YELLOWSTONE ABC'S
ACID, BASE, CHEMISTRY

Teacher's Guide

LESSON OVERVIEW

This three-part lesson ties together the concepts of pH, Yellowstone extremophiles, and the search for life beyond the Earth.

Part 1:

An instructor-led discussion with focusing activities teaches students about acids, bases, and pH. A laboratory activity has students test several substances to determine pH; students plot the values from their experiments on a pH scale. The instructor summarizes the results of the student pH tests and gives examples of strong acids and bases for students to add to their pH scale. The dangers of strong acids and bases are explained to students.

Part 2:

An instructor-led discussion engages students in identifying the needs common to all life on Earth and thinking about how acidic and basic conditions challenge living things. An activity identifies several alkaline and acidic thermal features in Yellowstone National Park and connects these pH values to those determined in Part 1 by having students plot them on the pH scale constructed in Part 1. A second activity introduces the concept of extremophiles, identifies the types of environments in which they are found, and relates them to the microbiology of Yellowstone thermal features.

Part 3:

A brief reading connects the concepts learned in Parts 1 and 2 and expands on this content. The reading relates students' new knowledge of extremophiles to the objectives of the NASA Astrobiology Institute and its research in Yellowstone. Mars and Europa are discussed as possible sites where extraterrestrial life may be found. The characteristics of the planet and moon are connected to Earth extremophiles that dwell in possible analogous environments. Questions follow the reading to recap its key points. An exit quiz assesses student knowledge of the lesson and its major themes.

GRADE LEVEL

Appropriate for grades 4-10

TIME REQUIRED

Part 1: Total time 55 minutes
- **Part 1.0** 10 minutes
- **Part 1.1** 35 minutes
- **Part 1.2** 10 minutes

Part 2: Total time 50 minutes
- **Part 2.0** 10 minutes
- **Part 2.1** 25 minutes
- **Part 2.2** 15 minutes

Part 3: Total time 45 minutes
- **Part 3.0** 20-35 (depending on how assigned)
- **Part 3.1** 10 minutes

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LEARNING OBJECTIVES

Through inquiry, dialogue, and activities, students learn about the following:

- The difference between acids and bases as well as the basic chemistry that defines them
- The pH scale
- How to test the pH of various solutions
- How to interpret pH test results
- The pH and temperature extremes of several Yellowstone thermal features
- Types of extremophiles and their environments
- The goals of astrobiology
- The reasons for the NASA Astrobiology Institute's research on microbes in Yellowstone
- Environments on Mars and Europa, possible Earth analog environments and extremophiles that live in these conditions

BACKGROUND CONTENT

Chemistry: This lesson assumes students have a basic knowledge of common elements from the periodic table of elements (hydrogen, oxygen, sulfur, carbon, chemical formula for water). Preferably they know the difference between a compound and an element, although this is not required.

Biology: This lesson assumes students have basic knowledge of what a microbe is, know that organisms have basic needs to survive, and have basic knowledge of the major biomes of the Earth.

Earth science: This lesson assumes that students know that Yellowstone National Park is home to one of the world's most diverse sets of thermal features and that they have a basic grasp of types of thermal features (geysers, mud pots, hot springs, etc.).

Space science: This lesson assumes that students have basic knowledge of the solar system.

CONTENT STANDARDS

Science Content Standard 1: Students, through the inquiry process, demonstrate the ability to design, conduct, evaluate, and communicate the results and form reasonable conclusions from scientific investigations.

Science Content Standard 2: Students, through the inquiry process, demonstrate knowledge of properties, forms, changes and interactions of physical and chemical systems.

Science Content Standard 3: Students, through the inquiry process, demonstrate knowledge of characteristics, structures and function of living things, the process and diversity of life, and how living organisms interact with each other and their environment.

Science Content Standard 4: Students, through the inquiry process, demonstrate knowledge of the composition, structures, processes and interactions of Earth's systems and other objects in space.

ANTICIPATORY SET

Anticipatory sets are integrated into each section of the lesson.

