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2006 Gulf of Mexico Expedition

It's a Gas! Or is it?

(adapted from the 2005 Submarine Ring of Fire Expedition)

Focus
Effects of temperature and pressure on solubility and phase state

Grade Level
7-8 (Physical Science/Earth Science)

Focus Question
How do principles of solubility and phase state help explain chemical phenomena observed around deep-sea volcanoes?

Learning Objectives
Students will be able to describe the effect of temperature and pressure on solubility of gases and solid materials.

Students will be able to describe the effect of temperature and pressure on the phase state of gases.

Students will be able to infer explanations for observed chemical phenomena around deep-sea volcanoes that are consistent with principles of solubility and phase state.

Materials
- ❒ Copies of "It's a Gas! Worksheet," one copy for each student or student group

Audio/Visual Materials
- ❒ None

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Classroom style if students are working individually, or groups of two to four students

Maximum Number of Students
30

Key Words
Gulf of Mexico
Phase state
Solubility

Background Information
On August 28, 2005, Hurricane Katrina swept across the Gulf of Mexico, gathering strength to become a Category 3 storm that proved to be the most costly—and one of the most deadly—hurricanes in U.S. history. Four days later, the Department of the Interior's Minerals Management Service (MMS) reported that oil production in the Gulf of Mexico had been reduced by over 90 percent, and that natural gas production had been reduced by more than 78 percent. In the weeks that followed, fuel shortages and soaring prices underscored the importance of the Gulf of Mexico to petroleum supplies in the United States.

In fact, the Gulf of Mexico produces more petroleum than any other region in the nation, even though its proven reserves are less than those in Alaska and Texas. The San Francisco *Chronicle* reports that oil companies are spending billions to find more crude oil and drill more wells. Even with the threat of more hurricanes, the Gulf of

Mexico has advantages: oil workers are not in danger of being kidnapped by armed insurgents as is the case in Nigeria; no foreign president threatens to raise oil companies' taxes, as has happened in Venezuela; and OPEC doesn't control oil production in the Gulf of Mexico. As of August 1, 2005, a total of 41,188 wells had been drilled in the Gulf, and 1,259 petroleum fields had been discovered.

Much of this new exploration is focussed on some of the deepest regions of the Gulf, made possible by improved technology and increasing crude oil prices (which have doubled in the last three years). In addition to new petroleum fields, this exploration has led to other discoveries as well. Some of the same conditions responsible for petroleum deposits also provide the basis for biological communities that receive energy from chemicals through a process called chemosynthesis (in contrast to photosynthesis that provide energy to terrestrial and shallow-water communities through processes in which sunlight is the basic energy source).

The first chemosynthetic communities were discovered in 1977 near the Galapagos Islands in the vicinity of underwater volcanic hot springs called hydrothermal vents, which usually occur along ridges separating the earth's tectonic plates. Hydrogen sulfide is abundant in the water erupting from hydrothermal vents, and is used by chemosynthetic bacteria that are the base of the vent community food chain. These bacteria obtain energy by oxidizing hydrogen sulfide to sulfur:

$$CO_2 + 4H_2S + O_2 > CH_2O + 4S + 3H_2O$$

(carbon dioxide plus sulfur dioxide plus oxygen yields organic matter, sulfur, and water). Visit http://www.pmel.noaa.gov/vents/home.html for more information and activities on hydrothermal vent communities.

Chemosynthetic communities in the Gulf of Mexico were found by accident in 1984. These communities are similar in that they are based upon energy produced by chemosynthesis; but while energy for the Galapagos communities is derived from underwater hot springs, deep sea chemosynthetic communities in the Gulf of Mexico are found in areas where hydrocarbon gases (often methane and hydrogen sulfide) and oil seep out of sediments. These areas, known as cold seeps, are commonly found along continental margins, and (like hydrothermal vents) are home to many species of organisms that have not been found anywhere else on Earth. Typical features of communities that have been studied so far include mounds of frozen crystals of methane and water called methane hydrate ice, that are home to polychaete worms. Brine pools, containing water four times saltier than normal seawater, have also been found. Researchers often find dead fish floating in the brine pool, apparently killed by the high salinity.

