ESS Environmental Science Institute

Extreme Life!

Lesson plan for grades K-2 Length of lesson: 45 minutes Adapted by: Louisa Torrance, Environmental Science Institute, 06/26/12 Authorship sources: NASA (extremophile card game)

SOURCES AND RESOURCES:

- NASA Extremophile Card Game & Guides <u>http://astrobio.terc.edu/samples/chpt12_act1.html</u>
- Extremophiles: Not So Extreme
 <u>http://www.space.com/175-extremophiles-extreme.html</u>
- Gelidibacter
 <u>http://www.bacterio.cict.fr/g/gelidibacter.html</u>
- Planet Distances (scale)
 <u>http://calgary.rasc.ca/images/iau0603Planets.jpg</u>

POTENTIAL CONCEPTS TEKS ADDRESSED THROUGH THIS LESSON:

- §112.11. Science, Kindergarten: B2(a) §112.12. Science, Grade 1: A4(a)
- §112.13. Science, Grade 2: A4(c), B2(e)

PERFORMANCE OBJECTIVES (in order of increasing difficulty to permit tailoring to various age groups):

Students will be able to:

- Understand that structurally simple organisms can live and thrive in extreme environments, use extremophiles vocabulary
- Create connections between natural environments on Earth and on other moons/planets
- Predict environments particular extremophiles will live in on Earth, and in space

MATERIALS (per group of four):

- Extremophile Card Game:
 - o Game Cards: PDF
 - Teacher Guide: <u>PDF</u>
 - Student Guide: PDF
- <u>Extremophile PowerPoint slides</u>
- <u>K-2 Background PowerPoint slides</u>
- Extreme Life! hand bills
- Europa prediction sheets

ESI Environmental Science Institute THE UNIVERSITY OF TEXAS AT AUSTIN

CONCEPTS:

There is potential for life in space because there are similar environments found on moons and planets that are similar to extreme environments (those possessing extreme temperatures, pressures, and environmental chemistry) on Earth. Students may be thinking in only terms of human survival, so providing examples of "extremophiles," will prepare students for thinking about how many forms life comes in, and the range of environments they are capable of living in. The card game introduces interesting and catchy vocabulary for young age groups, while also illustrating biological patterns across environments. Discussing Europa at the end of the lesson provides a relevant and exciting potential for life in our solar system.

BACKGROUND:

"Extremophiles" were coined in 1974 by a scientist named RD MacElroy to describe the microorganisms that thrived under conditions which we humans find intolerable. The word "Extremophile" comes from a combination of Greek and Latin meaning "someone who loves extremes." One of the first extremophiles to be discovered was the "thermophile," or heat loving, bacteria found in Yellowstone National Park Geysers. Other thermophiles can be found in hydrothermal vents deep beneath the ocean surface. The Archae *Pyrolobus fiimarii* can grow at a temperature of 113 C! They are able to prevent protein denaturation and breakdown of DNA, which is pretty impressive.

Yellowstone is also home to "acidophiles," or acid loving microbes. These organisms can thrive in a pH below 1! Acid mine drains are teeming with *Ferroplasma acidarmanus*, a microbe that loves to use its single cell membrane to grow under such acidic conditions.

Saline, or salt-rich water environments support "halophiles," the salt loving organisms. *Dunaliella salina* is an interesting algae which grows in sea salt fields, such as the South San Francisco Bay. They contain compounds that allow a balance of salt concentrations inside their membranes and the surrounding water.

Freezing, polar seas are also home to microbes, called "psychrophiles." Thanks to ocean salt, water can drop below it's typical freezing point of 0 C. Organisms living here are able to adapt the chemistry of their cell membranes to stay flexible and fluid.

