NOAA Ship *Okeanos Explorer:* America's Ship for Ocean Exploration. Image credit: NOAA. For more information, see the following Web site:
*http://oceanexplorer.noaa.gov/okeanos/welcome.html*

# Section 2:
# Key Topic – Ocean Exploration

The *Little Hercules* ROV shines its lights on deep-sea life at approximately 1500 meters depth offshore Kona, Hawaii. Image taken by OER's camera platform during ROV shakedown operations aboard NOAA Ship *Okeanos Explorer* on March 22, 2010. Image credit: NOAA Office of Ocean Exploration and Research.
*http://oceanexplorer.noaa.gov/okeanos/media/slideshow/gallery/ex03222010/hires/hercules_light.jpg*

Ocean Exploration and Research

## Come On Down!

(adapted from the 2002 Submarine Ring of Fire Expedition and the *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs and Wrecks)

### Focus
Ocean Exploration

### Grade Level
7-8 (Physical Science)

### Focus Question
What are some physical science principles that affect the operation of deep-sea submersibles?

### Learning Objectives
- Students will research the development and use of research vessels/vehicles used for deep-ocean exploration.
- Students will calculate the density of objects by determining the mass and volume.
- Students will explain the concept of neutral buoyancy, perform calculations related to neutral buoyancy, describe why it may be difficult to maintain neutral buoyancy in the ocean, and discuss some strategies for overcoming these difficulties.

### Materials
- Copies of *Underwater Robot Capability Survey*; one copy for each student group
- Copies of *Density and Buoyancy Investigation Guide*; one copy for each student group
- 100 ml graduated cylinder; one for each student group
- Sink or large containers for waste water
- Faucet or large container of water with a spigot or siphon to allow controlled dispensing
- Small objects that will fit into the 100 ml graduated cylinders, such as washers or nuts, small pieces of wood, rocks, pieces of modeling clay, corks, or similar objects; each student group should have a collection of at least four objects including some that will sink and others that will float
- Triple beam balance; one balance may be shared by several groups
- Stiff wire approximately 3 inches long or a straightened paper clip; one for each student group

### Audiovisual Materials
- Chalkboard, marker board, or overhead projector
- (Optional) Video or computer projection equipment to show images of submersibles

## Teaching Time
Two 45-minute class periods

## Seating Arrangement
Groups of two to four students

## Maximum Number of Students
32

## Key Words and Concepts
Density
Buoyancy
Submersible
Volume
Mass

## Background Information
*NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.*

*"We know more about the dead seas of Mars than our own ocean."*
*– Jean Michel Cousteau*

Our current estimation is that 95% of Earth's ocean is unexplored. At first, this may be hard to believe, particularly if we look at recent satellite maps of Earth's ocean floor. These maps seem to show seafloor features in considerable detail. But satellites can't see below the ocean's surface. The "images" of these features are estimates based on the height of the ocean's surface, which varies because the pull of gravity is affected by seafloor features. And if we consider the scale of these maps, it is easy to see how some things might be missed. To show our planet's entire ocean, a typical wall map has a scale of about 1 cm = 300 km. At that scale, the dot made by a 0.5 mm pencil represents an area of over 60 square miles! The fact is, most of the ocean floor has never been seen by human eyes.

On August 13, 2008, the NOAA Ship *Okeanos Explorer* was commissioned as "America's Ship for Ocean Exploration;" the only U.S. ship whose sole assignment is to systematically explore our largely unknown ocean for the purposes of discovery and the advancement of knowledge. To fulfill its mission, the *Okeanos Explorer* has specialized capabilities for finding new and unusual features in unexplored parts of Earth's ocean, and for gathering key information that will support more detailed investigations by subsequent expeditions. These capabilities include:

- Underwater mapping using multibeam sonar capable of producing high-resolution maps of the seafloor to depths of 6,000 meters;
- Underwater robots (remotely operated vehicles, or ROVs) that can investigate anomalies as deep as 6,000 meters; and
- Advanced broadband satellite communication and telepresence.

