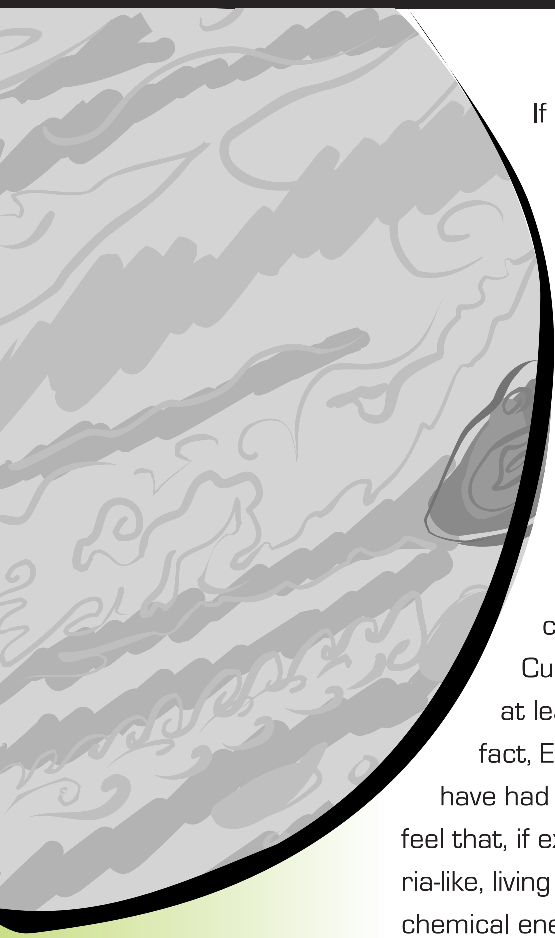
ACTIVITY 3

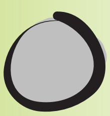
What makes a world habitable?

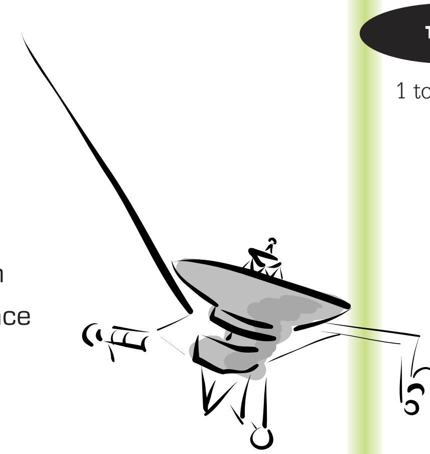


If life is playing a game of planetary hide and seek with us, then our job is to find it. But where in this immense solar system should we begin to look, and what should we be looking for? One way astrobiologists narrow the number of possible "hiding places" is to understand what makes a planet or moon habitable. They then look closely at these habitable places.

No life beyond Earth has ever been found. Does this mean that life is a rare accident that happened on Earth due to an extraordinary set of circumstances and is unlikely to happen elsewhere? Currently, all other planets and moons seem to lack at least one major requirement for life. Despite this fact, Europa, Mars, and possibly Titan seem to have or have had conditions conducive to life. Most astrobiologists feel that, if extraterrestrial life were found, it would be bacteria-like, living beneath a planet's or moon's surface, and using chemical energy for its needs.

Finding any kind of life beyond Earth would be a profound discovery. It would help us understand more about how planets and moons can generate the chemistry that leads to life and about the conditions that life can tolerate. Furthermore, it would help provide some important clues to the question of whether life is a rare or common occurrence in the universe.





PURPOSE

To assess the possibility of life in the solar system

CONTEXT

Activity 3 builds on the work the students have done defining and examining life. Students apply this work to the question of whether there is life on other planets and moons, a question that people have long pondered and that drives much of the space program. This activity also familiarizes students with the planetary bodies in the solar system.

TIME

1 to 2 class periods

Recommended Procedure

STEP 1 To get a sense of student understanding about habitability, ask students, "What makes a planet or moon a good home for living things?" Have each student write down an answer.

STEP 2 If you feel that students need a quick review of the key habitability factors, conduct a class discussion to develop a set of basic criteria. You might ask:

In general terms what does life need?

Answer: Life needs food, water, and conducive habitats (e.g., protection from radiation and suitable temperatures). Food is both a source of energy and raw materials for construction. Students will be able to make better use of the *Habitability Cards* if they are aware of food's dual roles.

What kinds of things might limit life?

Answer: Extreme temperatures, high levels of radiation such as ultraviolet radiation, and lack of food and water can limit life.

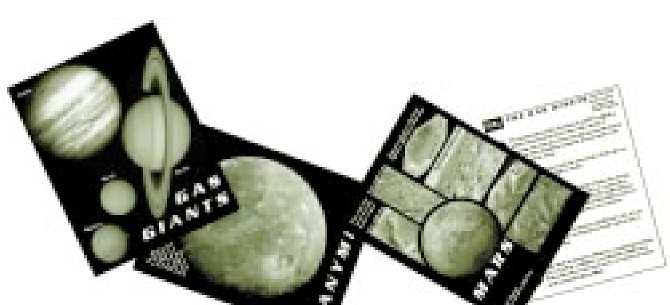
Students should come away from this discussion with a clearer (it does not have to be perfect!) sense of what makes a planet conducive for life. What they need before going on is a rudimentary set of criteria for judging the possibility of life on a planet.

STEP 3 To investigate the possibility of life in our solar system, have students use the *Habitability Cards* and the accompanying key to assess the habitability of each planet and moon in our solar system. [To make a set of cards, photocopy pages 29 to 34, double-sided if possible. Cut them into individual cards. To make them last longer, copy them onto card stock or laminate them.] On the Activity Guide, have each student rank each planet or moon as a likely, unlikely, or possible candidate for life and articulate the reasoning behind his or her determination.

STEP 4 If students have been working on their own, organize them in groups. Have each group select its top three candidates for life. Conduct a class discussion and record each group's analyses on a class chart. Have them state the reasoning behind their choices.

Since students typically take several minutes with each card, there is no need to prepare a large number of sets. Students can share cards, exchanging ones they have used for new ones. Alternatively, if you feel that trading will cause too much disruption in your class, organize the class in groups of six students and provide each group a complete set of *Habitability Cards*.