Several species of microbes are even able to withstand high UV radiation, either on mountaintops, or in space. Excellent repair mechanisms assist with the damage caused by such high radiation. *Deinococcus radiodurans,* a radiation resistant bacteria, was actually discovered in 1956, and was shown to grow under 60 Gy radiation. For perspective, 5 Gy is lethal to a human! Learning about where extremophiles live on Earth and how they adapt to these regions is not only interesting to study, but is also important for questioning the possibility of extraterrestrial life! Juxtaposing environments of planets, moons, and asteroids in space with extreme environments on Earth is a logical step in predicting the potential for life.



PREPARATION:

Have cards shuffled and prepared for student groups, along with enough hand bills for each student.

ENGAGE:

Teacher asks: What's the temperature like today? Does it feel good? What kind of places have really *extreme* temperatures? If you wanted to live there, would you be able to without any help?

Well guess what – LIFE IS EVERYWHERE! But maybe not the kind of life you and I are used to...

The awesome life that lives in hot springs, super salty lakes, freezing polar seas, and even in space – is smaller than the eye can see. These organisms are called extremophiles, and are tiny, very simple, and are smaller than we can see. They thrive in places that you and I could not live in. Just because you can't see an organism, doesn't mean it isn't there!

Are you an extremophile? *Thermus aquaticus* is a bacteria that can live in water that's 160 F! (Teachers can display the PowerPoint Slide of Extremophiles (see Materials) What would happen if *you* took a bath in water that hot? [Ouch!]

Gelidibacter algens (Teacher advances to Slide #2 of Extremophiles PowerPoint) lives in the sea ice and doesn't freeze – in fact they enjoy it! No sweater needed.

Further probing questions for the class: Where is somewhere really hot? [Volcanoes, deserts] Where is somewhere really cold? [Antarctica, snow capped mountains, icebergs] Where is somewhere really salty? [The ocean, Great Salt Lake] What about somewhere...not on Earth? (Teacher advances to Slide #3 of Extremophiles PowerPoint)

EXPLORE:

- 1. Prepare card stacks to be shuffled thoroughly and given to a group of 4 students. Before handing out cards, give groups a step by step sheet on the rules of the game (see Materials). Give an example of a matching set and explain why each card belongs together.
- 2. Give students 15 minutes to organize card groups. Assist groups by suggesting common words between the organism, earth environment, and space environment.

ESI Environmental Science Institute

THE UNIVERSITY OF TEXAS AT AUSTIN

- After all groups are made, hand out the categorized Extreme Life! hand bills (see Materials). These will
 provide names to each kind of extremophile. Read the hand bills aloud, and practice saying the names.
 Give students a minute to review their matches with the hand bills.
- 4. Have each group explain to the class one of the groupings they made, from any of the categories. All of the other students listen and hold up the hand sign they think matches. Continue until all categories have been represented.

EXPLAIN:

Teacher asks

- How many kinds of *extremophiles* did we find? Did any of the groups only exist on Earth, or were there also places in space?
- According to our study with the cards, there are organisms that can live in very extreme environments on Earth. BUT there are ALSO places in space that have the same kind of environment! These places would be great places to start looking for life!
- The life that we would find there looks VERY different from us. It is small, simple, and microbial. Just because an environment cannot sustain humans, doesn't mean life isn't there. Life is everywhere!

ELABORATE:

- 1. Hand out Europa prediction sheets (see Materials) to each group. Have a student be the Explorer to answer question 1, an Earth scientist for question 2, an Ice scientist for number 3, and a Heat scientist for number 4.
- 2. Have students study the unlabled photos of Europa and Antarctica. Have students guess which is which. Ask students to describe the environment (icy, grassy, etc).
- 3. Show the planets and where Europa is in relation to Earth. Ask students how Europa is different than Earth. [Smaller, a moon, farther from the sun].
- 4. Explain that on Europa, there is ice, and there is evidence of water heated from geophysical forces. Even though Europa is very far from the sun, could it have life? What kind of extremophiles might we find (using vocabulary from hand bills)?

EVALUATE:

Have students turn in completed prediction sheets at the end of class.