REQUIRED MATERIALS

Part 1.0

- Disposable cups (enough for each student plus several extra for the acidic and basic solutions)
- 4 cups water to make solutions, additional water for students to rinse with following the activities
- 1 tablespoon lemon juice
- 1 teaspoon baking soda, extra baking soda for students to taste
- Several pieces of sour candy, enough for each student to have one (shock tarts, sour patch kids, etc)

Part 1.1

- Student workbook, p. 1–2
- pH meter(s) or test strips
- A variety of acidic and basic solutions/substances (see lab materials list for details)
- Disposable cups
- Safety goggles, gloves, lab aprons/coats
- Poster size "pH scale" for pooling class data

Part 1.2

- Student workbook p. 1–2

Part 2.0

- Student workbook p. 3

Part 2.1

- Student workbook p. 3
- pH scale from Part 1.1

Part 2.2

- Student workbook p. 4
- Optional demo requires large glass beaker, hot plate, water, Celsius thermometer, raw egg

Part 3.0

- Student workbook p. 5–6

Part 3.1

- Exit quiz, student workbook p. 7

Part 1.0: Acids, Bases and pH

INSTRUCTOR-LED DISCUSSION

LESSON SUMMARY

This instructor-led discussion with focusing experiences gets students thinking about what they already know about acids and bases, has students explore the taste of weakly acidic and basic solutions, introduces the concept of pH, and discusses some of the most fundamental parts of acid/base chemistry.

LESSON PREPARATION AND MATERIALS:

- Prepare two different solutions in advance (Activities 1 and 3).

  For Activity 1, make a slightly acidic solution by mixing 1 ***tablespoon*** lemon juice and 2 cups of water. Provide a cup with plain water for comparison.

  For Activity 3, make a slightly basic solution by mixing 1 ***teaspoon*** of baking soda in 2 cups of water. Provide a cup with plain water for comparison.

  For Activity 2, provide sour candies for students to taste, at least one candy per student.

- Provide small amounts of baking soda for each student to taste.
- Provide cups of water for students to drink following their tasting.

ACIDS

Ask students:

- Does anyone know what an *acid* is?
  In what context have you heard the word used?
  What kinds of things (products or substances) does the term acid bring to mind?

  The students may state that acids are dangerous, can cause burns, are in soda, or citric juices, etc.

Activity 1

Ahead of time, prepare two glasses, one with plain water and one with a small amount of lemon juice in water (see lesson preparation).

Ask a student volunteer to take a sip from each cup.

- Which cup contains the plain water?
- How did you know?
- What does the other water taste like? (sour)

Activity 2

Give each student a sour candy (a sour patch kid or shock-tart, etc). Have the students place the candy in their mouths and suck on it for a moment before eating it.

- Ask the students what they experienced when sucking on the candy. Focus student comments on the fact that the taste was sour.
- Provide a cup of water for each student to rinse their mouth when they are done (also used in Activity 4).

BASES

Ask students:

- Does anyone know what a *base* is? In what context you have heard the word used? What kinds of things, if any, does the term base, basic or alkali bring to mind?
- Many students will not have much knowledge, so the instructor may need to guide the discussion. Explain that bases can be dangerous and can cause burns, and that many cleaning agents utilize bases.

Activity 3

Ahead of time, prepare two glasses, one with plain water and one with a small amount of baking soda dissolved in water (see lesson preparation).

Ask a student volunteer to take a sip from each cup.

- Which cup contains the plain water?
- How did you know?
- What does the other water taste like?

Activity 4

Give each student a small amount of baking soda. With clean hands, have the students dip their finger in the baking soda and put a small amount on their tongue. (A Q-tip may be used as an alternative to a finger.) Allow students to rinse their mouth when they are done.

Ask the students:

- What did you experience when tasting the baking soda?
- Focus student comments on the fact that the taste was bitter (many students will say its tastes gross, slippery, soapy, etc).

BUILDING THE CONCEPT

Discussion:

If students don't already know, briefly explain the difference between a compound and an element.

Ask students:

- What is the chemical formula for water? Is water a compound or an element? What are the elements that make up water and in what proportions?

  Write a summary of these concepts and the chemical formula for water on the board if necessary/appropriate.

Ask the students:

- Can you name any acids?

  Wait for student answers but provide examples if necessary. A good example is hydrochloric acid, HCl, because of its very simple chemistry.

- Other acids students may name are sulfuric acid (H_2SO_4), citric acid ($C_6H_8O_7$), nitric acid (HNO_3), and vinegar or acetic acid (CH_3COOH)*

  ** The site* http://chemistry.about.com/od/acidsbases/a/acidbaseformula.htm *provides a fairly comprehensive list of the chemical formulas of common acids and bases.*

Ask the students:

- Is HCl is a compound or an element? (compound)
- Which elements make up this acid? (hydrogen and chlorine)

Ask the students:

- Can you name any bases?

  Most will name baking soda because of the previous activity. Baking soda is sodium bicarbonate ($NaHCO_3$).

  Other common bases include:

  - magnesium hydroxide *(milk of magnesia)* – $Mg(OH)_2$
  - sodium hydroxide *(lye)* – NaOH
  - barium hydroxide – $Ba(OH)_2$
  - aluminum hydroxide – $Al(OH)_3$
  - ammonia – NH_3
  - bleach - NaOCl.

