



OVERVIEW

The HHMI film [How Giant Tube Worms Survive at Hydrothermal Vents](#) is one of 12 videos in the series “I Contain Multitudes,” which explores the fascinating powers of the *microbiome*—the world of bacteria, fungi and other microbes that live on and within larger forms of life, including ourselves.

In 1977, scientists discovered a diverse community of organisms inhabiting the deep-sea hydrothermal vents of the Pacific Ocean. While they had long predicted the presence of deep-sea vents on the ocean floor, they did not expect to find animal life there in the absence of sunlight. The sources of energy in these ecosystems are hydrogen sulfide (H₂S) and other inorganic chemicals that are abundant in the water that rises from the vents. Some species of bacteria can use these inorganic compounds in chemical reactions to produce sugar and other organic molecules in a process called chemosynthesis. The surprising discovery was that chemosynthesis could support a large and diverse ecosystem. Some animals living near hydrothermal vents, such as the giant tube worm, *Riftia pachyptila*, have a symbiotic relationship with species of chemosynthetic bacteria. In [How Giant Tube Worms Survive at Hydrothermal Vents](#), Dr. Colleen Cavanaugh describes how she first uncovered this symbiotic relationship and what it means for life deep in the ocean.

KEY CONCEPTS

- Through advances in engineering and technology, scientists have been able to explore new habitats and discover new life forms and metabolic strategies.
- Most ecosystems on Earth are sustained by photosynthesis at the base of the food chain. Hydrothermal vent ecosystems are powered by a process called chemosynthesis that produces energy from chemical reactions.
- Like photosynthesis, chemosynthesis results in the production of sugar and other organic compounds through the fixation of CO₂, but it uses chemicals like H₂S as the energy source rather than sunlight.
- Symbiosis is a close, long-term interaction between two or more different species of organisms. In some cases, both species benefit from the symbiotic relationship.

CURRICULUM CONNECTIONS

Standards	Curriculum Connections
NGSS (2013)	LS1.C, LS2.A, LS2.B
AP Biology (2015)	2.A.2, 2.D.1, 4.A.6, 4.B.2, 4.B.3
AP Environmental Science (2013)	I.A, II.A, II.B
IB Biology (2016)	2.9, 4.1, 4.2
IB Environmental Systems and Societies (2017)	2.1, 2.3
Vision and Change (2009)	CC2

PRIOR KNOWLEDGE

Students should

- have a basic understanding that organisms need energy to survive
- be familiar with the flow of energy through ecosystems
- be familiar with the process of photosynthesis and its importance in converting light energy into food.

PAUSE POINTS

The film may be viewed in its entirety or paused at specific points to review content with students. The table below lists suggested pause points, indicating the beginning and end times in minutes in the film.

	Begin	End	Content Description	Review Questions
1	0:00	2:43	<ul style="list-style-type: none"> In 1977, scientists explored deep-sea hydrothermal vents for the first time, where they discovered a rich and diverse ecosystem. Giant tube worms are central to the communities inhabiting the hydrothermal vents. 	<ul style="list-style-type: none"> Why were scientists surprised to find diverse life forms deep in the ocean? Compare and contrast the abiotic factors surrounding a deep-sea vent versus habitats near the surface of the ocean. (Use two columns of “check all that apply” for students to consider. You may include light versus dark, relatively constant water temperature versus hot water surrounded by areas of cold water, and so on.)
2	2:43	4:20	<ul style="list-style-type: none"> <i>Riftia pachyptila</i> have no digestive system; instead, they have an organ known as a trophosome. A trophosome is an internal organ found in some tube worms; it is home to bacteria that assist the tube worm in acquiring nutrients. The trophosome of <i>Riftia pachyptila</i> contains numerous sulfur crystals. 	<ul style="list-style-type: none"> What surprised scientists about the anatomy of tube worms? What did they find inside the trophosome of <i>Riftia pachyptila</i>? What is the source of the sulfur crystals in the trophosome of tube worms?
3	4:20	7:25	<ul style="list-style-type: none"> The trophosome of <i>Riftia pachyptila</i> contains sulfur-metabolizing bacteria; these bacteria produce energy-rich organic molecules that the worms can use for their metabolism and growth. Chemosynthesis is a process similar to photosynthesis, but it uses inorganic chemicals (such as H₂S) instead of sunlight as an energy source. Chemosynthesis, like photosynthesis, converts its energy inputs into energy stored in organic molecules. 	<ul style="list-style-type: none"> What is the energy source for the bacteria living inside the trophosome? Describe the process of chemosynthesis. How is it different from photosynthesis?
4	7:25	10:10	<ul style="list-style-type: none"> Chemosynthetic bacteria enter through tube worms’ body wall and then move into the trophosome. <i>Riftia pachyptila</i> breathe in O₂ and H₂S through the red plumes at the top of the worms. Blood carries both O₂ and H₂S into the trophosome, where chemosynthetic bacteria use both in chemosynthesis. 	<ul style="list-style-type: none"> Do the bacteria benefit from this symbiotic relationship? If yes, how? Do the tube worms benefit from this symbiotic relationship? If yes, how?