Game Cards

Organism Card	Organism Card
Acid-loving Bacteria	Acid-loving Bacteria
Little Known Fact: Scientists have found bacteria living at 0.0 pH growing on the walls of caves. Most organisms live within a pH range of 5-8.	Little Known Fact: Scientists have found bacteria living at 0.0 pH growing on the walls of caves. Most organisms live within a pH range of 5-8.
Organism Card	Organism Card
Salt-Loving Bacteria	Cold-Loving Bacteria
Little Known Fact: Scientists have found halophilic bacteria living in water that is 30% salt. By comparison, seawater and human blood are about 3.5% salt.	Little Known Fact: Scientists have found Cryotendolithotrophs living at minus 15 degrees Celsius. Earth's average tempera- ture is 15 degrees Celsius.
Organism Card	Organism Card
Salt-Loving Bacteria	Salt-Loving Bacteria
Little Known Fact: Scientists have found halophilic bacteria living in water that is 30% salt. By comparison, seawater and human blood are about 3.5% salt.	Little Known Fact: Scientists have found halophilic bacteria living in water that is 30% salt. By comparison, seawater and human blood are about 3.5% salt.
Organism Card Heat-Loving Bacteria Little Known Fact: Scientists have found Pyrococccus furiosus living in 113°C water.	Organism Card Heat-Loving Bacteria Little Known Fact: Scientists have found Pyrococccus furiosus living in 113°C water.
Organism Card	Organism Card
Heat-Loving Bacteria	Heat-Loving Bacteria
Little Known Fact:Scientists have found Pyrococccus furiosus living in 113°C water.	Little Known Fact: Scientists have found Pyrococccus furiosus living in 113°C water.
Radiation-Tolerant Bacteria	Radiation-Tolerant Bacteria
Little Known Fact: Scientists have found Deinococcus radio- durans living after being exposed to radiation levels of five million rads. It can tolerate high levels of both ultraviolet radiation and radioactive decay. The lethal dose for humans is 1000 rads.	Little Known Fact: Scientists have found Deinococcus radio- durans living after being exposed to radiation levels of five million rads. It can tolerate high levels of both ultraviolet radiation and radioactive decay. The lethal dose for humans is 1000 rads.

Organism Card	Organism Card	
Radiation-Tolerant Bacteria	Cold-Loving Bacteria	
Little Known Fact: Scientists have found Deinococcus radio- durans living after being exposed to radiation levels of five million rads. It can tolerate high levels of both ultraviolet radiation and radioactive decay. The lethal dose for humans is 1000 rads.	Little Known Fact: Scientists have found Cryotendolithotrophs living at minus 15 degrees Celsius. Earth's average tempera- ture is 15 degrees Celsius.	
Organism Card	Organism Card	
Cold-Loving Bacteria	Cold-Loving Bacteria	
Little Known Fact: Scientists have found Cryotendolithotrophs living at minus 15 degrees Celsius. Earth's average tempera- ture is 15 degrees Celsius.	Little Known Fact: Scientists have found Cryotendolithotrophs living at minus 15 degrees Celsius. Earth's average tempera- ture is 15 degrees Celsius.	
Earth Habitat Card	Earth Habitat Card	
Hot springs occur when groundwater is heated and rises to the surface.	Processes in Earth's crust produce extremely hot groundwa- ter.	
	E	
Earth Habitat Card	Earth Habitat Card	
Contact between volcanic magma and underground water produces pockets of hot water	The Arctic tundra has a layer of permafrost beneath it. Perma- frost is soil locked in water ice.	
E	Ē	
Earth Habitat Card	Earth Habitat Card	
Natural deposits of uranium can produce high levels of radia- tion.	When our atmosphere's ozone layer gets thin, Earth's surface can receive dangerous levels of harmful ultraviolet radiation.	
	E	
Earth Habitat Card	Earth Habitat Card	
Acidic groundwater is found beneath much of Earth's surface.	Acidic groundwater dissolves certain kinds of rocks, forming caves and producing an acidic environment for life.	
E	E	