Where hydrogen sulfide is present, large tubeworms (phylum Annelida) known as vestimentiferans are often found, sometimes growing in clusters of millions of individuals. These unusual animals do not have a mouth, stomach, or gut. Instead, they have a large organ called a trophosome that contains chemosynthetic bacteria. Vestimentiferans have a structure called a plume that consists of filaments (sometimes referred to as "tentacles") that extend into the water. The tentacles are bright red due to the presence of hemoglobin which can absorb hydrogen sulfide and oxygen which are transported to the bacteria in the trophosome. The bacteria produce organic molecules that provide nutrition to the tube worm. A similar symbiotic relationship is found in clams and mussels that have chemosynthetic bacteria living in their gills. Bacteria are also found living independently from other organisms in large bacterial mats A variety of other organisms are also found in cold seep communities, and probably use tubeworms, mussels, and bacterial mats as sources of food. These include snails, eels, starfish, crabs, lobsters, isopods, sea cucumbers, and fishes. Specific relationships between these organ-

isms have not been well-studied.
Deep-water chemosynthetic communities are fundamentally different from other biological systems, and there are many unanswered questions about the individual species and interactions between species found in these communities. These species include some of the most primitive living organisms (Archaea) that some scientists believe may have been the first life forms on Earth. Many species are new to science, and may prove to be important sources of unique drugs for the treatment of human diseases. Because their potential importance is not yet known, it is critical to protect these systems from adverse impacts caused by human activities.

Ironically, one of the most likely sources of such impacts is the same activity that led to the discovery of these systems in the first place: exploration and development of petroleum resources. MMS has the dual responsibility of managing these resources as well as protecting the environment from adverse impacts that might result from development activities. In 1988, MMS issued regulations specifically targeted toward protecting deep-water chemosynthetic communities. An essential part of the protection strategy requires identification of seafloor areas that could support chemosynthetic communities. These areas must be avoided by drilling, anchoring, pipeline installation, and other activities that involve disturbing the seafloor. Describing deep-water biological communities and evaluating their sensitivity to impacts from human activities are key objectives of the 2006 Gulf of Mexico Expedition.

The high pressure and low temperatures of the deep ocean environment can produce some fascinating chemical phenomena. In this activity, students will use their knowledge of solubility principles to develop possible explanations for these observations.

Learning Procedure

1. To prepare for this lesson, review
   - Introductory essays for the 2006 Gulf of Mexico Expedition at http://oceanexplorer.noaa.gov/explorations/06mexico/and
   - The Submarine Ring of Fire 2004 daily logs for April 6 and April 10 (http://oceanexplorer.noaa.gov/explorations/04fire/logs/april06/april06.html and http://oceanexplorer.noaa.gov/explorations/04fire/logs/april10/april10.html). You may also want to print copies of the photographs or download videos of "champagne" bubbles.

2. Briefly review and contrast chemosynthesis with photosynthesis: in both processes, organisms build sugars from carbon dioxide and water. This process requires energy; photosynthesizers obtain this energy from the sun, while chemosynthesizers obtain energy from chemical reactions. Point out that until recently it was well-accepted that photosynthesis was the basis of all major biological communities on Earth. Recognition of chemosynthetic communities has changed this view dramatically; indeed, many biologists now favor the idea that life on Earth may have begun in communities like those found near hydrothermal vents and cold seeps. Contrast hydrothermal vent communities with cold-seep communities. Visit http://www.bio.psu.edu/cold_seeps for a virtual tour of a cold seep community in the Gulf of Mexico.

3. You may want to review some basic principles of solubility with your students, or allow them to use the "It's a Gas!" worksheet to work through these principles on their own. Alternatively, if time permits you may want to demonstrate the "thought experiments" described on the worksheet. Some students may need help with "thought experiment" 3e if they are unfamiliar with the behavior of liquids in a vacuum.

The key points are:
- Solubility is the extent to which one substance (the solute) dissolves in another substance (the solvent).

