Research Experiences for Teachers (RET)
Center for Pre-College Programs & Newark College of Engineering
New Jersey Institute of Technology

MODULE
Catalysis, Chemical Reactions, and Nanoparticles-An Instructional Module

MODULE TOPIC:
Catalysis, Chemical Reactions, and Nanoparticles

RATIONALE:
This module is developed to incorporate my summer research on nanoparticle synthesis and characterization into the classroom. The objective is to increase student interest in nanoparticle technology. The use of nanoparticle catalysts in the industrial world is gaining momentum, and students of science and technology need to acquaint themselves with the role of catalysts in industrial processes. Students also need to be familiar with the effect that particle size (surface area) has on the activity of a catalyst. In addition, the role of temperature in shaping catalytic activity should be explored. This is evidently important based on results obtained during RET research. Results indicate that the particle size, and by extension the activity of the Pt catalysts prepared, was determined by the calcination temperature and the reduction temperature.

STANDARD(S) & INDICATOR(S):
(Note: This section should include all standards listed in the lessons.)
5.1.8.B1: Identify questions and make predictions that can be addressed by conducting an investigation
5.1.8.B2: Design and conduct investigations incorporating the use of a control.
5.1.8.B.4: Use quality controls to examine data sets and to examine evidence as a means of generating and reviewing explanations
5.6.12.B1: Explain that the rate of reactions among atoms and molecules depends on how often they encounter one another and that the rate is affected by nature of reactants, concentration, and the presence of a catalyst.

OBJECTIVE(S):
(Note: This section should include all objectives listed in the lessons.)
- Predict the effect of a catalyst on reaction rates.
- Formulate a hypothesis about the effect of particle size (surface area) on the activity of a catalyst

LIST OF LESSONS:
The first lesson involves a class experiment in which students investigate the role of a catalyst in a chemical process. Student will determine the rate of a specified reaction, with and without a catalyst.
In the second lesson, students will determine whether the particle size of a solid catalyst has any effect on the activity of the catalyst. To do this, students will carry out the same chemical reaction three separate times using the same catalyst, each time using a different solid (lump, crystals, powdered) form of the catalyst.

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LESSON #1
Catalysis, Reaction Rates, and Nanoparticles

LESSON TOPIC:
Catalysts and reactions: What role does a catalyst play in a chemical reaction?

STANDARD(S) & INDICATOR(S):
5.1.8.B1: Identify questions and make predictions that can be addressed by conducting an investigation
5.1.8.B2: Design and conduct investigations incorporating the use of a control.
5.1.8.B.4: Use quality controls to examine data sets and to examine evidence as a means of generating and reviewing explanations.
5.3.4.A2: Recognize and comprehend the orders of magnitude associated with large and small physical quantities
5.6.12.B1: Explain that the rate of reactions among atoms and molecules depends on how often they encounter one another and that the rate is affected by nature of reactants, concentration, and the presence of a catalyst.

OBJECTIVE(S): Students will be able to:
- Formulate a hypothesis about the effect of particle size (surface area) on the activity of a catalyst
- Measure the rate of decomposition of 3% H2O2 using equal masses of the following catalysts: a lump of KI, crystals of KI, powdered KI
- Collect and analyze data

MATERIALS:
EQUIPMENT: Vernier gas pressure sensor, temperature probe,
Laptop computer with Logger Pro 3.5 software installed, Vernier Lab Pro interface, one-holed rubber stopper, solid rubber stopper, test tube, 1-liter beaker, 2 10 mL graduated cylinders, temperature probe.
CHEMICALS: 3% H2O2 solution, samples of potassium iodide (crystals, lumps, powdered.

LIST OF HANDOUTS (attach original copies of each handout - teacher & student edition)
Activity 2: How does particle size affect the activity of a catalyst?

BACKGROUND INFORMATION:
It is known that the smaller the particle size of a substance, the more surface area is exposed to another reactant, and the faster the reaction between the two reactants. This is true in terms of reacting species.
Could this statement also be true in terms of a catalyst (that does not necessarily react)? There is evidence to suggest that particle size does affect the activity of a catalyst, especially in heterogeneous catalysis.

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CLASSROOM ACTIVITY DESCRIPTION (LABORATORY/EXERCISES/PROBLEMS) including detailed procedures:

Students will carry out a laboratory investigation to determine the effect of the particle size of a catalyst (KI) on the rate of decomposition of 3% hydrogen peroxide, using different particle sizes of the same catalyst. (See Activity 2 Worksheet for details of procedure)

SAMPLE QUESTIONS TO ELICIT CLASS DISCUSSION:

1. Suppose you have granulated sugar and a cube of sugar both with the same mass. Which sample do you expect to dissolve faster in the same amount of water at the same temperature? Explain your answer.
2. You are given three different forms of the same catalyst, KI. Predict, and explain, which form of the catalyst will provide the fastest rate for a reaction.

