

Aerospace Dimensions

SPACE ENVIRONMENT

MODULE 5



Civil Air Patrol
Maxwell Air Force Base, Alabama



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SPACE ENVIRONMENT

5
MODULE

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Introduction

The Aerospace Dimensions module, *Space Environment*, is the fifth of six modules, which combined, make up Phases I and II of Civil Air Patrol's Aerospace Education Program for cadets. Each module is meant to stand entirely on its own, so that each can be taught in any order. This enables new cadets coming into the program to study the same module, at the same time, with the other cadets. This builds a cohesiveness and cooperation among the cadets and encourages active group participation. This module is also appropriate for middle school students and can be used by teachers to supplement STEM-related subjects.

Inquiry-based **activities** were included to enhance the text and provide concept applicability. The activities were designed as group activities, but can be done individually, if desired. The activities for this module are located at the end of each chapter.



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National Academic Standard Alignment

Science Standards	Mathematics Standards	English Language Arts Standards	Social Studies Standards	Technology Standards
Science as Inquiry	1. Number and Operations Standard: <ul style="list-style-type: none"> Understand numbers, ways of representing numbers, relationships among numbers, and number systems Compute fluently and make reasonable estimates 	1. Reading for Perspective	8. Science, Technology, and Society	1. Understanding of the characteristics and scope of technology
Physical Science: <ul style="list-style-type: none"> Motions and forces Properties and changes of properties in matter Transfer of energy 	4. Measurement Standard: <ul style="list-style-type: none"> Apply appropriate techniques, tools, and formulas to determine measurements 	3. Evaluation Strategies		3. Understanding of the relationships among technologies and the connections between technology and other fields of study
Earth and Space Science: <ul style="list-style-type: none"> Earth in the solar system 	6. Problem Solving Standard: <ul style="list-style-type: none"> Solve problems that arise in mathematics and in other contexts 	4. Communication Skills		6. Understanding of the role of society in the development and use of technology
Science and Technology: <ul style="list-style-type: none"> Abilities of technological design 	10. Representation Standard: <ul style="list-style-type: none"> Create and use representations to organize, record, and communicate mathematical ideas 	7. Evaluating Data		
Unifying Concepts and Processes: <ul style="list-style-type: none"> Evidence, models, and explanation Constancy, change, and measurement Systems, order, and organization 		12. Applying Language Skills		



1 SPACE

Learning Outcomes

- Define outer space.
- Describe characteristics of space in terms of temperature, pressure, and gravity.
- Define microgravity.
- Define cislunar space.
- Distinguish between interplanetary and interstellar space.
- Define galaxy.
- Identify three types of galaxies.
- Define universe.

Important Terms

absolute zero - the point at which all molecules no longer move or have the least amount of energy; theoretically the absolute coldest temperature (0 degrees K, -273.15 degrees C, -459.67 degrees F)

cislunar space - the space between the Earth and the Moon

galaxy - an enormous collection of stars arranged in a particular shape

interplanetary space - space located within a solar system; for our solar system, it would extend from the Sun, out beyond the orbits of Neptune and minor planet Pluto, to a region known as the heliopause

interstellar space - the region in space between the stars in a galaxy

Kelvin - unit of measurement based on absolute zero and commonly used by scientists to measure temperature (abbreviated K)

microgravity - extremely low levels of gravity (for all intents and purposes, zero gravity)

space (or outer space) - from an Earth-based perspective would be the expanse that exists beyond our atmosphere and extends to the limits of the universe

universe - all encompassing term that includes everything; planets, stars, galaxies, and everything that is on them or in them

vacuum - space that is empty or nearly void of molecules (the term “perfect vacuum” applies to a specific volume that is completely devoid of molecules)

Van Allen belts - radiation belts around the Earth filled with charged particles (other planets are now known to have radiation belts, and the term also applies to them)

Since the beginning of time, man has looked to the stars with awe and wonder. Our universe has always fascinated scientists and other observers. What was once unexplored territory has now become a new frontier. Many space probes have taken very small steps into this overwhelming vastness we call our universe in search of knowledge and understanding. When we talk about the universe, several words may come to mind. Many people think of words like space, stars, planets, and solar systems. The Space Environment module will define these terms and help you to gain a better understanding of our universe.

You might wonder why this is important. All of our volumes have been talking about aerospace, and space is certainly a part of this overall concept. We are no longer limited in our thinking or our achievements to the immediate area of Earth’s atmosphere. For years, travel has occurred beyond that realm. The US has participated in unmanned and manned space missions for years, and our missions have included stops at space stations. In years past, American astronauts visited and

worked on the Russian space station Mir. Missions now involve astronauts staying in space for extended periods of time on the International *Space Station*. The number of people who have traveled to space increases with each passing year, and it is conceivable that some of us could travel to space during our lifetime. Let's take a brief look at some basic information that we should know in our quest for learning about our space environment and the universe.

SPACE IS A PLACE

First, space is a place. It literally is the entirety of the universe that lies beyond Earth's atmosphere. This does not happen at a particular point, but, rather, happens gradually. You may have heard space described as a void or a vacuum, but no place in the universe is truly empty. Eventually the molecules and atoms become so widely spaced that there is no interaction. We call this **space**. The Air Force and NASA define space as beginning at an altitude of 50 miles (80.5 km), and anyone who crosses this threshold is awarded astronaut wings. However, 62 miles, or 100 kilometers, is the most widely accepted altitude where space begins. An object orbiting the Earth has to be at an altitude of 80 or 90 miles (129 to 145 km) to stay in orbit. So, many consider this to be the beginning of space. The Earth's atmosphere gradually thins with an increase in altitude, so there is no tangible boundary or exact point between the Earth's atmosphere and space.

Space is a part of the universe. The **universe** includes everything: stars, planets, galaxies, and everything that is on them or in them. Let's talk about the concept of space first and then expand into a discussion of the universe.



CHARACTERISTICS OF SPACE

When we describe space as a physical place we must include its characteristics. What is the temperature like in space? What about pressure? Is there gravity in space?

Outer space is almost a perfect **vacuum**. A vacuum is defined as a space that is empty, meaning the space has no, or virtually no, molecules. A perfect vacuum would be a specific volume that contained no molecules, or atoms, or any thing whatsoever. Outer space is as near a perfect vacuum as can be obtained. Large bodies such as planets, moons, and stars have such a large gravitational pull that they prevent molecules from floating around in the space between these large bodies. There are some wandering gas molecules with extremely low density floating in outer space, so no place in the universe is truly empty. Because these wandering molecules are so far apart from one another, though, most scientists consider of space as a vacuum.

Oxygen

Regarding a lack of gas molecules, the oxygen levels needed to sustain human life do not exist in what is considered the vacuum of space. It would be impossible for us to travel or live in space without oxygen. We compensate for this by including an oxygen supply on all manned spacecraft.

Pressure

What about pressure in space? As explained in NASA's educational product, *Suited for Spacewalking*, "In space, the pressure is nearly zero. With virtually no pressure from the outside, air inside an unprotected human's lungs would immediately rush out in the vacuum of space. Dissolved gases in body fluids would expand, pushing solids and liquids apart. The skin would expand much like an inflating balloon. Bubbles would form in the bloodstream and render blood ineffective as a transporter of oxygen and nutrients to the body's cells. Furthermore, the sudden absence of external pressure balancing the internal pressure of body fluids and gases would rupture fragile tissues, such as eardrums and capillaries. The net effect on the body would be swelling, tissue damage, and a deprivation of oxygen to the brain that would result in unconsciousness in less than 15 seconds." We compensate for the lack of pressure by providing pressurized spacecraft and spacesuits for humans.

Temperature

In terms of the average temperature in the darkness of outer space, generally the temperature is near absolute zero. Temperature is based on the movement of molecules, and **absolute zero** is the point at which all molecules stop moving or have the least amount of energy. Absolute zero (or zero degrees Kelvin) is written as 0 K (-273° C or -459° F), which is theoretically the absolute coldest temperature that could exist. **Kelvin**, abbreviated K, is a unit of measurement based on absolute zero, and it is commonly used by scientists to measure temperature. Although there is hardly any movement of molecules in the darkness and near emptiness of

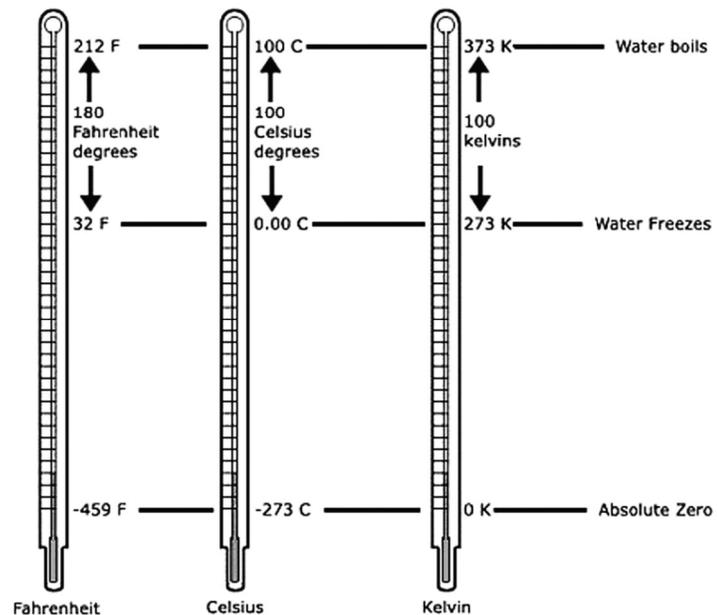


Image credit: NASA

much of outer space, there is still cosmic microwave background radiation (a form of electromagnetic radiation filling the universe), which means that the temperature in space is not quite at absolute zero, but rather about 2.725 K (-270° C or -455° F). Keep in mind that this average space temperature of 2.725 K is not the temperature for every point in space. For example, objects in Earth orbit may experience a temperature of over 393 K (120° C or 248° F) in sunlight areas and lower than 173 K (-100° C or -148° F) in Earth's shadow. To combat the temperature extremes, humans are able to control the temperature inside a spacecraft or spacesuit. The temperature illustration on the previous page provides an excellent graphic comparison.

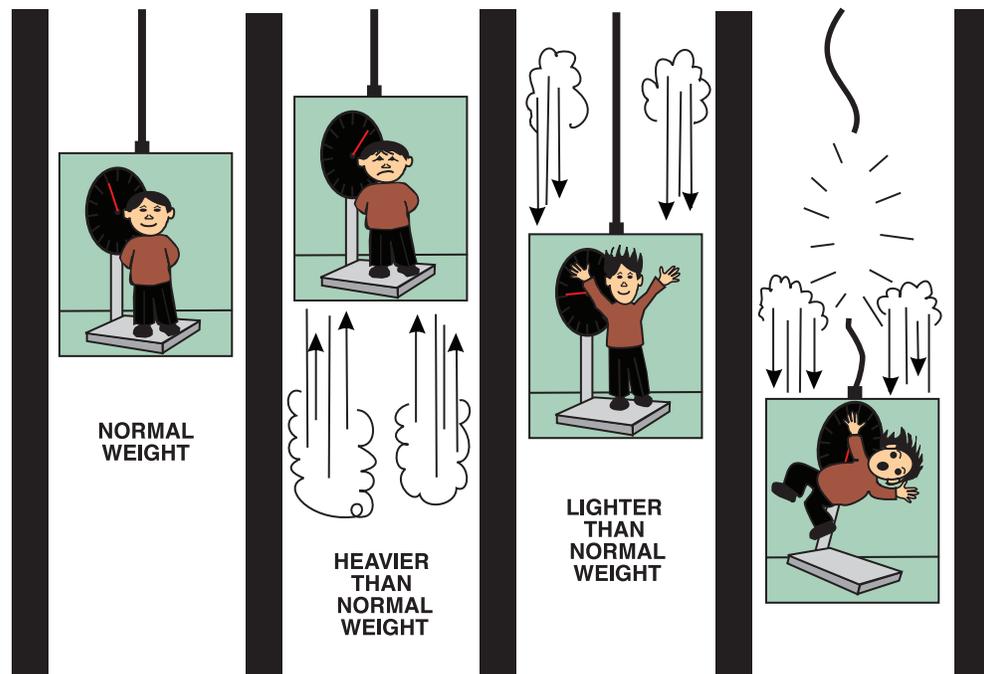
Gravity

When discussing the characteristics of space, a common misconception is that there is no gravity in space. Most of us have seen pictures of astronauts floating around in space, which leads us to believe that there is no gravity in space. The effect of floating in space is often referred to as zero-gravity or **microgravity**.

The prefix micro really means one part in a million, but we use it all of the time to simply mean something small. To actually go into space where the Earth's gravitational pull is one-millionth of that at the surface, you would have to travel 17 times farther away than the Moon (approximately 4 million miles). As you know, no human has traveled beyond the Moon yet. So, why do astronauts orbiting the Earth experience a feeling of weightlessness and float? It is because they are constantly falling around the Earth as they orbit in a state of "free fall." Rather than traveling to a distance 17 times farther away than the Moon, a microgravity environment can be created by free fall.

We can create a microgravity environment here on Earth. Imagine riding in an elevator to the top of a building. When you get to the top, imagine the elevator cables break, causing the elevator and you to fall. Since you and the elevator car are falling together, you feel like you are floating inside the car. You and the car are accelerating downward at the same rate due to gravity alone. If a scale were present, your weight would not register because the scale would be falling too. NASA

calls this floating condition microgravity. While orbiting the Earth, astronauts experience a microgravity environment as they constantly fall around the Earth. Because they are traveling at about 17,500 miles per hour, they are traveling fast enough to keep going around and around the Earth.



Picture D is an example of microgravity

“Did you know,” as explained in NASA’s *Suited for Spacewalking*, “that if you stepped off a roof that was five meters high, it would take you just one second to reach the ground? In a microgravity environment equal to one percent of Earth’s gravitational pull, the same drop would take 10 seconds. In a microgravity environment equal to one-millionth of Earth’s gravitational pull, the same drop would take 1,000 seconds or about 17 minutes.” (See associated Activities One, Two, and Three at the end of the chapter.)

Regions of Space

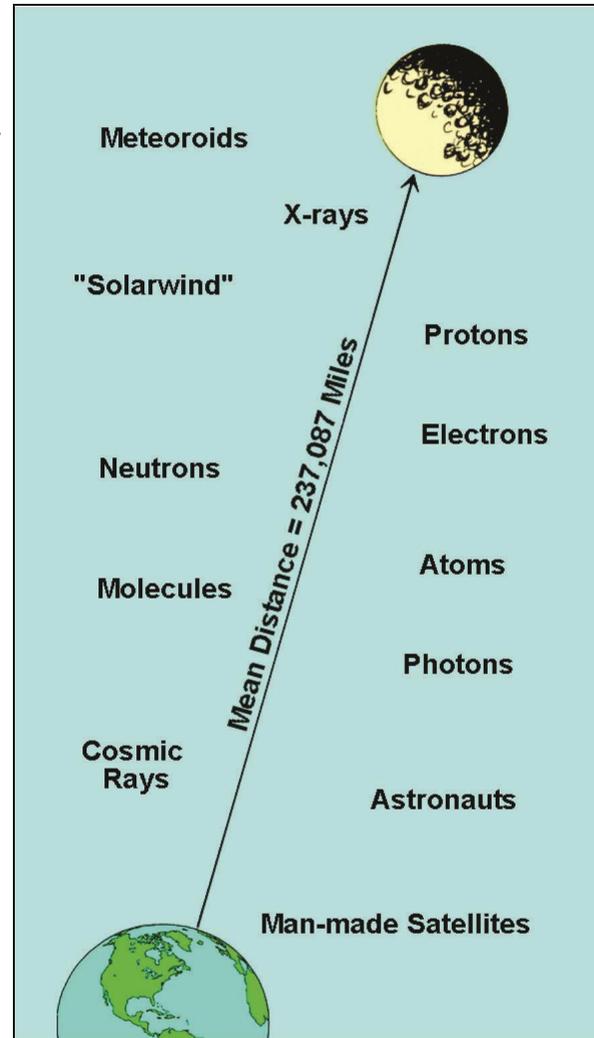
We can further describe space as cislunar, interplanetary, or interstellar space. **Cislunar space** is the space between the Earth and the Moon. This distance varies from month to month since the Moon’s orbit around the Earth is elliptical. The average distance between the Earth and its Moon is 237,087 miles (381,555 km).

Cislunar space is neither a void nor a perfect vacuum. Part of the Earth’s magnetosphere is found in cislunar space. The magnetosphere contains protons, electrons, and magnetic lines of force. Radiation storms emitting from the Sun are also located here. Cislunar space also contains micrometeoroids. Asteroids and comets entering cislunar space are extremely rare.

So, you can see cislunar space is far from being void. However, it is not overcrowded either. According to astronauts who have been there, space looks like the void it has been called. Apollo 8 astronaut William Anders said, “The sky is very, very stark. The sky is pitch black and the Moon is quite light. The contrast between the sky and the Moon is a vivid dark line.”

Interplanetary space is measured from the Sun to areas well beyond the orbits of Neptune and Pluto. In addition to the Sun, this portion of space in our solar system includes eight known planets, which we will explore in Chapter 4. It also contains numerous planetary satellites, dwarf planets, a huge belt of asteroids, charged particles, magnetic fields, dust, and more. This interplanetary space is often referred to as the Solar System. Interstellar space begins where the solar system ends and extends to any of the other stars within the Milky Way galaxy.

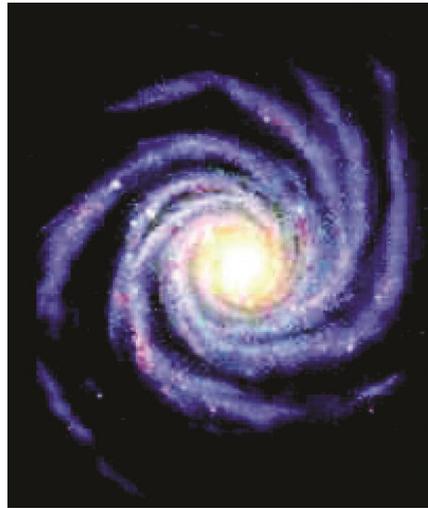
Now, we know a little about what space is like. We should remember that space is a part of the universe. The universe is the all-encompassing term that includes everything. Although the universe includes plants, animals, and humans, we want to talk about the part of the universe that includes galaxies.



Dimensions and some of the contents of cislunar space

GALAXIES

So, what is a **galaxy**? A galaxy is an enormous collection of stars, and these stars are arranged in a random shape. There are three main shapes of galaxies: elliptical, spiral, and irregular. Elliptical is oval shaped. Spiral has arms spiraling outward from a center. Irregular has no particular shape.



Artist's concept of the Milky Way
Galaxy - spiral galaxy



Elliptical galaxy

Our galaxy is the Milky Way Galaxy. The Milky Way is a huge collection of stars arranged in a spiral shape. The picture above shows the Milky Way from a deep space view. The Milky Way has a dense central bulge with arms spiraling outward. The center of our galaxy contains older red and yellow stars, while the arms have mostly hot, younger, blue stars. The scientific estimates of how many stars are in our galaxy vary considerably – the main reason being that it is impossible to count every one. The current estimate is anywhere between 100 billion and 400 billion stars.

The universe contains many galaxies and is continually expanding. Our Sun, which is the center of our solar system, is but a tiny spot in our galaxy, and our galaxy is just one of upwards of two trillion galaxies. The smallest galaxies have about 100,000 stars, while the largest have over a trillion stars.