Photocopied versions of the *Habitability Cards* are usually lackluster and uninspiring. You can download a full-color version of the *Habitability Cards* at **astrobio.terc.edu** or **astrobiology.arc.nasa.gov.**



CONCEPTS

- Except for Earth, each planet or moon currently has major limitations for life as we know it.
- Looking for habitable conditions is easier than looking for actual organisms.
- If extraterrestrial organisms exist in our solar system, they probably live underground and, thus, are very small.
- Europa, Mars, and Titan may have or have had habitable conditions.
- Sunlight intensity influences surface temperatures and whether organisms can use light as an energy source.
- Sunlight intensity on a planet or moon diminishes as the square of its distance from the sun.

SKILLS

- *Interpret* images and data and *Compare*, *Sort*, and *Categorize* that data
- *Generalize* and *Infer* from observations and *Draw* conclusions
- *Summarize* information, *Synthesize* understanding, and *Present* it clearly
- *Contribute* thoughtfully to group and class discussions

MATERIALS

- three to four sets of *Habitability Cards* (pages 29 to 34; laminate, if possible)
- one Activity Guide (page 36) and *Key to Habitability Factors* (page 35) for each student (copy back-to-back, if possible)

What makes a world habitable?

Math Extension

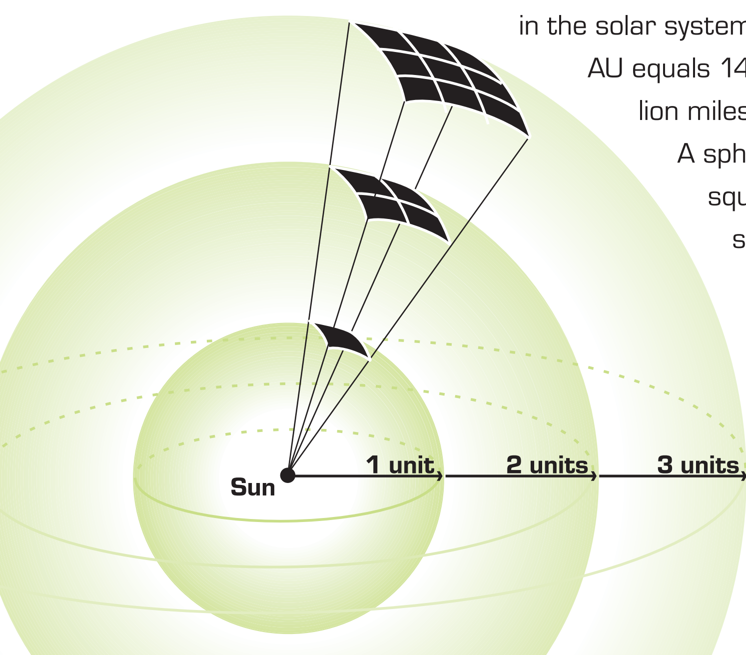
In the *Habitability Cards*, students read that, at certain distances from the sun, sunlight is too dim to be a viable energy source. The intensity of light diminishes as one moves further from the source. Students know this intuitively from observing how the brightness of a flashlight changes as one moves toward or away from a surface. Interestingly, the light changes in a predictable, measurable way that can be described by a mathematical formula called the **Inverse Square Law**. Any student comfortable with fractions and multiplying and dividing can calculate differences in light intensities.

The Inverse Square Law applies to fields that radiate evenly in all directions (e.g., light and magnetic and gravitational fields). Objects that generate such fields are called **point sources**. The diagram below shows the sun serving as a point source of light because it is in the center of a sphere of light traveling evenly in all directions.

As the light spreads out, its intensity per unit area decreases. To calculate the light intensity, one needs to know the light intensity at some reference point. For our solar system, astronomers use Earth as a reference point because they have measured the intensity of light reaching Earth from the sun to be 1370 watts per square meter (W/m^2).

To calculate the light intensity at any position in the solar system, one needs to have a reference intensity and to know the distance from the light source. A convenient unit for talking about distances in the solar system is the **astronomical unit** (AU.) One AU equals 149,597,870 kilometers (about 93 million miles), the distance from Earth to the sun. A sphere's surface area grows as the square of its radius. Therefore, light intensity depends on the square of the distance from the center of the sphere. Mathematically:

$$\textbf{difference in light intensity} = 1/\text{distance}^2$$



For example, Mars is 1.5 AU from the sun. We can use the Inverse

Square Law to see how the light intensity on Mars compares with the light intensity on Earth.

$$1/\text{distance}^2 = 1 / 1.5^2 = 1/ 2.25 = 0.44$$

The light intensity on Mars is 44% that of Earth's. Since the intensity on Earth is 1370 W/m^2, then the intensity on Mars is

$$0.44 \times 1370 \text{ W/m}^2 = 603 \text{ W/m}^2$$

By increasing the distance from the sun by just one-half an AU, the light intensity drops by more than half, relative to Earth.

Unlike the sun or a light bulb, both of which are point sources of light, overhead and slide projectors use mirrors and lenses to focus light. Consequently, the light from these projectors does not radiate evenly in all directions, and they are not point sources of light. Nonetheless, the model described in this Math Extension successfully approximates the Inverse Square Law, and light intensity does diminish with distance in close accordance with the 1/distance^2 relationship.

As with most models, this one has its limitations — it illustrates certain aspects of the Inverse Square Law well while misrepresenting others. With any model, students must be made aware of its strengths and limitations. So, even though the Inverse Square Law applies only to point sources, this model with its focused beam still demonstrates the inverse square relationship fairly well. For a truly accurate inverse square demonstration, use a light meter to measure the drop off in intensity around a 40 Watt (or less) light bulb.