HOMEWORK ACTIVITY/EXERCISES/PROBLEMS:

Write a two-page article on Catalytic Converter. Your article should answer the following questions:
What is a catalytic converter?
How does a catalytic converter work?
How does the size of the catalyst affect the efficiency of the converter
Your article should be original (NO COPY AND PASTE), typed (1.5 spacing), and should include references.

PARAMETERS TO EVALUATE STUDENT WORK PRODUCTS:

Student evaluation will be based on:
1. A laboratory report that includes:
   a. A table of the data collected (pressure of O2 evolved, and time)
   b. A copy of computer print-out of graph of pressure versus time
   c. The correct conclusions drawn from their investigation (i.e. a greater surface area (smaller particle size) of a catalyst enhances its efficiency)
2. Appropriate answer to the homework project. This should include a brief description of a catalytic converter, how it works, and references to modern converters that employ nanoparticle catalysts

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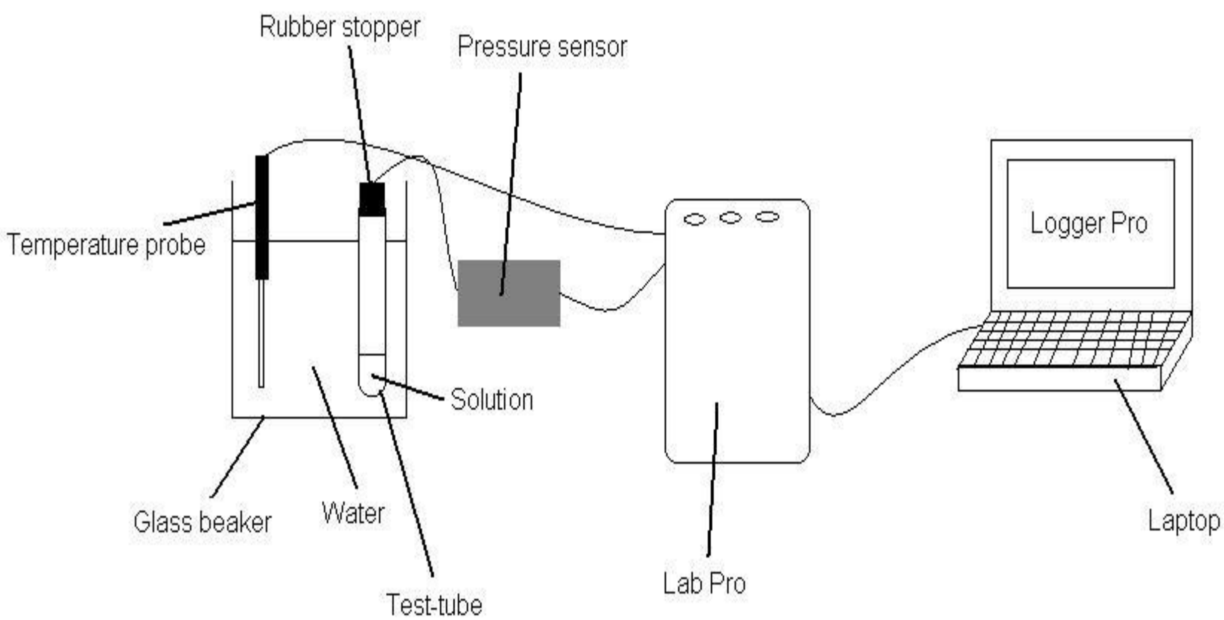
ACTIVITY 2
LABORATORY INVESTIGATION

Concept to investigate: How does particle size affect catalysis?

EQUIPMENT: Vernier gas pressure sensor, temperature probe, Laptop computer with Logger Pro 3.5 software installed, Vernier Lab Pro interface, one-holed rubber stopper, solid rubber stopper, test tube, 1-liter beaker, 2 10 mL graduated cylinders, milligram balance, digital thermometer.

