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2007 Cayman Island Twilight Zone Expedition

Now Take a Deep Breath

Focus
Physics and physiology of SCUBA diving

Grade Level
9-12 (Chemistry/Physics/Biology)

Focus Question
What physiological problems are associated with SCUBA diving, and how can these problems be overcome?

Learning Objectives
Students will be able to define Henry's Law, Boyle's Law, and Dalton's Law of Partial Pressures, and explain their relevance to SCUBA diving.

Students will be able to discuss the causes of air embolism, decompression sickness, nitrogen narcosis, and oxygen toxicity in SCUBA divers.

Students will be able to explain the advantages of gas mixtures such as Nitrox and Trimix and closed-circuit rebreather systems.

Materials
- ❒ Copies of "Student 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 student research

Seating Arrangement
Classroom style or groups of 2-4 students

Maximum Number of Students
30

Key Words
Coral Reefs
SCUBA
Henry's Law
Boyle's Law
Dalton's Law of Partial Pressures
Air embolism
Decompression sickness
Nitrogen narcosis
Oxygen toxicity
Nitrox
Trimix

Background Information
Coral reefs provide habitats for some of the most diverse biological communities on Earth. The high species diversity found on both shallow- and deep-water reefs makes these ecosystems very promising sources of powerful new antibiotic, anti-cancer and anti-inflammatory drugs. In addition, these reefs provide habitat for important food resources, and shallow reefs are an important part of coastal recreation and tourism industries and protect shorelines from erosion and storm damage. Despite the direct importance of coral reefs to many aspects of human well-being, shallow- and deep-water reefs are both threatened by human activities.

Around the world, shallow water coral reefs have been intensively studied by scientists using self-contained underwater breathing (SCUBA) equipment, while deep coral systems are being investigated with submersibles and remotely operated underwater vehicles (ROVs). Recent explorations have found a third type of coral ecosystem between depths of 50 m and 150 m: light-limited deep reefs living in what coral ecologists call the "twilight zone." These reefs have been studied much less than shallow and deep-water reefs because they are beyond the safe range of conventional SCUBA equipment, yet are too shallow and close to shore to justify the use of expensive submersibles and ROVs. The few studies of twilight zone reefs suggest that these ecosystems not only include species unique to this depth range, but may also provide important refuges and nursery habitats for corals and fishes that inhabit shallower reefs. This is particularly important in areas where shallow reefs are severely stressed, since twilight zone coral ecosystems may provide a natural option for recovery.

Scientific exploration of twilight zone coral reef ecosystems is urgently needed to provide information for their protection, as well as to identify potentially important sources of drugs and other biological products from organisms that are endemic to these systems. Helping to meet this need is the primary focus of the 2007 Ocean Explorer Cayman Island Twilight Zone Expedition. The technological keys for this expedition are new diving techniques that allow scientists to personally visit deep-water ecosystems without the need for expensive submersibles. This lesson introduces students to basic principles of physics and physiology that are the foundation for these new techniques.

Learning Procedure

1. To prepare for this lesson:
   - Review the introductory essays for the 2007 Cayman Island Twilight Zone Expedition at http://oceanexplorer.noaa.gov/explorations/07twilightzone/welcome.html as well as the Exploration Technology section of the Cayman Island Twilight Zone Expedition Expedition Education Module at http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/edu.html

   If you are not already familiar with coral reefs, you may also want to review the coral reef tutorials at nos.noaa.gov/education/kits/corals/, and http://oceanexplorer.noaa.gov/explorations/islands01/background/islands/sup10_lophelia.html for more background on *Lophelia* reefs.

2. Briefly review background information on the Cayman Island Twilight Zone Expedition, and the overall characteristics of coral reefs in shallow water, deep water, and intermediate depths (the "twilight zone"). Be sure students understand that shallow- and deepwater reefs both have a high diversity of species and large number of individual organisms, and that deep fore reef areas (the most seaward portion of a reef) probably do as well, but are virtually unexplored. Ask students to speculate on why deep fore reef areas seem to have been ignored. Students should realize that this is primarily the result of available technology. Give each student or student group a copy of the "Student Worksheet." Tell students that their assignment is to investigate some of the problems that confront diver scientists, and how these problems can be managed.

3 Lead a discussion of students' answers to questions on the Worksheet. The following points should be included:

   - 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.

   - 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.

- Boyle's Law is important to a diver 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, the expanding air can rupture his lungs. So the golden rule of diving is: Never hold your breath!

- Dalton's Law of Partial Pressures 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.

- Dalton's Law of Partial Pressures allows a diver to predict how much of a specific gas will dissolve in her blood at a given depth. This is important, because some gases become toxic or cause mental impairment when their partial pressure in the blood rises above a particular level.

