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2007: Exploring the Inner Space of the Celebes Sea

It's the Law!

Focus
Gas Laws

Grade Level
7-8 (Physical Science)

Focus Question
How do Boyle's Law, Charles' Law, Gay-Lussac's Law, Henry's Law, and Dalton's Law have practical application to SCUBA diving?

Learning Objectives
Students will be able to define the basic principles stated in Boyle's Law, Charles' Law, Gay-Lussac's Law, Henry's Law, and Dalton's Law.

Students will be able to explain the application of Boyle's Law, Charles' Law, Gay-Lussac's Law, Henry's Law, and Dalton's Law to observations or events related to SCUBA diving.

Materials
None

Audio/Visual Materials
None

Teaching Time
Two or more 45-minute class periods (see Learning Procedure, Step 3)

Seating Arrangement
Classroom style

Maximum Number of Students
30

Key Words
Celebes Sea
SCUBA diving
Gas laws
Boyle's Law
Charles' Law
Gay-Lussac's Law
Henry's Law
Dalton's Law
Pressure
Class discussion

Background Information
Indonesia is well-known as one of Earth's major centers of biodiversity. Although Indonesia covers only 1.3 percent of Earth's land surface, it includes:

- 10 percent of the world's flowering plant species;
- 12 percent of the world's mammal species;
- 16 percent of all reptile and amphibian species; and
- 17 percent of the world's bird species.

In addition, together with the Philippines and Great Barrier Reef, this region has more species of fishes, corals, mollusks, and crustaceans than any other location on Earth.

What, exactly, is meant by biodiversity, and why is it important? The term "biodiversity" is usually understood to include variety at several levels:

- variety of ecosystems: high biodiversity suggests many different ecosystems in a given area;
- variety of species: high biodiversity suggests many different species in a given area;
- variety of interactions between species; and
- variety within species (genetic diversity): high biodiversity suggests a relatively high level of genetic variety among individuals of the same species.

A simple definition of biodiversity could be "The variety of all forms of life, ranging in scale from genes to species to ecosystems."

Biodiversity is important to humans because our survival depends upon many other species and ecosystems. Some examples of our dependence on biodiversity include:

- fresh air containing oxygen;
- clean water;
- productive soils;
- food, medicines and natural products;
- natural resources that provide the basis for human economies; and
- natural beauty that improves our quality of life.

(adapted from the Biodiversity Project, http://www.biodiversityproject.org/bdimportant.htm)

Quite a lot is known about Indonesia's terrestrial and shallow-water ecosystems. But scientific knowledge and understanding of midwater ocean communities is generally sketchy, and many midwater animals have not been studied at all—even though the midwater ocean environment is our planet's largest ecosystem. Midwater animals range from microscopic zooplankton to the largest animals on Earth, provide a major source of nutrition for benthic (bottom) communities, and are an important link in the transfer of energy and materials from the top to the bottom of the ocean. Note that the term "midwater" as used here includes the entire water column, but the same term has also been used to refer to only part of the water column. Scientists often divide the ocean water column into three zones: the "epipelagic zone" (also called the "sunlit" or "euphotic" zone) from the surface to a depth of about 200 m; the "mesopelagic zone" between 200 m and 1100 m; and the "bathypelagic zone," which is deeper than 1100 m.

"Plankton" is a general term for organisms that drift or swim weakly in midwater environments, and includes plants (phytoplankton) as well as animals (zooplankton). Phytoplankton include major primary producers in aquatic food webs, and zooplankton are often the primary consumers that are a key link in transferring energy to other consumers in these food webs. Despite their importance, many types of zooplankton are not well-understood. This is partially because many zooplankton are fragile, jelly-like creatures that are easily damaged by nets and other devices that are traditionally used to collect midwater animals for study. Scientists participating in the 2007: Exploring the Inner Space of the Celebes Sea Expedition plan to use techniques known as blue-water diving to observe and collect fragile midwater animals.

Diving in the open ocean is quite different from nearshore diving, because there are no objects for visual reference, and it is very easy for divers to become disoriented. "Blue-water diving" techniques involve a system of lines and floats to create visual reference points, as well as procedures that help keep divers in touch with each other. One diver (called the "safety diver") holds an aluminum "trapeze," and descends to the desired depth along a weighted line attached to a surface float. Other divers are attached to safety lines that clip onto the trapeze. This system allows the safety diver to keep track of the "working" divers who are free to concentrate on research tasks.

Even with such specialized techniques, divers who use self-contained underwater breathing apparatus (SCUBA) still must be aware of how gases behave under pressure, and how the basic gas laws apply to SCUBA diving. In this lesson, students will be introduced to Boyle's Law, Charles' Law, Gay-Lussac's Law, Henry's Law, and Dalton's Law, and how these laws affect SCUBA divers.