Earth Habitat Card	Earth Habitat Card
Salt occurs in Earth's ocean water. The amount of salt in seawater is about four percent.	Radiation in Earth's crust comes from the decay of radioac- tive elements such as uranium.
F	E
Earth Habitat Card	Earth Habitat Card
Salt domes and brine (salty water) are often found in asso- ciation with petroleum deposits.	The Arctic ice cap is made of water ice.
F	E
Earth Habitat Card	Earth Habitat Card
Water ice over two kilometers thick covers Antarctica. The coldest temperature on Earth, minus 89 degrees Celsius, was recorded in Antarctica.	Greenland is covered with a two-kilometer-thick sheet of water ice.
E	E
Earth Habitat Card	Earth Habitat Card
The evaporation of large bodies of salt water has covered large areas of land with thick layers of salt.	Volcanic vents occur all along the 17,000 miles of Earth's mid-oceanic ridges. The water injected into the ocean environment is extremely hot.
E	E
Dossible Extratorrostrial Habitat Card	Possible Extratorrostrial Wabitat Card
Just beneath Europa's surface, there may be large pockets of salty brine.	volcanic activity. This combination would likely produce hot springs and underground pockets of hot water.
E	
Possible Extraterrestrial Habitat Card	Possible Extraterrestrial Habitat Card
Europa's ocean is probably very salty.	The decay of radioactive elements such as uranium in the Martian crust would generate high levels of radiation.

Possible Extraterrestrial Habitat Card	Possible Extraterrestrial Habitat Card
Mars may have a layer of water beneath its surface. On Earth, such groundwater is often acidic.	Acidic groundwater dissolves certain kinds of rocks, forming caves. Mars may have these kinds of rocks, resulting in an acidic environment for life.
Possible Extraterrestrial Habitat Card	Possible Extraterrestrial Habitat Card
Ultraviolet radiation and charged particles from the sun bom- bard the surface of Mars, which is completely unprotected from these kinds of harmful radiation.	Salt layers form when large bodies of salty water evaporate. Mars may have had large bodies of water that have since evaporated, possibly leaving layers of salt
Possible Extraterrestrial Habitat Card	Possible Extraterrestrial Habitat Card
Ultraviolet radiation bombards the surface of Europa, which is completely unprotected from this kind of harmful radiation.	Processes in the Martian crust may heat water below the surface, producing pockets of hot groundwater.
H	(F)
Possible Extraterrestrial Habitat Card	Possible Extraterrestrial Habitat Card
The Martian Polar Ice Cap is made of water ice.	The core of the Martian Southern Polar Ice Cap seems to be made of water ice.
H	
Possible Extraterrestrial Habitat Card	Possible Extraterrestrial Habitat Card
Most of the Martian surface has a layer of permafrost beneath it. Permafrost is soil locked in water ice.	Europa is completely covered by a one- to ten-kilometer thick shell of water ice.
(H)	
Possible Extraterrestrial Habitat Card	Possible Extraterrestrial Habitat Card
Evidence suggests that Europa may have considerable vol- canic activity beneath its ocean. This volcanic activity would	The Martian surface has deposits of a kind of iron oxide called hematite. Hematite is often associated with organisms





Project Director Jeffrey F. Lockwood, Ed.D.

Authors

Jodi E. Asbell-Clarke Daniel W. Barstow Teon E. Edwards James L. Larsen Jeffrey F. Lockwood Christopher H. Randall

Contributing Author

Brian Drayton

Principal Investigators

Dan Barstow – TERC David DesMarais – NASA Ames Paul Andres – Jet Propulsion Laboratory

This curriculum was developed by TERC, Cambridge, Massachusetts. Funded in part by a grant from the National Science Foundation.



Copyright © 2005 TERC, 2067 Massachusetts Avenue, Cambridge, MA 02140, 617.547.0430

ISBN 1-929877-00-5

Printed by Ambit Press, 5 Cambridge Center, Cambridge, MA 02142 617.876.3688



This material is based upon work supported by the National Science Foundation under Grant No. ESI9730728. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect views of the National Science Foundation.