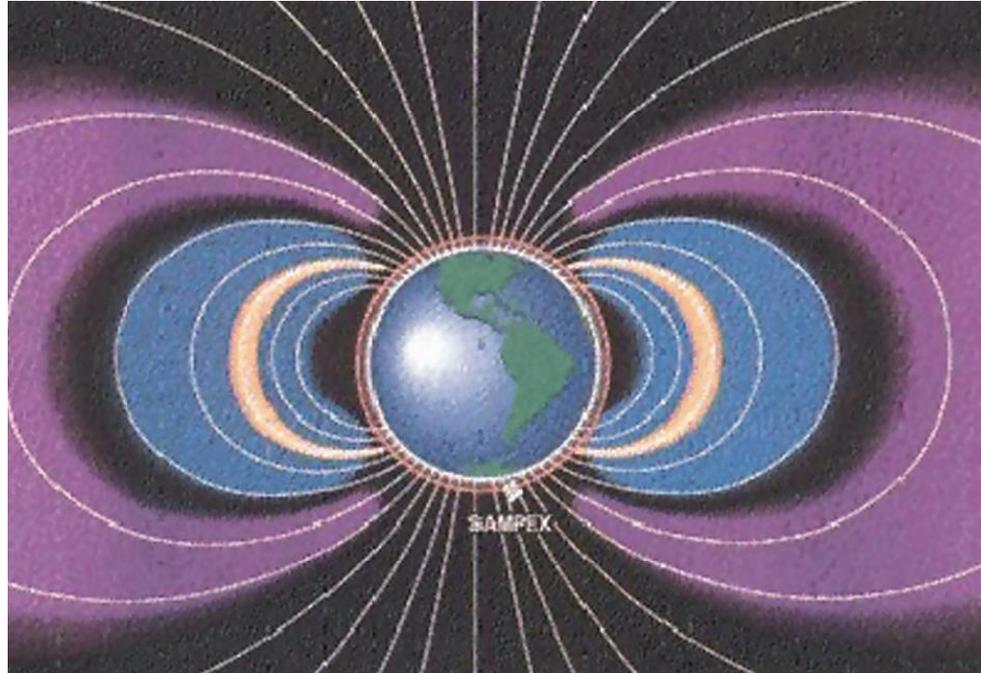
Our universe is huge! One way to think about this is by using distance. Long distances in space are measured in light years. A light year is about 6 trillion miles. Our galaxy is about 150,000 light years across. Again, our galaxy is only one of trillions of galaxies. Our universe is so vast it is almost incomprehensible. So, let's not worry about how big it is, and instead just take a brief look at the space environment around our planet, Earth. (See [associated Activity Four at the end of the chapter.](#))



Example of an Irregular galaxy

SPACE ENVIRONMENT AROUND THE EARTH

NASA's "Radbelts" Web site explains a great deal about the space environment around Earth (<http://radbelts.gsfc.nasa.gov/>). "Earth is surrounded by a magnetic field that looks something like the field you see around a toy magnet when you use iron filings to make it stand out better. You have probably seen this demonstrated in a science class. Earth's magnetic field is shaped something like a comet, with a long, invisible tail of magnetism stretching millions of miles beyond the Moon on the opposite



Van Allen Radiation Belts – Credit: NASA GSFC

side of the Sun. This magnetic field can act like a bottle, trapping fast-moving charged particles within an invisible magnetic prison. The particles are so numerous that they form into donut-shaped clouds with the Earth at the center, and stretching thousands of miles above Earth's surface above the equator. Scientists call these the '**Van Allen Radiation Belts**' because they were first discovered by Dr. James Van Allen using the instrument he designed and which was carried on the Explorer I satellite.

The word 'radiation' has to do with energy or matter moving through space. There are many forms of radiation that astronomers and physicists know about. Sunlight is a form of electromagnetic radiation, but so is ultraviolet radiation, infrared radiation, and gamma radiation. Any heated body produces electromagnetic radiation. We also use the term 'radiation' to describe fast-moving particles of matter. One form of these found in space is cosmic radiation or more commonly referred to as 'cosmic rays.' They are not made of light energy, but are actually the nuclei of atoms such as hydrogen, helium, iron, and others which travel through space at hundreds of thousands of kilometers per second. Some electrons in the cosmic rays travel at nearly the speed of light. Like other forms of radiation, they carry energy away from the place where they were created. When they are absorbed, they deliver this energy to the body that absorbs them.

The Van Allen Belts are formed by clouds and currents of particles that are trapped in Earth's magnetic field like fireflies trapped in a bottle. Artists like to draw them as though they look like dense clouds of gas. In fact, they are so dilute that astronauts don't even see them or feel them when they are outside in their space suits. Because you can't see them from the ground at all, scientists didn't know they existed until they could put sensitive instruments



inside satellites and study these clouds directly. They had speculated that something like them existed because they were predicted by certain mathematical models.

The Inner Belt (shown in blue in the diagram), between 600 and 3,000 miles (1,000 and 5,000 km), contains high-energy protons carrying energies of about 100 million volts, and electrons with energies of about 1 to 3 million volts. This is the belt that is a real hazard to astronauts working in space.

The Outer Belt (shown in purple), between 9,000 and 15,000 miles (16,000 and 24,000 km), consists of mostly electrons with energies of 5 to 20 million volts. This is the belt that is a hazard to communication satellites whose sensitive circuits can get damaged by the fast-moving particles. Where do the particles in the belts come from? One line of thinking says that they might come from the Sun. The Sun is, after all, a powerful and abundant source for particles like the ones found in the belts. A second idea is that they were once cosmic rays from outside the solar system that got trapped by Earth's magnetic field as they traveled by. A third idea is that they may be atoms and nuclei from Earth's atmosphere that have been fantastically boosted in energy to millions of volts by some process we don't yet understand. The particles are not labeled with their place of origin. This makes it very difficult for scientists to sort out how each of these ideas actually contributes to the belts themselves. But if you took a survey of space scientists today, they would probably agree that the first two ideas are the most likely.

Anyone who works and lives in space, or has satellites working in space, will be very concerned about the radiation belts. Radiation belts contain very high energy particles that can pass through the skin of a satellite and damage the sensitive circuitry inside. If the circuitry controls the way the satellite is pointing its antenna, the satellite can veer out of lock with ground-based receivers and be temporarily "lost." Unless satellite operators can anticipate and correct this problem, the satellite will be permanently lost. During the 1996-2008 sunspot cycle, we lost over \$2 billion in satellites from these kinds of problems. Scientists want to learn as much about the radiation belts as they can, so that they can better predict what will happen to satellites and humans operating in space.

Radiation belts and the particles that they contain are an important element of the space weather system. Space weather is a term that scientists use when they describe the changing conditions in the flows of matter and energy in space. These changes can have serious effects on the way that expensive and vital satellites operate. They can also have a big effect on the health of astronauts working and living in space.

Anytime that satellite technology or astronauts are being affected by forms of radiation in space, such as fast-moving particles and X-rays, this usually causes some changes to occur. Most of the time these changes are so minor that they have no real consequences either to the way that the satellite operates or the health of the astronaut. But sometimes, and especially during a severe solar storm or "space weather event," the conditions in space can change drastically. The term "space radiation effects" has to do with all of the different ways that these severe conditions can significantly change the way a satellite operates, or the health of an astronaut working and living in space.

When a high-energy particle penetrates a satellite's metal skin, its energy can be absorbed by microscopic electrical components in the circuitry of a satellite. The switch can be changed from "on" to "off" momentarily, or, if the energy is high enough, this can be a permanent change. If that switch is a piece of data in the satellite's memory, or a digit in a command or program, it can suddenly cause the satellite to veer out of control until a human operator on the ground can correct this problem. If the particle happens to collide with one of the pixels (picture elements) in the satellite's star-tracking camera, a false star might be created and this can confuse the satellite to think it is not pointing in the right direction. Other satellite effects can be even more dramatic. When severe solar storms affect Earth's upper atmosphere, the atmosphere heats up slightly and expands deeper into space. Satellites will feel more friction with the air they are passing through, and this can seriously affect their orbits.

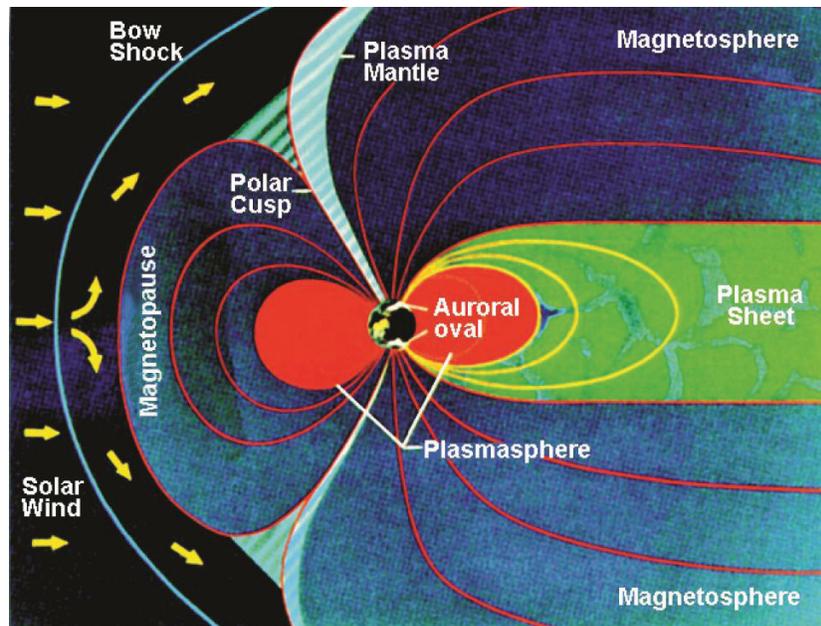
For astronauts, space radiation effects have to do with the amount of radiation (usually x-rays) that pass through the walls of their spacecraft or space station and penetrate into the body. Most people have an instinctive fear of radiation and its potential biological effects. No matter where you live, you receive a dose each day of environmental radiation which adds up to 360 millirems (4- 5 chest X-rays) per year, and you have no control over this. The daily dosage of radiation on the *Space Station* averages out to a little over one chest X-ray per day.

But what about the Apollo astronauts who traveled the most intense regions of the belts in their journey to the Moon? Fortunately, the travel time through the belts was only about 30 minutes. Their actual radiation exposures inside the Apollo spacecraft were not much more than the total dose received by space shuttle astronauts in a one-week stay in orbit. This fact counters some popular speculations that the Moon landings were a hoax because astronauts would have instantly died as they made the travel through the belts.

In reality, the Apollo astronauts might have experienced minor radiation sickness if they had been in their spacesuits on a spacewalk, but no spacewalk was ever scheduled for this very reason. The metal shielding provided by the spacecraft walls was more than enough to protect the astronauts from all but the most energetic and rare particles.

The magnetosphere begins at about 215 miles (346 km) above the Earth's surface and extends into interplanetary space. The magnetosphere is characterized by its magnetic field of force, which surrounds the Earth. This force field is strongest at the poles and weakest at the equator.

The shape of the magnetosphere is affected by solar winds. Solar winds strike the magnetosphere with such force that it forms a bow shock (see illustration). The bow shock is what distorts the Earth's magnetosphere.



Regions of the Magnetosphere

You have probably heard of the aurora borealis and the aurora australis. The aurora borealis (or northern lights) flashes brilliant colors in varying patterns across the northern skies, and the aurora australis presents a similar display in the Southern Hemisphere. Observers have determined that these displays occur at altitudes ranging from 60 to 600 miles above the Earth's surface. It has also been determined that these displays are associated with a zone of electrically-charged layers in the upper atmosphere called the ionosphere.

The ionosphere is a part of the atmosphere divided by its electrical activity. It gets its name from the gas particles that are ionized or charged. The ionosphere was discovered early in the twentieth century when scientists learned that radio waves were transmitted in the atmosphere and were reflected back.

The ionosphere is filled with ions. Ions are atoms that carry a positive or negative electrical charge as a result of losing or gaining one or more electrons. These ions concentrate in certain parts of the ionosphere and reflect radio waves.

The ionosphere is caused by powerful ultraviolet radiation from the Sun and the ultra high frequency cosmic rays from the stars. This radiation bombards the scattered atoms and molecules of nitrogen, oxygen, and other gases and knocks some of the electrons out of the atoms.



Summary

To briefly summarize this chapter, everything is part of the universe. Space, stars, planets, galaxies, plants, animals, and humans are all part of the universe. Temperature, atmosphere, gravity, magnetic fields, and other factors vary at different places within the universe. There are even different types of galaxies in our universe, but all galaxies are made up of an arrangement of huge masses of glowing objects: stars. We will shed a little more light on our universe by looking at stars in the next chapter. 10



1

ACTIVITY SECTION

STOP! Safety Precautions: Water on floors or tile can create a walking hazard. Also, make sure electrical cords and appliances are removed from the area before doing these activities.

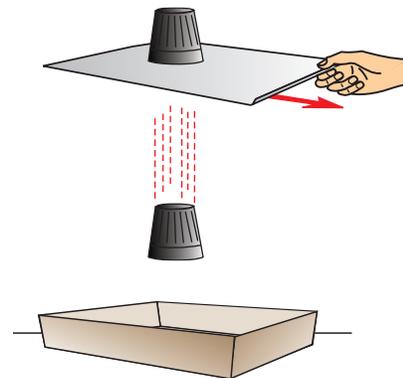
Activity One - Creating the Microgravity of Space

Purpose: The purpose of this activity is to demonstrate that free fall eliminates the local effects of gravity.

Materials: water, plastic-drinking cup, large cookie sheet with at least one edge that doesn't have a rim, empty soda pop can, a large pail (catch basin), towels (old bath towels for cleaning spills), and a step ladder

Procedure:

1. Place the catch basin in the center of an open area in your meeting room.
2. Fill the plastic cup with water.
3. Place the cookie sheet over the opening of the cup. Hold the cup tight to the cookie sheet while quickly inverting the sheet and cup.
4. Hold the cookie sheet and cup high above the catch basin. (This is where you may want to use the stepladder to get higher.)
5. While holding the cookie sheet level, quickly pull the cookie sheet straight out from under the cup.
6. The cup and the water will fall together.



Summary: This activity creates a microgravity environment similar to what you would find in space. In this activity, the cookie sheet holds the cup and water in place. Once the cookie sheet is removed, the water and cup fall together in a state of free fall, simulating microgravity. In space, as an object orbits the Earth the state of free fall remains constant until the object is acted on by another opposing force. Some sort of drag (such as the upper levels of Earth's atmosphere) would lower the speed of the orbit returning the object to Earth. Adding forward velocity (by firing a rocket engine in a precise direction) would take the object to a higher orbit.



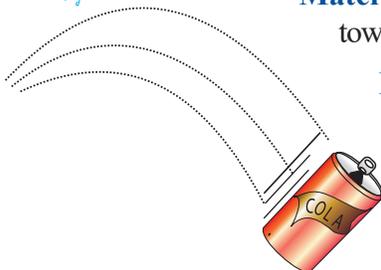
Activity Two - The Can Throw

Purpose: This activity also demonstrates microgravity and objects in a state of freefall.

Materials: empty aluminum soft drink can, sharp nail, catch basin, water, and towels

Procedure:

1. Punch a small hole with a nail near the bottom of an empty soft drink can.
2. Close the hole with your thumb and fill the can with water.
3. While holding the can over a catch basin, remove your thumb



to show that the water falls out of the can.

4. Close the hole again and stand back about 2 meters (approx 6 ft) from the basin. Toss the can through the air to the basin, being careful not to rotate the can in flight.
5. Observe the can as it falls through the air. The water will not fall out of the can during the fall through the air.

Summary: This activity reinforced the concept of microgravity and freefall. While the can is stationary, the water pours out, pulled by gravity; however, while the can is falling, the water remains inside the entire time it falls, as the water is falling at the same rate as the can.

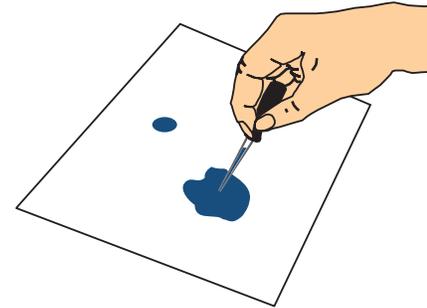
Activity Three - Surface Tension and Microgravity

Purpose: Use observation skills to compare shapes and sizes of drops of water that are falling freely through the air and that are lying on a solid surface. This activity demonstrates surface tension and how it changes the shape of the fluid at rest.

Materials: water, liquid dish detergent, toothpicks, eyedroppers, wax paper squares (8 x 8 inches), paper, and pencil for sketching

Procedure:

1. Fill an eyedropper with water.
2. Carefully squeeze the bulb of the dropper to form a drop at the end.
3. As the water drops through the air, note the shape of the water drop. Repeat and observe several drops. Note the shapes and the sizes.
4. Place a small drop of water on a square of wax paper.



Sketch

- the shape. Measure the diameter and height as best you can. Add a second drop of water. Sketch and measure.
5. Continue adding water to the first drop. What happens to the shape?
6. With the dropper, try to pull the drop over the wax paper. At some point, friction overcomes the surface tension and the drop breaks up. How large of a drop can you pull in one piece?
7. Add a small amount of liquid detergent to the drop. What happens?

Summary: Surface tension is a property of liquids wherein the surface of a liquid acts like a thin, easily bendable elastic covering. When water drops fall, they are spherical. When the water drop hits a surface, the molecules are attracted across the surface and inward. This causes the water to try to pull itself up into a shape that has the least surface area possible – the sphere. Because of gravity, the drops resting on a surface will fatten out somewhat. If liquid detergent is added, the soap molecules bond better than the water molecules, so the water molecules spread out more. The importance of surface tension research in microgravity is that surface tension driven flows can interfere with experiments involving fluids.

Activity Four - The Expanding Universe

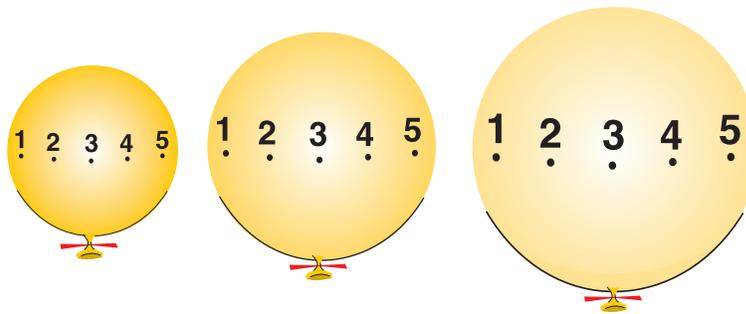
Purpose: This activity demonstrates the concept of the expanding universe.

Materials: balloon, marker, twist tie or paper clip, measuring tape, paper, and pencil

Procedures:

1. Partially inflate the balloon. Fasten the neck of the balloon with the twist tie or clip.
2. Make several dots around the balloon and label each dot with numbers (1, 2, 3, and so on).
See diagram below.
3. Measure and record the distance between each of the dots.
4. Remove the twist or clip, blow more air into the balloon and re-fasten the twist around the neck of the balloon.
5. Measure and record the distance between each of the dots again.
6. Remove the twist, fully inflate the balloon, and re-fasten the twist around the neck of the balloon.
7. Measure and record the distance between each of the dots a third time.
8. Discuss what happened to the dots as more air was put into the balloon. Discuss how this is like the expanding universe.

Summary: This activity simply shows that when more air is added to the balloon, the dots become farther apart. The dots represent stars, so as the air is expanded, the stars are farther apart. Most scientists believe that the universe is still expanding.





2 STARS

Learning Outcomes

- Define star.
- Define nebula.
- Describe the life cycle of a star.
- Interpret a Hertzsprung Russell diagram.