Recommended Procedure

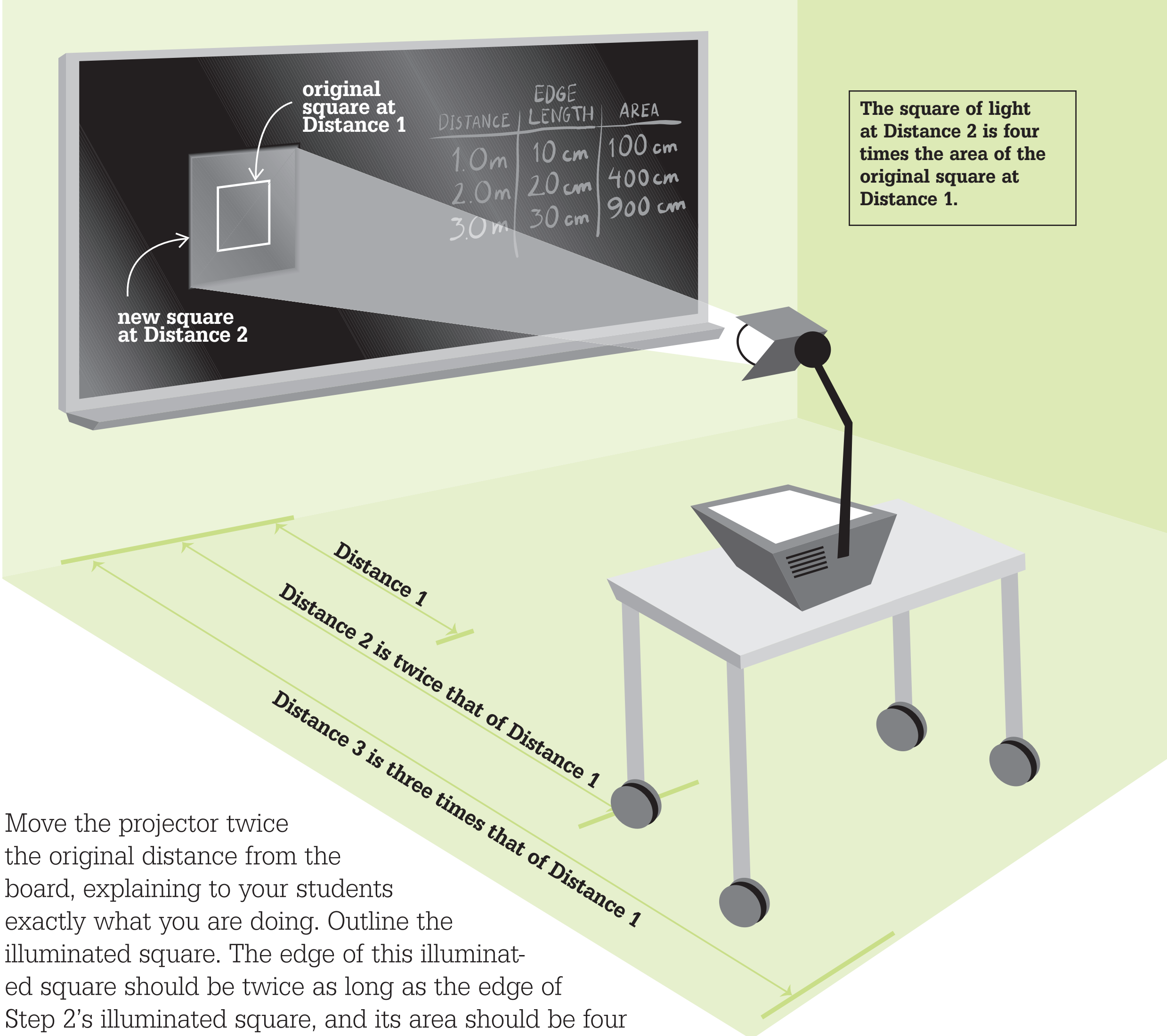
MATERIALS

- overhead projector

STEP 1 Set a slide or overhead projector either ten centimeters or one meter from a wall or board. Either of these distances will make the inverse square relationship readily apparent. (This distance can vary. It is really a function of how much space you have and the size of your screen.) Note the distance between the board and the bulb or lens.

STEP 2 Project light onto the board and outline the illuminated square. Use a three-column table to keep track of the distance from the board, the length of the illuminated square's edge, and the area of the illuminated square.

STEP 3 Have students predict what will happen to the illuminated square when you move the projector further from the board. (It increases in size.) Ask them how the light intensity changes when you move the projector further from the board. (It decreases.)



The square of light at Distance 2 is four times the area of the original square at Distance 1.

STEP 4 Move the projector twice the original distance from the board, explaining to your students exactly what you are doing. Outline the illuminated square. The edge of this illuminated square should be twice as long as the edge of Step 2's illuminated square, and its area should be four times the area of Step 2's square. Ask students how the light intensity has changed, now that the same amount of light has to cover four times the area. They should say that the light intensity within the square is one fourth of the original light intensity.

STEP 5 Ask students to predict what the intensity will be if you move the projector three times the original distance from the wall. When you move the projector this distance, the edge of this illuminated square should be three times as long as the edge of Step 2's illuminated square, and its area should be nine times the area of Step 2's square. Consequently, the amount of light hitting each unit area in Step 5 is about one ninth of the amount hitting each unit area in Step 2.

STEP 6 Have students create a graph comparing the projector's distance from the board with the area of the illuminated square. Then, introduce your students to the math of the Inverse Square Law. Refer to the distance, length, and area data from the table you created:

$^1/(\text{Distance 1})^2 = 1/1^2 = 1$	Define the intensity at Distance 1 as the reference intensity
$^1/(\text{Distance 2})^2 = 1/2^2 = 1/4$	A value of **1/4** means that the intensity per unit area at Distance 2 is 1/4 of the reference intensity
$^1/(\text{Distance 3})^2 = 1/3^2 = 1/9$	A value of **1/9** means that the intensity per unit area at Distance 3 is 1/9 of the reference intensity

STEP 7 Using the graph or applying the Inverse Square formula, ask students to predict the size of the illuminated area if the projector were moved four times the original distance. Try it, if possible. (Compared with the illuminated square in Step 2, the edge of Step 6's square will be four times as long and its area will be 16 times as large.)

STEP 8 The Inverse Square Law enables you to calculate light intensities relative to a known light intensity. Step 8 uses the light intensity of Earth (1370 W/m^2) as the known light intensity. Have your students calculate the light intensity for planets and moons in our solar system relative to Earth. Then have them create a graph of their calculated values against their distances from the sun.