Extreme Life Card Game

Purpose

To show that organisms living under extreme conditions on Earth can serve as analogs for extraterrestrial life

Overview

The teacher introduces today's games by playing *Concentration* with a special deck of 15 large-sized extremophile playing cards. Students make sets by matching three different kinds of cards—an *Organism* card, an *Earth Habitat* card, and a *Possible Extraterrestrial Habitat* card. A complete set illustrates the idea that if life can exist under extreme conditions on Earth, then it is conceivable that organisms might live under similar conditions on other worlds. Once they understand how to use the cards, students play *Go Fish* and *Concentration* with a similar deck of 48 cards.

Time: 100 minutes

Context

This activity explores some of the reasons for thinking that extraterrestrial life is possible. In doing so, it draws on concepts developed earlier in the course, such as understanding what life is, what it requires, and what makes a planet habitable. Students organized life-related factors into a concept map in Activity 1. In the next activity, students will estimate the amount of life in the universe, expanding their thinking about life elsewhere in the solar system.

Key Concepts

- Any search for extraterrestrial life must be based on what we know about life on Earth.
- Extremophiles live at the limits of what life's chemistry is able to tolerate.
- Places that mirror Earth's life-sustaining environments may harbor life.
- As we explore the solar system, we are finding evidence for habitable conditions.
- If extraterrestrial life is found in our solar system, it will most likely be microbial and inhabit environments considered extreme on Earth.

Key Skills

- Drawing conclusions and making inferences when creating sets
- Using extremophiles as analogs for extraterrestrial life
- *Conceptualizing* a plausible mission (optional)
- *Debating* the ethics of sending Earth life to another world (optional)

Materials

- Scissors (for teacher)
- Rubber bands (optional)
- Laminating materials (optional)
- BLM—Game Cards

Background

The assumption at work both in the search for extraterrestrial life and in this activity is that Earth's extremophiles can serve as models for life elsewhere. It is plausible to think that we may find evidence of life in any place that mirrors Earth's life-sustaining environments. In this activity, students play a card game. They match an extreme habitat on Earth with an extremophile that lives under those conditions. They then identify an extraterrestrial habitat similar to the Earth habitat. By grouping these three elements, students realize that promising extraterrestrial habitats, and maybe extraterrestrial life itself, may exist. Additionally, students ultimately grasp that if extraterrestrial life is found in our solar system, it will most likely resemble one of Earth's extremophile microbes.

Preparation

Make a copy of the Game Cards (BLM) for each team of 2-4 students.

- Cut out the cards.
- If possible, laminate the cards to make them reusable.
- Use rubber bands or other means to keep each set together.

Recommended Procedures

1. Introduce students to extremophiles

- a. Have students look at the table in *What's the Story*? to become familiar with some of the chemical and physical extremes tolerated by life.
- b. Conduct a brief class discussion to make sure students understand:
 - what extremophiles are
 - extremophiles require that the extreme conditions be ongoing. With extremophiles, we are talking about long-term conditions rather than short-term, one-time exposures.
 - the range of conditions that life can tolerate.
- 2. Introduce students to the Game Cards.
 - a. Have students read the directions in the Student Guide or demonstrate the games for the class.

- b. Make sure they understand:
- what constitutes a set—the three cards in a set are linked by a particular environmental condition
- that there are duplicates of the organism cards
- that the habitats described on the *Possible Extraterrestrial Habitat* cards are speculations based on current data. Confirming the existence of most of the features described on these cards requires further exploration.
- that, to date, no extraterrestrial life has been found. Matching specific Earth organisms to extraterrestrial habitats is an exercise in imagining how adaptations that help organisms succeed in harsh Earth environments might also help organisms survive harsh conditions on other worlds.
- 3. Have small groups of students play the games.
- 4. Conclude the activity.
 - a. Have students read What's the Story? Meet the Champions.
 - b. Have students answer the *Think About It* questions on their own, in groups, as homework, or as a class.
 - c. Discuss the Think About It questions.