Important Terms

black hole - regions in space where no radiation is emitted (with each hole created as a result of a collapsed massive star)

constellation - a grouping of stars, often named after mythical figures and animals

light year - the distance light travels in one Earth year

magnitude - measure of the brightness of a star

nebula – giant cloud of gas and dust in space

parsec – distance equal to 3.26 light years

pulsar - rapidly rotating star that flashes electromagnetic emissions in a set pattern

star - a wide range of celestial objects that produce various amounts of heat and other effects throughout their life cycles

STARS IN THE NIGHT SKY

Have you ever looked at the sky on a clear night, picked out a bright shining dot in the sky, and wondered if you were looking at a star or a planet? Any natural celestial object that emits its own light is a star. Stars vary dramatically in size, brightness, and “life expectancy.” There are even some stars that emit little to no light at all. (A nuclear reaction in a star causes atoms in the star to change. This process results in the release of energy which produces light.) Planets and moons CANNOT create their own light. Planets and moons that appear as shining dots in the sky are reflecting sunlight. So, it may be difficult for you to determine if the light you see in the night sky is being reflected from the object or generated from within the object; however, the odds are going to be that the point of light you see is a star. That’s because, on any given night, under the very best viewing conditions, there may be upwards of 5,000 stars visible to the naked eye, and of all those points of light, at most, only five of them will be planets (and only on rare occasions would you see all five at one time). When stargazing, you may want to use a star map to help you identify the stars visible in your location. Our Sun is a star.

Our Sun is the only star in our solar system, but when we look into the sky on a clear, dark night, we see a sky painted with a seemingly endless number of stars. Even though all the stars we see with our eyes are stars that are located in our own Milky Way Galaxy, they are very far away from us. In fact, the name of the closest star to us beyond the Sun is Proxima Centauri (also called Alpha Centauri C). Without a telescope, it cannot be seen in the night sky, and with a telescope, it can only be viewed from the southern hemisphere. Its stellar neighbors, Alpha Centauri A and Alpha Centauri B, are bright enough to be seen from Earth with the naked eye. Proxima Centauri is 4.2 light years from our Sun, and Alpha Centauri A and B are about 4.4 light years away. But, what is a light year?

MEASURING DISTANCES

Distances between the stars and solar systems vary and involve such high numbers of miles that it is staggering. Scientists, therefore, do not use miles, kilometers, or even astronomical units (which you will learn about later) to measure distances between stars. Instead, scientists use the units of measurement known as light years and parsecs to measure such extreme distances. A **light year** is the distance light can travel in one Earth year. This amounts to 5 trillion 878 billion statute miles (5,878,000,000,000 miles). Just how far is that? The book *The Stargazer's Guide to the Galaxy* puts it into perspective by stating, "You would have to make 32,000 round trips to the Sun and back to travel the distance of one light year." So, our nearest star, Proxima Centauri, is 4.2 light years (25 trillion miles) away. This means that the light from Proxima Centauri takes a little over four Earth years to reach us. When the number of light years between locations gets very large, parsecs are used; one **parsec** is 3.26 light years, or 19.2 trillion miles.

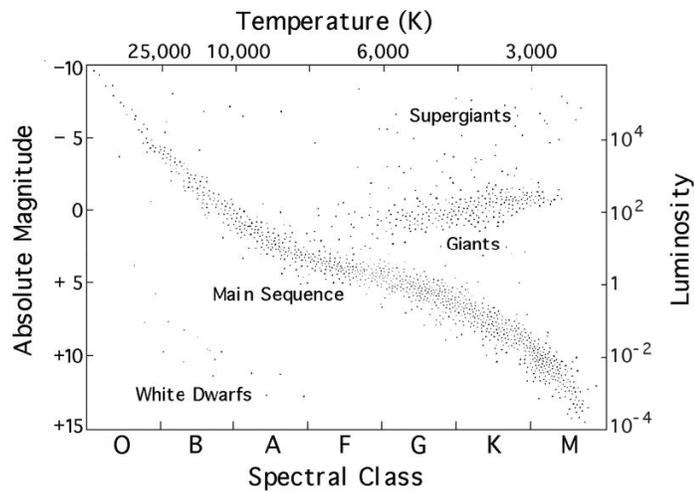
Why can some stars that are far away from Earth be seen and others cannot? It is due to their brightness and distance from Earth. A star has a number of properties such as size, mass, temperature, color, and brightness. Additionally, stars vary in the amount of energy they generate in the form of light and heat energy. Different amounts of energy released result in stars having different temperatures, and the temperature of a star determines its color. So, whether or not a star is visible from Earth using our eyes only depends on the properties of the star, including the distance of the star from Earth. (See associated Activity Five at the end of the chapter.)

MEASURING BRIGHTNESS

Magnitude is a measure of the brightness of a star. The lower the magnitude number, the brighter the star. A higher magnitude number indicates a dimmer star. For example, a star of magnitude 1.1 is brighter than a star whose magnitude is 4.5. Some stars have a magnitude with a negative number, which indicates a really bright star.

There are two different kinds of magnitude for a star: apparent magnitude and absolute magnitude. Apparent magnitude is the measure of the brightness of a star as viewed from Earth. Absolute magnitude is the star's brightness as it would be viewed from a distance of 10 parsecs, or 32.6 light years from Earth, regardless of actually how far away the star is from Earth. Absolute magnitude tells us the true brightness of a star. For example, the apparent magnitude of the Sun is -26.72, which indicates a very bright star. The reason the Sun appears so bright and has such a low apparent magnitude is because it is the closest star to Earth. The absolute magnitude of the Sun (the brightness of the Sun if it were viewed 32.6 light years from Earth), however, is +4.8. From Earth, a +4.8 magnitude star would appear dim; however, it would still be visible to the unaided eye.

Astronomers are scientists who study stars and other celestial bodies in space. An important tool that astronomers use to graphically organize information about stars and to see the relationships among them is the Hertzsprung-Russell diagram, called the H-R diagram. It is named after a Denmark astronomer and an American astronomer who independently developed the first



Hertzsprung-Russell or H-R Diagram

kind of this type of diagram in the early 1900s. The diagram plots stars according to their absolute magnitude and surface temperature.

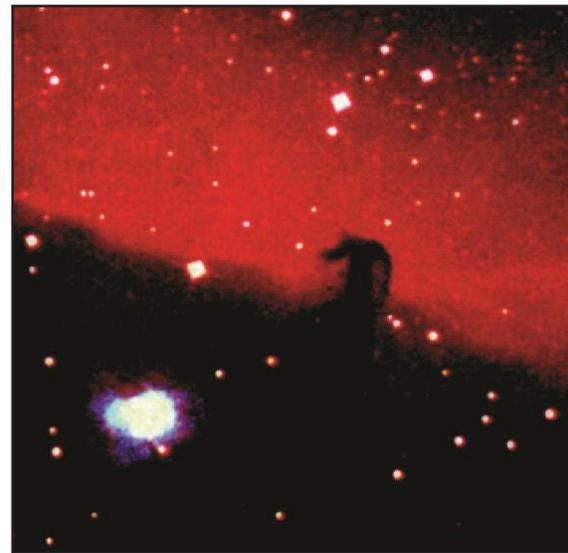
Class	Color	Temp (K)	Example	Life Span ('	Mass (x Sun)
O	deep blue	30,000+		1 million	40
B	bluish	11,000–30,000	Rigel	80 million	7
A	blue-white	7500–11,000	Sirius	2 billion	2
F	white	6000–7500	Procyon, Polaris	10 billion	1.3
G	yellow	5000–6000	Sun, Capella	20 billion	1
K	orange	3500–5000	Aldebaran	50 billion	0.8
M	red	<3500	Proxima Centauri		

Many H-R diagrams also include a star’s spectral classification. Stars are classified according to temperature, and a star’s surface temperature is used to place it in one, single-letter classification. The letters O, B, A, F, G, K, and M each represent stars with a specific temperature range. The letters are arranged in decreasing temperature, with class O stars being the hottest and blue in color. Class M stars are the coolest in temperature and are the color red. Our Sun has a surface temperature of about 5,800 K; therefore, it is classified as a G star, where stars range in temperature from 5,500-6,000 K. Do not confuse this measurement of K with the star class of K. K stands for Kelvin and is a unit of measurement used by scientists to measure temperature.

Just as people go through different stages from birth to death, stars go through different stages in their life cycle. H-R diagrams reveal where stars are in their life cycle, as reflected by several characteristics, including temperature. (See associated Activity Six at the end of the chapter.)



Rosette Nebula



Horsehead Nebula

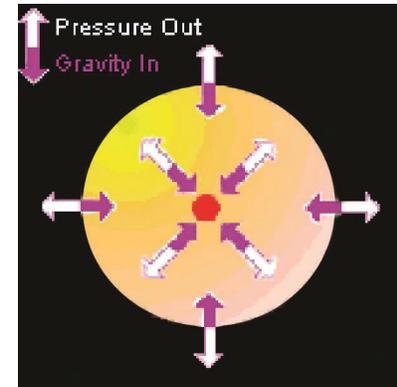
A STAR’S LIFE

Galaxies contain giant clouds called nebulae* that are spread throughout their expanse. A **nebula** is a cloud of gas and dust. The gases in these nebulae are made up of mostly hydrogen and lesser amounts of helium and other elements. Nebulae occur in regions where stars are forming, have exploded, or are shedding their outer layers toward the end of their lives. A nebula may be dark or bright. The dark nebulae are vast clouds of matter that have not yet formed

*The plural of nebula can be either *nebulas* or *nebulae*. *Nebulae* is the preferred usage within the astronomical community.

into stars. The bright nebulae may be studded with stars and send forth brilliant arrays of color. Some bright nebulae, such as the Crab Nebula, are the remnants of supernova stars that have exploded. Nebulae spin and move and can help define a galaxy's shape. Nebulae can also produce stars.

Most stars are composed of hydrogen and helium in their gaseous state. Stars have very powerful gravitational fields, and this gravity brings in and holds the gases together. The gravity pulls inward and the force generates a thermonuclear reaction known as fusion which produces an outward force. This creates a balance, preventing the star from collapsing under its own weight. The energy produced by the star is released in the form of light and heat. A star's fuel is the hydrogen that it is converting to the next heavier element, helium. Once the hydrogen is gone, the star can begin converting helium into carbon, which is a heavier element than helium. Some massive stars can even generate elements heavier than carbon. The bottom line, however, is that once the star's fuel is gone, the balance between its gravity and pressure is gone. This will result in the star's death. Let's investigate a little further about the life cycle of stars.



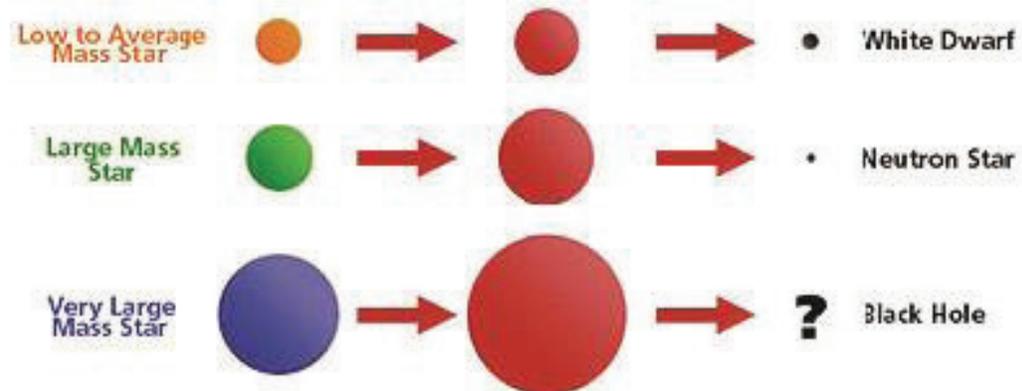
Star balance

LIFE CYCLE OF STARS

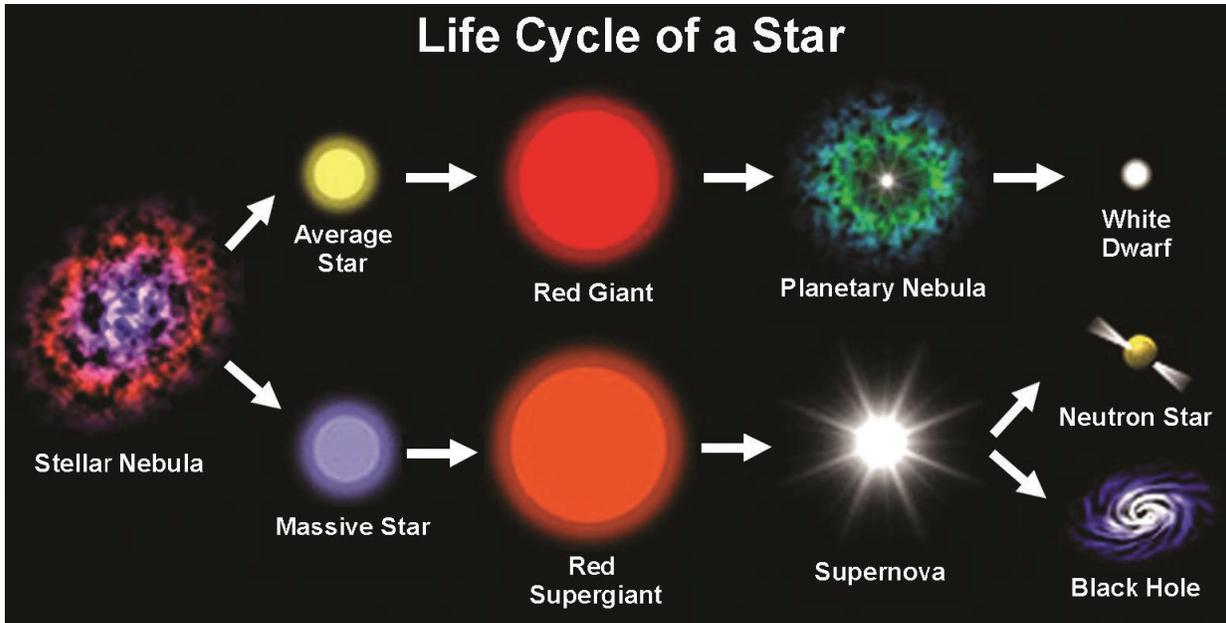
A protostar is the term used to identify a ball-shaped concentration of gases within a nebula that could become a star. Just like a human begins as a fetus in the mother's womb, a star begins as a protostar in a nebula. During this time, clumps of gas and dust are coming together at the central gravitational point within the nebula. The surrounding gas and dust will begin to revolve around the central point and take on the shape of a disk. As gravity draws in more clumps, more atoms are colliding and generating heat. Nuclear fusion, which occurs when temperatures are hot enough and pressure is great enough for the nuclei of atoms to fuse together rather than being repelled, can occur with very light elements at around 1 million Kelvin (K). This will cause the protostar to glow. Over a long period of time, the protostar may become a star if its core gets dense enough and hot enough to begin hydrogen fusion. Hydrogen fusion, a type of nuclear fusion, occurs in a star at around 10 million K. When hydrogen fusion occurs in a star, the hydrogen atoms fuse together to form the heavier element helium. When hydrogen fusion occurs, the protostar has become a star, and the mass of the new star will determine how long it lives and how it will die.

Once hydrogen fusion is occurring and the star is no longer growing, a star enters the main sequence phase, where it will spend the majority of its life. You might think of this phase as encompassing early life through adulthood. During this time the star is burning its fuel, hydrogen.

This results in hydrogen atoms fusing together to form helium in the core of the star. The star will do this for the majority of its life. If the star is a



high mass star, it may spend only a few million years in the main sequence phase. A high mass star is described as a star that has 8 times or more the mass of the Sun. A medium mass star is described as having less than 8 times the mass of the Sun, but at least one half the mass of the Sun. If a star has medium mass, like our Sun, it spends billions of years in the main sequence phase. Low mass stars are described as having less than one half the mass of the Sun. If the star is a low mass star, it is believed that it will spend hundreds of billions of years, perhaps even trillions of years, in the main sequence stage. The lower the mass of a star, the longer the star's life. The higher the mass of a star, the shorter the life of the star. (A short life is really millions of years, compared to billions or trillions of years.)



Medium Mass Stars

Medium-sized and medium mass stars like our Sun will live for billions of years. Stars like our Sun will expand into red giant stars toward the end of their lives. A red giant star's hydrogen fusion stops in its core, causing the star to begin to shrink inward due to gravity becoming greater than the gas pressure pushing outward. As this happens, it causes the star to heat up more, causing hydrogen outside its core to begin fusing. When that happens, the star's outer layers will expand a great deal. The surface temperature of a red giant cools to about 3,000 K as the heat spreads across a much larger surface area. The size of the star makes it appear bright, and the surface temperature of the star causes it to be red in color. (Remember that the surface temperature of a star affects its color.) The internal temperature of the red giant will get hot enough to support helium fusion in its core. Once it has burned all of its helium and once the core is no longer hot enough to support nuclear fusion, the star will begin to contract again. This time, it will cause such a great amount of energy to be released that the star will balloon out again. Just how large can a red giant become? It is believed that when our Sun becomes a red giant, it will grow so large that it could expand as far as the orbit of Earth, and maybe Mars! Think of a red giant star as a middle-aged star.

After millions of years, or maybe even close to a billion years living as a red giant star, the Sun will eventually collapse to become a white dwarf, which is the remaining core of the star. (Remember that it will collapse because its fuel supply is gone, so it can no longer maintain a balance between gravity pulling material in and the gas pressure going outward.) The outer lay-

ers of the once red giant blow off and become a nebula. The clouds of gas and dust can continue to move away revealing just the white dwarf. As a star becomes a white dwarf, it has a glowing hot temperature of around 100,000 K. White dwarfs have a mass about 1.4 times that of the Sun, and for many, their size will be about the size of the Earth. Although a white dwarf has no more fuel, it will cool very slowly. This dense star will glow until it has completely cooled, which may take billions of years. Once it no longer gives off any light, it becomes a black dwarf, marking the end of the star's life cycle. Since scientists believe that the universe isn't old enough to contain any black dwarfs yet, scientists report that there are currently no black dwarfs in existence.

High Mass Star

A high mass star will not end its life as a black dwarf. Once it moves out of the main sequence phase, it will become a red supergiant. Stars with a solar mass at least 8 times that of the Sun will be able to fuse together heavier elements. As was the case with the red giant fusing hydrogen outside its core, a red supergiant will be able to fuse helium outside of its core, and fuse hydrogen in a layer beyond the helium fusion. Different types of fusion will continue to take place in the core and in the other layers of the star due to the extreme temperature and pressure of the massive star. Elements, such as oxygen, nitrogen, and iron, will be created. The star's fuels will eventually run out, and the iron atoms will release a huge amount of energy. When this happens, the massive supergiant will explode. A star that explodes is called a supernova. When this occurs, matter is blasted out in many directions. This material can be used to create new stars in new nebulae.

The remaining core of a supernova will either be a neutron star or a black hole. The remaining core of a supernova becomes a neutron star if it has less than 3 times the mass of the Sun. A neutron star is made up of neutrons, and its initial temperature is around 10 million K. It is difficult to detect neutron stars, however, because of their small size. They are much smaller than white dwarfs. Remember that a white dwarf is about the size of Earth. A neutron star is a sphere that is typically about 12 miles (20 km) in diameter. Although small in size, one teaspoonful of a neutron star would weigh about a billion tons on Earth. Recalling that the density formula is simply mass/volume, the density of a neutron star is extreme in the extreme.

As NASA and World Book report, "A neutron star actually emits two continuous beams of radio energy. The beams flow away from the star in opposite directions. As the star rotates, the beams sweep around in space like searchlight beams. If one of the beams periodically sweeps over Earth, a radio telescope can detect it as a series of pulses. The telescope detects one pulse for each revolution of the star. A star that is detected in this way is known as a pulsar." A **pulsar** is known as a pulsating star because it flashes electromagnetic emissions in a set pattern. The astronomers who discovered a pulsar first thought Earth was being sent signals from intelligent



Supernova



Pulsar Kes 75 discovered by NASA's Chandra X-ray observatory

life in another solar system.