Begin by using Mercury as an example. On average, Mercury is 0.39 A.U. from the sun. According to the Inverse Square Law, the amount of light reaching Mercury is inversely proportional to Mercury's distance from the sun, so:

$$1/(0.39)^2 = 6.575$$

Thus, the amount of light reaching Mercury is more than six and a half times (657.5%) of the amount of light reaching Earth. To determine the light intensity on Mercury, use Earth's intensity, 1370 W/m^2, as a reference intensity

$$6.575 \times 1370\ W/m^2 = 9{,}008\ W/m^2$$

Planet or Moon	Distance from Sun (AU)	Light Intensity (relative to Earth)	Watts per Square Meter
Mercury	0.39	6.575	9008
Venus	0.72	1.929	2643
Earth & Moon	1.0	1.000	1370
Mars	1.5	0.444	603
Jupiter & its moons	5.2	0.037	51
Saturn & its moons	9.5	0.011	15
Uranus	19.2	0.0027	3.7
Neptune	30.1	0.0011	1.5
Pluto	39.5	0.0006	0.8

STEP 9 Briefly discuss the pattern students found and the idea of a **Habitable Zone** — the zone between the point where there is too much and too little sunlight. Beyond the inner edge of the Habitable Zone, it is too hot for life and surface water boils away. Beyond the outer edge of the Habitable Zone, liquid water freezes. Also, at some point beyond the outer edge of the Habitable Zone, sunlight becomes too dim to be a viable energy source for organisms living on or near the surface. Within the Habitable Zone, water can exist as a liquid, given the right atmospheric conditions.

fast facts THE GAS GIANTS

JUPITER
SATURN
URANUS
NEPTUNE

The temperature at the cloud tops is –200°C while the interior temperatures reach tens of thousands of degrees. The churning of the atmosphere causes temperatures of the circulating gasses to change greatly over short distances and periods of time.

The gas giants are made almost entirely of hydrogen and helium, with very small amounts of water.

Gas giants release large amounts of their own energy, keeping internal temperatures high and causing their atmospheres to circulate constantly. The violent storms created by this circulation would subject life to rapid and extreme changes in temperature and pressure.

Sunlight is dim but may be a viable energy source. Obtaining sufficient amounts of chemicals in a gaseous environment is difficult, making chemical energy an unlikely energy source.

A gas environment is too diffuse to concentrate nutrients and make them available in a predictable, reliable way. Having life arise or survive in such a constantly changing environment is highly unlikely.

fast facts VENUS

Venus has a thick carbon dioxide atmosphere that traps heat efficiently. The average surface temperature is 464°C.

There is no surface water. The atmosphere has trace amounts of water vapor (30 parts per million or 0.0000003%).

Venus's atmosphere is 92 times that of Earth's. It is 97% carbon dioxide.

The thick clouds prevent much sunlight from reaching the surface, so any life would have to depend on chemical energy. Sulfuric acid clouds provide a potential source of chemical energy.

In general, Venus and Earth have the same chemical composition, and Venus is volcanically active, giving it a way to cycle chemicals important to life.

fast facts EARTH

The average surface temperature is 15°C. Earth's maximum temperature is 51°C (Libya) and its minimum is –89°C (Antarctica).

On Earth, water exists in all three states. The water cycle delivers water to nearly every part of Earth.

Earth's atmosphere shields the surface from harmful ultraviolet radiation and most meteorites, insulates the Earth, and serves as a source of nutrients such as nitrogen and carbon.

Plants capture sunlight and make possible the food chain. High oxygen levels in the atmosphere enable life to use high-energy, carbon-based energy sources (e.g., sugar). Many microbes live off the chemical energy in inorganic compounds such as iron and sulfur.

Everything organisms need to build and maintain their bodies is already on Earth. Earth has processes such as plate tectonics to cycle chemicals important to life.

fast facts MARS

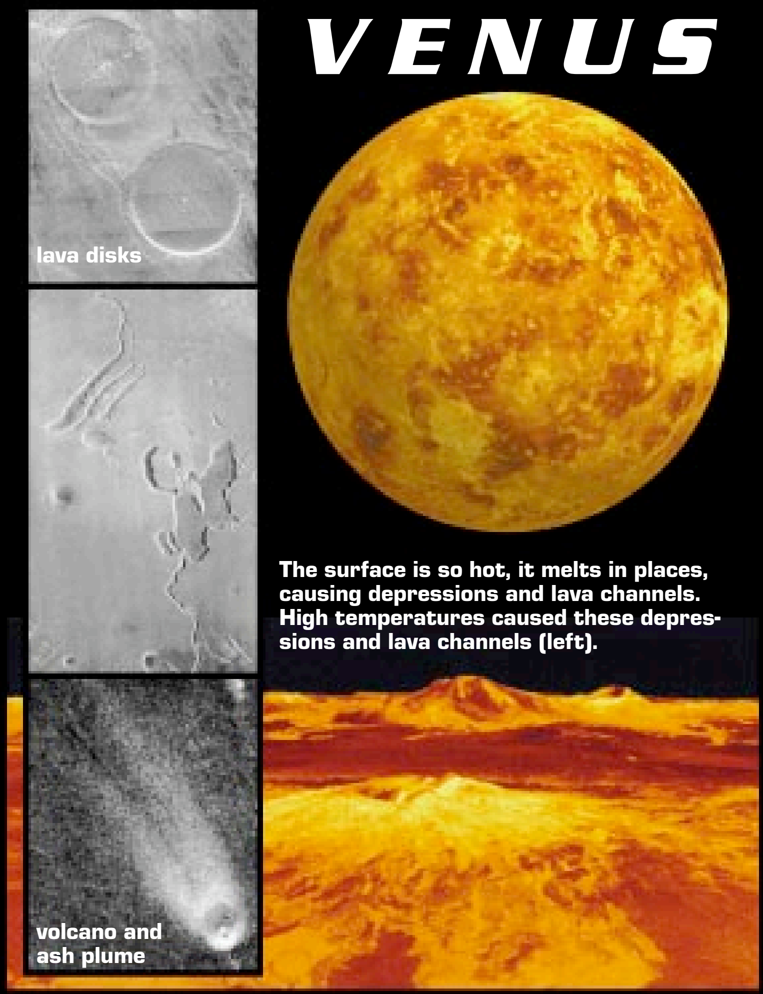
Even though the surface temperature can reach room temperature for a few minutes at mid latitudes, the average surface temperature is –63°C.

