The Solar System

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CHAPTER 1

The Solar System

CHAPTER OUTLINE

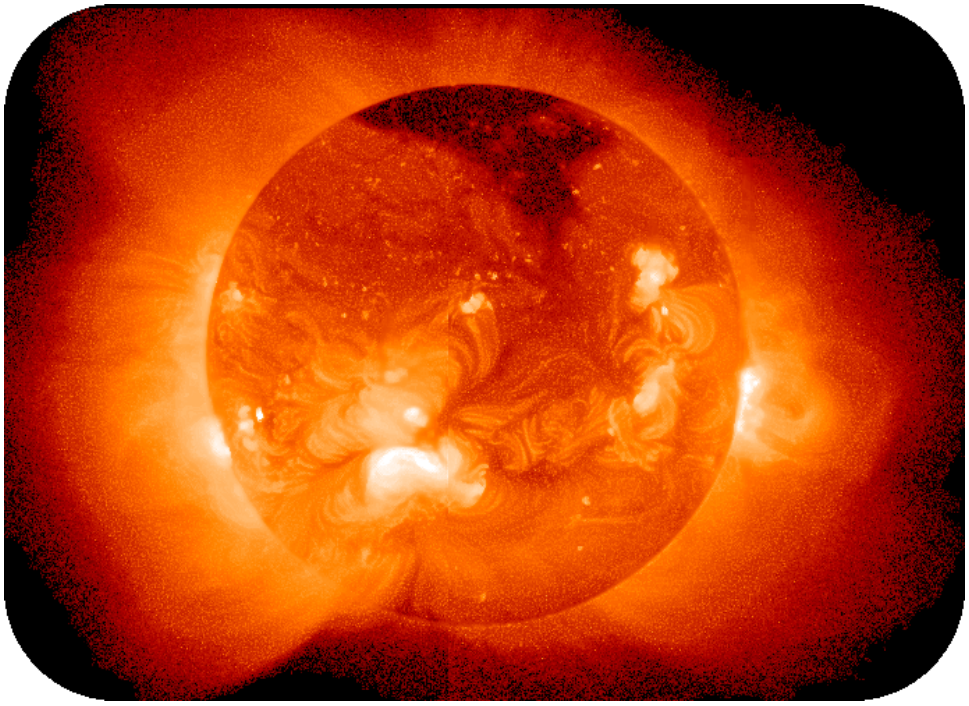
Introduction

There's no place like home.

Our solar system is enormous, with dwarf planets in orbit around the Sun tens of thousands of times further away than Earth. It took astronauts three days to get to our nearest neighbor, the Moon, and would take about six months each way for people to get to Mars and back. This image was the first ever taken that had Moon and Earth in the same frame, and it wasn't until 1977, when Voyager I was 7,250,000 miles away. But compared to the Milky Way Galaxy, the solar system is just a cozy little spot in a big world. There are lots of planets and lots of stars and lots of galaxies, but our planet is different. It is one (maybe one of many) that has intelligent life.

1.1 Interior of the Sun

- Define plasma and nuclear fusion.
- Describe the internal and atmospheric layers of the Sun.



Can you visit the Sun?

Of course not. In Greek mythology, Icarus, got too close and his wax wings melted. Today, we have other ways to see the Sun. Spacecraft take photos and some have instruments that allow us to study the interior. Unlike Icarus, we don't need to worry about our wax wings melting.

Layers of the Sun

The Sun is a sphere, composed almost entirely of the elements hydrogen and helium. The Sun is not solid, nor is it a typical gas. Most atoms in the Sun exist as **plasma**, a fourth state of matter made up of superheated gas with a positive electrical charge.

Internal Structure

Because the Sun is not solid, it does not have a defined outer boundary. It does, however, have a definite internal structure with identifiable layers (**Figure** 1.1). From inward to outward they are:

- The Sun's central core is plasma with a temperature of around 27 million°C. At such high temperatures hydrogen combines to form helium by **nuclear fusion**, a process that releases vast amounts of energy. This energy moves outward, towards the outer layers of the Sun.

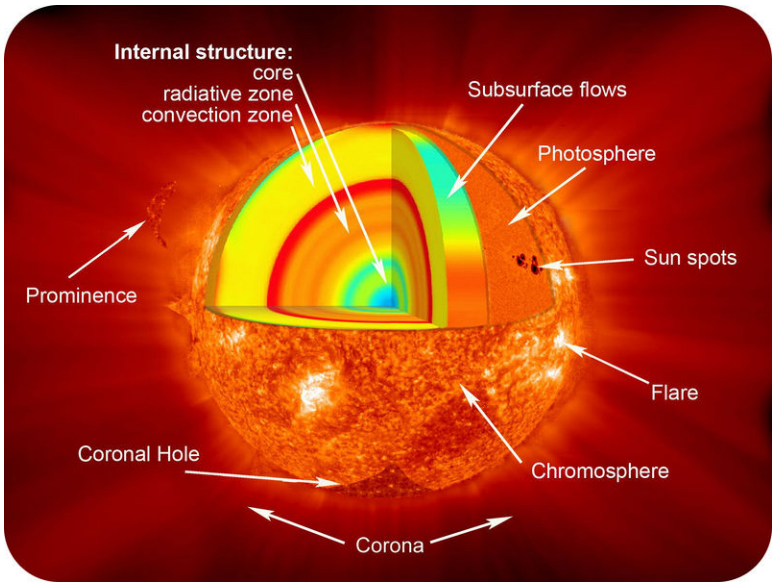
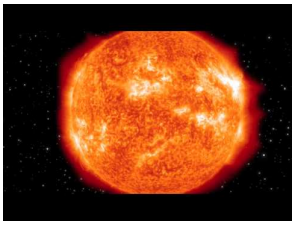


FIGURE 1.1
The layers of the Sun.

- The **radiative zone**, just outside the core, has a temperature of about 7 million°C. The energy released in the core travels extremely slowly through the radiative zone. A particle of light, called a **photon**, travels only a few millimeters before it hits another particle. The photon is absorbed and then released again. A photon may take as long as 50 million years to travel all the way through the radiative zone.
- In the **convection zone**, hot material from near the radiative zone rises, cools at the Sun's surface, and then plunges back downward to the radiative zone. Convective movement helps to create solar flares and sunspots.

The first video describes the basics of our Sun, including how it is powered by nuclear reactions: http://www.youtube.com/watch?v=JHf3dG0Bx7I (8:34).



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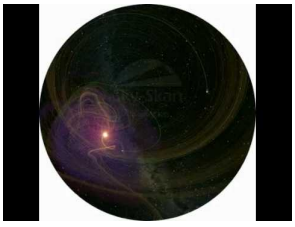
The second video discusses what powers the Sun and what is its influence on Earth and the rest of the solar system: http://www.youtube.com/watch?v=S6VRKKh6gyA (8:25).



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The Outer Layers

The next three layers make up the Sun's atmosphere. Since there are no solid layers to any part of the Sun, these boundaries are fuzzy and indistinct.

- The **photosphere** is the visible surface of the Sun, the region that emits sunlight. The photosphere is relatively cool —only about 6,700°C. The photosphere has several different colors, including oranges, yellow and reds. This characteristic gives it a grainy appearance.
- The **chromosphere** is a thin zone, about 2,000 km thick, that glows red as it is heated by energy from the photosphere (**Figure** 1.2). Temperatures in the chromosphere range from about 4,000°C to about 10,000°C. Jets of gas fire up through the chromosphere at speeds up to 72,000 km per hour, reaching heights as high as 10,000 km.

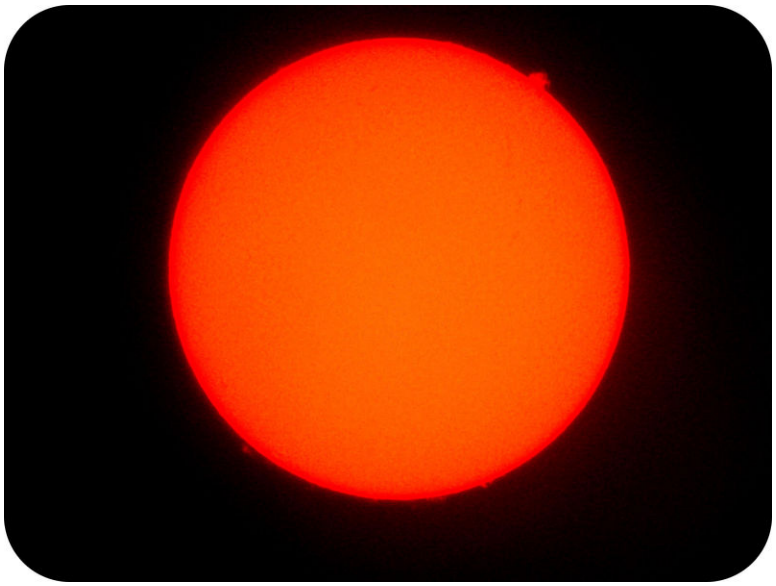


FIGURE 1.2

The chromosphere as seen through a filter.

- The **corona** is the outermost plasma layer. It is the Sun's halo or "crown." The corona's temperature of 2 to 5 million^{o}C is much hotter than the photosphere (**Figure** 1.3).

The movie "Seeing a Star in a New Light" can be seen here: http://sdo.gsfc.nasa.gov/gallery/youtube.php .

Summary

- The Sun is made mostly of plasma, a fourth state of matter made up of superheated gas with a positive electrical charge.
- At the Sun's center is plasma, where nuclear fusion takes place. The radiative zone is outside the core. The convection zone, where convection takes place, is located outward from that.
- The photosphere is the visible surface of the Sun, where sunlight is emitted from. The reddish chromosphere is heated by the photosphere and the outer corona is the Sun's crown.

Practice

Use this resource to answer the questions that follow.

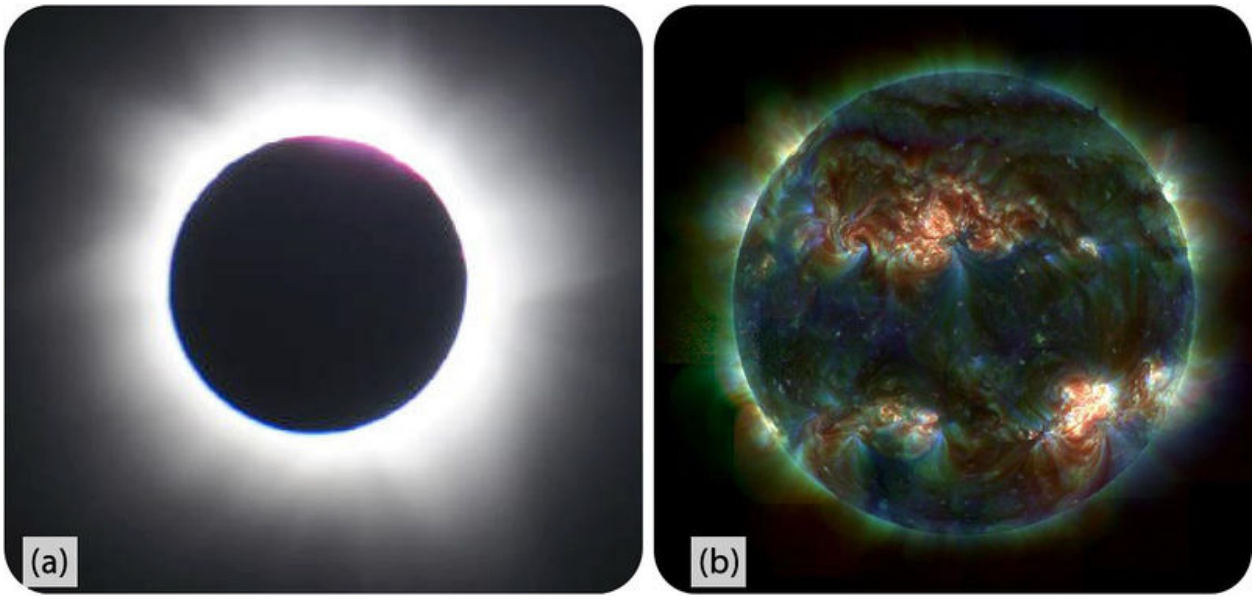


FIGURE 1.3

(a) During a solar eclipse, the Sun's corona is visible extending millions of kilometers into space. (b) The corona and coronal loops in the lower solar atmosphere taken by the TRACE space telescope.

https://www.youtube.com/watch?v=kxUqDvQ0QyI

1. What is the Sun? What are the stars?
2. What is happening in the Sun's core?
3. What keeps the Sun from exploding or collapsing?
4. How far is Earth from the Sun; what is that equal to in astronomical units?
5. What are the layers of the Sun from inside to outside?
6. What is the photosphere?
7. How does the temperature of the Sun change from the center to the surface? Whee is the density highest?
8. Which direction does heat flow?
9. How does energy move near the center of the Sun? What zone is that?
10. How is energy moving in the convection zone?

https://www.youtube.com/watch?v=hwjJ23Ex8KY

1. What is the temperature structure of the atmosphere from inner to outer? why does this happen?
2. What is the chromosphere? What interesting features does it contain?
3. What is the corona?

Practice Answers

- The Sun (1/2)

1. A star; suns that are far away.

2. There is thermonuclear fusion converting hydrogen to helium and releasing energy.
3. The outward force of nuclear explosions and the inward force of gravity.
4. 150 million km, 93 million miles; by definition equals 1 astronomical unit (AU
5. core, radiative zone, convective zone, photosphere, corona
6. The lower yellow surface that we see.
7. From 15 million to 6000 kelvin; it is densest at the center.
8. From hot to cooler.
9. It moves by photon radiation through the radiative zone.
10. It is convecting!

- The Sun (2/2)

1. It is a little cooler above the surface but then gets much hotter. It might have to do with the magnetic field.
2. The chromosphere is the lower part of the atmosphere; it contains millions of thin columns called spicules, each a jet of hot gas.
3. The corona is the outer part of the atmosphere.

Review

1. The Sun is very dense, so is there solid matter at the center? Why or why not?
2. What are the inner layers of the Sun and what are their characteristics?
3. What are the outer layers of the Sun and what are their characteristics?
4. What powers the Sun?

Review Answers

1. The center is very dense plasma; it is not solid. It is formed as hydrogen fuses into helium with a lot of energy released.
2. The core is where nuclear fusion takes place; it is exceedingly hot. The radiative zone is where energy travels very slowly outside the core. The convection zone is where convection moves heat to the surface; convection helps create surface features.
3. The photosphere is the visible surface; it is relatively cool and appears yellow. The chromosphere is very thin and glows red. It is hotter than the photosphere. The corona is the outermost plasma layer; it is the halo we see during a solar eclipse.
4. The fusion of hydrogen into helium.

1.2 Surface Features of the Sun

- Describe the major features of the Sun's surface, such as flares and sunspots.

Can solar activity get you lost?

Large explosions on the Sun's surface can disrupt the high-precision GPS systems that are used by airlines. Radars and long-range radio communications may also be temporarily lost.

Surface Features

The Sun's surface features are quite visible, but only with special equipment. For example, sunspots are only visible with special light-filtering lenses.

Sunspots

The most noticeable surface features of the Sun are cooler, darker areas known as **sunspots** (**Figure** 1.4). Sunspots are located where loops of the Sun's magnetic field break through the surface and disrupt the smooth transfer of heat from lower layers of the Sun, making them cooler, darker, and marked by intense magnetic activity. Sunspots usually occur in pairs. When a loop of the Sun's magnetic field breaks through the surface, a sunspot is created where the loop comes out and where it goes back in again. Sunspots usually occur in 11-year cycles, increasing from a minimum number to a maximum number and then gradually decreasing to a minimum number again.

Solar Flares

There are other types of interruptions of the Sun's magnetic energy. If a loop of the Sun's magnetic field snaps and breaks, it creates **solar flares**, which are violent explosions that release huge amounts of energy (**Figure** 1.5).

A movie of the flare is seen here: http://www.youtube.com/watch?v=MDacxUQWeRw .

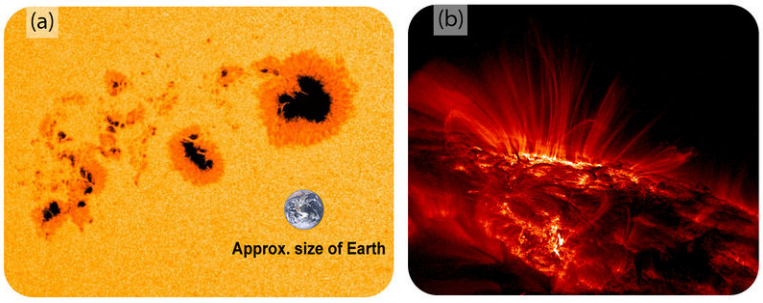


FIGURE 1.4
(a) Sunspots. (b) A close-up of a sunspot taken in ultraviolet light.

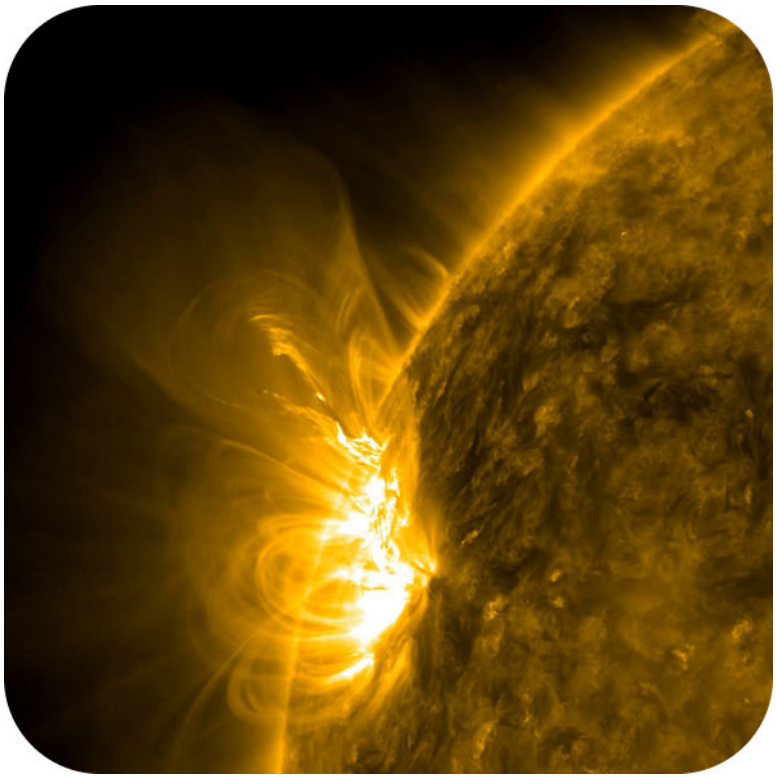


FIGURE 1.5
Magnetic activity leads up to a small solar flare.

A strong solar flare can turn into a coronal mass ejection. A solar flare or coronal mass ejection releases streams of highly energetic particles that make up the solar wind. The solar wind can be dangerous to spacecraft and astronauts because it sends out large amounts of radiation that can harm the human body. Solar flares have knocked out entire power grids and disturbed radio, satellite, and cell phone communications.

Solar Prominences

Another highly visible feature on the Sun are **solar prominences**. If plasma flows along a loop of the Sun's magnetic field from sunspot to sunspot, it forms a glowing arch that reaches thousands of kilometers into the Sun's atmosphere. Prominences can last lengths of time ranging from a day to several months. Prominences are also visible during a total solar eclipse.

Solar prominences are displayed in this video from NASA's Solar Dynamics Observatory (SDO): http://www.youtube.com/watch?v=QrmUUcr4HXg .

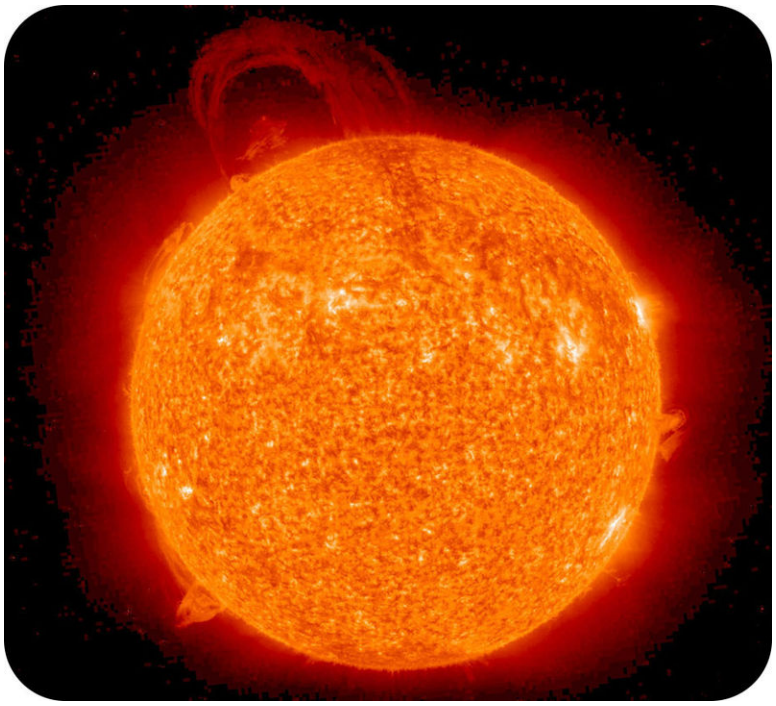


FIGURE 1.6
A solar prominence.

