Blue shark © W. B. Evans

INVESTIGATION 4

Designing a Submersible

In this Investigation, students design submersibles that are neutrally buoyant and can travel through water. The first activity, "What is Neutral Buoyancy?," introduces the concept of neutral buoyancy, a key feature of DeepWorker 2000 and your students' designs. The second activity provides an opportunity to understand some of the chemistry behind DeepWorker's air purification system.

BACKGROUND INFORMATION

Meet DeepWorker

ACTIVITIES

What is Neutral Buoyancy?
Purifying the Air for DeepWorker Pilots
Design a Submersible

LEARNING OBJECTIVES

Students will:

- Define neutral buoyancy in their own words;
- Describe the chemistry behind purifying air for DeepWorker pilots;
- Describe some of the limitations scientists face when exploring the sea;
- Design a neutrally buoyant submersible capable of traveling through water.

STANDARDS

Science Education Standards
Developing abilities in technological design

Developing understandings about science and technology

ACTIVITY

What Is Neutral Buoyancy?

Guiding Question

What is neutral buoyancy and how does it affect a submersible's design?

Discussion

Density is a basic property of matter that measures the amount of mass of an object per unit volume (D = M/V). The density of freshwater is 1g/cm^3; the density of seawater is greater and varies considerably depending upon salinity and temperature. (For seawater with a salinity of 34.5 parts per thousand and a temperature of 15° C, the density is 1.025 g/cm^3). In the ocean, solids are generally more dense than seawater. They tend to sink while gases are less dense and tend to rise. Water has an unusual property: its solid phase (ice) is less dense than most other solids, enabling it to float in liquid water. Buoyancy is the tendency of a fluid (gas or liquid) to exert an upward force on an object that is submerged in it. An object that is positively buoyant will float, one that is negatively buoyant will sink, while a substance that is neutrally buoyant displaces a quantity of matter of equal density. An object placed in seawater is more buoyant than the same object placed in freshwater. This is because the dissolved salts in seawater cause the water to be more dense.

The volume of freshwater displaced by an object can be used to determine the mass required to make it neutrally buoyant. Remember that:

1 mL H_2O @ 4° C=1cm^3=1 gram.

Materials

- ❑ Lead shot
- ❑ 13 x 100 mm test tube
- ❑ #00 rubber stopper
- ❑ Milligram balance
- ❑ 100 milliliter (mL) graduated cylinder
- ❑ Water
- ❑ Indelible marker

Procedure

This activity may be used as a lab or demonstration.

1 Carefully measure freshwater into a 100 mL graduated cylinder so the bottom of the meniscus is precisely on the 80.0 mL line when viewed at eye level.

2 Mass a clean, dry 13 x 100 mL test tube and #00 rubber stopper on a milligram balance.

3 Add enough lead shot to the test tube (about half full) to make it negatively buoyant. Seal it with a tightly-fitting rubber stopper. Make a mark on the outside of the glass to record how far the stopper is inserted into the test tube.

4 Gently slide the test tube, stopper end down, into the graduated cylinder by tilting the glassware to one side.

5 Read the new volume in the graduated cylinder and determine the amount of water that has been displaced by the sealed test tube. Be sure no air bubbles have been trapped before taking this measurement. (Ask students why this is important: the trapped air displaces water, giving an inaccurate measurement.) Subtract the initial water volume (80.0 mL) from the (greater) final volume and convert to mass in grams.

6 Pour out the water and remove the weighted test tube from the graduated cylinder. Empty the test tube and replace the rubber stopper to the same mark on the glass. Refill the graduated cylinder to the 80.0 mL line and drop the empty tube in with the stopper end down. What volume does this positively buoyant object displace?

7 Remove the test tube again and add just enough lead shot to equal the mass of the displaced water. Refill the graduated cylinder with water to the 80.0 mL line and slide the neutrally buoyant test tube back in. Does the tube now rest in the water column rather than sink or float? Make any adjustments necessary to achieve neutral buoyancy.

Data and Calculations:

Mass of test tube and stopper = ____g

Final volume (____mL) - initial volume (80.0 mL) = H_2O volume displaced (_____mL)

Mass of displaced water (1 mL = 1g) = ____g

Conclusion

Compare what would happen if the same activity were done using seawater at 4°C. How would the shot weight need to be adjusted in seawater? Guide the discussion to consider how neutral buoyancy relates to submersibles, how students might address this in their designs, and how this feature benefits research.

ACTIVITY

Purifying the Air for DeepWorker Pilots

Guiding Question

How is the air in DeepWorker continually purified for pilots?