Learning Procedure

1. To prepare for this lesson, review the introductory essays for the 2007: Exploring the Inner Space of the Celebes Sea Expedition at http://oceanexplorer.noaa.gov/explorations/07philippines/. You can view many images of planktonic organisms at http://www.imagequest3d.com/catalogue/larvalforms/, but be aware of copyright restrictions posted on the Web site.

   Numerous demonstrations have been created to introduce various gas laws, and are described on many Internet Web sites. Some of these use specialized apparatus, while others are quite simple. Many instructors have their own favorite gas law demonstrations. If you do not, the following may be useful:
   - Boyle's Law: The "Cartesian Diver" is one of the classic demonstrations; see file 59 of the Royal Society of Chemistry's "Classic Chemistry Experiments" (http://www.chemsoc.org/networks/learnnet/classic_exp.htm). For an animated demonstration of Boyle's Law, see http://www.grc.nasa.gov/WWW/K-12/airplane/aboyle.html

   - Charles' Law: A glass bottle, balloon, and heat source are all you need; see http://library.thinkquest.org/12596/bonus_charles.html; for a quantitative demonstration, see http://chemed.chem.purdue.edu/demos/demosheets/4.14.html

   - Gay-Lussac's Law: Several ways to do the "egg in a bottle" trick; see http://www.geocities.com/boogerhollow11/EgginBottle.html

   - Henry's Law: For a demonstration involving root beer, see www.apsu.edu/ROBERTSONR/TSTA%20Presentation/NSTA%202005.pdf. Please be sure to note the safety precautions for this activity: allow for some gas escape, do not screw the lid onto the container so tightly that the gas pressure could cause the container to burst, and do not use a glass container (clear plastic is safer).

   - Dalton's Law: For a "virtual experiment," see http://www.chm.davidson.edu/ChemistryApplets/GasLaws/DaltonsLaw.html

   You can find other "virtual demonstrations" for gas laws at http://www.chemtopics.com/unit07/munit7.htm

2. Briefly introduce the 2007: Exploring the Inner Space of the Celebes Sea Expedition, focusing on the importance of midwater animals and why these animals have not been well-studied. You may want to briefly describe the problems of SCUBA diving in the open ocean and some of the blue-water diving techniques used to overcome these problems.

3. Using the demonstrations referenced in step 1, or your own favorites, introduce students to Boyle's Law, Charles' Law, Gay-Lussac's Law, Henry's Law, and Dalton's Law. Note that in some standards and texts, the first three laws may be combined as the Combined Gas Law:

   $$\frac{P_1 \bullet V_1}{T_1} = \frac{P_2 \bullet V_2}{T_2}$$

   Where P = absolute pressure, V = volume, and T = absolute temperature

   If students are unfamiliar with the behavior of gases, it may be easier to consider these factors two-at-a-time (i.e., as three separate "laws").

   At the conclusion of each demonstration, challenge students with the following problems related to SCUBA diving, and lead a discussion of students' answers. You may want to have each student write their own response to the problems prior to group discussion. Depending upon the amount of discussion and students' grasp of the individual gas laws, this activity may require several class periods.

Discussions should include the following points:

(a) Boyle's Law

Challenge Question:

SCUBA divers often wear a wet suit to help keep them warm while diving. A wet suit is made of foam rubber or similar material that traps small air bubbles. The air bubbles provide insulation, but also cause divers to float. To overcome the tendency to float, divers carry weights. But as divers descend, their wet suit becomes less buoyant. When this happens, the problem is how to deal with the weights they brought from the surface. Most divers blow air from their tank into an inflatable vest called a buoyancy compensator ("BC" for short) to balance the extra weight. When a diver returns to the surface, she has to release air from her BC to keep from rising too quickly. How does Boyle's law explain what happens to the wet suit and BC? Hint: The pressure on a diver's body increases by one atmosphere for every ten meters of depth. So at the surface, a diver is under a pressure of one atmosphere (about 14 lb per square inch). Ten m down, the diver is under a pressure of two atmospheres; 20 m down, the pressure is three atmospheres, and so on.

Discussion points:

- Boyle's Law states that the product of the volume and pressure of a gas held at a constant temperature is equal to a constant (PV = k). So, if the pressure of the gas doubles, the volume will be decreased by half; and if the volume of a gas doubles, the pressure must decrease by half.

- As a diver descends, the pressure increases, so the volume of the air bubbles in her wetsuit decreases. This makes the wetsuit less buoyant, so she has to put some air into her BC to compensate. When she ascends, the pressure decreases and her wetsuit becomes more buoyant. In addition, the volume of the air she put into her BC also increases, making her BC more buoyant. So she has to release air from her BC, or else she would pop to the surface like a cork! This could be really bad, because…

- Boyle's Law is also important to divers because it means that if a diver takes a lungful of air while he is underwater, that air will expand in his lungs as he rises to the surface. If he holds his breath, or ascends too rapidly (like a cork) the expanding air can rupture his lungs. So the golden rules of diving are: Never hold your breath, and don't ascend more rapidly than your smallest bubbles.