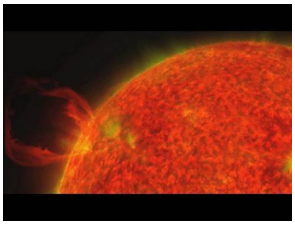
Most of the imagery comes from SDO's AIA instrument; different colors represent different temperatures, a common technique for observing solar features. SDO sees the entire disk of the Sun in extremely high spatial and temporal resolution, allowing scientists to zoom in on notable events such as flares, waves, and sunspots.

Solar Dynamics Observatory

The video above was taken from the SDO, the most advanced spacecraft ever designed to study the Sun. During its five-year mission, SDO will examine the Sun's magnetic field and also provide a better understanding of the role the Sun plays in Earth's atmospheric chemistry and climate. Since just after its launch on February 11, 2010, SDO is providing images with clarity 10 times better than high-definition television and will return more comprehensive science data faster than any other solar-observing spacecraft.

The Solar Dynamics Observatory is a NASA spacecraft launched in early 2010 is obtaining IMAX-like images of the Sun every second of the day, generating more data than any NASA mission in history. The data will allow researchers to learn about solar storms and other phenomena that can cause blackouts and harm astronauts.

Find out more at http://www.kqed.org/quest/television/journey-into-the-sun .



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Summary

- Sunspots occur in pairs because each is one side of a loop of the Sun's magnetic field that reaches the Sun's surface. These spots are cooler and darker than the rest of the Sun's surface and they are marked by intense magnetic activity.
- Solar prominences are the plasma loops that connect two sunspots.
- Solar flares and coronal mass ejections are eruptions of highly energetic particles that can erupt from the Sun's surface and cause problems with power grids and communications on Earth.

Making Connections

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Practice

Use these resources to answer the questions that follow.

http://www.youtube.com/watch?v=uHdJ1lAHejw

MEDIA

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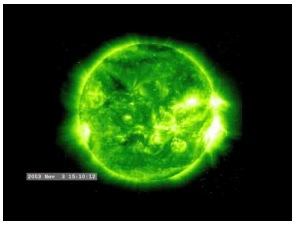
URL: http://gamma.ck12.org/flx/render/embeddedobject/1471

1. What are sunspots?
2. What about the Sun interests scientists?
3. How is the sunspot related to convection in the sun?
4. How does the temperature of a sunspot compare to the rest of the Sun's surface?

http://www.youtube.com/watch?v=mIsJO9UWSBg



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1. How can solar flares affect the Earth?
2. What is the solar cycle?

3. What is a solar flare?
4. What causes solar flares?
5. When was the largest solar flare recorded? What was its rating?
6. Who monitors the Sun? Why is this important?

Practice Answers

- Sunspots

1. Sunspots are areas of strong magnetic field; it is the effect of the magnetic field on the photosphere.
2. How the magnetic field is generated, how it evolves, and the types of physical processes that occur within it.
3. The magnetic field is reducing the effectiveness of convection; the sunspot is not as hot as the surroundings because it has less heat traveling to the surface below it.
4. The sunspot is 4000-degrees instead of 5000-degrees for the surrounding material.

- Solar Flares

1. They can damage satellites and ground based technologies and power grids.
2. Every 11 years they become bigger and more common.
3. A solar flare is an explosion on the surface of the sun. They release tremendous energy.
4. When the powerful magnetic fields around the sun interconnect.
5. In 2003 during the last solar maximum, it overloaded the sensors: It was X17 and was estimated at X45.
6. NASA and NOAA. X-class flares can harm technological infrastructure and astronauts in space.

Review

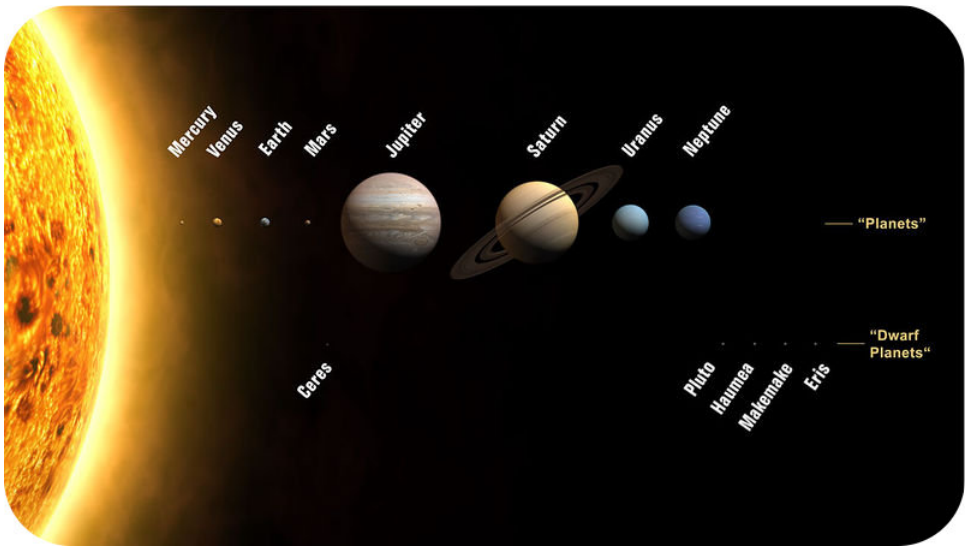
1. What are sunspots and what is a sunspot cycle?
2. How are solar prominences related to sunspots?
3. What is being learned from the Solar Dynamics Observatory?

Review Answers

1. Sunspots are cooler, darker areas of the Sun where the magnetic field breaks through the surface. The cycle is 11 years from minimum through maximum and back to minimum.
2. Plasma flows along a loop of the magnetic field between sunspots and forms a glowing red arch that reaches high into the atmosphere.
3. It is examining the Sun's magnetic field to understand the effects the Sun can have on Earth.

1.3 Planets of the Solar System

- Define astronomical unit.
- Identify the solar system's eight planets and their characteristics, including size and length of orbit relative to Earth.



Who is in the Sun's family?

The family includes the Sun, its eight planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune), and the five known dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris). In the image above, relative sizes of the Sun, planets, and dwarf planets and their positions relative to each other are correct, but the relative distances are not.

Eight Planets

Since the time of Copernicus, Kepler, and Galileo, we have learned a lot more about our solar system. Astronomers have discovered two more planets (Uranus and Neptune), five dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris), more than 150 moons, and many, many asteroids and other small objects.

Although the Sun is just an average star compared to other stars, it is by far the largest object in the solar system. The Sun is more than 500 times the mass of everything else in the solar system combined! **Table** 1.1 gives data on the sizes of the Sun and planets relative to Earth.

TABLE 1.1: Sizes of Solar System Objects Relative to Earth

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Sun	333,000 Earth's mass	109.2 Earth's diameter
Mercury	0.06 Earth's mass	0.39 Earth's diameter
Venus	0.82 Earth's mass	0.95 Earth's diameter
Earth	1.00 Earth's mass	1.00 Earth's diameter

TABLE 1.1: (continued)

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Mars	0.11 Earth's mass	0.53 Earth's diameter
Jupiter	317.8 Earth's mass	11.21 Earth's diameter
Saturn	95.2 Earth's mass	9.41 Earth's diameter
Uranus	14.6 Earth's mass	3.98 Earth's diameter
Neptune	17.2 Earth's mass	3.81 Earth's diameter

Orbits and Rotations

Distances in the solar system are often measured in **astronomical units** (AU). One astronomical unit is defined as the distance from Earth to the Sun. 1 AU equals about 150 million km, or 93 million miles. **Table** 1.2 shows the distances to the planets (the average radius of orbits) in AU. The table also shows how long it takes each planet to spin on its axis (the length of a day) and how long it takes each planet to complete an orbit (the length of a year); in particular, notice how slowly Venus rotates relative to Earth.

TABLE 1.2: Distances to the Planets and Properties of Orbits Relative to Earth's Orbit

Planet	Average Distance from Sun (AU)	Length of Day (In Earth Days)	Length of Year (In Earth Years)
Mercury	0.39 AU	56.84 days	0.24 years
Venus	0.72	243.02	0.62
Earth	1.00	1.00	1.00
Mars	1.52	1.03	1.88
Jupiter	5.20	0.41	11.86
Saturn	9.54	0.43	29.46
Uranus	19.22	0.72	84.01
Neptune	30.06	0.67	164.8

Here is a website that illustrates both the sizes of the planets, and the distance between them: http://www.scalesolarsystem.66ghz.com/#sun .

Summary

- The planets of the solar system, with increasing distance from the Sun, are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. The five known dwarf planets are Ceres, Pluto, Makemake, Haumea, and Eris.
- Solar system distances are measured as multiples of the distance between Earth and Sun, which is defined as one astronomical unit (AU).
- All planets and dwarf planets orbit the Sun and rotate on their axes.

Making Connections

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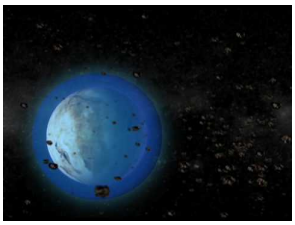
Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=z_RAEESmsrs



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1. How old is our solar system?
2. How did the planets form?
3. What are the two main regions of the solar system?
4. List the inner planets.
5. List the outer planets.
6. What are the requirements to be a planet?
7. Why was Pluto demoted?
8. What is the Kuiper Belt?
9. What is the scattered disk?
10. What is the heliosphere?

Practice Answers

1. 4.6 billion years
2. What was left over after the birth of the Sun collided with floating debris and gravity held them together.
3. Inner outer solar system.
4. Mercury, Venus, Earth and Mars
5. Jupiter, Saturn, Uranus and Neptune.
6. It must orbit the sun, it must have enough gravity to have spherical shape and it must have cleared its area of space of debris.
7. Similar, even larger, bodies are in the solar system.
8. The Kuiper Belt is a gigantic region filled with asteroids and comets.
9. A belt of strangely orbiting objects way beyond the Kuiper belt.
10. The heliosphere is an immense magnetic bubble that forms the outer edge of the solar system. The boundary of the solar system with interstellar space.

Review

1. Why does the number of dwarf planets recognized by astronomers in the solar system sometimes increase?

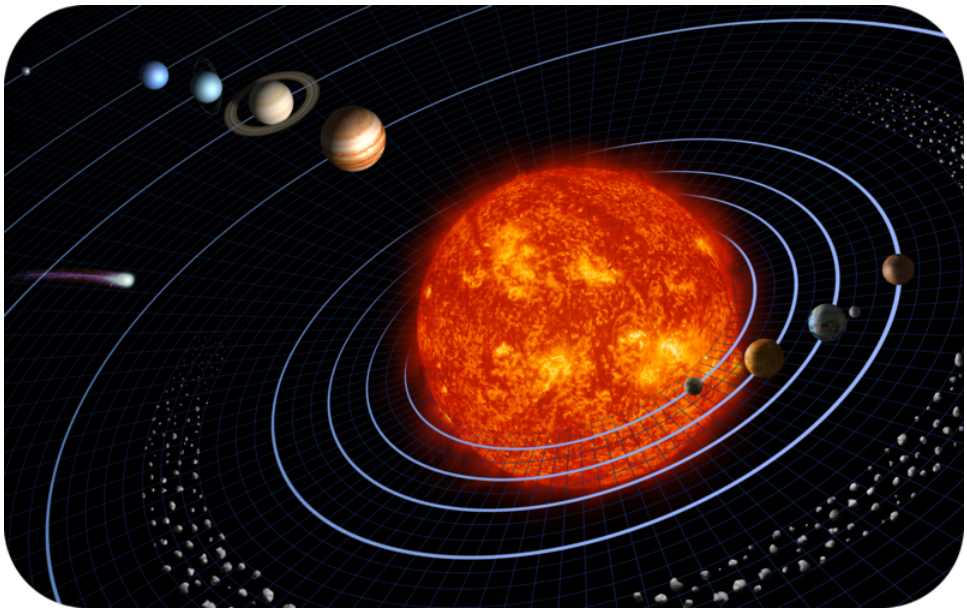
2. What is the order of planets and dwarf planets by distance from the Sun?
3. What is an astronomical unit? Why is this unit used to measure distances in the solar system?

Review Answers

1. More dwarf plants are discovered or more is learned about known bodies that makes them fit the definition of a dwarf planet.
2. Mercury, Venus, Earth, Mars, Ceres, Jupiter, Saturn Uranus, Neptune, Pluto, Haumea, Makemake, Eris
3. The distance from Earth to Sun is one astronomical unit. It is 150 million km or 93 million miles. It is an easy unit to use in the solar system and can be remembered.

1.4 Planet Orbits in the Solar System

- Describe the size and shape of planetary orbits.



"Accordingly, since nothing prevents the earth from moving...

...I suggest that we should now consider also whether several motions suit it, so that it can be regarded as one of the planets. For, it is not the center of all the revolutions." - Nicolaus Copernicus

The Size and Shape of Orbits

Figure 1.7 shows the relative sizes of the orbits of the planets, asteroid belt, and Kuiper belt. In general, the farther away from the Sun, the greater the distance from one planet's orbit to the next. The orbits of the planets are not circular but slightly elliptical, with the Sun located at one of the foci (see opening image).

While studying the solar system, Johannes Kepler discovered the relationship between the time it takes a planet to make one complete orbit around the Sun, its "orbital period," and the distance from the Sun to the planet. If the orbital period of a planet is known, then it is possible to determine the planet's distance from the Sun. This is how astronomers without modern telescopes could determine the distances to other planets within the solar system.

How old are you on Earth? How old would you be if you lived on Jupiter? How many days is it until your birthday on Earth? How many days until your birthday if you lived on Saturn?

Scaling the solar system creates a scale to measure all objects in solar system: http://www.youtube.com/watch?v=-6szEDHMxP4 (4:44).

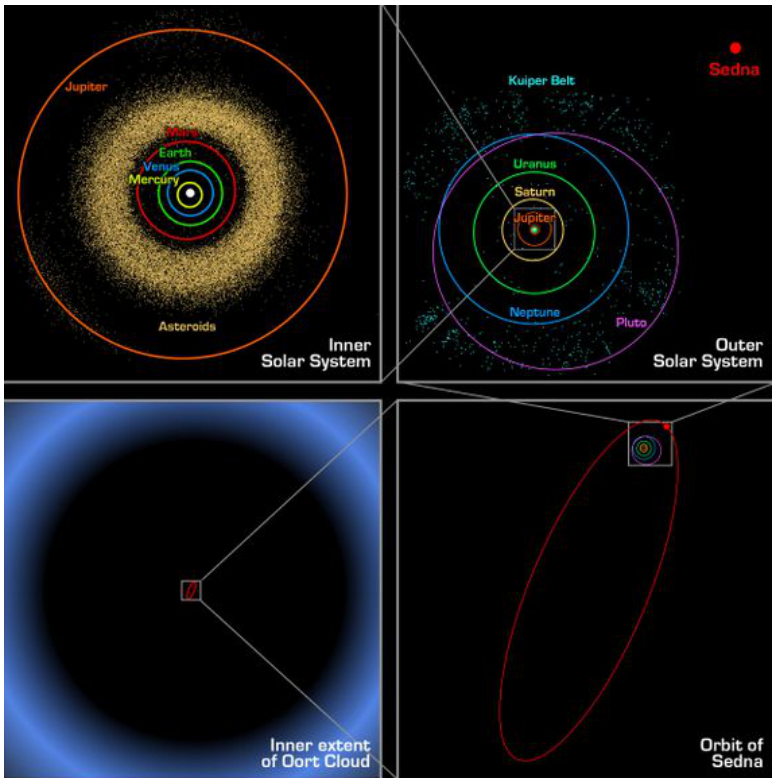


FIGURE 1.7

The relative sizes of the orbits of planets in the solar system. The inner solar system and asteroid belt is on the upper left. The upper right shows the outer planets and the Kuiper belt.

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Summary

- The eight planets orbit the Sun along slightly elliptical paths, with Sun located at one of the foci.
- Kepler discovered that by using a planet's orbital period, it is possible to determine its distance from the Sun.
- The farther the planets are from the Sun, the greater their distance from each other.

Practice

Use this resource to answer the questions that follow.

http://www.classzone.com/books/earth_science/terc/content/visualizations/es2701/es2701page01.cfm?chapter_no=visualization

1. What does this animation show?
2. Describe what you see in this animation.
3. How long would it take to travel the solar system on today's fastest spacecraft?
4. How long would the trip take at the speed of light?
5. How fast is this animation?

Practice Answers

1. It shows the planets passing by a point with distances to scale.
2. You see the planets passing by a point starting at the sun. The amount of time it takes for each to pass shows the vastness of the outer planets from each other.
3. It would take 10 years on the fastest spacecraft.
4. It would take 5.5 hours at the speed of light.
5. This animation is over 300 times the speed of light.

Review

1. When you look at the diagram of planet orbits, which planetoid (planet-like object) doesn't fit the criteria of a planet?
2. How did Johannes Kepler determine a planet's distance from the Sun?
3. Why would your age - the number of orbits you have made around the Sun - be different on a different planet? Would you be younger or older?

Review Answers

1. Pluto
2. He used the length of time it took for the planet to make one complete orbit around the Sun, the orbital period, to determine distance.
3. Yes; for planets closer to the Sun than Earth you'd be older and for planets further from the Sun than Earth you'd be younger.

1.5 Gravity in the Solar System

- Define Newton's Universal Law of Gravitation.
- Explain the influence of gravity on the relative positions of Earth to the Sun and the Moon.

"I have not as yet been able to discover the reason for these properties of gravity from phenomena, and I do not feign hypotheses." - Isaac Newton, in *Philosophiae Naturalis Principia Mathematica*, 1687.

The Role of Gravity

Isaac Newton first described gravity as the force that causes objects to fall to the ground and also the force that keeps the Moon circling Earth instead of flying off into space in a straight line. Newton defined the Universal Law of Gravitation, which states that a force of attraction, called **gravity**, exists between all objects in the universe (**Figure** 1.8). The strength of the gravitational force depends on how much mass the objects have and how far apart they are from each other. The greater the objects' mass, the greater the force of attraction; in addition, the greater the distance between objects, the smaller the force of attraction.

The distance between the Sun and each of its planets is very large, but the Sun and each of the planets are also very large. Gravity keeps each planet orbiting the Sun because the star and its planets are very large objects. The force of gravity also holds moons in orbit around planets.

BigThink video: Who was the greatest physicist in history? According to Neal deGrasse Tyson, it was Sir Isaac Newton: http://bigthink.com/ideas/13154 .

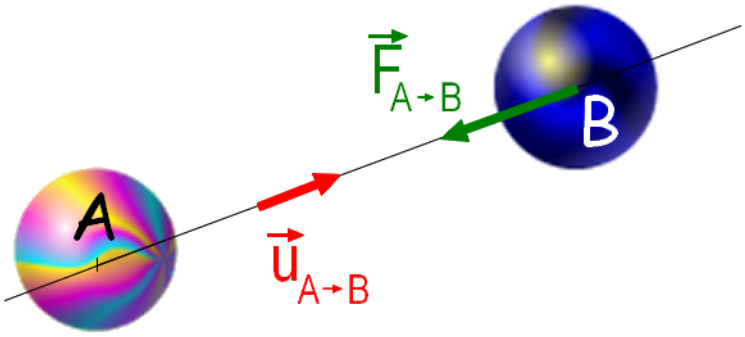


FIGURE 1.8

The force of gravity exists between all objects in the universe; the strength of the force depends on the mass of the objects and the distance between them.

Summary

- Newton developed the Universal Law of Gravitation, which recognizes the gravitational attraction between objects.
- All objects have a force of attraction between them that is proportional to their mass and distance from each other.
- Gravity keeps the planets orbiting the Sun because they are very large, just as gravity keeps satellites orbiting the planets.

Practice

Use this resource to answer the questions that follow.

http://www.youtube.com/watch?v=Jk5E-CrE1zg

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1453

1. How long have the Earth and Moon existed?
2. What evidence shows that the Moon's gravity affects the Earth?
3. What does Newton's law of gravitation state?
4. What happens as mass increases?
5. What happens as distance increases?

Practice Answers

1. 4.5 billion years
2. Moon's pull is evidence in the tides.
3. The force of gravity between two objects is equal to the universal gravitational constant times the mass of each object divided by the square of the distance between the centers of the two objects.
4. As mass increases so does gravitational force; gravitational pull is directly proportional to mass.

5. As the distance increases the force decreases; it is inversely proportional.

Review

1. Why is the gravitational attraction of the Moon to Earth greater than the attraction of Earth to Sun?
2. Why doesn't the Moon fly off into space? Why does an apple fall to the ground rather than orbiting Earth at a distance?
3. What is the Universal Law of Gravitation?

Review Answers

1. The Moon is very close to Earth and the Sun is much further away.
2. The Moon doesn't fly off into space due to the force of gravity. For an apple the force of gravity is so much greater than its mass that it can't orbit.
3. The strength of the force of gravity between two objects is directly related to the mass of the two objects and inversely related to their distance from each other.

1.6 Inner versus Outer Planets

- Compare and contrast the inner and outer planets.

"The Sun, with all those planets revolving around it and dependent on it...

"...can still ripen a bunch of grapes as if it had nothing else in the universe to do." —Galileo Galilei

The Inner Planets

The **inner planets**, or **terrestrial planets**, are the four planets closest to the Sun: Mercury, Venus, Earth, and Mars. **Figure** 1.9 shows the relative sizes of these four inner planets.

Unlike the outer planets, which have many satellites, Mercury and Venus do not have moons, Earth has one, and Mars has two. Of course, the inner planets have shorter orbits around the Sun, and they all spin more slowly. Geologically, the inner planets are all made of cooled igneous rock with iron cores, and all have been geologically active, at least early in their history. None of the inner planets has rings.