CHEMICALS: 3% Hydrogen Peroxide (H_2O_2) solution, potassium iodide (lumps, crystals, powdered)



PROCEDURE

1. Set up the apparatus as shown above.
2. Measure 10 mL of H_2O_2 solution in a separate test tube, use a solid rubber stopper to stopper the test tube, and place it in a room-temperature water bath (in a 1-liter beaker);
3. Connect a Gas Pressure Sensor to Channel 1 of the Vernier computer interface. Connect the interface to the computer with the appropriate cable.
4. Use the plastic tubing to connect the one-holed rubber stopper to the Gas Pressure Sensor.
5. Start the Logger Pro program on your computer. Open the file "12 Peroxide" from the *Chemistry with Vernier* folder.
6. Remove the solid stopper from the test tube containing H_2O_2 solution. Carefully transfer 0.05 g of KI crystals into the H_2O_2 solution, all the while leaving the H_2O_2 test tube in the water bath. Quickly seal the tube with the one-holed stopper connected to the Gas Pressure Sensor.

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7. Click [Collect] to begin data collection. Data will be collected for three minutes
8. When data collection is complete, carefully remove the stopper to relieve the pressure.
9. Examine the graph for this part of the lab. Select a linear region just beyond the initial flat portion of the graph that covers one minute of reaction. Click the Linear Regression button to calculate the best-fit linear equation. Record the slope as the initial rate of the reaction.
10. Carry out a second trial.
11. Repeat steps 2-11 with 0.05 g powdered KI (catalyst) and with 0.05 g lump of KI

DATA

INITIAL RATE OF REACTION (kPa/s)

KI Catalyst used	Trial 1	Trail 2
Lump		
Crystals		
Powdered		

QUESTIONS

- Explain why a catalyst was used for the decomposition of H2O2 instead of heat?
- In which reaction was the initial rate slowest? Fastest?
- What could have accounted for the differences in the initial rates of the reaction?
- What was the purpose of the water bath and the temperature probe in the experimental set-up?
- Formulate a hypothesis on the effect of particle size (surface area) on the activity of a catalyst.

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LESSON #2
The Role of Catalysts in Reactions

LESSON TOPIC:
How does particle size affect the activity of a catalyst?

RATIONALE:
The use of nanoparticle catalysts in the industrial world is gaining momentum, and students of science and technology need to acquaint themselves with the role of catalysts in chemical processes. What this lesson is intended to do is to bring what students may have read about catalysts under investigation.

STANDARD(S) & INDICATOR(S):
5.1.8.B1: Identify questions and make predictions that can be addressed by conducting an investigation
5.1.8.B2: Design and conduct investigations incorporating the use of a control.
5.1.8.B.4: Use quality controls to examine data sets and to examine evidence as a means of generating and reviewing explanations
5.6.12.B1: Explain that the rate of reactions among atoms and molecules depends on how often they encounter one another and that the rate is affected by nature of reactants, concentration, and the presence of a catalyst.

OBJECTIVE(S): Students will be able to:
- Predict the effect of a catalyst on reaction rates
- Set up apparatus for gas collection
- Measure the rate of decomposition of KClO3 without a catalyst, and with MnO2 catalyst
- Plot a graph of volume of O2 gas evolved (mL) versus time (s), for both reactions above
- Draw conclusions from experimental results

MATERIALS:
EQUIPMENT: Ring stand, utility clamp, large test tube, two-holed rubber stopper, long-stemmed funnel, rubber tubing, graduated gas-collection jar, stopwatch, water trough, laboratory burner
CHEMICALS: Potassium chlorate, KClO3 (solid), manganese dioxide, MnO2 (powder).

LIST OF HANDOUTS (attach original copies of each handout - teacher & student edition)
Activity 1 Worksheet: What Role does a Catalyst play in a Chemical Reaction?

CLASSROOM ACTIVITY DESCRIPTION (LABORATORY/EXERCISES/PROBLEMS) including detailed procedures:
Students will be directed to carry out a laboratory investigation that will lead them to answer the question “What role does a catalyst play in a chemical reaction?” (See Activity 1 Worksheet for detailed procedure)

1. Set up the apparatus as shown below for the preparation of potassium chlorate.
2. Fill the graduated gas-collection jar with water, cover the mouth, and invert into a water trough so no water is lost from the jar.