- Is baking soda a compound or an element? (compound)
- What are its constituent elements? (sodium, hydrogen, carbon, oxygen)

Write the chemical formulas of the acids and bases discussed on the board before moving on, they will be used in the next part of the discussion. To be most effective, list acids and bases two separate columns with the appropriate heading on each. You may want to add examples if time/interest allows.

WHAT IS AN ACID? WHAT IS A BASE?

DISCUSSION

Now students are ready to learn what it is, chemically, that makes something an acid or base. Remind the students that the acids and bases just discussed were all compounds.

Ask students:

- We now know that acids taste sour and bases taste bitter, we know that they are compounds, and we've even listed a couple of examples, but what is it that makes something an acid or base?

Ask students:

- Look at the chemical formulas on the board for acids. Is there an element that is in every single acid listed? They should identify that *hydrogen* is present in every acid.

  WARNING: this same approach (look for the constituent always present) doesn't really work for all bases, although it is true of some of the bases given as examples above. You may want to discuss this with students (keep in mind that pH actually measures the hydrogen ion concentration in a solution not the concentration of hydroxide, OH^-). Some bases do not have hydroxide molecules but ways to capture hydrogen ions.

  Explain to the students that acids are compounds that separate into their different parts when they are added to water, and that bases sometimes separate into different parts but other times stay together and make the water molecules separate.

WHAT IS AN ACID?

Explain to the students that an acid is a compound that breaks apart when added to water to release hydrogen atoms. These hydrogen atoms are very reactive and they want to bond with other elements, which means that they can break molecules apart in order to bond. This is very destructive and can cause effects we associate with acids like stinging and chemical burns. The higher the concentration of hydrogen ions, the stronger the acid.

WHAT IS A BASE?

Explain to the students that a base is a compound that breaks down in water or breaks down the water molecules to produce hydroxide molecules (OH^-). These hydroxide molecules (ions) are also very reactive, and they want to bond with other elements, which means that they can break molecules apart in order to bond. This is very destructive and can cause effects we associate with bases, like cleaning power and chemical burns. The higher the concentration of hydroxide, the stronger the base. Solutions that are bases are often called alkaline.

WHAT IS PH?

Ask the students:

- Does anyone know what pH is?

  Explain that the strength of an acid or base is measured on a scale called the pH scale.

- The scale ranges from 0 to 14 with the middle value, 7, being neutral (neither acidic nor basic).
- Zero is the strongest acid and 14 is the strongest base.
- The pH scale is actually a measure of how many hydrogen ions are in the solution, it doesn't measure the number of hydroxide (OH^-) molecules.
- You can add the information that hydroxide molecules lessen the number of hydrogen ions in the solution because it reacts with every loose H^+ ion to make water.

For more advanced students, explain the pH scale as a logarithmic measure.

- Every time you go down a number on the scale (i.e. from 7 to 6) there are 10 times more hydrogen ions.
- Every time you go up a number on the scale (i.e. from 7 to 8) there are 10 times fewer hydrogen ions.
- This means that your stomach acid (pH 2) is 100,000 times more acidic than neutral water (pH 7), not just 5 times more acidic as you might assume. The number difference on the pH scale has to be the exponent of a 10 multiplier, because it is logarithmic. $10^5 =$ 10*10*10*10*10 = 100,000

CLOSURE

Summarize and connect the information back to the opening activities

- Remind the students that acids have free hydrogen molecules floating around whereas bases have a lot of free hydroxide molecules (or ways to capture hydrogen ions) floating around.
- The free hydrogens in an acid like to react with other materials (like the saliva on your tongue. This creates the stinging, sour sensation.
- For bases, the free OH^-'s also like to react with materials (like the saliva on your tongue) but in a different way, and their reaction creates the bitter taste.

In the next activity, students will get the opportunity to test a variety of solutions and determine if they are acids or bases.

Part 1.1: Plotting on the pH scale laboratory activity

LESSON SUMMARY

In this activity, students are given a variety of solutions and asked to determine the pH of each. Students then affix the name of the solution on a pH scale (either on their own copy or a class copy). The pH values of solutions too dangerous for use in class are provided to the students. (These values are given in the teacher instructions and expected results sections.)

LESSON PREPARATION AND MATERIALS

This activity can be conducted in a variety of ways depending on the availability of resources, size of the class, and physical setup of the classroom. Students can do the lab as individuals, with partners, as small groups, or it can be done by the instructor as a demo (with student assistance). Preparing the solutions in advance saves time and reduces the chance for spilling. Keep clean-up materials handy. To be most effective, select a variety of solutions from the list below that includes a mixture of acids, bases and a neutral solution. Seven solutions works well (three acidic, three basic, one neutral).