The Outer Planets

The four planets farthest from the Sun are the **outer planets**. **Figure** 1.10 shows the relative sizes of the outer planets and the Sun. These planets are much larger than the inner planets and are made primarily of gases and liquids, so they are also called **gas giants**.

The gas giants are made up primarily of hydrogen and helium, the same elements that make up most of the Sun. Astronomers think that hydrogen and helium gases comprised much of the solar system when it first formed. Since the inner planets didn't have enough mass to hold on to these light gases, their hydrogen and helium floated away into space. The Sun and the massive outer planets had enough gravity to keep hydrogen and helium from drifting away.

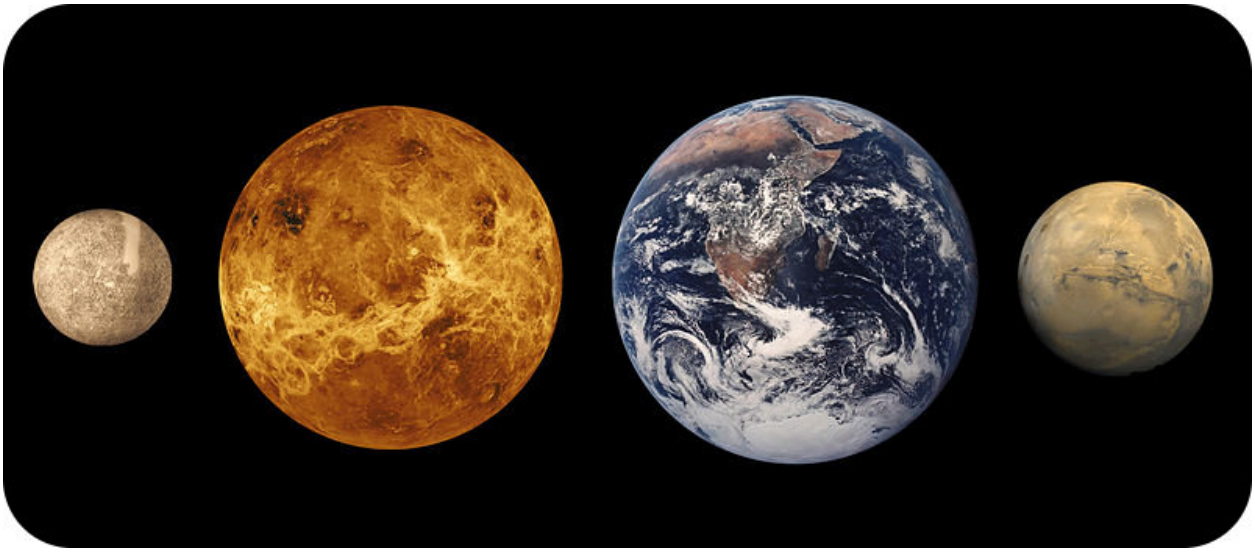


FIGURE 1.9

This composite shows the relative sizes of the four inner planets. From left to right, they are Mercury, Venus, Earth, and Mars.

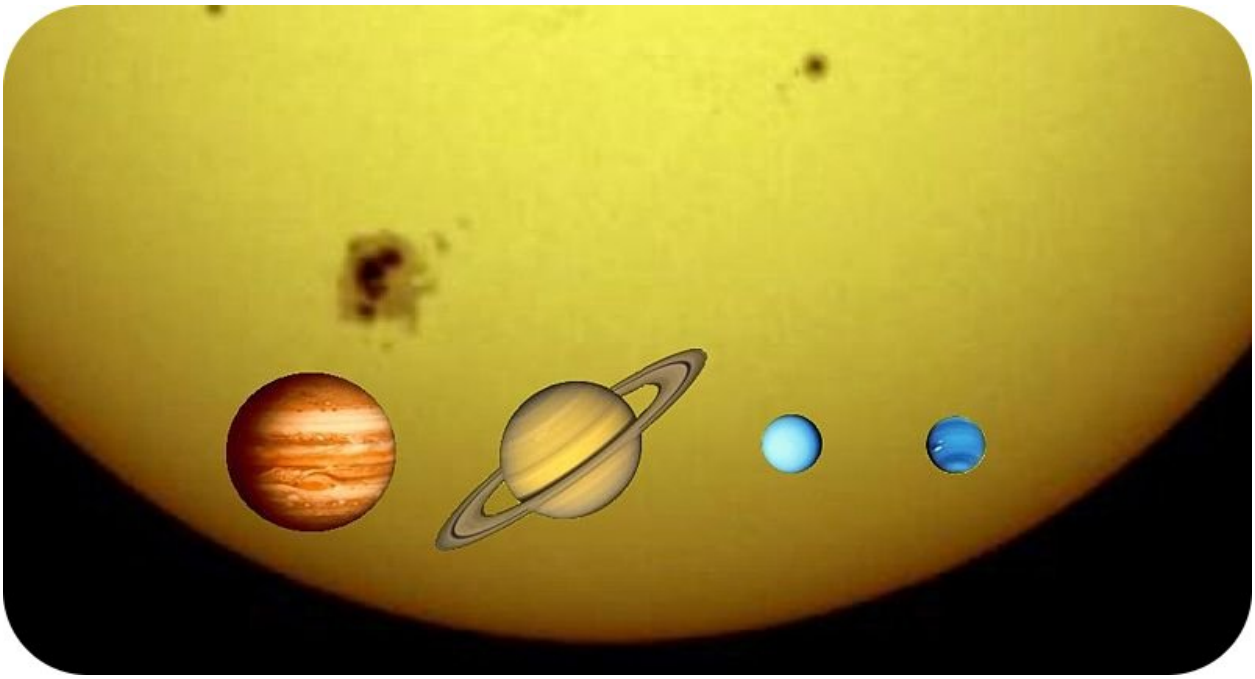


FIGURE 1.10

This image shows the four outer planets and the Sun, with sizes to scale. From left to right, the outer planets are Jupiter, Saturn, Uranus, and Neptune.

All of the outer planets have numerous moons. They all also have **planetary rings**, composed of dust and other small particles that encircle the planet in a thin plane.

Summary

- The four inner planets have slower orbits, slower spin, no rings, and they are made of rock and metal.
- The four outer planets have faster orbits and spins, a composition of gases and liquids, numerous moons, and rings.
- The outer planets are made of hydrogen and helium, so they are called gas giants.

Practice

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=1_oHcMXFC18

1. Which are the inner planets?
2. Which are the outer planets?
3. Where are the two groups?
4. What are the sizes? What are the masses?
5. What is the composition of the inner planets and how does that affect density
6. What sort of bodies do the inner planets have? What sort of atmosphere?
7. What sort of bodies do the outer planets have? What sort of atmosphere?
8. What is the rotation of the inner versus the outer planets?
9. What is the orbital speed of the inner versus the outer planets?
10. Which planets have the most moons, inner or outer? Why is this?
11. Which of the two planet groups have rings?

Practice Answers

1. Mercury, Venus, Earth, Mars
2. Jupiter, Saturn, Uranus, Neptune
3. close to sun versus far from sun
4. small versus large; not massive versus massive
5. The inner planets are made of rocks and metals, which means they are relatively dense.
6. The outer planets are made of gases, which means they are not very dense.
7. The inner planets have a terrestrial body with a thin or o atmosphere.
8. The outer plants have a huge atmosphere with possibly a small rocky core.
9. slow versus differential rotation at a fast speed
10. fast because they are close to the Sun versus slow because they are far from the Sun
11. Outer
12. Outer

Review

1. What are the four inner planets? What are the four outer planets?

What is the difference in composition between the inner and outer planets? What accounts for the difference?

1. Why do the outer planets have more moons? Why do they have rings?

Review Answers

1. Mercury, Venus, Earth, Mars; Jupiter, Saturn, Uranus, Neptune
2. The inner planets are made of rocks and metals. The outer planets are mostly gases with maybe some rocks at the core. The denser materials were drawn toward the Sun by gravity so they are in the inner solar system. The gases remain further out.
3. The gas giants are large enough to capture passing asteroids, which enter orbit around them. They also have debris orbiting them, which is why they have rings.

1.7 Mercury

- Describe the characteristics of Mercury.

How did tiny Mercury get its name?

Mercury was named for the Roman messenger god who traveled rapidly on his winged sandals. From the vantage point of Earth, the planet Mercury travels swiftly across the face of the Sun.

Mercury

The smallest planet, Mercury, is the planet closest to the Sun. Because Mercury is so close to the Sun, it is difficult to observe from Earth, even with a telescope. However, the Mariner 10 spacecraft, shown in **Figure** 1.11, visited

Mercury from 1974 to 1975.

The MESSENGER spacecraft has been studying Mercury in detail since 2005. The craft is currently in orbit around the planet, where it is creating detailed maps. MESSENGER stands for Mercury Surface, Space Environment, Geochemistry and Ranging.

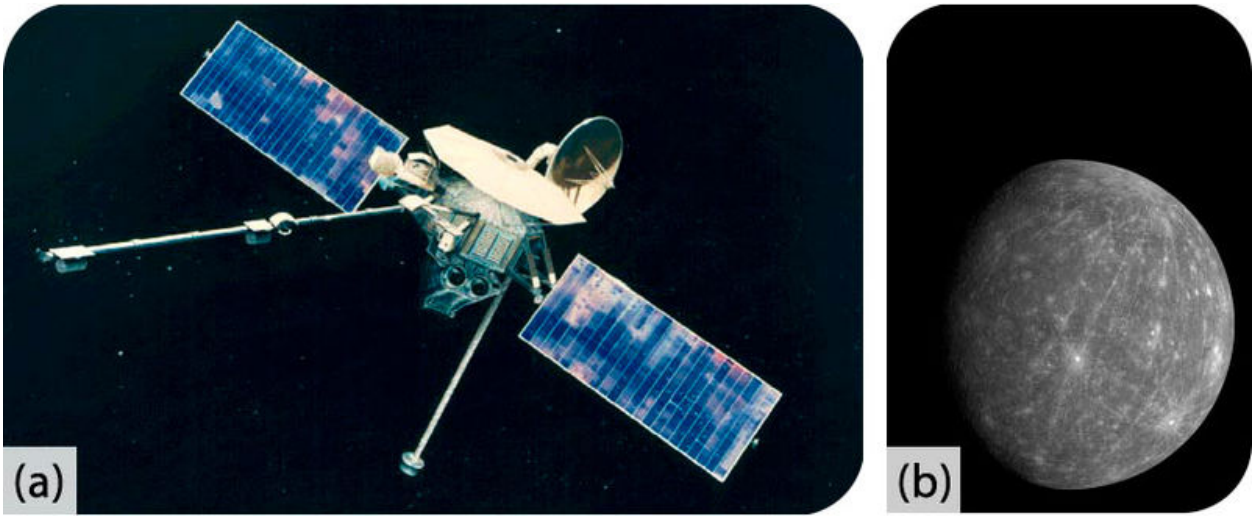


FIGURE 1.11

(a) Mariner 10 made three flybys of Mercury in 1974 and 1975. (b) A 2008 image of compiled from a flyby by MESSENGER.

As **Figure** 1.12 shows, the surface of Mercury is covered with craters, like Earth's Moon. Ancient impact craters means that for billions of years Mercury hasn't changed much geologically. Also, with very little atmosphere, the processes of weathering and erosion do not wear down structures on the planet.

There are many images, movies, and activities on the MESSENGER site: http://messenger.jhuapl.edu/index.php

Short Year, Long Days

Mercury is named for the Roman messenger god, who could run extremely quickly, just as the planet moves very quickly in its orbit around the Sun. A year on Mercury —the length of time it takes to orbit the Sun —is just 88 Earth days.

Despite its very short years, Mercury has very long days. A day is defined as the time it takes a planet to turn on its axis. Mercury rotates slowly on its axis, turning exactly three times for every two times it orbits the Sun. Therefore, each day on Mercury is 57 Earth days long. In other words, on Mercury, a year is only a Mercury day and a half long!

Extreme Temperatures

Mercury is close to the Sun, so it can get very hot. However, Mercury has virtually no atmosphere, no water to insulate the surface, and it rotates very slowly. For these reasons, temperatures on the surface of Mercury vary widely. In direct sunlight, the surface can be as hot as 427°C (801°F). On the dark side, or in the shadows inside

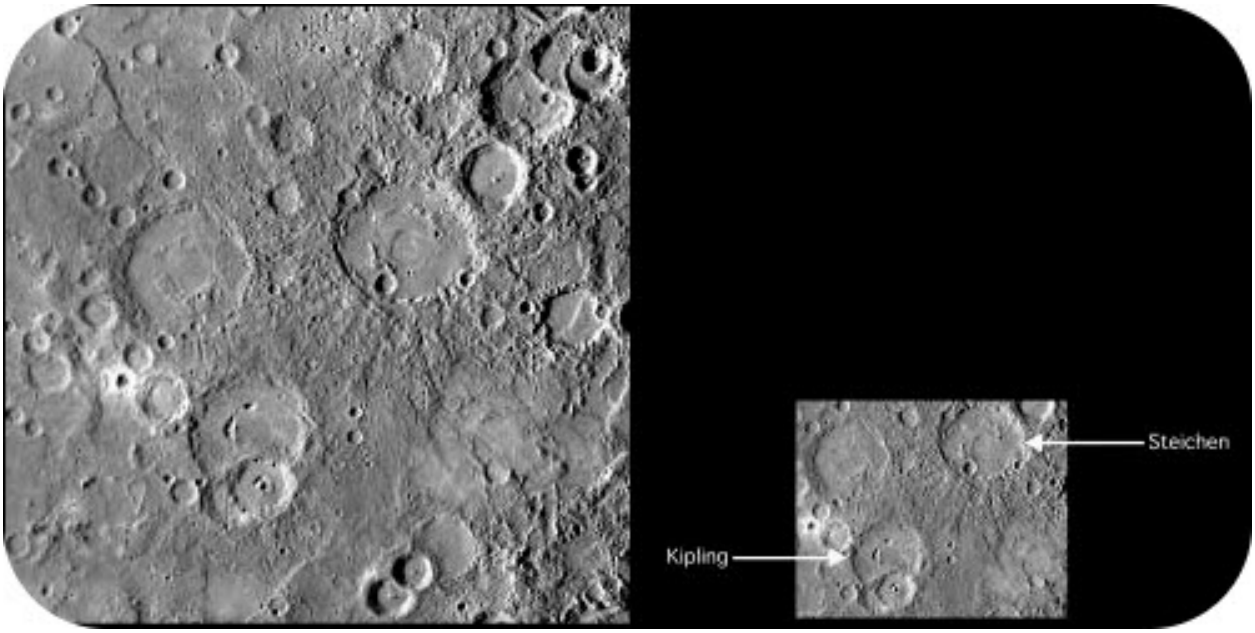


FIGURE 1.12

Mercury is covered with craters, like Earth's Moon. MESSENGER has taken extremely detailed pictures of the planet's surface.

craters, the surface can be as cold as -183°C (-297°F)! Although most of Mercury is extremely dry, scientists think there may be a small amount of water in the form of ice at the poles of Mercury, in areas that never receive direct sunlight.

A Liquid Metal Core

Figure 1.13 shows a diagram of Mercury's interior. Mercury is one of the densest planets. It's relatively large, liquid core, made mostly of melted iron, takes up about 42% of the planet's volume.

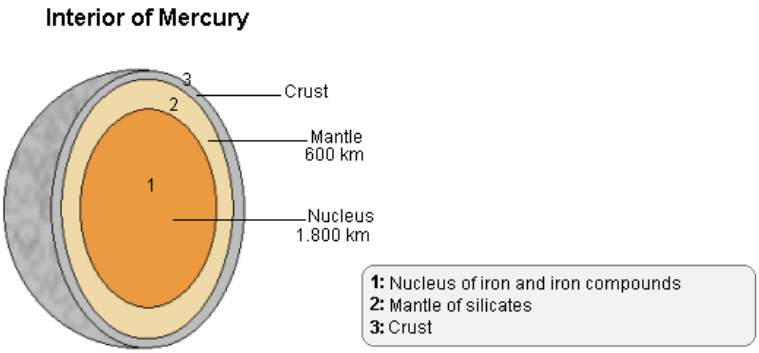


FIGURE 1.13

Mercury contains a thin crust, a mantle, and a large, liquid core that is rich in iron.

Summary

- Mercury appears to be moving rapidly because it's so close to the Sun.
- Mercury has short years, just 88 Earth days, but long days, about 57 Earth days.
- Mercury is extremely hot and has a liquid metal core.

Practice

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=6KY-oB2i9lo

1. What is the location and size of Mercury?
2. Why do the temperatures on Mercury vary so much?
3. Why was Mercury named for the messenger god Mercury?
4. Why is Mercury so dense?
5. What are the features of its core?
6. Why is the landscape similar to our Moon's?
7. Why hasn't the surface of Mercury changed over it's history, except for the addition of more impact craters?
8. How can ice be found on such a hot planet?
9. Why does it take so much rocket fuel to send a spacecraft to Mercury?
10. What do probes to Mercury reveal?

Practice Answers

1. It is the smallest planet and it is closest to the Sun.
2. It is super close to the Sun, which accounts for the high temperatures. The low temperatures are where the Sun never hits.
3. It is so close to the Sun that it appears to race across it; it's orbital period is only 88 days.
4. It is 2/3 metallic and 1/3 silica-rich rocks.
5. It's very large, making up 42% of the mass, and it's molten.
6. Asteroids and comets have been striking the planet for all time, just as they have the Moon. This is because the planet is dense and draws them in and there is no atmosphere for protection.
7. It is geologically inactive and has no plate tectonics. It has no weathering and erosion.
8. It is deep in craters that never see the Sun.
9. It has to fight the pull of the Sun's gravity to not get dragged in.
10. They map the surface.

Want to know more about Mercury? See https://www.windows2universe.org/mercury/mercury.html&edu=high .

Review

1. Why is a year on Mercury only 88 days long?
2. Why is Mercury mostly really hot, but very cold in spots?
3. Think about the formation of the solar system. Why is Mercury the densest planet?

Review Answers

1. Mercury is close to the Sun so it doesn't take very long for it to make one obit.

2. It is very close to the Sun so it's mostly hot. In the bottoms of some very deep craters, the Sun never shines so they can be very cold.
3. The dense materials were drawn into the center by the Sun's gravity and Mercury is closest to the Sun so it is densest.

1.8 Venus

- Describe the characteristics of Venus.

"Venus favors the bold". —Ovid, a Roman poet.

Our nearest planetary neighbor, Venus, was named after the Roman goddess of love because it appeared as the brightest and most beautiful star in the skies. Most of the planet's features are named for real or mythological women.

Venus

Venus' thick clouds reflect sunlight well, so Venus is very bright. When it is visible, Venus is the brightest object in the sky besides the Sun and the Moon. Because the orbit of Venus is inside Earth's orbit, Venus always appears close to the Sun. When Venus rises just before the Sun rises, the bright object is called the morning star. When it sets just after the Sun sets, it is the evening star.

Of the planets, Venus is most similar to Earth in size and density. Venus is also our nearest neighbor. The planet's interior structure is similar to Earth's, with a large iron core and a silicate mantle (**Figure** 1.14). But the resemblance between the two inner planets ends there.

Find out more about Venus at the following link: http://www.nasa.gov/worldbook/venus_worldbook.html .

Motion

Venus rotates in a direction opposite the other planets and opposite to the direction it orbits the Sun. This rotation is extremely slow, only one turn every 243 Earth days. This is longer than a year on Venus —it takes Venus only 224 days to orbit the Sun.

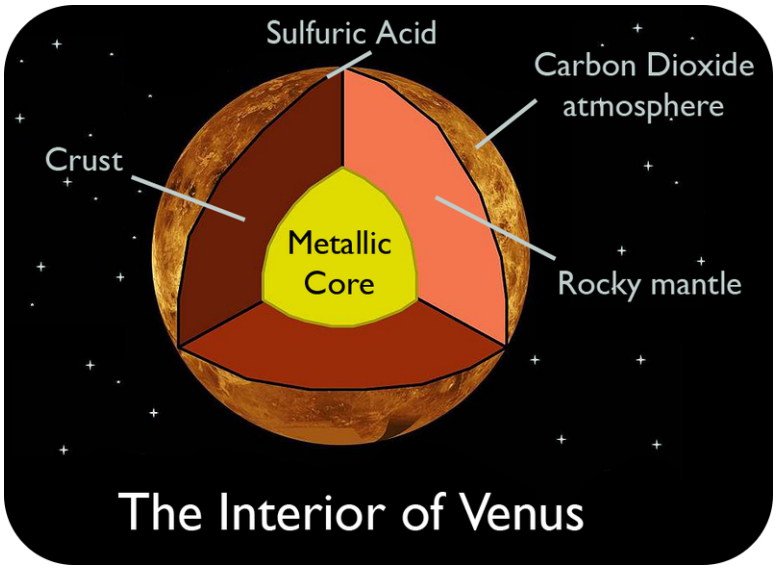


FIGURE 1.14
Diagram of Venus's interior, which is similar to Earth's.

Extreme Atmosphere

Venus is covered by a thick layer of clouds, as shown in pictures of Venus taken at ultraviolet wavelengths (**Figure** 1.15).

FIGURE 1.15
This ultraviolet image from the Pioneer Venus Orbiter shows thick layers of clouds in the atmosphere of Venus.

