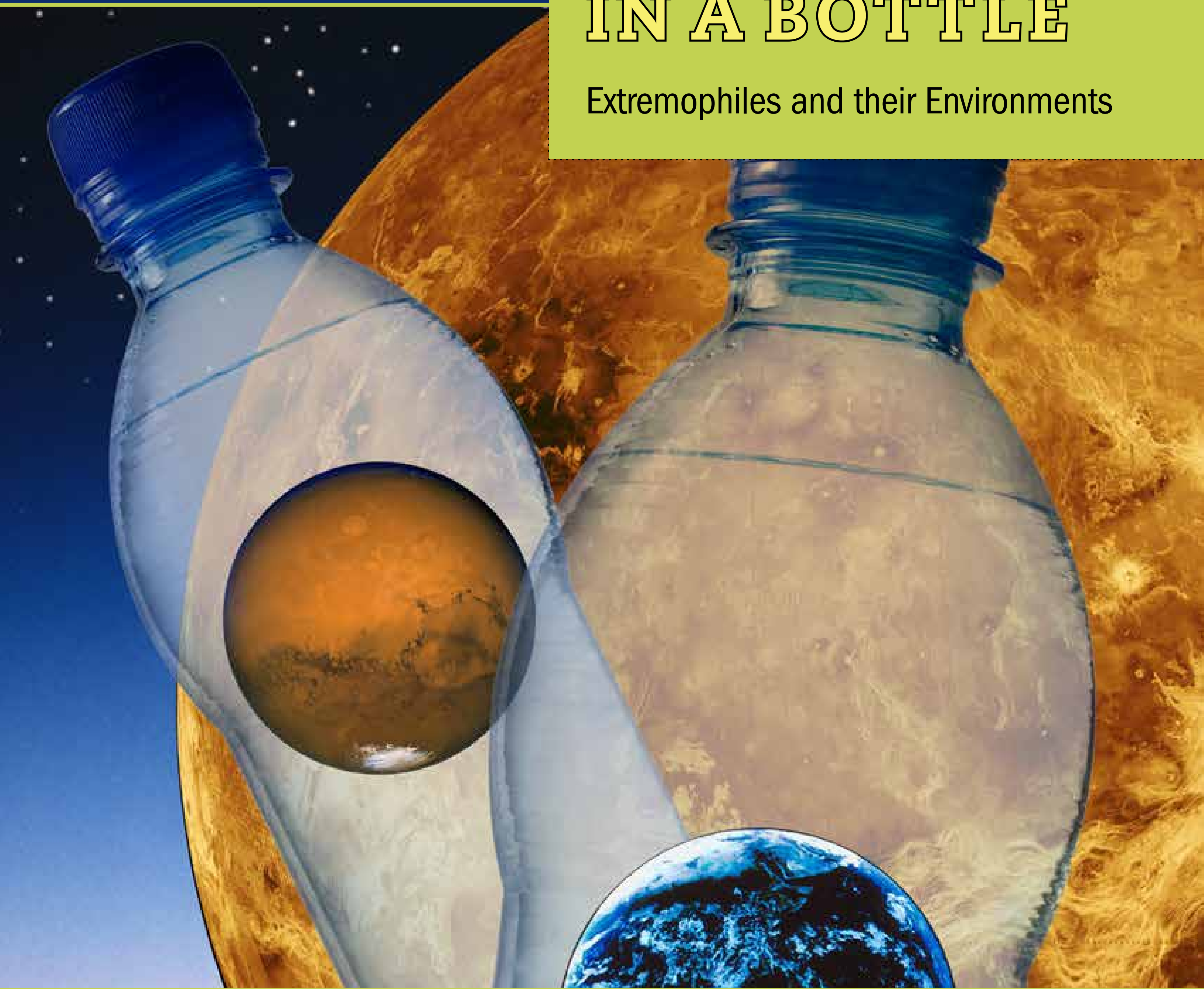
PLANET IN A BOTTLE

Extremophiles and their Environments



Student Workbook

MONTANA STATE UNIVERSITY
Astrobiology Biogeocatalysis Research Center

The Astrobiology Biogeocatalysis Research Center at Montana State University

Our team supports the work of the NASA Astrobiology Institute (NAI), a multidisciplinary umbrella for conducting research on the origin and evolution of life on Earth and elsewhere in the universe.

The origin of life, sustainable energy, and global climate change are intimately linked, and the answers we seek to solve our energy needs of the future are etched into Earth's history. ABRC's work supports NASA's missions, such as Mars exploration and possibilities of habitation of other worlds. Our research also focuses on the future of life on Earth. These efforts support the fundamental groundwork for Goal 3 (Origins of Life) of the NASA Astrobiology Roadmap.

ABRC involves investigators with expertise in geochemistry, experimental and theoretical physical chemistry, materials science, nanoscience, and iron-sulfur cluster biochemistry who work to define and conduct integrated research and education in astrobiology.

