



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>

Section 4: Key Topic – Energy

Animals of the Fire Ice

Focus

What are animals that have been found feeding on methane hydrates, and how may they interact with other species?

Grade Level

5-6 (Life Science)

Focus Question

What animals have been found feeding on methane hydrates and how may they interact with other species?

Learning Objectives

- Students will define and describe methane hydrate ice worms and hydrate shrimp.
- Students will infer how methane hydrate ice worms and hydrate shrimp obtain their food.
- Students will infer how methane hydrate ice worms and hydrate shrimp may interact with other species in the biological communities of which they are part.

Materials

- Copies of the *Fire Ice Animals Investigation Guide*, one for each student group
- Copies of the *Methane Hydrate Model Construction Guide Student Handout*, one for each student group
- Materials for constructing a methane hydrate model:

For constructing a pentagon:

- Paper, unlined 8-1/2" x 11"
- Pencil
- Protractor or compass

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

- Scissors
- Cardboard or card stock (enough to make 7 pentagons)
- Ruler, 12-inch
- 11 - Bamboo skewers, 12" long
- 20 - Styrofoam balls, 1/2" to 1" diameter
- 4 - Styrofoam balls, 1" diameter
- 1 - Styrofoam ball, 1-1/2" 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
- (Optional) Materials for constructing posters or three-dimensional models (see Learning Procedure, Step 7)

Audiovisual Materials

- None

Teaching Time

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

Seating Arrangement

Groups of four to six students

Maximum Number of Students

32

Key Words and Concepts

Cold seeps
Methane hydrate
Clathrate
Methanogenic Archaea
Polychaete
Alvinocarid shrimp
Ice worm
Hydrate shrimp

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

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,*

www.sciencenews.org/pages/pdfs/data/1996/150-19/15019-12.pdf

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 Archaea. These Archaea 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.



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



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

Besides providing entertainment for oceanographers, methane hydrate deposits are significant for several other reasons:

- 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.
- Methane hydrates can decompose to release large amounts of methane which is a greenhouse gas that could have (and may already have had) major consequences to the Earth's climate.
- Sudden release of pressurized methane gas may cause submarine landslides which in turn can trigger catastrophic tsunamis.
- Methane hydrates are associated with unusual and possibly unique biological communities containing previously-unknown species that may be sources of beneficial pharmaceutical materials.

The biological communities associated with methane hydrates are chemosynthetic, and include food webs that are based on the energy of chemical compounds (in contrast to photosynthetic communities whose food webs are based on photosynthesis that uses energy from the sun). Ocean Exploration expeditions to the Gulf of Mexico have found methane hydrates in the vicinity of “cold seeps,” which are areas where hydrocarbons are seeping onto the ocean floor. In some of these areas, explorers have observed polychaete worms that appeared to be actively sculpting methane hydrate ices, and expeditions to other locations (such as the 2001 Deep East Expedition) observed shrimp that appeared to be feeding directly on methane hydrate ices (visit <http://oceanexplorer.noaa.gov/explorations/03mex/welcome.html>, <http://oceanexplorer.noaa.gov/explorations/02mexico/welcome.html>, and <http://oceanexplorer.noaa.gov/explorations/deepeast01/deepeast01.html> for more information).

What are these “fire ice animals” doing? Are they actually consuming methane hydrate ices for food? Until more detailed studies are done on these animals, we won't know for sure. But we can use what is already known about other shrimps and polychaete worms to infer some possible answers. These inferences can lead to hypotheses about the relationships between the animals and methane hydrate ices, and can form the basis for experiments to find out more about these strange deep-sea animals.

In this activity, students will research cold-seep communities and typical feeding habits of polychaetes and shrimp to make inferences about the relationships between fire ice animals and methane hydrates.

Learning Procedure

1. To prepare for this lesson:

- 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 lesson, *To Boldly Go . . .*
- 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 Deep East Expedition to the Blake Ridge and the 2003 Windows on the Deep Expedition.
- Review questions on the *Fire Ice Animals Investigation Guide*.
- Review procedures on the *Methane Hydrate Model Construction Guide (Educator's Version)*, 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 at the end of the *Educator's Version*. Alternatively, this activity may be done as a briefer demonstration using dodecahedrons constructed by the educator. In either case, you will need to complete Step 2 in advance. If you plan to construct the model as a demonstration, you should also complete Part 1 of the *Student Handout*.