Venus' clouds are not made of water vapor like Earth's clouds. Clouds on Venus are made mostly of carbon dioxide with a bit of sulfur dioxide. They also contain corrosive sulfuric acid. Because carbon dioxide is a greenhouse gas, the atmosphere traps heat from the Sun and creates a powerful greenhouse effect. Even though Venus is further from the Sun than Mercury, the greenhouse effect makes Venus the hottest planet. Temperatures at the surface reach 465°C (860°F). That's hot enough to melt lead.

The atmosphere of Venus is full of acid, its pressure is crushing, and the enormous amount of carbon dioxide causes runaway greenhouse effect: http://www.youtube.com/watch?v=HqFVxWfVtoo (2:05).

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1464

The atmosphere of Venus is so thick that the atmospheric pressure on the planet's surface is 90 times greater than the atmospheric pressure on Earth's surface. The dense atmosphere totally obscures the surface of Venus, even from spacecraft orbiting the planet.

Venus's Surface

Since spacecraft cannot see through the thick atmosphere, radar is used to map Venus' surface. Many features found on the surface are similar to Earth and yet are very different. **Figure** 1.16 shows a topographical map of Venus produced by the Magellan probe using radar.

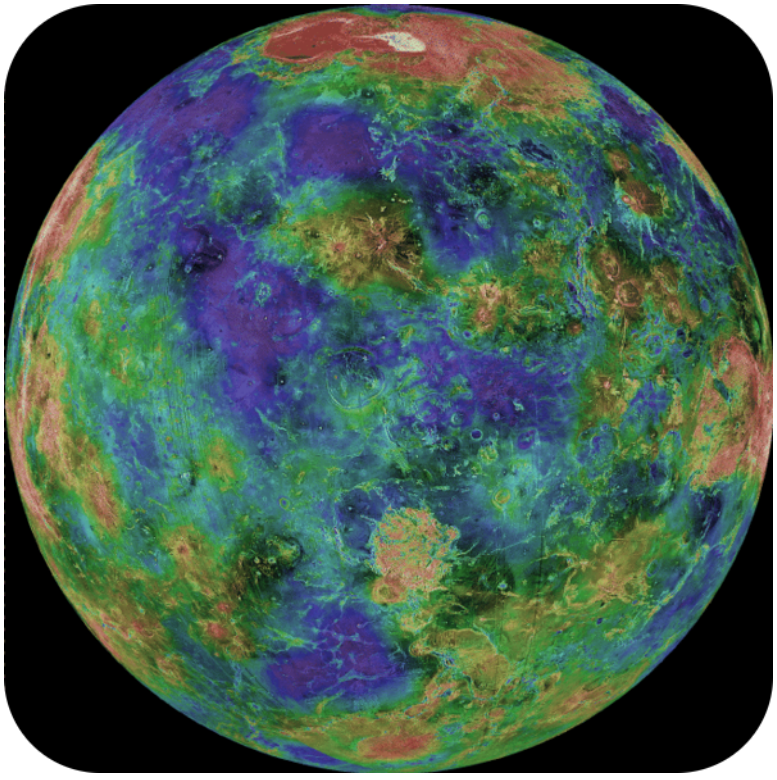


FIGURE 1.16

This false color image of Venus was made from radar data collected by the Magellan probe between 1990 and 1994. What features can you identify?

Orbiting spacecraft have used radar to reveal mountains, valleys, and canyons. Most of the surface has large areas of volcanoes surrounded by plains of lava. In fact, Venus has many more volcanoes than any other planet in the solar system, and some of those volcanoes are very large.

Most of the volcanoes are no longer active, but scientists have found evidence that there is some active volcanism (**Figure** 1.17). Think about what you know about the geology of Earth and what produces volcanoes. What does the presence of volcanoes suggest about the geology of Venus? What evidence would you look for to find the causes of volcanism on Venus?

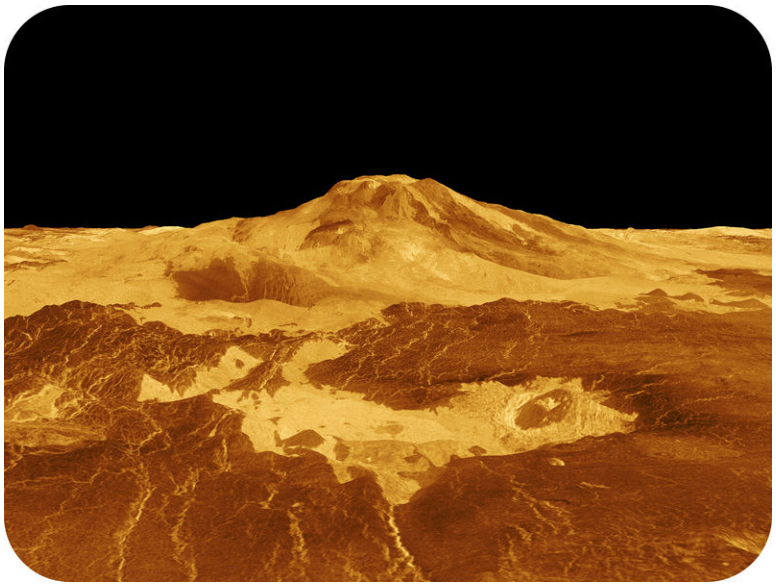


FIGURE 1.17

This image of the Maat Mons volcano with lava beds in the foreground was generated by a computer from radar data. The reddish-orange color is close to what scientists think the color of sunlight would look like on the surface of Venus.

Venus also has very few impact craters compared with Mercury and the Moon. What is the significance of this? Earth has fewer impact craters than Mercury and the Moon, too. Is this for the same reason that Venus has fewer impact craters?

It's difficult for scientists to figure out the geological history of Venus. The environment is too harsh for a rover to go there. It is even more difficult for students to figure out the geological history of a distant planet based on the information given here. Still, we can piece together a few things.

On Earth, volcanism is generated because the planet's interior is hot. Much of the volcanic activity is caused by plate tectonic activity. But on Venus, there is no evidence of plate boundaries and volcanic features do not line up the way they do at plate boundaries.

Because the density of impact craters can be used to determine how old a planet's surface is, the small number of impact craters means that Venus' surface is young. Scientists think that there is frequent, planet-wide resurfacing of Venus with volcanism taking place in many locations. The cause is heat that builds up below the surface, which has no escape until finally it destroys the crust and results in volcanoes.

Summary

- Venus has a very thick, carbon dioxide-rich atmosphere, so the planet has a very strong greenhouse effect.
- The surface of Venus has very few impact craters, so it must be very young. This suggests that the planet experiences volcanism and has a hot interior.
- Venus has a lot of volcanoes, including some very large ones.

Practice

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=h8KrQuPklAw

1. Where is Venus relative to the Sun and relative to Earth?
2. In what characteristics is Venus similar to Earth?
3. In what way is Venus least like Earth?
4. Why is Venus so hot? Describe how this works?
5. Why are meteors often incinerated before reaching the surface of Venus?
6. Why does Venus shine so brightly in our sky?
7. How did Venus go from a more Earth-like planet to the hot cauldron it is today?
8. What is the internal structure of Venus?
9. Why does Venus have so many and such large volcanoes?
10. Why does Venus have such long days? How long is a day relative to a year on Venus?
11. What is a retrograde rotation?
12. Why is Venus so hard to study?

Practice Answers

1. It is the second planet out from the Sun and the closest planet to Earth.
2. It is similar to Earth in size, gravity and composition.
3. It is the most hostile planet in the solar system because it is very hot.
4. Venus has runaway greenhouse effect. It has a dense carbon dioxide rich atmosphere - global warming out of control.
5. The atmosphere is thick and corrosive.
6. The atmosphere is so thick that most solar radiation reflects off the surface and the extra light is visible on Earth.
7. Venus had a lot water and being so close to the Sun the water evaporated and went up into the upper atmosphere. It was so hot that the hydrogen and oxygen separated so there was no water, so it was super hot.
8. It has an iron core and a molten mantle.
9. The interior is hot and active.
10. Venus rotates very slowly; a day is longer than a year!
11. Venus spins the opposite way from Earth.
12. It is hard to see with visible light because the atmosphere is so thick and it the surface is so hot that a probe can't last long.

Want to know more about Venus? See https://www.windows2universe.org/venus/venus.html .

Review

1. Under what conditions is a planet subject to such a large greenhouse effect?
2. Why does the number of impact craters on the surface of a planet indicate the conditions found in the interior?
3. Why does Venus always appear to be near the Sun when viewed from Earth?

Review Answers

1. A thick atmosphere that is rich in greenhouse gases, like carbon dioxide, makes a powerful greenhouse effect.

2. Venus appears to have fewer impact craters than it should, but it has more volcanoes than any planet in the solar system. This means that the interior is hot and volcanic eruptions may wipe out evidence of impacts. Also the thick atmosphere protects the surface from meteorite impacts.
3. It's orbit is small so it never gets too far from the Sun. Even at its greatest distance it appears close to the Sun from our viewpoint.

1.9 Moon

- Describe the characteristics of Earth's Moon.

That's one small step for [a] man, one giant leap for mankind. —Neil Armstrong

On July 20, 1969, hundreds of millions of people all over the world witnessed something incredible. Never before had a human being walked on a planetary body other than Earth. But on that day, Neil Armstrong and Buzz Aldrin walked on the Moon. The footprints the men left behind are the first signs of life ever on the Moon. Scientists have learned a great deal about the Moon from the Apollo missions and from rovers and satellites sent to the Moon for study.

Lunar Characteristics

The Moon is Earth's only natural satellite, a body that moves around a larger body in space. The Moon orbits Earth for the same reason Earth orbits the Sun —gravity. The Moon is 3,476 km in diameter, about one-fourth the size of Earth. The satellite is also not as dense as the Earth; gravity on the Moon is only one-sixth as strong as it is on Earth. An astronaut can jump six times as high on the Moon as on Earth!

The Moon makes one complete orbit around the Earth every 27.3 days. The Moon also rotates on its axis once every 27.3 days. Do you know what this means? The same side of the Moon always faces Earth, so that side of the Moon

is what we always see in the night sky (**Figure** 1.18). The Moon makes no light of its own, but instead only reflects light from the Sun.

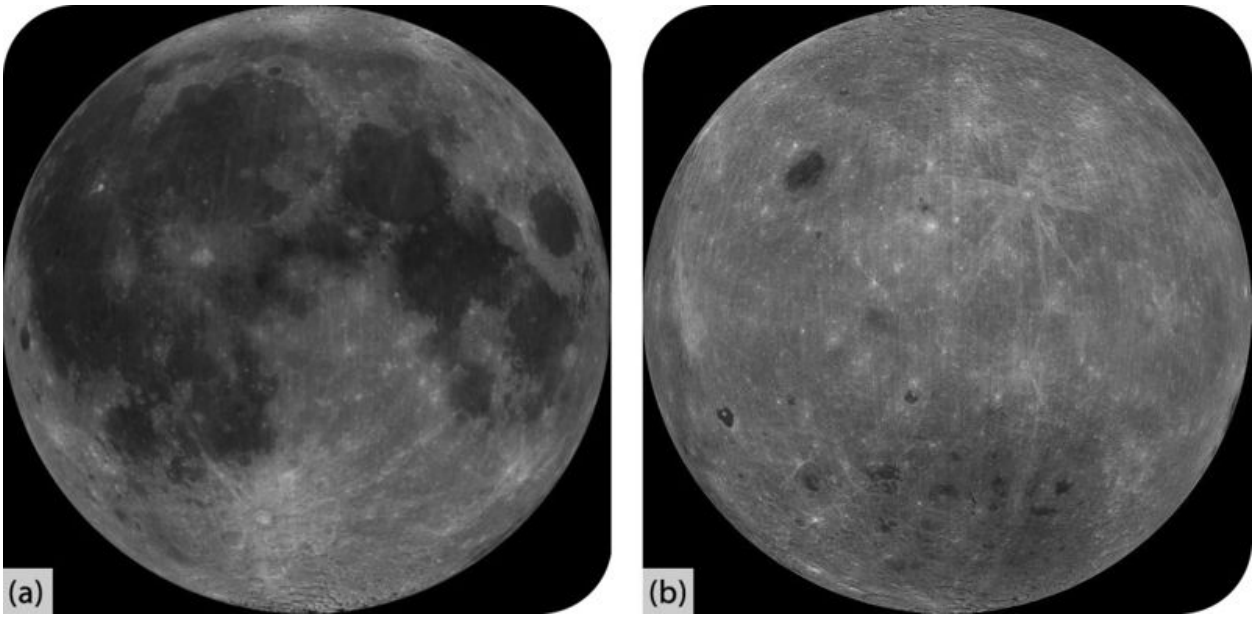


FIGURE 1.18

(a) The near side of the Moon faces Earth continually. It has a thinner crust with many more maria (flat areas of basaltic rock). (b) The far side of the Moon has only been seen by spacecraft. It has a thicker crust and far fewer maria (flat areas of basaltic rock).

The Lunar Surface

The Moon has no atmosphere. Since an atmosphere moderates temperature, the Moon's average surface temperature during the day is approximately 225°F, but drops to -243°F at night. The coldest temperatures, around -397°F, occur in craters in the permanently shaded south polar basin. These are among the coldest temperatures recorded in the entire solar system.

Earth's landscape is extremely varied, with mountains, valleys, plains and hills. This landscape is always changing as plate tectonics builds new features and weathering and erosion destroys them. The landscape of the Moon is very different. With no plate tectonics, features are not built. With no atmosphere, features are not destroyed. Still, the Moon has a unique surface. **Lunar** surface features include the bowl-shaped **craters** that are caused by meteorite impacts (**Figure** 1.19). If Earth did not have plate tectonics or erosion, its surface would also be covered with meteorite craters.

Even from Earth, the Moon has visible dark areas and light areas. The dark areas are called **maria**, which means "seas" because that's what the ancients thought they were. In fact, the maria are not water but solid, flat areas of basaltic lava. From about 3.0 to 3.5 billion years ago the Moon was continually bombarded by meteorites. Some of these meteorites were so large that they broke through the Moon's newly formed surface. Then, magma flowed out and filled the craters. Scientists estimate this meteorite-caused volcanic activity on the Moon ceased about 1.2 billion years ago, but most occurred long before that.

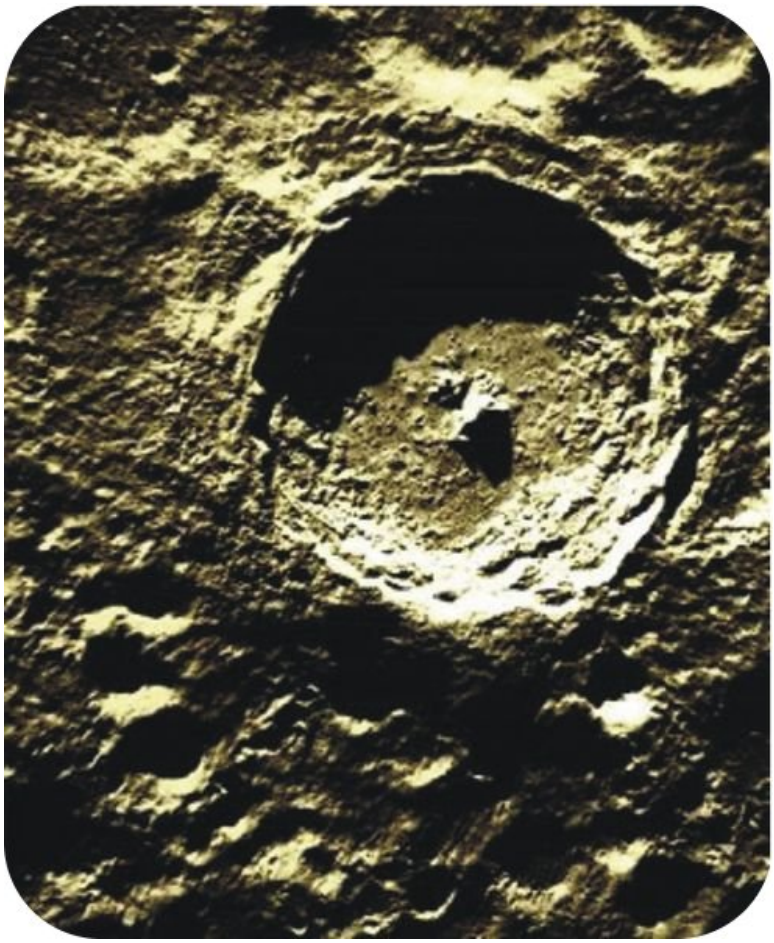


FIGURE 1.19
A crater on the surface of the Moon.

The lighter parts of the Moon are called **terrae** or highlands (**Figure** 1.20). The terrae are higher than the maria and include several high mountain ranges. The terrae are the light silicate minerals that precipitated out of the ancient magma ocean and formed the early lunar crust.

There are no lakes, rivers, or even small puddles anywhere to be found on the Moon's surface, but water in the form of ice has been found in the extremely cold craters and bound up in the lunar soil. Despite the possible presence of water, the lack of an atmosphere and the extreme temperatures make it no surprise to scientists that the Moon has absolutely no evidence of life.

Life from Earth has visited the Moon and there are footprints of astronauts on the lunar surface. With no wind, rain, or living thing to disturb them, these footprints will remain as long as the Moon exists. Only an impact with a meteorite could destroy them.

Interior of the Moon

Like Earth, the Moon has a distinct crust, mantle, and core. What is known about the Moon's interior was determined from the analysis of rock samples gathered by astronauts and from unmanned spacecraft sent to the Moon (**Figure** 1.21).

- The Moon's small core, 600 to 800 kilometers in diameter, is mostly iron with some sulfur and nickel.

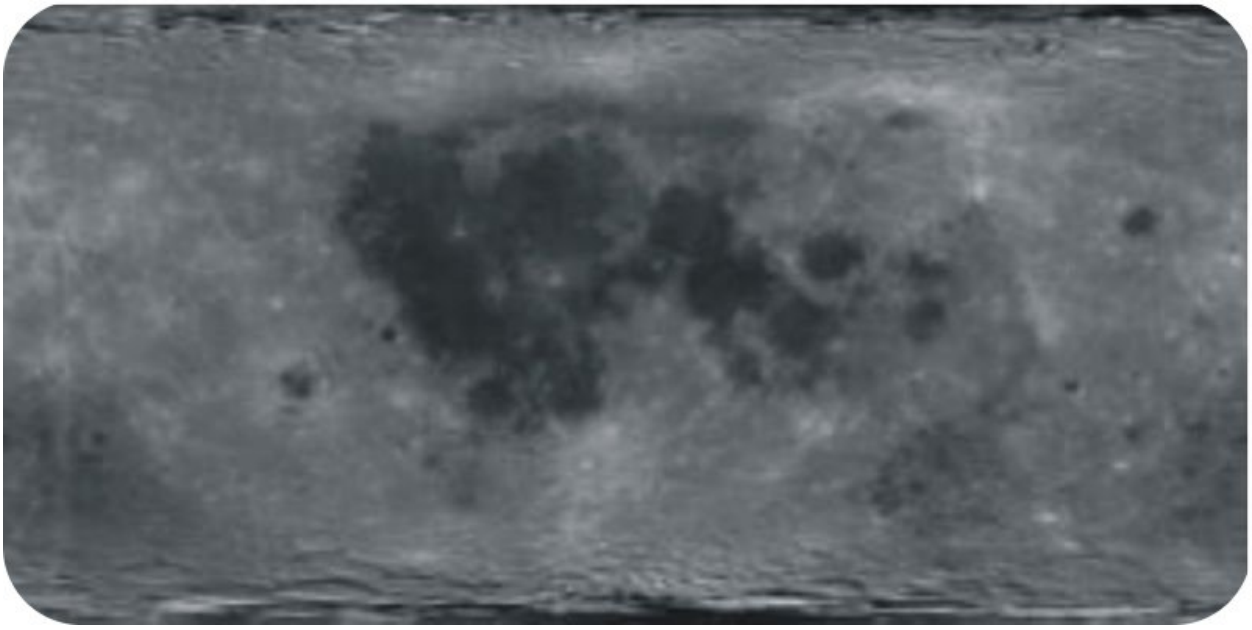


FIGURE 1.20

A close-up of the Moon, showing maria (the dark areas) and terrae (the light areas); maria covers around 16% of the Moon's surface, mostly on the side of the Moon we see.

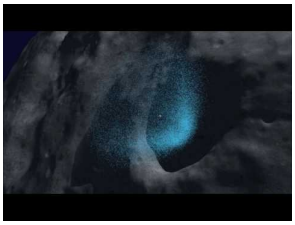
FIGURE 1.21

The Moon's internal structure shows a small metallic core (yellow), a primitive mantle (orange), a depleted mantle (blue), and a crust (gray).

- The mantle is composed of the minerals olivine and orthopyroxene. Analysis of Moon rocks indicates that there may also be high levels of iron and titanium in the lunar mantle.
- The crust is composed of igneous rock rich in the elements oxygen, silicon, magnesium, and aluminum. The crust is about 60 km thick on the near side of the Moon and about 100 km thick on the far side.

LCROSS crashed into the Moon in May 2009. This QUEST video describes the mission. After watching, look up the mission to see what they found!

Watch it at http://science.kqed.org/quest/video/nasa-ames-rocket-to-the-moon/ .



MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/114951

Summary

- The Moon revolves around Earth as they orbit the Sun; the same side of Moon always faces Earth.
- The lunar surface has dark basalt maria and light highlands called terrae.
- The Moon has a crust, mantle, and core, but no water or atmosphere.

Making Connections

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/60984

Practice

Use the resource below to answer the questions that follow.