- Solubility is affected by temperature and pressure.
- The solubility of most solids increases as temperature and pressure increase.
- The solubility of most gases decreases as temperature increases.
- The solubility of most gases increases as pressure increases.
- As temperature increases, the phase of a substance changes from solid to liquid to gas.
- Decreasing pressure favors change from liquid to gas phase; conversely, increasing pressure favors change from gas to liquid phase.

Be sure students realize that while the solubility of most materials increases with increasing temperature, there are substances whose solubility declines as temperature increases.

4. Provide each student or student group with a copy of the "It's A Gas! Worksheet." Have students complete the review questions and develop explanations for the observation problems.

5. Discuss students' proposed explanations for the observations described on the worksheet.

   Knowing that solubility of most substances increases with increasing temperature, students may hypothesize that the hot fluids escaping from the volcano contained dissolved metals, and that these precipitated when the fluid cooled to form chimneys. Similarly, precipitated metal particles could be expected to cause the fluid to appear dark and resemble black smoke.

   High pressure could cause substances that we normally think of as gases to change to a liquid phase. The sticky bubbles could have been liquid carbon dioxide, methane, or another substance that would be a gas at the sea surface. Since pressure also increases the solubility of gases, the fluids in deep-sea habitats can contain high concentrations of dissolved gases.

   Students may hypothesize that the ice-like substance in a solid phase is due to high pressure, and that its phase changed to liquid and then gas due to reduced pressure as the ROV surfaced. Gas hydrates are ice-like materials found in deep-sea habitats, and belong to a class of substances known as clathrates. These substances, which only exist at high pressures, are formed when the molecules of one material (water, in this case) form an open lattice that encloses molecules of another material (such as methane or carbon dioxide) without actually forming chemical bonds between the two materials (see http://mfnl.xjtu.edu.cn/gov-doe-netl/scng/hydrate/about-hydrates/about_hydrates.htm as well as the Ocean Exploration Windows to the Deep expedition http://oceanexplorer.noaa.gov/explorations/03windows/background/hydrates/hydrates.html for more information).

The Bridge Connection

www.vims.edu/bridge/ – Click on "Ocean Science Topics" then "Habitats," then "Deep Sea" for links to information and activities about deep-sea chemosynthetic communities.

The "Me" Connection

Have students write a brief essay describing how information gained from exploring deep-sea habitats could be of personal importance.

Connections to Other Subjects

English/Language Arts, Geography

Assessment

Worksheets and class discussions offer opportunities for assessment.

Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/06mexico/ for daily logs and updates about discoveries on the 2006 Gulf of Mexico Expedition.

Resources

NOAA Learning Objects

http://www.learningdemo.com/noaa/ Click on the links to

Lessons 3, 5, and 6 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, and Deep-Sea Benthos.

Other Relevant Lesson Plans from the Ocean Exploration Program

Monsters of the Deep (6 pages, 464k)) (from the 2002 Gulf of Mexico Expedition)
[http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_monsters_gr78.pdf]

Focus: Predator-prey relationships between cold-seep communities and the surrounding deep-sea environment (Life Science)

Students will be able to describe major features of cold seep communities, and list at least five organisms typical of these communities; and will be able to infer probable trophic relationships among organisms typical of cold-seep communities and the surrounding deep-sea environment. Students will also be able to describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, and describe at least five deep-sea predator organisms.

One Tough Worm (8 pages, 476k)) (from the 2002 Gulf of Mexico Expedition)
[http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_toughworm.pdf]

Focus: Physiological adaptations to toxic and hypoxic environments (Life Science)

Students will be able to explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and describe three physiological adaptations that enhance an organism's ability to extract oxygen from its environment. Students will also be able to describe the problems posed by hydrogen sulfide for aerobic organisms, and explain three strategies for dealing with these problems.

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

Focus: Ocean Exploration

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.

Let's Go to the Video Tape! (7 pages, 552k) (from the 2003 Gulf of Mexico Deep Sea Habitats Expedition)
[http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_letsgo.pdf]

Focus: Characteristics of biological communities on deep-water reef habitats (Life Science)

Students will recognize and identify some of the fauna groups found in deep-sea coral reef communities, infer possible reasons for observed distribution of groups of animals in deep-sea coral reef communities, and discuss the meaning of "biological diversity." Students will compare and contrast the concepts of "variety" and "relative abundance" as they relate to biological diversity, and given abundance and distribution data of species, will be able to calculate an appropriate numeric indicator that describes the biological diversity of a community.