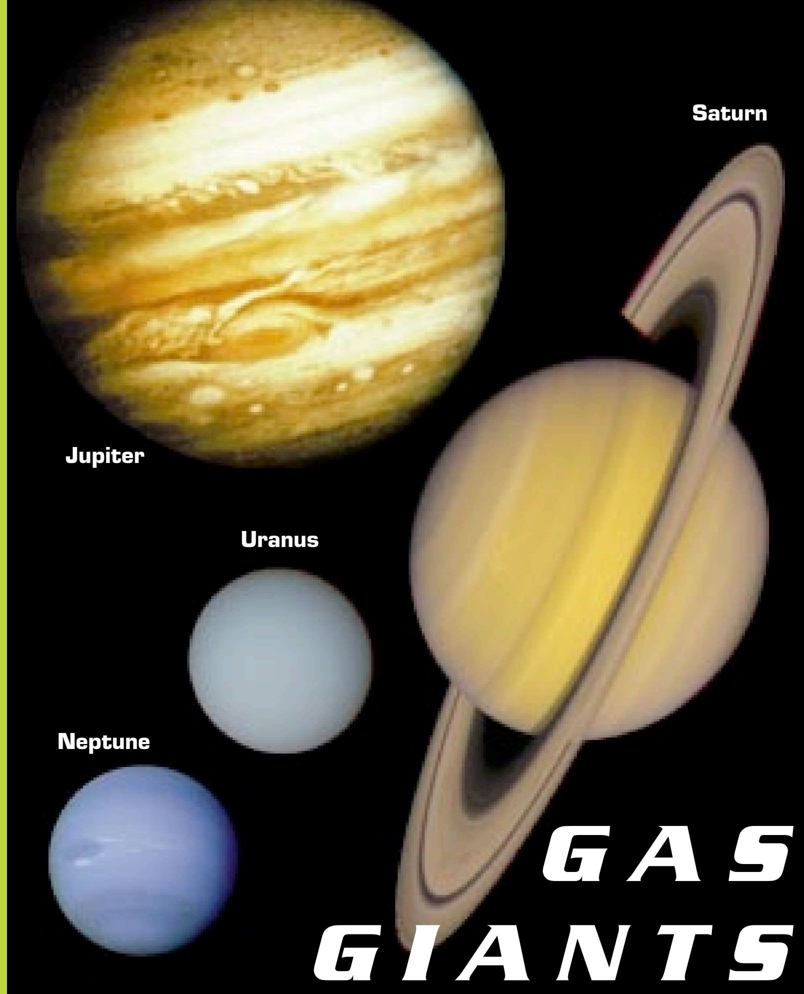
Though there is no surface water, features suggest that Mars once had flowing surface water. There are also indications of thick layers of permafrost, soil locked in water ice. The Northern and Southern ice caps contain water ice.

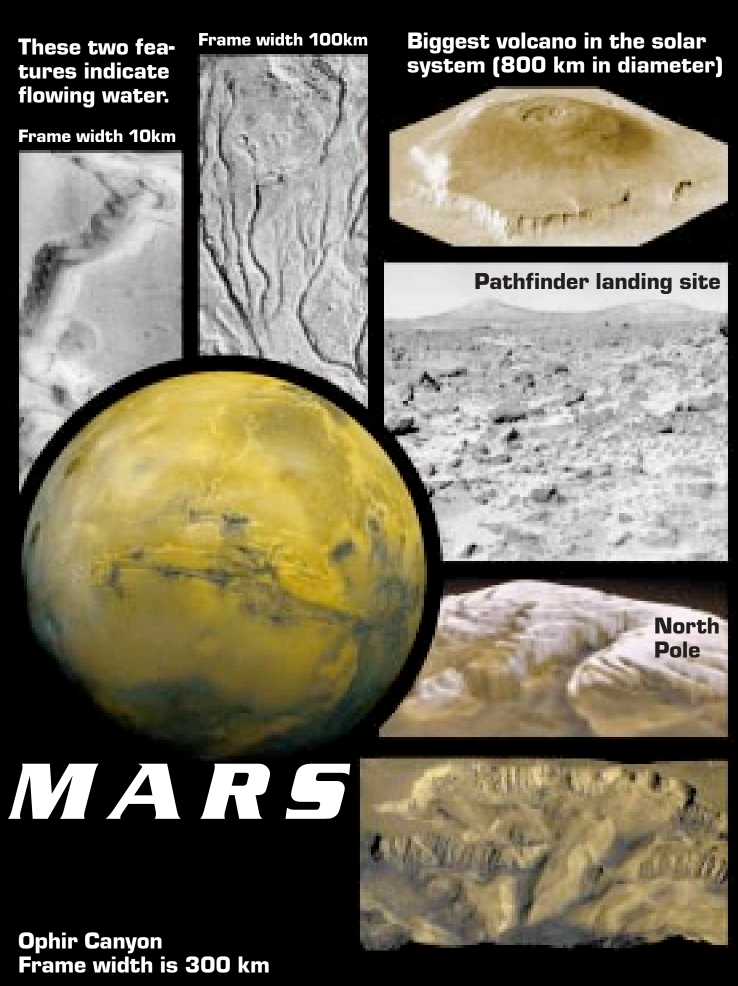
The Martian atmosphere is 95% carbon dioxide. The atmospheric pressure is so low (one-thousandth that of Earth's) that surface water quickly boils away. The atmosphere is too thin to protect or insulate the surface of Mars significantly.

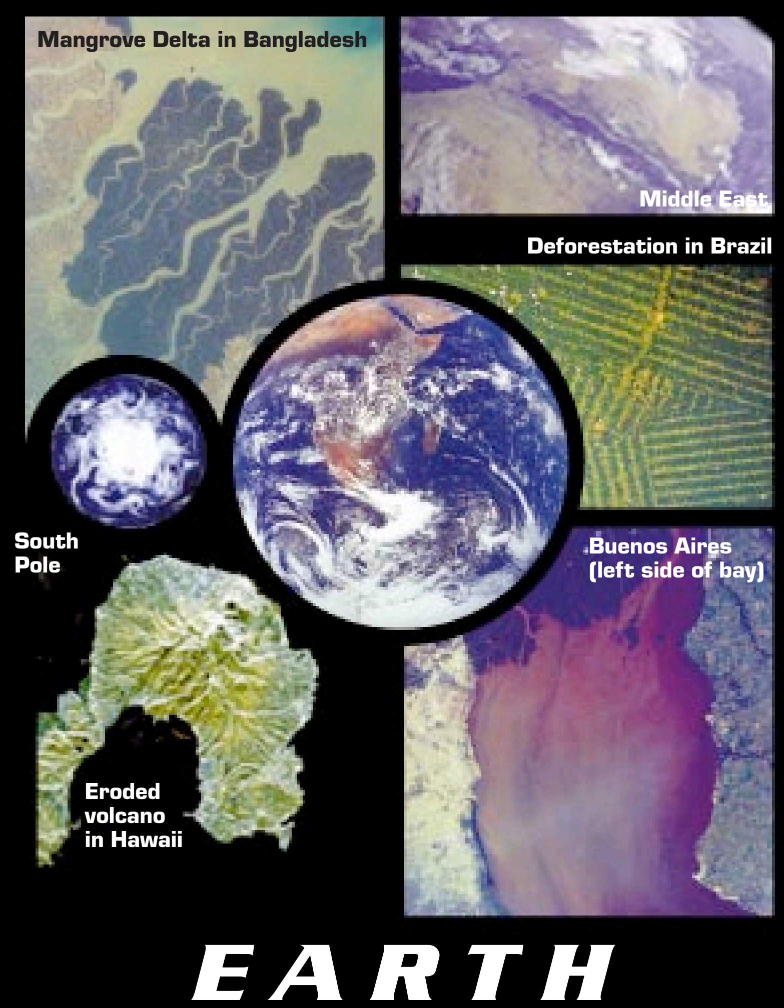
Mars is on the edge of the Habitable Zone, making sunlight a possible energy source. Chemicals made available by volcanic activity early in Mars's history may once have been a possible energy source.