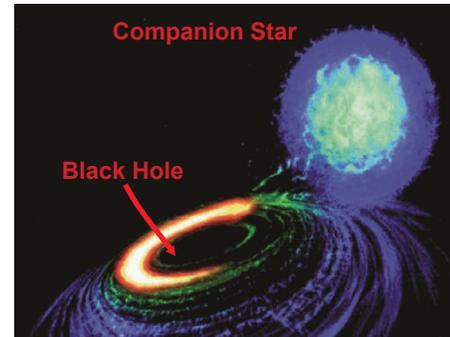
If the remaining core of a supernova has 3 or more times the mass of the Sun, it implodes creating a **black hole**. Its gravitational force is so strong, nothing can escape from it. As reported on NASA's Imagine the Universe Web site, "But contrary to popular myth, a black hole is not a cosmic vacuum cleaner. If our Sun was suddenly replaced with a black hole of the same mass, the Earth's orbit around the Sun would be unchanged. (Of course the Earth's temperature would change, and there would be no solar wind or solar magnetic storms affecting us.) To be 'sucked' into a black hole, one has to cross inside a boundary known as the Schwarzschild (pronounced swars-shield) radius. At this radius, the escape speed is equal to the speed of light, and once light passes through, even it cannot escape. If the Sun was replaced with a black hole that had the same mass as the Sun, the Schwarzschild radius would be 3 km, or 1.9 miles, (compared to the Sun's radius of nearly 700,000 km or 434,960 miles). Hence, the Earth would have to get very close to get sucked into a black hole at the center of our Solar System."

Black holes can be detected by X-rays that are shed as matter is drawn towards the hole. As atoms move closer to the black hole, they heat up. When the atoms heat up to a few million K, they give off X-rays. These X-rays are released before they cross the Schwarzschild radius, and we can, therefore, detect them.

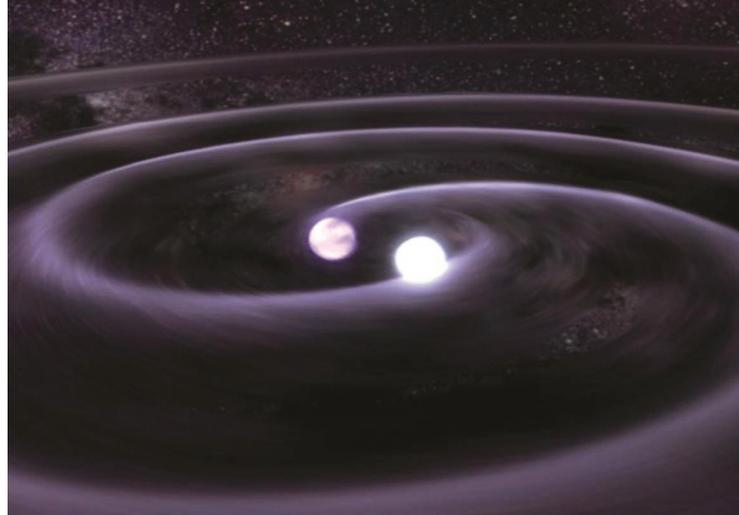
Low Mass Stars

As mentioned earlier, low mass stars have the longest lives. The low mass stars have a solar mass of about less than half the mass of the Sun down to about a 0.08 solar mass. They have a cooler temperature than intermediate and high mass stars. Red dwarfs are low mass stars and are the most common kind of stars in the universe. Our nearest star, beyond the Sun, Proximus Centauri, is a red dwarf. Red dwarfs cannot be seen using just our eyes. After their long duration as a main sequence star, they will become white dwarfs and eventually black dwarfs.

It is possible for an object with less than 0.08 solar mass to form; however, these objects are known as brown dwarfs, or failed stars. The failed stars are too cool to ever achieve hydrogen fusion. They are very hard to detect because they are so small and extremely dim.



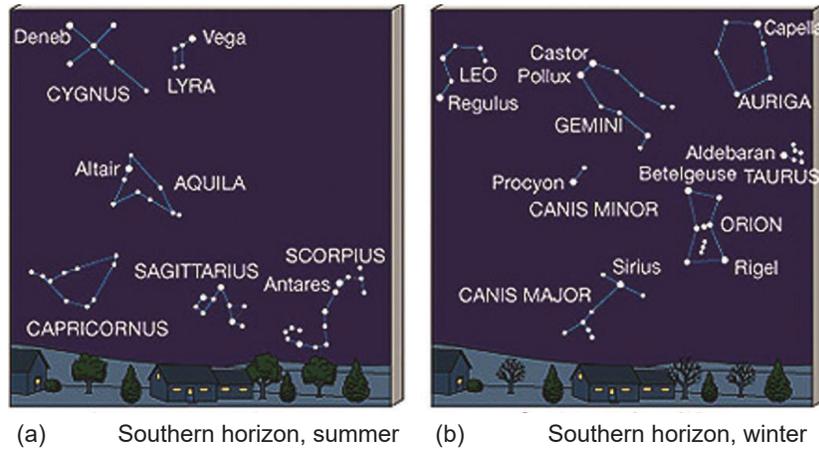
Artist illustration of a black hole pulling mass from a companion star



In the binary star system known as J0806, two dense white dwarf stars orbit each other. The stars seem destined to merge.

MULTIPLE STARS

Of stars that do form, many have a second star with which they share the same center of gravity. The brighter of the two is called the primary star and the other is called the companion star. About half of all stars come in pairs with the stars sharing the same gravitational center. These are called binary stars. When looking at the night sky, a star that looks like a single shining star could actually be part of a binary system.



A **constellation** is a grouping of stars. Identifying groups of stars by named constellations has been traced as far back as 2000 B.C.E. Things like a lion, a scorpion, or a dog were used. This is how constellations were named. The stars in these constellations are not really related; they only appear to be as we view them from Earth. There are 88 constellations in use by astronomers today. Some of the more well known ones are: Ursa Major (the Big Dipper is part of it), Orion, and Cassiopeia. (See associated Activity Seven at the end of the chapter.)

Summary

This chapter revealed to you interesting information about stars. Stars are huge masses of gases that give off light and heat energy due to nuclear fusion occurring in their cores. Remember that a star's mass will determine how long it will live and how it will die. The next chapter begins a study on our solar system, looking specifically at our Sun, Moon, and a few other celestial bodies, such as comets, meteoroids, and asteroids.



ACTIVITY SECTION 2

Activity Five - Analyzing Starlight

Purpose: The purpose of this activity is to show the difference in wavelengths of various light sources by making a simple spectroscope.

Materials: You must plan ahead, and this activity involves a cost. To do this activity you must obtain a diffraction grating. Edmund Scientific, 101 East Gloucester Pike, Barrington, New Jersey 08007-1830 sells one. Their phone number is (609) 573-6250 and their website is www.scientificsonline.com. Two sheets of diffraction grating measuring 6"x12" costs less than \$10. These sheets will need to be cut; one sheet will make 18 two-inch squares. You also need one cardboard tube per person (paper towels, toilet tissue, or gift wrapping tubes), scissors or hobby knives, cellophane tape, colored markers or pencils, typing or computer paper, and flashlights or other light sources. (Twenty five diffraction gratings mounted in 2"x2" cardboard slide mounts can be purchased for \$21.95. These can be used straight from the package to build a set of spectroscopes.)

Procedures:

1. Cover both ends of a cardboard tube with paper and fasten with tape.
2. Make a thin slit in the paper at one end of the tube. (Only a narrow band of light should show through this slit.)
3. Make a small hole (1/8") in the paper at the other end of the tube.
4. Put the diffraction grating over the small hole and fasten it with tape.
5. Point the slit toward an available light source. Use a flashlight or other light source, do not look directly at the Sun.
6. Move the tube slowly to the right or left so as to make an image appear.
7. Using a sheet of paper, sketch the light pattern observed using the colored markers or pencils.
8. Observe two other light sources, if possible, and sketch the light patterns observed.
9. Compare and discuss each light-source pattern.

Summary: A diffraction grating is a tool that separates colors in light. Using this tool helps to create a spectroscope, which will allow you to see the light patterns and color spectrums of different light sources. Stars give off light, and as such, they have different light patterns. The spectroscope can help you see the light patterns of stars in the night sky.

Activity Six - Measuring the Brightness of the Stars

Purpose: This activity is designed to determine approximate magnitude of stars.

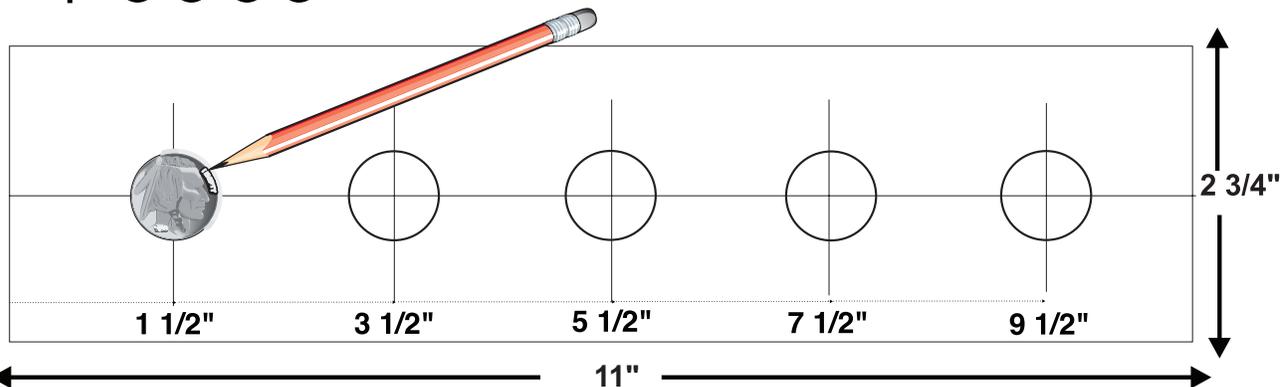
Materials: 2 pieces of cardboard (or 2 file folders), a strip of clear cellophane, nickel, pencil, scissors or exacto knife, stapler, and ruler

Procedures:

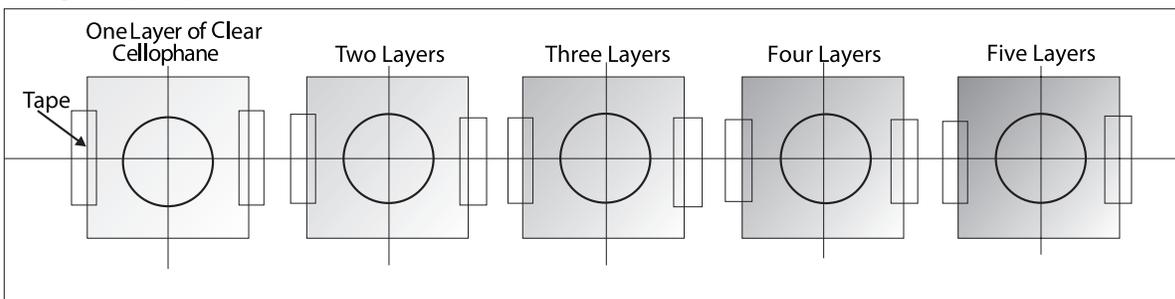
1. Cut two pieces of cardboard, 11" long by 2-3/4" wide.

2. Use a ruler to mark one cardboard at five equidistant points: 1-1/2", 3-1/2", 5-1/2", 7-1/2", and 9-1/2".
3. Use a nickel to trace a circle over each of the marks, centering the circles between the top and the bottom edges of the cardboard strip. Carefully cut out the five circles.
4. Trace the cutouts onto the second piece of cardboard. Carefully cut out these five circles, too.
5. Cut 15 squares of cellophane, each 1-1/2"x1-1/2".
6. Working with one strip of cardboard, cover the first hole with one square of cellophane; cover the second hole with two squares of cellophane; cover the third hole with three squares of cellophane, the fourth hole with four squares of cellophane; and cover the fifth hole with five squares of cellophane. Use small pieces of tape to secure the squares, as necessary.
7. Carefully place the second piece of cardboard on top of the secured cellophane squares, being certain to line up the holes in the two pieces of cardboard. Staple the cardboard strips together.

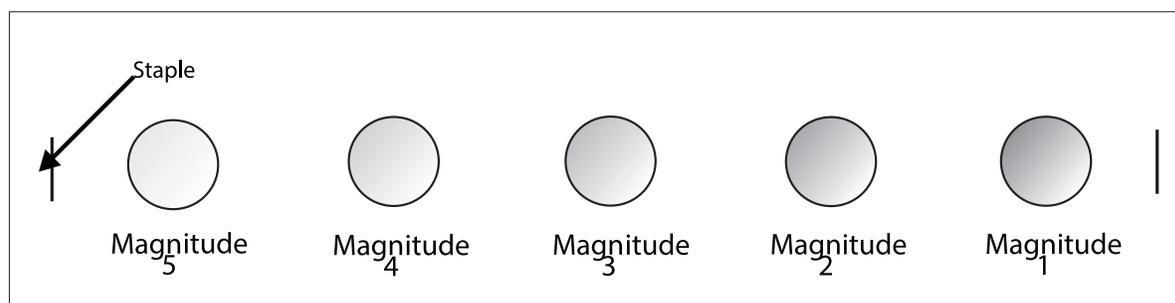
Steps 1 2 3 4



Steps 5 6



Steps 7 8 9



8. Label the hole covered with five squares of cellophane as magnitude 1; label the others in order, with the hole having only one piece of cellophane over it being labeled as magnitude 5.
9. To use the magnitude strip begin by looking at a star using only your uncovered eye. Then look at the star through the magnitude strip, looking through hole 1. If you can see the star through hole number 1, the star is a first magnitude (or brighter) star. If you cannot see it, try looking through the hole 2. Keep moving down the magnitude strip until you can see the star. Stars that are seen through the 4th hole are fourth magnitude stars; stars that can not be seen through the fifth hole, but can be seen with the uncovered eye, are sixth magnitude stars.

Summary: Magnitude refers to the brightness of a star. Observing stars through the magnitude strip reveals the approximate magnitude of the stars, ranging from a first magnitude star (very bright and can be seen through five layers of cellophane) to a sixth magnitude star (dim stars that could not be seen through the magnitude 5 hole on the magnitude strip, but could only be seen with a clear view from the uncovered eye). Knowing the approximate magnitude of stars can help better judge approximate age and distance, as explained in the chapter.

Activity Seven - Astronomy In A Tube

Purpose: Become familiar with star patterns (constellations) visible in the night sky.

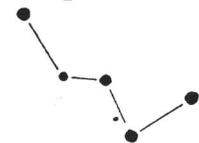
Materials: an empty Pringles potato chip can with its opaque plastic lid, black construction paper, hammer, nail, push pin (or similar item), scissors, constellation pattern, silver marker (or similar writing tool)

Procedures:

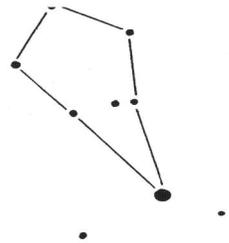
1. Draw a constellation pattern from the patterns below on a 2.75 inch circular piece of black construction paper using a silver marker or some other writing tool that will produce a visible image on black paper (that is, don't choose a dark colored marker to write on black paper).

CONSTELLATION PATTERNS

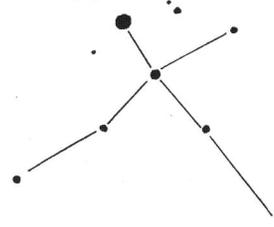
Cassiopeia



Bootes



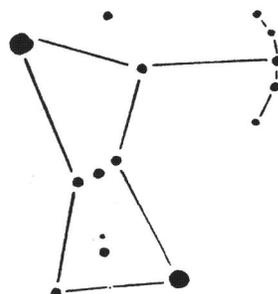
Cygnus



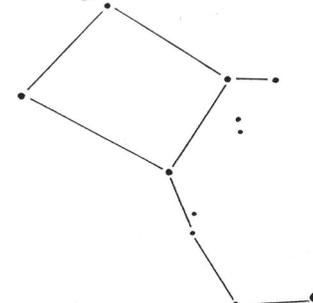
Corona Borealis



Orion



Pegasus



- 
2. Use a pushpin to make a small hole in the center of each star in your constellation and cut out the circular paper pattern.
 3. Using a hammer, put a nail-sized hole through the center of the metal end of the Pringles can cover. (SAFETY: Use caution hammering the nail. Adult supervision is recommended.)
 4. Place your piece of circular black paper under the plastic lid of the potato chip can, put the lid on the open end of the can, point the constellation drawing toward a light source, look through the hole in the metal end of the can, and see the star pattern as it would appear in the night sky.

Summary: Stars are arranged in groups which we refer to as constellations. This activity emphasizes selected star patterns visible in the night sky. It is hoped that a greater interest in specific constellations will lead to deeper investigation into the wonderment and ever-changing night sky throughout the year.

OUR SOLAR SYSTEM: SUN, MOON, & MORE

Learning Outcomes

- Define astronomical unit (AU).
- Distinguish between solar flares, solar prominences, and sunspots.
- Describe the Moon in terms of temperature, atmosphere, gravity, and terrain.
- Identify the phases of the Moon.
- Explain what causes a solar and lunar eclipse.
- Define comet.
- Explain the differences between an asteroid, meteoroid, meteor, and meteorite.

Important Terms

asteroid - a small rocky body orbiting the Sun; usually found in the asteroid belt

astronomical unit (AU) - unit of measurement used to measure distances in our solar system

comet - a small, icy body orbiting the Sun

meteor - a small streak of light; when a meteoroid enters the Earth's (or any other planet's) atmosphere it becomes a meteor

meteorite - a meteor that enters Earth's atmosphere and actually hits Earth's surface

meteoroid - clump of dust or rock orbiting the Sun (a meteoroid can also become a meteorite without ever becoming a meteor if it strikes a celestial body that does not have an atmosphere—such as the Moon)

micrometeorite - very small dust-sized bits of matter that are no longer free-floating in space

photosphere - thin shell of the Sun's outer layer; the visible surface of the Sun

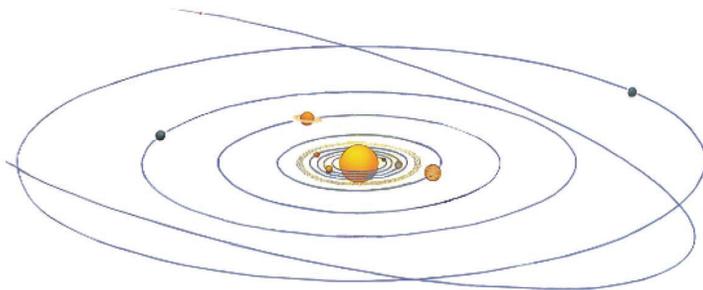
solar flares - short-lived high energy discharges from the Sun

solar prominences - larger energy discharges from the Sun that can be thousands of miles high and last for months

solar system - the Sun and the bodies that orbit around it (by strict definition, "solar" refers only to our Sun; however, with the new discoveries of planets orbiting other stars, it is not uncommon to refer to them as solar systems as well)

sunspots - darker, cooler areas of the Sun

When you hear "solar system" what do you think of? Most of us probably think of the planets within our solar system. Some of us might think about the Sun. These are good responses because they are part of our solar system. What is our solar system? Our **solar system** is the Sun, the planets and their satellites, asteroids, comets, and any celestial body that comes under the gravitational influence of our Sun. This gravitational influence means that these bodies orbit the Sun. The word solar means anything pertaining to or proceeding from the Sun. So, the Sun is the key feature of our solar system. Our solar system, however, is just one of many in the universe. In 2010, astronomers reported that approximately 15% of the stars in the Milky Way



Galaxy may be part of systems like our solar system – and that is just within our galaxy. “With billions of stars out there, even narrowing the odds to 15% leaves a few hundred million systems that might be like ours,” said astronomer Andrew Gould.