Think About It

1. How can life and conditions on Earth be used as a model for life on other worlds?

If a habitat on another world poses challenges similar to one found on Earth, and life has evolved to sustain itself in that Earth habitat, it follows that this extraterrestrial life will be similar to what we find on Earth.

2. If you could genetically engineer new extremophiles that combined the traits of two different kinds of extremophiles, which two traits would you merge if your extremophile were sent to live on Mars? On Europa? Explain why you chose the traits you did for each world.

Be open to any possibility that makes sense and is explained well. Students should draw on the information presented in the What's the Story? and on the Organism, Earth Habitat, and Possible Extraterrestrial Habitat cards. For Mars and Europa, a student might want to combine a radiation-tolerant bacterium with a cold-tolerant bacterium, because the surface of both worlds have a high incidence of radiation and are extremely cold.

3. Describe the kind of extraterrestrial life we are most likely to find in our solar system. Why do you think it is the most likely kind?

If we find life, it most likely will be microbial. Microbial life is diverse and simple enough to adapt to just about any environment. For example, microbes are the major inhabitants of Earth's extreme environments. Conditions on other worlds in our solar system can be similar to the extreme conditions found on Earth. Thus, it is possible that any life forms we find will be similar to those on Earth that have met similar challenges. 4. What would finding evidence of microbial life on another world suggest about life in general?

The simplest answer is that finding life on other worlds suggests that if conditions are right, life will evolve anywhere. If the life is similar to what we find on Earth, then life may be based on the same basic plan. The discovery of evidence of extraterrestrial microbial life might usher in new thinking about how life may travel from world to world.

5. Draw two pictures. One should show the kind of extraterrestrial life we might reasonably expect to find in our solar system. The other should show what you think most people imagine is out there. If the drawings are different, explain why you think they are different.

Students should be able to differentiate between what scientists believe are the most likely candidates for extraterrestrial life—prokaryotes—and the popular belief that life will be some kind of UFO–driving humanoid like those depicted on television or in movies.





Project Director Jeffrey F. Lockwood, Ed.D.

Authors

Jodi E. Asbell-Clarke Daniel W. Barstow Teon E. Edwards James L. Larsen Jeffrey F. Lockwood Christopher H. Randall

Contributing Author

Brian Drayton

Principal Investigators

Dan Barstow – TERC David DesMarais – NASA Ames Paul Andres – Jet Propulsion Laboratory

This curriculum was developed by TERC, Cambridge, Massachusetts. Funded in part by a grant from the National Science Foundation.



Copyright © 2005 TERC, 2067 Massachusetts Avenue, Cambridge, MA 02140, 617.547.0430

ISBN 1-929877-00-5

Printed by Ambit Press, 5 Cambridge Center, Cambridge, MA 02142 617.876.3688



This material is based upon work supported by the National Science Foundation under Grant No. ESI9730728. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect views of the National Science Foundation.



Extreme Life Card Game

Our solar system has nine planets and over 80 moons. Of all these worlds, only Earth is known to have life. Consequently, we must base any search for extraterrestrial life on what we know about life here. Starting around 1980, we began discovering organisms living in places once considered extreme and uninhabitable. These bacteria and bacteria-like organisms are called **extremophiles** (philia is Greek for "love"). No one expected to find organisms living under such extreme conditions, which shows how much we still have to learn about life!



Figure 12-3: These microscopic organisms live in caves under highly acidic conditions.

If life on Earth can thrive under extreme conditions, then might organisms live under similar conditions on other worlds? As we explore the solar system, we find evidence of conditions that may support extremophiles. Consequently, Earth's extremophiles may serve as models for life elsewhere.

What You Need to Do

- 1. Read *Rules for Life on the Edge Card Games*, which describes the different card games you can play in this activity.
- 2. Get a pack of game cards from your teacher and play the game of *Concentration* or *Go Fish*. During the game, pay attention to each set that is made.
- 3. Read What's the Story? Meet the Champions, and answer the Think About It questions.

