Reaction Rates and Catalysts in Ethanol Production

(One Activity)

Grades: 5-8, 9-12

Topic: Biomass

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Reaction Rates and Catalysts in Ethanol Production

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Grade Level/Subject

This lesson is intended for use in a high school chemistry class. The lesson could be adapted for a middle school physical science class or AP Chemistry as well.

Standards

Colorado Content Standards

Standard 1: Students understand the processes of scientific investigation and design, conduct, communicate about, and evaluate such investigations.

Standard 2.3: Students understand that interactions can produce changes in a system, although the total quantities of matter and energy remain unchanged.

Standard 5: Students know and understand interrelationships among science, technology, and human activity and how they can affect the world.

Standard 6: Students understand that science involves a particular way of knowing and understand common connections among scientific disciplines.

Overview

Ethanol is produced by fermenting sugar. The sugar can be simple sugars and starches found in the kernels of corn, or it can be found in the polymers of sugar molecules known more commonly as cellulose. In order to improve the efficiency and decrease the cost associated with ethanol production, cellulose can be used as a source of sugar for fermentation, if it can be broken down into its component sugar molecules. This process, called hydrolysis, is the subject of a major research effort today. The current methods of hydrolysis involve using either sulfuric acid and high temperatures or complex biological enzymes. Both methods have their drawbacks, so the search is on for an alternative catalyst which will be easier to use and produces the fast reaction rates required for large scale production.

Students will have the opportunity to investigate alternative catalysts for the degradation of hydrogen peroxide, which will be used as a model system for the breaking down of cellulose into sugar. After identifying other potential catalysts, students will develop their own research question relating to catalysts and conduct an additional experiment of

their own design to investigate their question. This lesson not only involves a system similar to one used in the production of ethanol, it also give students the opportunity to conduct research in a manner similar to that of research scientists. Use of the scientific method and presentation of research is emphasized.

This module can be used later in the school year as a lead in to equilibrium as it introduces the idea of reaction rates and activation energy. Parts of this module would also fit in with lessons on polymers or simply on qualitative/quantitative observations.

Learning Objectives

- Students will be introduced to the steps involved with the production of ethanol from cellulose.
- Students will be introduced to catalysts and gain an understanding of how they work.
- Students will understand the factors that affect reaction rate.
- Students will be able to make qualitative and quantitative observations.
- Students will be able to use the scientific method to design an experiment and properly control variables.
- Students will be able to use computer software to display data and communicate results.
- Students will be able to interpret and draw reaction progress diagrams for catalyzed and uncatalyzed reactions.

Time Allotted

Five 45 minute periods are needed to complete the entire module. Any of the days can be combined to accommodate block scheduling.

The break down is:
Day 1: Introduction
Day 2: Lab, part 1
Day 3: Lab, part 2
Day 4: Data analysis and time in computer lab
Day 5: Class presentations

The time required for this unit can be reduced if an alternate report format is used (other than the PowerPoint presentation) or if only one part of the lab is done. Also note that days 4 and 5 can be separated from the others by a few days.

Vocabulary

Catalyst
Decomposition
Cellulose
Biomass
Ethanol
Sugar
Polymer
Enthalpy
Endothermic
Exothermic
Renewable energy
Non-renewable energy
Microsoft Excel
Spreadsheet
Microsoft PowerPoint
Anticatalyst

Resources/Materials

- 3% hydrogen peroxide
- Microwell plates
- Pipettes
- Manganese dioxide
- A variety of other possible catalysts (suggest zinc oxide, copper oxide, sugar, salts, sand, other manganese compounds, etc.)
- Access to computers with Excel and PowerPoint or similar software
- Test tubes, hot plates, ice baths, and any other equipment needed for independent student experiments

Prerequisite Knowledge

Students should know how to make and record observations in a lab notebook

Students should have some experience with designing their own experiments, or time should be added to the module to allow for this to be taught.

Students should be familiar with the different types of reactions, especially decomposition reactions.

Students should have had some exposure to thermodynamics and familiarity with endothermic and exothermic reactions.

Main Activities

Day One:

The following material can be presented as a teacher-led discussion, as a PowerPoint presentation, or assigned to small groups to be researched using reference materials.