THE SUN

The Sun is the most important element of our solar system. Without its heat and light, the Earth would be a lifeless, ice covered planet. On Earth, the Sun sustains our lives, and it gives energy which provides food and oxygen. It stirs our atmosphere and initiates our weather (a process that meteorologists refer to as insolation—the “sol” in insolation comes from solar).

The Sun is a star. All other bodies of the solar system revolve around it. Because of this, the Sun is the point of reference for most facts about our solar system. When people talk about distances in our solar system, they tell how far something is from the Sun. For instance, the Earth is 93 million miles from the Sun. Because distances of most planets from the Sun are millions of miles away, scientists use a unit of measurement called the astronomical unit (AU) to measure distances within our solar system. Because we are most familiar with the distance from Earth to the Sun, the distance of 93 million miles (149,668,992 km) is the measurement upon which the astronomical unit is based. The distance of 93 million miles equals 1 AU. The measurement of 2 AU equals 186 million miles, and so on. So, you may say either, “The Earth is an average of 93 million miles from the Sun,” or, “The average distance between the Sun and the Earth is 1 AU.” Venus, as another example, is about 0.7 AU from the Sun. How far away is Neptune? It is about 30 AU from the Sun. Try calculating how many miles that is if 1 AU equals 93 million miles. You are correct if your answer is about 3 billion miles (2.793 to be more precise).

When talking about the size of planets, one often compares them to the size of the Sun. It is very nearly 109 times the diameter of Earth, and has about 333,000 times the mass. If the Sun were hollow, you could fit approximately 1 million Earths inside it. Our solar system, our world, could not exist without the Sun.

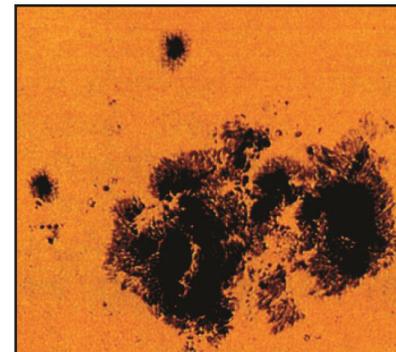
The Sun is a medium-sized star composed of about 90% hydrogen, 9% helium, and minor amounts of several other elements. Its diameter is 864,000 miles (1,390,473 km). The temperature of the Sun ranges from 7592° F (4,200° C or 4473 K) in its coolest regions to over 27,000,032° F (15 million degrees C or 15,000,273 K) at its center.

As just mentioned, the Sun consists mostly of hydrogen and helium. The hydrogen is converted into helium by nuclear fusion. This process generates and releases the Sun’s energy in all directions, all of the time. It is generally accepted that the Sun is a giant thermonuclear reactor, releasing a tremendous amount of energy.

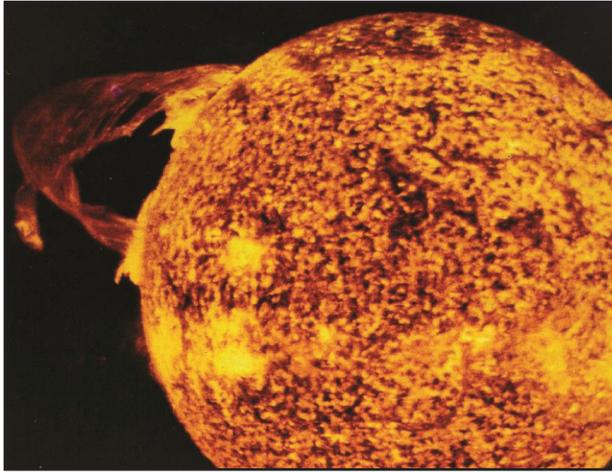
The core of the Sun is so hot that no solid or liquid molecules can exist. Virtually, all atoms remain in a plasma state. The energy released within the core has to make its way to the surface, atom by atom. It’s theorized if the Sun’s fusion reaction were to suddenly halt, it would take more than 100,000 years before any effect would show on the surface of the Sun.

The very thin shell of the Sun’s outer layer is called the **photosphere**. This is the part of the Sun that gives off light. It is also the visible surface that we see. This shell is composed mostly of hydrogen and helium, and is very hot. Its temperature is more than 10,000° F.

The outer layers of the Sun indicate constant motion and violent activity. Solar disturbances occur all of the time. Sometimes they last for less than a second, and other times they last for years. These solar disturbances are usually associated with sunspots. **Sunspots** are darker, cooler areas of the Sun. From



Sunspots



The Sun showing solar prominences

these sunspots, solar flares and solar prominences occur.

Solar flares are short-lived, high-energy discharges, that are potentially dangerous. They can harm satellites, ground systems, spacecraft, and astronauts. We monitor the Sun's activity closely so we can react quickly when flares occur. The less dangerous electromagnetic radiation from a flare will reach Earth in less than 9 minutes. The more dangerous high-energy particles may take 15 minutes to 3 days to get here. Space operators must be prepared to act quickly. As explained in NASA's Radbelts website, "During the Apollo program, there were several near-misses between the astronauts walking on

the surface of the Moon and a deadly solar storm event. The *Apollo 12* astronauts walked on the Moon only a few short weeks after a major solar proton flare would have bathed the astronauts in a 100 rem blast of radiation. Another major flare that occurred halfway between the *Apollo 16* and *Apollo 17* missions would have had a much more deadly outcome had it arrived while astronauts were outside their spacecraft on the lunar surface. Within a few minutes, the astronauts would have been killed on the spot with an incredible 7000 rem blast of radiation."

Solar prominences are larger and longer lasting high-energy discharges. Prominences can reach thousands of miles and last for months. On rare occasions here on Earth, we may experience an event known as a solar eclipse. This occurs during the daylight hours when the Moon moves directly between the Sun and the Earth, blocking the Sun for a short time as it continues its orbit around the Earth. This is rare, however, because the Moon's orbital path around the Earth is tilted at about 5° compared to the orbital path of the Earth around the Sun. You will learn more about this when you read about lunar eclipses. (See associated Activity Eight at the end of the chapter.)

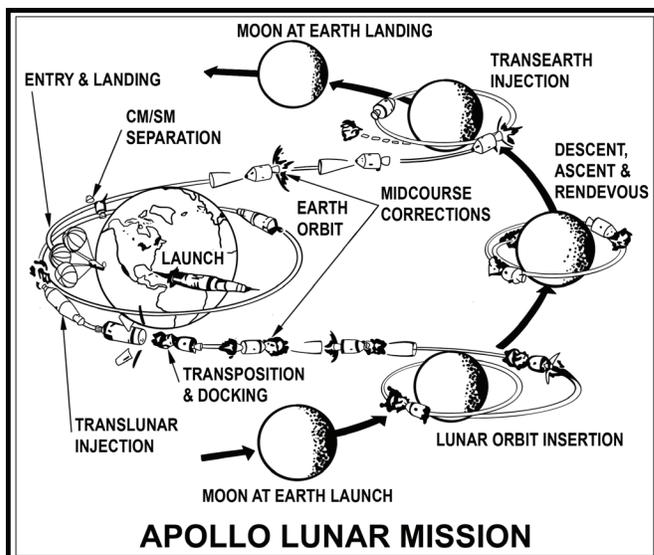
THE MOON

The Earth has one moon, and its proper name is the Moon. It is situated in an elliptical (oval-shaped) orbit around the Earth. Because it is elliptical and not circular, the Moon's distance from the Earth changes slightly. The distance varies from approximately 252,000 miles (405,555 km) at its farthest point to 221,000 miles (355,665 km) at its nearest point, with the average distance being close to 240,000 miles (386,243 km). You could fit about 30 Earths between the Earth and the Moon. While the Earth's diameter is about 7,920 miles (12,746 km), Earth's Moon has a diameter of about 2,155 miles (3,468 km), which is close to $\frac{1}{4}$ of the Earth's diameter. If you could travel to the Moon in a car at a speed of 65 miles per hour, you could reach the Moon in about 154 days. The Apollo astronauts who traveled to the Moon had to reach a speed of about 25,000 miles per hour to break out of Earth orbit. They made it to the Moon in just under 3 days traveling at an average speed of about 3,418 miles (5,500 km) per hour. (See associated Activity Nine at the end of the chapter.)



The Earth's Moon

The Moon's gravitational pull is weak compared to that of Earth's; therefore, the weight of objects on the Moon would be different compared to Earth. The gravitational pull of the Moon is $\frac{1}{6}$ that of Earth's. This means, if someone weighs 90 pounds on Earth, the person would only weigh 15 pounds on the Moon. Divide your weight by 6 to determine how much you would weigh on the Moon.



Due to this weaker gravitational pull, the Moon has no atmosphere. The gravity of the Moon is too weak to trap any gases, such as oxygen, carbon dioxide, nitrogen, and so on. Because of this, there is no wind or air of any kind on the Moon. Sound travels through air; therefore, there are no sounds on the Moon. The astronauts who went to the Moon during NASA's Apollo Program were able to communicate due to the breathable air in their spacecraft. On the lunar surface, each astronaut had breathable air in his space suit, which would then allow them to communicate with each other via radio.

While there are no oceans, lakes, streams, or polar ice caps on the Moon, sci-

entists had reason to believe that water ice might exist on the Moon due to evidence from past unmanned lunar missions. Scientists were excited to find conclusive evidence of water near the Moon thanks to data obtained from NASA's LCROSS (Lunar Crater Observation and Sensing Satellite) mission. In 2009, the LCROSS probe collected and transmitted information about a plume of lunar dust and particles created by the impact of a two-ton rocket stage slamming into a lunar crater. The crater, which is visible from Earth and is named Cabeus, is permanently shadowed near the Moon's south pole. This is important because the temperature of sunlit areas on the Moon can reach 250° F (121° C), which means water would quickly evaporate, and the gases would easily escape into space due to the Moon's weak gravitational pull. For water to exist, it would need to be in the form of ice, which would only be possible in a dark or shaded area on the Moon, such as the crater Cabeus. The initial data from the LCROSS mission revealed approximately 24 gallons of water. As for LCROSS, it also slammed into the crater, as planned, approximately 4 minutes after the rocket. Follow-on missions have confirmed that there are significant amounts of water ice at the lunar poles (quantities in the hundreds of millions of tons). The discovery is significant in terms of establishing lunar bases because it eliminates what would otherwise be a major undertaking transporting vital water from Earth for the inhabitants.

The Moon consists mainly of solid rock covered with dust. This fine dust covers the entire surface of the Moon. There are two theories on how the dust got there. Some think the impact of meteoroids striking the surface pulverized lunar matter into dust, which settled to the surface slowly and evenly. Others think the dust is cosmic dust from space that the Moon's gravitational pull brought to the surface.

Primarily, the Moon has two types of terrain, highlands and lowlands. The highlands are filled with craters surrounded by mountains, and the lowlands are filled with craters that have been flooded with molten lava and appear as dark areas called maria (Latin for sea, which in early astronomy was taken in the literal sense because observers interpreted the areas to be bodies of water).

The Moon has many different kinds of rocks. We learned this from the lunar landings. Moon basalt is a dark gray rock with tiny holes from which gas has escaped. It closely resembles Earth basalt, but contains different mineral combinations. On the Moon, basaltic lava makes up the dark, smooth surfaces of the lunar plains, which cover about half of the visible side of the Moon.



One of the many impact craters on the lunar surface

Probably the most common rock on the Moon is anorthosite. This rock is composed almost entirely of one mineral, feldspar. Anorthosite is found in the highlands of the Moon and shows up from Earth as the light areas of the Moon. Anorthosite is rare on Earth, but is found in Greenland and is believed to be an ancient rock.

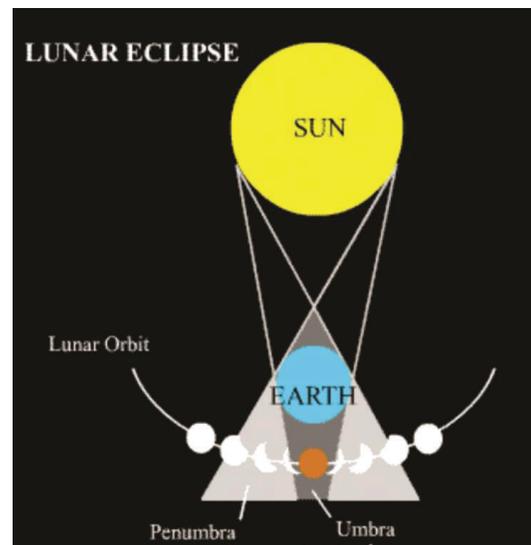
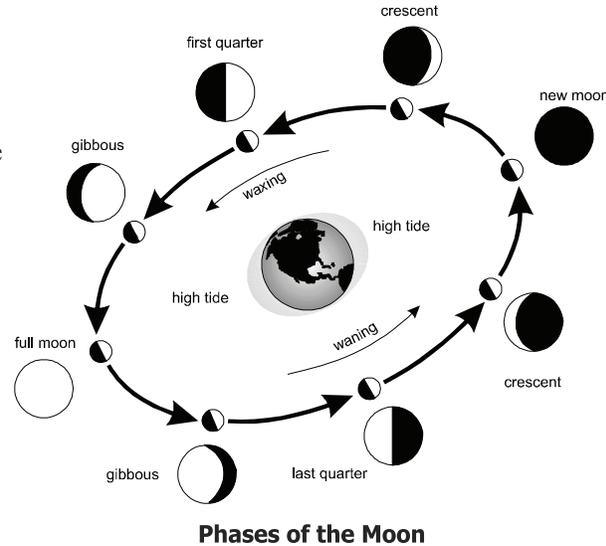
The Moon rotates on its axis in the same amount of time it takes to orbit the Earth (27 days). This is due to an effect known as tidal locking, and as a result, the Moon always presents the same side (known as the near side) toward Earth. The amount of surface we see, the phase of the Moon, depends on how much of the near side of the Moon is in the sunlight. As the Moon rotates around the Earth, its position relative to the Sun changes. As seen from the Earth, this means that a part of the surface of the Moon that is in shadow is facing the Earth. When the Moon is on the side of the Earth nearer the Sun, the Moon is new. When it is on the opposite side of the Earth the Moon is full. Study the diagram of the Moon phases to help you understand the shapes of the Moon that are visible at different times during the month. (See associated Activity Ten at the end of the chapter.)

Sometimes, the Moon passes directly in Earth's shadow. When this happens, part or all of the Moon may not be visible. This is called a lunar eclipse and occurs when the Sun, Earth, and Moon line up in just the right way. If the Moon passes through the penumbra, the light shadow cast by the Earth, the Moon is partially eclipsed. If the Moon passes through the umbra, the darkest part of the shadow cast by the Earth, the Moon is totally eclipsed. When the Earth's shadow prevents the entire surface facing the Earth to be blocked, it is called a total lunar eclipse. If the Moon rotates around the Earth each month, why doesn't a lunar eclipse occur each month? It is because the Moon is tilted about 5° in its orbital path around Earth compared to the orbital path of the Earth around the Sun; therefore, the Moon usually passes a little above or below the Earth. As explained at Space.com, "To visualize, think of two Hula Hoops (one inside of the other) — one big and one small — floating on the surface of a pool. Push the inner one down so that half of it is below the surface and half above. When the Moon gets into the ecliptic — right at the surface of the pool — during its full phase, then a lunar eclipse occurs."

A Moon day lasts 27 Earth days; the time it takes to orbit the Earth. Daytime on the Moon lasts about 13-14 Earth days, one half the orbit time; the other half being nighttime.

Temperatures on the Moon can rise above 250°F (121°C) during the day. Nighttime temperatures can go below -250°F (-157°C).

Although the Earth and stars are beautiful when observing them from the Moon, the Moon is a quiet, barren place with a black sky. To date, only twelve astronauts have walked on the Moon's surface as part of six Apollo missions between 1969 and 1972. Apollo 11 astronaut Buzz Aldrin described the Moon as "magnificent desolation." With no atmosphere, no running water, and extreme



temperatures, the Moon is a gray, lifeless ball orbiting the Earth. Without spacesuits and life-supporting vehicles or habitats, humans could not survive on our Moon. (See associated Activity Eleven at the end of the chapter.)

OTHER BODIES

Asteroids, comets, and meteoroids orbit the Sun and are therefore part of our solar system. Collectively, they are thought of as debris orbiting in space. You might wonder why they are important to us. Well, one reason is safety. Space planners and space travelers need to consider these phenomena as they prepare to go deeper into space. Let's take a quick look at each of these individually and learn a little more about them.

Asteroids are chunks of rock that range in size from large boulders to some that are a few hundred miles across. Most asteroids in our solar system travel in an orbit between Mars and Jupiter. This area is known as the asteroid belt.

The first asteroid was discovered by an Italian astronomer, Guiseppe Piazzi, in 1801. Since that time, more than 15,000 asteroids have been found and catalogued. Scientists speculate that there are probably millions more of them in our solar system. Scientists know of more than 200 asteroids whose orbits come close to our Earth and are capable of hitting us. However, the closest any have come is about 100,000 miles (160,934 km).

Spacecraft have flown through the asteroid belt and found that large distances separate asteroids. In October 1991, the asteroid known as Gaspra was visited by the *Galileo* spacecraft and became the first asteroid to have high-resolution images taken of it. Gaspra is composed of metal-rich silicates and looks like a lumpy potato-shaped rock.

In 1997, the spacecraft *Near Earth Asteroid Rendezvous (NEAR)* made a high-speed, close encounter with the asteroid Mathilde. Scientists found Mathilde to be a carbon-rich asteroid. NEAR went on to encounter the asteroid Eros in 1999-2000. Eros had numerous boulders protruding above the surrounding surface.

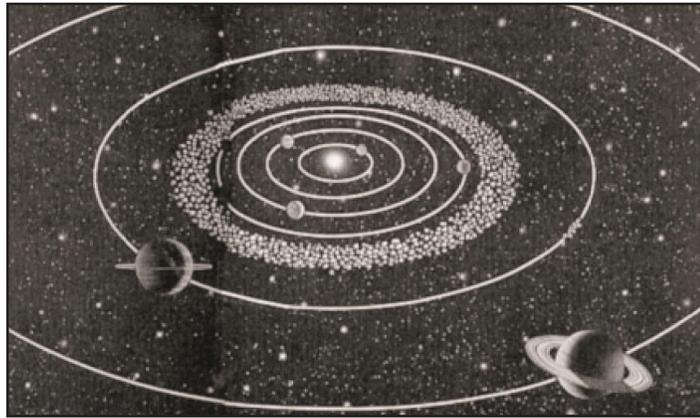
Earth-based observations of asteroids continue, too. In May 2000, scientists observed the boulder Kleopatra with the 1,000 radio foot telescope of the Arecibo Observatory. Kleopatra is a metallic, dog bone-shaped rock the size of the state of New Jersey.



Comet

A **comet** is described as a giant dirty snowball. It is irregularly shaped with a tiny nucleus composed of frozen gases, water, dust, and icy lumps. Comets are usually a few miles across. Comets generally travel around the outer regions of our solar system, but sometimes they are bumped off their orbit and head toward the Sun. As they approach the Sun, they dramatically increase in brightness. As the comet moves closer to the Sun, its ice parts begin melting into a gaseous and dusty tail that can extend for millions of miles. The tail gives the false impression that the comet is growing in size; however, the effect is simply the dust and ice particles being blown away from the comet by the solar wind. In actuality, the comet gets smaller and smaller with each near encounter with the sun.

