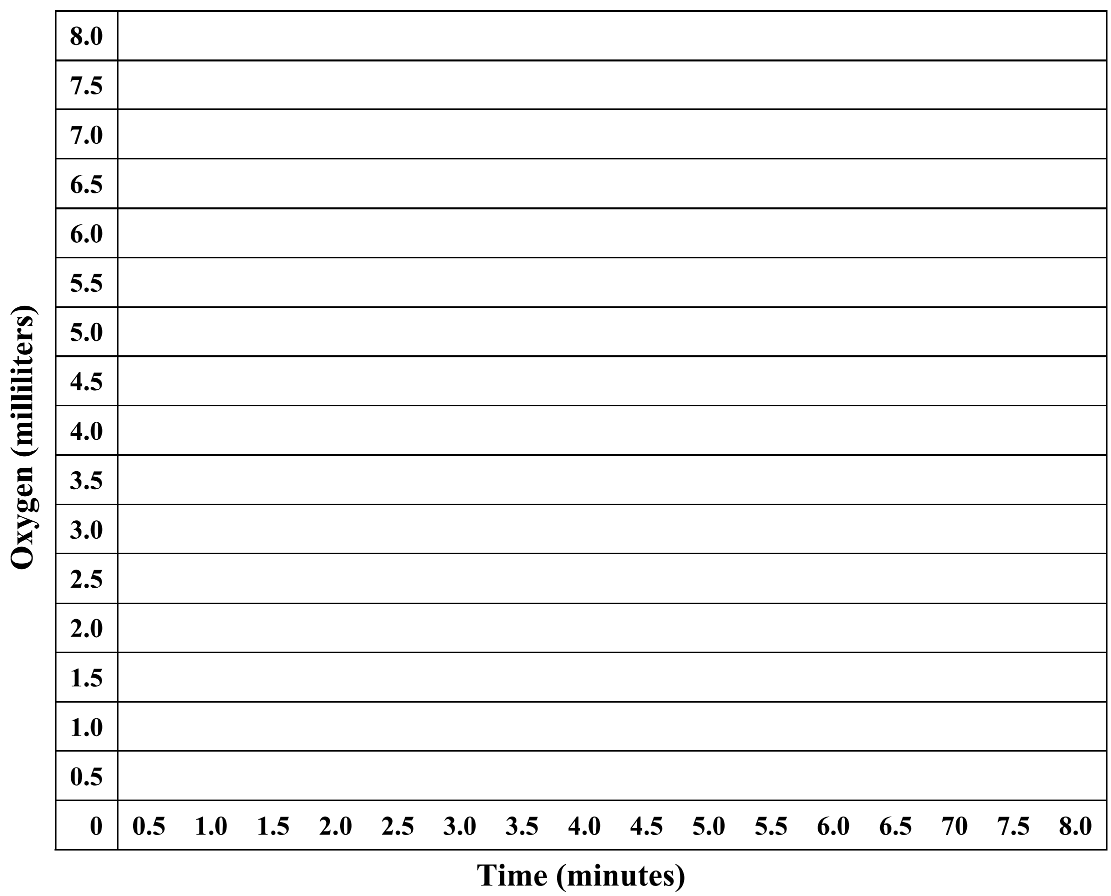
Analyze the Results

1. Record the data collected by the other groups in the class for milliliters of oxygen released each minute for the five-minute trial period.

Time (min)	Group 1	Group 2	Group 3	Group 4
1	*0.75*	*1.0*	*1.5*	*0.5*
2	*1.5*	*2.0*	*2.8*	*1.0*
3	*2.25*	*3.0*	*4.3*	*1.6*
4	*3.0*	*4.0*	*5.9*	*2.0*
5	*3.75*	*5.0*	*7.6*	*2.5*

2. Make a graph of the class data for the reaction rate of hydrogen peroxide decomposition using Chart Wizard on Excel or graphing the data on the graph provided below. (This will be used in the next class.) *Students should do an x/y plot with time as the independent variable and milliliters of oxygen collected as the dependent variable.*

Title:



3. Calculate the rate of the reaction you tested. Please show your work!

   The reaction rate is the slope of the line, change in volume over time. This reaction will not have gone to completion (r =0) in this time period, so just taking the total volume divided by 5 minutes gives a comparative rate in ml/min.

4. Describe any general trends you see from examining the graph that you prepared.

   The larger spheres produce oxygen more slowly than the smaller ones. The small spheres have the fastest rate; next are the cylinders.

Draw Conclusions

1. If size is the variable, how does the size of the alginate/manganese dioxide spheres affect the rate of the reaction?

   The greater the surface area of the catalyst, the faster the rate of the reaction; small spheres of the same total mass have greater total surface area and hence a faster rate of reaction.

2. Which group had the faster rate of reaction?

   The groups with small cylinders or very small spheres should have the fastest rates.

3. What factors were controlled in this reaction?

   temperature, volume of peroxide, volume of reaction container, mass of alginate structures

4. How do these findings relate to the design of nanocatalysts for catalytic converters?

   To design nanocatalyts using gold nanoparticles, the size must be carefully controlled. In addition, the gold nanoparticles must be coated with silica to keep them from fusing when the hot exhaust hits the surface of the catalytic converter.