Strong bases or acids should not be handled by students. Depending on the age group of your students, you may want to do bleach as a demo. Obviously, students should use care when handling the solutions. ***Acids and bases should not be mixed.***

NOTE: Students should use proper lab safety precautions including eye protection, aprons/lab coats, and gloves.

Testing materials

- small plastic dixie cups or glass beakers
- pH test strips or pH meter

An assortment of the following:

- lemon juice
- orange juice
- bleach
- vinegar
- ammonia
- distilled water
- tap water
- baking soda (mixed with water to make a slurry)
- egg white
- egg yolk
- milk
- cola
- tomato juice
- pureed strawberries
- black coffee
- borax (mixed with water to make a slurry)
- toothpaste

TEACHER INSTRUCTIONS FOR THE LAB:

1. Distribute the student workbook and lab materials to students. (Safety equipment, cups containing solutions, test strips or pH meters, etc.)
2. Students should write down the name of their assigned solutions in the left hand column of the table on page 1 of their student workbook.
3. Have students follow the pH meter or test strip instructions to test each solution.
4. Students fill in the table on page 1 of their workbook with the pH values they have determined for each solution and then write whether the solution is acidic, basic, or neutral.
5. Students plot the pH values on their pH scale by listing the name and pH value of the solution next to the appropriate number on the individual pH scale on page 2 of their student workbook.
6. Have students add the following pH values to their pH scale for solutions not tested in class:
    - **battery acid** pH = 0
    - **stomach acid** pH = 2
    - **human blood** pH = 7.4
    - **ocean water** pH = 8 (but varies)
    - **lye** (oven & drain cleaners) pH = 13
    - Also give the pH values of any solutions that you did not offer as experimental solutions *(see Expected Results table, p. 8).*
7. Have students clean up their stations and return safety materials before moving on.
8. Have students post their pH results onto a larger, class version, pH scale.

EXPECTED RESULTS

lemon juice	pH 2.2–2.4	*(lemon juice is about 5% citric acid)*
orange juice	pH ~4	*(also contains citric acid but in a lower concentration)*
bleach	pH ~12	*(Household bleach is a 3-6% solution of sodium hypochlorite (NaClO)*
vinegar	pH 2.5	*(Vinegar is about 5% acetic acid)*
ammonia	pH ~11	*(Household ammonia is about 5-10% NH^3 in water)*
distilled water	pH 7.0	
baking soda	pH 8.3	*(Sodium bicarbonate $NaHCO^3$)*
egg white	pH 7.8	
egg yolk	pH 6	*(contain fatty acids, pantothenic acid (B6 vitamin), and folic acid)*
milk	pH 6.7	
cola	pH ~3	*(contains phosphoric and citric acids)*
tomato juice	pH 4.5	*(contains malic acid and citric acid)*
strawberries	pH 3.5	*(contains malic acid, citric acid, and ascorbic acid (vitamin C))*
black coffee	pH 5	
borax	pH 9.2	
toothpaste	pH 9.9	
tap water	pH ~7 but varies	
Non-tested substances:		
battery acid	pH 0	
stomach acid	pH 2	
human blood	pH 7.4	*(tightly regulated by the body)*
ocean water	pH 8 but varies	
lye (oven & drain cleaners)	pH 13	*(contain high concentrations of sodium hydroxide NaOH)*

Part 1.2: Strong acids and bases impact life

POST-LAB DISCUSSION

LESSON SUMMARY

This post-lab discussion recaps what was learned about acids and bases in the lab and builds on the concept of the pH scale. It also introduces the idea of the relative strengths of acids and bases and their impact on living tissue.

LESSON PREPARATION AND MATERIALS

No special preparation required, but student workbook is necessary.

DISCUSSION

Ask students:

- Do acids taste sour or bitter? (sour)
- Which solution is sourer, orange juice or lemon juice? (lemon juice)
- According to your experiment, which is more acidic? (lemon juice)
- So how does the pH number reflect the strength of the acid? (the lower the number the stronger the acid)

Ask students:

- What would happen if you drank lemon juice or a solution that was more acidic than lemon juice? (Students should identify that the lemon juice would be almost intolerably sour and a more acidic solution would be even sourer, or even dangerous).

  Explain to the students that the pH scale is a measure not just of whether a solution is acidic or basic, but of *how* acidic or basic the solution is. Recall that solutions with a pH of 7 are considered neutral (neither acidic nor basic). Those with a pH lower than 7 are acids, and the lower the number, the stronger the acid.