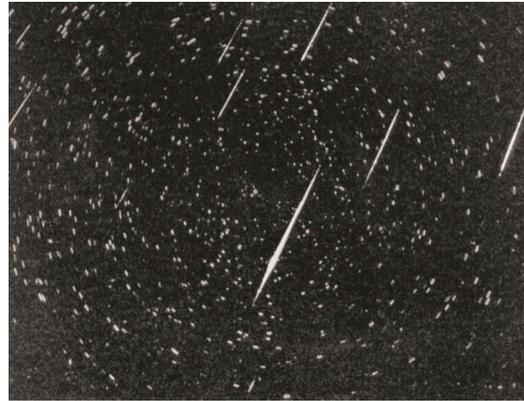
Sometimes, comets remain in their new orbits and repeat their journey; therefore, scientists can sometimes predict future travel paths of comets. For instance, Halley's Comet reappears every 76 years. It last appeared in 1986 and will return in 2061.



The asteroid belt between the orbits of Mars and Jupiter

English astronomer Sir Edmund Halley first suggested that comets were members of our solar system. After studying bright objects in the sky, he predicted the appearance of a comet in 1758 and it now bears his name.

Very small, dust-particle size bits of matter are called **micrometeoroides**. From this size upward, these tiny particles of dust and sand orbiting the Sun are called meteoroids. **Meteoroids** are usually leftover from a comet. If a meteoroid enters the Earth's atmosphere it is called a meteor. If the **meteor** is large enough to penetrate our atmosphere and actually hit the surface of the Earth it is called a **meteorite**.



Meteor shower

About seventeen meteors manage to reach the surface of the Earth each day; however, few of them are ever located or recovered. Meteors that burn up before reaching Earth's surface are far more common. Friction causes a meteor to heat and glow and begin to disintegrate leaving a trail of luminous matter. When there are many meteors seen in the sky within a period of an hour, it is called a meteor shower. Meteors are also referred to as shooting stars. They can be seen on just about any night if you get out in the country away from the city lights.

Meteorites are the pieces of matter that remain when debris does not burn up completely as it passes through the atmosphere and lands on the surface of the planet. Most meteorites are basketball size or smaller, but larger pieces have been found. Some meteorites were small pieces of an asteroid; others have proved to be material blasted off the surface of the Moon following an impact on its surface. Other meteorites have been determined to originate on Mars.

The recent recovery of a carbonaceous chondrite meteorite from the Yukon has excited scientists who say that its very primitive composition and pristine condition may tell us what the initial materials were like that went into making up the Earth, Moon, and Sun. Only about two percent of meteorites are carbonaceous chondrites containing many forms of carbon and organics, the basic building blocks of life. This type of meteorite would be easily broken down while it was passing through the Earth's atmosphere, so recovery is quite rare.

(See associated Activity Twelve at the end of the chapter.)

Summary

The Sun is a star and is a most important element of our solar system. The Sun releases a tremendous amount of energy in the form of heat and light, which is essential for life on Earth. The Moon, on the other hand, does not produce heat or light. Its environment is very different from Earth's, and without spacesuits and life-supporting vehicles or habitats, humans could not survive on our Moon. In the final analysis, it can't really be stated which is the more important element of our solar system. Earth could not sustain life without the Sun; yet in the absence of Earth, there is no other planet in the solar system that is suitable to support human life.

Our solar system also includes comets, meteoroids, and asteroids. After reading detailed information about these objects, you should be able to explain how they are different from one another.

When thinking about our solar system, you probably immediately think of planets. In the last chapter, we will visit each of the planets in our solar system.



ACTIVITY SECTION 3

Activity Eight - Build a Solar Cooker

Purpose: This is the practical way to show how energy from the Sun can be used. Note that this activity requires a sunny or at least mostly sunny day in order to work properly.

Materials: shoe box, aluminum foil, plastic wrap, a skewer, and some hot dogs

Procedures:

1. Line the shoe box with the foil.
2. Insert a skewer through one of the short sides.
3. Insert the skewer through a hot dog (lengthwise) and then stick the skewer into the other short side of the box.
4. Cover with the plastic wrap.
5. Place the solar cooker in sunlight and let the Sun cook your lunch. You could try baking cookies from refrigerated cookie dough, as well.

Summary: The solar cooker uses sunlight as its energy source. The aluminum foil helps keep the light and heat from the Sun in the cooking area, increasing its intensity. The plastic wrap over the top allows the sunlight to enter the box, but helps prevent heat from escaping. The temperature inside the solar cooker then becomes hot enough to heat the hot dog. A discussion of how solar energy can be used in our country would be beneficial at this time.

Activity Nine - Earth-Moon Distance

Purpose: This activity will give both a visual and mathematical comparison of the distance to the Moon from the Earth using scale models to represent the actual objects.

Materials: world globe (important that the globe is 12 inches in diameter), tennis ball, string (at least 30 feet long), reference book or internet site (as noted below), measuring tape, and calculator or pencil/paper for calculators

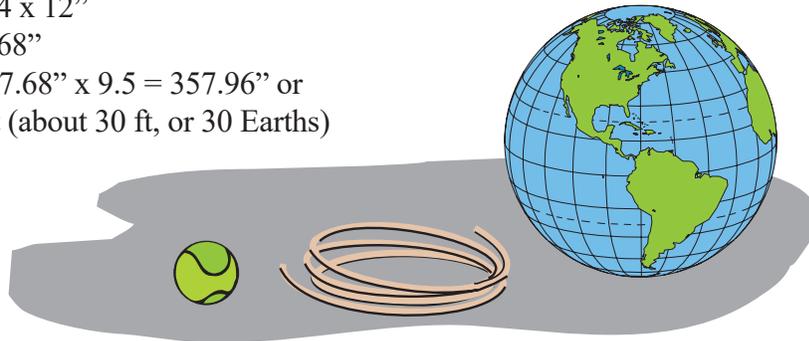
Procedures:

1. With the tennis ball representing the Moon, ask students to place the tennis ball at a distance from the globe that represents how far the Moon is from the Earth. (Use the information found on page 28 that states that you could fit about 30 Earths between the Earth and the Moon.) This will be a visual representation of the distance from the Earth to the Moon.
2. Next, as a mathematical representation of the distance, and a way to actually measure the scaled distance, ask students to determine the circumference of the Earth by consulting a reference book or using the internet, or use the summary information on next page. Using this circumference, the students should use the information on page 28 that tells that the distance from the Earth to the Moon is about 240,000 miles and determine how many times the circumference of the Earth it would take to measure the distance from the Earth to the Moon. To do this, the students should divide the distance to the Moon by the Earth's circumference. (The summary will give the mathematical outcome.)

3. Compare the earlier visual idea of the distance between the Earth and the Moon with measured distance based on the Earth's circumference. To do this, wrap the string around the globe 9.5 times. Then hold one end of the string at the surface of the Earth and stretch the string across the classroom. The other end of the string represents the distance of the Earth to the Moon. Measure the distance.

Summary: The Earth's circumference is about 25,000 miles. The distance from the Earth to the Moon is about 240,000 miles. When you divide the distance between the Earth and the Moon by the circumference of the Earth you get 9.6 or, averaged 9.5. Using this scale, the distance from the model Earth to the model Moon should be 9.5 times the circumference of the model Earth, or about 30 Earths away, as calculated in the equation below.

Mathematically: $C = \pi d$
 $C = 3.14 \times 12''$
 $C = 37.68''$
Then, $37.68'' \times 9.5 = 357.96''$ or
29.83 ft (about 30 ft, or 30 Earths)



Activity Ten - Seeing the Moon

Purpose: Demonstrate why we see different portions of the Moon (phases of the Moon) illuminated in the sky due to light and shadows.

Materials: a dark room, a bright light source (a table lamp), a small ball (tennis or baseball), and the demonstrator (a person doing the demonstration for the others)

Procedures:

1. Hold the ball at arm's length toward the bright lamp.
2. Ensure the room is dark except for the table lamp. With the lamp representing the Sun, the head of the demonstrator becomes the Earth, and the ball is the Moon.
3. The demonstrator should stand in place; slowly turning to the left so that the ball in the out stretched hand moves in a complete circle. Observers will be able to see the changing phases of the Moon on the ball.

Summary: As shown in the illustration of the phases of the Moon on shown in the reading, as the Moon makes its 27-day orbit of the Earth, the amount of sunlight that reaches the Moon when it is not in the Earth's shadow determines the surface of the Moon that can be seen from Earth.

Activity Eleven - Lost on the Moon - Survival

Purpose: This activity accomplishes several things: the analysis of the Moon's atmosphere, the evaluation of the importance of available materials while on the Moon, the identification of similarities and differences between the Earth and Moon, the use of critical thinking skills, and the promotion of team building.

Background: Your spaceship has just crash-landed on the dark side of the Moon. You were scheduled to rendezvous with your mother ship 200 miles away, on the lighted surface of the Moon, but the rough landing has destroyed your ship and ruined all but the 15 items listed below.

Since your crew's survival depends upon reaching the mother ship, you must choose the most critical items available for the 200-mile trek across the Moon's surface. You must determine the "priority" of survival items and list them. Back on Earth, NASA would have given you their priority, but no contact can be made. The decision is yours. How would your team skills compare to those of the NASA home team? It's fun to compare your answers with those of NASA and other teams.

Materials: checklist of items provided, a pencil or pen

	ITEMS	NASA RANKING	YOUR RANKING	ERROR POINTS	GROUP RANKING	GROUP POINTS
1	Box of matches					
2	Food concentrate					
3	50' of nylon rope					
4	Parachute silk					
5	Solar powered heating unit					
6	Two 45 caliber pistols					
7	One case of Pet milk					
8	Stellar map					
9	Two 100-pound oxygen tanks					
10	Self-inflating life rafts					
11	Magnetic compass					
12	Five gallons of water					
13	Signal Flares					
14	First aid kit containing injection needles					
15	Solar powered FM transceiver					
	TOTALS					

Procedure:

1. Divide the group into small teams.
2. Hand out a copy of the problem or read it to the teams.
3. Have students rank the 15 items in their order of priority.
4. After the students are done, have them discuss and justify their rankings to the other teams.
5. Show the students the NASA rankings.
6. Calculate the error points for individuals and teams, using the NASA ranking on the next page. Calculate error points for the absolute difference between the NASA ranking and the individual or group ranking. Scoring:
 - 0-26 = Excellent
 - 27-32 = Good
 - 33-45 = Fair
 - 46-112 = Still lost on the Moon

Summary: An understanding of the lunar environment and an ability to critically think and discuss ideas are necessary to make good judgments regarding the importance of the items on the survival list. Working as a team to make these selections is beneficial in making good decisions.

RANKINGS

	ITEMS	NASA RANKING	REASON			
1	Box of matches	15	no air on the Moon so matches will not light			
2	Food concentrate	4	efficient means of supplying requirements			
3	50' of nylon rope	6	useful in scaling cliffs or in case of injury			
4	Parachute silk	8	possible use as a sun shield			
5	Solar powered heating unit	13	not functional on dark side of Moon			
6	Two 45 caliber pistols	11	possible means of self propulsion			
7	One case of Pet Milk	12	bulkier duplication of energy source			
8	Stellar map	3	primary means of navigation to the Moon base			
9	Two 100-pound oxygen tanks	1	the most pressing survival requirement			
10	Self-inflating life raft	9	Carbon dioxide bottle in raft might be used as a propulsion source			
11	Magnetic compass	14	magnetic fields of Moon are not polarized so compass is useless			
12	Five gallons of water	2	replacement of tremendous liquid loss on lighted side of Moon			
13	Signal flares	10	distress signal when Moon base is sighted			
14	First aid kit containing injection needles	7	needles for medicine and vitamins fit special suit aperture			
15	Solar powered FM transceiver	5	for communication with Moon base in line of sight			
	TOTALS					

Calculate error points for the absolute difference between the NASA ranking and the individual or group ranking. Scoring: 0-26 Excellent
 26-32 Good
 33-45 Average
 46-55 Fair
 56-112 Still lost on the Moon

Activity Twelve - Meteoroids and Space Debris

Purpose: Demonstrate the penetrating power of a projectile with a small mass and how it differs depending on the velocity (speed and direction).

Materials: two or three raw potatoes (depending on group size), several large diameter plastic straws (Each person should get a chance to participate.)

Procedure:

1. Hold the raw potato in one hand.
2. While grasping the straw with the other hand, stab the potato with a quick sharp motion. The straw should completely penetrate the potato. **CAUTION** - Don't strike your other hand.
3. Again, hold the potato and now stab it with the straw using a slow push. The straw should bend instead of penetrating the potato.

Summary: Even a small mass can penetrate many things if its velocity is high enough. This was demonstrated by the straw penetrating the potato. Meteoroids and space debris traveling at high speeds pose significant hazards, particularly to space walking astronauts. Spacesuit material is made of special layers of materials to help protect astronauts from meteoroids and small space debris.

OUR SOLAR SYSTEM: THE PLANETS

Learning Outcomes

- Define planet.
- State basic facts about each of the planets in our solar system.
- Define and identify dwarf planets.

Officially, our solar system contains eight planets. Most of us can probably name them, and are somewhat familiar with them. In 2006, the International Astronomical Union (IAU), the governing body of astronomy, revised the definition of “planet,” which removed Pluto from the traditional planet category.

The IAU’s definition of planet is "a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and (c) has cleared the neighborhood around its orbit." Let’s take a few moments and look at some interesting facts about each planet, as well as Pluto. We’ll start with Mercury and go in order of each planet’s distance from the Sun.

Mercury

Mercury is the closest planet to the Sun, yet it is the most difficult to see because of the Sun’s glare on it. (Don’t look for Mercury while the Sun is in the sky. It could damage your eyes.) Mercury is slightly larger than the Earth’s moon and is the smallest of the eight planets.

Mercury is only 36 million miles (0.39 AU) from the Sun and revolves around the Sun every 88 days. It has a very elliptical orbit, and it moves about 30 miles (48 km) every second. Mercury rotates very slowly, taking 59 Earth days to complete one rotation on its axis.

Mercury, which has no moons, has a rocky, crusty surface with many craters resembling the craters of the Earth’s moon. These craters were formed when comets, asteroids, and meteoroids crashed into the planet. Mercury also has many lava flows

and quake faults on its surface. These craters, flows, and faults have shaped the surface of the planet.

Except for small amounts of helium and hydrogen, Mercury has no atmosphere. Scientists believe that Mercury has an iron core that extends through most of the planet. Mercury has significant temperature differences. Its daytime temperature reaches 800° F (427° C), while its nighttime temperatures reach -300° F (184° C).

Pictures of Mercury’s surface were first taken from the *Mariner 10* spacecraft that made flybys in 1974 and 1975, photographing about 45% of the surface of Mercury. The pictures displayed Mercury’s many craters and loose, porous soil. It also gave indications



Mercury



The surface of Mercury as seen from *Mariner 10*

that ice existed at its poles, in deep craters, where the Sun could not melt it. In the three *Mariner 10* flybys, it was discovered that a magnetic field and extremely thin atmosphere existed.

In order to learn more about Mercury, NASA created the MESSENGER Program (standing for MErcury Surface, Space ENvironment, GEOchemistry, and Ranging) Launched on August 2, 2004, MESSENGER conducted its first of three flybys of Mercury on January 14, 2008. Information collected from MESSENGER'S three flybys along with the key images taken from *Mariner 10* helped to produce the first global map of Mercury in December of 2009. Beginning an orbital mission in 2011, MESSENGER was the first spacecraft to orbit Mercury. Through the MESSENGER Program, scientists will gain valuable information to better understand Mercury's geological history, extreme density, magnetic field, core, poles, and exosphere. On April 30, 2015, NASA commanded the spacecraft to deorbit Mercury whereupon it crashed onto its surface.

Venus

Next, is Venus. It is the closest planet to Earth in both distance and size and is often referred to as Earth's sister. Venus is 67 million miles (0.7 AU) from the Sun. It takes 225 days to revolve around the Sun. It is a very hot planet with temperatures in excess of 850° F (454° C). In fact, Venus is the hottest planet in the solar system.

Even with the heat, Venus is covered with clouds. These clouds are made of water vapor and sulfuric acid, and they rotate at a different rate than the planet. These clouds rotate every four days; much faster than the 243 Earth days it takes for Venus to rotate on its axis. Venus is the only known planet to rotate in a clockwise manner and has the slowest rotational speed of any planet in the solar system.

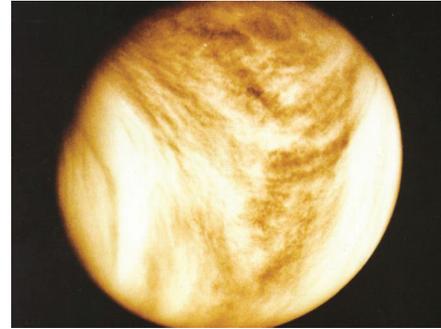
The atmosphere is 96% carbon dioxide and 4% nitrogen. There are also small amounts of water, oxygen, and sulfur. Scientists believe volcanic activity is responsible for the sulfur found in the atmosphere. Because of this thick layer of carbon dioxide and the clouds, the heat cannot escape. Therefore, there is very little temperature change on Venus.

The surface of Venus is a relatively smooth, hot desert. It does have some highlands and craters, too. Venus is the easiest planet to see at night and is the brightest of all. You can even see it in the daytime if you know where to look. Since it is the brightest planet that can be seen from Earth, Venus is referred to as the Evening Star. Venus has no moons.

Since Venus is the closest planet to Earth, for a time, it was the most visited by our spacecraft. *Mariner 2*, 5, and 10 visited Venus, as did *Pioneer 1* and 2. Mars now holds the title of the most visited planet by American spacecraft. The USSR's *Venera 9* and 10 also visited Venus.

The *Magellan* spacecraft, launched in May of 1989 aboard the Space Shuttle *Atlantis*, was sent to orbit Venus from 1990-1994. It collected radar images and was able to map more than 98% of the planet's surface. As a result of the mission, it was verified that volcanic materials cover most of Venus.

Venus continues to be visited by spacecraft. The *Venus Express*, a European Space Agency spacecraft that was launched in November of 2005, and functioned through December of 2014. Also, in the summer of 2010, Japan launched the Venus Climate Orbiter "*Planet-C*," nicknamed "*Akatsuki*," which means "dawn." *Akatsuki* should reveal much detail about the climate and atmosphere of Venus. As explained by Japan Aerospace Exploration Agency (JAXA), "The Venus Climate Orbiter 'AKATSUKI' (PLANET-C) is the world's first planetary meteorological observation satellite to unveil the mysteries of wind on Venus. It will explore the mechanism of the Venus climate by observing the atmospheric movement and cloud formation process." In learning about Venus, scientists also believe that they will develop a deeper understanding of Earth's environment: past, present, and future. The spacecraft is expected to remain operational through 2021.



Venus

Earth

As far as we know, Earth is the only planet that sustains life. Therefore, it is a unique planet. Earth is approximately 1 AU (93 million miles) from the Sun, and it takes the planet about 365 days to make one revolution around the Sun, which is one Earth year. Remember that the average distance from the Earth to the Sun is a straight line from the Earth to the Sun. The average distance that the Earth travels in its orbit around the Sun (circumference of Earth's orbit) is about 584 million miles (939,856,896 km). If the Earth has to travel about 584 million miles to make a complete orbit around the Sun, and it takes about 365 days to do this, you can figure out about how fast the Earth is traveling around the Sun. By dividing the distance the Earth travels around the Sun over a period of 365 days, and then dividing that result by 24 (number of hours in a day), you would end up with a calculated speed of approximately 66,700 mph (or nearly 19 miles per second).