- **Space School - The Moon** at http://www.youtube.com/watch?v=0HtG9opCmOE (5:30)

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/10265

1. What is the Moon?

2. How far is the Moon from Earth? Where will it be relative to its current location 100 years from now?
3. What did Galileo prove about the Moon? How did he do that?
4. Where did the Moon come from?
5. What is the Moon like relative to Earth?
6. Why do we always see the same side of the Moon?
7. Describe the Moon's structure.
8. What are maria?
9. What are terrae?
10. What created the craters on the Moon?
11. If a small meteor went toward the Moon's surface and one the same size went toward Earth's surface, which would actually reach the surface and why?
12. If there is water on the Moon, how did it get there and where is it?
13. What is an eclipse?
14. What is a lunar eclipse?
15. What is a total solar eclipse?
16. Why is the Moon unique?
17. Who was the first person on the Moon?

Practice Answers

1. The Moon is Earth's only natural satellite.
2. The Moon is located 239,000 miles away from Earth; in 100 years, it will be 150 inches farther away.
3. He examined the lunar surface through his telescope to prove that the Moon is a sphere.
4. Earth was struck by a giant impactor; the material that flew up into space came together by gravity and formed the Moon.
5. The Moon has no life, no atmosphere, and no seasons. If it has water, it is as ice in the bottom of craters.
6. The Moon is locked to Earth; it takes the same amount of time to rotate once on its axis and to orbit Earth once so we always see the same side.
7. The structure is the same as Earth's with a core, mantle and crust.
8. Maria are flatlands that are hardened pools of lava over craters.
9. Terrae are highlands that formed as the Moon's crust was shattered by meteorite impacts.
10. The craters on the Moon were created by intense bombardment by meteorites.
11. The one heading toward Earth's surface would burn up in the atmosphere; the one heading toward the Moon's surface would hit it since there is no atmosphere for protection.
12. Comets may have brought in water; if it exists it is at the bottom of craters as ice.
13. An eclipse occurs when the Earth, Moon, and Sun are in alignment.
14. A lunar eclipse occurs when the Earth moves between the Sun and Moon.
15. A total lunar eclipse occurs when the Moon moves between the Sun and Earth and blocks out the Sun's light entirely.
16. It is the only non-Earth body that humans have visited.
17. Neil Armstrong was the first person to walk on the Moon, as part of the Apollo 11 mission.

Review

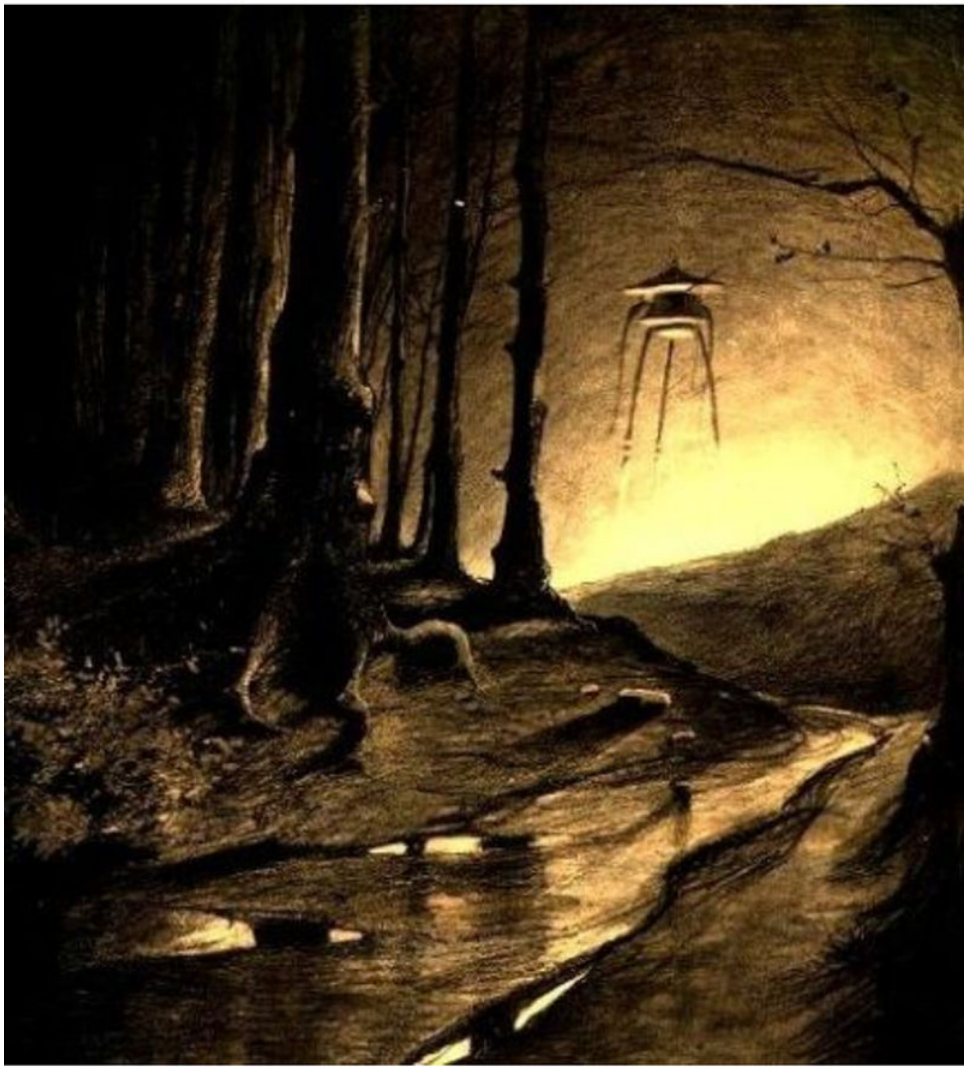
1. Explain why one side of the Moon always faces toward Earth and the other side always faces away from Earth.
2. How did the Moon's terrae form?
3. What is significant about the Moon's core?

Review Answers

1. The Moon's orbit around Earth and rotation on its axis is the same length so we always see one side of the Moon.
2. The terrae are the highlands. They are formed of light silica minerals that floated in the ancient magma ocean and formed the crust.
3. The core is small, which may be the result of the massive materials staying on Earth after the collision that formed the Moon.

1.10 Mars

- Describe the characteristics of Mars.



"Ladies and gentlemen, I have a grave announcement to make...

...Incredible as it may seem, strange beings who landed in New Jersey tonight are the vanguard of an invading army from Mars." —Orson Welles, "The War of the Worlds" radio broadcast, October 30, 1938.

Orson Welles caused a panic when some people took his news bulletins, meant to be a radio drama anthology, as the truth. No evidence of life has been found on Mars. Would people believe it if he broadcasted this today? Would you?

Characteristics

Mars is the fourth planet from the Sun, and the first planet beyond Earth's orbit (**Figure** 1.22). Mars is a quite different from Earth and yet more similar than any other planet. Mars is smaller, colder, drier, and appears to have no life, but volcanoes are common to both planets and Mars has many.

Mars is easy to observe, so Mars has been studied more thoroughly than any other extraterrestrial planet. Space probes, rovers, and orbiting satellites have all yielded information to planetary geologists. Although no humans have ever set foot on Mars, both NASA and the European Space Agency have set goals of sending people to Mars sometime between 2030 and 2040.

Find out all you want to know about Mars at http://mars.jpl.nasa.gov/extreme/ .

FIGURE 1.22

This image of Mars, taken by the Hubble Space Telescope in October, 2005, shows the planet's red color, a small ice cap on the south pole, and a dust storm.

A Red Planet

Viewed from Earth, Mars is reddish in color. The ancient Greeks and Romans named the planet after the god of war. The surface is not red from blood but from large amounts of iron oxide in the soil.

The Martian atmosphere is very thin relative to Earth's and has much lower atmospheric pressure. Although the atmosphere is made up mostly of carbon dioxide, the planet has only a weak greenhouse effect, so temperatures are only slightly higher than if the planet had no atmosphere.

Surface Features

Mars has mountains, canyons, and other features similar to Earth. Some of these surface features are amazing for their size! Olympus Mons is a shield volcano, similar to the volcanoes that make up the Hawaiian Islands. But Olympus Mons is also the largest mountain in the solar system (**Figure** 1.23).

Mars also has the largest canyon in the solar system, Valles Marineris (**Figure** 1.24).

Mars has more impact craters than Earth, though fewer than the Moon. A video comparing geologic features on Mars and Earth is seen here: http://news.discovery.com/videos/space-3-questions-mars-tectonics.html .

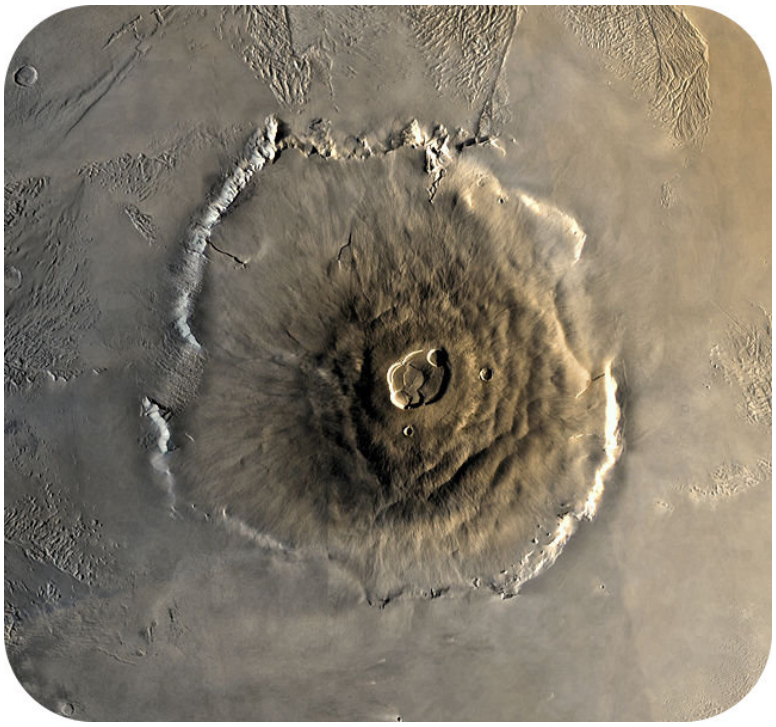


FIGURE 1.23

Olympus Mons is about 27 km (16.7 miles/88,580 ft) above the Martian surface, more than three times taller than Mount Everest. The volcano's base is about the size of the state of Arizona.

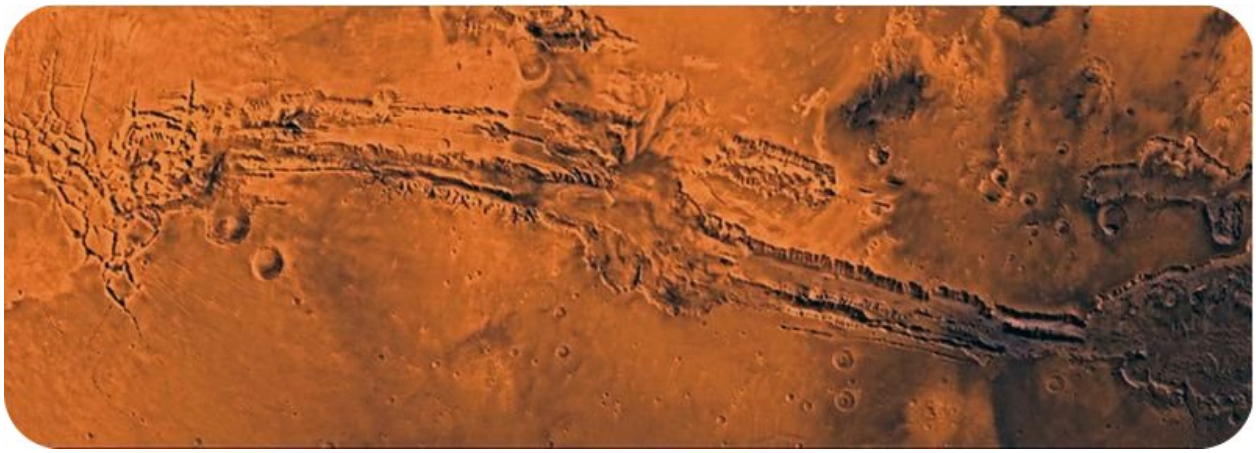


FIGURE 1.24

Valles Marineris is 4,000 km (2,500 mi) long, as long as Europe is wide, and one-fifth the circumference of Mars. The canyon is 7 km (4.3 mi) deep. By comparison, the Grand Canyon on Earth is only 446 km (277 mi) long and about 2 km (1.2 mi) deep.

Is There Water on Mars?

Water cannot stay in liquid form on Mars because the atmospheric pressure is too low. However, there is a lot of water in the form of ice and even prominent ice caps (**Figure** 1.25). Scientists also think that there is a lot of ice

present just under the Martian surface. This ice can melt when volcanoes erupt, and water can flow across the surface temporarily.

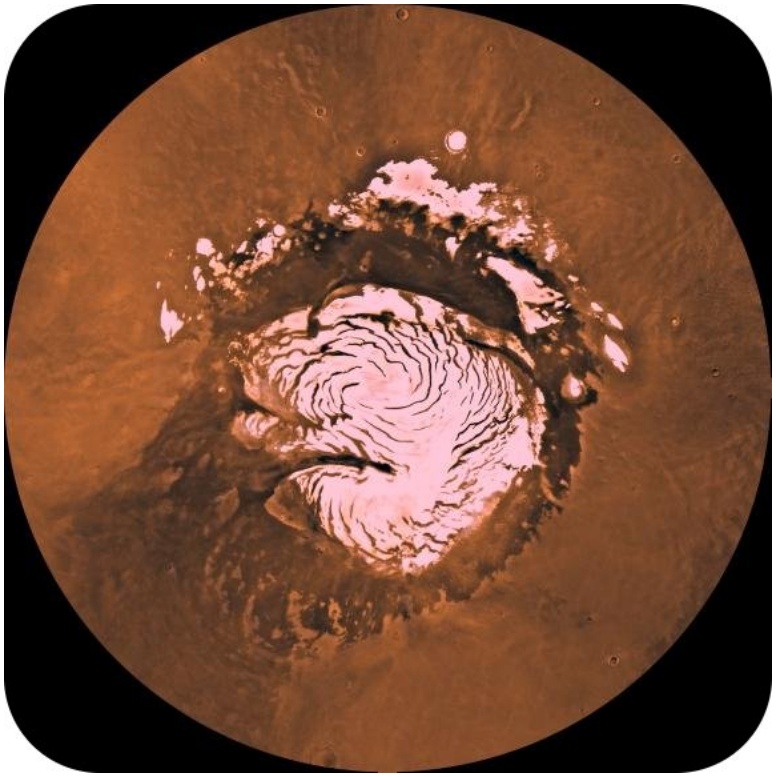


FIGURE 1.25
The north polar ice cap on Mars.

Scientists think that water once flowed over the Martian surface because there are surface features that look like water-eroded canyons. The presence of water on Mars, even though it is now frozen as ice, suggests that it might have been possible for life to exist on Mars in the past.

A video of the top five Phoenix Lander sites on Mars is seen here: http://news.discovery.com/videos/space-top-5-mars-phoenix-lander-images.html .

Two Martian Moons

Mars has two very small moons that are irregular rocky bodies (**Figure** 1.26). Phobos and Deimos are named after characters in Greek mythology —the two sons of Ares, who followed their father into war. Ares is equivalent to the Roman god Mars.

An animation of the moons orbiting Mars is seen here: http://commons.wikimedia.org/wiki/File:Orbits_of_Phobos_and_Deimos.gif .

The Mars Science Laboratory was launched on November 26, 2011 and will search for any evidence that the Red Planet was once capable of supporting life. Curiosity is a car-sized rover that will scour the red planet for clues after it lands in August 2012.

See more at http://science.kqed.org/quest/video/searching-for-life-on-mars/ .

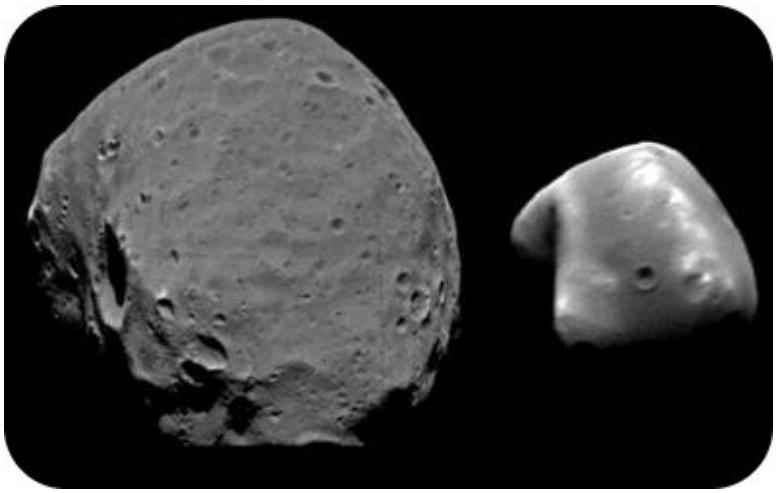


FIGURE 1.26

Mars has two small moons, Phobos (left) and Deimos (right). Both were discovered in 1877 and are thought to be captured asteroids.

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/114953

Summary

- Mars is the easiest planet to study because it doesn't have thick clouds obscuring its surface.
- The surface of Mars has volcanoes and channels that were once filled with water.
- Mars has two moons that are thought to be captured asteroids.

Practice

Use this resource to answer the questions that follow.

https://www.youtube.com/results?search_query=space+school+Mars

1. Why did people once think that intelligent life lived on Mars?
2. What is the Martian core like? Why is it thought to be solid?
3. Why does Mars have seasons? Why are the seasons not the same length as Earth's seasons?
4. How long is a Martian year? Why is it so long?
5. What geographical features does Mars have that are similar to Earth's?
6. Why is Mars red?
7. What does the oxidation of volcanic rocks tell us about Mars?
8. Why is Olympus Mons so big?
9. Compare the martian atmosphere with Earth's atmosphere. What does this mean for greenhouse effect on Mars?
10. Why does Mars have dust devils?
11. How are the martian moons different from Earth's moon?
12. Describe water currently on Mars.
13. How do scientists know that there was once liquid water on Mars?

14. What evidence is there that there once may have been life on Mars?
15. Why is Mars so studied by humans?

Practice Answers

1. There appeared to be long straight channels, which they thought could only have been created by intelligent and industrious aliens.
2. It has an iron, nickel and sulfur core with no magnetic field so it is thought to be solid.
3. Mars has seasons because it is tilted on its axis, but it has a very eccentric orbit. Spring is 2 months longer than autumn in the Northern hemisphere.
4. A year on mars is 687 days because it is farther from the Sun and it's orbit is larger.
5. Mars has rolling plains, mountain ranges, giant canyons, volcanoes; polar ice caps.
6. The surface is made of iron-rich volcanic rock that has oxidized so it is red.
7. The planet was warmer and wetter than it is today; the planet may once have had life.
8. There is no plate tectonic movement so the volcano has been spewing lava in the very same spot for hundreds of millions of years.
9. It was once like Earth's but now it is just 1% of ours and it so mostly all carbon dioxide. There is little greenhouse effect so the atmosphere can't trap heat.
10. It has enough of an atmosphere to have intense winds.
11. There are two of them and they are both captured asteroids. Earth's moon formed from Earth. Phobos races around Mars.
12. Mars has polar ice caps that contain a lot of water; all water is either gas or ice, not liquid.
13. There is the mineral hematite, which can only form in the presence of water.
14. There was once liquid water; there is now methane, ammonia and formaldehyde in the atmosphere, which are byproducts of biological life that would dissipate quickly in the atmosphere.
15. It is easy to get to and it has the possibility of having had life.

Want to know more about Mars? See https://www.windows2universe.org/mars/mars.html .

Review

1. Why is Mars red?
2. Why doesn't Mars have liquid water now? What evidence is there that Mars once had liquid water?
3. Is the surface of Mars young, like the surface of Venus? How would you know?

Review Answers

1. The rock is full of iron, which has oxidized to red iron oxide.
2. The atmospheric pressure is too low for water to be a liquid. Surface features look like water-eroded canyons.
3. The surface is young since Mars has fewer impact craters than the Moon or Mercury. It has volcanoes that have erupted and covered up impact craters.

1.11 Jupiter

- Describe the characteristics of Jupiter.

"What Jupiter? Do not trifle. There is no Jupiter." —Aristophanes

The Romans named the largest planet for their most important god. They followed the tradition of the Greeks, who had similarly named the planet Zeus. They built a temple to Jupiter on the hill. Was Aristophanes denying the existence of the most important Roman god?

Characteristics

Jupiter is enormous, the largest object in the solar system besides the Sun. Although Jupiter is over 1,300 times Earth's volume, it has only 318 times the mass of Earth. Like the other gas giants, it is much less dense than Earth.

Because Jupiter is so large, it reflects a lot of sunlight. Jupiter is extremely bright in the night sky; only the Moon and Venus are brighter (**Figure** 1.27). This brightness is all the more impressive because Jupiter is quite far from the Earth —5.20 AUs away. It takes Jupiter about 12 Earth years to orbit once around the Sun.

Check out NASA's world book to learn more about Jupiter: http://www.nasa.gov/worldbook/jupiter_worldbook.html .

A Ball of Gas and Liquid

Astronauts trying to land a spaceship on the surface of Jupiter would find that there is no solid surface at all! Jupiter is made mostly of hydrogen, with some helium, and small amounts of other elements (**Figure** 1.28). Jupiter's atmosphere is composed of hydrogen and helium. Deeper within the planet, pressure compresses the gases into a liquid. Some evidence suggests that Jupiter may have a small rocky core of heavier elements at its center.