We are proud of our interdisciplinary research and teaching, and are committed to communicating and educating the public about our science and helping to train and inspire the next generation of scientists.

The nearby natural laboratory of Yellowstone National Park provides ABRC with unique field research opportunities. Life in the extreme environments of Yellowstone's thermal features is thought to resemble conditions of early Earth. Yellowstone's abundant and unique thermal features give researchers insights into the origin, evolution and future of life.

Whether you are a potential MSU student, a research investigator, a teacher or a citizen, we welcome you to the world of astrobiology. ABRC is committed to sharing our work and its impact with the people of Montana and beyond, through formal and informal education; public outreach; and communications to many different audiences.

Our outreach and education activities are strengthened by many factors, including MSU's proximity to Yellowstone National Park, the expertise and experience of our faculty and close partners, the outstanding commitment from our MSU students to share their work with the public, and a rich network of partners, including the Montana Library Association, Museum of the Rockies, Space Public Outreach Team and Hopa Mountain. We also work closely with the other teams from the NASA Astrobiology Institute.

Please feel free to contact us with any questions, and enjoy exploring our website: **http://abrc.montana.edu**

MONTANA STATE UNIVERSITY | EXTENDED UNIVERSITY

MONTANA STATE UNIVERSITY | Astrobiology Biogeocatalysis Research Center

This learning module was developed by Montana State University Extended University in collaboration with the Astrobiology Biogeocatalysis Research Center at Montana State University. For additional astrobiology education resources, visit http://abrc.montana.edu/outreach/ and for even more research-based educational resources for community and schools, visit http://eu.montana.edu/outreach/resources/

THE GOLDILOCKS ZONE

Goldilocks and the Three Bears

Once upon a time, there was a little girl named Goldilocks. She went for a walk in the forest. Pretty soon she came upon a house. She knocked and when no one answered, she walked right in. She entered the kitchen of the little house, and at the table she found three bowls of porridge. Goldilocks was hungry. She tasted the porridge from the first bowl. "This porridge is too hot!" she exclaimed. So, she tasted the porridge from the second bowl. "This porridge is too cold," she said. So, she tasted the last bowl of porridge. "Ahhh, this porridge is just right," she said happily and she ate it all up.

The "Goldilocks Zone"

What could the story of Goldilocks and the Three Bears have to do with planets and space? Believe it or not, scientists use the Goldilocks story as a way to explain how perfect the Earth is for life. Because, when it comes to supporting life, the Earth is not too cold, not too hot, but just right! Earth is just right for a couple of reasons. It's the right size to have an atmosphere and the right distance from the Sun to have a moderate temperature. These conditions define the "Goldilocks Zone" or the habitable zone. Both of these characteristics help the Earth have water in a liquid form, and having liquid water is the most important factor for supporting life–at least life like we find here on Earth.

It turns out that having liquid water is pretty rare in our solar system. If a planet is too small, it may not have enough gravity to hold an atmosphere. If it is too large, it is likely to be a planet composed mainly of gas (e.g., gas giant) with a thick hydrogen atmosphere. If the planet is just the right size, it can have an atmosphere and maybe even one that is capable of supporting life.

But it's not just the size of the planet that's important, it's also how close it is to a star. If a planet is too far from a star, it will be too cold to have liquid water. If it is too close, it will be too hot to have liquid water.

Scientists use the words "Goldilocks Zone" to describe an orbit around a star that is just right for liquid water to exist on the surface. Any planets in orbit around the star in this zone may be able to have liquid water. This may mean that the planet can support life. This is certainly the case for Earth!