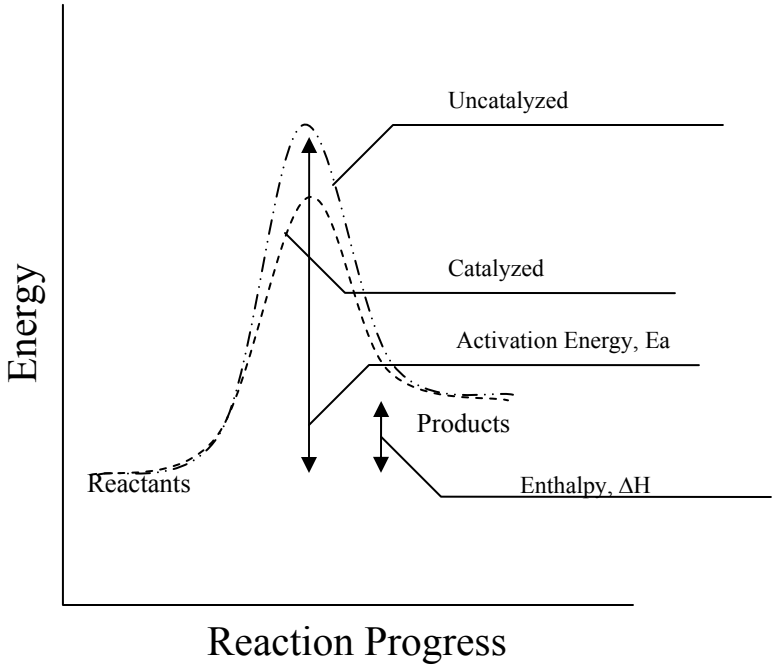
Part 1 -- Introduction to reaction rates and catalysts

- What is required for a reaction to take place?
  - the right molecules must collide with each other in the right orientation and with enough energy to overcome the activation energy barrier.

- What factors can increase the likelihood of a reaction taking place?
  - increasing the speed and therefore the energy of the molecules by raising the temperature
  - increasing the concentration so odds of collision go up
  - somehow lowering the activation energy barrier

- How can the activation energy barrier be lowered?
  - use a catalyst (which creates an alternate pathway)

- Reaction Pathway diagram



Part 2 -- Connection to renewable energy and ethanol production

- What are some sources of energy?
  - coal
  - sun
  - wind
  - gasoline
  - wood
  - biomass

  - geothermal
  - nuclear
  - hydrogen
  - ethanol

- Which of those sources of energy are in limited supply?
  - coal
  - gasoline

- What does it mean to be a renewable source of energy?
- Ethanol is a liquid fuel which is considered renewable because it is made from corn, which is a fast growing crop.
  - Sugar from corn kernels is fermented to make ethanol
  - Most of the corn plant is made of cellulose, which consists of chains of sugar that cannot be directly fermented into ethanol. Cellulose is a polymer of sugar.
  - A catalyst must be used to break the bonds holding the sugar molecules together in cellulose, such that the sugar can then be fermented into alcohol.
  - Using the cellulose to make ethanol will make the production of ethanol much less costly in terms of money and energy.
  - The 2 current catalysts have drawbacks, so scientists are interested in finding different catalysts to break the cellulose down into sugar molecules.

$$\text{cellulose} \xrightarrow{\text{catalyst}} \text{glucose} \quad \text{or} \quad \text{cellulose} + \text{catalyst} \rightarrow \text{glucose} + \text{catalyst}$$

Day 2: Alternative catalysts for a model decomposition reaction

Guided Inquiry Lab:

Student Directions

You are going to be doing research on alternative catalysts for a model system. Instead of breaking cellulose into sugar molecules, you are going to be breaking hydrogen peroxide (H_2O_2) down into oxygen (O_2) and water (H_2O).

Write a balanced equation for this process

$$\text{_____} \xrightarrow{\text{catalyst}} \text{_____} + \text{_____}$$

or

_____ + catalyst → _____ + _____ + catalyst

One known catalyst for our model system is MnO_2, which works well and relatively quickly. But what if we needed the reaction to happen a little less quickly for some reason (say, to waste less hydrogen peroxide in our micro-mole rockets experiment)? One way might be to simply use less of the catalyst (we'd need to test that to see if it would work), but another would be to find an alternative catalyst that doesn't work quite as well and therefore would take longer to complete the breakdown of the hydrogen peroxide.

The research question is given for this part: "What compounds can be used to decompose hydrogen peroxide and how does their effectiveness compare to manganese dioxide?"

Your initial research will have two main parts:

1) Test a variety of compounds for their potential use as a catalyst. Use about 20 drops of H_2O_2 in a microwell and add a tiny sample of the test compound (about the size of a flea). Start by testing the manganese dioxide in this manner to see what a positive result looks like. Test as many or few substances as you like, but try and find at least 2 other compounds that have some ability to break down the hydrogen peroxide. Be sure to keep careful records of which compounds you tested and the results. Record your observations in an organized table. (These tests will be qualitative.)
2) Taking the compounds which showed potential as a catalyst, perform additional tests to rank them from most effective (rank=1) to least effective. Support your rankings with data and a graph! (These tests will be quantitative.)
    a. What is the independent variable in these experiments? What factors will stay constant?
    b. What is the dependent variable? (What measurement will you make?)
    c. How does the measurement relate to effectiveness?
    d. How many trials will you conduct for each condition?