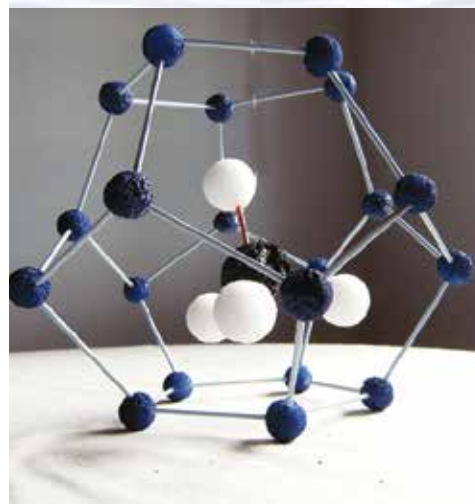
2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons that ocean exploration is important, which should include further 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.pmel.noaa.gov/vents/> for more information and activities on hydrothermal vent communities.

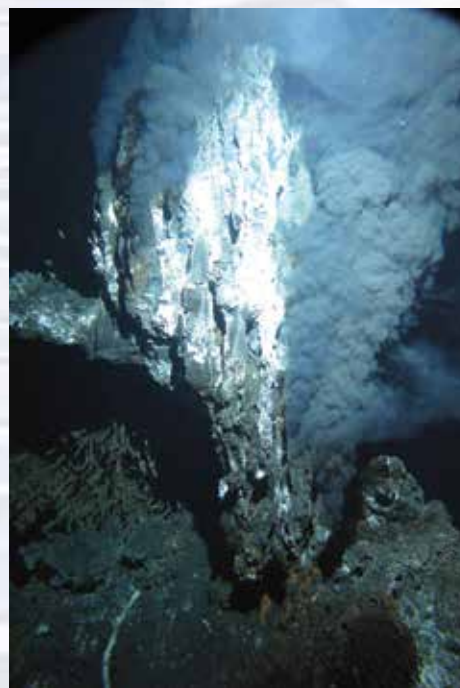
3. Lead a discussion about recently-discovered deep-sea chemosynthetic communities (hydrothermal vents and cold seeps). Emphasize the contrast between communities that depend upon chemosynthesis with those dependent upon photosynthesis. You may want to point out that through both processes, organisms 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. Review the concepts of food chains or webs, emphasizing that the entire chain or web depends upon primary producers at the base of the chain (or web) that are able to create energy-rich food from non-living components in the surrounding environment.

4. Briefly describe methane hydrates. If you will be using student-constructed dodecahedrons for this activity, have students complete Parts 1 and 2 of the *Methane Hydrate Model Construction Guide*. Alternatively, complete Part 2 as a demonstration.

5. Tell students that expeditions to deep-sea communities often discover new and unusual types of living organisms. Two of these organisms are a type of polychaete called an ice worm and a type of crustacean called a hydrate shrimp. Explain that the ice worms make burrows in methane hydrate ices, and that hydrate shrimp have been seen crawling on top of methane hydrate ices, possibly feeding on the ice surface. Explain that scientists are not certain about the relationships between these animals and methane hydrates, nor how the fire ice animals obtain their food. To plan investigations to answer these questions, we need to use existing knowledge about other types of shrimp, polychaetes, and chemosynthetic communities to make hypotheses that are the basis for experiments and observations to learn more about these animals. Provide each group with a copy of the *Fire Ice Animals Investigation Guide*, and tell students that their assignment is to find out what is known about polychaetes and shrimps in cold-seep communities, how other polychaetes and shrimps obtain their food, and to make hypotheses about the relationships between methane hydrates, ice worms, and hydrate shrimp.



A methane hydrate model. Image credit: Mellie Lewis, College of Exploration



A black smoker chimney named 'Boardwalk' emitting 644°F (340°C) hydrothermal fluids in the northeastern Pacific Ocean at a depth of 7,260 feet (2,200 m). Microbes grow within and on the surface of such mineral formations. Image credit: James F. Holden, UMass Amherst.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/hires/boardwalk_black_smoker_hires.jpg



The *Little Hercules* ROV shines its lights on a veritable field of sulphide chimneys and rocks covered with shrimp. In a short period of time, a thriving community over a large area of diffuse venting was revealed. Image courtesy of NOAA *Okeanos Explorer* Program, INDEX-SATAL 2010.

http://oceanexplorer.noaa.gov/okeanos/explorations/10index/logs/hires/active_venting_hires.jpg

6. Have each student group present the results of their investigation, then lead a discussion of students' hypotheses. Encourage imagination and creativity, but challenge students to explain how their hypotheses are consistent with existing knowledge. Possible relationships could include:
 - Shrimp and/or worms are directly using methane hydrate as a source of food (this is not particularly likely, since other shrimps and polychaetes are heterotrophic).
 - Shrimp and/or worms are consuming methane hydrate which is used by symbiotic chemosynthetic bacteria living inside the animals (this would be analogous to many similar symbioses, and a variety of bacteria have been found to be closely associated with ice worms).
 - Shrimp and/or worms are grazing the surface or interior of methane hydrate ices, and are eating chemosynthetic bacteria that use methane hydrate as an energy source (bacterial mats have been found in cold-seep communities, and grazing or deposit-feeding is common among other shrimp and polychaetes).
 - Ice shrimp that burrow into methane hydrate ices could be deriving protection from predators (burrowing behavior is typical among many other polychaetes).