Mars and Earth have the same general chemical composition. Mars was volcanically active for its first two to three billion years, giving it a way to cycle chemicals important to life.


VENUS
lava disks
The surface is so hot, it melts in places, causing depressions and lava channels. High temperatures caused these depressions and lava channels (left).
volcano and
ash plume

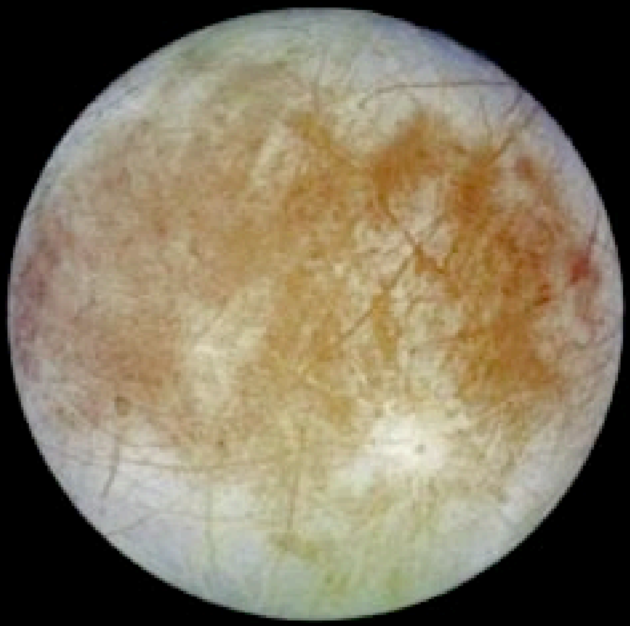

Saturn
Jupiter
Uranus
Neptune
GAS
GIANTS


These two features indicate flowing water.
Frame width 10km
Frame width 100km
Biggest volcano in the solar system (800 km in diameter)
Pathfinder landing site
North
Pole
MARS
Ophir Canyon
Frame width is 300 km


Mangrove Delta in Bangladesh
Middle East
Deforestation in Brazil
South
Pole
Buenos Aires
(left side of bay)
Eroded
volcano
in Hawaii
EARTH

The bright patches are a highly reflective material such as ice that oozed from the interior. Ganymede is Jupiter's largest moon.

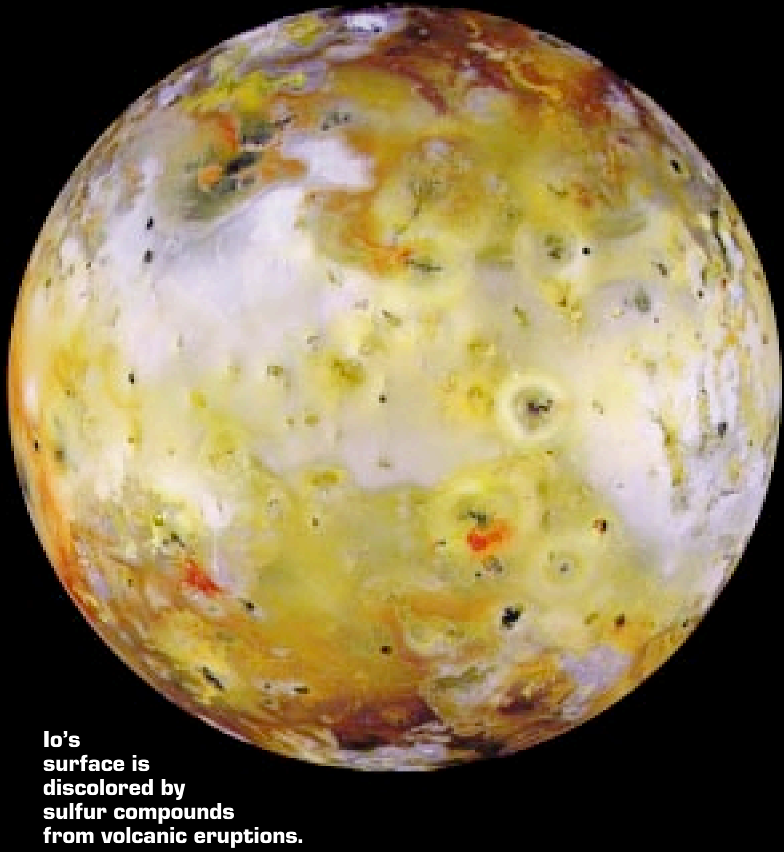
GANYMEDE



EUROPA

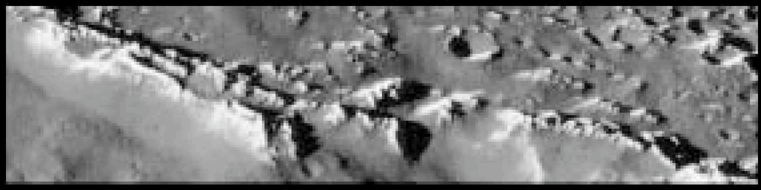
Surface close-up. Frame width is 50 km.

IO



Io's surface is discolored by sulfur compounds from volcanic eruptions.

Computer-generated surface view.



CALLISTO

Callisto is the most heavily cratered object in the solar system.

fast facts EUROPA JUPITER'S MOON

At noon on the equator, the average surface temperature is –145°C.

Europa is covered with a one- to ten-kilometer-thick crust of water ice. There is strong evidence that this crust may cover a 60–100-km deep ocean of water. An ocean of this size would hold more water than there is on Earth!

There is no atmosphere.

Sunlight may be a viable energy source. Scientists think Europa's core is hot enough to have volcanic activity beneath its ocean. Such activity might make energy-rich compounds such as sulfur compounds available. Europa's ice crust is also thickly dusted with another potential energy source, sulfur compounds from Io's eruptions.

