The NOAA Ship *Okeanos Explorer*

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

What's the Big Deal?

An essential component of the NOAA Office of Ocean Exploration and Research mission is to enhance understanding of science, technology, engineering, and mathematics used in exploring the ocean, and build interest in careers that support ocean-related work. To help fulfill this mission, the Okeanos Explorer *Education Materials Collection is being developed to encourage educators and students to become personally involved with the voyages and discoveries of the* Okeanos Explorer*—America's first Federal ship dedicated to Ocean Exploration. Leader's Guides for Classroom Explorers focus on three themes: "Why Do We Explore?" (reasons for ocean exploration), "How Do We Explore?" (exploration methods), and "What Do We Expect to Find?" (recent discoveries that give us clues about what we may find in Earth's largely unknown ocean). Each Leader's Guide provides background information, links to resources, and an overview of recommended lesson plans on the Ocean Explorer Web site (*http://oceanexplorer.noaa.gov*). An Initial Inquiry Lesson for each of the three themes leads student inquiries that provide an overview of key topics. A series of lessons for each theme guides student investigations that explore these topics in greater depth. In the future additional guides will be added to the Education Materials Collection to support the involvement of citizen scientists.*

This lesson guides student inquiry into the key topic of Energy within the "Why Do We Explore?" theme.

Focus

Significance of methane hydrates

Grade Level

9-12 (Earth Science)

Focus Question

Why should a NOAA Ocean Exploration expedition focus investigations on methane hydrates?

Learning Objectives

- Students will be able to define methane hydrates, describe where these substances are typically found, and explain how they are believed to be formed.
- Students will be able to describe at least three ways in which methane hydrates could have a direct impact on their own lives.
- Students will be able to describe how additional knowledge of methane hydrates expected to be found during Ocean Exploration and Research expeditions could provide human benefits.

Materials

- Copies of *Methane Hydrate Inquiry Guide*, one for each student group
- Copies of the *Methane Hydrate Molecule Construction Guide*, one for each student group
- Materials for constructing a methane hydrate molecule model:

  For constructing a pentagon:
  - Paper, unlined 8-1/2" X 11"
  - Pencil
  - Protractor or compass

  For constructing the dodecahedron, clathrate cage, methane molecule and methane hydrate model:
  - Scissors
  - Cardboard or card stock (enough to make 13 pentagons)
  - Ruler, 12-inch
  - 11 - Bamboo skewers, 12" long
  - 20 - Styrofoam balls, 1/2" diameter
  - 4 - Styrofoam balls, 1-1/2" diameter
  - 1 - Styrofoam ball, 1" diameter
  - Tape, wrapping or strapping
  - Spray paint, water-based latex; dark blue, light blue, red, and black
  - Fishing line, 8 lb test; or light colored thread

Audiovisual Materials

- None

Teaching Time

One or two 45-minute class periods plus time for student research

Seating Arrangement

Five groups of 3-6 students

Maximum Number of Students

32

Key Words and Concepts

Cold seeps
Methane hydrate
Methanogenic Archaeobacteria
Clathrate
Greenhouse gases
Greenhouse effect
Paleocene extinction event
Cambrian explosion
Alternative energy
Natural hazards

Background Information

> For kicks, oceanographer William P. Dillon likes to surprise visitors to his lab by taking ordinary-looking ice balls and setting them on fire. 'They're easy to light. You just put a match to them and they will go,' says Dillon, a researcher with the U.S. Geological Survey (USGS) in Woods Hole, Mass. If the truth be told, this is not typical ice. The prop in Dillon's show is a curious and poorly known structure called methane hydrate.
>
> from "The Mother Lode of Natural Gas"
> by Rich Monastersky.
> http://journals2.iranscience.net:800/www.sciencenews.org/www.sciencenews.org/Sn_arch/11_9_96/Bob1.htm

Methane hydrate looks like ice, but as the "ice" melts it releases methane gas which can be a fuel source. Image credit: Gary Klinkhammer, OSU-COAS