- **Ask students** to discuss what they think having a very low pH means. Considering the effect of lemon juice on the tissues in your mouth, what would a more acidic solution do to your tissues? (Students should identify that the stronger the acid, the more dangerous it is for living tissue.)

Ask students:

- What it was like to taste baking soda? (Most will discuss the bitter taste.)
- What would happen if you drank a solution that was more basic than baking soda? (Students should connect that this would be even more bitter and unpleasant.)

  Explain that solutions with pH values higher than 7 are considered bases. For bases, the higher the number the more basic, or alkaline, the solution. Like strong acids, strong bases can damage living tissues.

Ask students:

- Why were you given the pH values for battery acid, lye, and stomach acid, etc?

  Answers will vary, but focus on answers that discuss the dangers associated with strong acids or bases. You may want to read the warning label from oven cleaner, drain cleaner, or battery acid to accentuate the point that strong acids and strong bases are dangerous for organisms.

  Explain that both acids and bases can cause serious damage to organisms. Both can produce what is called a chemical burn. Strong acids are called *corrosive* whereas strong bases are described as *caustic*. Corrosive and caustic substances will destroy or irreversibly damage a substance with which it comes into contact. For most organisms the main hazard from exposure is damage to tissues (eyes, skin, and the underlying tissues; inhalation or ingestion of a corrosive or caustic substance can cause respiratory and gastrointestinal damage).

CLOSURE:

Recap the major points of the lab activity:

1. Many household substances are acids or bases.
2. The stronger the acid the lower its pH; conversely, the stronger the base the higher its pH.
3. Both strong acids and bases can be destructive to organisms because they destroy living tissue.

Part 2.0: Challenging life in Yellowstone

INSTRUCTOR-LED DISCUSSION

LESSON SUMMARY:

This discussion asks students to think about things that all organisms need to survive by focusing first on humans, then fish, and then considering microbes. Variations in the environment such as temperature and pH are discussed. Students are asked to reflect on what environmental factors limit life and how extreme they think conditions can be and still support life. The goal is to get students to relate the pH of substances tested in Part 1.1 (and those too dangerous to test) to the pH of Yellowstone thermal features that support unique and thriving microbial communities.

LESSON PREPARATION AND MATERIALS:

Students will need the student workbook to answer a question that closes the discussion.

DISCUSSION:

Ask students:

- Brainstorm: what makes a good habitable environment for humans?

  Answers from students may highlight reasonable temperature conditions, abundant and easy to obtain resources (water, food, energy source), shelter, safety (a general lack of dangerous materials or pollutants), etc.

Ask the students to consider a fish (or some other water-dwelling organism that is easy to conceptualize) and construct a similar list. You may want to highlight that the needs of fish are similar to those of humans in a basic sense.

  Explain to students that all living things from the largest to the smallest have similar needs: a suitable environment, some way to get energy, and an availability of resources. However, the specifics of those needs depend greatly on the type of organism.

  Have students give an example of some need that a fish has that is very different than the need of a human or vice versa. A logical example may be fish need to live in water, whereas humans need water but can't live in it. Therefore, what is suitable for one organism is not always suitable for another.

Ask students:

- Consider microbes like bacteria. Are they living? Do they have needs? Do they consume resources? Do they need a suitable environment?

  Students should be able to reason that, yes, bacteria must also have similar needs to fish and humans.

  Explain to the students that the diversity of living things on our planet, their evolution, and the identification of things like niches is a result of all organisms finding a way to satisfy their needs, hopefully without having to compete too much for them. (This is an appropriate time to discuss briefly the different types of niches or ecosystems if students need a refresher). It would be useful to highlight Earth's more extreme environments (deserts, the Arctic, bottom of the ocean, etc.) and discuss briefly what conditions make those environments challenging for organisms. If time allows, briefly discuss some adaptations that allow plants or animals in these regions to survive.

Ask students:

- After learning about acids and bases, do you think an acidic or basic environment is good for life or harmful to it? (Most students will reply harmful.)

  Explain that it depends on *how* acidic or basic an environment is, and on the type of life.

Ask students:

- Where do we find liquid water on the Earth? (Students should identify oceans, rivers, lakes, swamps, etc.)
- What is the pH of those types of water? (6-8 depending on the local conditions)

  Explain that the pH of fresh water can vary a lot depending on lake/river conditions and pollution, but a good range is 6.0 to 8.0. Also recall that distilled water is neutral (pH 7) and tap water tends to be neutral, too. The pH of the ocean is around 8. So most organisms that live in water can probably deal with slightly acidic or basic conditions, right?

Ask students:

- Would you expect an organism to be able to live in water that had a pH of 1 or 10? Have students explain their answer.

Ask students to think about the fish again.