Europa is a solid body and the materials for life are likely to be present. Possible volcanic activity and a large ocean provide several ways to cycle chemicals important to life.

fast facts GANYMEDE JUPITER'S MOON

At noon on the equator, the average surface temperature is –121°C.

Ganymede's surface and upper layers are an even mixture of rock and water ice. There is no known source of heat to melt the ice.

There is virtually no atmosphere.

Sunlight may be a viable energy source. There are no known geologic processes to make chemicals available to organisms that rely on chemical energy.

Ganymede is a solid body and probably has the necessary materials for life. However, Ganymede seems to lack any processes that are necessary to cycle chemicals important to life.

fast facts CALLISTO JUPITER'S MOON

At noon on the equator, the average surface temperature is –108°C.

Callisto appears to be an ice-rock mix through and through. Its low density suggests that it contains large amounts of water ice. Some scientists think there is a salt-water layer beneath the surface.

There is virtually no atmosphere.

Sunlight may be a viable energy source. If there is a salt-water layer beneath the surface, organisms may be able to rely on chemical energy.

Callisto is a solid body and probably has the necessary materials for life. However, Callisto seems to lack any processes that are necessary to cycle chemicals important to life.

fast facts IO JUPITER'S MOON

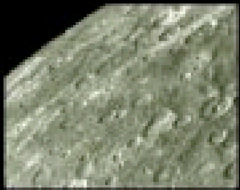
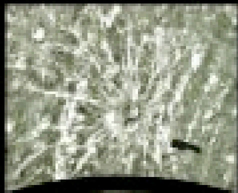
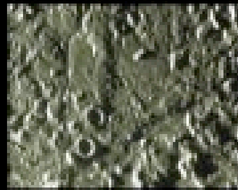
At noon on the equator, the average surface temperature is –150°C. In areas with volcanic activity, the lava flowing across the surface can reach 1,250°C.

Io experiences almost constant volcanic activity, making it the most active volcanic body in the solar system. This activity and the hot interior drive out any water, and there is no known liquid water or water ice on Io.

There is essentially no atmosphere. A thin cloud of sulfur compounds from Io's constant volcanic activity surrounds Io.

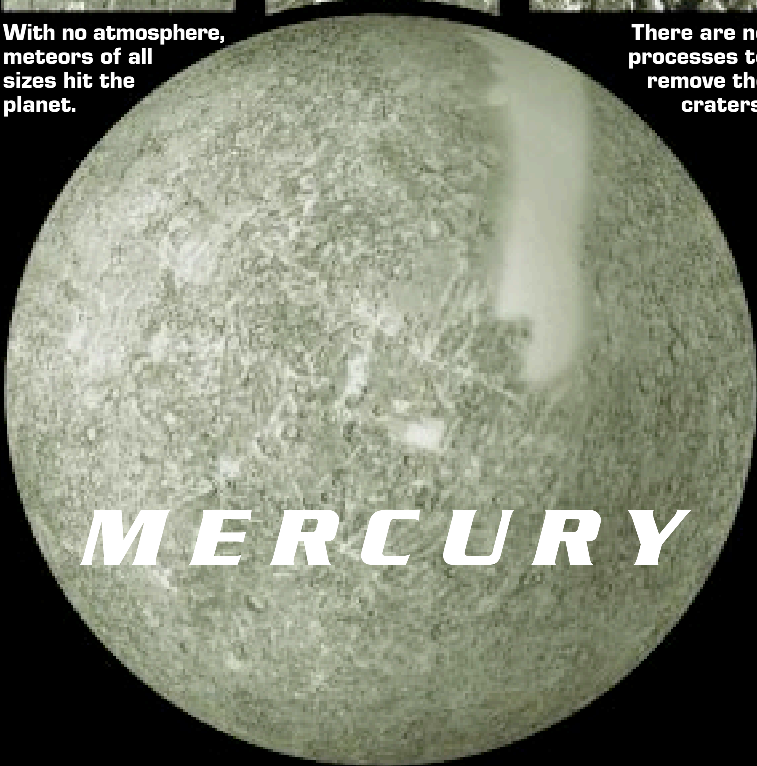
Sunlight may be a viable energy source. Volcanic activity has coated Io's surface with compounds such as sulfur and sulfur dioxide. On Earth, many microbes use such compounds as an energy source.

Io is a solid body and the materials for life are likely to be present. Volcanic activity could cycle chemicals important to life.

With no atmosphere, meteors of all sizes hit the planet.

There are no processes to remove the craters.

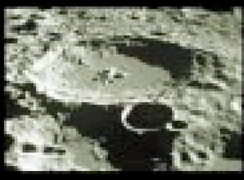


MERCURY

Because no spacecraft has ever visited Pluto, this computer-generated image based on telescopic observations is among the most accurate depictions we have of Pluto.

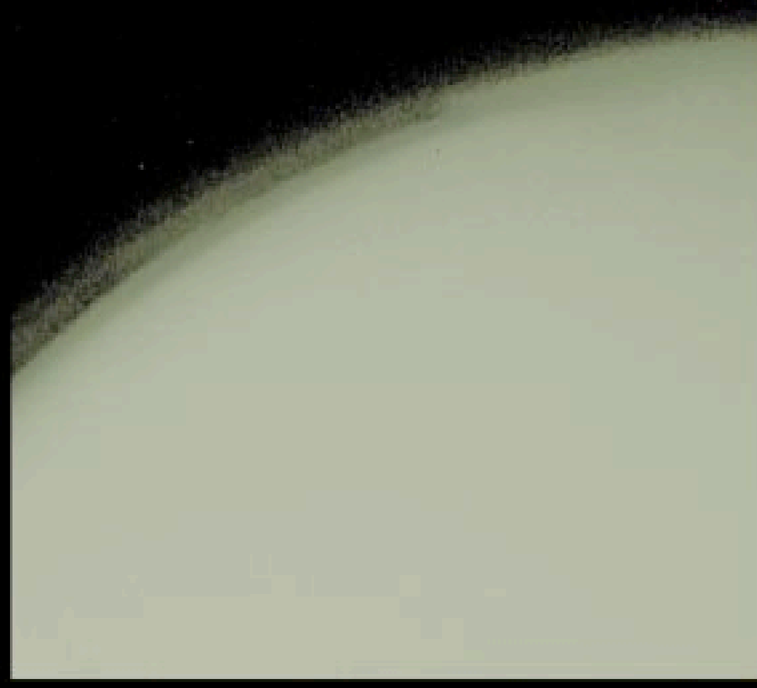
PLUTO

EARTH'S MOON


TITAN

A thick, hazy atmosphere envelops Titan. The closest a spacecraft has come to Titan is about 400,000 km.



fast facts PLUTO

The average surface temperature is −225°C.