Capability for broadband telecommunications provides the foundation for telepresence: technologies that allow people to observe and interact with events at a remote location. This allows live images to be transmitted from the seafloor to scientists ashore,

A spectacular photo of the NOAA Ship *Okeanos Explorer* Control Room while ROV operations are underway. Image credit: NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

### *Okeanos Explorer* Vital Statistics:
Commissioned: August 13, 2008; Seattle, Washington
Length: 224 feet
Breadth: 43 feet
Draft: 15 feet
Displacement: 2,298.3 metric tons
Berthing: 46, including crew and mission support
Operations: Ship crewed by NOAA Commissioned Officer Corps and civilians through NOAA's Office of Marine and Aviation Operations (OMAO); Mission equipment operated by NOAA's Office of Ocean Exploration and Research

For more information, visit *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
Follow voyages of America's ship for ocean exploration with the *Okeanos Explorer* Atlas at *http://www.ncddc.noaa.gov/website/google_maps/OkeanosExplorer/mapsOkeanos.htm*

classrooms, newsrooms and living rooms, and opens new educational opportunities, which are a major part of *Okeanos Explorer's* mission for advancement of knowledge. In addition, telepresence makes it possible for shipboard equipment to be controlled by scientists in shore-based Exploration Command Centers. In this way, scientific expertise can be brought to the exploration team as soon as discoveries are made, and at a fraction of the cost of traditional oceanographic expeditions.

Some of the most exciting discoveries in modern ocean exploration have been made with the assistance of underwater robots. In this lesson, students will determine the density and buoyancy of various objects, and will use their knowledge of buoyancy principles to calculate the floatation that is theoretically needed to achieve neutral buoyancy; a characteristic that is often required for manned and unmanned submersibles.

## Learning Procedure

[NOTE: Like all technologies in active use, ROVs are under constant improvement, development and replacement. Consequently, some of the underwater robots referenced in this lesson may no longer be in active service when students undertake this investigation. This does not constitute an obstacle to achieving the Learning Objectives of this lesson, but may require some additional research as Web sites are updated to reflect changes in underwater robotic technology.]

1. To prepare for this lesson:
   a. Review introductory information on the NOAA Ship *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*. You may also want to consider having students complete some or all of the lesson, *To Boldly Go….*
   b. Review the Ocean Explorer Web pages on underwater robotic vehicles, indexed at *http://oceanexplorer.noaa.gov/technology/subs/subs.html* and the essay on ROV *Little Hercules* at *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/rov/rov.html*.
   c. Review procedures described in the *Density and Buoyancy Investigation Guide* (page 65), and prepare materials needed by student groups to complete this activity.
   d. If your students use Lego® robotics or Vernier® calculator-based laboratory materials, you may want to consider alternative procedures described on the *Using Electronic Force Sensors to Measure Buoyancy* information sheet.
   e. Depending upon available time, you may also want to have students complete the activity described in Step 5 of the lesson, *I, Robot, Can Do That!* (*http://oceanexplorer.noaa.gov/explorations/05lostcity/background/edu/media/lostcity05_i_robot.pdf*). In this activity, students identify which of the robots they have studied are best suited to a series of underwater missions.

2. If you have not previously done so, introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, and briefly review the major technological capabilities of the ship. Say that robotic submersibles are a key component of many ocean exploration expeditions, and tell students that their assignment is to investigate some of these robots. Assign one of the following robots to each student group, and provide each group with a copy of *Underwater Robot Capability Survey*:
   *Autonomous Benthic Explorer (ABE)*

*Little Hercules*
*Remotely Operated Platform for Ocean Science (ROPOS)*
General Purpose Remotely Operated Vehicles (ROVs)
*RCV-150*
*Tiburon*

You may want to direct students to the Ocean Explorer Web pages on underwater robotic vehicles (see 1b. above). If students do not have access to the internet, provide copies of the relevant materials to each group.

3. Have each student group present a brief oral report of the capabilities of their assigned robot. The following points should be included:

***Autonomous Benthic Explorer (ABE)***
- Capable of operating to depths up to 5,000 meters
- Autonomous vehicle; no tether to support ship
- Tools: video cameras, conductivity and temperature sensors, depth recorder, magnetometer, sonar, wax core sampler, navigation system
- Developed to monitor underwater areas over a long period of time
- Follows instructions programmed prior to launch; data are not available until robot is recovered
- Operates independently during missions, but requires technicians and engineers for maintenance, as well as data managers to retrieve information stored in computer memory
- NOTE: ABE was lost during the INSPIRE: Chile Margin 2010 Expedition; see *http://oceanexplorer.noaa.gov/explorations/10chile/logs/mar7a/mar7a.html*