Besides speeding around the Sun, the Earth also moves by rotating on its axis. One day on Earth is the time it takes for the Earth to spin once on its axis, which is almost exactly 24 hours. Because the Earth spins on its axis once every 24 hours, we experience day and night. If Earth's circumference at the equator is about 24,900 miles (40,074 km), and it takes 24 hours for a point on Earth's equator to make one complete rotation, about how fast is the Earth spinning on its axis? You are correct if you calculated a little over 1,000 miles per hour (or a little over a quarter of a mile per second).

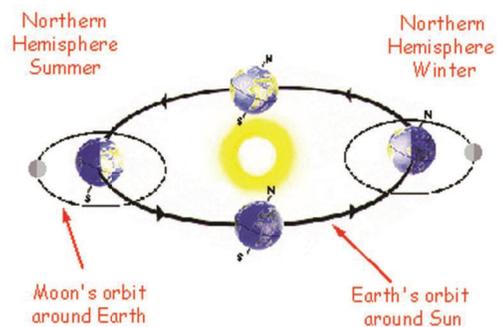
Earth has four seasons because of the tilt of the Earth on its axis. Earth is tilted almost 23.5° on its axis. Because of this, different parts of the Earth receive different amounts of direct sunlight at different times of the year. For example, when the northern hemisphere experiences summer, the northern hemisphere is tilted more towards the Sun, and the rays of the Sun hit the northern hemisphere at a more direct angle. It, therefore, is not the distance between the Earth and the Sun that creates the seasons, but rather the tilt of the Earth on its axis.

Twice during the year, Earth experiences a solstice. A solstice occurs when the Sun is at its highest or lowest point in the sky. This occurs in the summer and winter. The summer solstice for the Northern Hemisphere occurs on or about June 21 and the winter solstice occurs on or about December 21. After the summer solstice, the hours we receive daylight slowly get fewer and fewer until we reach the winter solstice, which is the shortest day of the year in terms of daylight. After the winter solstice, the amount of daylight hours slowly increases until the summer solstice, which is the longest day of the year in terms of daylight hours.

Twice a year, the Earth experiences an equinox. An equinox occurs when the amount of daylight hours and nighttime hours are about the same due to the position of Earth in its orbit around the Sun, which causes the concentration of direct sunlight to be closest to the equator. The vernal equinox for the Northern Hemisphere occurs on or about March 21 and marks the beginning of spring. The days will continue to get longer in terms of daylight hours up until the summer solstice, which marks the beginning of summer. The autumnal equinox occurs on or about September 21 and marks the beginning of fall. The days will continue to get shorter in terms of daylight hours and cooler as the winter solstice draws near. The exact moments of the equinoxes and solstices vary from year to year due to minor variations in the speed of the Earth as it travels around the Sun.



Earth



Tilt and seasons

Our atmosphere contains 78% nitrogen and 21% oxygen, with small amounts of argon, carbon dioxide, neon, helium, ozone, and hydrogen. This atmosphere provides the oxygen that we breathe and keeps the temperature of water as liquid, so that life is possible. Our atmosphere also acts like a protective blanket. It contains clouds, and these clouds, along with the chemical composition of the atmosphere, help absorb a significant amount of the Sun's radiation.

A common question people have about Earth is, "Why is the sky blue?" NASA has an explanation that is fairly easy to understand. "The light from the Sun looks white, but it is really made up of all the colors of the rainbow (which scientists refer to as the spectrum). When white light shines through a prism, the light is separated into all its colors. Like energy passing through the ocean, light energy travels in waves, too. Some light travels in short, choppy waves. Other light travels in long, lazy waves. Blue light waves are shorter than red light waves. Sunlight reaches Earth's atmosphere and is scattered in all directions by all the gases and particles in the air. Blue light is scattered in all directions by the tiny molecules of air in Earth's atmosphere. Blue is scattered more than other colors because it travels as shorter, smaller waves. This is why we see a blue sky most of the time."

The surface of our planet is covered with over 70% water, with the Pacific Ocean accounting for over 50% all by itself. Orbiting Earth is its one moon, as discussed in the previous chapter. The Moon's gravity pulls on Earth and Earth's gravity pulls on the Moon. This mutual attraction is strong enough to pull the water in the Earth's oceans slightly towards the Moon, creating tides. Note that the Sun also has an effect on the Earth's tides, but to a lesser effect due to its much greater distance.

While 70% of Earth is covered in water, the remaining 30% is covered with various land features. The Earth has many diverse features from smooth pastures, to plateaus and small hills, to tremendous mountains. We have lush forests and barren deserts. Our planet sustains not only human life, but plant life and animal life, too. From a variety of life forms to landscapes to climates, Earth is an interesting planet to study—so much so that NASA organized its Earth observing missions into a program it called "Mission to Planet Earth." These missions focus on studying Earth using heavily instrumented spacecraft to better understand its geology, climate, and human induced changes. Mission to Planet Earth has since been renamed "NASA Earth Science."

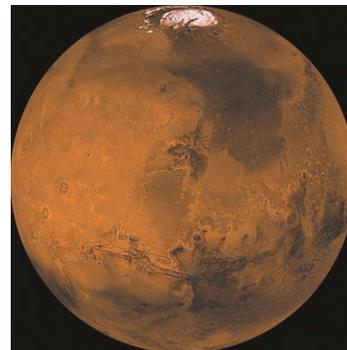
Mars

Of all of the planets, Mars probably fascinates us the most. Over the years, it has been the most publicized in books and movies, and just about everyone knows it as the Red Planet. This is due to its red color which can be seen even with the naked eye. This color is due to the rock and dust covering the surface of Mars. It has been analyzed and found to have a high iron content, so it has a rusty look. Because of the decreased gravitational pull of Mars, the blowing dust on Mars rises easily, which also contributes to the atmosphere's reddish pink appearance.

Mars is about half as big as Earth and has about 1/9 the mass of the Earth. Because its gravitational pull is about 1/3 that of Earth's, objects weigh only about 1/3 of what they weigh on Earth. For example, if a person weighed 130 pounds on Earth, he or she would weigh only 43 pounds on Mars.

Mars has farther to travel around the Sun than Earth, but it takes about the same time as Earth to rotate once on its axis. The length of a Martian day is about the same as an Earth day at 24 hours 37 minutes. A Martian year is about 687 Earth days, which is about twice as long as an Earth year. What is your age in Martian years? Divide your age by two for a close estimate.

Although the atmosphere of Mars is much less dense than Earth's, Mars has an atmosphere that supports a weather system. The atmosphere, which consists of 95% carbon dioxide,



Mars

3% nitrogen and traces of oxygen, carbon monoxide, and water, includes clouds and winds. Blowing dust storms occur periodically over the surface. Daytime surface temperatures near the equator on Mars can reach above 70° F (21° C), while nighttime temperatures can dip to -130° F (-90° C). The average planet temperature is about - 80° F (-62° C). Although a cold planet overall, Mars does have four seasons due to the tilt of its axis, which is about 25°.

The surface of Mars is covered with deserts, high mountains, deep craters, valleys, and huge volcanoes. One of Mars's volcanoes, Olympus Mons, is the highest known mountain in our solar system. It is about 370 miles (595 km) across and 17 miles (27 km) high. That is much taller than Mt. Everest which is about 5.5 miles high. The largest known canyon in our solar system is Mars's Valles Marineras. At 2,490 miles (4,007 km), it stretches nearly 1/5 the circumference of the planet. If placed on the continental United States, it would stretch from the west coast to the east coast. Some parts of the canyon reach between four and five miles deep, compared to the Grand Canyon's lowest depth of about one mile (1.6 km).

Another geological feature on Mars is its polar ice caps. The polar ice caps are made of frozen carbon dioxide, or dry ice, and water ice. The water ice is located below frozen carbon dioxide. The ice caps wax (get bigger) and wane (shrink) with the seasons, waxing in winter and waning in the summer.

Orbiting Mars are its two small moons, Phobos and Deimos. Named after Greek mythological figures, their names translate to fear and panic. Scientists believe that these potato-shaped moons are actually asteroids that got captured by the gravitational pull of Mars. Phobos, slightly larger than Deimos, orbits closer to its planet than any other moon in our solar system, orbiting about 3,700 miles (5,955 km) from the planet. It is believed that in as little as ten million years, Phobos might crash into Mars or break apart before it reaches Mars, resulting in smaller pieces of rocks orbiting Mars.

Mars's average distance from the Sun is approximately 141.6 million miles, which is about 1.5 AU. If you could drive to Mars when Earth and Mars are closest together, it would take about 66.5 years traveling at 60 mph. Depending on their positions in their orbits, the closest distance between Earth and Mars is about 35 million miles (56,327,040 km), but they can reach a maximum distance of about 250 million miles (402,336,000 km). The distance between the two planets is critical to planning missions to Mars.

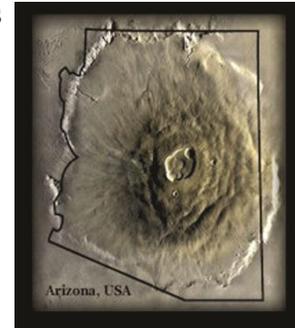


Sojourner rover next to rock named "Yogi"

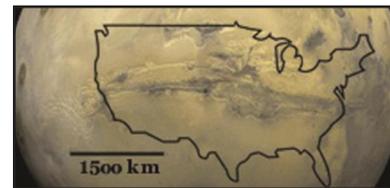
In the mid to late 1960s, the *Mariner* spacecraft made flybys of Mars and took lots of photos. Pictures revealed Mars's surface to be like the Earth's moon. Then in the mid 1970s the Mars Viking missions were launched. The primary mission of *Viking I* and *Viking 2* was to determine if life ever existed on Mars. Unfortunately, the experiments were inconclusive even though more water was found on Mars than had been expected.

In July 1997, the space probe called the *Mars Pathfinder* landed on Mars. The next day the *Pathfinder's* rover, *Sojourner*, began its exploration of the planet. The *Sojourner* was two feet long and one foot tall. It studied the surface, analyzed the soil and rocks, and conducted scientific experiments on Mars.

Two other rovers, *Spirit* and *Opportunity*, landed on the Martian surface in January 2004. Their missions were extended for the fifth time in 2007. These rovers were able to study the geology of Mars, which provides great insight into explanations of the past and present environment of Mars. NASA reported, "*Opportunity* has returned dramatic evidence that its area of Mars stayed wet for an extended period of time long ago, with condi-



Olympus Mons with the state of Arizona outlined



Valles Marineras compared to the area of the United States

tions that could have been suitable for sustaining microbial life. *Spirit* has found evidence in the region it is exploring that water in some form has altered the mineral composition of some soils and rocks.” Originally scheduled for a 90-day mission, these rovers far exceeded their life expectancies, with *Spirit* surviving through March 2010 and *Opportunity* lasting until June 2018.

In July of 2008, a NASA spacecraft, the *Phoenix Mars Lander*, confirmed water on Mars. *Phoenix* had a scoop device that was able to dig up subsurface soil samples. It was also able to heat the samples and analyze them. “We have water,” said William Boynton of the University of Arizona, lead scientist for the *Thermal and Evolved-Gas Analyzer*, or *TEGA*. “We’ve seen evidence for this water ice before in observations by the Mars *Odyssey* orbiter and in disappearing chunks observed by *Phoenix* last month, but this is the first time Martian water has been touched and tasted.” *Phoenix* landed on Mars on May 25, 2008 in the northern polar plains and operated for five months, two months longer than scheduled. Its mission not only confirmed water ice on Mars, but also provided more insight into its climate, soil, and history.

The Mars *Odyssey* orbiter mentioned above has truly made a name for itself. Launched in 2001 (the year made famous by the popular movie of the same name) it was specifically named “*Odyssey*” to pay homage to both the movie as well as its writer and scientific consultant, noted author Sir Arthur C. Clarke. The *Odyssey* orbiter has the distinction of being the longest surviving Martian space probe. In April 2021 it will surpass twenty years of service and is expected to continue functioning to at least 2025. Along with detecting water ice on Mars, the orbiter has mapped chemical elements on Mars and collected radiation data. The Jet Propulsion Laboratory (JPL) in Pasadena, CA reported that “infrared mapping showed that a mineral called olivine is widespread. This indicated the environment has been quite dry, because water exposure alters olivine into other minerals.” An instrument on *Odyssey* found that Mars’s radiation level is two to three times higher than that around Earth. In addition to these accomplishments, the Mars *Odyssey* helped study landing sites for *Spirit*, *Opportunity*, and *Phoenix* and provided communication relay support to them.

More recently, the *Curiosity* rover (the size of a small SUV) has been operational on the surface since 2012. It is equipped with a very sophisticated laboratory with which to analyze soil and rock samples. NASA will continue to fund the mission for as long as the rover is active. The *Perseverance* rover launched in 2020 and was equipped with its own UAV to conduct aerial searches for potential locations to investigate. It will also collect samples that will be encapsulated for return to Earth on a future mission. Next to Earth, Mars certainly has the most favorable conditions of any of the other planets in our solar system. It is the last in a line of what is considered the inner terrestrial planets.

Jupiter

Jupiter is the first in the line of the outer, gaseous planets in our solar system. It is about 483.6 million miles from the Sun, which is about 5.2 AU. Remember, 1 AU equals 93 million miles. At its closest distance to Earth, Jupiter comes to within 398 million miles (804,672,000 km). So, if you drove about 60 mph, it would take you hundreds of years, actually close to 1,000 years, to reach Jupiter.

Jupiter is the largest planet in our solar system. Its diameter is about 88,700 miles (142,749 km). About 11 Earths could fit across the diameter of Jupiter. Jupiter is so big that if it were empty, every planet in our solar system could fit inside it. If you were only putting Earths inside it, it could hold about 1,320 Earths. Even though Jupiter is the largest planet in our solar system, it still isn’t as big as the Sun. About 915 Jupiters could fit inside the Sun.

Jupiter is so massive that it would take about 318 Earths to equal the mass of Jupiter. Although it has a huge mass, it has a low density because it is composed primarily of hydrogen, the lightest element. Jupiter’s large size, huge mass, and low density create a gravitational pull



Jupiter

on Jupiter that is about 2.5 times that of Earth's.

Jupiter takes approximately 12 years to complete one orbit of the Sun. Even though Jupiter is huge, it rotates on its axis very quickly, about every ten hours. This causes a flattening effect at the poles and a bulging effect at the equator. This fast rotation also enhances the weather patterns on Jupiter. It creates high winds and giant storms on Jupiter, where the temperature ranges from over 60,000° F (33,316° C) at its center, to -220° F (-140° C) at the upper cloud layers.

Jupiter is a gas giant. Hydrogen is the most prominent gas (about 90%), followed by helium, methane, and ammonia. The temperatures and pressures existing in Jupiter's core affect hydrogen in such a way so as to give it metallic properties (most notably, it can conduct electricity). Scientists refer to this condition as "metallic hydrogen." The outer core of Jupiter is composed of liquid hydrogen and helium, and these mix with the gaseous atmosphere to form belts of clouds. These belts are very colorful, but change rapidly due to the high winds associated with the quick rotation of the planet. These belts make Jupiter look like a striped ball with a giant red spot in the lower half. The Great Red Spot is a distinguishing feature of Jupiter. This spot is a giant storm that is 30,000 miles (48,280 km) long and 10,000 miles (16,093 km) wide. It has been in existence at least since the first telescopic observations were made in the 1600s, nearly 360 years ago.

A great deal of atmospheric activity on Jupiter is similar to that of Earth. However, Jupiter's storms seem to be powered by the planet itself rather than by the Sun, as they are on Earth. Jupiter's highly-compressed hydrogen at its center also causes the planet to emit almost 70 percent more heat than it absorbs from the Sun. This leads scientists to speculate that the source of Jupiter's stormy turbulence is the planet itself.

An odd and almost eerie characteristic of Jupiter (and all of the gas giant planets for that matter) is that they have no solid surfaces. The images of the planets that we have all seen simply show the upper layers of the atmosphere. Farther down into the atmosphere, the gases gradually transition into liquid form with no clear delineation like we see on Earth. As a result of these conditions, no humans will ever set foot on Jupiter or any of the outer planets. Incidentally, this is one of the



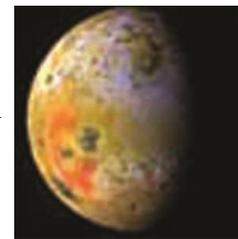
Galileo Spacecraft

main ways astronomers classify the planets of our solar system: terrestrial vs. gaseous (terrestrial meaning they are made of rocks and solid metals and each has a clearly defined surface).

To learn more about Jupiter and its moons, spacecraft have been launched toward this gas giant since as early as the 1970s. The *Pioneer* probes, launched in the early 1970s, were the first to visit Jupiter. They discovered that the banded structure of the atmosphere was not present near the poles. The poles had a thick blue-sky atmosphere. Detailed studies showed rapid motions among the clouds and changes in the wind speeds. In 1977, the *Voyager* probes were launched to study the outer planets. In 1979, *Voyager 1* discovered rings around Jupiter. Jupiter's rings are dark and difficult to see, unlike those of Saturn. It was the spacecraft *Galileo* that

revealed that the rings around Jupiter are formed by dust.

The *Galileo* mission was launched in October 1989 with the help of the Space Shuttle *Atlantis*. Its mission was to study Jupiter's atmosphere and moons. After flybys of Earth and Venus, it captured the first close-up picture of an asteroid in 1991 on its way to Jupiter. It also discovered the first known asteroid to have a moon, which was named *Dactyl*. It observed the comet Shoemaker-Levy crash into Jupiter in 1994. *Galileo* began exploring Jupiter and its moons in 1995. After several extensions of its mission, *Galileo's* journey finally came to an end on Sept. 21, 2003 after disintegrating in Jupiter's atmosphere. *Galileo* provided about 14,000 pictures and returned important information about Jupiter and its moons.



Io

As of 2020, Jupiter had 79 officially recognized moons. Ganymede,

Callisto, Io, and Europa are the four largest moons of Jupiter. These four are called the Galilean moons, named after their discoverer, Galileo Galilei, who observed them in 1610. The icy Ganymede Moon is the largest moon in our solar system. It is larger than the planet Mercury, but not quite as big as Mars. NASA's *Galileo* spacecraft indicated the presence of a magnetic field, making Ganymede the only known moon to have one. In 1996, the *Hubble Space Telescope* detected a thin atmosphere containing oxygen, but the atmosphere is too thin to support life.

Callisto is covered with craters, and, in 1999, the *Galileo* spacecraft detected a thin atmosphere of carbon dioxide.

Io also has a thin atmosphere, and it has active volcanoes that eject sulfuric acid. A NASA reference describes Io as "a giant pizza covered with melted cheese and splotches of tomato and ripe olives; Io is the most volcanically active body in the solar system." NASA's *Galileo* spacecraft revealed that the volcanic activity on Io is 100 times greater than Earth's. With the exception of the volcanic areas, Io has a very cold surface temperature.

Europa appears to be the smoothest celestial body in our solar system and has a thin atmosphere. "Europa's oxygen atmosphere is so tenuous that its surface pressure is barely one hundred billionth that of the Earth," said Principal Investigator Doyle Hall, of Johns Hopkins. "If all the oxygen on Europa were compressed to the surface pressure of Earth's atmosphere, it would fill only about a dozen Houston Astrodomes. It is truly amazing that the *Hubble Space Telescope* can detect such tenuous trace of gas so far away." It is thought that there is a liquid ocean under Europa's icy surface. Based on the information returned from *Galileo*, it could have two times as much water as all of the oceans on Earth. Could organisms exist in that ocean? Scientists have speculated that there could be marine life under the icy crust. The idea is not so far-fetched, as NASA hopes to send a probe there to investigate further.