FIGURE 1.27

This image of Jupiter was taken by Voyager 2 in 1979. The colors were later enhanced to bring out more details.

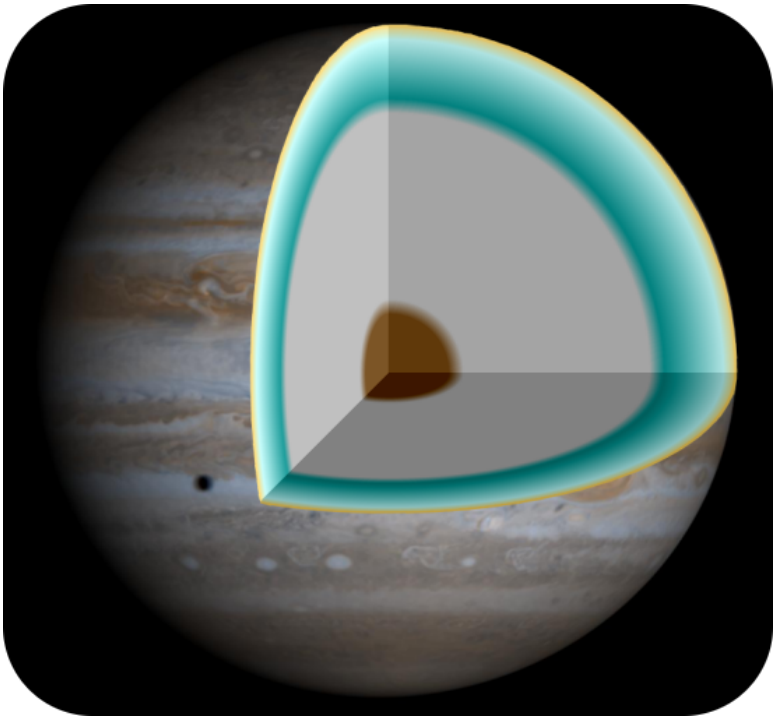


FIGURE 1.28

Jupiter's structure.

A Stormy Atmosphere

The upper layer of Jupiter's atmosphere contains clouds of ammonia (NH_3) in bands of different colors. These bands rotate around the planet, but also swirl around in turbulent storms. The **Great Red Spot** (**Figure** 1.29) is an enormous, oval-shaped storm found south of Jupiter's equator. This storm is more than three times as wide as the entire Earth. Clouds in the storm rotate in a counterclockwise direction, making one complete turn every six days or so. The Great Red Spot has been on Jupiter for at least 300 years, since astronomers could first see the storm through telescopes. Do you think the Great Red Spot is a permanent feature on Jupiter? How could you know?

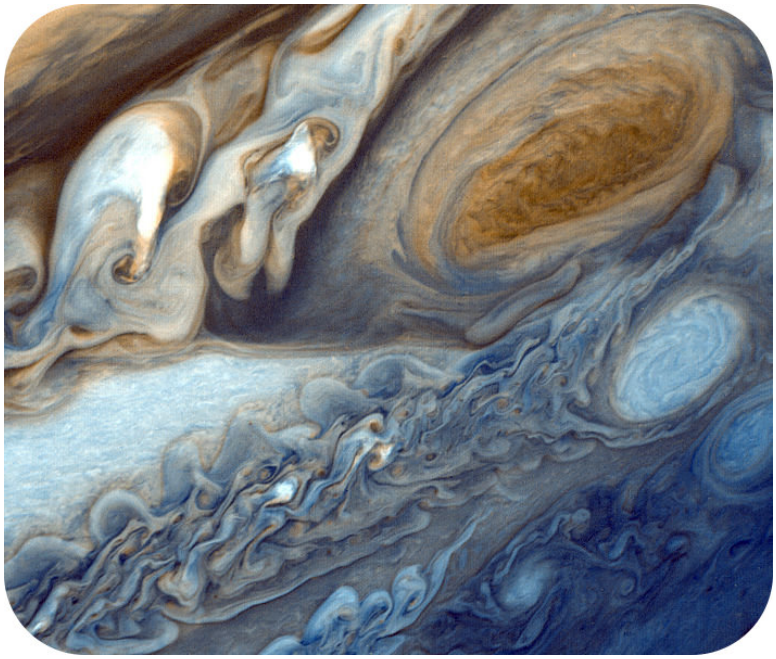


FIGURE 1.29

This image of Jupiter's Great Red Spot (upper right of image) was taken by the Voyager 1 spacecraft. The white storm just below the Great Red Spot is about the same diameter as Earth.

Jupiter's Moons and Rings

Jupiter has a very large number of moons —63 have been discovered so far. Four are big enough and bright enough to be seen from Earth, using no more than a pair of binoculars. These moons —Io, Europa, Ganymede, and Callisto —were first discovered by Galileo in 1610, so they are sometimes referred to as the **Galilean moons** (**Figure** 1.30). The Galilean moons are larger than the dwarf planets Pluto, Ceres, and Eris. Ganymede is not only the biggest moon in the solar system; it is even larger than the planet Mercury!

Scientists are particularly interested in Europa because it may be a place to find extraterrestrial life. What features might make a satellite so far from the Sun a candidate for life? Although the surface of Europa is a smooth layer of ice, there is evidence that there is an ocean of liquid water underneath (**Figure** 1.31). Europa also has a continual source of energy —it is heated as it is stretched and squashed by tidal forces from Jupiter. Numerous missions have been planned to explore Europa, including plans to drill through the ice and send a probe into the ocean. However, no such mission has yet been attempted.

In 1979, two spacecraft —Voyager 1 and Voyager 2 —visited Jupiter and its moons. Photos from the Voyager missions showed that Jupiter has a ring system. This ring system is very faint, so it is difficult to observe from Earth.

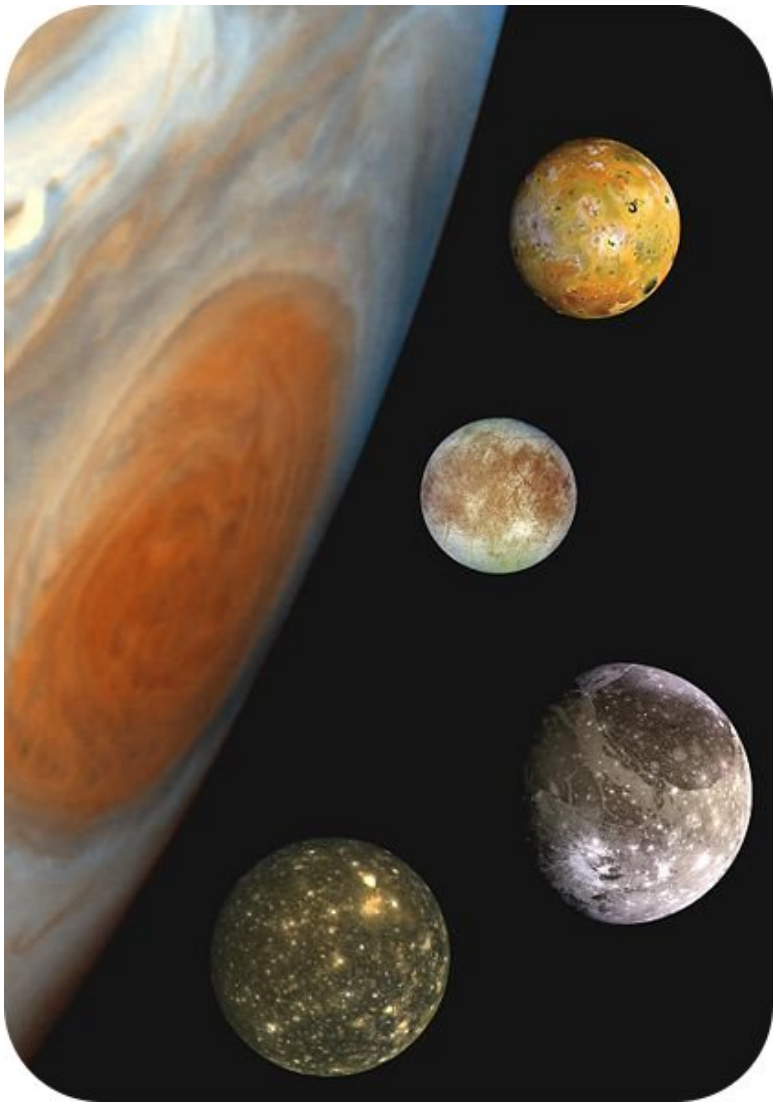


FIGURE 1.30

This composite image shows the four Galilean moons and their sizes relative to the Great Red Spot. From top to bottom, the moons are Io, Europa, Ganymede, and Callisto. Jupiter's Great Red Spot is in the background. Sizes are to scale.

Summary

- Jupiter is mostly hydrogen with some helium, and may contain a small rocky core.
- Jupiter has a thick atmosphere containing the Great Red Spot, a storm that has been going for at least 300 years.
- One of Jupiter's moons, Europa, appears to have a liquid ocean beneath the surface due to tidal forces from the massive planet; this ocean could be a place for life.

Practice

Use this resource to answer the questions that follow.

http://www.sciencechannel.com/video-topics/space-videos/space-school-jupiter.htm

1. What types of material is Jupiter made of (solid, liquid, gas)? Where is its solid surface?
2. What is Jupiter's composition? What does this composition mirror?
3. What is the core of Jupiter like?

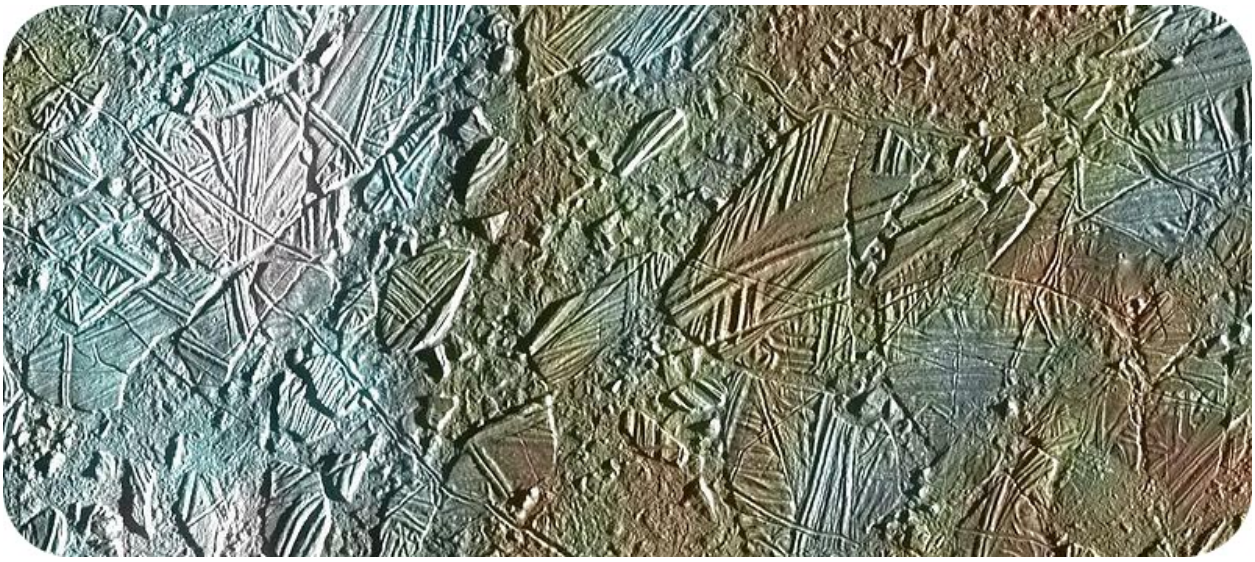


FIGURE 1.31

An enhanced color image of a portion of Europa's icy surface. The surface ice may have motions similar to plate tectonics on Earth.

4. What lies above the core?
5. What are the colorful bands across the planet and what do the different colors indicate?
6. What are Jupiter's high temperatures due to? What does that mean?
7. Why doesn't Jupiter become a star?
8. What causes the huge storms on Jupiter?
9. What is the Great Red Spot? How long has it been on Jupiter?
10. What about the Great Red Spot changes over time? What doesn't change?
11. Why do we owe gratitude to Jupiter?
12. What is important about the four inner moons?
13. What is important about Europa?
14. What are most of Jupiter's moons?
15. Why do probes get crashed into Jupiter rather than being left in orbit?

Practice Answers

1. Jupiter is made of gas and liquid and has no solid surface. The gas gets denser inward.
2. Mostly hydrogen with some helium and a small amount of methane, water and ammonia. This is similar to the composition of the entire solar nebula.
3. It is thought to be solid, rocky and very large.
4. Liquid, metallic hydrogen.
5. The colorful bands indicate clouds at different altitudes: blue: lowest; browns and white: middle; reds: highest.
6. Gravitational compression: this is the intense pressure on the core due to gravity.
7. It is not massive enough for nuclear fusion to begin.
8. Heat from the core collides with cold atmosphere.

9. It is a giant storm; it has been observed fir 30 years so it is at least that old.
10. It's size changes but its location relative to the equator does not.
11. It's size and location deflect many large asteroids from coming our way.
12. They are close to the planet and spherical in shape; they formed around the same time as Jupiter.
13. Europa has a lot of water; it could have life.
14. They are probably captured asteroids.
15. If they hit a moon they might contaminate it with bacteria, which would ruin future studies of life on the moons.

Want to know more about Jupiter? See https://www.windows2universe.org/jupiter/jupiter.html .

Review

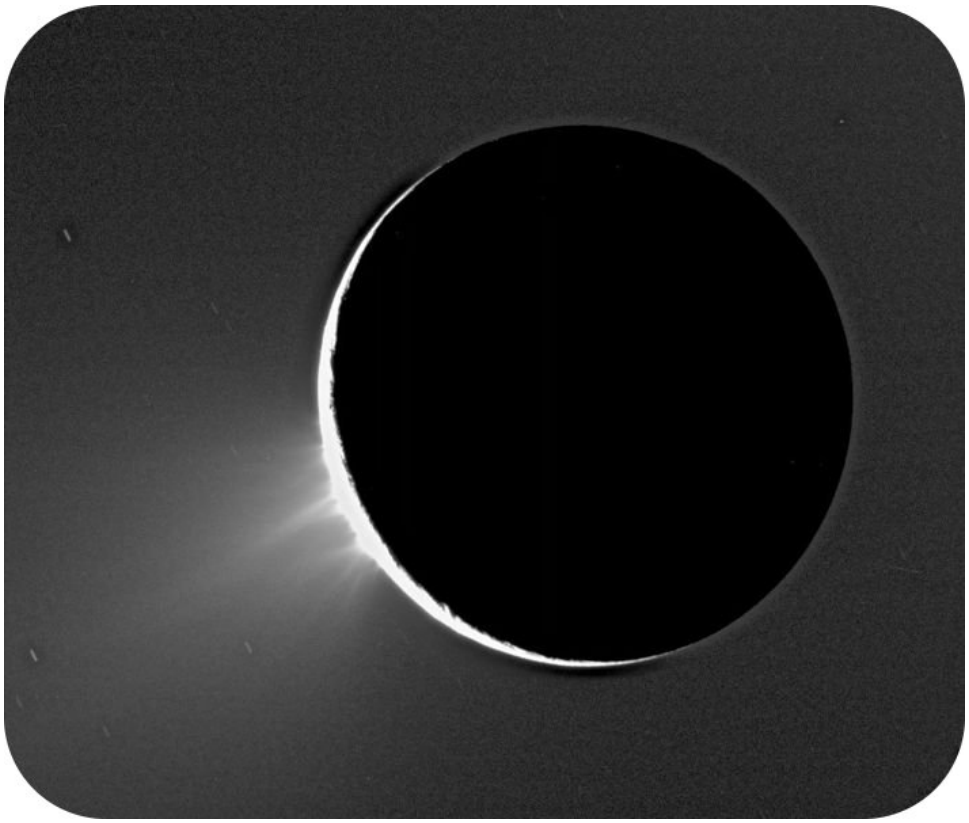
1. Why is the Great Red Spot thought to be a storm?
2. What is Jupiter made of?
3. Why is Europa one of the few locations in the solar system where scientists think there could possibly be life?
4. What is the source of heat on Europa?

Review Answers

1. It changes size and the clouds are seen rotating.
2. Jupiter is made of hydrogen and helium with trace amounts of other elements.
3. Europa has water ice and appears to have an ocean of liquid water beneath the ice since the body has heat.
4. The pull of Jupiter's gravity is the source of heat.

1.12 Saturn

- Describe the characteristics of Saturn.



Is there life elsewhere in the Solar System?

Saturn's moon, Enceladus, may be the most habitable spot in the solar system, other than Earth, for life as we know it. These plumes indicate the presence of water and the internal heat to create liquid water. Is there life? No one knows yet.

Saturn

Saturn, shown in **Figure** 1.32, is famous for its beautiful rings. Although all the gas giants have rings, only Saturn's can be easily seen from Earth. In Roman mythology, Saturn was the father of Jupiter.

Saturn's mass is about 95 times the mass of Earth, and its volume is 755 times Earth's volume, making it the second largest planet in the solar system. Saturn is also the least dense planet in the solar system. It is less dense than water. What would happen if you had a large enough bathtub to put Saturn in? Saturn would float! Saturn orbits the Sun once about every 30 Earth years.

Like Jupiter, Saturn is made mostly of hydrogen and helium gases in the outer layers and liquids at greater depths. The upper atmosphere has clouds in bands of different colors. These rotate rapidly around the planet, but there seems to be less turbulence and fewer storms on Saturn than on Jupiter. One interesting phenomenon that has been observed in the storms on Saturn is the presence of thunder and lightning (see video, below). The planet likely has a small rocky and metallic core.

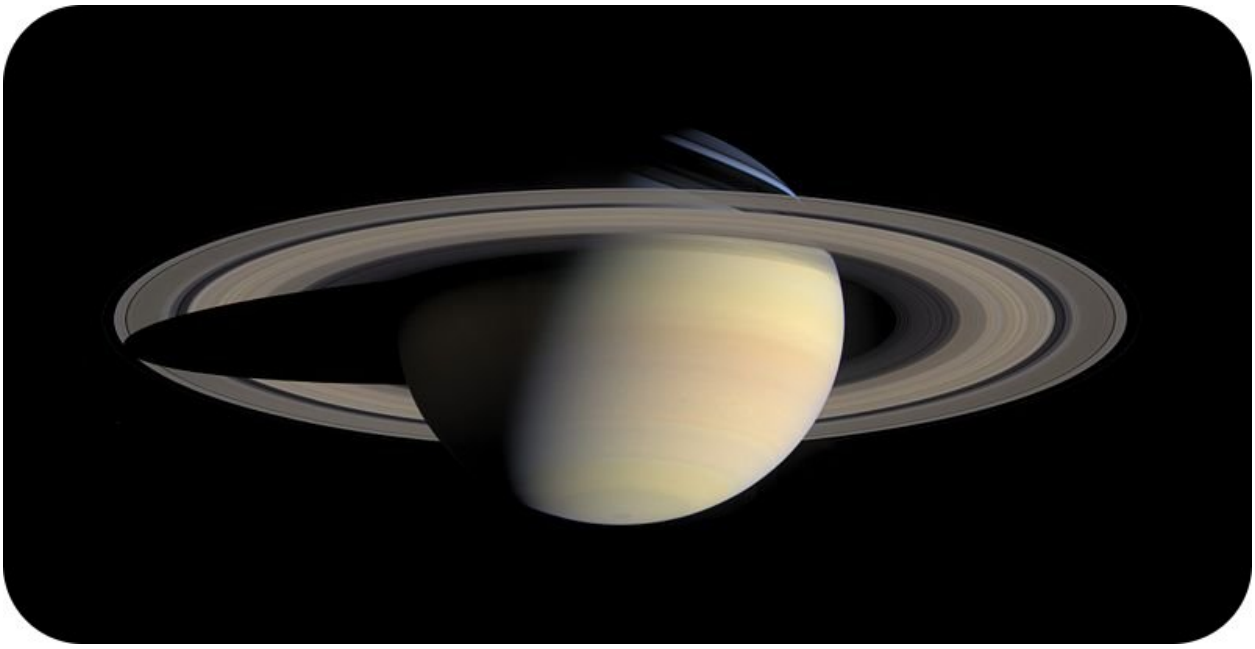


FIGURE 1.32

This image of Saturn and its rings is a composite of pictures taken by the Cassini orbiter in 2008

Cassini scientists waited years for the right conditions to produce the first movie that shows lightning on another planet, Saturn: http://saturn.jpl.nasa.gov/video/videodetails/?videoID=210 .

More videos from the Cassini mission are indexed here: http://saturn.jpl.nasa.gov/video/ .

Saturn's Rings

In 1610, Galileo first observed Saturn's rings with his telescope, but he thought they might be two large moons, one on either side of the planet. In 1659, the Dutch astronomer Christian Huygens realized that the features were rings (**Figure** 1.33).

Saturn's rings circle the planet's equator and appear tilted because Saturn itself is tilted about 27 degrees. The rings do not touch the planet.

The Voyager 1 and 2 spacecraft in 1980 and 1981 sent back detailed pictures of Saturn, its rings, and some of its moons. Saturn's rings are made of particles of water and ice, with some dust and rocks (**Figure** 1.34). There are several gaps in the rings that scientists think have originated because the material was cleared out by the gravitational pull within the rings, or by the gravitational forces of Saturn and of moons outside the rings.

The rings were likely formed by the breakup of one of Saturn's moons or from material that never accreted into the planet when Saturn originally formed.

