

THE EXTREME ENVIRONMENTS OF EARTH AND THE CREATURES THAT LIVE THERE

GOALS

- Explore the environmental conditions that limit life on Earth
- Identify the characteristics of different extremophiles
- Explore optimum environmental conditions in which extremophiles thrive
- Consider cause and effect relationship between environment and organism success within that environment
- Learn about extreme environments within our solar system and reason about the possibility of life within those environments

PART A: INTRODUCTION TO EXTREMOPHILES

1. As a group, *describe* environments on Earth that you believe would not allow any form of life to exist. List specific examples, and explain *why* these environments cannot support life.

2. After surveying a large number of college and high school aged students, it was discovered that the three most common environments listed as being unable to support life were (1) environments in which there is no oxygen, (2) environments with extreme temperature (too hot/too cold), and (3) environments without access to water.
 - a. Did your group include any of these environments? Which ones?

 - b. If not, do you feel that you should have? Explain why or why not.

3. Scientists are currently searching for life on other planets and moons both within and outside our solar system. What types of life forms do you think they are most likely to find (1) animals, (2) plants, or (3) microorganisms? Explain your reasoning.

Activity 3

4. Refer to the pages entitled *Extremophile Data Sheet* found at the end of this activity. Carefully read through the information provided. Use this information to complete the *Extremophile Data Table* also found at the end of this activity.
5. Now that you have read the information sheets and completed the chart, refer back to the environments listed in question 2. Do you think that any of these environments *actually* present conditions too extreme for life to exist? Explain why you think so.
6. During class, you overhear two students discussing extremophiles. Carefully read the discussion below and answer the following question.

Student #1: Xerophiles are extremophiles that prefer environments that are very dry. They can live in places that never have any water.

Student #2: I disagree. Although xerophiles do thrive in extremely dry environments, they need at least a little water part of the time in order to survive. I think all life as we know it needs some water to live.

Do you agree or disagree with either or both of the students? Explain your reasoning for each.

7. What is the greatest temperature in which extremophiles are known to live? What do we call the extremophiles that prefer living in these temperatures?
8. What is the lowest temperature in which extremophiles are known to live? What do we call the extremophiles that prefer living in these temperatures?
9. What are the names of the two types of extremophiles that can live in each of the conditions of extreme pH? What are the pH ranges in which they live?

10. What is the one environmental condition that *all life* needs in order to survive on Earth?

PART B: WHO LIVES WHERE?

In this activity you will investigate three hypothetical environments and three bacterial life forms. For each environment and bacteria, we have provided a table (on the following page) with a partial list of characteristics that describe: (1) how the different environments support life and (2) the different needs of each bacteria that allow it to thrive in a particular environment. You will examine the characteristics that are provided for each environment and bacteria and then, based on this information, complete each table by deciding which type of bacteria can live in each of the environments.

In the first column of the table below we have listed the essential characteristics that you will need to consider when trying to match a bacteria and its environment. In the column next to each characteristic are the possible ranges of values for each characteristic.

CHARACTERISTICS	RANGE OF VALUES
Temperature	0°C – 100°C
Salinity	Low, Medium or High <5% to 25%
pH level	1 – 14 (pure water has a pH of 7)
Energy Sources/Requirements	Sunlight (photons) or Chemical Potential (energy)
Carbon Sources/Requirements	Organic (sugars/proteins/fats) or Inorganic (CO ₂ or HCO ₃)
Oxygen provided by the environment or used by bacteria	Yes or No

1. First, decide which bacteria type (A, B, or C) match each environment (X, Y, or Z). Only one type of bacteria match each environment. Once you have matched each type of bacteria with a single environment, completely fill in all the blanks in each of the tables with the corresponding information provided.

Environment X

Temperature	2°C
Salinity	12%
pH level	
Energy Source	Light-Photons
Carbon Source	Inorganic
Oxygen Provided	

Environment Y

Temperature	90°C
Salinity	12%
pH level	
Energy Source	
Carbon Source	Inorganic
Oxygen Provided	No

Environment Z

Temperature	25°C
Salinity	22%
pH level	
Energy Source	
Carbon Source	Organic
Oxygen Provided	No

Bacteria Type A

Preferred Temperature	20°C – 30°C
Preferred Salinity	
Preferred pH level	7
Energy Source used	Chemical Potential
Carbon Source used	
Oxygen needed	

Bacteria Type B

Preferred Temperature	
Preferred Salinity	
Preferred pH level	7
Energy Source used	
Carbon Source used	CO ₂
Oxygen needed	Yes

Bacteria Type C

Preferred Temperature	
Preferred Salinity	
Preferred pH level	3
Energy Source used	Chemical Potential
Carbon Source used	CO ₂
Oxygen needed	

2. State which bacteria type (A, B, or C) you decided could live in which environment (X, Y, or Z).

3. Now that you have completed each of your environment cards, state each of the conditions that make it an extreme environment. It is not necessary to consider the energy source or the carbon source in this description. (Note: You may want to revisit the definition of extreme environments in the first paragraph of your *Extremophiles Data Sheet*)

Environment X:

Environment Y:

Environment Z:

4. For bacteria type A, which of the conditions of the other two environments made them too extreme for bacteria type A to survive? (In what ways does bacteria type A not match these environments?)