- Chemosynthesis is a widespread form of metabolism and may have been the earliest form of metabolism on Earth.

BACKGROUND

Chemosynthesis, like photosynthesis, is a process by which living organisms convert energy in their environment into energy stored in organic molecules. While it may be less well-known than photosynthesis, chemosynthesis is widespread; it is found in any habitat where hydrogen sulfide and oxygen are common. Different species of both archaea and bacteria are able to perform chemosynthesis.

Deep-sea hydrothermal vent ecosystems rely on chemosynthesis to produce energy-rich organic molecules that are used as food by a diversity of organisms. Chemosynthetic bacteria are the primary producers in these communities. They exist both as free-living organisms and in a symbiotic relationship within the cells or body of other organisms, such as the tube worm *Riftia pachyptila* (Figure 1).

Free-living bacteria are consumed by filter-feeding mollusks, such as clams and mussels; arthropods, such as shrimp and amphipods; vent plankton; and other secondary producers. Bacteria that exist in a symbiotic relationship within other organisms “feed” their host internally by providing organic compounds for energy and growth. In turn, the host assists the bacteria by providing a protective environment and by obtaining oxygen, hydrogen sulfide, and other nutrients needed for chemosynthesis from the seawater.

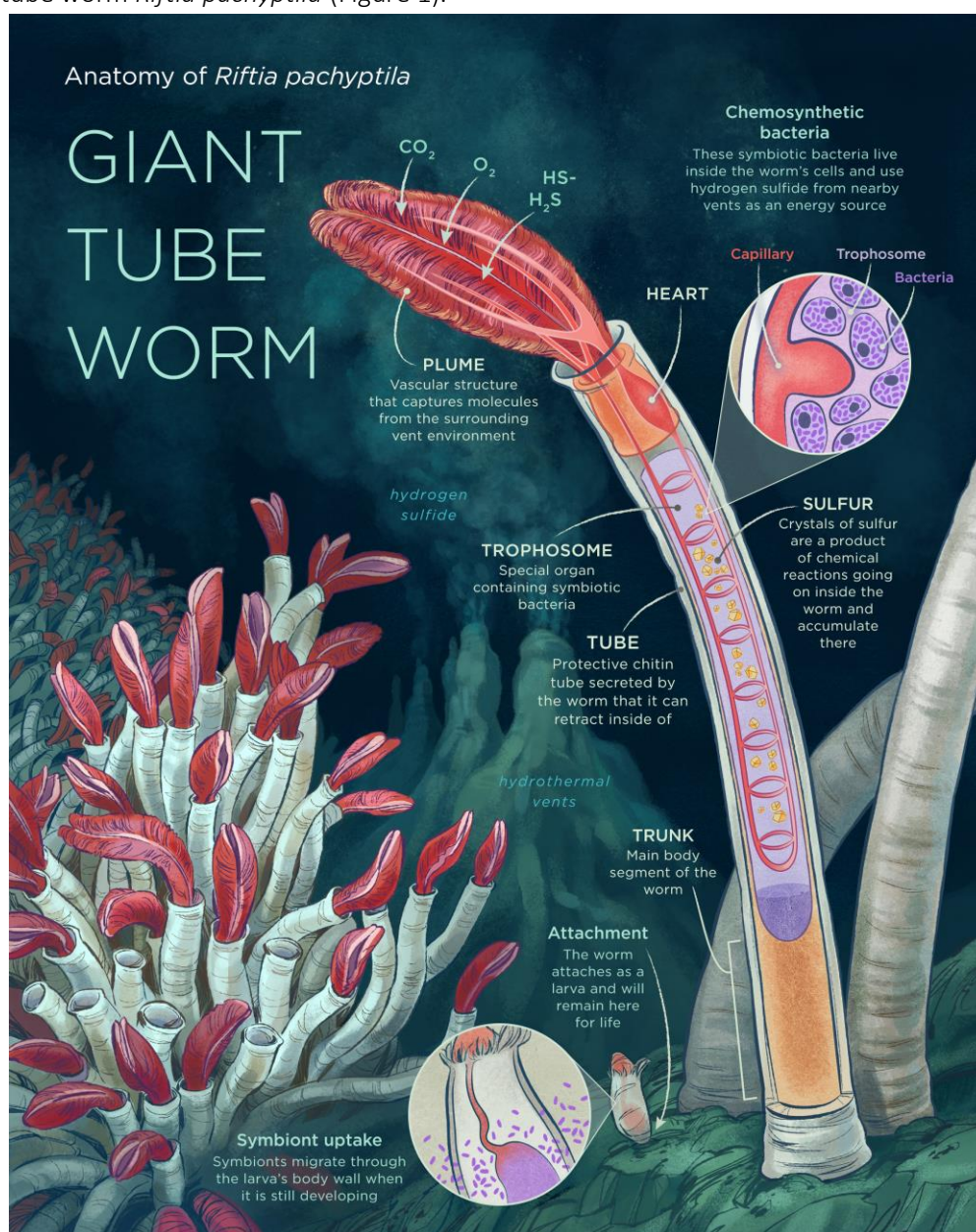


Figure 1. The anatomy of the tube worm *Riftia pachyptila*.

DISCUSSION POINTS

- Before watching the video, it may be helpful to remind students that all organisms need two things to survive: energy to fuel their metabolism and carbon to make compounds. Depending on the environment, and the energy and carbon sources available, different organisms have evolved different metabolic strategies.

Metabolism	Energy Source	Carbon Source	Which Organism
Photosynthesis	Light	CO ₂	Plants, algae, cyanobacteria
Chemosynthesis	Inorganic chemicals	CO ₂	Bacteria, Archaea
Heterotrophy	Organic compounds	Organic	Animals, Fungi, Protists

- Chemosynthesis is a widespread and ancient metabolism. The atmosphere of early Earth was very different than it is today; it lacked oxygen and other gases that absorb harmful radiation. This means that the ocean might have provided more a favorable habitat for early life. The first forms of chemosynthesis did not use oxygen in chemical reactions. In addition to H₂S, hydrothermal vent fluids contain methane and ammonia, which could have been used in chemosynthesis instead of oxygen. Similarly, primitive forms of photosynthesis probably used H₂S as a source of electrons. Around 2.8 billion years ago, cyanobacteria evolved a form of photosynthesis that uses oxygen. It took hundreds of millions of years for oxygen to accumulate in Earth's atmosphere, but once it did, it set the stage for all animal and plant life as we know it today, and for modern forms of chemosynthesis, such as described in the video, which require oxygen.