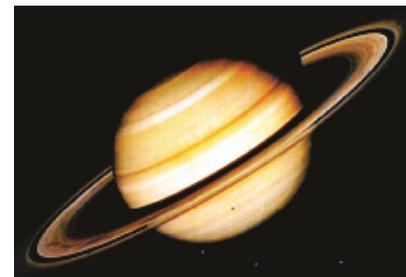
Other planetary spacecraft, such as *Ulysses*, *Cassini-Huygens*, and *New Horizons*, have flown by Jupiter on their way to other destinations. The NASA Juno mission is currently under way in orbit around Jupiter's poles. As part of NASA's *New Frontiers* missions, this polar orbiter will study Jupiter's atmosphere, magnetic field, inner structure, and polar magnetosphere. Upon completion of its mission in 2021, ground controllers plan to de-orbit Juno, whereupon it will burn up in Jupiter's atmosphere.

Saturn

About 887 million miles (or 9.5 AU) from the Sun, Saturn is the sixth planet in our solar system and second in the line of outer, gaseous planets. Its diameter is 74,898 miles (120,537 km) across, meaning that about $9\frac{1}{2}$ Earths could fit across it. As the second largest planet in our solar system, Saturn could hold nearly 765 Earths inside it. Saturn, however, is the only planet in our solar system that is less dense than water. This means Saturn could actually float in a body of water, if the body of water was large enough to hold Saturn. Objects weigh close to what they weigh here on Earth as the gravitational pull on Saturn is about 1.08 times that on Earth.

Like Jupiter, Saturn rotates at a very fast 10 hours. However, it takes over 29 years to revolve around the Sun. Also like Jupiter, the combination of fast rotation and gaseous and liquid atmosphere creates clouds, storms, and very strong winds. The winds of Saturn have been known to reach 1,100 miles per hour (1770 km).

When we think of Saturn, we think of its rings. The rings are easily the most recognizable features of Saturn. Through a telescope, the rings are spectacular. They are made of ice chunks, dust, and rocks ranging from tiny particles to large boulders, or the size of grains of sugar to houses. The main rings are made up of hundreds of narrow ringlets. The entire ring system is about one mile thick and extends about 250,000 miles (402,336 km) from the planet. There are seven distinct rings, each designated by a letter ranging from A to G, around Saturn. The first five were discovered by *Galileo* in 1610, and the final two lettered rings were discovered by the



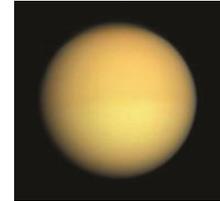
Saturn

Pioneer spacecraft. There are also several other faint unnamed rings made up of very fine icy particles.

The planet itself has an icy rock core surrounded by metallic hydrogen with an outer layer of hydrogen and helium. The hydrogen and helium are mainly liquid and turn to gas as they get to the outer surface.

At the top layer of the atmosphere, the temperature ranges from -280°F (-173°C) to -170°F (-113°C). About 200 miles lower, the temperature is as high as 134°F (57°C). Like Jupiter, Saturn gets much hotter at its core: over $15,000^{\circ}\text{F}$. *Pioneer* and *Voyager* passed by Saturn in the late 1970s and early 1980s and produced much information about the planet. For instance, it was found that Saturn's outermost region contained its atmosphere and cloud layers. Saturn's three main cloud layers are thought to consist of (from top down) ammonia ice, ammonia hydro sulfide ice, and water ice.

To date, 82 moons have been identified orbiting Saturn, but only 53 (as of 2020) of them have been named. Titan, one of Saturn's moons, is currently the only moon known to have clouds and a thick atmosphere. Its atmosphere is made up of about 95% hydrogen and 3-5% methane, along with some small amounts of other compounds. It has an orange, hazy sky, and its temperature approaches -289°F (-178°C) at increasing depths. Its seasons, although all extremely cold, last about 7 years each.

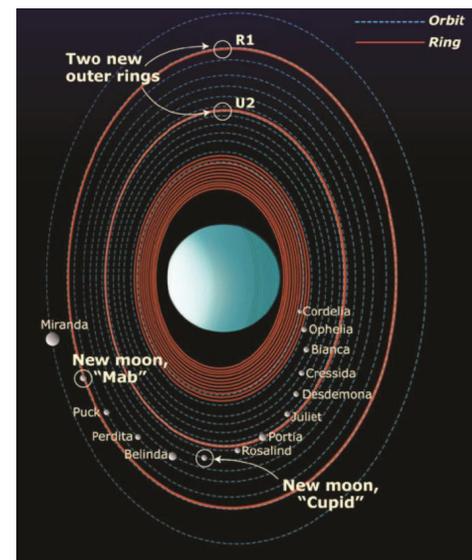


Titan, one of Saturn's moons

We have learned, and continue to learn, a great deal about Saturn and its moons due to the *Cassini-Huygens* mission, a joint mission between the European Space Agency, the Italian Space Agency, and NASA. Launched in 1997, the spacecraft arrived at Saturn in 2004. The *Cassini* spacecraft did gravity-assist flybys of Venus and Earth, and performed a flyby of Jupiter as it traveled to Saturn at a speed of 70,700 mph. (If you drove 60 mph using the same path that *Cassini* took to get to Jupiter, about 2 billion miles, it would take you 5,600 years.) Scheduled to end in 2008, the project received two extensions, which kept it in operation until September 2017, at which time NASA commanded a de-orbit burn which resulted in its destruction.

In January 2005, the *Huygens* probe, which was fitted to the *Cassini* orbiter, detached and landed on Titan. This is the first time a probe landed on a celestial body in the outer solar system. NASA reported that "Huygens captured the most attention for providing the first view from inside Titan's atmosphere and on its surface. The pictures of drainage channels and pebble-sized ice blocks surprised scientists with the extent of the moon's similarity to Earth. They showed evidence of erosion from methane and ethane rain. Combining these images with detections of methane and other gases emanating from the surface, scientists came to believe Titan had a hydrologic cycle (the continuous process of evaporation, cloud formation, condensation, and rain) similar to Earth's, though Titan's cycle depends on methane and ethane rather than water. Titan is the only other body in the solar system, other than Earth, believed to have an active hydrologic cycle, and that is known to have stable liquid on its surface."

It is important to note, this liquid is not water; it is mostly methane, which, like water, can take the form of a gas, liquid, and solid. NASA and JPL's *Cassini* Web site reports that "methane, instead of water, forms Titan's clouds, rivers, and lakes. *Cassini* RADAR Team member Dr. Ralph Lorenz has determined that with Titan's low gravity and dense atmosphere, methane raindrops could grow twice as large as Earth's raindrops, and they would fall more slowly, drifting down like snowflakes. Scientists think it rains perhaps only every few decades, but when it



Saturn

rains on Titan, it really pours.”

In a 2009 Space.com article, it was stated that “Saturn's moon Titan may be worlds away from Earth, but the two bodies have some characteristics in common: wind, rain, volcanoes, tectonics, and other Earth-like processes all sculpt features on Titan, but act in an environment more frigid than Antarctica. ‘It is really surprising how closely Titan's surface resembles Earth’s,’ said Rosaly Lopes, a planetary geologist at NASA’s JPL in Pasadena, Calif. ‘In fact, Titan looks more like the Earth than any other body in the solar system, despite the huge differences in temperature and other environmental conditions.’”

In Feb. 2010, NASA reported, “Cassini’s travel scrap book includes more than 210,000 images: information gathered during more than 125 revolutions around Saturn, 67 flybys of Titan, and eight close flybys of Enceladus. *Cassini* has revealed unexpected details in the planet’s signature rings, and observations of Titan have given scientists a glimpse of what Earth might have been like before life evolved.” NASA does have plans for future Saturn exploration missions; however, these are in the very early stages of development.

Uranus

Uranus is about 1.7 billion miles (19.18 AU) from the Sun, about twice as far as Saturn. Uranus is the first planet to be located with the help of a telescope, and it was discovered by astronomer William Herschel in 1781. It has only been since the mid 1980s that we have been able to increase our knowledge of Uranus. This was due to the US unmanned *Voyager 2* mission which took the spacecraft on a flyby of Uranus in 1986.

Uranus is the third largest planet in our solar system, and, like Jupiter and Saturn, it is a gas giant. Uranus has a rocky core surrounded by water, ammonia, and methane, in both ice and liquid form. The outer layer consists of hydrogen and helium gases. There is also methane in the upper atmosphere, and this gives Uranus a bluish green color.

It takes Uranus 84 years to revolve around the Sun, and it rotates in about 18 hours. The average temperature is about -350°F (-212°C). Its environment is super cold because hardly any solar radiation reaches it. One unique thing about Uranus is that it spins on its side. Scientists think that possibly some large body may have bumped into it, resulting in its current position. Because it is tilted 60° on its axis, daylight lasts 42 years followed by 42 years of night. This means that even though the planet is rotating on its axis every 18 hours, it continues to face the sunlight for 42 years because of the 60° tilt.

Like Saturn and Jupiter, the planet has rings around it. It actually has 11 very narrow, black rings. They are made of dust and chunks of rock. They are very dark and hard to see. Additionally, Uranus has 27 known moons. These moons are made of rocks and ice, and many of the moons, such as Juliet, are named after characters in literature written by the famous English poet and playwright William Shakespeare. In 2005, the *Hubble Space Telescope* provided new images and information about its rings and moons. On its 1986 visit, the *Voyager 2* spacecraft passed within 51,000 miles of the planet and discovered eleven moons in addition to making many other scientific observations.

Neptune

Neptune is the outermost of the gas planets and is the fourth largest planet in our solar system. It was discovered in 1846 when scientists determined that something was affecting the orbit of Uranus. Neptune is about 3 billion miles (30 AU) from the Sun, and it takes 165 Earth years to complete an orbit. So, one year on Neptune equals a little over 60,000 Earth days. A Neptune day lasts about 19 hours. During the day, daylight on Neptune is about 1/900 the brightness as it is on Earth because it is so far away from the Sun, making high noon on Neptune seem like a dim twilight.



Uranus

Neptune and Uranus are so similar they are sometimes called twins. Although a bit smaller than Uranus, both Neptune and Uranus could each hold about 60 Earths inside them. Neptune's gravitational pull and average temperature are also very similar to that of Uranus. Neptune has a rocky core surrounded by water, ammonia, and methane. The atmosphere consists of hydrogen, helium, and methane. Methane absorbs red light, not blue; therefore, Uranus and Neptune appear to have a blue tint, with Neptune's color being a bit more of a vivid, brighter blue. Regarding methane, pictures of Neptune show bright clouds of methane ice crystals are present. Like Uranus, we learned a great deal about Neptune thanks to *Voyager 2*.



Neptune

Neptune is a windy planet, the windiest in our solar system. It has recorded winds of 1,500 miles per hour, which is close to the top speed of an F/A-18 Hornet, which is Mach 2. Storms similar to those on Jupiter were found during the *Voyager 2* fly-by. Several large dark spots, or storms, were also found. The largest of the storms, the Great Dark Spot, was about the size of the Earth. The original Great Dark Spot was gone when Hubble took photographs of Neptune in 1995.

Pictures indicate that Neptune has a very thin ring system, which is hard to detect. The ring system around Neptune is narrow and very faint. The rings are composed of dust particles that scientists believe were made by tiny meteoroids smashing into Neptune's moons.

Neptune has 13 known moons, the largest of which is Triton. Triton is approximately three fourths the size of Earth's moon and circles Neptune in 5.875 days. The strange thing about its movement is that it rotates backwards compared to the other moons of Neptune. *Voyager 2* showed active geyser-like eruptions on Triton spewing invisible nitrogen gas and dark dust particles several kilometers into space.

Manned missions to the giant outer planets will never involve a landing. Future astronauts will most likely walk on the surfaces of their many moons. According to information released by NASA, trying to land on Neptune, or any of the other large planets, is a really bad idea. Like the other three giant planets, it is a big ball of gas that gradually becomes a hot liquid well below the clouds. As mentioned previously, there's nothing on which to land. Any spacecraft dropping below the cloud tops would be torn by intense winds, frozen by super cold temperatures, and eventually smashed by the sheer weight of the atmosphere above, which, by the way, is poisonous to humans.

Pluto

A planet or not a planet? Astronomer Clyde Tombaugh discovered Pluto in February 1930. Pluto remained our official ninth planet until 2006 when the International Astronomical Union (IAU) changed the definition of "planet." Pluto then no longer met all of the requirements to stay in the same league as the other eight planets. Pluto was removed from "classical planet" status because it did not meet one of the new requirements needed to be a planet. That requirement is that the object must dominate its orbital path. Pluto's orbit actually crosses Neptune's, and Pluto orbits in an area of icy rock bodies called the Kuiper (pronounced KY-per) Belt. The Kuiper Belt is located beyond Neptune's orbit and reaches a little past the outermost point of Pluto's orbit to the edge of our solar system.



Pluto Discovery Image—This represents the best image of Pluto possible in the early 20th century (the tiny dot that the arrow points to, is Pluto)

Pluto was reclassified as a dwarf planet. A dwarf planet is “a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass to assume a hydrostatic equilibrium (nearly round) shape, (c) has not cleared the neighborhood around its orbit, and (d) is not a satellite.” About two years after being reclassified to dwarf planet, the IAU created a special class of dwarf planets known as plutoids, which includes and is named after Pluto. Plutoids are dwarf planets that are located beyond Neptune. All plutoids are dwarf planets, but not all dwarf planets are plutoids. For example, between Mars and Jupiter, there is a dwarf planet called Ceres. It is not a plutoid because it is not located beyond Neptune, as is the case with Pluto. Interestingly, Ceres was originally considered the eighth planet (having preceded Neptune’s discovery by some 45 years). When its true size was determined in the 1850s (only 583 miles in diameter), it was then reclassified as an asteroid, and to this day it holds the distinction of being the largest object in the “asteroid belt.” It is the only object in the solar system that carries the dual classification of dwarf planet and asteroid.

An interesting characteristic about Pluto is its strange orbit. It is more elongated than any of the other traditional planets, and sometimes is actually closer to the Sun than Neptune. For about 20 of Pluto’s 248 year trip around the Sun, its orbit cuts inside Neptune’s, making it closer to the Sun than Neptune. The last time Pluto’s orbit was inside Neptune’s was from 1979-1999. The next time that will happen will be in the 2227-2247 time frame.

When classified as a planet, Pluto was the smallest of all of the planets in our solar system. Pluto’s diameter is about 2/3 that of Earth’s moon, and Pluto is almost 4 billion miles (39.53 AU) from the Sun. Pluto rotates once on its axis every 6.387 Earth days.

Pluto is a yellowish object that is dark and frozen. The Sun would appear as a bright shining star in the sky, and the average temperature on Pluto has been measured to range between a high of -361°F to a low of -400°F .

Pluto is believed to have a rocky core with a water and ice layer above the core. The surface is made up of just over 98 percent nitrogen ice, with traces of methane and carbon monoxide.

Pluto has five known moons (in order of discovery): Charon (1978), Nix & Hydra (both 2005), Kerberos (2011), and Styx (2012). Charon was discovered—quite by accident—by astronomer James Christy while studying photographic plates in order to make refinements in Pluto’s orbital path. Christy observed deformities (which Christy characterized as a blob) in some of the Pluto images. The blob would change position at regular intervals. Christy correctly deduced that the moving blob was actually a moon. Charon is almost exactly half the diameter of Pluto and orbits at a distance of only 12,000 miles. The two objects are in mutual tidal lock, which means that Pluto keeps the same hemisphere facing Charon and vice versa.

In 2006, NASA launched a dedicated Pluto exploration mission called New Horizons. The space probe arrived at Pluto in July 2015 and returned a wealth of scientific data. It photographed a 600 mile wide glacier of nitrogen as well as mountains of water ice. Other data suggests that Pluto may have a liquid ocean underneath the solid surface. The most spectacular aspect of the visit were the hundreds of high definition images of Pluto and its five moons.

Summary

We have eight planets and a number of dwarf planets that make up our solar system. It includes so many objects: our Sun, planets, and moons. It also includes other celestial bodies such as asteroids, comets, and meteoroids. Our solar system is just a small part of our galaxy which is just a small piece of the great big universe. (See associated Activity Thirteen and Fourteen at the end of the chapter.)



Pluto and its largest moon, Charon, taken from the New Horizons spacecraft
Image courtesy NASA

ACTIVITY SECTION 4

Activity Thirteen - How Old Are You

Purpose: Use math skills to determine your age on other planets

Materials: chart provided, pencil, paper, and calculator

Procedures:

1. Calculate your age in Earth days. One year = 365 days.
2. Calculate your age in Earth days for the other planets in the solar system.
3. Then convert the Earth days into Earth years.

Example: 14 years old on Earth = $365 \times 14 = 5110$ Earth days.

Summary: No two planets in our solar system take the same amount of time to make one revolution around the Sun; therefore, a person's age on Earth would not be the same if he/she lived on another planet. For example, a person who was 12 Earth years old (4,380 Earth days) would be almost 50 years old on Mercury and just a little over 1 year old on Jupiter.

Earth	one year = 365 days
Mercury	one year = 88 Earth days
Venus	one year = 243 Earth days
Mars	one year = 687 Earth days
Jupiter	one year = 11.5 Earth years
Saturn	one year = 29.5 Earth years
Uranus	one year = 84 Earth years
Neptune	one year = 165 Earth years

Activity Fourteen - Creating a Clay Model of the Solar System

Purpose: Use math skills and clay to create a visual scale model of the Solar System.

Materials: 8 index cards, marker, 3 pounds of clay (or dough)

Procedures: Using a marker, label the 8 index cards with the names of the 8 planets. Then using 3 pounds of modeling clay, follow the 7 steps listed below.

Step 1. Divide the clay into 10 equal parts (tenths).

- Use 6 tenths to make Jupiter.
- Use 3 tenths to make Saturn.
- Use the remaining clay (1 tenth) in step 2.

Step 2. Divide the remaining clay into tenths.

- Add 5 tenths to Saturn.
- Use 2 tenths to make Neptune.
- Use 2 tenths to make Uranus.
- Use the remaining clay (1 tenth) in step 3.

Step 3. Divide the remaining clay into fourths.

- Add 3 fourths to Saturn.
- Use the remaining clay (1 fourth) in step 4.

Step 4. Divide the remaining clay into tenths.

- Use 2 tenths to make Earth.
- Use 2 tenths to make Venus.
- Add 4 tenths to Uranus.
- Combine the remaining clay (2 tenths) and use in step 5.

Step 5. Divide the remaining clay into tenths.

- Use 1 tenth to make Mars.
- Add 4 tenths to Neptune.
- Add 4 tenths to Uranus.
- Use the remaining clay (1 tenth) in step 6.

Step 6. Divide the remaining clay into tenths.

- Use 7 tenths to make Mercury.
- Add 2 tenths to Uranus.
- Use the remaining clay (1 tenth) in step 7.

Step 7. Divide the remaining clay into tenths.

- Add 9 tenths to Uranus.

Summary: No two planets are exactly the same size. This activity makes it easy to compare and contrast the size of the planets in our solar system to one another.

Check your work!

When you finish making your 8 planets, you should double-check your work!

Use a metric ruler to measure the diameter of your clay planets in millimeters (mm).

The diameter of your planets should be close to the “scale diameter” measurements in the chart.

Object	Actual Diameter (km)	Scale Diameter (mm)	Distance from Sun (AU)
Sun	1,391,900	993	—
Mercury	4,878	3.5	0.4
Venus	12,104	8.6	0.7
Earth	12,755	9.1	1.0
Mars	6790	4.8	1.5
Asteroid Belt	1 to 1,000	0.0007 to 0.7	2.0 to 4.0
Jupiter	142,796	102	5.2
Saturn	120,660	86	9.5
Uranus	51,118	36	19.2
Neptune	49,528	35	30.0