Learning Threads: Scientific Inquiry

Scientific inquiry includes formulating and revising scientific explanations and models using logic and evidence.

Learning Threads: Habitability

Organisms have specific requirements for life that must be provided by their habitat, including energy sources, water, and raw materials that are available in a form that is usable to the organisms.



What's the Story?

Meet the Champions: Extremophiles

Thanks to advancing technology, the past 20 years have seen the discovery of prokaryotes living under conditions we consider extreme and uninhabitable. **Extremophiles** are bacteria and archaea that tolerate conditions we find harsh. Of course, whether an environment is extreme depends on how well adapted you are to it. Many kinds of extremophiles would die in conditions we like—we are extremophiles to them! The table below lists some extremophiles and the chemical or physical extremes they tolerate.



Figure 12-4: Coring into the Antarctic ice sheet to collect cold-loving extremophiles

Hottest	113°C	<i>Pyrolobus fumarii</i> (Volcano Island, Italy). Earth's average surface temperature is 15°C.
Coldest	-15°C	Crypotendoliths (Antarctica)
Deepest underground	3.2 km	These bacteria live in the spaces between rock grains in Earth's crust and are exposed to high levels of pressure, heat, and radiation.
Most acidic	рН 0.0	These bacteria grow in caves. The acid-base scale is called the pH scale, where 0 is the most acidic and 14 is the most basic. Most life lives within a pH range of 5 to 8.
Most basic	рН 11	These bacteria are found in areas where large bodies of water have evaporated, leaving behind layers of basic minerals.
Highest radiation dose	5 million rads	<i>Deinococcus radiodurans</i> is a common soil organism. A dose of 1000 rads will kill a person. Less than 1 rad per year is normal and zero rads is ideal.
Longest in space	6 years	<i>Bacillus subtilis</i> lived for six years in an orbiting NASA satellite that exposed test organisms to the extreme conditions of outer space.
Highest pressure	1200 times atmospheric pressure	These bacteria live at the bottom of the Marianas Trench, the deepest point beneath Earth's oceans. Typically, atmospheric pressure at sea level is 1013 millibars (14.7 pounds per sq. inch)
Saltiest	30% salt	Halophilic bacteria live in water with a 30% salt content. By compari- son, seawater and human blood are about 3.5% salt. Fresh water has virtually no salt.

Why are all the extremophiles in the table bacteria or bacteria-like organisms? Why are they not more like cockroaches, plants, or us? The reason is that these simple prokaryotes can survive the harsh conditions much better than more complex multicellular life can. With fewer parts and fewer internal processes to coordinate, less can go wrong. When something does go wrong, it is easier to repair the damage and keep the organism alive.



Figure 12-5: These bacteria live in tubeworms found at hydrothermal vents. Extreme temperatures and pressures are part of the challenge to life in this environment.

Extremophiles live at the limits of what life's chemistry is able to tolerate. If organisms on Earth can thrive under harsh conditions, then one might reasonably expect that similar conditions on other worlds might support life, as well. In fact, as we explore our solar system, we find mounting evidence for extraterrestrial conditions that may support extremophiles. It is plausible to think that we may find evidence of life in any place that mirrors Earth's lifesustaining environments. Some people will only be happy once we find a Hollywood-style extraterrestrial. However, astrobiologists would be ecstatic if we found evidence of even a simple microbe anywhere beyond Earth. That would suggest that life occurs whenever the conditions are right. Furthermore, once microbes inhabit a world, more advanced life can begin to develop. The first life on Earth was microbial, and look at us now!



Figure 12-6: Cold-loving bacteria

Checking In

- 1. What is an extremophile?
- 2. Could humans be considered extremophiles? Explain.
- 3. Why are extremophiles more likely to be bacteria or bacteria-like?
- 4. Create a table showing the maximum (a) temperature, (b) acid, (c) base, (d) salt, and (e) radiation levels that life can tolerate. Also, show the typical level that humans tolerate.