Have students discuss what sort of investigations might be undertaken to test their hypotheses.

7. (Optional) Have student groups construct a poster or three-dimensional model illustrating their ideas about a methane hydrate community. You may provide materials, or challenge students to find their own, such as colored paper, color markers, modeling clay, glitter (to represent bacteria), Styrofoam pieces (to represent methane hydrates), etc.

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 a short essay on how additional knowledge about “fire ice animals” could be important to their own lives.

Connections to Other Subjects

English/Language Arts, Earth Science, Physical Science

Assessment

Students' responses to *Investigation 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. Review Ocean Energy Overview in *Diving Deeper*, page 26.

Multimedia Discovery Missions

<http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html> Click on the links to Lessons 3, 5, 6, 11, and 12 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, Deep-Sea Benthos, 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 5-6)

A Piece of Cake (from the Cayman Islands Twilight Zone 2007 Expedition)

<http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/cake.pdf>

Focus: Spatial heterogeneity in deepwater coral communities (Life Science)

Students will explain what a habitat is, describe at least three functions or benefits that habitats provide, and describe some habitats that are typical of deepwater hard bottom communities. Students will also explain how organisms, such as deepwater corals and sponges, add to the variety of habitats in areas such as the Cayman Islands.

Deep Gardens (from the Cayman Islands Twilight Zone 2007 Expedition)

<http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/deepgardens.pdf>

Focus: Comparison of deep-sea and shallow-water tropical coral communities (Life Science)

Students will compare and contrast deep-sea coral communities with their shallow-water counterparts, describe three types of coral associated with deep-sea coral communities, and explain three benefits associated with deep-sea coral communities. Students will explain why many scientists are concerned about the future of deep-sea coral communities.

Let's Make a Tubeworm! (from the 2002 Gulf of Mexico Expedition)

http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_tube_gr56.pdf

Focus: Symbiotic relationships in cold-seep communities (Life Science)

Students will describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, describe major features of cold-seep communities, and list at least five organisms typical of these communities. Students will also define symbiosis, describe two examples of symbiosis in cold-seep communities, describe the anatomy of vestimentiferans, and explain how these organisms obtain their food.

Journey to the Unknown & Why Do We Explore

(from the 2002 Galapagos Rift Expedition)

http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr5_6_11.pdf

Focus: Ocean Exploration (Life Science/Earth Science/Physical Science)

Students will experience the excitement of discovery and problem-solving to learn about organisms that live in extreme environments in the deep ocean and come to understand the importance of ocean exploration.

Chemists with No Backbones (from the 2003 Deep Sea Medicines Expedition)

http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/meds_chemnobackbones.pdf

Focus: Benthic invertebrates that produce pharmacologically-active substances (Life Science)

Students will identify at least three groups of benthic invertebrates that are known to produce pharmacologically-active compounds and will describe why



pharmacologically-active compounds derived from benthic invertebrates may be important in treating human diseases. Students will also infer why sessile marine invertebrates appear to be promising sources of new drugs.

Keep Away (from the 2006 Expedition to the Deep Slope)

http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_keepaway.pdf

Focus: Effects of pollution on diversity in benthic communities (Life Science)

Students will discuss the meaning of biological diversity and compare and contrast the concepts of variety and relative abundance as they relate to biological diversity. Given information on the number of individuals, number of species, and biological diversity at a series of sites, students will make inferences about the possible effects of oil drilling operations on benthic communities.

What's In That Cake? (from the 2006 Expedition to the Deep Slope)

http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_cake.pdf

Focus: Exploration of deep-sea habitats (Life Science)

Students will explain what a habitat is, describe at least three functions or benefits that habitats provide, and describe some habitats that are typical of the Gulf of Mexico. Students will also describe and discuss at least three difficulties involved in studying deep-sea habitats and describe and explain at least three techniques scientists use to sample habitats, such as those found in the Gulf of Mexico.

Other Resources

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.