- Could that fish survive if the water temperature changed? What if it became very cold or very hot? What if the water froze or was near boiling? Students should identify that this would be too extreme of a variation for a fish to survive.

Ask students to reflect on what pH, water temperature and living things have to do with Yellowstone and write a brief answer to the "Ask Yourself" question on page 3 of their workbook. Invite students to share their answers before moving on.

Explain to the students that in the next activity they will learn that many of the thermal features in Yellowstone aren't just hot; they are acidic or basic too.

Part 2.1: Yellowstone thermal feature pH

ACTIVITY: ADDING TO THE PH METER

LESSON SUMMARY:

This activity asks students to look at the temperature and pH conditions of several thermal features in Yellowstone. Students determine if the feature is acidic or basic and compare the pH to substances tested in the lab. The class adds more pH values to the pH scale constructed in Part 1.1.

LESSON PREPARATION AND MATERIALS:

Students will need the student workbook. The class will add to the pH scale. An optional demo highlights the challenging temperature conditions found in Yellowstone's hottest thermal features (see footnote in Part 2.2).

TEACHER INSTRUCTIONS FOR THE ACTIVITY:

1. Have students examine the list of Yellowstone thermal features on page 3 or their workbook and determine if they are acidic or basic, based on the pH given.
2. Have students correlate the values of the solutions they tested in the lab investigation to the thermal feature's pH and write the name of any solution that is close in pH to the listed thermal feature (possible answers are given in the table below).
3. As a class, plot all the pH values from the lesson on the class pH scale (students should also plot it on their individual pH scales). Visually, the best result includes the student data from the lab, the thermal features from the table, pH's of the given solutions (battery acid, lye, etc.), and the pH of any solutions not given in the lab. This gives students the best visual comparison of pH values.
4. Have students answer the questions on page 3 of their workbook using the thermal feature table.

Thermal feature	*pH*	*Water temperature*	*Acidic or basic*	*Similar solution?*
Amethyst Geyser	1.4	35.9° C/96.6° F	acidic	Stomach acid
Black Dragon's Caldron	2	51.4° C/ 124.5° F	acidic	Lemon juice
Arrowhead Spring	8.5	75.5° C/ 167.9° F	basic	Baking soda
Palette Spring and Terrace	6.5	68° C/ 154.4° F	acidic	Milk, egg yolk
Mud Geyser	2.5	43.5° C/ 110.3°F	acidic	vinegar
Mud Volcano	3	86° C/ 186.8° F	acidic	cola
Blue Mud Steam Vent	4.9	91° C/ 195.8°F	acidic	Black coffee
Blood Geyser	8.5	90° C/ 194° F	basic	Baking soda
Deluge Geyser	9.1	86° C/ 186.8° F	basic	Borax
Grand Prismatic Spring	8.3	23.3° C / 73.9°F	basic	Baking soda
Crested Pool	9.4	93° C / 199.4°F	basic	toothpaste

Which feature is the most acidic?
Amethyst Geyser

Which thermal feature is the most basic?
Crested Pool

Which thermal feature is closest to neutral?
Palette Spring and Terrace

Which thermal feature is closest to the boiling point of water? (Hint: water boils at 100°C/212°F)
Crested Pool

DISCUSSION:

Direct the students to look over the temperature and pH data. You may want to remind them that water boils at 212° F and that water at 150° F will cause serious (third degree) burns in as little as 2 seconds.

Ask the students:

- Now that you have looked at the temperature and pH of several features in Yellowstone, do you think life exists in the thermal features in Yellowstone? Or are conditions too hot, too acidic, or too basic? Why or why not?

  Discuss the students' ideas about the habitability of the thermal features. Explain that despite the extreme thermal and pH conditions, complex communities of microbes live and even thrive in Yellowstone's hot springs, mud pots, and geysers. This includes the thermal features listed on the table! Surprisingly, life finds a way even in water near boiling and as acidic as stomach acid!

Part 2.2: Matching extremophiles

ACTIVITY: LIFE IN THE EXTREME!

LESSON SUMMARY:

This section introduces the concept of microbes that live in the most challenging conditions on Earth. A matching activity challenges students to use logic and any familiar root words to match the extremophile with its preferred environment.

LESSON PREPARATION AND MATERIALS:

No special preparation required, but student workbook is necessary.

Ask students:

- Does anyone know the special name for microbes that live in conditions we consider extreme?

Explain that such microbes are called "extremophiles." An extremophile is an organism that thrives in and may even require physically or chemically extreme conditions, conditions that the majority of life on Earth cannot survive.