***Remotely Operated Platform for Ocean Science (ROPOS)***
- Capable of operating to depths up to 5,000 meters
- 5,500 m of electrical-optical cable tether
- Tools: two digital video cameras; two manipulator arms that can be fitted with different sampling tools (stainless steel jaws, manipulator feedback sensors, rope cutters, snap hooks, core tubes); variable-speed suction sampler and rotating sampling tray; sonar; telemetry system
- Can also be outfitted with up to eight custom-designed tools such as a hot-fluid sampler; chemical scanner; tubeworm stainer; rock-coring drill; rock-cutting chainsaw; laser-illuminated, range gated camera; and downward-looking digital scanning sonar
- Wide variety of observation tools provides scientists with exceptional flexibility so they can quickly respond to new and unexpected discoveries
- A "typical" dive requires at least four people (and sometimes more): the "Hot Seat" scientist, pilot, manipulator operator, and data/event logger

**General Purpose Remotely Operated Vehicles (ROVs)**
- Depth capability varies
- Operated by one or more persons aboard a surface vessel
- Linked to the ship by a group of cables that carry electrical signals back and forth between the operator and the vehicle
- Tools: most are equipped with at least a video camera and lights
- Additional equipment may include a still camera, a manipulator or cutting arm, water samplers, and instruments that measure water clarity, light penetration, and temperature
- Also used for educational programs at aquaria and to link to scientific expeditions live via the internet

The ABE autonomous underwater vehicle (free-swimming robot). ABE (full name: Autonomous Benthic Explorer) has been used on multiple expeditions to find new hydrothermal vents in the deep ocean all over the world, from New Zealand to South Africa and from Brazil to Ecuador. Photo credit: Christopher German.
*http://oceanexplorer.noaa.gov/explorations/10chile/background/exploration/media/exploration1.html*

*Epitaph for ABE:*
*Under the wide and restless sea,*
*Lies my grave, now let me be;*
*Glad did I work and now I rest,*
*Now by deadlines no longer stressed.*
*And I lay me down with a will.*

*This be the verse you grave for me;*
*"Here lies ABE where it longed to be;*
*Home is the sailor, home to the sea,*
*Here it rests, now let it be."*
*~ Al Bradley (after Robert Louis Stevenson)*

*ROPOS* being deployed for deepwater operations inside its steel cage.
*http://oceanexplorer.noaa.gov/technology/subs/ropos/media/roposfirstdive.html*

Left-to-Right: Dave Wright, Tom Kok, and Brian Bingham look up for a moment while operating the ROV. Every day presents the pilot, co-pilot, and navigator with new and unforeseen challenges. Image credit: C. Verplanck, NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

*Okeanos Explorer* crew launch the vehicle during test dives off Hawaii. Image credit: NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.
*http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/launch_hires.jpg*

The control room stations for the ROV *Tiburon* used on the 2006 Davidson Seamount Expedition. From left to right, the stations are: Co-pilot, Pilot, Science, Annotation, and Navigation. Image credit: NOAA/MBARI 2006. For more information, please visit
*http://oceanexplorer.noaa.gov/explorations/06davidson/logs/feb02/feb02.html*
*http://oceanexplorer.noaa.gov/explorations/06davidson/logs/feb02/media/control_room.html*

- Range in size from that of a bread box to a small truck
- Often kept aboard vessels doing submersible operations for safety, and so the ROV can take the place of the submersible when it cannot be used because of weather or maintenance problems
- Can also be used to investigate questionable dive sites before a sub is deployed to reduce risk to the subs and their pilots

***Little Hercules***
- Capable of operating to depths of 4,000 meters
- Provided first and only images of John Kennedy's PT boat, PT-109
- Operated by pilots via a fiberoptic multiplexer system
- Equipped with ultra-short baseline tracking system (USBL)
- Tools:
  - Full color imaging sonar
  - Conductivity-Temperature-Depth sensor
  - Two color CCD cameras
  - High definition video camera
  - Depth and altitude sensors
- Mission ROV for 2010 INDEX-SATAL Expedition in Indonesia (see *http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/rov/rov.html* for more information)