Methane hydrate is a type of clathrate, a chemical substance in which the molecules of one material (water, in this case) form an open lattice that encloses molecules of another material (methane) without actually forming chemical bonds between the two materials. Methane is produced in many environments by a group of Archaea known as methanogenic Archaeobacteria. These Archaeobacteria obtain energy by anaerobic metabolism through which they break down the organic material contained in once-living plants and animals. When this process takes place in deep ocean sediments, methane molecules are surrounded by water molecules, and conditions of low temperature and high pressure allow stable ice-like methane hydrates to form. Besides providing entertainment for oceanographers, methane hydrate deposits are significant for several other reasons. A

Iceworms (*Hesiocaeca methanicola*) infest a piece of orange methane hydrate at 540 m depth in the Gulf of Mexico. During the Paleocene epoch, lower sea levels could have led to huge releases of methane from frozen hydrates and contributed to global warming. Today, methane hydrates may be growing unstable due to warmer ocean temperatures. Image credit: Ian MacDonald.
http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/iceworms_600.jpg

major interest is the possibility of methane hydrates as an energy source. The U.S. Geological Survey has estimated that on a global scale, methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined. In addition to their potential importance as an energy source, scientists have found that methane hydrates are associated with unusual and possibly unique biological communities. In September, 2001, the Ocean Exploration Deep East expedition explored the crest of the Blake Ridge at a depth of 2,154 m, and found methane hydrate-associated communities containing previously-unknown species that may be sources of beneficial pharmaceutical materials.

While such potential benefits are exciting, methane hydrates may also cause big problems. Although methane hydrates remain stable in deep-sea sediments for long periods of time, as the sediments become deeper and deeper they are heated by the Earth's core. Eventually, temperature within the sediments rises to a point at which the clathrates are no longer stable and free methane gas is released (at a water depth of 2 km, this point is reached at a sediment depth of about 500 m). The pressurized gas remains trapped beneath hundreds of meters of sediments that are cemented together by still-frozen methane hydrates. If the overlying sediments are disrupted by an earthquake or underwater landslide, the pressurized methane can escape suddenly, producing a violent underwater explosion that may result in disastrous tsunamis.

The release of large quantities of methane gas can have other consequences as well. Methane is one of the so-called greenhouse gases. In the atmosphere, these gases allow solar radiation to pass through to the surface of the Earth, but absorb heat radiation that is reflected back from the Earth's surface, thus warming the atmosphere. A sudden release of methane from deep-sea sediments could increase this effect, since methane has more than 30 times the heat-trapping ability of carbon dioxide.

In 1995, Australian paleoceanographer Gerald Dickens suggested that a sudden release of methane from submarine sediments during the Paleocene Epoch (at the end of the Tertiary Period, about 55 million years ago) caused a greenhouse effect that raised the temperatures in the deep ocean by about 6° C. The result was the extinction of many deep-sea organisms known as the Paleocene extinction event. More recently, other scientists (e.g., Kirschvink and Raub, 2003; Simpson, 2000) have suggested that similar events could have contributed to mass extinctions during the Jurassic Period (183 million years ago), as well as to the sudden appearance of many new animal phyla during the Cambrian Period (the Cambrian Explosion, about 520 million years ago).

This lesson guides a student inquiry into the significance of methane hydrates.

Learning Procedure

1. To prepare for this lesson:
   - If you have not previously done so, review introductory information on the NOAA Ship *Okeanos Explorer* at http://oceanexplorer.noaa.gov/okeanos/welcome.html. You may also want to consider having students complete some or all of the Initial Inquiry Lesson, "To Boldly Go" (http://oceanexplorer.noaa.gov/okeanos/edu/leadersguide/media/09toboldlygo.pdf).
   - Visit http://oceanexplorer. noaa.gov/explorations/deepeast01/logs/oct1/oct1.html and http://oceanexplorer.noaa.gov/explorations/03windows/welcome.html for background on the 2001 Ocean Exploration Deep East expedition to the Blake Ridge and the 2003 Windows on the Deep Ocean Exploration expedition.
   - Review questions on the *Methane Hydrates Inquiry Guide*.
   - Review procedures on the *Methane Hydrate Molecule Construction Guide*, and gather necessary materials. This activity may be done as a cross-curricular mathematics lesson using student-constructed pentagons and dodecahedrons. Correlations with National Math Education Standards and Expectations are provided in Appendix A.