Please send your comments to:

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Acknowledgments

Produced by Mel Goodwin, PhD, Marine Biologist and Science Writer, Charleston, SC for NOAA. Design/layout: Coastal Images Graphic Design, Charleston, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: <http://oceanexplorer.noaa.gov>



Fire Ice Animals Investigation Guide

Background Research & Analysis

Expeditions to deep-sea communities often discover new and unusual types of living organisms. Two examples are polychaete worms called ice worms and crustaceans called hydrate shrimp. These animals have been seen on (and in) methane hydrates, which are ice-like substances formed when molecules of frozen water surround molecules of methane gas. If you hold a piece of methane hydrate in your hand, you can set it on fire, so methane hydrates have been nick-named “fire ice.”

Ice worms make burrows in methane hydrates, and hydrate shrimp have been seen crawling on top of the ice surface, possibly feeding. Scientists are not certain about the relationships between these animals and methane hydrates, nor how the fire ice animals obtain their food. To plan investigations to answer these questions, we need to use existing knowledge about other types of shrimp, polychaetes, and chemosynthetic communities to develop hypotheses that guide experiments and observations to learn more about these animals.

Your assignment is to find out what is known about polychaetes and shrimp in cold-seep communities, how other polychaetes and shrimp obtain their food, and to make hypotheses about the relationships between methane hydrates, ice worms, and hydrate shrimp. You can find information on feeding habits of shrimp and polychaetes in general in encyclopedias and general biology books. Information at <http://www.wetwebmedia.com/polychaetes.btm> and <http://www.wetwebmedia.com/marine/inverts/arthropoda/shrimp/corlband.btm> may also be useful, although the emphasis of this site is on aquaria. There is not much information presently available on hydrate shrimp, other than the fact that they have been observed on methane hydrates at the Blake Ridge off the coast of South Carolina. Two good sources of information on ice worms are <http://www-ocean.tamu.edu/Quarterdeck/QD5.3/macdonald.html> and http://nai.arc.nasa.gov/news_stories/news_detail.cfm?ID=86. If you do keyword searches to find additional references, you need to know that the name “ice worm” has also been used to describe animals that inhabit glaciers and similar environments, so you should also include “methane” in your search query.

When you have completed your research, answer the following questions:

1. What is the basis of food webs in cold-seep communities?
2. What have explorers to cold-seep communities observed about ice worms and hydrate shrimp?
3. How do polychaetes and shrimp, in general, obtain their food?
4. What are the relationships that you hypothesize between ice worms, hydrate shrimp, and methane hydrates?



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



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

Methane Hydrate Model Construction Guide (*Educator's Version*)

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.

Materials

Materials for constructing a methane hydrate model

For constructing a pentagon:

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

For constructing the dodecahedron half, 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" to 1" diameter
- 4 - Styrofoam balls, 1" diameter
- 1 - Styrofoam ball, 1-1/2" 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

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 math textbooks or in the links below.

Procedure

1. General Notes:
 - For grade 5-6 students, the educator may want to demonstrate each step of drawing the pentagon as students follow along.
 - Use a good quality latex spray paint; oil-based paints containing organic solvents tend to melt the Styrofoam.
 - When constructing the clathrate cage, the educator should demonstrate each step as students follow along.
 - Be sure the skewers are inserted into the middle of the Styrofoam balls.
2. (Advance Preparation) 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 1-1/2" Styrofoam ball black to represent the carbon atom
 - e. Note: the four 1" Styrofoam balls remain white to represent hydrogen atoms
 - f. Cutting skewers at an angle, cut light blue skewer sticks into thirty 3-3/4" lengths. Cut the red skewer stick into four 2" lengths.
3. Lead an introductory discussion of how mathematical models help us understand science concepts.
4. Tell students that they will be using concepts and skills they have learned in the math class to build a pentagonal dodecahedron, a clathrate cage, and methane hydrate model.
5. Give each student group a copy of the *Methane Model Construction Student Handout*. Have each group complete Part 1.
6. Have each group complete Part 2, or do this part as a demonstration.
7. Count the vertices, edges, and faces of the completed dodecahedron. Discuss the symmetry of the dodecahedron.

Be sure students understand that 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.

Resources

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



Common Core State Standards for Mathematics

Grade 5:

5.G.B.4. Classify two-dimensional figures in a hierarchy based on properties.

Grade 6:

7.G.A.2. Draw (freehand, with ruler and protractor, and with technology) geometric shapes with given conditions.

High School:

HSG.MG.A.1. Use geometric shapes, their measures, and their properties to describe objects.