EXTREMOPHILES THRIVE IN *EXTREME* CONDITIONS

Thermophiles
very hot water

Hyperthermophiles
boiling or near-boiling water

Acidophiles
water that is acidic

Thermoacidophiles
water that is hot and acidic

Alkaliphiles
water with a basic pH

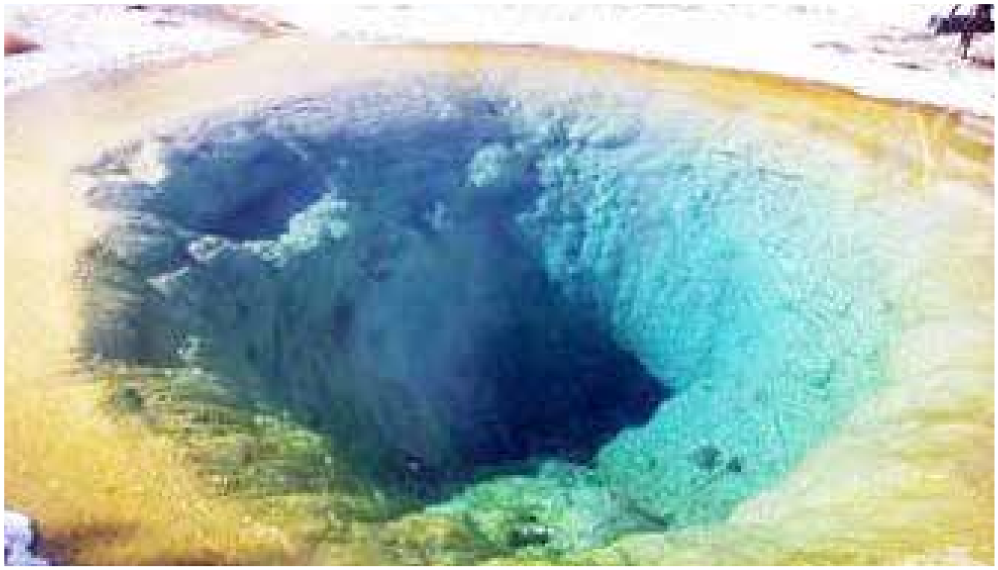
Endoliths
surfaces or pore spaces of rocks

Psychrophiles
freezing conditions

Xerophiles
very dry conditions

Barophiles
bottom of the ocean

Anaerobes
without oxygen



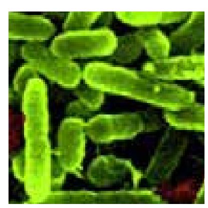
The glorious colors of Yellowstone's thermal features are caused by organisms that live in them.

Extremophiles and the Goldilocks Zone

Most life on Earth prefers a temperate environment: not too hot and not too cold. However, not ALL life needs this. There are many types of organisms, mostly microbes called ***extremophiles***, that thrive in conditions most people would consider too extreme for life.

Yellowstone National Park is home to a lot of different kinds of extremophiles. A group of microbes called ***thermophiles*** live in the thermal features found in Yellowstone. They thrive in the scalding hot water found in geysers, hot springs, and mud pots. There is even a group of thermophiles called the ***hyperthermophiles*** that like it even hotter. They prefer boiling and near boiling water. Microbes called ***acidophiles*** can live in water as acidic as stomach acid. ***Thermoacidophiles*** prefer water that is both hot *and* acidic. Another group of extremophiles that live in Yellowstone are the alkaliphiles. ***Alkaliphiles*** are happy to live in pools with a basic pH (bases are the opposite of acids) and some live in waters that are as basic as ammonia or baking soda.

Yellowstone's hot springs and geysers aren't the only places in the park that host extremophiles, however. Yellowstone is host to a type of extremophile called endoliths. ***Endoliths*** prefer to live on the surface or in the pore spaces of rocks, where they consume minerals to survive. There are also ***psychrophiles***; these cold-loving organisms thrive in the freezing conditions found in the Arctic, Antarctic, and high in the mountains. Psychrophiles live in small cavities found in glacial ice and snowfields. When you look at the wide range of temperatures where extremophiles live, too hot or too cold doesn't seem to be too much of a problem.



Other extremophiles can withstand extreme conditions besides temperature and acid. Some microbes live with extremely little water, like in the desert. These dry-loving microorganisms are called ***xerophiles***. Some microbes, called ***barophiles***, live in the very bottom of the ocean where the water is so heavy and the pressure is so great that it would crush a human. Humans and animals need oxygen to live, but some microbes called ***anaerobes*** live completely without oxygen; oxygen is even toxic to them. Anaerobes are found within places like your intestines or a cow's stomach. Microbes are found everywhere on the planet!

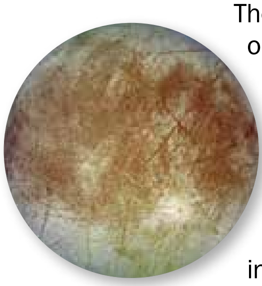
Anaerobes can live in places where there is no oxygen—like a cow's stomach.

What's extreme for Earth is normal elsewhere in the universe

Scientists are interested in extremophiles for a lot of different reasons, but one of the big reasons is that extremophiles may show us what kind of life forms could be found in the extreme environments elsewhere in our solar system. Scientists are interested in several off-Earth locations that could potentially have life, particularly Mars, Europa, and Titan. These places have their own set of challenging conditions for life, but many scientists believe that if they have life, it's probably an extremophile. Here is why...

People have been looking for life on Mars since it was first spotted in a telescope. Recent visits to the planet by satellites, probes, and rovers have found Mars to be a cold, rocky planet with a thin atmosphere, polar ice caps, and ice in the soil. These aren't conditions we'd consider livable, but what about other life forms?