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, which should include further understanding of energy resources in the ocean.

   Lead an introductory discussion about the 2001 Deep East expedition to the Blake Ridge and the 2003 Windows on the Deep expedition. Briefly describe methane hydrates and why these substances are potentially important to human populations. You may also want to visit http://www.bio.psu.edu/cold_seeps for a virtual tour of a cold-seep community in the Gulf of Mexico, and http://www.pmel.noaa.gov/vents/ for more information and activities on hydrothermal vent communities.

3. Provide each student group with a copy of the *Methane Hydrates Inquiry Guide* and the *Methane Hydrate Molecule Construction Guide*. Tell students that they will be expected to present a group report, including a model of a methane hydrate molecule, that addresses these questions, and participate in a class discussion of their results. Now, on with the Inquiry!

4. Lead a discussion of students' research results. Referring to students' models, begin with a discussion of what methane hydrates are, where they are found, and how they are formed. Next, ask for a group that can explain one way in which methane hydrates are significant to humans. Continue this process until all five groups have had a chance to present one piece of the whole story. Now, ask students what scientific research priorities and public policies should be established concerning methane hydrates. Encourage students to comment on the potential significance of global warming, alternative energy sources, useful biological products, and natural hazards.

Be sure the following points are included in the discussion:

(1) A clathrate is a chemical substance in which molecules of one material (e.g., water) form an open solid lattice that encloses, without chemical bonding, molecules of another material (e.g., methane).

(2) Methane hydrate is a clathrate in which a lattice of water molecules encloses a molecule of methane.

(3) In general, methane hydrates formed under conditions of low temperature and high pressure, such as are found in deep ocean environments. See http://oceanexplorer.noaa.gov/explorations/03windows/background/hydrates/media/fig1_phase_diagram.html for a phase diagram illustrating combinations of pressure and temperature that are suitable for methane hydrate formation.

(4) Clathrates have been known as a type of chemical substance since the 1800's, but methane hydrates first received serious attention when they were found to be plugging natural gas pipelines, particularly pipelines

located in cold environments. In the late 1960s, naturally-occurring methane hydrate was observed in subsurface sediments in Western Siberia and Alaska. Marine methane hydrate deposits were first found in the Black Sea and subsequently in cores of ocean bottom sediments collected by the R/V *Glomar Challenger* from many areas of Earth's ocean.

(5) Methane is a greenhouse gas that is ten times more effective than carbon dioxide in causing climate warming. Carbon isotope variations in carbonate rocks and sediments indicate that large-scale releases of methane from ocean hydrates could have occurred at various times in Earth's history, including the Pre-cambrian and Cretaceous Periods. Such releases could have caused significant climate change that may be related to extinction events, as well as to the rapid evolution of new species during the Cambrian Period.

(6) Methane can be released from methane hydrates when deposits are disrupted by earthquakes or landslides; or when pressure on hydrates is reduced due to a sea-level drop, such as occurred during glacial periods; or when clathrates become unstable due to warming.

(7) Methane is a fossil fuel that could be used in many of the same ways that other fossil fuels (e.g., coal and petroleum) are used. According to the U.S. Department of Energy, the quantity of methane potentially available is enormous. For example, the U.S. domestic natural gas recoverable resource is roughly 2,300 trillion cubic feet (Tcf). In the case of methane hydrates, the potentially-recoverable domestic resource base could be on the order of 5,000 Tcf.

(8) Oil and gas drilling and production activities may disturb methane hydrate deposits that are near the sea floor surface, and such disruption poses hazards to personnel and equipment. Ongoing natural phenomena (e.g., subsidence and uplift of the sea floor, global climatic cycles, changes in ocean circulation patterns, changes in global sea level) continually alter the temperature and pressure conditions in sea-bottom sediments. These processes affect the stability of natural methane hydrates, and can result in potentially massive destabilization of these hydrates. If a large quantity of methane enters the atmosphere, it will reside there for roughly 10-20 years, during which it will act

as a very efficient greenhouse gas. Over the longer term, the atmospheric impact of methane will continue at lesser levels as the methane slowly dissipates through oxidation into water and carbon dioxide.