All water is permanently frozen as ice.

There is essentially no atmosphere.

At this distance from the sun, sunlight is too dim to be a viable energy source. Organisms would need to rely on chemical energy.

Pluto and Earth have the same general chemical composition, but Pluto lacks any processes that are necessary to cycle chemicals important to life.

fast facts MERCURY

The temperature on the side facing the sun is 252°C. On the dark side, it is −183°C.

There is no surface water or water in the atmosphere.

There is essentially no atmosphere.

Living on or near the surface is impossible, so life would have to live underground and depend on chemical energy.

Mercury and Earth have the same general chemical composition, but Mercury lacks the processes that are necessary to cycle chemicals important to life.

fast facts TITAN SATURN'S MOON

The average surface temperature is −179°C.

Water-ice icebergs might float in an ocean of ethane-methane liquid or slush. There is virtually no water in the atmosphere.

Titan has an atmospheric pressure 1.5 times that of Earth. It is 90–97% nitrogen and 3–10% methane, a composition more like Earth's than the carbon dioxide atmospheres of Mars and Venus.

At this distance from the sun, sunlight is too dim to be a viable energy source. Organisms would need to rely on chemical energy.

Sunlight-driven reactions can turn methane into amino acids, the building blocks of life. They could join into large, complex molecules and rain down on the surface. There, they could accumulate, covering the surface with thick, gooey deposits of hydrocarbons. These conditions may be similar to those on early Earth.

fast facts EARTH'S MOON

There is no atmosphere to moderate temperatures, and temperature depends entirely on how much sunlight falls on the surface. While the overall average surface temperature is −23°C, the daytime average is 107°C and the nighttime average is −153°C.

There is no known liquid water on the moon. In 1998, NASA's Lunar Prospector spacecraft detected water ice at each of the moon's poles.

There is no atmosphere. Without an atmosphere, the surface experiences large and rapid temperature swings, which are hard for organisms to cope with.

The moon receives the same amount of sunlight as Earth, making the sun a viable energy source. Chemicals made available by volcanic activity early in the moon's history may once have been a possible energy source.

The moon and Earth have the same general chemical composition, but the moon lacks any processes that are necessary to cycle chemicals important to life.

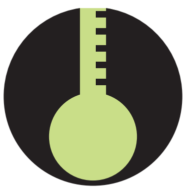
What makes a world habitable?

A key of habitability factors

Name ______________________________

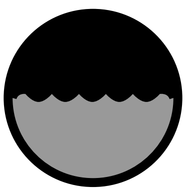
Date ______________________________

Temperature



At about 125°C, protein and carbohydrate molecules and genetic material (e.g., DNA and RNA) start to break down. Cold temperatures cause chemicals in a living cell to react too slowly to support the reactions necessary for life. Thus, life seems to be limited to a temperature range of about minus 15°C to 115°C.

Water

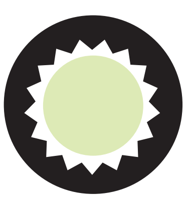


Life as we know it requires liquid water. It can be available on an irregular basis with organisms going dormant until it becomes available, but, eventually, it needs to be available. On a cold planet or moon, there must be internal heat to melt ice or permafrost. On a hot planet or moon, the water will boil away or evaporate unless it is far beneath the surface.

Atmosphere

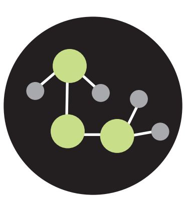
Atmospheres can insulate a planet or moon and protect life from harmful ultraviolet radiation and small- and medium-sized meteorite impacts. In addition, atmospheres can serve as an important source of biochemicals. For example, nitrogen from nitrogen gas can be used for proteins, and carbon from carbon dioxide and methane can be used for carbohydrates and fats. Atmospheres also moderate day-night and seasonal temperature swings. However, to serve as an effective shield or insulator, the atmosphere has to be fairly substantial, as it is on Earth, Venus, and Titan. A planet or moon depends on its gravity to hold an atmosphere. A small-sized body such as Pluto or Earth's moon has too little gravity to hold onto an atmosphere, making life on or near the surface difficult.

Energy



Organisms use either light or chemical energy to run their life processes. At some point, light energy from the sun becomes too dim to be a viable energy source. On Earth, many microbes obtain energy from the sulfur, iron, and manganese compounds present in the Earth's crust and surface layers. When they absorb such compounds and break them down, they obtain a small amount of energy from this chemical change. This energy is sufficient to power microbial life.

Nutrients



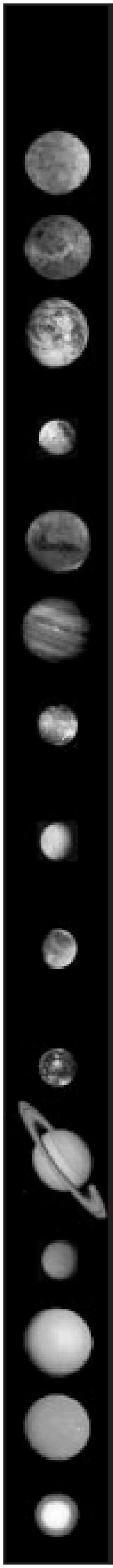
The solid planets and moons in our solar system have the same general chemical composition. As a result, the necessary raw materials to construct and maintain an organism's body are in place. However, a planet or moon needs to have processes such as plate tectonics or volcanic activity to make these chemicals constantly available. In addition, liquid water is a powerful solvent and is an important vehicle for transporting and delivering dissolved chemicals. Therefore, planets or moons with volcanic activity, plate tectonics, or a way to cycle liquid water have a way to supply the chemicals required by living organisms.

What makes a world habitable?

Searching for a habitable world

Name ______________________________

Date ______________________________



Planet/Moon	LIFE IS LIKELY	LIFE IS POSSIBLE	LIFE IS UNLIKELY	Rationale
MERCURY				
VENUS				
EARTH				
Earth's MOON				
MARS				
JUPITER				
Jupiter's Moon IO				
Jupiter's Moon EUROPA				
Jupiter's Moon GANYMEDE				
Jupiter's Moon CALLISTO				
SATURN				
Saturn's Moon TITAN				
URANUS				
NEPTUNE				
PLUTO				