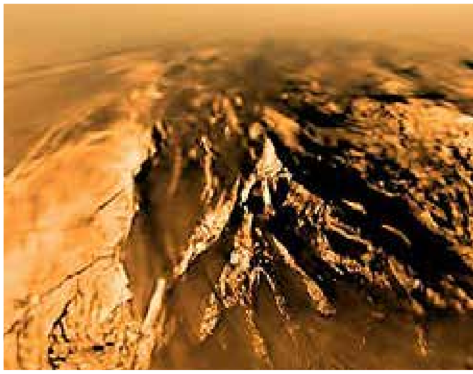
Scientists think that Mars could be home to microbes that live in or under the ice or in rocks because Earth has extremophilic organisms that thrive in these conditions. It is possible that the planet supports endoliths, psychrophiles, anaerobes, or some other form of extremophile life.



The gas giant Jupiter, largest planet in our solar system, has several moons. One of the moons, Europa, has received a lot of attention from scientists, because it appears that under the icy surface of the moon, there is an ocean of liquid water. Europa's frozen surface has many interesting patterns in the ice. The patterns seem to be formed by the ice flowing and cracking. Scientists have also learned that the planet's core is heated by friction from Jupiter's intense gravity. This heat may be enough to make submarine volcanoes that warm the ocean below the ice. Scientists know that life abounds on Earth at deep sea volcanic vents where the pressure is crushing, the water is cold, and it's very dark, similar to what we think it might be like in Europa's ocean. Perhaps Europa has life in its oceans living at thermal vents, tolerating hot water like the thermophiles found in Yellowstone. Maybe cold-loving cryophiles populate Europa's icy surface, like the cryophiles found in Earth's glaciers. Scientists are very interested in finding out more about Europa, and several space agencies, including NASA, are designing missions to explore Jupiter's moons.

TOP OF PAGE: A NASA image of Mars.
LEFT: Europa, as seen by the Galileo spacecraft.

The strangest environment in our solar system that scientists are studying for signs of life is Saturn's largest moon, Titan. Titan is interesting because it has an atmosphere. It is the only moon in the solar system that has an atmosphere. The atmosphere is thick and smog-like. It is so thick that when the Voyager spacecraft flew by, taking pictures in 1980, scientists couldn't see Titan's surface. This is one of the reasons scientists decided to send a probe to the surface of Titan. Images from the Huygens probe, which landed on Titan in 2005, shows what appear to be river-like drainage channels and areas that look like a shoreline. The place where the probe landed looks a lot like a dry river bed, similar to what you might see on Earth. The surface of Titan is cold: about -290° F. This is too cold for liquid water to exist, but there is frozen water present. There is evidence of liquid on Titan but it's not water: it's liquid methane, and it makes up large lakes in several locations on the moon. Without liquid water, the likelihood of life seems pretty slim, but the fact that there are types of methane-loving extremophiles here on Earth may mean there could be a similar life-form on Titan. The Cassini Solstice Mission continues to explore Saturn's moons, sending back more information about Titan's strange surface.



THE SURFACE OF TITAN: 2005 Image collected by the European Space Agency's Huygens Descent Imager.

Many of the environments described here can be studied directly on Earth because of the fascinating microbes we call extremophiles. Though Mars, Europa and Titan are not directly in the Goldilocks Zone, studying extremophiles extends our understanding of the range of conditions where life can survive. For instance, ice-loving psychrophiles would think Mama Bear's "too cold" porridge is just right, and heat-loving thermophiles would think Papa Bear's "too hot" porridge is just right. Finding out more about these 'alien' creatures here on Earth may tell us the likelihood of their living on other planets or moons.

MATCHING GAME

Part 1. Matching Game

Match the extremophile with the type of extreme condition in which it thrives.
Draw a line connecting the microbe and its preferred condition.

EXTREMOPHILE	ENVIRONMENT
Anaerobe	*Very dry*
Psychrophile	*Hot*
Hyperthermophile	*Cold*
Endolith	*Acidic*
Thermophile	*Basic*
Acidophile	*Very, very hot*
Alkalophile	*Crushing pressure*
Barophile	*Rocky*
Xenophile	*No oxygen*