(9) In September, 2001, the Ocean Exploration Deep East expedition explored the crest of the Blake Ridge at a depth of 2,154 m, and found methane hydrate-associated communities containing previously-unknown species that may be sources of beneficial pharmaceutical materials.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over "Ocean Science Topics," then click "Habitats," the "Deep Sea" for links to resources about hydrothermal vents and chemosynthetic communities.

The "Me" Connection

Have students write an essay describing why ocean exploration expeditions are, or are not, relevant and important to them personally.

Connections to Other Subjects

English/Language Arts, Biology, Chemistry, Mathematics

Assessment

Students' responses to *Inquiry Guide* questions and class discussions provide opportunities for assessment.

Extensions

1. Follow events aboard the *Okeanos Explorer* at http://oceanexplorer.noaa.gov/okeanos/welcome.html.
2. Have students investigate events in Earth's history that may have been influenced in some way by methane hydrates. The next-to-last paragraph in the Background section refers to some of these.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html
Click on the links to Lessons 5, 11, and 12 for interactive multimedia presentations and Learning Activities on Chemosynthesis and Hydrothermal Vent Life, Energy from the Oceans, and Food, Water, and Medicine from the Sea.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

(All of the following Lesson Plans are targeted toward grades 9-12)

This Life Stinks
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/GOM%2006%20Stinks.pdf
(9 pages, 276 Kb) (from the 2006 Expedition to the Deep Slope)

Focus: Methane-based chemosynthetic processes (Physical Science)

In this activity, students will be able to define the process of chemosynthesis, and contrast this process with photosynthesis. Students will also explain the process of methane-based chemosynthesis and explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

The Big Burp: Where's the Proof?
http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/burp.pdf
(5 pages, 364k) (from the 2007 Expedition to the Deep Slope)

Focus: Potential role of methane hydrates in global warming (Earth Science)

In this activity, students will be able to describe the overall events that occurred during the Cambrian Explosion and Paleocene Extinction events and will be able to define methane hydrates and hypothesize how these substances could contribute to global warming. Students will also be able to describe and explain evidence to support the hypothesis that methane hydrates contributed to the Cambrian Explosion and Paleocene Extinction events.

The Benthic Drugstore
http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/drugstore.pdf
(8 pages; 278kb PDF) (from the Cayman Islands Twilight Zone 2007 Expedition)

Focus: Pharmacologically-active chemicals derived from marine invertebrates (Life Science/Chemistry)

In this activity, students will be able to identify at least three pharmacologically-active chemicals derived from marine invertebrates, describe the disease-fighting action of at least three pharmacologically-active chemicals derived from marine invertebrates, and infer why sessile marine invertebrates appear to be promising sources of new drugs.

Chemosynthesis for the Classroom
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/GOM%2006%20Chemo.pdf
(9 pages, 276k) (from the 2006 Expedition to the Deep Slope)

Focus: Chemosynthetic bacteria and succession in chemosynthetic communities (Chemistry/Biology)

Students will observe the development of chemosynthetic bacterial communities and will recognize that organisms modify their environment in ways that create opportunities for other organisms to thrive. Students will also be able to explain the process of chemosynthesis and the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

Other 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://celebrating200years.noaa.gov/edufun/book/welcome.html#book – A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focussing on the exploration, understanding, and protection of Earth as a whole system

http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/maincontent.htm – Web site for the National Methane Hydrate Research and Development Program

http://marine.usgs.gov/fact-sheets/gas-hydrates/title.html – Gas (Methane) Hydrates – A New Frontier; Web page from

the U.S. Geological Survey's Marine and Coastal Geology Program

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.mbari.org/staff/vrijen/PDFS/VanDover_2003DSR.pdf)

MacDonald, I. and S. Joye. 1997. Lair of the "Ice Worm." Quarterdeck 5(3); http://www-ocean.tamu.edu/Quarterdeck/QD5.3/macdonald.html; article on cold-seep communities and ice worms