An animation of dark spokes in Saturn's rings is seen here: http://en.wikipedia.org/wiki/File:Saturn_ring_spokes_PIA11144_300px_secs15.5to23_20080926.ogv . The spokes appear seasonally and their origin is as yet unknown.

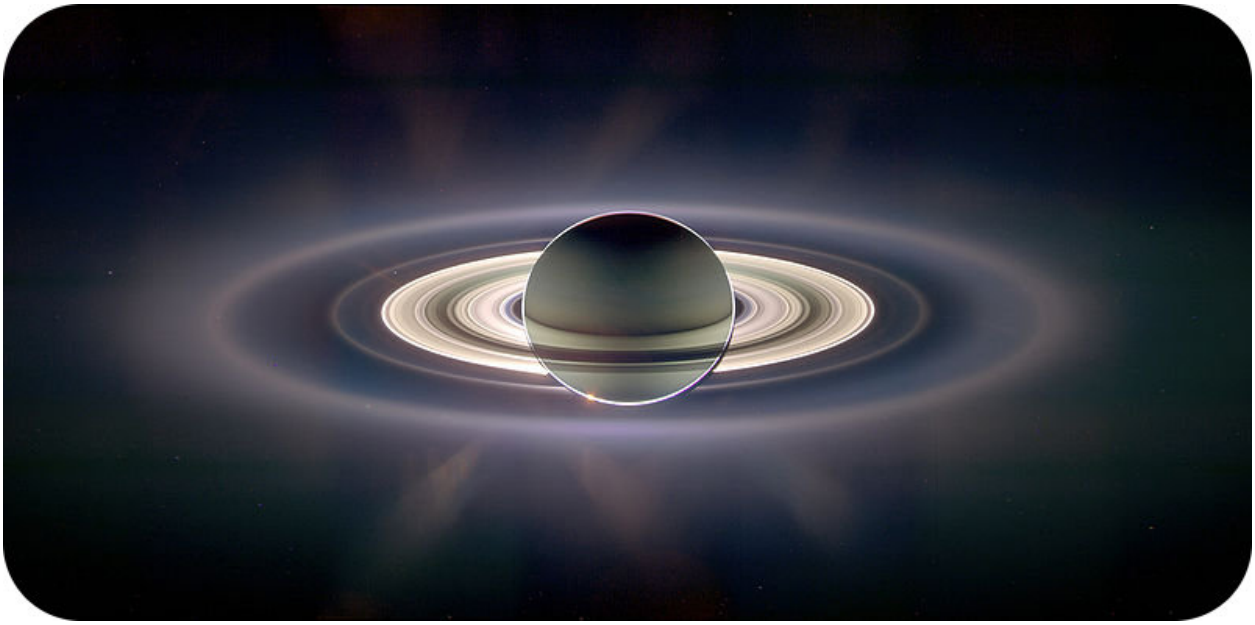


FIGURE 1.33

A color-exaggerated mosaic of Saturn and its rings taken by Cassini as Saturn eclipses the Sun.

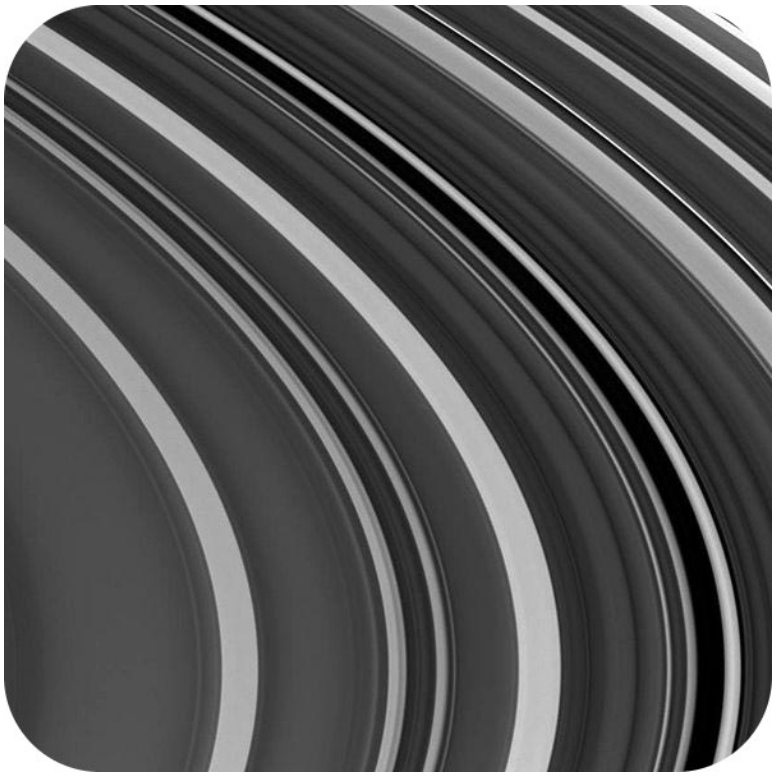


FIGURE 1.34

A close-up of Saturn's outer C ring showing areas with higher particle concentration and gaps.

Saturn's Moons

Most of Saturn's moons are very small, and only seven are large enough for gravity to have made them spherical. Only Titan is larger than Earth's Moon at about 1.5 times its size. Titan is even larger than the planet Mercury.

Scientists are interested in Titan because its atmosphere is similar to what Earth's was like before life developed. Nitrogen is dominant and methane is the second most abundant gas. Titan may have a layer of liquid water and ammonia under a layer of surface ice. Lakes of liquid methane (CH_4) and ethane (C_2H_6) are found on Titan's surface. Although conditions are similar enough to those of early Earth for scientists to speculate that extremely primitive life may exist on Titan, the extreme cold and lack of carbon dioxide make it unlikely (**Figure** 1.35).

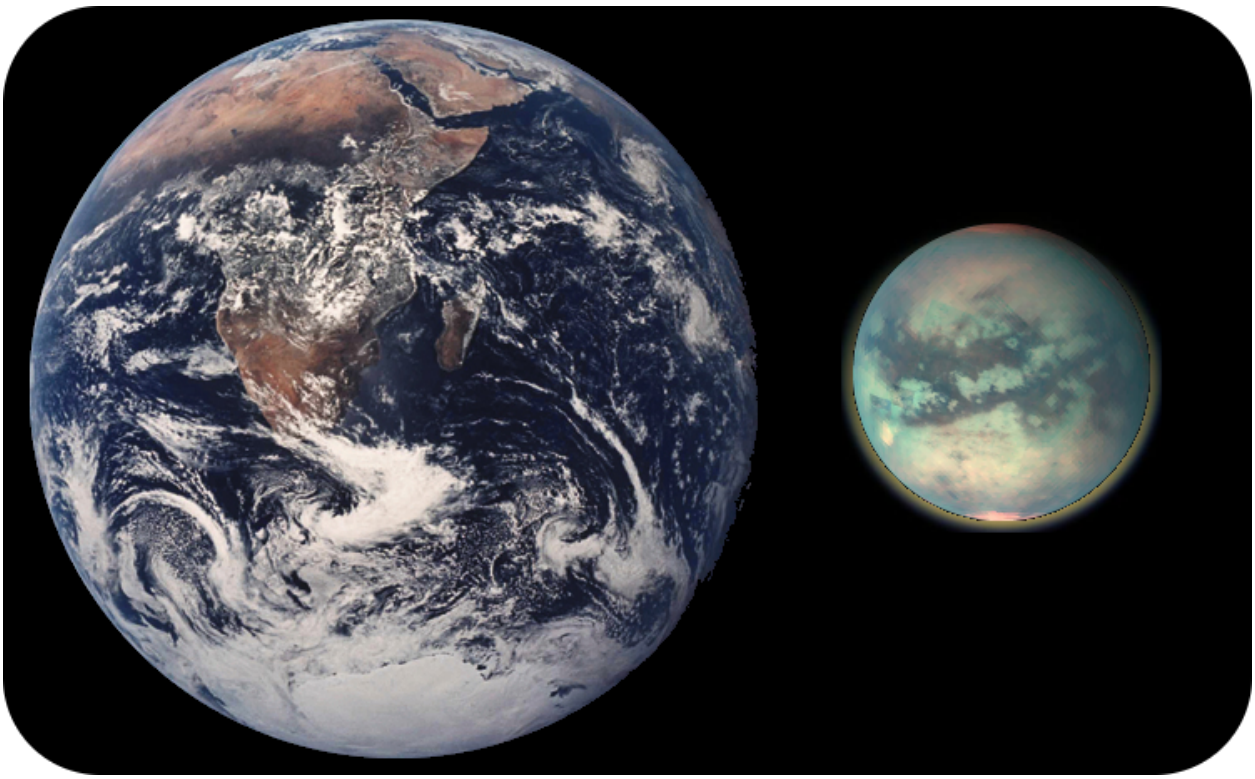


FIGURE 1.35

This composite image compares Saturn's largest moon, Titan (right) to Earth (left).

An incredible virtual tour of Titan as learned from Cassini-Huygens is in this video: http://saturn.jpl.nasa.gov/multimedia/flash/Titan/index.html .

Saturn's tiny moon, Enceladus, is also the subject of a video: http://saturn.jpl.nasa.gov/multimedia/flash/Enceladus/enceladus.html .

Summary

- Like Jupiter, Saturn is made of hydrogen and helium.
- Saturn's rings are composed of water and ice, with some dust and rock.
- Titan has an atmosphere dominated by nitrogen and methane, and may have liquid water beneath the ice.

Practice

Use this resource to answer the questions that follow.

1. What is the relative size and composition of Saturn's core?
2. What is the layer just outside the core composed of?
3. What is the composition of the rest of the planet?
4. Why does Saturn radiate more energy into space than it receives from the Sun?
5. Why does Saturn have distinctive colored bands surrounding it?
6. What are the features of the "dragon storm?"
7. What are the rings made up of?
8. Why are the rings visible?
9. What do scientists think is the origin of Saturn's rings?
10. What are most of Saturn's moons?
11. What is interesting about Titan?
12. What did Huygens discover about Titan?

Practice Answers

1. Saturn has a relatively small core of ice and rock.
2. It is liquid metallic hydrogen.
3. hydrogen, helium, molecular hydrogen, water, methane, and ammonia
4. The energy is generated from graduate cooling, which leads to compression and heats up the core.
5. Different layers of atmosphere make the different colors.
6. It is like a massive white clouds and has white plumes, emits radio waves, and has tremendously fast winds?
7. They are made of millions of particles orbiting the planet: mostly water ice, dust and rock.
8. The particles are highly reflective so they light up.
9. They are the material from an ancient moon that crumbled.
10. captured asteroids
11. Titan is the second largest moon in the solar system. It is the only known moon to have a significant atmosphere; it may resemble young Earth's. But it doesn't have liquid water.
12. It has liquid methane and may have secrets about origin of life on Earth.

Want to know more about Saturn? See https://www.windows2universe.org/saturn/saturn.html .

Review

1. What features of Enceladus lead scientists to think that the moon could have life?
2. What caused Saturn's rings to form?
3. What features of Titan make it a possible location for life, but why do scientists think that this is unlikely?

Review Answers

1. Plumes indicate the presence of water and internal heat.
2. The rings are particles of ice, dust and rocks that are probably a broken up moon.
3. Titan's atmosphere is similar to early Earth's; it is extremely cold and has no carbon dioxide so life is unlikely.

1.13 Uranus

- Describe the characteristics of Uranus.

Uranus was the father of Saturn.

Uranus is an icy blue-green ball named for the ancient Greek god of the heavens. The planet's satellites are named for the characters of Shakespeare and Alexander Pope.

Uranus

Uranus (YOOR-uh-nuhs) is named for the Greek god of the sky. From Earth, Uranus is so faint that it was unnoticed by ancient observers. William Herschel first discovered the planet in 1781.

Although Uranus is very large, it is extremely far away, about 2.8 billion km (1.8 billion mi) from the Sun. Light from the Sun takes about 2 hours and 40 minutes to reach Uranus. Uranus orbits the Sun once about every 84 Earth years.

Uranus has a mass about 14 times the mass of Earth, but it is much less dense than Earth. Gravity at the surface of Uranus is weaker than on Earth's surface, so if you were at the top of the clouds on Uranus, you would weigh about 10% less than what you weigh on Earth.

An Icy Blue-Green Ball

Like Jupiter and Saturn, Uranus is composed mainly of hydrogen and helium, with an outer gas layer that gives way to liquid on the inside. Uranus has a higher percentage of icy materials, such as water, ammonia (NH_3), and methane (CH_4), than Jupiter and Saturn.

When sunlight reflects off Uranus, clouds of methane filter out red light, giving the planet a blue-green color. There are bands of clouds in the atmosphere of Uranus, but they are hard to see in normal light, so the planet looks like a plain blue ball.

The Sideways Planet

Most of the planets in the solar system rotate on their axes in the same direction that they move around the Sun. Uranus, though, is tilted on its side, so its axis is almost parallel to its orbit. In other words, it rotates like a top that was turned so that it was spinning parallel to the floor. Scientists think that Uranus was probably knocked over by a collision with another planet-sized object billions of years ago.

Rings and Moons of Uranus

Uranus has a faint system of rings (**Figure** 1.36). The rings circle the planet's equator, but because Uranus is tilted on its side, the rings are almost perpendicular to the planet's orbit.

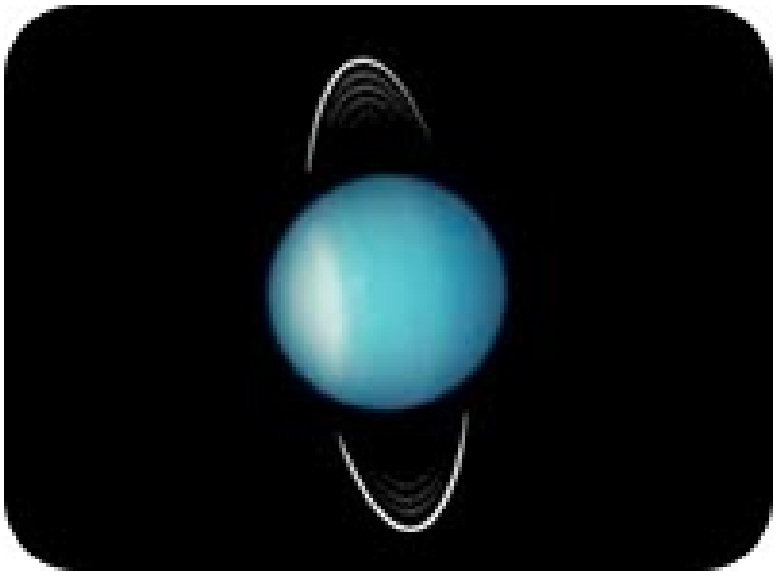


FIGURE 1.36

This image from the Hubble Space Telescope shows the faint rings of Uranus. The planet is tilted on its side, so the rings are nearly vertical.

Uranus has 27 known moons and all but a few of them are named for characters from the plays of William Shakespeare. The five biggest moons of Uranus —Miranda, Ariel, Umbriel, Titania, and Oberon —are shown in **Figure** 1.37.

Summary

- Uranus is composed of hydrogen and helium, but methane clouds filter red light and give the planet a blue-green color.
- The rotational axis of Uranus is tilted almost parallel to its orbit.

FIGURE 1.37
These Voyager 2 photos have been resized to show the relative sizes of the five main moons of Uranus.

- Uranus has rings that are nearly perpendicular to the planet's orbit.

Practice

Use this resource to answer the questions that follow.

1. What is the rotation of Uranus like?
2. What is the gravity of Uranus compared with the gravity of Earth? Why do you think that is the case?
3. What is the weather like on Uranus? What causes violent storms?
4. What is the core of the planet? What is the mantle?
5. What unusual feature is found in the core and how does it form?
6. What makes up the outer layer of Uranus?
7. Why does Uranus appear blue?
8. Why is Uranus tipped on its side?
9. What is the effect of the tipped orbit on the planet's seasons? Does Uranus have seasons? Why or why not?
10. How are Uranus' rings different from Saturn's?

Practice Answers

1. It is very fast so a day is only 18 hours long.
2. It is about 91%. Uranus has low mass compared with Earth.
3. The planet has violent winds and thunderstorms; also hurricanes. Evey 42 years the dark side comes into the light.
4. The core is solid and rocky and it is surrounded by a mantle of ice.
5. The core has such high pressure on it's carbon-rich core that diamonds form.
6. Hydrogen and helium gas, possibly with a liquid ocean including ammonia.
7. Atmospheric methane absorbs red light.
8. Perhaps due to a long ago collision
9. The north pole receives sunlight only half the year. The planet is so far from the Sun that it doesn't really have seasons.
10. They are smaller and tilted on their side; the outer one is blue, indicating water ice.

Want to know more about Uranus? See https://www.windows2universe.org/uranus/uranus.html .

Review

1. Why would you weigh only 90% of your Earth weight on Uranus?
2. Why is Uranus tilted on its side?
3. Why is Uranus blue?

Review Answers

1. Uranus is much less dense than Earth so it's gravity is weaker.
2. It was probably struck by a collision with a large object earlier in the history of the solar system.
3. Atmospheric methane filters out red light.

1.14 Neptune

- Describe the characteristics of Neptune.

How do you think Neptune got its name?

Because of its blue color, Neptune was named for the Roman god of the sea. This statue of Neptune is at the Trevi Fountain in Rome.

Neptune

Neptune, shown in **Figure** 1.38, is the only major planet that can't be seen from Earth without a telescope. Scientists predicted the existence of Neptune before it was discovered because Uranus did not always appear exactly where

it should appear. They knew that the gravitational pull of another planet beyond Uranus must be affecting Uranus' orbit.

Neptune was discovered in 1846, in the position that had been predicted, and it was named Neptune for the Roman god of the sea because of its bluish color.

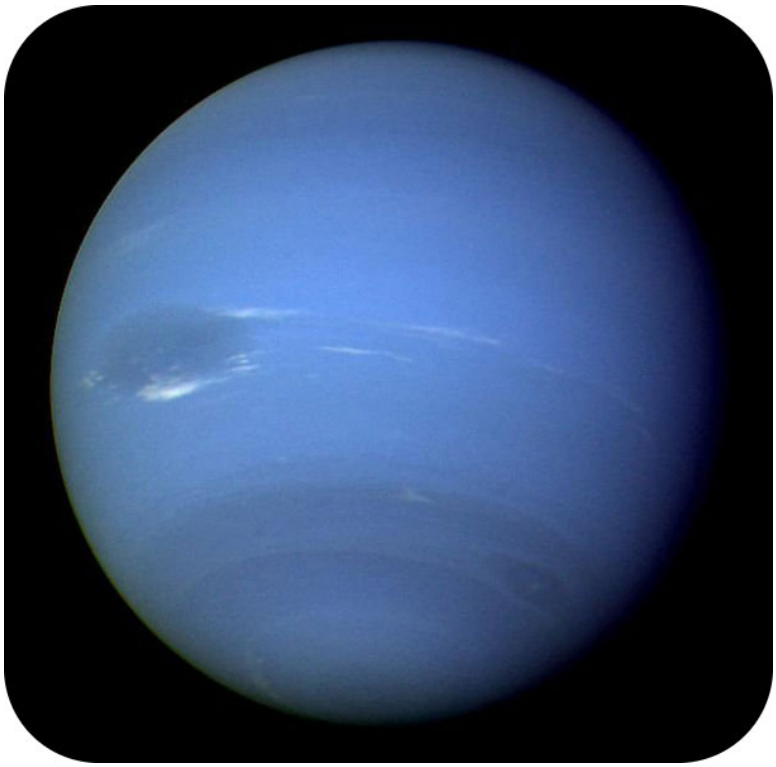


FIGURE 1.38

This image of Neptune was taken by Voyager 2 in 1989. The Great Dark Spot seen on the left center in the picture has since disappeared, but a similar dark spot has appeared on another part of the planet.

In many respects, Neptune is similar to Uranus (**Figure** 1.39). Neptune has slightly more mass than Uranus, but it is slightly smaller in size. Neptune is much farther from the Sun, at nearly 4.5 billion km (2.8 billion mi). The planet's slow orbit means that it takes 165 Earth years to go once around the Sun.

Extremes of Cold and Wind

Neptune's blue color is mostly because of frozen methane (CH_4). When Voyager 2 visited Neptune in 1986, there was a large dark-blue spot, which scientists named the Great Dark Spot, south of the equator. When the Hubble Space Telescope took pictures of Neptune in 1994, the Great Dark Spot had disappeared, but another dark spot had appeared north of the equator. Astronomers think that both of these spots represent gaps in the methane clouds on Neptune.

The changing appearance of Neptune is caused by its turbulent atmosphere. The winds on Neptune are stronger than on any other planet in the solar system, reaching speeds of 1,100 km/h (700 mi/h), close to the speed of sound. This extreme weather surprised astronomers, since the planet receives little energy from the Sun to power weather systems. Neptune's core is 7000°C (12,632°C) which means that it produces more energy than it receives from the Sun. Neptune is also one of the coldest places in the solar system. Temperatures at the top of the clouds are about -218°C (-360°F).