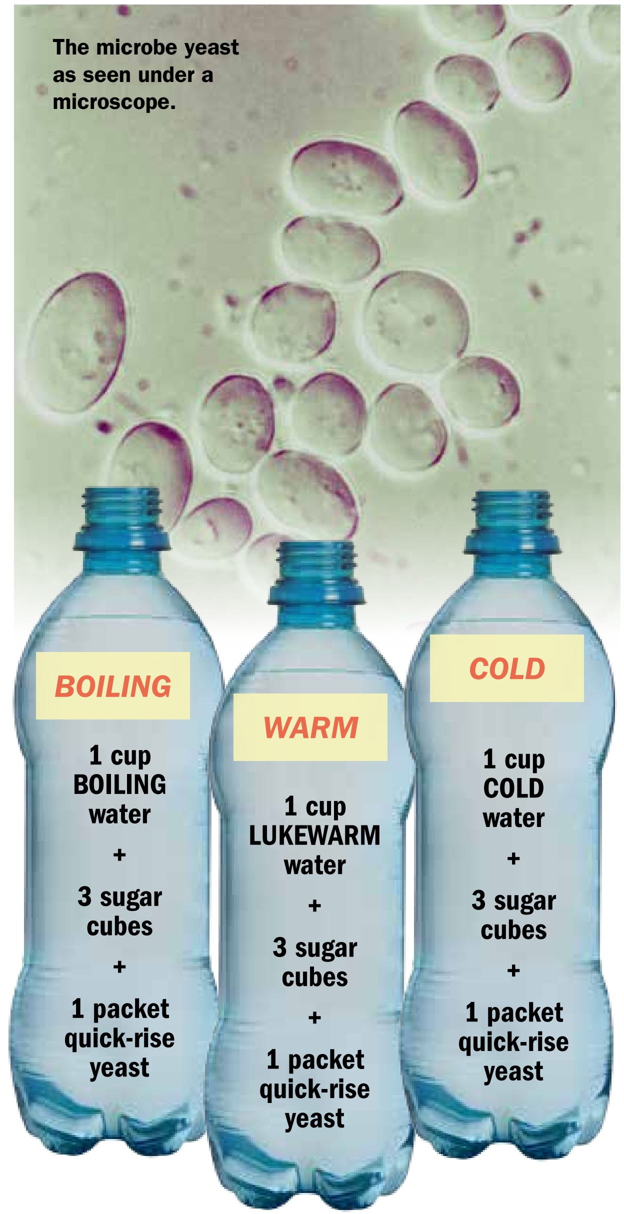
Part 2. Who could live here?

Planet XR-2B5 has a thick atmosphere that contains only carbon dioxide (CO2), and no oxygen. The atmosphere is so thick, its pressure would crush a human being. This planet is very hot because of the carbon dioxide as well. What kinds of extremophiles might be able to live here?

PLANET IN A BOTTLE

PART 1

Now that you know about the Goldilocks zone and other places in our solar system that may harbor life, let's explore how the conditions on a planet or moon impact life. In this activity, we will explore the effect of different conditions on the growth of yeast to show how having "just right" conditions influences the success of life.



The microbe yeast as seen under a microscope.

Experiment

Three model planets will be constructed out of plastic soda bottles to study how temperature affects living things. Yeast will be our model organism, because its activity can be measured by the CO_2 gas it produces from sugar.

VARIABLE: **Temperature**

1. Add 1 cup of boiling water to one soda bottle, 1 cup lukewarm water to another bottle, and 1 cup cold water to the third. Label each bottle clearly.
2. Add 3 sugar cubes and a packet of quick-rise yeast to each bottle. Swirl to mix.
3. After balloons have been stretched (you might want to blow them up and deflate them), stretch a balloon over the top of each bottle and secure with duct or masking tape to it make air-tight.
4. Place the boiling water "planet" in a hot water bath, leave the lukewarm "planet" out, and place the cold water "planet" in an ice bath.
5. Start the timer, then measure and record the circumference of each balloon at **10 minute** intervals**.**

Write up your lab report as you go to keep track of the scientific method you are performing. Fill out the objective, hypothesis, and materials before you begin measuring.

PART 1

Lab Report

PLANET IN A BOTTLE

OBJECTIVE: **What are we doing in the experiment and why? What are we trying to understand or show?**

HYPOTHESIS: **What do you think will happen in each of the bottles and why?**

MATERIALS: **What materials are used in this experiment?**

PROCEDURE: **What steps were used to do the experiment?**

PLANET IN A BOTTLE

PART 1

Lab Report

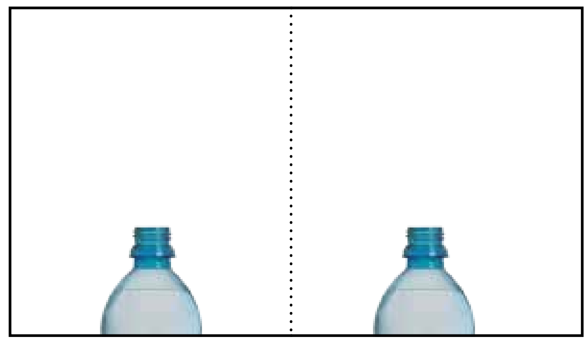
Results

Fill in the data table below with the balloon measurements from the experiment.

Time (minutes elapsed since you started timing)	**Boiling water** (balloon circumference in inches)	**Lukewarm water** (balloon circumference in inches)	**Cold water** (balloon circumference in inches)
min.	in.	in.	in.

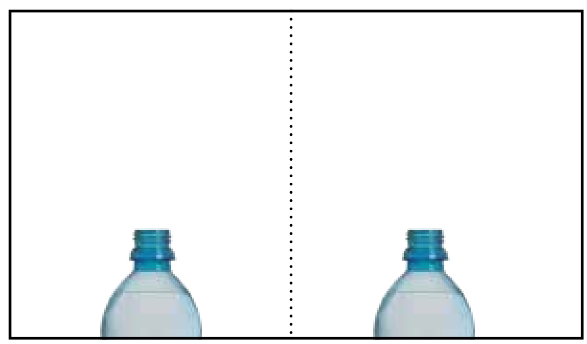
Draw a diagram of the balloon on each bottle at the beginning of the experiment and at the end of the experiment.

