Penn State RET in Interdisciplinary Materials

Student Worksheet

Salad Motors

Introduction: Micro and nano motors are the focus of cutting-edge research. These tiny motors use the chemicals in their environment as fuel and convert the energy released from the breakdown of the fuel to mechanical energy. The phenomena that affect objects at the micro and nano scale are difficult to visualize in a classroom. "Salad Motors" is an experiment that uses macro motors to model micro and nano motors.

Hydrogen peroxide (H_2O_2), a toxic by-product of cell metabolism, was used as a fuel for underwater propulsion in Germany in 1934. H_2O_2 also has a long history of use in the aerospace industry. The enzyme catalase, which is found naturally in many fruits and vegetables, decomposes H_2O_2 into water and oxygen. This chemical reaction is exploited in this experiment to propel macro motors though the action of bubble propulsion. Reactions catalyzed by enzymes can be speeded up, slowed down, or stopped by changing the following factors: temperature, pH, concentration of reactants, and the presence of inhibitors.

(Catalase)

$2H_2O_2 \rightarrow O_2 + 2H_2O$ $\Delta H = -98.3$ KJ/mol

Background Reading:

How to Build Nanotech Motors: Scientific American.
<http://www.sciam.com/article.cfm?id=how-to-build-nanotech-motors&print=true>

Safety Information:

- Wear gloves to protect your hands from the oxidizing power of H_2O_2.
- Wear safety goggles.
- Use caution when cutting pieces of fruits and vegetables with the Exacto® knife.
- Dispose motors and fruits and vegetables into the trash cans.
- Discard used H_2O_2 in the beakers of labelled "H_2O_2 Waste."
- Keep metal objects away from the H_2O_2 (H_2O_2 reacts with metals).

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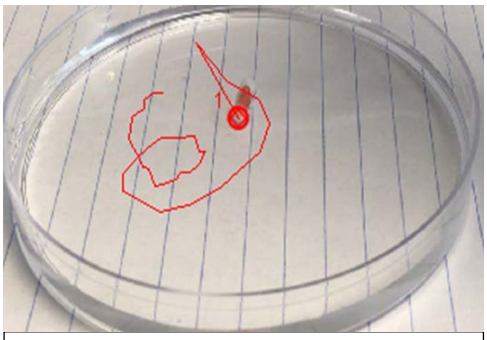
Materials: (for one laboratory group)



Salad motor pathway in a petri dish.

- 6 plastic pipette tips (0.5 cm)
- 1 Exacto® knife
- 1 sheet of paper towel
- 1 plastic petri dish (90 mm in diameter)
- 1 plastic tweezers
- 2 pieces each of produce (carrot, or potato, or cucumber, or red pepper with apple) 0.75 cm x 1cm x 1cm
- 1 cotton applicator
- 1 50 mL beaker
- 1 hot plate
- 20 mL of paraffin wax
- 1 iPad with camera
- 50 mL vial of 3% H_2O_2
- 50 mL vial of 10% H_2O_2
- 50 mL vial of 30% H_2O_2
- ice in Styrofoam container with lid
- 25 mL graduated cylinder
- neoprene gloves
- 1-metric ruler

Demonstration: *(~ 5 minutes)*

- Observe the demonstration performed by your instructor.
- If all the motors are fueled by the reaction of catalase on the H_2O_2, and rank the motors by speed with the fastest motor being first.

- What is the basis of your ranking?

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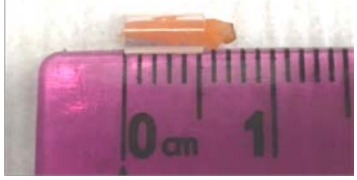
Procedure: *(~40 minutes)*

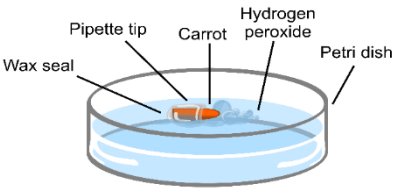
Spread the paper towel on the laboratory station.