- In the video, we learn that chemosynthesis is at the base of the food chain in hydrothermal vent ecosystems. Chemosynthetic bacteria are the primary producers of deep-sea vent ecosystems. They rely on H₂S and other chemicals to provide the energy required to make organic compounds from inorganic carbon sources. These organic compounds, along with minerals from the vents themselves, support a much larger and more diverse community of animals than you would expect to find in the deep sea.
- Food webs are typically taught using more familiar, photosynthesis-based communities, such as grasslands, forests, or even marine tidal systems. Challenge students to consider what a food web would look like for a hydrothermal vent ecosystem. Ask students "How does the consumption of food and other organic compounds in a symbiotic relationship differ from the traditional producer-consumer relationship?"
- While students are generally familiar with the process of photosynthesis and its importance in providing food and energy for most communities, they are less familiar with the role of chemosynthesis. However, in this video, Dr. Colleen Cavanaugh says that chemosynthesis is found anywhere that H₂S and O₂ are found. What kinds of ecosystems, besides deep-sea vents, have abundant H₂S? Is there evidence for chemosynthesis in these habitats? Is there evidence of symbiosis with chemosynthetic microbes in these habitats? Have students research such questions and report their findings to the class. Some of the references at the end of this document are good places to start.
- The plume of the tube worm (see Figure 1) is functionally similar to the gill of a marine animal. It is well-supplied with blood and has a large surface area to allow O₂ and H₂S to diffuse in from the water. Once in the plume's blood, these chemicals bind hemoglobin and are transported throughout the worm's body. H₂S is toxic to cells because it inhibits respiration by interfering with cytochrome c oxidase (that's also how the poison cyanide works!). In addition, H₂S (and cyanide) has high affinity for hemoglobin. In most animals that's a problem because H₂S competes with O₂ for binding hemoglobin, so having H₂S in blood can lead to anoxia. Tube worm hemoglobin is different in that it is able to carry O₂ without being inhibited by H₂S. Inside the trophosome, H₂S is broken down by bacteria and does not have a chance to harm the worm's cells.