Living by the Code (5 pages, 400k) (from the 2003 Deep Sea Medicines Expedition)
[http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/Meds_LivingCode.pdf]

Focus: Functions of cell organelles and the genetic code in chemical synthesis (life science)

Students will be able to explain why new drugs are needed to treat cardiovascular disease, cancer, inflammation, and infections; infer why sessile marine invertebrates appear to be promising sources of new drugs; and explain the overall process through which cells manufacture chemicals. Students will also be able to explain why it may be important to synthesize new drugs, rather than relying on the natural production of drugs.

Mapping Deep-sea Habitats in the Northwestern Hawaiian Islands (7 pages, 80kb) (from the 2002 Northwestern Hawaiian Islands Expedition)
[http://oceanexplorer.noaa.gov/explorations/02hawaii/background/education/media/nwhi_mapping.pdf]

Focus: Bathymetric mapping of deep-sea habitats (Earth Science - This activity can be easily modified for Grades 5-6)

Students will be able to create a two-dimensional topographic map given bathymetric survey data, will create a three-dimensional model of landforms from a two-dimensional topographic map, and will be able to interpret two- and three-dimensional topographic data.

Other Resources and Links

http://www.gomr.mms.gov/index_common.html – Minerals Management Service Web site

http://www.gomr.mms.gov/homepg/lagniapp/chemcomp.pdf – "Chemosynthetic Communities in the Gulf of Mexico" teaching guide to accompany a poster with the same title, introducing the topic of chemosynthetic communities and other ecological concepts to middle and high school students.

http://www.gomr.mms.gov/homepg/lagniapp/lagniapp.html – Kids Page on the Minerals Management Service Web site, with posters, teaching guides and other resources on various marine science topics

http://www.coast-nopp.org/ – Resource Guide from the Consortium for Oceanographic Activities for Students and Teachers. Contains modules, guides, and lesson plans related to oceanography and coastal processes

http://cosee-central-gom.org/ – Web site for The Center for Ocean Sciences Education Excellence: Central Gulf of Mexico (COSEE-CGOM)

http://www.energybulletin.net/4901.html – Article "Out of Gas: Sediments in Northern Gulf of Mexico Not Right for Methane Gas Hydrate Formation, Study Shows" published by Georgia Research Tech News, 21 Mar 2005

http://www.ridge2000.org/eo/index.htm – Links to other deep ocean exploration Web sites

http://www-ocean.tamu.edu/education/oceanworld-old/resources/general_links.htm – Links to other ocean-related Web sites

http://www.accessexcellence.org/BF/bf01/arp/bf01p1.html – Verbatim transcript of a slide show on coping with toxic sulfide environments

Paull, C.K., B. Hecker, C. Commeau, R.P. Feeman-Lynde, C. Nuemann, W.P. Corso, G. Golubic, J. Hook, E. Sikes, and J. Curray. 1984. Biological communities at Florida Escarpment resemble hydrothermal vent communities. Science 226:965-967 – Early report on cold seep communities.

http://dbhs.wvusd.k12.ca.us/webdocs/ChemTeamIndex.html – Web site for help with basic chemical concepts including oxidation-reduction reactions

http://www.geol.ucsb.edu/faculty/valentine/Valentine%202002.pdf – Review of methane-based chemosynthetic processes

Van Dover, C.L., et al. 2003. Blake Ridge methane seeps: characterization of a soft-sediment,

chemosynthetically based ecosystem. Deep-Sea Research Part I 50:281–300. (available as a PDF file at http://www.geomar.de/projekte/sfb_574/abstracts/vanDover_et_al_2003.pdf)

National Science Education Standards

Content Standard A: Science As Inquiry
- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard B: Physical Science
- Properties and changes of properties in matter

Content Standard D: Earth and Space Science
- Structure of the Earth system

Content Standard F: Science in Personal and Social Perspectives
- Science and technology in society

Content Standard G: History and Nature of Science
- Nature of science

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 4.
The ocean makes Earth habitable.
- *Fundamental Concept b.* The first life is thought to have started in the ocean. The earliest evidence of life is found in the ocean.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.
- *Fundamental Concept a.* Ocean life ranges in size from the smallest virus to the largest animal that has lived on Earth, the blue whale.
- *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 g.* There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps rely only on chemical energy and chemosynthetic organisms to support life.