Siegel, L. J. 2001. Café Methane. http://nai.arc.nasa.gov/news_stories/news_detail.cfm?ID=86; article on cold-seep communities and ice worms from NASA's Astrobiology Institute

Kirschvink, J. L. and T. D. Raub. 2003. A methane fuse for the Cambrian explosion: carbon cycles and true polar wander. Comptes Rendus Geoscience 335:65-78. Journal article on the possible role of methane release in rapid diversification of animal groups. Also available on-line at http://www.gps.caltech.edu/users/jkirschvink/pdfs/KirschvinkRaubComptesRendus.pdf

Simpson, S. 2000. Methane fever. Scientific American (Feb. 2000) pp 24-27. Article about role of methane release in the Paleocene extinction event

http://www.uky.edu/KGS/education/geologictimescale.pdf and http://www.uky.edu/KGS/education/activities.html#time – Great resources on geological time and major events in Earth's history

http://www.divediscover.whoi.edu/vents/index.html – "Dive and Discover: Hydrothermal Vents;" another great hydrothermal vent site from Woods Hole Oceanographic Institution

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 matter
- Conservation of energy and increase in disorder
- Interactions of energy and matter

Content Standard C: Life Science

- Biological evolution

Content Standard D: Earth and Space Science

- Energy in the Earth system
- Origin and evolution of the Earth system

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,

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 3.

The ocean supports a great diversity of life and ecosystems.

Fundamental Concept a. The ocean controls weather and climate by dominating the Earth's energy, water and carbon systems.

Fundamental Concept e. The ocean dominates the Earth's carbon cycle. Half the primary productivity on Earth takes place in the sunlit layers of the ocean and the ocean absorbs roughly half of all carbon dioxide added to the atmosphere.

Fundamental Concept f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.

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 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.

Send Us Your Feedback

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

For More Information

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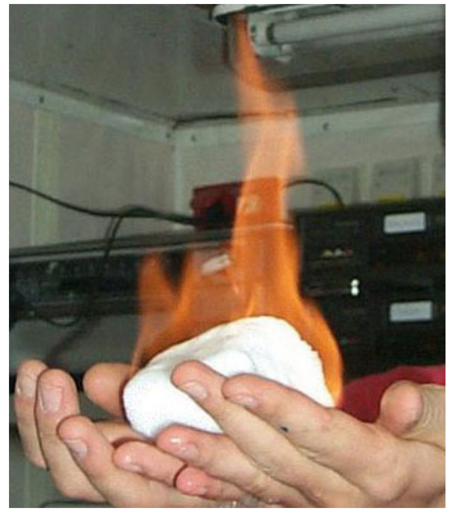
Methane Hydrates Inquiry Guide

Research Questions

1. What is a clathrate?



Methane hydrate looks like ice, but as the "ice" melts it releases methane gas which can be a fuel source. Image credit: Gary Klinkhammer, OSU-COAS

2. What is methane hydrate? Include a model of a methane hydrate with your written report (refer to the *Methane Hydrate Molecule Construction Guide*).

3. How are methane hydrates formed?

4. Where are methane hydrates found?

5. What is the effect of methane in the atmosphere? Is there any evidence of a direct effect on life on Earth in geological time?

Methane Hydrates Inquiry Guide - Page 2

6. In what ways can methane be released from methane hydrates?

7. Is there any practical use for methane hydrates?

8. Do methane hydrates pose any immediate danger to coastal areas?

9. Are any unusual biological organisms or communities associated with methane hydrates? If so, do these communities have any known or potential significance to humans?