***Tiburon* (ROV)**
- Capable of operating to depths of 4,000 meters
- Controlled from a special control room on board its tender vessel, the R/V *Western Flyer*
- Tether contains electrical wires and fiber-optic strands
- Electrical thrusters and manipulators, rather than hydraulic systems, allow vehicle to move quietly through the water, causing less disturbance to animals being observed
- Variable buoyancy system allows the vehicle to float motionless in the water without the constant use of the thrusters
- Lower half of the vehicle is a modular toolsled, which can be exchanged with other toolsleds to carry out specific missions: benthic (or bottom) toolsled has an extra manipulator arm and extensive sample-carrying space for geological and biological samples; "midwater" toolsled used to explore the biology of open ocean creatures; rock coring toolsled has been used to take oriented rock cores from the seafloor.

***RCV-150***
- Capable of operating to depths of 914 m
- Tethered to support ship via a double armored electro-optical umbilical
- Tools: color video camera, 1500 watts of lighting, micro conductivity/temperature/depth sensor, sonar, manipulator with a six-inch cutoff wheel
- Controlled by a single pilot from a control console located in the tracking room of the support ship
- Small size compared to a submersible allows ROV to have high maneuverability; can get close to the bottom and allow the cameras to peer under ledges and into nooks and crannies
- Primary data collected is video
- Has been used to conduct surveys of bottomfish in Hawai'i

4. Give each student group a copy of the *Density and Buoyancy Investigation Guide* and a collection of objects whose density and buoyancy are to be determined. If necessary, explain how to use the balance, where students are to obtain water, and how they should dispose of wastewater.

5. Lead a discussion of students' results. In Part A of the *Investigation Guide*, students should realize that they need to know mass and volume to find the density of an object. Since the volume of many substances changes in response to temperature, it is also true that the density of an object also depends upon temperature. But temperature changes usually have very small effects on density compared to the effects of changing mass and volume. Students should also observe that objects that float have lower densities than objects that sink.

   In Part B, students should realize that increasing the volume of an object will increase the volume and weight of fluid displaced when the object is immersed, and thus will increase the buoyant force acting on the object.

   Most science standards do not expect elementary students to distinguish between mass and weight, but middle school (Grades 6-8) students are expected to make this distinction. These concepts can be easily confused when dealing with density and buoyancy, because when students use a balance to determine mass they are actually measuring weight (mass multiplied by the force of gravity). This works out because the balance is calibrated to take gravity into account, but under zero gravity conditions the balance would not give an accurate estimate of mass. So if we want to calculate the buoyant force acting on an object based on the weight of displaced fluid, we have to use units of weight such as pounds. If we want to use metric units of force (Newtons) we have to multiply the mass of the displaced fluid (in kg) by the acceleration of gravity (about 9.81 $m/sec^2$). Since these metric units, as well as the concepts of gravitational acceleration, are usually taught in higher grade levels, we do not have students calculate actual buoyant force in this lesson. But if students discuss buoyant force in terms of grams or kilograms, it is important to remind them that these are units of mass and that buoyancy involves units of weight.

   These considerations are not a problem for the *Apply* portion of Part B, because the mass of the robot and mass of water displaced by the float are both acted upon by the same acceleration due to gravity ( 9.81 $m/sec^2$). To make the robot neutrally buoyant, the volume of water displaced by the float must have a mass that is equal the mass of the robot (400 kg). Since the density of water is 1,000 $kg/m^3$, the volume of water that has a mass of 400 kg is:

   $$400 \text{ kg} \div 1{,}000 \text{ kg/m}^3 = 0.4 \text{ m}^3$$

   To calculate the diameter of a cylinder that is 750 cm long that has a volume of 0.4 $m^3$, first calculate the radius of a 750 cm long cyclinder that has this volume:

   $$\pi \bullet r^2 \bullet L = 0.4 \text{ m}^3$$
   $$\pi \bullet r^2 \bullet 0.75 \text{ m} = 0.4 \text{ m}^3$$
   $$\pi \bullet r^2 = 0.4 \text{ m}^3 \div 0.75 \text{ m}$$
   $$\pi \bullet r^2 = 0.533 \text{ m}^2$$
   $$r^2 = 0.170 \text{ m}^2$$
   $$r = 0.412 \text{ m}$$

So, the diameter of the cylinder is

$$D = 2r = 2\ (0.412\ m) = 0.824\ m$$

Discuss some of the factors that might make it difficult to maintain neutral buoyancy. Temperature could have a relatively minor effect as discussed above. Pressure would be a much more serious consideration, since at depths of 400 m to 1,500 m, for example, the pressure would be roughly 40 to 150 times greater than surface pressure. This presents serious design considerations, since there would be a large pressure difference between the inside and outside of the cylinder if the cylinder contained air at normal atmospheric pressure. Even a slight compression of a floatation cylinder could change its volume so that it would no longer provide neutral buoyancy.