- Henry's Law tells divers that breathing gas at higher-than-normal pressures will cause their bodies to absorb more gases than are absorbed at lower pressures. Absorbed gases can cause decompression sickness as well as toxic effects, and divers must follow certain procedures to avoid these problems.

- To a scuba diver Henry's Law tells us that at higher pressure our bodies will absorb more gases. At great depths, the amount of nitrogen (and other gases) absorbed into our blood and tissue is greater than the amount absorbed at shallow depths. That is why a diver going to 100′ has a greater risk of decompression illness than a diver who dives only 30 feet. Since the shallow diver has absorbed less gas, it is less likely to come out of solution in the body.

- An air embolism is a bubble of air or other gas that is large enough to wholly or partially block a blood vessel. Air embolism in a diver might result from breath-holding as the diver rises from deep to shallow water, since the air in the diver's lungs would expand as the external pressure decreased. If the air expanded enough, it could rupture the lungs and allow bubbles of air to enter the bloodstream.

- Decompression sickness results from bubbles forming in a diver's blood. If the bubbles are of sufficient size, they may block important blood vessels, causing pain, paralysis, or death. Such bubbles can form when a diver ascends so rapidly that dissolved gases do not have time to diffuse out of the blood, similar to the result of rapidly opening a can of carbonated soda. 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.

- Nitrogen narcosis is an effect similar to alcohol intoxication that may occur when the partial pressure of nitrogen in a diver's blood rises above about 3 atmospheres (corresponding to a depth of about 30 m). The severity of the impairment depends upon individual susceptibility as well as environmental conditions (temperature, time of day, etc.).

- Oxygen may become toxic at partial pressures above 1.4 atmospheres, causing convulsions. Individual thresholds vary widely and depend upon degree of exertion as well as environmental conditions.

- At the surface, pure oxygen has a partial pressure of 1.0 atmosphere. Since pressure increases by 1.0 atm for every 10 m of depth, the 1.4 atm threshold for oxygen toxicity would be reached at a depth of 4 m, or about 13 ft. Note that pure oxygen is sometimes used at depths of 6 m or less to shorten decompression times. This is possible because resting raises the threshold at which toxicity appears.

- Air contains about 21% oxygen, so the partial pressure of oxygen in the blood is about 0.21 atmosphere at the surface. At 10 m, the partial pressure would be 0.42 atm, increasing by 1 atm for every 10 m of depth. So the threshold of 1.4 atm would be reached at a depth of 60 m or 196 ft.

- Nitrox mixtures contain nitrogen and oxygen but with less nitrogen and more oxygen than ordinary air. Nitrox mixtures can be used at moderate depths without risking oxygen toxicity, and allow divers to greatly decrease the time needed for decompression.

- Trimix is a breathing gas mixture composed of helium, oxygen, and a third gas which is usually nitrogen. The advantage of trimix is that the concentrations of oxygen and nitrogen are reduced so that divers may descend to greater depths without risking oxygen toxicity or nitrogen narcosis. In addition, the density of the breathing mixture is reduced compared to air, which makes it easier to breathe at higher pressures.

- Closed-circuit rebreather systems recapture oxygen in exhaled breathing gas, allowing a diver to carry much less breathing gas. In addition, modern closed circuit rebreathers constantly monitor oxygen levels in the breathing mixture and are able to adjust the oxygen concentration to a level that is optimum for the divers' depth. The result is much shorter decompression times and much less risk of oxygen toxicity.

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 in which they imagine themselves to be coral reef scientists, and explain their personal preference for exploration using SCUBA techniques, human occupied submersibles, or remotely operated vehicles (ROVs).

Connections to Other Subjects

English/Language Arts; Geography; Mathematics

Evaluation

Worksheets and discussions provide opportunities for assessment.

Extensions

1. Visit oceanexplorer.noaa.gov to keep up to date with the latest Cayman Island Twilight Zone 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 3 and 12 for interactive multimedia presentations and Learning Activities on deep-sea corals and biotechnology.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

History's Thermometers [http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/thermo9_12.pdf] (5 pages, 80k) (from the 2002 Alaska Seamount Expedition)

Focus: Use of deep-water corals be used to determine long-term patterns of climate change (Physics)

In this activity, students will be able to explain the concept of paleoclimatological proxies, learn how oxygen isotope ratios are related to water temperature, and interpret data on oxygen isotope ratios to make inferences about climate and climate change in the geologic past.

Cut-off Genes [http://oceanexplorer.noaa.gov/explorations/04mountains/background/edu/media/MTS04.genes.pdf] (12 pages, 648k) (from the Mountains in the Sea 2004 Expedition)

Focus: Gene sequencing and phylogenetic expressions (Life Science)

In this activity, students will be able to explain the concept of gene-sequence analysis; and, given gene sequence data, will be able to draw inferences about phylogenetic similarities of different organisms.