Research Tips

1. Try a keyword search using the following terms, alone or in combination: Cold seeps, Methane hydrate, Clathrate, Methanogenic Archaeobacteria Paleocene extinction, Energy hazard

   Note: Use quotation marks or underlined spaces to tell your search engine to look for two-word phrases as a single term

2. Explore the following Web sites:
   http://oceanexplorer.noaa.gov
   http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/maincontent.htm
   http://marine.usgs.gov/fact-sheets/gas-hydrates/title.html

Methane Hydrate Molecule Construction Guide

Materials

Materials for constructing a methane hydrate molecule model:

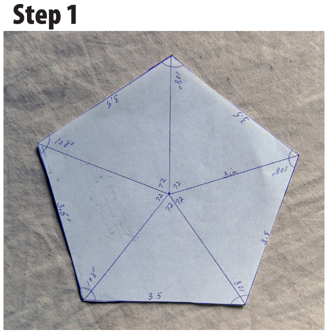
For constructing a pentagon:

- Paper, unlined 8-1/2” X 11”
- Pencil
- Protractor or compass

For constructing the dodecahedron, clathrate cage, methane molecule and methane hydrate model:

- Scissors
- Cardboard or card stock (enough to make 13 pentagons)
- Ruler, 12-inch
- 11 - Bamboo skewers, 12” long
- 20 - Styrofoam balls, 1/2” diameter
- 4 - Styrofoam balls, 1-1/2” diameter
- 1 - Styrofoam ball, 1” diameter
- Tape, wrapping or strapping
- Spray paint, water-based latex; dark blue, light blue, red, and black
- Fishing line, 8 lb test; or light colored thread

Step 1



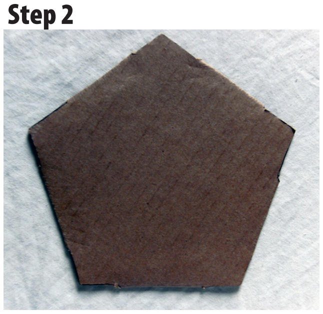
Procedure

1. General Notes:
   - Use a good quality latex spray paint; oil-based paints containing organic solvents tend to melt the Styrofoam.
   - Be sure the skewers are inserted into the middle of the Styrofoam balls.

Part 1 – Build a pentagonal dodecahedron

1. Draw a pentagon on paper and cut it out. Each side of the pentagon should be four inches long.

Step 2



2. Trace the paper pentagon onto cardboard or card stock and cut in out. Each group will cut out 13 pentagons.

3. Lay one pentagon on a flat surface and surround it with five more pentagons matched side to side. Tape the five outside pentagons to the center pentagon.

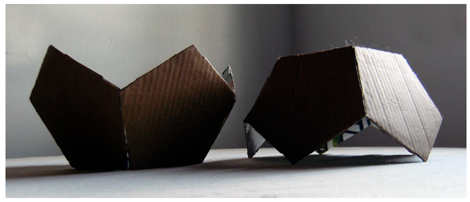
Step 3

4. Carefully pull up one pair of pentagons and tape their common sides together. Repeat until the five pentagons have been taped together, forming a five-sided bowl. This is the bottom half of the pentagonal dodecahedron.

Methane Hydrate Molecule Construction Guide - Page 2

5. Repeat Steps 3 and 4 to make the top half of the pentagonal dodecahedron. The two halves are identical. Place the top half over the bottom half to form the pentagonal dodecahedron. Do not tape the bottom to the top.

Step 5



Part 2 – Build the Model Molecules

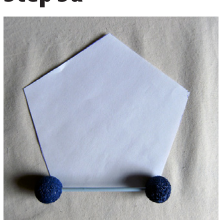
1. Spray paint skewers and Styrofoam balls:
   a. Paint ten skewers light blue to represent hydrogen bonds between water molecules
   b. Paint one skewer red to represent the electrostatic bonds in the methane molecule
   c. Paint twenty 1/2" Styrofoam balls dark blue to represent water molecules
   d. Paint one 1" Styrofoam ball black to represent the carbon atom
   e. Note: the 4 1-1/2" Styrofoam balls remain white to represent hydrogen atoms

2. Cut light blue skewer sticks into thirty 3-3/4" lengths. Cut the red skewer stick into four 2" lengths.

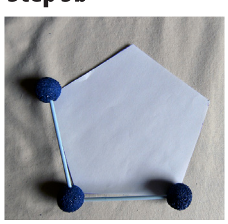
Build the clathrate cage:

3. Place the 13th pentagon on a flat surface. Place a blue stick on one side and two blue balls at each end. Carefully insert the end of the blue stick into the middle of each ball. Repeat with three more balls and four more sticks to form a ball-and-stick pentagon.