- Students may be familiar with other organisms that have evolved in ecosystems that lack light, such as cave fauna that lack pigmentation and sight organs. Why would such adaptations have evolved in different cave communities? Are similar adaptations also common in deep-sea vent communities? Are there adaptations to no light that have evolved in vent communities but not in cave communities?
- This guide does not use the term “prokaryotes” to refer to chemosynthetic organisms. While the term is still widely used, evolutionarily, bacteria and archaea are as different from one another as bacteria are from eukaryotes. Mounting evidence in fact shows that eukaryotes evolved from archaea.

STUDENT HANDOUT

We designed the student handout as a learning assessment that probes students’ understanding of the key concepts addressed in the film, which can be used to assess students’ prior knowledge before watching the film or to guide students as they watch the film. We encourage you to choose the use that best fits your learning objectives and your students’ needs. Moreover, because the vocabulary and concepts are complex, we encourage you to modify the handout as needed (e.g., reducing the number of questions, explanations of complicated vocabulary for English learner students).

ANSWERS

- [Key Concept A] Researchers on the first Alvin dive in 1977 were looking for
 - life on the ocean floor.
 - new habitats for humans to colonize.
 - hydrothermal vents.**
 - minerals that could be mined.
- [Key Concept A] What surprised the researchers on Alvin when they arrived at the hydrothermal vents?
 - hot water temperatures
 - volcanic activity
 - low light levels
 - an abundance of life.**
- [Key Concept D] Describe the appearance and features of the giant tube worm, *Riftia pachyptila*.
Mature *Riftia pachyptila* are long worms that can be up to 5 or 6 feet tall. They live inside a tube that is attached to the substrate. The worm can fully retract into the tube for protection, but generally its fleshy, blood-filled, bright-red plume is exposed outside the tube.
- [Key Concept D] The anatomy of the tube worms surprised Dr. Jones because
 - there were two hearts.
 - the worms had no mouth and gut.**
 - their circulatory system had hemoglobin.
 - there was no respiratory system.
- [Key Concept D] What is a trophosome?
A trophosome is an organ that houses symbiotic bacteria in tube worms. This organ replaces their digestive system, because the symbiotic bacteria living in the trophosome can provide organic nutrients and other compounds for energy and growth.

6. [Key Concepts B and C] The trophosome of *Riftia pachyptila* was found to be full of sulfur crystals. Why were there sulfur crystals in the trophosome?
- The trophosome filters toxic sulfides from the water and converts it to sulfur crystals, which are less toxic.
 - The trophosome absorbs sulfides in order to digest it for energy.
 - Giant tube worms produce and store sulfur crystals because predators don't like the taste of them.
 - Bacteria in the trophosome use sulfides as an energy source for making organic compounds, and sulfur is a byproduct of the bacterial metabolism.***
7. [Key Concept C] Compare and contrast the processes of photosynthesis and chemosynthesis in the table below.

	Photosynthesis	Chemosynthesis
Kinds of organisms that can convert energy using this process	<i>Plants and algae.</i> (The film only says plants, so if students are only using the film as a resource, they aren't likely to say algae.)	<i>Bacteria and archaea</i>
Source of energy	<i>Sunlight</i>	<i>H₂S</i>
Reactants needed for this process	CO ₂ H ₂ O	<i>H₂S</i> <i>O₂</i> <i>CO₂</i>
Chemical products of this process	C ₆ H ₁₂ O ₆ O ₂	<i>C₆H₁₂O₆</i> <i>H₂O</i> <i>S</i> (sulfur could be in any one of sulfur intermediates such as S ₂ O ₃ ²⁻ , SO ₄ ²⁻ , etc.)

8. [Key Concept C] A student read online that chemosynthesis only occurs in hydrothermal vent communities in the deep sea. Was the source the student read a reliable one? Defend your claim with information from this film.

According to the film, and specifically Dr. Cavanaugh, chemosynthesis may occur wherever there is abundant H₂S and O₂.

9. [Key Concept D] Symbiosis is defined as a close, prolonged association that is of benefit to at least one of the partners. Is the relationship between *Riftia pachyptila* and the chemosynthetic bacteria an example of symbiosis? Defend your claim with evidence. ***This is an example of symbiosis.***

"A close, prolonged association"

Riftia and the bacteria in its trophosome are definitely close; the bacteria live inside Riftia. This is also a prolonged association; once the bacteria come inside the worm, they live there (and reproduce there).

"Of benefit to at least one of the partners"

In this example, both species benefit. The worm obtains energy-rich organic compounds from the bacteria. The bacteria obtain the ingredients needed for metabolism and growth from the blood of the worm.

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AUTHORS

Satoshi Amagai, PhD, HHMI; Mary Colvard, consultant; and Keri Shingleton, PhD, Holland Hall, Tulsa, OK
Scientific review by Colleen Cavanaugh, PhD, Harvard University
Illustration by Natalya Zahn