Discussion

The DeepWorker 2000 submersible uses "re-breather" technology to chemically remove carbon dioxide generated from aerobic respiration and a pair of high pressure cylinders to replenish the oxygen gas metabolized by aerobic respiration. This lab allows students to calculate the volume of carbon dioxide gas that can be removed from DeepWorker's cabin by the absorbent chemical "Soda-Lime." Soda-Lime, which is a mixture of caustic soda and lime [NaOH and $Ca(OH)_2$], is a chemical scrubber used to remove carbon dioxide from the air that has been expired by the pilot. SodaSorb® (the brand of soda-lime used by DeepWorker) is manufactured by the W.R. Grace Company in the United States. SodaSorb® consists of 70–80% $Ca(OH)_2$, 16–20% H_2O, 1–2% NaOH, and 0–1% KOH.

The mechanism for this exothermic reaction is:

$H_2O(l) + CO_2(g)$ ——> $H_2CO_3(aq)$
$2NaOH(s) + H_2CO_3(aq)$ ——> $Na_2CO_3(s) + 2H_2O(l)$
$Ca(OH)_2(s) + H_2CO_3(aq)$ ——> $CaCO_3(s) + 2H_2O(l)$

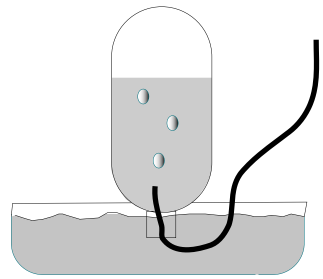
There is a net production of three H_2O molecules for every molecule of CO_2 absorbed. Some chemical absorbents employ an indicator that changes color when the reactant is exhausted. The ethyl violet indicator in SodaSorb® changes from white to purple when the chemical can absorb no additional CO_2.

When a person breathes, 0.82L of CO_2 is exhaled for every liter of oxygen inhaled. An oxygen generation system should either produce a larger volume of O_2 than the volume of CO_2 consumed or make-up for the difference with a supplemental oxygen supply. A gas "regulator" is used to deliver oxygen to DeepWorker's cabin at the proper rate. Pressure gauges monitor the supply of O_2 gas in DeepWorker's twin cylinders.

The temperature of the absorbent influences the effectiveness of the reaction. SodaSorb® works much better in the relatively warm cabin of DeepWorker.

Materials

- ❑ Safety equipment (rubber gloves and eye protection)
- ❑ SodaSorb® (To order by phone, call 1-800-GET-SODA.)
- ❑ Timer
- ❑ Milligram balance



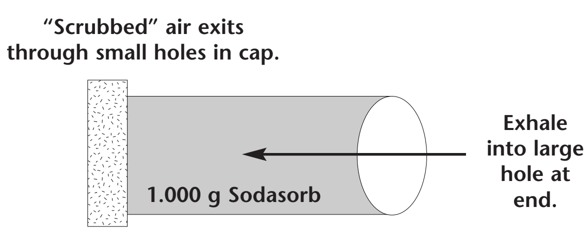
HOMEMADE SPIROMETER

- ❑ Spirometer
- ❑ Gas collecting device (see illustration below)
- ❑ Calculator

Procedure

This activity may be used as a lab or demonstration.

1 Mass out 1.000 gram of SodaSorb® on a milligram balance and place it in a gas collecting device. Be careful to avoid packing the solid too tightly and be certain not to breathe the dust.



DEVICE USED TO COLLECT EXPIRED BREATH THAT CONTAINS CHEMICAL ABSORBENT.

2 Determine the tidal volume of gas that you produce in one minute by exhaling into a spirometer. An adequate homemade spirometer can be constructed with an overturned bottle of water, a dish pan, and a length of rubber hose.

3 Begin exhaling at a normal rate into the gas collecting device and use a timer to determine how long you can continue before the ethyl violet indicator in the SodaSorb® turns purple. Assume that the chemical is exhausted at the first sign of a color change.

4 Determine the volume of gas that you exhaled by multiplying the time in minutes by the volume produced per minute.

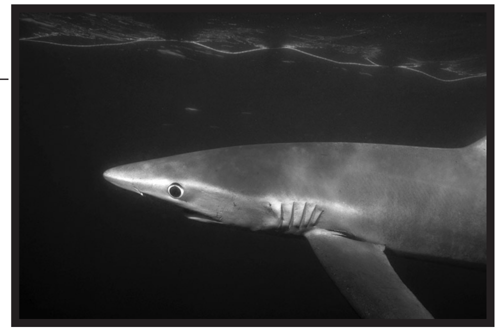
5 Given that the average person at rest has 3.6 percent CO_2 (g) by volume in their expired breath, calculate the volume of CO_2 (g) that was absorbed by the SodaSorb®.

Data and Calculations

Volume of expired breath per minute: _______ liters

Time elapsed before indicator changes: _________ minutes

Volume of CO_2 absorbed per gram of SodaSorb®: ___________



ACTIVITY

Designing a Submersible

Guiding Question

How does a submersible's design address the limitations inherent to exploring the sea?