Salinity also affects buoyancy, and some of your students have probably found that it is easier to float in seawater than in freshwater. The reason, of course, is that the density of seawater is greater than freshwater (at the same temperature); so the weight of seawater displaced by an object will be greater than the weight of freshwater displaced by the same object, and the resulting buoyant force is greater in seawater. Salinity often varies at different locations in the water column. Again, even slight variations can be enough to upset neutral buoyancy in an underwater floatation system.

Several strategies can be used to compensate for buoyancy changes. One way to do this is to change the volume of a float by adding or removing air; SCUBA divers use this strategy to adjust their buoyancy by adding or removing air to their buoyancy compensator. Another approach is to provide more floatation than is necessary for neutral buoyancy, then add weight to the system; usually by pumping water in or out of an enclosed space. Ballast tanks on submarines are based on this strategy.

## The BRIDGE Connection

*www.vims.edu/bridge/* – In the "Site Navigation" menu on the left, click "Ocean Science Topics," then "Human Activities," then "Technology" for links to resources about submersibles, ROVs, and other technologies used in underwater exploration.

## The "Me" Connection

Have students write a brief essay describing how robots are (or may be) of personal benefit.

## Connections to Other Subjects

English/Language Arts, Life Science, Mathematics

## Assessment

Reports and discussions in Steps 3 and 4 provide opportunities for assessment.

## Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. Build your own underwater robot! See books by Harry Bohm under "Resources."

## Multimedia Discovery Missions

*http://www.montereyinstitute.org/noaa/* Click on the links to Lessons 3, 6, 11, and 12 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Deep-Sea Benthos, Energy from the Oceans, and Food, Water, and Medicine from the Sea.

## Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

**Call to Arms** (Grades 5-6)
(from the 2008 Deepwater Coral Expedition: Reefs, Rigs, and Wrecks)
*http://oceanexplorer.noaa.gov/explorations/08lophelia/background/edu/media/calltoarms.pdf*
Focus: Robotic Analogues for Human Structures (Physical Science/Life Science)
Students will describe the types of motion found in the human arm, and describe four common robotic arm designs that mimic some or all of these functions.

**I, Robot, Can Do That!** (Grades 7-8)
(from the Thunder Bay Sinkholes 2008 Expedition)
*http://oceanexplorer.noaa.gov/explorations/08thunderbay/background/edu/media/robot.pdf*
Focus: Underwater Robotic Vehicles for Scientific Exploration (Physical Science/Life Science)
Students will describe and contrast at least three types of underwater robots used for scientific explorations, discuss the advantages and disadvantages of using underwater robots in scientific explorations, and identify robotic vehicles best suited to carry out certain tasks.

**The Robot Explorer** (Grades 9-12) (from the 2009 Bermuda Caves Expedition)
*http://oceanexplorer.noaa.gov/explorations/09bermuda/background/edu/media/09robot.pdf*
Focus: Remotely operated vehicles for exploring anchialine caves (Physics/Earth Science/Technology)
Students will discuss remotely operated vehicles and onboard systems used for exploring anchialine caves, and will explain the design and construction process for a simple robot explorer.

**My Wet Robot** (Grades 9-12) (from the PHAEDRA 2006 Expedition)
*http://oceanexplorer.noaa.gov/explorations/06greece/background/edu/media/wet_robot.pdf*
Focus: Underwater Robotic Vehicles (Physical Science)
Students will discuss the advantages and disadvantages of using underwater robots in scientific explorations, identify key design requirements for a robotic vehicle that is capable of carrying out specific exploration tasks, describe practical approaches to meet identified design requirements, and (optionally) construct a robotic vehicle capable of carrying out an assigned task.