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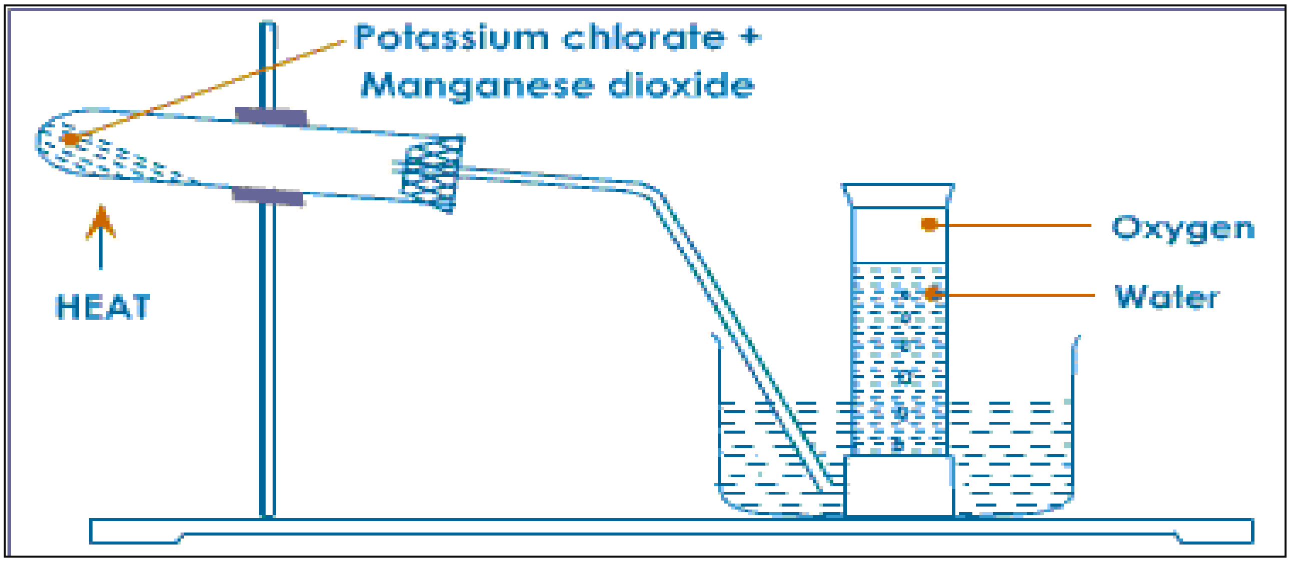
3. Place 10 grams of potassium chlorate, $KClO_3$ into a large test tube, insert a stopper assembly equipped with a delivery tube (bent glass tubing) as shown.
4. Gently heat the bottom of the test tube and measure the rate of evolution of oxygen gas by measuring the volume of water displaced every thirty second for 5 minutes.
5. Carry out a second trial. Record your observations on the data table below.



6. Repeat the procedure above, but this time, add a pea-size amount of manganese dioxide, MnO_2 to the potassium chlorate in the test tube.
7. Carry out a second trial. Record your observations on Data Table 2 below.

Data Table 1

TIME (S)		**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**
VOLUME OF O2 PRODUCED	NO MnO2 ADDED (Trial 1)										
VOLUME OF O2 PRODUCED	NO MnO2 ADDED (Trial 2)										

Data Table 2

TIME(s)		**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**
VOLUME OF O2 PRODUCED (mL)	WITH MnO2 (Trial 1)										
VOLUME OF O2 PRODUCED (mL)	WITH MnO2 (Trial 2)										

ANALYSIS & CONCLUSIONS

1. Compute the average volume of O_2 gas produced (for trials 1 and 2) for each data set.

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2. On the same graph, plot average volume of O2 gas produced (ml) versus time (s) for both data sets.
3. Describe the effect of adding MnO2 on the rate of decomposition of KClO3.
4. What is the purpose of a catalyst?

SAMPLE QUESTIONS TO ELICIT CLASS DISCUSSION:

- Describe in your own words the effect of MnO2 on the reaction rate.
- Based on the results of this laboratory investigation, develop a hypothesis on the effect of catalysts on reaction rates.

HOMEWORK ACTIVITY/EXERCISES/PROBLEMS:

Answer the following questions (Answers to be submitted to teacher)

- Explain the effect of a catalyst on reaction rates in terms of the collision theory.
- What are enzymes? Name TWO enzymes and describe their functions.

PARAMETERS TO EVALUATE STUDENT WORK PRODUCTS:

A laboratory report that includes:

- A table of the data collected (volume of O2 evolved, and time)
- Appropriate graphical representation of their data (axes labeled correctly, etc)
- The correct conclusions drawn from their investigation (i.e. a catalyst speeds up a reaction)
- Appropriate answers should be provided to homework questions.
  - Answers should include the fact that a catalyst lowers the activation energy allowing more energetic collisions to occur per unit time, thus increasing the rate of a reaction
  - Students' answers should mention that enzymes are biological catalysts. Students should also describe briefly the specific catalytic activity of each of TWO named enzymes.

REFERENCES:

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