Teacher's Preparatory Guide

The Surface Area-to-Volume Ratio of Nanoparticles: Part I

Purpose This lab is designed to help students understand how nanoparticles may be more effective catalysts by investigating how the surface area-to-volume ratio of a substance is affected as its shape changes. This lab is meant to complement a chemistry unit on catalysts. Understanding how catalysts work involves studying chemical reactions at the molecular and atomic scale. For this reason, *catalysis* can be considered one of the earliest forms of nanoscale science.

Time required Two 50-minute class periods or one 90-minute block day

Level Middle school or High school

Teacher Background Follow the link below for an easy-to-read article about how surface-to-volume ratio and nanoparticle catalysts may help fuel automobiles.
http://www.memagazine.org/nanoapr05/balls/balls.html
This link is a short, sweet article explaining the introduction in the student worksheet:
http://www.guardian.co.uk/uk_news/story/0,3604,1291039,00.html

Strategies This activity works well individually. Before beginning the activity, review with students how to calculate surface area and volume of a cube, box, ball, and cylinder (in student worksheet).

Materials
- 8.5 inch × 11 inch sheet of waxed paper
- modeling clay, the size of a walnut (3 per student)
- metric ruler
- calipers, with metric markings
- pencil
- calculator
- small rectangular box

Advance Preparation Purchase modeling clay at a crafts store. Waxed paper can be purchased at a grocery store. The wax paper is not necessary, but will assist with cleanup. You may wish to purchase calipers at a science supply house or a hardware or hobby store to increase the accuracy of measuring the ball and cylinder. Inexpensive ($5/each) calipers can be purchased online at Widget Supply http://www.widgetsupply.com/page/WS/PROD/measure/BKH29

Safety Information None

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Resources: Links are provided in the Teacher background section.

National Science Education Standards

Content Standard A

- Abilities necessary to do scientific inquiry

Content Standard B

- Structure and properties of matter
- Chemical reactions

Guided Dialog Before beginning the lab, review the meaning of these terms:
Reactant *A substance that is part of the initial materials needed for a chemical reaction.*
Product *A substance that is produced by the chemical reaction.*
Catalyst *A substance that is used to increase the reaction rate of a chemical reaction but does not become part of the end products—it remains unaltered during the reaction.*

Ask students: What happens during a *chemical reaction? Chemical reactions occur when the reactants (particles) come into contact with each other and form new products.*

What factors affect what products are formed? *Whether or not the reactant atoms are compatable (it depends on the number of valence electrons in the atoms); whether the atoms will meet fast enough to make a new product*

How would an increase in surface area-to-volume ratio for a catalyst increase its effectiveness? *As the surface to volume ratio increases a greater amount of a substance comes in contact with surrounding material This results in a greater proportion of the material being exposed for potential reaction.*

What factors affect whether an industry can inexpensively make a product or whether the product would cost more to make? *The chemical reaction rate—in order to make a profit, industries try to use reactants and catalysts that will react very quickly to form the products they will sell.*

How can industries determine how quickly the chemicals will react? *by calculating the surface area-to-volume ratio (A/V) of the reactants*

Remind students that catalysts *accelerate* a chemical reaction without interfering with the finished product by helping the reactants to meet much more quickly. Now, begin the lab.

Cleanup Storage of materials. Clay can also be reused for Part II of the unit.

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Student Worksheet or Guide

The Surface Area-to-Volume Ratio of Nanoparticles: Part I

Introduction

Plants can now be turned into a car fuel based on alcohol, but the exhaust has pollutants, like carbon dioxide. We need your help to make a clean burning fuel cell that combines hydrogen and oxygen to make energy, steam, and nothing else. The fuel cell itself has already been invented, but we still haven't been able to cheaply make a hydrogen source. Many oil refineries use a platinum catalyst to make fuel, but platinum is so rare that it's worth more than gold. We must find a cheaper alternative!

Nickel is for more abundant than platinum, and much cheaper. If we can find a way to use nickel instead of platinum, we might make hydrogen fuel cells affordable for the masses! Nickel, if it is made small enough, can react with air like dynamite. Help us make a device that will make hydrogen using only air, water vapor, and sunflower oil using two nanoparticle catalysts—one based on carbon, and the other based on nickel. What shape should we use for the nickel nanoparticles to make them more explosive?

Materials

- waxed paper sheet
- modeling clay, the size of a walnut (3/student)
- metric ruler
- calipers, with metric markings
- pencil
- calculator
- small rectangular box

Make a Prediction

*Example prediction: I think that a ball shape will be more explosive because it has no edges.*____________________

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Procedure

1. Place the wax paper atop your desk. For each of the steps below, be sure to use all of the clay. Do not remove any clay between measurements.
2. Press the clay into a cube.
3. Use the ruler to measure the size of each side. Write each measurement in the table on the next page.
4. Press the clay into a flat, rectangular box.
5. Use the ruler to measure the size of each side. Write each measurement in the table on the next page.