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Cleanup: Alginate structures should be removed from the peroxide solution and rinsed in tap water. They may be dried or stored in 5% calcium chloride to be used by other students if necessary. The hydrogen peroxide solution may be rinsed down the drain with excess water. Any glass powder that might spill when making the mixture may safely be put in the trash. Solutions should be disposed per school disposal procedures.

Resources: Materials may be found at-

Source	Items
any pharmacy **(or any scientific supply company)**	• 3% hydrogen peroxide • medicine cups • plastic syringes • plastic cups
any hardware store **or discount store**	• household plastic screen • plastic shoe box
any grocery store	• cheesecloth • 300 ml plastic bottles
http://willpowder.net/ and also scientific suppliers **http://www.flinnsci.com/store/Scripts/ck_prodList**.asp	• alginate
Potters Industries Inc., PO Box 840, Valley Forge, PA 19482-0840 (610) 651-4700	• Spheriglass glass powder
Nutrasweet Kelco Co., 8355 Aero Drive, San Diego, CA 92123	• Keltone LV alginate
Sunnyside Sea Farms, 475 Kellogg Way, Goleta, CA (805) 964-5844 http://www.seafarms.com	• alginate • calcium chloride
Fisher Scientific http://www.fishersci.com, or **VWR Lab Shop** http://vwrlabshop.com, or **other chemical or science education suppliers**	• manganese dioxide powder • calcium chloride • potassium iodide • Vernier calipers • Tygon® tubing (VWR Item #63009-178) • cork borer • balance • dropping pipette • weighing paper • ring stand

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	• clamp • graduated cylinder • 250 ml Erlenmeyer flask • file for etching glass to cut glass tubing
DeFalco's Home Wine & Beer Supplies http://www.defalcos.com/products/Fermentation-Locks-Stoppers/Fermentation-Locks-Stoppers.html	• S-shaped bubbler lock (plastic) (Item #: 2967504)

Enhancing Understanding: Cover this section *after* the activity if time permits or in the next class period.
Compare and contrast the hydrogen peroxide catalytic reaction to the reactions in a catalytic converter. *Example answer: Both reactions involve reactants that are converted to products with the help of a catalyst. One product in this hydrogen peroxide reaction is a gas, and in the emission stream that reacts in the catalytic converter most of the substances are gases. The hydrogen peroxide decomposition is greatly enhanced through increased surface area of the catalyst that is used, and thus nanoparticles with great surface area to volume ratios are found on the surfaces of the catalytic converter.*

Going Further: Students who have a good grasp of the content of the lab can be further challenged as outlined below:
The experiment could be repeated with different concentrations of hydrogen peroxide or different amounts of manganese dioxide in the alginate/glass mix. Using the same alginate-glass sphere model, students could investigate the catalysts found in living systems (enzymes). They might compare the ability of catalase to decompose hydrogen peroxide to the rate of reaction found with the inorganic catalyst manganese dioxide. Potatoes, liver, turnips, blood, and yeast all contain the enzyme catalase.

Assessment:
Guided Inquiry
Students submit a lab report that includes their observations, data, and analysis of results from labs 1 and 2. The lab experiments can be written in a *formal lab report style* that includes the hypotheses generated in each part of the lab, a brief description of the procedures followed (materials and methods), presentation of the data in the results section, and analysis of the findings in the discussion section. Teachers should look for:

- ability to state the hypotheses (10 points)
- accuracy in stating what was done (10 points)
- accuracy in recording and graphing the data (40 points)
- analysis and discussion of their findings and the class findings (50 points)

Students submit the data tables and graphs of their findings and answer the questions written in the lab. Similar guidelines are used for assessing student understanding in the various parts of the report that is submitted.

Independent Inquiry
Each group should contribute points to class discussion. Students should be able to turn in completed lab procedures with an appropriate method for completing challenges #1 and #2 and

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answer the questions with reasonable responses. Extra credit points can be assigned for completing challenge #3.

National Science Education Standards (Grades 9–12)
Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Structure and properties of matter
- Chemical reactions

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

California Science Education Standards (Grades 9–12)
Chemistry, Content Standard 6: Solutions

a. Students know the definitions of *solute* and *solvent*.

Chemistry, Content Standard 8: Reaction Rates

a. Students know the rate of reaction is the decrease in concentration of reactants or the increase in concentration of products with time.
b. Students know how reaction rates depend on such factors as concentration, temperature, and pressure.
c. Students know the role a catalyst plays in increasing the reaction rate.
d. Students know the definition and role of activation energy in a chemical reaction.

Investigation and Experimentation, Content Standard 1

a. Select and use appropriate tools and technology to perform tests, collect data, analyze relationships, and display data.
b. Identify and communicate sources of unavoidable experimental error.
c. Identify possible reasons for inconsistent results, such as sources of error or uncontrolled conditions.
d. Formulate explanations by using logic and evidence.
g. Recognize the usefulness and limitations of models and theories as scientific representations of reality.
j. Recognize the issues of statistical variability and the need for controlled tests.
l. Analyze situations and solve problems that require combining and applying concepts from more than one area of science.
m. Investigate a science-based societal issue by researching the literature, analyzing data, and communicating the findings.

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