Day 3: Further investigation of catalysts and reaction rates

Student Directions

Choose 1 additional research question and design and conduct an additional experiment to answer the question. Your question and experiment design must be approved before you begin experimental work. For this investigation, you must choose only one independent variable.

Suggested Questions:
How does temperature affect the decomposition of hydrogen peroxide?
How does the amount of catalyst affect reaction rate?
How does total volume affect reaction rate?
How does agitation affect reaction rate?
What effect does combining catalysts have on reaction rate?
Write your own question.

Complete the following diagram to discuss your experiment with your teacher and classmates.

Title: The Effect of _____ on the _____

Hypothesis: If _____ then _____ because _____.

Independent Variable (IV)				
Levels of IV				
Number of Trials				

Dependent Variable

Constants:

Note: Students can present their experimental plans to the class prior to experimentation to help them refine their methods and plans.

Day 4: Data Analysis and Presentation Preparation

Students will need access to computers in order to graph their data and prepare their PowerPoint presentations.

Presentation Guidelines (see example)
Title Slide – Topic, presenter names, date

Presentation Outline – What will you be telling us about?
Research question – Variables, controls.
Experimental design – What did you do to test the question?
Results – What did you find out? Include graphs.
Conclusions – What did you take away from this research? How is it useful? How does it relate to class? To life?

Day 5: Class Presentations

Students will present short (3-5 min) PowerPoint presentations to the class on their individual research questions. The audience should write 1-2 sentences summarizing the major findings of each research project.

Evaluation

- A short pre- and post-test will be administered to students to measure their increase in content knowledge. Suggested questions are as follows.

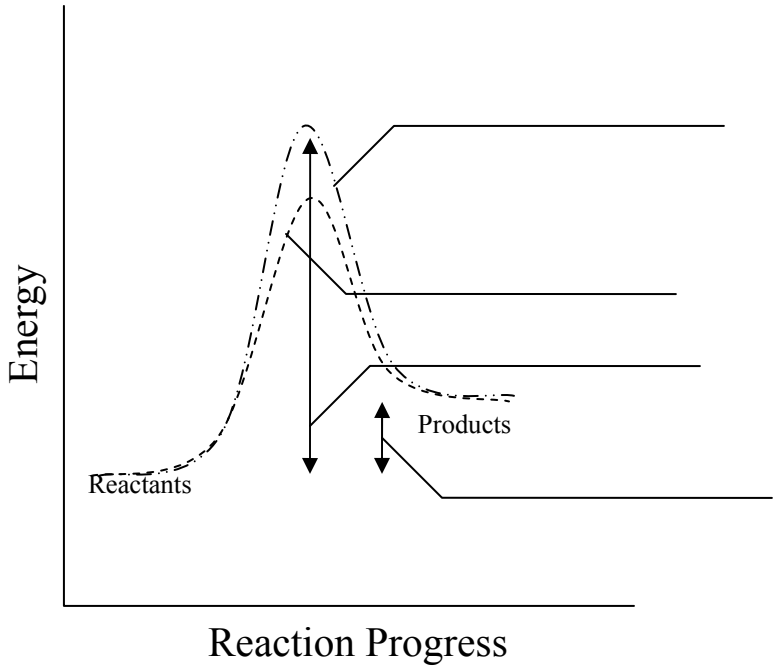
1. What is required for a reaction to take place? (Circle any/all that apply.)
    a. The right molecules must collide with each other.
    b. The temperature must be high.
    c. Bonds must be broken.
    d. The reacting molecules must collide with enough energy to overcome the activation energy barrier.
    e. The products must have lower energy than the reactants.
    f. A catalyst must be present.

2. Which of the following chemical equations represent(s) a catalyzed reaction? (circle any/all that apply)
    a. $C_2H_4 + O_2 \rightarrow CO_2 + H_2O$
    b. $CH_3CH_2OH(g) + HCl(g) + H_2SO_4 \rightarrow CH_3CH_2Cl + H_2O(\ell) + H_2SO_4$
    c. $H_2C{=}CH_2(g) + H_2(g) \rightarrow H_3CH\text{-}CH_3(g)$
    d. $H_2C{=}CH_2(g) + H_2(g) + Pt(s) \rightarrow H_3CH\text{-}CH_3(g) + Pt(s)$

3. Which of the following would **not** increase the rate of a reaction? (Circle any/all that apply.)
    a. Increasing the concentration of reactants.
    b. Increasing the activation energy barrier.
    c. Increasing the temperature.
    d. Adding a catalyst.