BOILING WATER



Beginning **End**

LUKEWARM WATER



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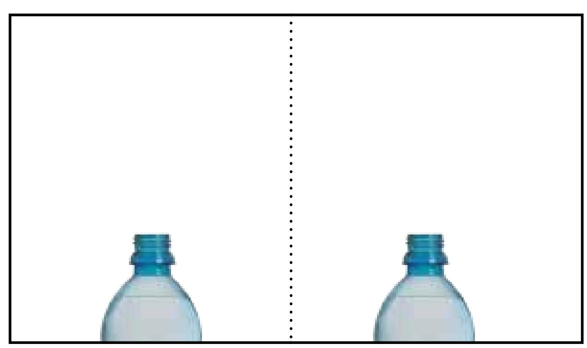
COLD WATER



Beginning **End**

PART 1
Lab Report

PLANET IN A BOTTLE

Discussion: **Answer the questions below to create your discussion section.**

How much did each balloon expand during the experiment?

Which bottle had the best balloon growth? Why do you think this might be?

What does the size of the balloon say about how much the yeast liked the conditions in the bottle?

PLANET IN A BOTTLE

PART 1
Lab Report

Did the results of the experiment support your hypothesis? Why or why not?

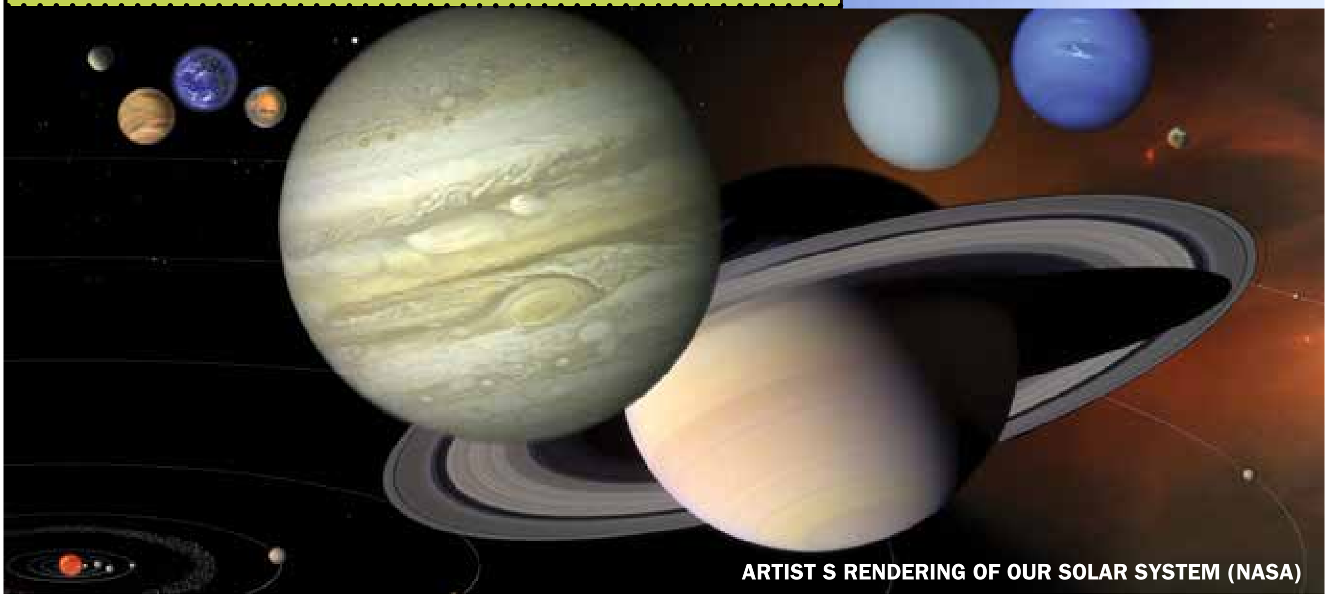
Which bottle represents the Goldilocks zone? Why?

What do the results of the experiment tell you about the Goldilocks zone?

Do you think yeast are extremophiles? Why or why not?

PLANET IN A BOTTLE

PART 2



ARTIST S RENDERING OF OUR SOLAR SYSTEM (NASA)

Design a planet

For this activity you get to design your own planet in a bottle experiment. In the first planet in a bottle experiment, we were testing only the effect of temperature on the growth of yeast. Would you like to see how yeast react to a different set of conditions—for example, the cold, dry surface of Mars? Or how about the hot, acidic, high pressure conditions found on Venus? If you wanted to see how yeast tolerated these types of environments, how would you make a bottle experiment to test it? What would you put in your bottle?

