Teacher's Preparatory Guide

How Catalysts Work—a Nanoscale Phenomenon

Purpose This demonstration helps students understand how catalysts work on the nanoscale. This is a great way to introduce or review *reactants, catalysts, and adsorption, desorption, and diffusion.* Use this demonstration after the *Surface Area-to-Volume Ratio of Nanoparticles* lab.

Time Required 30-minutes in class for demonstration and discussion, plus additional time for completing the student worksheet. Alternatively, the worksheet could be assigned as homework.

Level High school

Teacher Background Catalysts are more effective when they are small enough to fall within the range of 1–100 nanometers (nm) in size (the *nano*scale). The active sites of a catalyst increase or are more readily available in nanoscale structures, causing chemical reactions to speed up. An *active site* is the area of the catalyst where reactants combine and a new product forms.

Not all the surface of nanoparticle serves as an active site, though. In some cases, the active site may be at the edge or surface. Researchers ask, "Could increasing the surface area of a nanoscale catalyst increase the reaction rates, forming products much faster (higher yield)?" Catalysts are deemed improved if products form faster than before, and it's not as expensive to make the product as before.

Special tools capable of observing nanoscale objects allow scientists a way to investigate how catalysts work. The tools used in the study of catalysts vary depending on the products being produced. For example, some researchers use vacuum chambers with a gas spectrophotomer or a mass spectrophotomer to study and understand how catalysts work at the nanoscale.

Review the following concepts with students about the surface area-to-volume ratio (A/V):

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

Catalysts accelerate a chemical reaction without interfering with the finished product by helping the reactants to meet much more quickly. *How* a catalyst performs this task is a branch of chemistry being extensively studied today. The catalytic process has 3 steps that take place at the catalyst's surface: *adsorption, diffusion, and desorption* of the reactants and products. How fast these three steps—adsorption, diffusion, and desorption—take place at the surface of the catalyst depend on its surface area-to-volume ratio.

National Science Content Standards

Content Standard B

- Structure and properties of matter
- Chemical reactions

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Demonstration

Materials

- a bottle of vanilla extract (or another extract)
- a snapper hand

Advance Preparation Buy a "snapper hand" (about $1.50) from http://www.officeplayground.com/snapperhand.html to demonstrate adsorption. Smaller versions of snapper hands can sometimes be found in 25-cent children's toy machines at a grocery or department store. Buy a bottle of vanilla extract from a grocery store.

Safety Information None

Procedure: How Catalysts Work

Adsorption

- Throw a clean, dry snapper hand against a vertical surface such as a wall or a cabinet. Tell them that this is called *adsorption.* Ask students to explain why the snapper hand sticks: *chemicals in the snapper hand are attracted to and bond with the wall, friction*

- Ask students to define *adsorption,* based on the demonstration. *Adsorption is the process by which particles stick to the surface of another substance.*

- Ask students to give other examples of adsorption. *Example answers: cooked spaghetti sticking to a wall, dopamine molecules that attach to brain receptors.*

- Ask students to describe what would happen if the snapper hand were a catalyst and the wall is a reactant. *The snapper hand would react with the surface of the wall and a product would form.*

- Leave the snapper hand stuck to the wall until you discuss desorption.

Diffusion

- Open the bottle of extract. Ask students: When the bottle is opened, how do they detect the scent of what is inside the bottle? What happens to the molecules? *Molecules travel out of the bottle, through the air, and into someone's nose, where the scent may or may not be registered by the brain.*

- Explain that this process is called *diffusion.* The molecules inside the bottle of extract were very crowded and went to an area that is less crowded. Guide students to a common definition of ***diffusion***. *The process by which particles move from crowded areas (areas of high concentration) to less crowded areas (an area of low concentration) through some other medium.*

- Ask the question again: With this definition of diffusion, how would it be possible for the molecules on the surface of the snapper hand to diffuse into the wall? *The*

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molecules in the snapper hand would need to be at a higher concentration than the molecules in the wall.

Desorption

- Peel the snapper hand from the vertical surface. Explain that this is an example of *desorption.* Ask students to infer the meaning of ***desorption.*** *Desorption is process by which a particle becomes unstuck from a surface.*

Cleanup Wash the snapper hand with clean water and air-dry before putting away.