Essential Principle 6.
The ocean and humans are inextricably interconnected.
- *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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Student Handout
It's A Gas Worksheet

Substances may exist as solids, liquids, or gases. These are called "phases," and the phase of a specific substance is affected by temperature and pressure.

A solution is a mixture in which the molecules of one substance are evenly distributed among the molecules of another substance. Often, a solution forms when one substance (called the solute) dissolves in another substance (the solvent). So, in a sugar solution the sugar is the solute and water is the solvent. Solutions may be solids, liquids, or gases.

Solubility is the extent to which a solute dissolves in a solvent, and is also affected by temperature and pressure.

A. Here are some "thought experiments" based on your own experience that may help you figure out how temperature and pressure affect solubility and phase.

1. Solubility of gases

a. What happens when you remove the cap from a bottle of soda?

____

b. Is the pressure in the bottle higher or lower after you remove the cap?

____

c. What do you think happens to the solubility of a gas when the pressure increases?

____

d. If you removed the caps from a bottle of ice-cold soda and a bottle of soda at room temperature, what differences would you expect?

____

e. What do you think happens to the solubility of a gas when temperature increases?

____

2. Solubility of solids

a. Suppose you pour salt into a glass of water until no more will dissolve (this is called a saturated solution). What could you do to get even more salt dissolved in the solution?

____

b. If you have a saturated solution, what do you expect to happen if the solution is cooled in a refrigerator?

____

c. What do you think happens to the solubility of most solids when the temperature increases?

____

3. Phases

a. What is the phase of water at room temperature?

____

b. What happens if you raise the temperature of water above 100°C?

____

c. What happens if you lower the temperature of water below 0°C?

____

d. If a substance is in a solid phase at room temperature, what do you think happens to the phase of the substance as temperature increases?

____

e. If you put a glass of water into an air-tight container and then pump all of the air out of the container, what will happen to the water?

____

What does this suggest about the effect of reduced pressure on the phase of a substance?

____

What does this suggest about the effect of increased pressure on the phase of a substance?

____

B. Use these principles to develop explanations for the following observations made by scientists exploring deep-sea volcanoes on the Ring of Fire Expeditions:

1. Using a remotely operated vehicle (ROV) carrying a video camera, scientists found hot fluids escaping from the side of the East Diamante volcano. Often, the fluids were escaping from vertical formations that resemble chimneys. Chemical examination showed that one of these chimneys was composed of iron, zinc, and minerals of barium and copper. How do the principles of solubility help explain how these chimneys are formed?

2. Scientists exploring the East Diamante volcano also observed that many of the chimneys appeared to be emitting black smoke. How do the principles of solubility help explain something that looks like black smoke?

3. During their first dive at Eifuku volcano, Ring of Fire scientists saw cloudy bubbles rising from the sediment around small white chimneys. The bubbles were sticky, and did not tend to fuse together to form bigger bubbles the way most gas bubbles do. How does the effect of pressure on phase help explain these bubbles?

4. Some of the white chimneys at Eifuku were emitting a cloudy white fluid whose temperature was 103°C, even though the temperature of the surrounding seawater was 2°C. Scientists used the ROV to collect samples of the fluid in a plastic tube for analysis. While the ROV was still on the sea floor (at a depth of 1,650 m), some fluffy white material formed inside the plastic tube. As the ROV rose toward the surface, the fluid in the tube began to bubble vigorously. By the time the ROV had reached a depth of 50 m, all of the solid white material was gone and the plastic tube contained only clear gas and seawater. How do the effects of temperature and pressure on solubility and phase help explain these observations?