(b) Charles' Law

Challenge Question:

As SCUBA divers descend, they often encounter layers of water that are significantly colder than water at the surface. Suppose a diver blows air into his BC at the surface until he is neutrally buoyant (which means he neither rises nor sinks in the water). As he swims deeper, he enters a layer of much colder water, and soon finds that he is sinking rapidly through the water. How does Charles' Law explain what happened?

Discussion points:

- Charles' Law states that the volume of a given amount of gas is directly proportional to the Kelvin temperature, provided the amount of gas and the pressure remain fixed.

- As the diver enters colder water, the temperature of the air in his BC is reduced. Charles' Law predicts that the volume of air will also be reduced in proportion to the change in temperature. Since buoyancy depends upon the volume of air in the BC, buoyancy will also be decreased, causing the diver to sink.

(c) Gay-Lussac's Law

Challenge Question:

A careless diver leaves a full SCUBA tank in the trunk of a car during a hot summer day. After several hours, a deafening whistle comes from the trunk and the diver finds that her tank is empty. She says, "Man, I should have expected this to happen because of Gay-Lussac's Law!" What did she mean?

Discussion points:

- Gay-Lussac's Law states that for a fixed amount of gas (fixed number of moles) at a fixed volume, the pressure of the gas is proportional to the temperature.

- When a filled SCUBA tank is heated, the amount of gas stays the same, and so does the volume of the tank, but the pressure inside the tank increases as the temperature rises. Eventually, the pressure can reach the point at which the safety disk inside the tank valve ruptures, allowing the air inside the tank to escape; and making a very loud noise as it does so!

(d) Henry's Law

Challenge Question:

At a depth of 20 m, a SCUBA diver's body is exposed to a pressure of three atmospheres. If the diver is breathing ordinary air, she is breathing a mixture of several gases; mostly nitrogen (%), and oxygen (%). Suppose the diver remains at this depth for one hour, and then returns to the surface. What does Henry's Law predict will happen to gases dissolved in the diver's blood?

Discussion Points:

- Henry's Law states that the mass of a gas which dissolves in a volume of liquid is proportional to the pressure of the gas. So, as the pressure goes up, more gas will dissolve; and as the pressure decreases, some of the dissolved gas will "undissolve." Imagine taking the top off of a bottle of soda to visualize what "undissolve" looks like (the dissolved substance forms bubbles as it changes back into a gas state).

- Henry's Law predicts that gases dissolved in the diver's blood under three atmospheres of pressure will "undissolve" when the pressure is reduced to one atmosphere (at the surface). In fact, if the diver ascends too rapidly, bubbles will form in her blood and may cause decompression sickness (also known as "the bends"). This is why divers must ascend slowly, and sometimes must pause for a while at shallower depths, to allow time for the dissolved gases to leave their blood without forming bubbles (like very slowly removing the cap from a bottle of soda).

(e) Dalton's Law

Challenge Question:

Ordinary air contains about 78% nitrogen, 21% oxygen, and small amounts of several other gases. As a diver descends, the pressure of the air he is breathing increases by about one atm for every 10 m of depth. Oxygen may become toxic and cause convulsions if it is breathed at a pressure above 1.4 atmospheres. According to Dalton's Law, at what depth should a SCUBA diver be concerned about oxygen toxicity if he is breathing ordinary air?

Discussion Points:

- Dalton's Law states that the pressure exerted by a mixture of gases is equal to the sum of the pressures that would be exerted by the gases individually.

- Since air contains about 21% oxygen, so the pressure of oxygen at the surface is about 0.21 atmosphere. Since pressure increases by one atmosphere for every 10 m of depth, the relationship between depth and pressure is

(pressure) = 1 atm + (depth in m) ÷ (10 m/atm)

So the pressure of air at 10 m would be
1 atm + (10 m) ÷ (10 m/atm) = 2 atm

and the pressure of oxygen at 10 m would be
(21% O_2) • (2 atm) = 0.42 atm O_2

So, the depth at which oxygen would have a pressure of 1.4 atm is
(depth in m) = [(1.4 atm) ÷ (21% O_2) - 1 atm] • [10 m/atm]
= [6.66 atm - 1 atm] • [10 m/atm]
= 56.6 m

If your students aren't up to the algebra, just focus on the idea that the pressure of a mixture of gases is divided among each of the gases in the mixture, in proportion to the concentration of each gas in the mixture.

The Bridge Connection

www.vims.edu/bridge/ – In the "Site Navigation" menu on the left, click on "Ocean Science Topics," then "Human Activities," then "Recreation" for links to resources about SCUBA diving

The "Me" Connection

Have students write a brief essay describing how one or more of the gas laws might be directly relevant to their own lives.