Environment __:

Environment __:

5. For bacteria type B, which of the conditions of the other two environments made them too extreme for bacteria type B to survive? (In what ways does bacteria type B not match these environments?)

Environment __:

Environment __:

6. For bacteria type C, which of the conditions of the other two environments made them too extreme for bacteria type C to survive? (In what ways does bacteria type C not match these environments?)

Environment __:

Environment __:

Activity 3

7. If the number of photons that arrive at environment Y were to decrease to nearly zero would the bacteria that you chose still be able to thrive in this environment? Explain why or why not.

8. Would your answer to question 7 change if we were instead considering environment X or Z and the corresponding bacteria? Explain your reasoning.

9. If the bacteria you chose to pair with environment Z was placed in an environment without oxygen, would the bacteria that you chose still be able to thrive? Explain why or why not.

10. Would your answer to question 9 change if we were instead considering the bacteria you chose to pair with environment X or Y? Explain your reasoning.

11. Are the bacteria you considered in questions 9 and 10 aerobic bacteria or anaerobic?

12. Which type of bacteria (A, B, or C) uses a carbon source that is organic and which type uses a source of inorganic carbon?

13. Which of these hypothetical bacteria (A, B, or C) is a:

Thermophile: ____

Psychrophile: ____

Halophile: ____

Activity 3

4. During class, your professor tells you that many Jupiter-sized planets have been discovered orbiting other stars in our galaxy. She describes that some of these gas giant planets are close enough to their companion stars that the planet's average temperature could be high enough for the presence of liquid water. You subsequently overhear two students discussing the possibility of finding life in the galaxy. Carefully read the discussion below and answer the following question.

Student #1: I don't think there's any chance life can be found on any of these newly discovered gas giants because there isn't any water or even any surface for life to form on. Discovering Jupiter-sized planets won't ever lead to us finding life outside our solar system.

Student #2: I disagree. It's not about the possibility of finding life on the Jupiter-sized planets. Big planets like Jupiter can also have lots of moons orbiting them. That is where we might find life.

Do you agree or disagree with either or both of the students? Explain your reasoning for each.

Extremophile Data Sheet

Can you imagine living in an environment as salty as the Dead Sea? Or how about a place where the temperature is continually below the freezing point of water? Could you survive in an environment without oxygen? The term *extreme environment* is used to describe any environment that is extreme with respect to human tolerances. Human existence would be difficult at best in any of these conditions. However, scientists have found that life, in some form, exists in virtually every environment on Earth. Most of this life is in the form of microorganisms. Microorganisms that thrive in extreme environments are called *extremophiles*. Extremophiles are further classified according to the environments in which they thrive. Examples of specific extremophile classifications are thermophiles, psychrophiles, acidophiles, alkalophiles, barophiles, xerophiles, halophiles, and anaerobes. Listed below is information about each of these extremophiles, including optimum conditions for existence as well as examples of specific microorganisms.

Thermophiles (*hot-loving*):

Preferred Environmental Conditions

- These microorganisms not only survive in areas of high temperature, they thrive there.
- Temperature Range: 42°C to 113°C (107°F to 236°F)
- Thrive in temperatures well over the boiling point of water!

Preferred Environments

- Bottom of the ocean near geothermal vents
- Hot springs in Yellowstone National Park

Examples of Thermophilic Microorganisms

- Thermus aquaticus* – organism famously used in polymerase chain reaction (PCR) that enables geneticists to amplify DNA
- Pyrolobus fumarii* – microorganism that has an optimum growth temperature of 106°C. This hearty critter has been known to survive the extreme temperatures of autoclaving (121°C) for over an hour. (Autoclaving is a process used to sterilize hospital equipment.)

Psychrophiles (*cold-loving*):

Preferred Environmental Conditions

- Microorganisms that live in temperatures that linger around the freezing point of water and sometimes lower!
- Temperature Range: -3°C to 20°C (26°F to 68°F)

Preferred Environments

- Antarctic snowfields
- Surface of glaciers
- Deep in ocean away from hydrothermal vents (constant temperature of 1°C-3°C)

Extremophile Data Sheet

Examples of Psychrophilic Microorganisms

- Heteromita globosa* – found in the snowfields in Antarctica
- Chlamydomonas nivalis* – snow algae known to turn the surface of glaciers pinkish-red

Acidophiles (*acid-loving*):

Preferred Environmental Conditions

- Microorganisms that thrive in extremely acidic conditions. These critters actually prefer to live in liquids similar to sulfuric acid!
- pH Range: less than pH 5

Preferred Environments

- Sulfur hot pots of Yellowstone National Park
- Volcanic soils
- Gastric fluids of the stomach

Examples of Acidophilic Microorganisms

- Cyanidium caldarium* - organism that can grow (albeit slowly) in a pH as low as ZERO
- The *Sulfolobus* species – lives in a preferred pH of less than 2, found in Yellowstone hot pots

Alkalophiles (*base-loving*):