**The Roving Robotic Chemist** (Grades 9-12)
(from the PHAEDRA 2006 Expedition)
*http://oceanexplorer.noaa.gov/explorations/06greece/background/edu/media/robot_chemist.pdf*
Focus: Mass Spectrometry (Chemistry)

Students will explain the basic principles underlying mass spectrometry, discuss the advantages of in-situ mass spectrometry, explain the concept of dynamic re-tasking as it applies to an autonomous underwater vehicle, and develop and justify a sampling strategy that could be incorporated into a program to guide an AUV searching for chemical clues to specific geologic features.

**Where's My 'Bot?** (Grades 9-12) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)
*http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wheresbot.pdf*
Focus: Marine Navigation (Earth Science/Mathematics)
Students will estimate geographic position based on speed and direction of travel, and integrate these calculations with GPS data to estimate the set and drift of currents.

**The Robot Archaeologist** (Grades 9-12) (from the AUVfest 2008 Expedition)
*http://oceanexplorer.noaa.gov/explorations/08auvfest/background/edu/media/robot.pdf*
Focus: Marine Archaeology/Marine Navigation (Earth Science/Mathematics)
Students will design an archaeological survey strategy for an autonomous underwater vehicle (AUV); calculate expected position of the AUV based on speed and direction of travel; and calculate course correction required to compensate for the set and drift of currents.

## Other Resources

See page 217 for Other Resources.

## Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

### Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.
Please send your comments to:
*oceanexeducation@noaa.gov*

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# Underwater Robot Capability Survey

**Name of Robotic Vehicle**

**Maximum Operating Depth**

**Tethered or Autonomous**

**Minimum Number of Crew Required for Operation**

**Tools**

**Special Capabilities or Advantages**

**Other Details**

# Density and Buoyancy Investigation Guide

## A. Density

### Background

Density is a physical property of matter that is related to an object's mass (the amount of material in the object) and volume (the object's physical size). You know that a handful of styrofoam weighs much less than a handful of rocks. This is because the density of the styrofoam is less than the density of the rocks. Density is usually defined as "mass per unit volume," and the density of an object or substance is stated in "grams per cubic centimeter."

### Inquire

Your task is to measure the density of objects in the collection provided by your teacher. What two properties of each object do you need to know to find the object's density?

Measure the mass of each object using a balance as directed by your teacher. Record these measurements on the data sheet.

Now measure the volume of each object. The easiest way to do this is to immerse the object in water in a graduated cylinder and measure the increase in water volume. Put water into a graduated cylinder so the cylinder is about half full. Record the volume of the water on the data sheet in the "Volume Without Object" column. Drop the object into the cylinder and record the new volume on the data sheet in the "Volume With Object" column. If the object floats, you will need to push it down with a piece of stiff wire until the object is completely submerged. Subtract "Volume Without Object" from "Volume With Object" and record the result in the "Object Volume" column.

Calculate the density of each object by dividing the mass by the volume, and record the results on the data sheet in the "Density" column. Hint: One milliliter is the same as one cubic centimeter.

Record the buoyancy of the object in the last column.

What do you notice about the density of objects that sink compared to objects that float?

## B. Buoyancy

### Background

Read the following explanation of Archimedes' Principle:
The idea of buoyancy was summed up by a Greek mathematician named Archimedes: any object, wholly or partly immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object. Today, this definition is called Archimedes' Principle. Archimedes is considered one of the three greatest mathematicians of all time (the other two are Newton and Gauss). Archimedes was born in 287 B.C., in Syracuse, Greece. He was a master at mathematics and spent most of his time thinking about new problems to solve.

Many of these problems came from Hiero, the king of Syracuse. Archimedes came up with his famous principle while trying to solve this problem: The king ordered a gold crown and gave the goldsmith the exact amount of metal to make it. When Hiero received it, the crown had the correct weight but the king suspected that some silver had been substituted for the gold. He did not know how to prove it, so he asked Archimedes for help.

One day while thinking this over, Archimedes went for a bath and water overflowed the tub. He recognized that there was a relationship between the amount of water that overflowed the tub and the amount of his body that was submerged. This observation gave him the means to find the volume of an irregularly shaped object, such as the king's crown. With this information, Archimedes could find out how much a volume of gold equal to the volume of the crown would weigh. If the weight of the same volume of gold turned out to be the same as the weight of the crown, then he would know that the crown was made of gold. But if the weight of the same volume of gold was different from the weight of the crown, then he would know that the crown was not pure gold after all.