Feeding in the Flow [http://oceanexplorer.noaa.gov/explorations/03bump/background/edu/media/03cbfeedflow.pdf] (6 pages, 268k) (from the 2003 Charleston Bump Expedition)

Focus: Effect of water currents on feeding efficiency in corals (Life Science)

In this activity, students will be able to describe at least two ways in which current flow may affect the feeding efficiency of particle-feeding organisms and explain how interactions between current flow and the morphology of a particle-feeding organism may affect the organism's feeding efficiency. Students will also be able to identify at least two environmental factors in addition to current flow that may affect the morphology of reef-building corals.

Cool Corals [http://oceanexplorer.noaa.gov/explorations/03edge/background/edu/media/cool.pdf] (7 pages, 476k) (from the 2003 Life on the Edge Expedition)

Focus: Biology and ecology of *Lophelia* corals (Life Science)

In this activity, students will describe the basic morphology of *Lophelia* corals and explain the significance of these organisms, interpret preliminary observations on the behavior of *Lophelia* polyps, and infer possible explanations for these observations. Students will also discuss why biological communities associated with *Lophelia* corals are the focus of major worldwide conservation efforts.

Keep It Complex! [http://oceanexplorer.noaa.gov/explorations/03bump/background/edu/media/03cb_complex.pdf] (5 pages, 272k) (from The Charleston Bump 2003 Expedition)

Focus: Effects of habitat complexity on biological diversity (Life Science)

In this activity, students will be able to describe the significance of complexity in benthic habitats to organisms that live in these habitats and will describe at least three attributes of benthic habitats that can increase the physical complexity of these habitats. Students will also be able to give examples of organisms that increase the structural complexity of their communities and infer and explain relationships between species diversity and habitat complexity in benthic communities.

Are You Related? [http://oceanexplorer.noaa.gov/explorations/05deepcorals/background/edu/media/05deepcorals_related.pdf] (11 pages, 465k) (from the Florida Coast Deep Corals 2005 Expedition)

Focus: Molecular genetics of deepwater corals (Life Science)

In this activity, students will define "microsatellite markers" and explain how they may be used to identify different populations and species, explain two definitions of "species," and describe processes that result in speciation. Students will also use microsatellite data to make inferences about populations of deep-sea corals.

How Does Your (Coral) Garden Grow? [http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_growth.pdf] (6 pages, 456k) (from the Gulf of Mexico Deep Sea Habitats 2003 Expedition)

Focus: Growth rate estimates based on isotope ratios (Life Science/Chemistry)

In this activity, students will identify and briefly explain two methods for estimating the age of hard corals, learn how oxygen isotope ratios are related to water temperature, and interpret data on oxygen isotope ratios to make inferences about the growth rate of deep-sea corals.

How Diverse is That? [http://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.

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 image gallery

http://www.mcbi.org/publications/pub_pdfs/Deep-Sea%20Coral%20issue%20of%20Current.pdf – A special issue of Current: the Journal of Marine Education on deep-sea corals.

http://www.science.fau.edu/drugs.htm – An overview article on drugs from the sea

http://www.ucmp.berkeley.edu/cnidaria/cnidaria.html – Introduction to Cnidaria from the University of California Museum of Paleontology

http://www.woodrow.org/teachers/bi/1993/ – Background and activities from the 1993 Woodrow Wilson Biology Institute on biotechnology

Morgan, L. E. 2005. What are deep-sea corals? Current 21(4):2-4; available online at http://www.mcbi.org/what/what_pdfs/Current_Magazine/What_are_DSC.pdf

Roberts, S. and M. Hirshfield. Deep Sea Corals: Out of sight but no longer out of mind. http://www.oceana.org/fileadmin/oceana/uploads/reports/oceana_coral_report_final.pdf — Background on deep-water coral reefs

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
- Structure and properties of water
- Chemical reactions

Content Standard C: Life Science
- The cell

Content Standard E: Science and Technology
- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives
- Natural resources
- Environmental quality
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

Content Standard G: History and Nature of Science
- Science as a human endeavor

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 explor-

ers 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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Student Handout

1. What are Henry's Law, Boyle's Law, and Dalton's Law of Partial Pressures?

2. How are these laws relevant to SCUBA diving?

3. What is an air embolism, and how might this happen to a SCUBA diver?

4. What is decompression sickness? Why doesn't oxygen in air cause decompression sickness?

5. What is nitrogen narcosis?

6. At what partial pressure does oxygen become toxic?

7. What is the maximum depth for a diver breathing pure oxygen without risking oxygen toxicity?

8. What is the maximum depth for a diver breathing normal air without risking oxygen toxicity?

9. What are the advantages of gas mixtures such as Nitrox and Trimix?

10. What are the advantages of closed-circuit rebreather systems?