Preferred Environmental Conditions

- Microorganisms that prefer to live in very alkaline environments
- pH Range: greater than pH 9

Preferred Environments

- Soda lakes in Africa
- Soils with high carbonate soils

Examples of Alkalophilic Microorganisms

- Spirulina* – a cyanobacteria found living in a soda lake with pH ~10

Extremophile Data Sheet

Barophiles (*pressure-loving*):

Preferred Environmental Conditions

- These microorganisms thrive under high pressure
- Pressure Range: pressures hundreds of times greater than 1 atm (Note: We exist surrounded by a pressure of about 1 atm at sea level)

Preferred Environments

- Deep ocean environments
- Equipment sterilized using high pressure

Examples of Barophilic Microorganisms

- Entire eukaryotic communities on the continental shelf
- Sea Cucumbers
- Microorganisms around deep sea black smokers

Xerophiles (*dry-loving*):

Preferred Environmental Conditions

- Microorganisms that grow in *extremely* dry environments with only intermittent moisture

Preferred Environments

- Deserts
- Antarctica dry valleys
- Cereals, dried fruit, candy
- On stones

Examples of Xerophilic Microorganisms

- Xeromyces bisporus* – xerophilic fungi living on dried foods
- Metallogenium* – a genus of desert bacteria that produce magnetite

Halophiles (*salt-loving*):

Preferred Environmental Conditions

- Microorganisms that thrive in environments with high concentrations of salt
- Salt concentration: >5% for optimum growth (sea water is about 3%)

Extremophile Data Sheet

Preferred Environments

- Soda and salt lakes/bodies of water (ie: Great Salt Lake)
- Salted fish and meats (beef jerky)

Examples of Halophilic Microorganisms

- Halobacterium* – can live in salt concentrations of up to 30%
- Staphylococcus* – a type of bacteria that causes staph infection
- Streptococcus* – a type of bacteria that causes some human diseases

Anaerobes (*oxygen-hating*):

Preferred Environmental Conditions

- Many anaerobes do not function efficiently with oxygen present in the immediate environment.
- Anaerobes may use gases other than oxygen (ie: sulfur dioxide, carbon dioxide) for respiration

Preferred Environments

- Mammalian intestinal tracts
- Ocean and lake sediments
- Hydrothermal vents and some underground waters

Examples of Anaerobic Microorganisms

- Clostridium* – found in all of the example preferred environments listed above for anaerobes and can cause food spoilage
- Methanogens* – type of microorganism found in anoxic conditions such as animal digestive tracts or ocean/lake sediments that produces methane

Extremophile Data Table

NAME	PREFERS	AVOIDS	ENVIRONMENT	ADDITIONAL INFO	EXAMPLES OF ORGANISMS
<i>Thermophiles</i>	High temperatures 42oC to 113oC (107oF to 236oF)				
<i>Psychrophiles</i>					
<i>Acidophiles</i>					
<i>Alkalophiles</i>					
<i>Barophiles</i>					Microorganisms around deep sea black smokers
<i>Xerophiles</i>					
<i>Halophiles</i>					
<i>Anaerobes</i>			Animal digestive tracts, ocean/lake sediments		

Extreme Environments Beyond Earth

For comparison:

Earth atmosphere: 78% nitrogen, 21% oxygen, 1% argon, and 0.03% carbon dioxide, variable water content

Earth average temperature: 15°C (59°F)

Mars

- very thin and unbreathable atmosphere of 0.005 bar (1 bar is the approximate pressure on Earth at sea level)
- atmosphere contains 95% carbon dioxide, 3% nitrogen, 1.5% argon, trace amounts of water
- average temperature of -53°C (-63.4°F), temperature occasionally rises above the freezing point in equatorial regions
- polar ice caps made of CO₂ ice, water ice, and dust
- evidence for abundant surface water in the past and current possibility of abundant subsurface water

Venus

- extremely high atmospheric pressure of 90 bars (equivalent to the pressure at an ocean depth of nearly 0.6 miles)
- atmosphere contains 96.5% carbon dioxide, 3.5% nitrogen
- virtually no water at all
- clouds of sulfuric acid droplets
- mean surface temperature of 470°C (878°F)

Europa (moon of Jupiter)

- extremely thin atmosphere, with oxygen as a major constituent
- water ice surface
- strong evidence of water oceans beneath thick water ice crust
- water ice crust subject to partial melting due to tidal heating
- surface temperature of -150°C (-238°F)

Titan (moon of Saturn)

- thick atmosphere of 1.5 bars is ~90% nitrogen and smaller amounts of methane, ethane, and argon
- surface temperature of -180°C (-292°F)
- composed of rock and ice (ice is primarily a combination of water, methane, and ammonia)
- surface oceans likely a mixture of ethane and methane
- possible deep underground oceans of ammonia and water

Io (moon of Jupiter)

- average is about -143°C (-225°F), however, frequent lava flows cause a great range in surface temperature
- extremely active volcanism
- thin, sulfur dioxide atmosphere
- boiling sulfur and sulfur dioxide geysers with temps as high as 326°C (620°F) with measured vent temperatures as high as 2000°C (3632°F)