Ideas to get started

For your experiment, you may want to try to mimic the conditions on another planet or moon in our solar system, or you may want to make up your own unique planet, or you may want to simply test a single variable like we did in the first experiment.

Also, you could choose to mimic the conditions in one of the hot springs in Yellowstone National Park, because scientists study the extremophiles living there as analogs to those that could live on other planets.

To try and make a model of one of Yellowstone's hot springs, or our solar system's planets or moons, you will need to find out what conditions are like there. This may require some research on your part. This website lists temperature and other conditions for some of the hot springs in Yellowstone and tells what types of extremophiles live there: http://microbewiki.kenyon.edu/index.php/Yellowstone_Hot_Springs

NASA has a website with lots of information about the planets and moons of the solar system that you may find helpful: http://solarsystem.nasa.gov/planets/profile.cfm Your school or local library may have lots of great books on our solar system.

To make your experiment test a single variable, you must pick only *one* thing to change (this is what real scientists try to do).Your teacher can help you with suggestions of what to change. A hint is to think about things you could add to or take away from the bottle that would make it different from the experiment in Part One. Be sure to check with your teacher about the materials you want to use and remember that your materials must be able to fit into your bottle.

PLANET IN A BOTTLE

PART 2
Lab Report

OBJECTIVE: **What variable are you testing, or on what planet/moon/hot spring are you trying to model in your experiment?**

What materials are you using to mimic a planet/ moon, or how are you testing the variable you choose?

HYPOTHESIS: **What do you think will happen in your experiment? Why?**

MATERIALS: **What materials did you choose to use for your experiment? Why?**

PROCEDURE: **What steps did you use to create your planet?**

PART 2

Lab Report

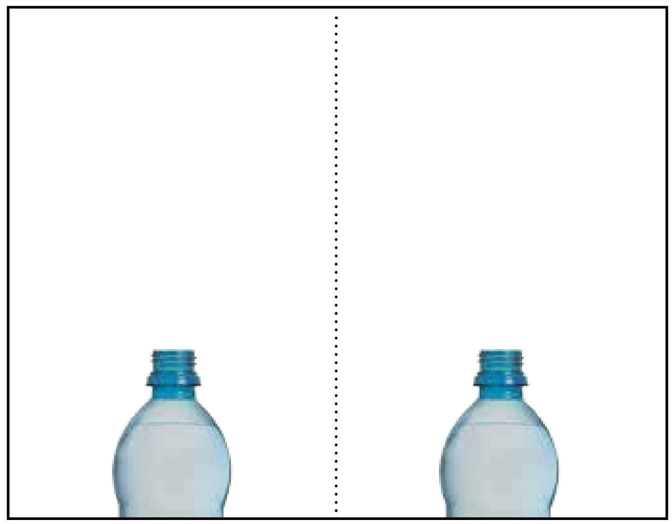
PLANET IN A BOTTLE

Results

Fill in the data table below with the balloon measurements from the experiment.

Time (in minutes)	**Balloon circumference** (in inches)

Draw a diagram of the balloon on your bottle at the beginning of the experiment and at the end of the experiment.



Beginning **End**

PLANET IN A BOTTLE

PART 2
Lab Report

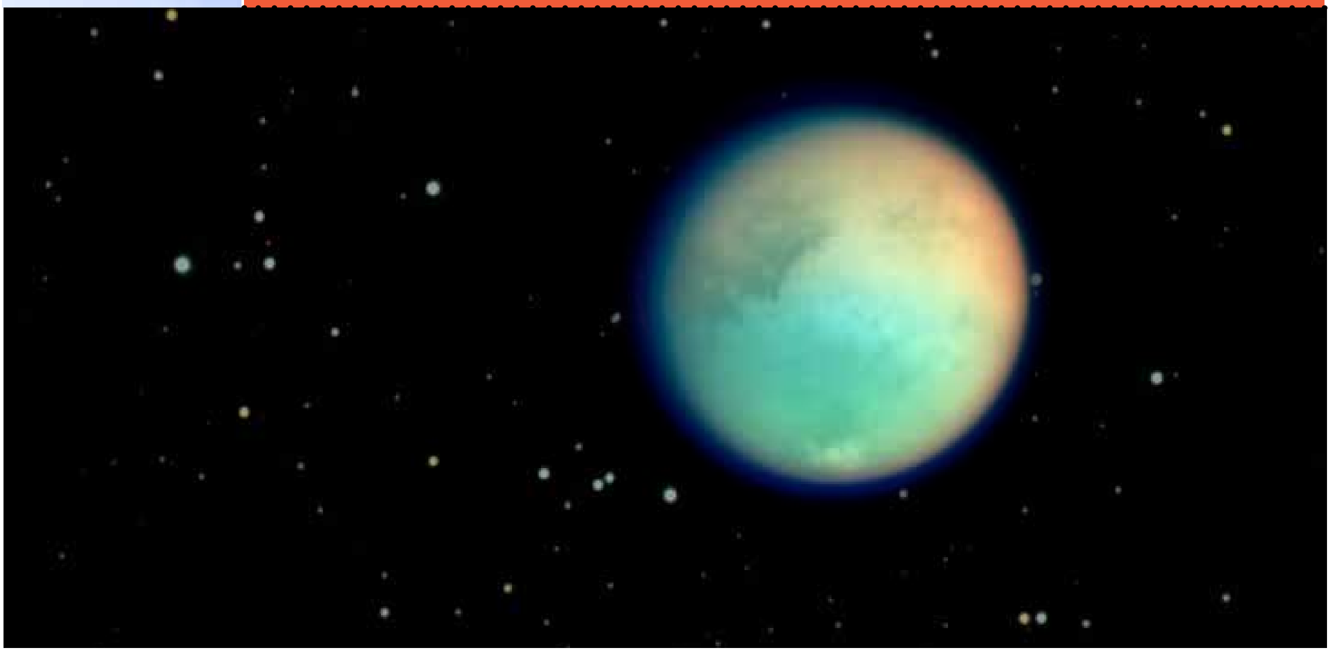
Discussion: **Answer the questions below to create your discussion section.**