Discussion

The *Sustainable Seas Expeditions* will use a small submersible to explore, conduct research in, and promote conservation of the nation's 13 marine sanctuaries. This one-person vehicle must be simple enough to operate so pilots may complete their mission, yet sophisticated enough to safely reach depths of up to 600 meters (2,000 feet). By researching, constructing, and testing a small scale model prototype of a submersible, students will discover some of the design characteristics that make this vehicle so important to ocean exploration.

Materials

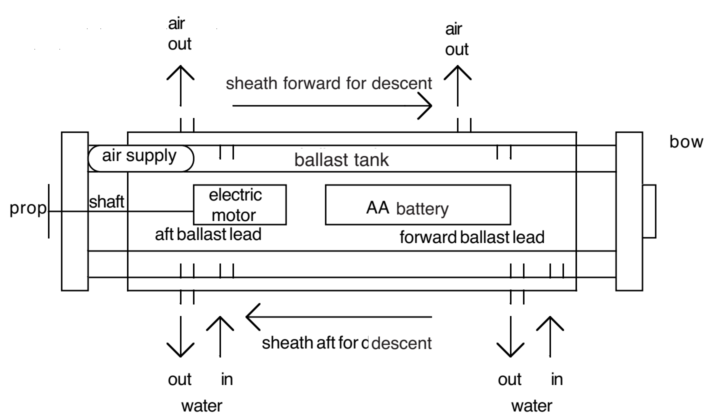
- ❑ A small aquarium (25 cm deep, 25 cm wide, 50 cm long), child's pool, or other container filled with clear, fresh water at ambient room temperature for testing submersibles
- ❑ **Submersible Specifications** handout, one for each group
- ❑ *Sustainable Seas Expeditions* poster
- ❑ Copy of **Meet DeepWorker Background Information** for each group
- ❑ Materials for submersibles such as PVC pipe, batteries, and propellers to be determined by student teams

Procedure

1 Tell students that their goal is to work with a classmate to design, build, and test a submersible prototype that is neutrally buoyant and can travel through water. A small aquarium or other container, filled with clear, fresh water at ambient room temperature, will be available to test and demonstrate their submersibles.

2 Explain to students that their submersibles must meet certain specifications. Give them the **Submersible Specifications** and copies of the **Meet DeepWorker Background Information** sheet.

3 Set a date for students to demonstrate and explain their submersibles with each other, including what worked, what didn't work, and how they redesigned their vehicle accordingly.



Sample Student Design: Pressure hull of PVC pipe with sealed end caps inside ballast hull. The submarine descends when soft ballast tanks are flooded with water and ascends when ballast is blown (air replaces water). Hard ballast of lead shot is located inside pressure hull. When outer plastic trim sheath moves forward, air escapes from top vents. When sheath moves aft, water escapes from bottom vents as ballast air supply ruptures.

SUBMERSIBLE SPECIFICATIONS

Your submersible prototype must meet the following specifications:

- It must displace at least .250kg of fresh water when fully submerged and can be no longer than 20cm from bow to stern with a beam (width) or height no greater than 20cm.
- It must be neutrally buoyant.
- It cannot be directly touched after it is deployed into the "ocean." Remote controls or tether lines may be used to operate controls on the submersible. A transducer may be deployed into the "ocean."
- The submersible must be built by you "from scratch"; for example, a commercial submarine retrofitted for this activity is not allowed.
- You and your partner will provide all materials for your submersible. It is not necessary to spend a lot of money to build a successful prototype.
- Your device must be safe.

Keep a Log

Keep a log of your activities. As part of the project, write a detailed description of your research and development, including what worked, what didn't work, and how you revised your design accordingly. Include a schematic, an explanation of all systems (ballast, steering, propulsion, remote control), and a bibliography. Use at least five references total from a variety of sources: journal articles, books, and web sites on the Internet. Include references to these sources as part of your written work.

Supplies and Where to Get Them

Rudders, hydroplanes, thrusters, and propellers should be considered in your design as part of the propulsion system. Batteries, electric motors, elastic bands, teacher-approved chemical reactions, compressed gas (air or carbon dioxide only), and lead shot for ballast are possible methods you may use to power your submersible and achieve neutral buoyancy. Care should be taken to ensure that thruster propellers are not a hazard. PVC pipe and plastic containers are possible materials for the frame of your submersible. All of the materials listed here are available in local hobby and hardware stores. You may already have some materials at home.

For More Information

Web sites Submarine Kits: www.32ndparallel.com/

Electronics & Hardware for Model Submarines: www.rcboats.com/

Ideas for Homebuilt Submarines: www.webcom.com/sknkwrks/submarin.htm