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2007: Exploring the Inner Space of the Celebes Sea

Outta Gas

Focus
Gas laws

Grade Level
9-12 (Chemistry/Physics)

Focus Question
How can Boyle's Law, Charles' Law, Gay-Lussac's Law, Henry's Law, and Dalton's Law be used to predict the behavior of gases used in SCUBA diving?

Learning Objectives
Students will define Boyle's Law, Charles' Law, Gay-Lussac's Law, Henry's Law, and Dalton's Law.

Students will use Boyle's Law, Charles' Law, Gay-Lussac's Law, Henry's Law, and Dalton's Law to solve practical problems related to SCUBA diving.

Materials
- ❒ "Blue Water Diving Worksheet," one copy for each student or student group

Audio/Visual Materials
None

Teaching Time
One or two 45-minute class periods plus time for students to complete worksheet

Seating Arrangement
Classroom style

Maximum Number of Students
30

Key Words
Celebes Sea
SCUBA diving
Gas laws
Ideal Gas Law
Boyle's Law
Charles' Law
Gay-Lussac's Law
Henry's Law
Dalton's Law
Pressure
Worksheet
Mathematics

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 be behavior of gases 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.

   If students are not familiar with the fundamental concepts embodied in Boyle's Law, Charles' Law, Gay-Lussac's Law, Henry's Law, and Dalton's Law, you may want to introduce these concepts using activities described in the "It's the Law!" lesson.

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. Discuss the Ideal Gas Law ($P \bullet V = n \bullet R \bullet T$). Students should recognize that this "law" describes the interaction between four variables: pressure, volume, number of gas molecules, and temperature. Be sure students understand that "pressure" refers to absolute pressure (in the case of SCUBA diving, the combined pressure of the atmosphere and water), and that they are familiar with the system of units to be used. The appropriate SI units are:
   - pressure in pascals (Pa)
   - volume in cubic meters (m^3)
   - number of molecules in moles (mol)
   - temperature in degrees Kelvin (°K)
   - R has a value of 8.314 joules per mole per degree Kelvin (j/mol/°K)

   However, other units are commonly used when gas laws are applied to SCUBA diving:
   - pressure in pounds per square inch (psi) or atmospheres (atm); 1 atm = 101,325 Pa = 14.7 psi
   - volume in liters or cubic feet; 1 l = 10^{-3} m^3; 1 ft^3 = 28.3 l
   - R has a value of 0.082 L · atm/mol/°K

   Students should also understand that when the Ideal Gas Law is used to describe the behavior of a fixed quantity of gas, the equation can be written as

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

   Where P_1, V_1, and T_1 are the initial pressure, volume, and temperature, respectively, and P_2, V_2, and T_2 are the pressure, volume, and temperature after one or more of these variables has changed.

4. Provide each student or student group with a copy of "Blue Water Diving Worksheet." When students have solved the Worksheet problems, lead a discussion of their answers. The following points should be included:

   (1) 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.

(2) 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.

(3) 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.

(4) 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.

(5) 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.

(6) For every ten meters of depth, water pressure increases by approximately one atmosphere (101,325 Pa).

(7a) Absolute pressure changes from 1 atm at the surface to 3 atm at 20 m. So,

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

$$\frac{1 \text{ atm} \bullet 5.0 \text{ l}}{T_{constant}} = \frac{3 \text{ atm} \bullet V_2}{T_{constant}}$$

$$V_2 = 5 \text{ l} \div 3 = 1.7 \text{ l}$$

(7b) Since the partial pressure of oxygen increases by three, Henry's Law predicts that the amount of dissolved oxygen will also increase by three.

(7c) As the diver returns to the surface, the absolute pressure changes from 3 atm to 1 atm, so the partial pressure will be reduced to one-third. This rapid decrease in the partial pressure of oxygen in the lungs can cause loss of consciousness known as "deep-water blackout."

(8a) When she takes a breath at 20 m, the air in her lungs has a pressure of 3 atm.

(8b) The volume of air in her lungs when she takes a deep breath at 20 m is 5 liters.