Phile is the Latin root for "loving" so extremophile literally means *extreme loving*. Explain that scientists have identified many different kinds of extremophiles and that they are divided into groups based on the type of environment they like to live in. Have students write down the definition of extremophile on page 4 of their workbook and then work on the "Life in the extreme" part of their workbook.* Answers are given at right.

THERMOPHILE DEMO

This is a good demo to set up while students work on the matching exercise, if you have a classroom setup that allows. Set up a beaker of water on a hotplate. Bring the water to a boil and attach a thermometer. Once a rolling boil is obtained, crack an egg and add it to the water. Ask students to observe what happens to the egg. It should cook completely in about a minute. Note the temperature and ask students to identify which thermal features in the table are near this temperature. Explain that the egg is made of materials/molecules common in living things. What does this say about the special adaptations that thermophiles must have to survive boiling or near boiling water?

LIFE IN THE EXTREME!

Extreme environments:

a. These microbes are happiest at pH levels between 0 and 3.

b. An organism that lives in the microscopic spaces in rocks.

c. These microbes grow best at pH levels of 9 or above.

d. These organisms live in boiling and near boiling water; they thrive in temperatures between 80–122° C (176-25° F).

e. An organism that can grow in extremely dry conditions.

f. These guys like it hot! Preferably between 60–80° C (140-176° F)

g. These organisms can live in water with high levels of heavy metals such as cadmium, arsenic, copper, and zinc.

h. An organism capable of survival, growth or reproduction at temperatures of -15° C or lower.

i. An organism that likes water that is both hot and acidic.

j. A microbe that requires extremely salty conditions in order to grow.

Extremophiles: *(answers)*

f. *Thermophile*

d. *Hyperthermophile*

a. *Acidophile*

c. *Alkaliphile*

b. *Endolith*

j. *Halophile*

h. *Psychrophile*

g. *Metallotolerant*

i. *Thermoacidophile*

e. *Xerophile*

What types of extremophiles do you think are found in Yellowstone's thermal features?

*Thermophiles, hyperthermophiles, Acidophiles, alkaliphiles, thermoacidophiles.**

**Specific examples of Yellowstone extremophiles can be found at:* http://hydrogen.montana.edu/ysextremophiles.html

Part 3.0: Yellowstone, Hot Springs, and Extraterrestrial Life

READING WITH QUESTIONS

LESSON SUMMARY:

The following reading (which corresponds to the reading in student workbook, p. 5–6) connects the concepts of pH and extremophiles with astrobiology and the search for extraterrestrial life. The reading can be used in class in one of two ways: 1) Class reading: students take turns reading aloud and discuss the concepts and questions with the instructor as they progress through. 2) Individual reading: students read individually and discuss as a group at the end. Mars and Europa are discussed as possible sites where extraterrestrial life may be found. The characteristics of the planet and moon are connected to Earth extremophiles that dwell in analogous environments. Questions follow the reading and recap its key points. Answers for the reading questions are given below.

Yellowstone, Hot Springs, and Extraterrestrial Life

When you look at the microbiology of Yellowstone, you see creatures making a living in ways very different from what we would expect. The thermal features of Yellowstone National Park are home to many extremophiles including thermophiles, hyperthermophiles, acidophiles, thermoacidophiles, alkaliphiles, and metallotolerant organisms. In the Park, scientists have found different microbes and even microbial communities that can thrive without light or oxygen, in temperatures near boiling, and with pH levels that would destroy most of Earth's life forms. Some use the sun for energy, others use sulfur, and still others use hydrogen. Yellowstone's extreme microbes have adapted to use the resources available in their environments—resources that most plants and animal can't use. The microbes of Yellowstone's thermal areas have a truly unique ecosystem on the modern Earth, but what about in Earth's past?

Aside from how interesting and unique extremophiles are, scientists study them because they may give us the best idea about early life on Earth. Scientists think that extremophiles were some of the first forms of life on the planet, because they thrive in conditions that are similar to what early Earth was like. The conditions on Earth's surface when life first started to evolve, 3.5 to 4 billion years ago, were very different than they are now. Earth was probably a lot hotter. Scientists estimate it had an average surface temperature of 55-85° C (131-185° F). They also think that the conditions in Yellowstone's sulfuric pools may resemble what Earth's early surface waters were like. These types of conditions would make early Earth a horrible place for humans to live, but extremophiles would feel right at home.