Archimedes had solved the problem! He was so excited that he ran naked through the streets of Syracuse shouting "I have found it!". As it turned out, the crown was not pure gold, so the goldsmith was brought to justice and Archimedes never took another bath...(just kidding!).

(from *Discover Your World with NOAA: An Activity Book*; *http://celebrating200years.noaa.gov/edufun/book/welcome.html*)

### Inquire

If the volume of an object increases but the mass of the object does not change, how does this affect the buoyant force acting on the object when it is immersed in a fluid?

### Apply

Underwater robots usually are designed to be able to achieve neutral buoyancy (they do not sink or float, but stay suspended in the middle of the water) while they are performing various tasks. One way to adjust buoyancy is to pump water in or out of floatation cylinders that are attached to the frame of the robot. This changes the volume of air that is contained inside the cylinders, and therefore changes their buoyancy.

Suppose you have an underwater robot that has a mass of 400 kg in fresh water without any extra floatation. What is the minimum diameter of a cylinder that is 750 cm long that will provide enough floatation to make the robot neutrally buoyant? Assume that the cylinder is made from a material that is weightless in water.

*Hints:*

(a) The formula for the volume of a cylinder is $\pi \bullet r^2 \bullet L$, where r is the radius of the cylinder and L is the length of the cylinder.

(b) One cubic meter of fresh water has a mass of 1,000 kilograms at 5° C

Why might it be difficult to maintain neutral buoyancy, even if the floatation cylinder had the correct dimensions? What strategies could be used to overcome these difficulties?

# Density and Buoyancy Investigation Data Sheet

| Object | Mass | Volume | Volume | Object | Density | Buoyancy |
|---|---|---|---|---|---|---|
| | (g) | Without Object (ml) | With Object (ml) | Volume (ml) | (g/cm3) | S = sinks<br>F = Floats<br>N = Neutral |
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# Using Electronic Force Sensors to Measure Buoyancy

Electronic force sensors can be adapted to measure buoyancy. Incorporating this approach to measurements in Part A of the *Density and Buoyancy Investigation Guide* provides additional opportunities for hands-on student problem-solving, as well as experience with using calculators or computers for data logging and analysis.

Vernier Software and Technology (*http://www.vernier.com*) offers a dual-range sensor that can be used as a replacement for a hand-held spring scale, and attaches to graphing calculators as well as interfaces that allow sensor readings to be stored and analyzed by personal computers. The sensor may be mounted on a ring stand and used to measure the weight of objects attached to a hook built into the sensor. If these objects are immersed in a container of water, the change in weight provides a measure of buoyancy.

Adapters are available to allow the Lego Mindstorms® RCX and NXT microcontroller bricks to accept Vernier and other third-party sensors that can provide data to personal computers via RoboLab® software (*http://www.vernier.com/engineering/lego-nxt/*). Since many middle schools participate in First Lego League competitions, students may already be familiar with procedures for acquiring data using these microcontrollers and software.

Less expensive force sensors are also available. FlexiForce® sensors, for example, are very thin printed circuits that can be used to measure force between two surfaces. Since these sensors are essentially variable resistors whose resistance decreases as force is applied, the change in resistance can be read with an inexpensive ohmmeter. By calibrating the sensor with objects whose weight is known, a graph can be constructed that converts sensor resistance into units of force (see *http://www.tekscan.com/pdfs/FlexiforceUserManual.pdf* for details). To use this type of sensor for buoyancy measurements, it is necessary to devise a way for the object being tested to apply pressure to the sensor. One solution is illustrated in Figure 1, but students will probably create many others as well.

A variety of Web pages provide directions for constructing simple force sensors from very inexpensive materials (*e.g.*, *http://www.instructables.com/id/How-to-Make-Bi-Directional-Flex-Sensors/*). Many of these also are devices whose resistance changes as they are subjected to pressure or flexing, and are based on plastic or cloth materials that include substances that make these materials conductive to electricity. The plastic bags used in the electronics industry to ship static-sensitive components are one example, and are readily available at little or no cost. Offering students the option of constructing their own sensors provides additional opportunities for creativity and problem-solving.

*Note: Mention of proprietary names does not imply endorsement by NOAA.*

**Figure 1: Force Sensor**