Did the balloon expand during the experiment?

What does the growth of the balloon say about how much the yeast liked the conditions in the bottle?

Did the experiment support your hypothesis? Why or why not?

EXTREME PLANET PROJECT



In this project, you get to design a planet and an extremophile to live on it. You also get to report to your classmates about your creation and write about your discovery in a newspaper article to share the news with the world!

Design a Planet on NASA's AstroVenture website

Go to the AstroVenture "Design a Planet" website at *http://astroventure.arc.nasa.gov/DAP/index.html*

Watch the introduction. Then, click on "Design a Planet Tutorial" and find out how to use the website to make your planet.

Once you feel confident that you understand the process, try your hand at making a planet by choosing "Design a Planet Regular or Lite." Be sure to read the text boxes for each characteristic of your planet so that you understand their role in making a planet habitable or uninhabitable.

Try designing a planet several times and see what types of planets are created by different combinations of characteristics.

Design a Planet on NASA's JPL Extreme Planet Makeover website

Go to the Jet Propulsion Laboratory's Extreme Planet Makeover website at:
http://184.72.55.19/system/interactable/1/index.html
or navigate there by going to
http://planetquest.jpl.nasa.gov/

Design a planet by adjusting the planetary attributes (found at the bottom of the page). Again, be sure to read the text boxes that appear as you scroll over each option, so that you can understand how each attribute influences the planet you create. Play around with the attributes and see what types of planets you can create.

EXTREME PLANET PROJECT

Design a planet on Astroventure or Extreme Planet Makeover

1. Name your planet and describe its characteristics, such as:
   - AU from a star (an AU, or astronomical unit, is the average distance between the Sun and Earth)
   - size
   - average temperature
   - presence or absence of plate tectonics
   - whether it is a rocky planet or gas planet
   - whether or not it has an atmosphere

   Write these facts down from Astroventure or Extreme Planet Makeover.

   ***Note:** Just because your planet couldn't support human life doesn't mean that an extremophile can't live there. You are free to make any type of planet, as long as you can explain how your extremophile is able to live on it!*
2. Use your knowledge of your new planet and of Earth's extremophiles to design an extremophile that lives on your planet.
3. Draw a picture of your planet and its extremophile.
4. Write up some facts about your planet and its extremophile and prepare to present your creation to your classmates. Here are some ideas to get you thinking about the details you will want to include.

Questions about your planet:

What is the name of your planet?

What is it like on the surface of your planet?

Could humans survive on its surface? Why or why not? Is there water there? Is it liquid, ice, gas?

Is there weather on your planet?

Is the climate the same everywhere on your planet or does your planet have different climates?

Are there oceans?

Questions about your extremophile:

How big is your extremophile?

How does your extremophile get energy? (Does it get it from the sun, from eating other things, from using chemicals found on your planet?)

How does your extremophile interact with its environment? Is it the only form of life on your planet?

What special adaptations help the extremophile cope with life on your planet? Could your extremophile survive on Earth?

EXTREME PLANET PROJECT

Extra! Extra! Life found on another planet!!!!

Newspaper article

Write a newspaper article about your planet and its extremophile. Be sure to make your story a good summary of the information that includes the *who, what, when, where, why,* and *how* found in any good news story. Remember that if this were a real story, it would be huge news, so make your story exciting. Keep in mind the questions about your planet and extremophile (listed above) when writing your article so that you can give your readers lots of cool details. Major news stories often include pictures, so include a picture of your planet and its extremophile in your article.