The microscopic life in Yellowstone is as rich, diverse, and interesting as all the large animals you see in the park. Yellowstone's microbes are so unique and fascinating that even NASA is interested in them. Why is NASA studying the extremophiles in Yellowstone? The NASA Astrobiology Institute is a group of scientists and researchers from around the world. They work together to understand what the limits of life are so that they can look for life elsewhere in our solar system and the universe. After decades of exploring with probes and satellites, we have found that no other object in our solar system is quite like Earth. The conditions on the surface of our neighbors in space are very different than our cozy corner of the universe. Our neighbors are bigger or smaller, hotter or colder, shrouded in toxic clouds or lacking an atmosphere, covered in volcanoes or frozen in ice, and very unlike Earth. If scientists want to find life elsewhere in the solar system, that life will have to be able to deal with some extreme conditions. Therefore, many scientists think that if we find life elsewhere in the universe, it may resemble the organisms living in Earth's most extreme environments.

Where else might there be life in our solar system? Two candidates in Earth's neighborhood are promising places to look for extremophilic life.

MARS

Our neighbor Mars is a promising place to look for life because it is similar to Earth in many ways. Mars is similar in size and also is about the same distance from the sun. This means it is in the *habitable zone* of the solar system: not too hot and not too cold. Mars has a thin atmosphere and its surface is made up of rocks and soil like the Earth's. There is even evidence that Mars had some plate tectonics and perhaps even water flowing on its surface sometime in its past. Modern Mars has water in the form of polar ice caps, and some scientists think that there may be liquid water deep below the surface. But there's a reason people don't live on Mars: it is cold and dry, and its puny atmosphere doesn't provide much protection from blasts of solar radiation from space. Mars isn't such a nice place for humans, but what about microbes? Could they deal with Martian conditions?

On Earth we have extremophiles called xerophiles that can live with very little water. They have been found in the cold deserts of the Chilean Atacama Desert, a place that gets less than .004 inches of rain a year, and in the dry valleys of Antarctica. Perhaps water in the form of ice isn't such a big problem for life either. Earth's icy poles, glaciers, and snowfields support cold-loving psychrophiles and other forms of life.

What about the thin Martian atmosphere? Because Mars has a thin atmosphere, its surface gets blasted by a lot of solar radiation and that's hard on living things. Life forms on Mars would probably have to live below the surface where the radiation can't penetrate. On Earth we have many different microbes capable of living in conditions the might exist below Mars' surface. There are the endoliths that can live inside rocks, piezophiles that can withstand great pressure, and hypoliths that live under rocks in cold deserts. A group of NASA researchers recently identified large plumes of methane being released from Mars, a hint that methane-producing microbes may be present and active. Who knows what life forms may be lurking in the Martian soil?

EUROPA

Europa is one of Jupiter's moons and is covered in ice. Scientists believe that below Europa's frozen surface lies a liquid ocean of water that is kept relatively warm by volcanic activity within the moon. Although it's possible that Europa has some form of psychrophile living on its frozen surface, what astrobiologists are really curious about is what's going on under the ice. They think that the volcanic activity could create conditions like we find in Yellowstone, a place where extremophiles thrive. Or, it may create conditions similar to the hydrothermal vents found deep in Earth's oceans, places where sunlight never reaches and yet are teeming with life, including extremophiles. A place with warm water oceans supplied with chemicals by volcanic activity sounds like the perfect place for extremophiles!

READING QUESTIONS

1. Why does the NASA's Astrobiology Institute study Yellowstone's extremophiles?

   Because the extremophiles of Yellowstone live in conditions that may be found in other parts of the solar system or universe.

2. Based on what scientists have discovered about extremophiles in Yellowstone, could life exist on a planet that has liquid water that is near boiling? What about highly acidic or basic?

   Yes

3. What environments on Mars may be home to life?

   Soil, rocks, ice, any liquid water.

4. What two characteristics of Europa make it a good candidate for life?

   A possible ocean below the ice and volcanic activity.

FINAL CLOSURE AND ASSESSMENT:

Use the "What do you know?" quiz (p. 7, student workbook) as an exit quiz to assess how much students have retained from the lesson. *(See answer key, p. 18.)*

Part 3.1 Exit Quiz | WHAT DO YOU KNOW?

ANSWER KEY

For the list below put an A in front of substances that are acidic and a B in front of substances that are basic.

B Bleach
A Lemon juice
A Cola
A Vinegar
B Ammonia
B Baking soda
B Toothpaste
A Black coffee

Which of the following types of extremophiles are found in Yellowstone's thermal features?

Thermophile
Hyperthermophile
Acidophile
Alkaliphile

True or False

T pH is a measure of the number of hydrogen ions in a solution.

F Acids have pH values higher than 7 and bases have pH values lower than 7.

F Extremophiles are only found in Yellowstone.

F You can get chemical burns from strong acids but not from strong bases.

F Acids taste sour; bases taste bitter.

F Mars has a thick atmosphere that shields it from solar radiation.

T Scientists think Europa has a liquid ocean under its icy surface.