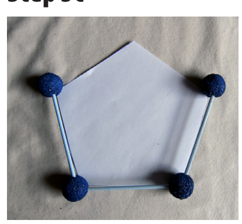
Step 3a



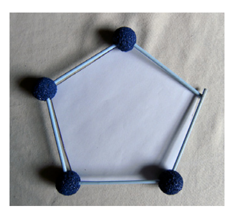
Step 3b



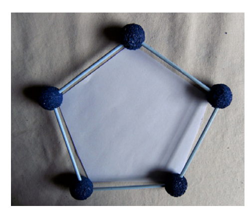
Step 3c



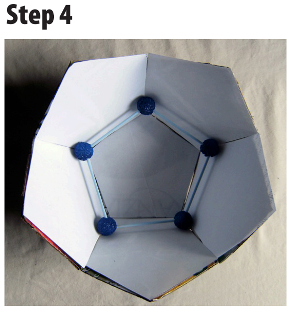
Step 3d



Step 3e



Step 4



4. Place the ball-and-stick pentagon in one of the dodecahedron halves—be careful, it will lay approximately an inch up from the bottom. The dodecahedron half (bowl) is used as a template to build the ball and stick dodecahedron with the correct stick angle.

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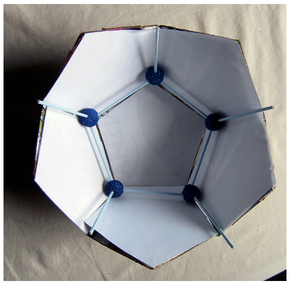
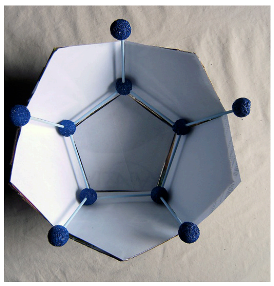
Step 5



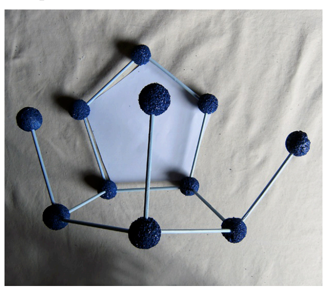
5. Place five light blue sticks inside the center of each of the dark blue balls using the dodecahedron half as a guide for the correct stick angle. It's very important to insert the sticks into the center of the ball at the same angle as the side of the dodecahedron half.

Step 6



6. Insert a dark blue ball on top of each light blue stick. Carefully remove the incomplete cage from the dodecahedron and place it on a flat surface.

Step 7

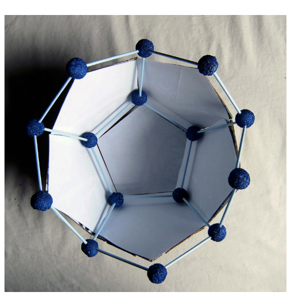


7. Use the 13th pentagon to complete the bottom half of the cage. Turn the ball-and-stick model onto one side and, using the pentagon to determine the correct angle, insert a light blue stick into the center of the two dark blue balls. Then, attach another dark blue ball to connect the two light blue sticks you've just attached. This makes the second face and second pentagon of the cage. The first face was the bottom.

8. Repeat Step 7 four more times to form the remaining faces for the bottom half of the cage.

9. Repeat Steps 3, 4, and 5 to construct the top half of the cage.

Step 8



10. Carefully place the bottom half of the cage into the bottom of the cardboard dodecahedron. Attach the two halves of the cage together: Working together with your partners, hold the top half of the cage over the bottom half. The two halves will only fit together one way. Rotate the top half until all of the unattached sticks line-up with a ball. Insert each light blue stick into the center of the corresponding dark blue ball.