Methane Hydrate Model Construction Guide

Part 1 – Build half of a pentagonal dodecahedron

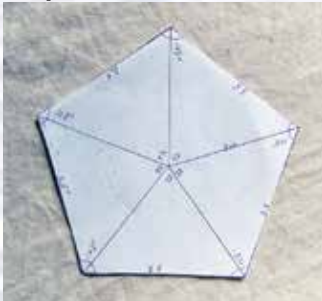
1. Draw a pentagon on paper and cut it out. Each side of the pentagon should be four inches long (72° angles). Option: Use Adobe Illustrator or Corel Draw.
2. Trace the paper pentagon onto cardboard or card stock and cut it out. Your group will need 7 pentagons.
3. Lay one pentagon on a flat surface and surround it with five more pentagons matched side to side. Tape the five outside pentagons to the center pentagon.
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 half of a pentagonal dodecahedron.

Part 2 – Build the Model

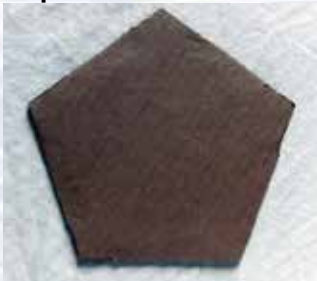
Build the clathrate cage:

1. Place the 7th 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 1



Step 2



Step 3



Step 1a



Step 1b



Step 1c



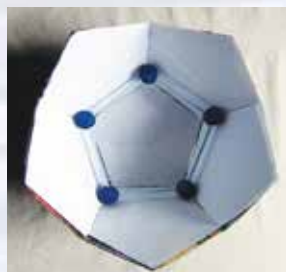
Step 1d



Step 1e



Step 2



2. Place the ball-and-stick pentagon in the dodecahedron half – be careful, it will lie 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.

3. 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.

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

5. Use the 7th 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.

6. Repeat Step 5 four more times to form the remaining faces for the bottom half of the cage.

7. Repeat Steps 1, 2, and 3 to construct the top half of the cage.

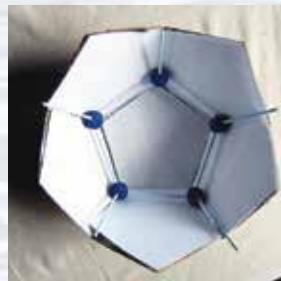
8. Carefully place the bottom half of the cage into the bottom of the cardboard bowl.

9. Carefully, 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.

Build the Methane Molecule:

10. 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 3



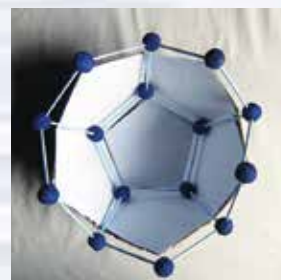
Step 4



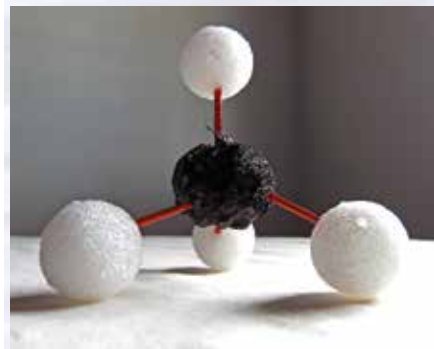
Step 5



Step 8



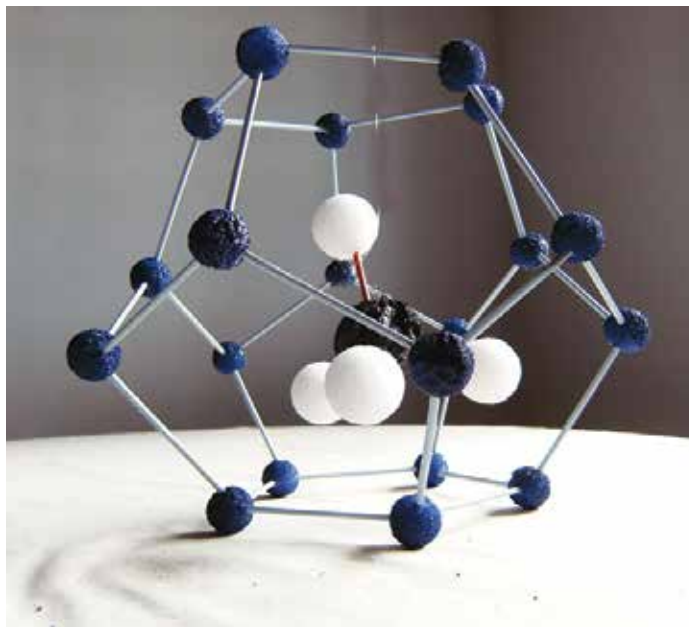
Step 10



Assemble the Methane Hydrate Model:

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

Step 11



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