Rules for Life on the Edge Card Games

The games in today's activity show how life and conditions on Earth can be used as a model for life on other worlds. In this deck, there are three kinds of cards:

Card Type 1: Organism Card	Card Type 2: Earth Habitat Card	Card Type 3: Possible Extraterrestrial Habitat Card
extremophile	where this extremophile lives	habitat similar to the Earth habi- tat that could be home to the organism on the Organism card

Making a Set

In each game described below, you need to make sets. A set requires that you match one of each kind of card shown above. For example, the organism on the *Organism* card must be able to live in the environment shown on the *Earth Habitat* card. To complete the set, the habitat on the *Possible Extraterrestrial Habitat* card must be similar to the habitat on the *Earth Habitat* card. In a valid set, the organism can live in the Earth environment and possibly in the extraterrestrial habitat.

Condition	Number of sets in the deck
Hot	4
Cold	4
Acid	2
Salt	3
Radiation	3

Game 1: Go Fish

- Deal five cards to each player. Place the remaining cards face down for a draw deck.
- The first player tries to build or complete a set by asking any other player for a particular card. For example, he or she might ask, "Do you have the card for an organism that loves salt?"

If the person asked has such a card, he or she must give it. If not, that person says, "Go fish," and the first player takes the card from the top of the draw deck.

- The player checks whether he or she now has a valid set. If (s)he does, (s)he must lay it down and explain why it is valid. Other players can challenge the set if they disagree. Any disagreement is resolved by a group vote.
- Play continues in a clockwise fashion. The game ends when someone gets rid of all his or her cards. The person with the most sets wins.

Game 2: Concentration

- Place all 48 cards face down, one at a time, in a neat arrangement.
- The first player turns over three cards.

If the cards do not form a set, turn the cards back over.

If the three cards form a set, the person who turned them over must decide if the set is valid, and if it is, explain why. Other players can challenge the set if they disagree. Cards are left face up or removed from the play area once they are matched.

• Play continues in a clockwise fashion. The game ends when all 16 sets have been formed. The player with the most sets wins.



Think and Reflect

Think About It

- 1. How can life and conditions on Earth be used as a model for life on other worlds?
- 2. If you could genetically engineer new extremophiles that combined the traits of two different kinds of extremophiles, which two traits would you merge if your extremophile were sent to live on Mars? On Europa? Explain why you chose the traits you did for each world.
- 3. Describe the kind of extraterrestrial life we are most likely to find in our solar system. Why do you think it is the most likely kind?
- 4. What would finding evidence of microbial life on another world suggest about life in general?
- 5. Draw two pictures. One should show the kind of extraterrestrial life we might reasonably expect to find in our solar system. The other should show what you think most people imagine is out there. If the drawings are different, explain why you think they are different.

Reflecting on the Activity and the Challenge

Scientists are interested in Earth's analogs as a way to understand the kind of life we may expect to find in similar environments that may be present on other worlds in our solar system. For example, Earth's hydrothermal vents support life forms that derive their energy and carbon from sources that may be similar to habitats that might lie below the ice on an ocean floor found on Jupiter's moon Europa. Are any of the habitats you studied in this activity similar to those found on your world? Which organisms found on Earth might serve as analogs for the organisms you design to inhabit your world?

THERMOPHILE! (loves heat)

PYSCHROPHILE! (loves cold)

HALOPHILE! (Ioves salt)

RADIORESISTANT! (loves radiation)

ACIDOPHILE! (loves acid)

Extreme Life on Europa!

1. EXPLORER: under the photo, write "Earth" or "Europa".



What kind of environment do these photos look like? Hot? Cold? Wet?

2. EARTH SCIENTIST: What is different between Europa and Earth?

3. ICE SCIENTIST: Could Europa have life here? What kind of life?

4. HEAT SCIENTIST: Could Europa have life here? What kind of life?