Connections to Other Subjects

Life Science, Mathematics

Assessment

Discussions and written responses (if assigned) provide opportunities for assessment.

Extensions

1. Visit oceanexplorer.noaa.gov to keep up to date with the latest 2007: Exploring the Inner Space of the Celebes Sea Expedition discoveries, and to find out what researchers are learning about deep fore reef communities.

2. Visit the Newton's Apple Teacher Guide for SCUBA diving at http://www.newtonsapple.tv/TeacherGuide.php?id=1673.

Multimedia Learning Objects

http://www.learningdemo.com/noaa/ – Click on the links to Lessons 8 and 12 for interactive multimedia presentations and Learning Activities on Ocean Currents and Food, Water, and Medicine from the Sea.

Other Relevant Lesson Plans from the Ocean Exploration Program

Come on Down! [http://www.oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr7_8_l1.pdf] (6 pages, 464k) (from the 2002 Galapagos Rift Expedition)

Focus: Ocean Exploration

In this activity, 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 construct a device that exhibits neutral buoyancy.

A Matter of Density [http://www.oceanexplorer.noaa.gov/explorations/04mountains/background/edu/media/MTS04.density.pdf] (6 pages, 416k) (from the 2004 Mountains in the Sea Expedition)

Focus: Temperature, density, and salinity in the deep sea (Physical Science)

In this activity, students will be able to explain the relationship among temperature, salinity, and density; and, given CTD (conductivity, temperature, and density) data, students will be able to calculate density and construct density profiles of a water column. Students will also be able to explain the concept of sigma-t, and explain how density differences may affect the distribution of organisms in a deep-sea environment.

Who Has the Light? [http://www.oceanexplorer.noaa.gov/explorations/04deepscope/background/edu/media/WhoHasLight.pdf] (PDF, 200Kb) (from the 2004 Operation Deep Scope Expedition)

Focus: Bioluminescence in deep-sea organisms

In this activity, students compare and contrast chemiluminescence, bioluminescence, fluorescence, and phosphorescence. Students also explain at least three ways in which the ability to produce light may be useful to deep-sea organisms and explain how scientists may be able to use light-producing processes in deep-sea organisms to obtain new observations of these organisms.

It's a Gas! Or Is It? [http://www.oceanexplorer.noaa.gov/explorations/05fire/background/edu/media/rof05_gas.pdf] (9 pages, 270Kb) (from the New Zealand American Submarine Ring of Fire 2005 Expedition)

Focus: Effects of temperature and pressure on solubility and phase state (Physical Science/Earth Science)

In this lesson, students will be able to describe the effect of temperature and pressure on solubility of gases and solid materials; describe the effect of temperature and pressure on the phase state of gases; and infer explanations for observed chemical phenomena around deep-sea volcanoes that are consistent with principles of solubility and phase state.

Other Links and Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://oceanexplorer.noaa.gov – Web site for NOAA's Ocean Exploration program

http://oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html – Ocean Explorer photograph gallery

Hamner, W. M. 1975. Underwater observations of blue-water plankton: Logistics, techniques, and safety procedures for divers at sea. Limnology and Oceanography 20:1045-1051; available online at http://aslo.org/lo/toc/vol_20/issue_6/1045.pdf.

http://www.imagequest3d.com/catalogue/larvalforms/ – Image Quest 3-D Web site, featuring images of numerous marine organisms; all images are copyrighted, but are still great to look at

http://www.pbs.org/wgbh/nova/lasalle/buoybasics.html – "Buoyancy Basics" Web site from NOVA

http://www.grc.nasa.gov/WWW/K-12/airplane/aboyle.html – Animated demonstration of Boyle's Law from NASA's Glenn Research Center

http://www.chemsoc.org/networks/learnnet/classic_exp.htm – The Royal Society of Chemistry's "Classic Chemistry Experiments"

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Properties & changes of properties in matter

Content Standard F: Science in Personal and Social Perspectives

- Personal health
- Science and technology in society

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.

Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.

Fundamental Concept c. Some major groups are found exclusively in the ocean. The diversity of major groups of organisms is much greater in the ocean than on land.

Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.

Fundamental Concept e. The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the seafloor. Most of the living space on Earth is in the ocean.

Fundamental Concept f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy." Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

Essential Principle 6.
The ocean and humans are inextricably interconnected.

Fundamental Concept a. The ocean affects every human life. It supplies freshwater (most rain comes from the ocean) and nearly all Earth's oxygen. It moderates the Earth's climate, influences our weather, and affects human health.

Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.

Fundamental Concept e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7.
The ocean is largely unexplored.

Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

Fundamental Concept c. Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.

Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

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We value your feedback on this lesson.
Please send your comments to:
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