- Heat the wax in the 50 mL beaker on the hot plate.
- Choose a vegetable piece (carrot, potato, cucumber, or red pepper) and a piece of apple.
- While the wax is melting, use the 1 Exacto® knife to cut a thin sliver of the vegetable piece and "load" a plastic pipette tip with the vegetable so that a tiny part of it protrudes out of the plastic piece. Look at the figure to the right. The motor should now be closer to 0.75 cm in length.

Motor Scale



- To make the motor asymmetrical, seal the open end of the motor with a small amount of wax using the tweezers to hold the motor in one hand and the cotton applicator, dipped in wax, to seal the open end of the motor with the other hand. Gently blow on the hot wax to cool the wax seal.
- Prepare 6 motors (3 with vegetable pieces and 3 with apple pieces) using the technique above.
- In the Styrofoam containers, you have 3 labelled vials with H_2O_2 (3%, 10%, and 30%). Pour 25 mL of 30% H_2O_2 into the petri dish provided. Turn on the iPad camera, and choose the video option. Place the iPad in front of the petri dish so that the whole petri dish fills the view of the camera. Do not move the petri dish or the camera.
- Clean up the work station.
- Mass a motor, and place the vegetable motor in the petri dish of H_2O_2 and record the motion of the motor for 2 minutes.
- Repeat the above procedure for all the motors you made.
- Record your observations. Load all 6 videos onto a computer.
- Go online and open the Video Analysis and Modeling Tool. << http://physlets.org/tracker/>>



Experimental Set-Up

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- Drag and drop one of the videos of a motor into the program. Set the axes (move them to frame the petri dish) and the calibration bar (90mm for the width of the petri dish). Track the motor's movements by skipping every 100 frames.
- Once you have the "x" and "y" coordinates for each movement, use the distance formula to calculate speed of each displacement. Use a program like Microsoft's Excel or Apple's Numbers to calculate speed. Average the speeds for that motor.
- Repeat the procedure above for all the motors you made.

Data Tables and Calculations: *(~40 minutes)*

Calculate speed (v) = total distance (d) /total time (t)
Distance formula d = $\sqrt{(\Delta x)^2 + (\Delta y)}^2$
Use an Excel worksheet.

Group Data

H_2O_2	Apple Motor #1	Speed of Motor #1 (mm/s)	Mass # 1 (mg)	_____ Motor #2	Speed of Motor #2 (mm/s)	Mass #2 (mg)
3%						
10%						
30%						

Class Speed Data

H_2O_2	*Apple Motor Speed (mm/s)*	*Carrot Motor Speed (mm/s)*	*Cucumber Motor Speed (mm/s)*	*Potato Motor Speed (mm/s)*	*Red Pepper Motor Speed (mm/s)*
3%					
10%					
30%					

Students can calculate kinetic energy (KE) = ½ mv^2. Units should be in pico Joules (pJ).

Class Kinetic Energy Data

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H_2O_2	*Apple Motor KE (pJ)*	*Carrot Motor KE (pJ)*	*Cucumber Motor KE (pJ)*	*Potato Motor KE (pJ)*	*Red Pepper Motor KE (pJ)*
3%					
10%					
30%					

Closing Questions: *(Homework)*

1. Which motor seemed to be the overall champion, and what percent of H_2O_2 fuel did it run on?

2. Comment on the activity of the apple motor. What role did the apple motor play in this activity?

3. Is there a pattern in the data collected for the 3 motors in 3 percentages of fuel? Explain.

4. Name some common fuels. Identify the fuel that the salad motors use.

5. Viscosity of the substrate changes as the fuel is used up. Explain.

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6. What evidence is available in this activity to demonstrate that energy is present in chemical bonds?

7. Draw the forces acting on a motor as it propels over the surface of the substrate. Which is the strongest force working against the forward motion of the motor?

8. Explain the role that inertia plays on a macro motor vs the role that inertia plays on a micro or nano motor.

9. Explain how Newton's Second Law of Motion may be used to explain the motion of the motor.

10. How can the enzyme in the decomposition reaction of H_2O_2 be denatured? How would denaturation of the enzyme affect a motor's activity?

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