4. Which of the following is/are characteristics of catalysts? (Circle any/all that apply.)
    a. Catalysts are consumed in the reaction.
    b. Catalysts lower the activation energy barrier.
    c. Catalysts can be homogenous or heterogeneous.
    d. Catalysts increase the amount of product made.
    e. Catalysts can be recovered at the end of the reaction.

5. In the diagram below, label the two reaction pathways as either **catalyzed** or **uncatalyzed**. Also label the activation energy $\mathbf{E_a}$, and enthalpy **ΔH**. on the diagram.



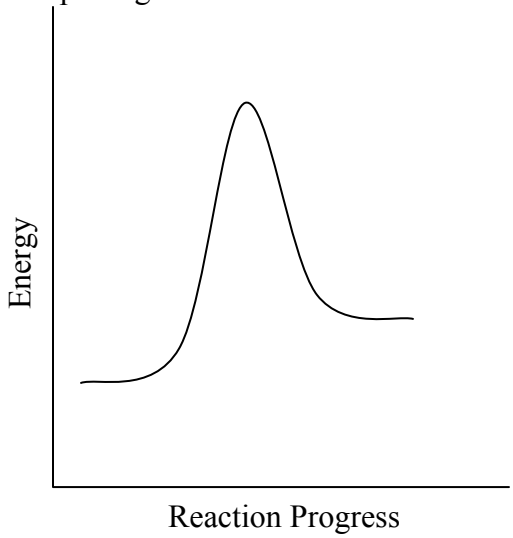
- To further evaluate and develop student understanding at the end of the unit, the following questions will be answered. These questions should be discussed before the post-test is given.

A) Food preservatives are added to food to slow the spoiling process, which is a chemical change. Different preservatives work in different ways: some help remove water, others attack microbes which spoil food. Other preservatives work by displacing oxygen, which is required for many food spoiling organisms to function. Dr. Ilona has just invented a new food preservative which she believes works as an "anticatalyst."

1) What do you think she means by "anticatalyst"?

2) Write a technical definition for anticatalyst. Use the term activation energy in your definition. If you choose to look up the word first, use the first definition to guide your response. The dictionary definition does not use the term activation energy in the definition. (Sorry!)

3) Add a reaction pathway to the graph below for the "anticatalyzed" reaction of food spoiling.



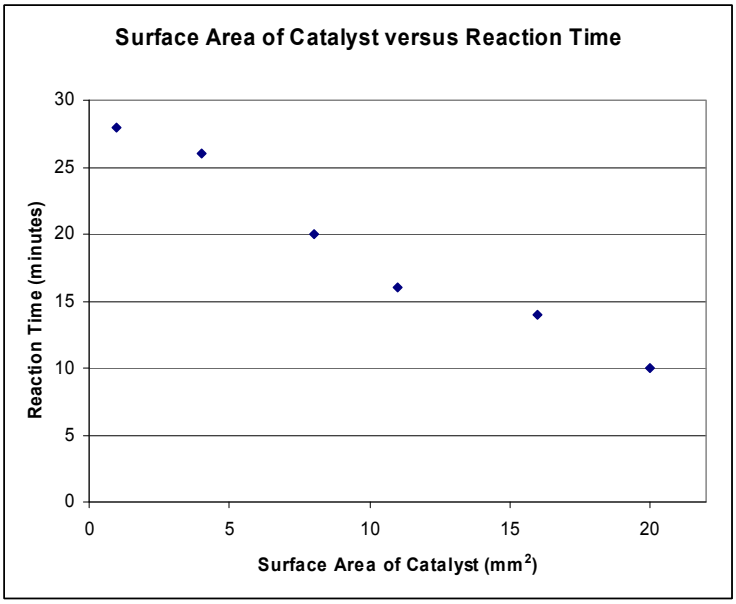
4) What are three questions you would like to ask Dr. Ilona about her new discovery?

B) "When Marco joined the company, he was a real catalyst for change."

5) What do you think is meant by this statement?

6) Choose a book you have read in the last year. Describe how one of the characters was a catalyst (or anticatalyst) for an event in the book.

C) Below is a graph of data from an experiment to see how the surface area of a catalyst affected reaction rate.



8) Write one sentence describing the results of the experiment. Make sure your sentence includes the terms catalyst, surface area, and reaction time.

9) Does this graph indicate an inverse or direct relationship between surface area of catalyst and reaction time?

- Lab notebooks will be evaluated using a standard rubric. Lab notebooks should include data and observations, graphs, procedures, etc.

- PowerPoint presentations will be evaluated using a rubric provided to students at the start of the unit.