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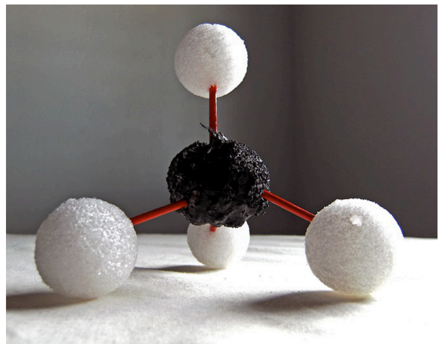
Build the Methane Molecule:

11. Insert four red sticks into the black Styrofoam ball so that they are evenly spaced (when the model is placed on a flat surface, three of the sticks and the black ball should look like a tripod with the fourth stick pointing straight up. Attach a white Styrofoam ball to the other end of each of the red sticks.

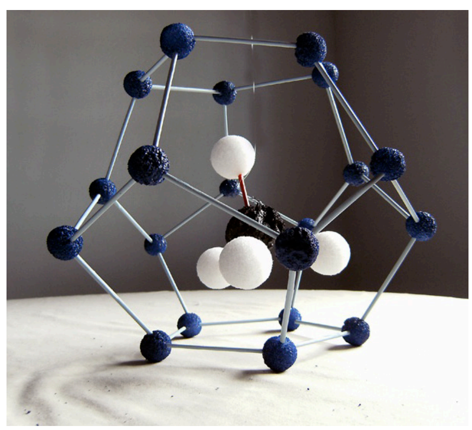
Step 11



Assemble the Methane Hydrate Molecule Model

12. Suspend the methane molecule model in the middle of the clathrate cage by attaching fishing line from one of its electrostatic bonds (red sticks) to two opposing hydrostatic bonds (light blue sticks) at the top of the cage. Your Methane Hydrate Molecule Model is finished!

Step 12



Note: Each of the dark blue Styrofoam balls represents a water molecule consisting of two hydrogen atoms and one oxygen atom. To keep the model simple, we don't show all of these atoms separately.

All photographs by Mellie Lewis, Teacher Facilitator, The College of Exploration.

Appendix A

Adapting the Methane Hydrate Molecule Construction Activity as a Cross-curricular Mathematics Lesson

Learning Objectives

- Students will demonstrate geometric properties through hands on manipulation of geometric shapes.
- Students will be able to construct a pentagonal dodecahedron.
- Students will be able to construct a model of a methane hydrate molecule.

Teaching Time

Three or four 50-minute class periods or may be sent home as an enrichment activity

Definitions

- Polygon – a geometric shape made up of vertices that are connected with line segments
- Vertex – a point where the sides of an angle meet
- Pentagon – a geometric shape with five equal sides and five 108° angles
- Dodecahedron – a three-dimensional geometric shape that has 12 faces (regular pentagons), 20 vertices, and 30 edges

Prerequisite Skills

Students should have basic knowledge of geometric shapes and know how to draw a pentagon. If not, directions for drawing a pentagon using a compass or protractor may be found in middle school mathematics textbooks or in the links below.

Procedure

1. Lead an introductory discussion of how mathematical models help us understand science concepts.
2. Tell students that they will be using concepts and skills they have learned in mathematics class to build a pentagonal dodecahedron, a clathrate cage, and methane hydrate model.
3. Provide students with copies of the *Methane Hydrate Molecule Construction Guide* and required materials.

Resources

http://wiki.answers.com/Q/How_would_you_draw_a_regular_pentagon
http://www.barryscientific.com/lessons/polygon.html

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National Math Education Standards and Expectations

Analyze characteristics and properties of two-and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships

In grades 9-12 all students should-

- Analyze properties and determine attributes of two- and three-dimensional objects;
- Explore relationships (including congruence and similarity) among classes of two- and three-dimensional geometric objects, make and test conjectures about them, and solve problems involving them.

Use visualization, spatial reason, and geometric modeling to solve problems

In grades 9-12 all students should-

- Draw and construct representations of two- and three-dimensional geometric objects using a variety of tools;
- Use geometric models to gain insights into, and answer questions in, other areas of mathematics;
- Use geometric ideas to solve problems in, and gain insights into, other disciplines and other areas of interest such as art and architecture.