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6. Roll the clay into a ball.
7. Use the calipers to measure the ball's diameter. Write your measurement in the table on the next page.
8. Roll the clay into a cylinder.
9. Use the calipers to measure the diameter of the cylinder. Write your measurement in the table below.
10. Use the ruler to measure the length of the cylinder. Write your measurement in the table below.

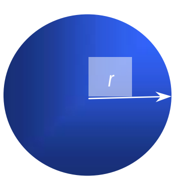
Record Your Observations

Measurements of Objects

	Diameter (cm)	Length (cm)	Width (cm)	Height (cm)
Cube		*2.0*	*2.0*	*2.0*
Box		*2.0*	*4.0*	*1.0*
Ball	*4.0*			
Cylinder	*14.7*			*0.2*

Analyze the Results

Calculate the volume *(V)* of each shape using the formulae below. Write your answer in the table on the next page.

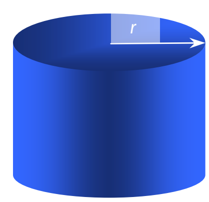


Ball

Volume of a box *length* × *width* × *height*

Volume of a ball $\frac{4}{3}$л *(radius)*^{3}

Volume of a cylinder л × *height* × (radius



Cylinder

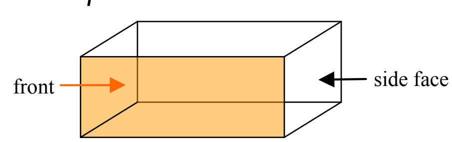
11. Calculate the surface area (A) of each shape using the formulae below. Write your answer in the table on the next page.

Surface area of a cube *length* × *width* × *number of sides*

Surface area of a box

(4 × *length* × *width*)$_{\text{front face}}$

\+ (2 × *length* × *width*)$_{\text{side face}}$



Box

Surface Area of a ball 4л × *(radius)*^{2}

Surface Area of cylinder 2л *(radius)*^{2} + 2л × *radius* × *height*

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12. For each shape, calculate the ratio of the surface area to volume by dividing the surface area by the volume. Write this ratio in the table.

	Surface area (cm^2)	Volume (cm^3)	Ratio Surface Area / Volume
Cube	*24 cm^2*	*8 cm^3*	*3*
Box	*88 cm^2*	*48 cm^3*	*1.83*
Ball	*100.48 cm^2*	*33.49 cm^3*	*3*
Cylinder	*348.47 cm^2*	*33.49 cm^3*	*10.40*

Draw Conclusions

1. Which shape had the smallest surface area-to-volume ratio? *the ball*
2. Which shape had the largest surface area-to-volume ratio? *the cylinder*
3. Of the shapes you tested, which shape would you recommend as the most reactive catalyst? Explain. *The cylinder, because it has the greatest surface area/volume ratio.*
4. Why are manufacturers interested in using nanoparticles for catalysts? *Manufacturers want to make their products cheaply. They can do this by using inexpensive materials that can be quickly made. Nanoparticles have a high surface area-to-volume ratio and would react very quickly.*
5. Apart from cost, why do you think this company is considering using nickel nanoparticles for fuel cells? **(Hint:** Look at the periodic table of elements.) *Nickel is in the same group as platinum on the periodic table of elements, which means it has the same number of electrons in its outer shell. This means that nickel has the potential to react in a way that is similar to platinun.*

Enhancing understanding Cover this section *after* the activity.
Nanotechnology may revolutionize the use of catalysis in chemical manufacturing. In the chemical industry, catalysts play a very big role in making many of the products which we use everyday. Fuels, such as gasoline and other petroleum-derived substances, cleaning supplies (ammonia, detergents, soaps), and pharmaceuticals are only a few examples that are dependent on catalysts to make their manufacturing economically viable. As we better understand the properties and characteristics of nanoscale particles, manufacturing companies are turning to the research universities for information that may help them improve their catalytic dependent

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production processes. These industries are often searching for better, more efficient (economical) processes.

Review the following with students:

If the:
A/V ratio is high →the reactants will quickly/efficiently react
A/V ratio is low→the reaction will slowly react

Going Further Students who have a good grasp of the surface area-to-volume ratio can be further challenged with these questions:
What would happen to the volume of the modeling clay if you made a million balls all of the same diameter? *The volume will remain the same because you would still have the same amount of clay.*
What would happen to the surface area of the clay if you made two identical balls? *The surface area of the clay would increase.*

Assessment
Students should be able to correctly calculate surface area, volume, and the ratio of surface area/volume (i.e., their answers in #12 should be correct) based on their measurements used in the "Record your Observations—Measurements of Objects" table.
Other assessments could include: Using Part II as an assessment tool for Part 1, set up stations where students would determine the surface area-to-volume ratio of objects in the stations, developing a rubric for grading the success of both parts of the lab.

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