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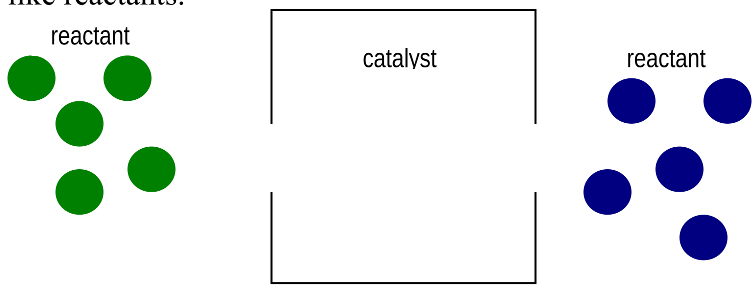
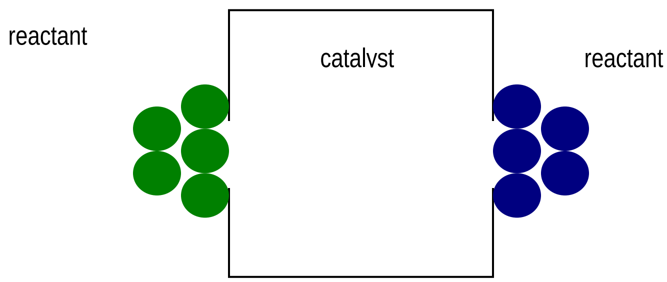
Guided Dialog Draw the diagram below on the board to help students visualize *reactants, catalysts, adsorption, desorption, and diffusion.* Explain that a chemist would like the product (a gas) and a reactant (a gas) to meet. You may wish to use an analogy of a matchmaker firm trying to pair guys with girls (both are reactants). Trouble is, they are unlikely to encounter each other. Ask students why they are unlikely to meet. *Example answers: they are too far away to be attracted to each other, they are attracted to other things besides each other*

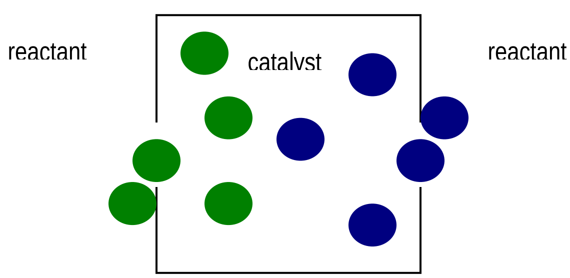
The matchmaker firm decides to add a catalyst—a new single's club with music, dancing, and food. The guys and girls are curious and interested in the single's club. They are attracted to the catalyst, just like reactants.



The boys and girls (reactants) are attracted to the club (catalyst) door. They crowd the door and stick to the walls and door, hoping to get in next. ***Adsorption*** is when something sticks to a surface. ***Desorption*** is when something becomes unstuck from a surface.



As the guys and girls (reactants) enter the club (catalyst), they move about the club and encounter each other—this is called ***diffusion.***



If a match is successful, a guy-girl couple is likely to have a date (product).

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Student Worksheet with Answer Key

1. Suppose you break open a rotten egg and the odor overtakes the room. What process is this? *The odor permeates throughout the room because of diffusion.*
2. The odor in the egg is caused by H_2S gas. Explain, in terms of gas concentration, why the odor permeates the entire room.

   The concentration of the odor is highest within the egg. When the shell is broken, gas is released. The gas molecules move from the area of high concentration to the area of low concentration until the whole space contains the same concentration of the gas.
3. Define catalyst. *A catalyst is a substance that speeds up a chemical reaction.*
4. A clay made of nanoscale particles (particles that range from 1–100 nm in size) adsorbs to the surface of a ball. The ball's molecules are larger than the nanoparticles in the clay. Explain what circumstances would be necessary for diffusion to occur at the surface.

   Diffusion would occur if the nanoclay were more dense than the ball's surface
5. Does diffusion through a catalyst change the reaction rate? Explain. *Yes. Catalysts increase the reaction rate by making it easier for the reactants to find each other. A product forms when the reactants find each other.*

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6. What term describes mud sticking to your shoe? *Adsorption*
7. How does the adsorption to a catalyst increase the chemical reaction rate?
   A reactant that sticks to the surface of a catalyst (adsorb) is more likely to find another reactant that also sticks to the surface of the catalyst. The reactants combine to form a product.
8. A chemical reaction will only occur if the conditions are right and the reactants come in contact with one another. Use the terms *adsorption, diffusion,* and *desorption* to explain how to form a product more quickly than without a catalyst? Explain.
   The reactant particles stick (adsorb) to the catalyst's surface. Since the reactant particles are at a high concentration on the surface, they move (diffuse) into the catalyst. The reactants meet within the catalyst, and form a product. Once the product forms, the catalyst releases (desorbs) the product particles.

Assessment

Ask students to come up with their own example of adsorption, diffusion, and desorption. Students should be able to distinguish between adsorption, diffusion, and desorption. Students' answer to question 8 above will demonstrate their ability to relate these terms to how catalysts work.

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