(8c) If she took a deep breath and returned to the surface while holding her breath, the volume of air in her lungs would expand by a factor of three (pressure changes from 3 atm to 1 atm). This would cause the alveoli and small capillaries in her lungs to rupture, causing massive bleeding and probably death.

(9) Since

$$1 \text{ ft}^3 = 28.3 \text{ l}$$

the filled tank contains

$$80 \text{ ft}^3 = 80 \bullet 28.3 \text{ l} = 2{,}264 \text{ l}$$

Since

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

assuming constant temperature, at 30 m depth, the gas in the tank would have a volume of

$$\frac{1 \text{ atm} \bullet 2{,}264 \text{ l}}{T_{constant}} = \frac{4 \text{ atm} \bullet V_2}{T_{constant}}$$

$$V_2 = (2{,}264 \text{ l}) \div 4 = 566 \text{ l}$$

and this volume is equivalent to

$$(566 \text{ l}) \div (0.5 \text{ l/breath}) = 1{,}132 \text{ breaths}$$

(10) Once again,

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

Remembering to use absolute pressure,
P_1 = 3,000 psi + 14.7 psi = 3,015 psi

and
P_2 = 3,000 psi + 0.2 • 3,000 psi = 3,600 psi

Also, remembering to convert temperature to degrees Kelvin

20°C = 20 + 273 = 293°K

Since the volume of the tank is constant,

$$\frac{3{,}015 \text{ psi} \bullet V_{constant}}{293°K} = \frac{3{,}600 \text{ psi} \bullet V_{constant}}{T_2}$$

So

T_2 = (3,600 psi • 293°K) ÷ 3,015 psi = 350°K

which is equivalent to a Celsius temperature of 350 - 273 = 77°C

(11) According to Dalton's Law, the pressure exerted by a mixture of gases is equal to the sum of the pressures that would be exerted by the gases individually. So if the partial pressure of nitrogen is 3.5 atm, the total pressure of the breathing air is

3.5 atm ÷ 0.78 = 4.49 atm

Since this is absolute pressure,

4.49 atm absolute = 1 atm air pressure + 3.49 atm water pressure

Since pressure increases by about 1 atm for every 10 m depth, the equivalent depth is

(3.49 atm) • (10 m/atm) = 34.9 m

12. According to Henry's Law, the mass of a gas that dissolves in a volume of liquid is proportional to the pressure of the gas. This means that as a diver descends to greater depths, progressively more breathing gases will dissolve in her blood. When she returns to the surface, these gases become less soluble because the external pressure is reduced, and the gases begin to diffuse out of her blood. If the ascent is too rapid, bubbles can form in the blood. If the bubbles are large enough they may block important blood vessels causing pain, paralysis, or death. Decompression sickness in divers usually involves bubbles of nitrogen. Oxygen in air does not form such bubbles because much of the oxygen dissolved in a diver's blood is quickly bound by hemoglobin, and normal metabolism further reduces blood oxygen concentration.

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

Biology, 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.

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

3. For another activity involving graphing, calculators, Henry's Law, and "the bends," see http://dwb.unl.edu/calculators/pdf/Bends.pdf

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

Blinded By the Light!! [http://www.oceanexplorer.noaa.gov/explorations/02sab/background/edu/media/sab_blinded.pdf] (6 pages, 460k) (from the Islands in the Stream 2002: Exploring Underwater Oases Expedition)

Focus: Physical Science – Absorption, Scattering, and Reflection of Light in the Deep Sea

In this activity, students will recognize that the colors they see are a result of the reflection of light and that other colors of light are absorbed; predict what color an object will appear when light of different colors is shined upon it; predict what color(s) will be produced when different colors of light are mixed; and identify the three primary colors and three secondary colors of light.

Drifting Downward [http://www.oceanexplorer.noaa.gov/explorations/02sab/background/edu/media/sab_drifting.pdf] (6 pages, 464k) (from the Islands in the Stream 2002: Exploring Underwater Oases Expedition)

Focus: Biology – Adaptations of planktonic organisms in the ocean

In this activity, students will describe the characteristics of plankton; develop abilities necessary to do scientific inquiry; test the effects of different salinity and temperature on the vertical movement of a model of a planktonic organism; and calculate the velocity of the plankton model.

How Diverse is That? [http://www.oceanexplorer.noaa.gov/explorations/03windows/background/education/media/03win_hdiverse.pdf] (6 pages, 552k) (from the 2003 Windows to the Deep Expedition)

Focus: Quantifying biological diversity (Life Science)

In this activity, students will be able to discuss the meaning of "biological diversity" and will be able to compare and contrast the concepts of "variety" and "relative abundance" as they relate to biological diversity. Given abundance and distribution data of species in two communities, students will be able to calculate an appropriate numeric indicator that describes the biological diversity of these communities.

Where Is That Light Coming From? [http://www.oceanexplorer.noaa.gov/explorations/04deepscope/background/edu/media/WhereisLight.pdf] (PDF, 208Kb) (from the 2004 Operation Deep Scope Expedition)

Focus: Bioluminescence

In this activity, students explain the role of luciferins, luciferases, and co-factors in bioluminescence and the general sequence of the light-emitting process. Additionally, students discuss the major types of luciferins found in marine organisms, define the lux operon and discuss at least three ways that bioluminescence may benefit deep-sea organisms. Students give an example of at least one organism that actually receives each of the benefits discussed.

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.

Send Us Your Feedback

We value your feedback on this lesson.
Please send your comments to:
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Blue Water Diving Worksheet

1. Define Boyle's Law

2. Define Charles' Law

3. Define Gay-Lussac's Law

4. Define Henry's Law

5. Define Dalton's Law

6. How is water depth related to the pressure experienced by a free-swimming diver?

7. An experienced diver takes a deep breath at the surface, and rapidly swims to a depth of 20 m without SCUBA equipment.

   (a) If the total volume of air in her lungs is 5.0 liters at the surface, what is the volume of air in her lungs at a depth of 20 m (assume the temperature remains constant)?

   (b) According to Henry's Law, what happens to the amount of dissolved oxygen in the diver's blood at a depth of 20 m?

   (c) As the diver returns to the surface, what happens to the partial pressure of oxygen in her lungs?

8. The same experienced diver decides to repeat her descent with SCUBA equipment.

   (a) When she takes a breath at 20 m, what is the pressure of air in her lungs?

   (b) What is the volume of air in her lungs when she takes a deep breath at 20 m?

   (c) Suppose she suddenly realizes her air tank is almost empty. What would happen if she took a deep breath and returned to the surface while holding her breath?

9. The capacity of SCUBA tanks is often stated as "the amount of breathing gas the tank will hold at its maximum rated service pressure." "Amount" is typically stated as the equivalent volume at a pressure of 1.0 atm. So, if an 80 ft^3 tank is filled to its rated pressure of 3,000 psi, the gas in the tank would have a volume of 80 ft^3 at a pressure of 1.0 atm.

   Suppose a diver has a SCUBA tank with a capacity of 80 ft^3. If the tidal volume (the amount of air he breathes in or out during normal respiration) is 500 ml, how many breaths should he expect from his tank at a depth of 30 m?

10. Valves on SCUBA tanks should always be equipped with "burst disks" that rupture if the pressure inside the tank exceeds the tank's pressure rating. Suppose a SCUBA tank is filled to its maximum rated pressure of 3,000 psi, and the tank has a "burst disk" that is designed to rupture if the pressure rises more than 20% above the tank's rated pressure. The tank's owner puts the filled tank into

the trunk of his car, then parks his car in a shadeless shopping mall. What temperature will cause the "burst disk" to rupture if temperature inside the dive shop where the tank was filled was 20°C?

11. Nitrogen narcosis (sometimes called "rapture of the deep") is a state similar to alcohol intoxication that usually occurs in divers at depths greater than 30 m. To avoid nitrogen narcosis, some diving authorities recommend that divers should not be exposed to partial pressures of nitrogen above 3.5 atm absolute. Using this recommendation, what is the maximum safe depth for a diver breathing ordinary air (which contains about 78% nitrogen)?

12. How is Henry's Law related to decompression sickness? Why doesn't oxygen in breathing air cause decompression sickness?