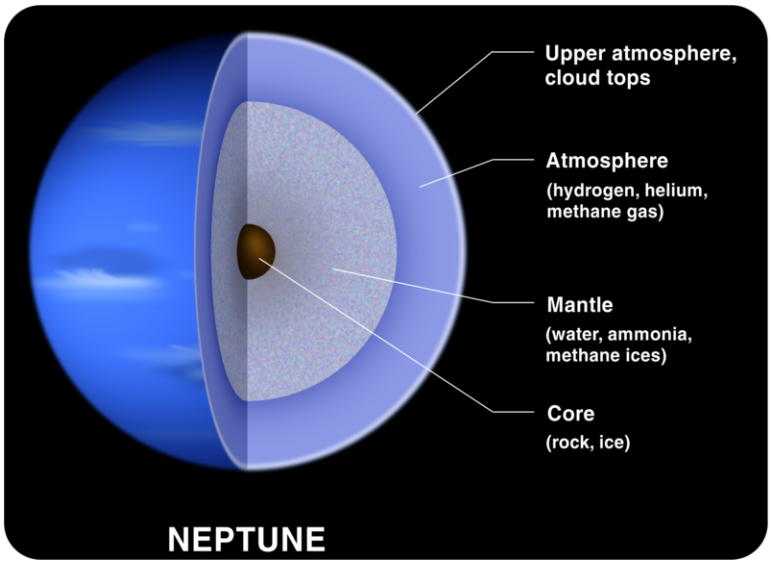


FIGURE 1.39

Neptune's composition is that of a gas giant: (1) upper atmosphere, (2) atmosphere composed of hydrogen, helium and methane gas, (3) mantle of water, ammonia and methane ice, (4) core of rock and ice.

Neptune's Rings and Moons

Neptune has faint rings of ice and dust that may change or disappear in fairly short time frames.

Neptune has 13 known moons. Triton, shown in **Figure** 1.40, is the only one of them that has enough mass to be spherical in shape. Triton orbits in the direction opposite to the orbit of Neptune. Scientists think Triton did not form around Neptune, but instead was captured by Neptune's gravity as it passed by.

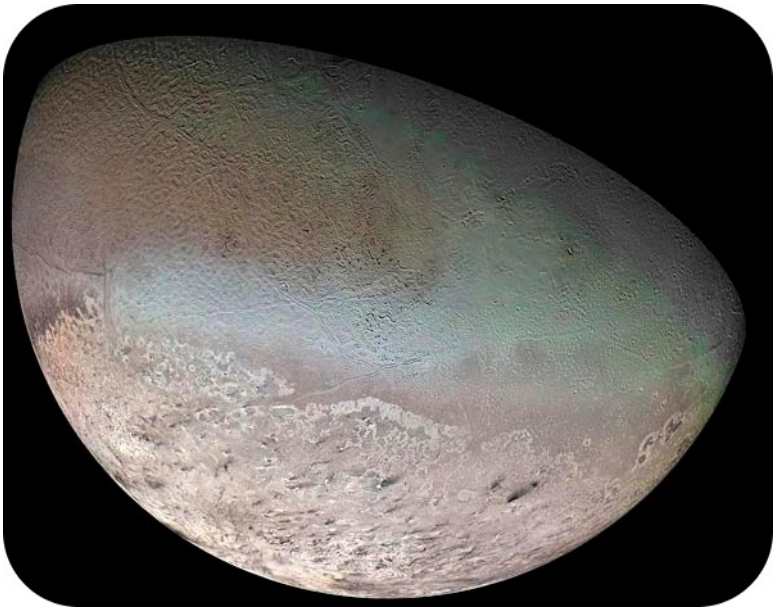


FIGURE 1.40

This image of Triton, Neptune's largest moon, was taken by Voyager 2 in 1989.

Fly by Neptune's moon Triton by watching this video: http://www.space.com/common/media/video/player.php?videoRef=mm32_SunDeath#playerTop .

Summary

- Neptune is so far from Earth that it can't be seen without a telescope.
- Neptune has a turbulent atmosphere, which changes the planet's appearance. The blue color is due to frozen methane.
- Neptune has 13 moons, including Triton, which orbits in the opposite direction from Neptune.

Practice

Use this resource to answer the questions that follow. https://www.youtube.com/watch?v=EmUvTH7sveg

1. How was Neptune found?
2. What is the structure of Neptune?
3. What is the atmosphere composed of? Why is Neptune blue?
4. What is the atmosphere of Neptune like?
5. What causes the intense winds on Neptune? Why aren't the winds caused by the Sun?
6. How long is a season on Neptune?
7. What is Triton? What is unusual about it?
8. What is the probably origin of Neptune's rings?
9. Why do we know so little about Neptune?

Practice Answers

1. Irregularities in the orbit of Uranus allowed scientists to predict where another planet might be and there was Neptune.
2. It has a rocky core surrounded by thick layers of ice and gas.
3. 80$ hydrogen, 19% helium + methane, which absorbs the red light and makes the planet appear blue.
4. The atmosphere is very thick and active with huge storms and the fastest winds in the solar system.
5. The planet's internal heat cause the winds; Neptune is too far from the Sun for it to generate powerful storms.
6. 40 years!
7. It was probably a dwarf planet that was pulled into the orbit of Neptune. It is geologically active with geysers that erupt nitrogen.
8. The rings are probably dust particles that resulted when meteorites smashed into Neptune's moons.
9. It is very far away and has not been visited as much as other planets.

Want to know more about Neptune? See https://www.windows2universe.org/neptune/neptune.html .

Review

1. Why did scientists think that there was a planet beyond Uranus before it had been identified as a planet in a telescope?
2. Describe the moons of Neptune and where they originated.
3. What causes the dark spots in Neptune's appearance? Why do they come and go?

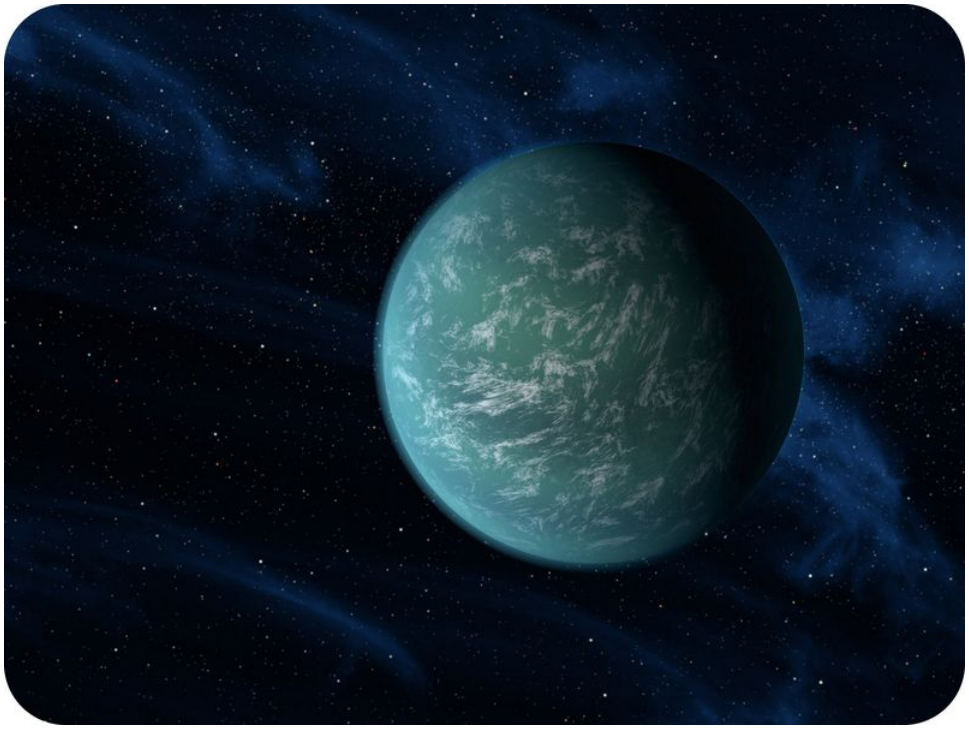
Review Answers

1. It affects the orbit of the planet Uranus and it was calculated to be where it is.
2. Triton is the only one that is spherical; scientists think it is a dwarf planet that was captured by the planet. The others are captured asteroids.

3. The dark spots are storms. The storms may end and new storms may begin.

1.15 Exoplanets

- Define exoplanet.
- Explain how scientists locate exoplanets.



Is there life on other planets?

Several planets, like Kepler-22b, have recently been discovered that are in the habitable zones of a sun-like star. This means that the planet could have liquid water, which is necessary for life on Earth. This planet is larger than Earth, but may have pleasant surface temperatures. Still,the chances that it harbors life are slim, but there are likely many more Earth-like planets in the universe.

Extrasolar Planets or Exoplanets

Since the early 1990s, astronomers have discovered other solar systems, with planets orbiting stars other than our own Sun. These are called "extrasolar planets" or simply **exoplanets** (see **Figure** 1.41). Exoplanets are not in our solar system, but are found in other solar systems.

Some extrasolar planets have been directly imaged, but most have been discovered by indirect methods. One technique involves detecting the very slight motion of a star periodically moving toward and away from us along our line-of-sight (also known as a star's "radial velocity"). This periodic motion can be attributed to the gravitational pull of a planet or, sometimes, another star orbiting the star.

An animation showing how the orbit of a smaller body, such as a planet or small star, can be identified by the effect it has on the orbit of a larger star is seen here from above: http://upload.wikimedia.org/wikipedia/commons/5/59/Orbit3.gif . This is in line with the plane of the system: http://en.wikipedia.org/wiki/File:Dopspec-inline.gif .

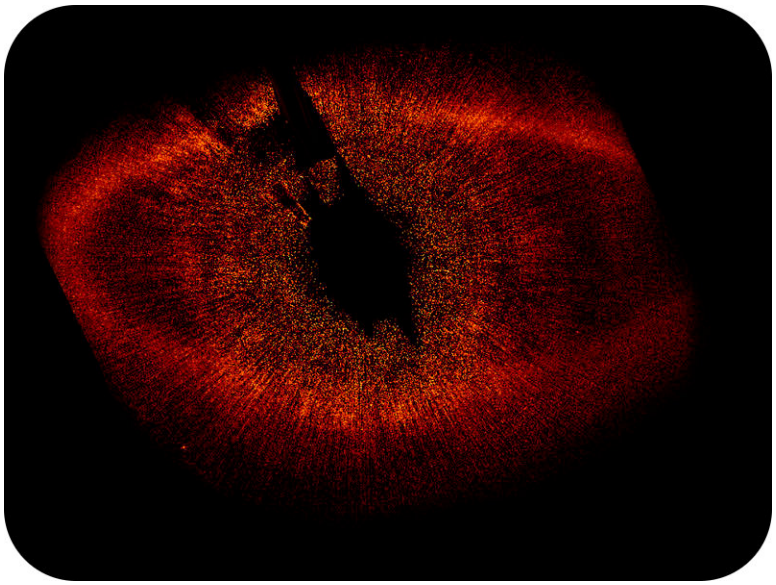


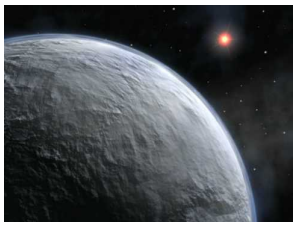
FIGURE 1.41

The extrasolar planet Fomalhaut is surrounded by a large disk of gas. The disk is not centered on the planet, suggesting that another planet may be pulling on the gas as well.

A planet may also be identified by measuring a star's brightness over time. A temporary, periodic decrease in light emitted from a star can occur when a planet crosses in front of, or "transits," the star it is orbiting, momentarily blocking out some of the starlight.

More than 1800 extrasolar planets have been identified and confirmed and the rate of discovery is increasing rapidly.

Extrasolar Planet from the ESA discusses extrasolar planets and particularly a planetary system very similar to our solar system: http://www.youtube.com/watch?v=ouJahDONTWc (3:29).



MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1462

An introduction to extrasolar planets from NASA is available at: http://www.youtube.com/watch?v=oeeZCHDNTvQ (3:14).

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/1463

According to NASA, a statistical analysis shows that the Milky Way galaxy contains 100 million planets. That's a lot of exoplanets!

http://science.kqed.org/quest/audio/exoplanets/

MEDIA
Click image to the left for use the URL below.
URL: http://gamma.ck12.org/flx/render/embeddedobject/60944

Hundreds of exoplanets have now been discovered. To learn something about how planet hunters find these balls of rock they usually can't even see, watch this QUEST video at http://www.kqed.org/quest/television/the-planet-hunters .

MEDIA
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URL: http://gamma.ck12.org/flx/render/embeddedobject/114952

Summary

- Now that scientists know how to identify extrasolar planets, the numbers of confirmed examples are increasing rapidly.
- An exoplanet may decrease a star's brightness as it passes in front of it.
- The gravitational pull of a planet may be detected in the slight motion of a star.

Practice

Use this resource to answer the questions that follow.

https://www.youtube.com/watch?v=cvET91EYoyc

1. What did the Greeks think was the structure of the solar system?
2. What did "atomos" mean in ancient Greek and how does that word indicate what they thought of the stuff that was "out there?"
3. What was mission of the Kepler telescope?
4. As of the time this video was made how many possible exoplanets were identified? How many confirmed exoplanets?
5. How did the Kepler telescope identify exoplanets?
6. What is an Earth-like planet?
7. Does a planet in the habitable zone for sure have life or not have life? Why or why not?
8. What is the question we're really interested in?

Practice Answers

1. Earth was in the center of a set of spheres including the Moon, Sun, stars and everything else.
2. Atomos is indivisible and indicates that they thought the stuff out there was made of the same things Earth is made of. Stars were far away suns.
3. It was to hunt for extrasolar planets.
4. 3,602 candidates; 1,047 confirmed
5. It looked for a shadow to pass across the planet's star.

6. It is a planet in the habitable zone where it is not to hot or cold, not too dim or bright, the zone is not too big or small and the planet is made of rock instead of gas, and maybe water could be on the surface.
7. No, the planet might be too hot or cold or not have a conducive atmosphere for life.
8. What is the chance that there is intelligent life out there?

Review

1. What is an exoplanet?
2. Where are exoplanets located? How are exoplanets discovered?
3. Why are scientists so interested in exoplanets?

Review Answers

1. An extrasolar planet is a planet that is outside our solar system.
2. Exoplanets are far from Earth. Mostly they are found by detecting changes in the motion of a star or by the planet going in front o the star and dimming its light very faintly.
3. If there is intelligent life elsewhere in our part of the Milky Way Galaxy it will be on an exoplanet, most likely an Earth-like exoplanet.

1.16 Asteroids

- Describe asteroids and the asteroid belt.
- Explain what affects asteroids may have on Earth and other planets.

Could human life end with an asteroid?

Asteroid impacts have played an enormous role in creating Earth and in altering the course of the evolution of life. It is most likely that an asteroid impact brought the end of the dinosaurs and many other lifeforms at the end of the Mesozoic. Could one asteroid do it again?

Asteroids

Asteroids are very small, rocky bodies that orbit the Sun. "Asteroid" means "star-like," and in a telescope, asteroids look like points of light, just like stars. Asteroids are irregularly shaped because they do not have enough gravity to become round. They are also too small to maintain an atmosphere, and without internal heat they are not geologically active (**Figure** 1.42). Collisions with other bodies may break up the asteroid or create craters on its surface.

Asteroid impacts have had dramatic impacts on the shaping of the planets, including Earth. Early impacts caused the planets to grow as they cleared their portions of space. An impact with an asteroid about the size of Mars caused fragments of Earth to fly into space and ultimately create the Moon. Asteroid impacts are linked to mass extinctions throughout Earth's history.

FIGURE 1.42

In 1991, Asteroid 951 Gaspra was the first asteroid photographed at close range. Gaspra is a medium-sized asteroid, measuring about 19 by 12 by 11 km (12 by 7.5 by 7 mi).

The Asteroid Belt

Hundreds of thousands of asteroids have been discovered in our solar system. They are still being discovered at a rate of about 5,000 new asteroids per month. The majority of the asteroids are found in between the orbits of Mars and Jupiter, in a region called the **asteroid belt**, as shown in **Figure** 1.43. Although there are many thousands of asteroids in the asteroid belt, their total mass adds up to only about 4% of Earth's Moon.

Scientists think that the bodies in the asteroid belt formed during the formation of the solar system. The asteroids might have come together to make a single planet, but they were pulled apart by the intense gravity of Jupiter.

Near-Earth Asteroids

More than 4,500 asteroids cross Earth's orbit; they are **near-Earth asteroids**. Between 500 and 1,000 of these are over 1 km in diameter.

Any object whose orbit crosses Earth's can collide with Earth, and many asteroids do. On average, each year a rock about 5–10 m in diameter hits Earth (**Figure** 1.44). Since past asteroid impacts have been implicated in mass extinctions, astronomers are always on the lookout for new asteroids, and follow the known near-Earth asteroids closely, so they can predict a possible collision as early as possible.

Asteroid Missions

Scientists are interested in asteroids because they are representatives of the earliest solar system (**Figure** 1.45). Eventually asteroids could be mined for rare minerals or for construction projects in space. A few missions have studied asteroids directly. NASA's DAWN mission explored asteroid Vesta in 2011 and 2012 and will visit dwarf planet Ceres in 2015.

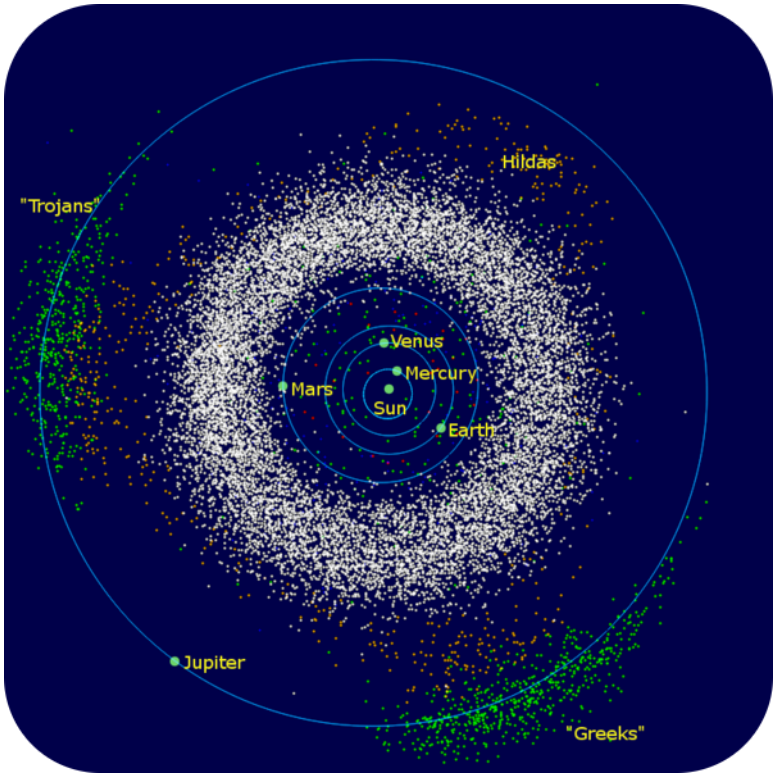


FIGURE 1.43

The white dots in the figure are asteroids in the main asteroid belt. Other groups of asteroids closer to Jupiter are called the Hildas (orange), the Trojans (green), and the Greeks (also green).

FIGURE 1.44

A painting of what an asteroid a few kilometers across might look like as it strikes Earth.

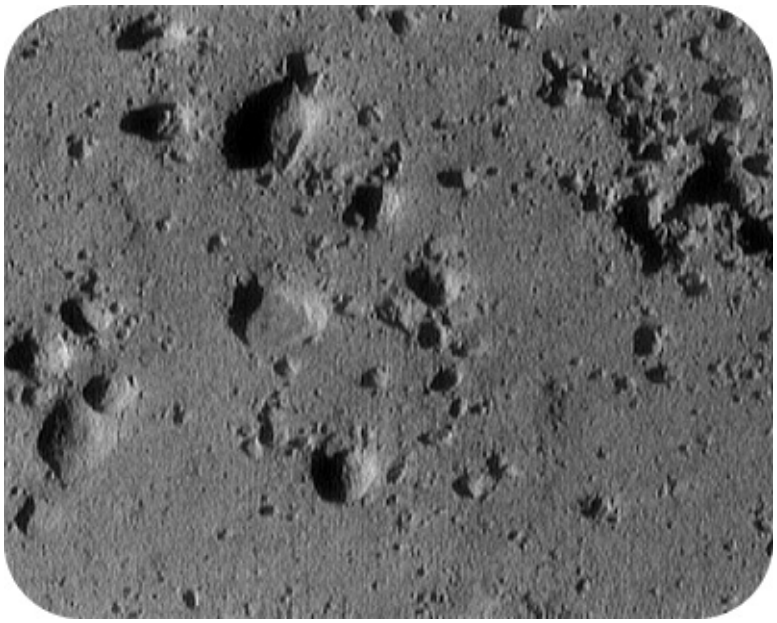


FIGURE 1.45

The NEAR Shoemaker probe took this photo as it was about to land on 433 Eros in 2001.

KQED: Asteroid Hunters

Thousands of objects, including comets and asteroids, are zooming around our solar system; some could be on a collision course with Earth. QUEST explores how these Near Earth Objects are being tracked and what scientists are saying should be done to prevent a deadly impact. Learn more at: http://science.kqed.org/quest/video/asteroid-hunters/ .

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/114950

Summary

- Asteroids are small rocky bodies that orbit the Sun and sometimes strike Earth.
- Most asteroids reside in the asteroid belt, between Mars and Jupiter.
- Near-earth asteroids are the ones most likely to strike Earth, and scientists are always looking out for a large one that may impact our planet and cause problems.

Practice

Use these resources to answer the questions that follow.

http://www.sciencechannel.com/video-topics/space-videos/asteroids.htm

- Rogue Asteroids

1. Why are most asteroids no threat to Earth? Why are some a potential threat?
2. Why are rogue asteroids dragged into near-Earth space?
3. What would happen if a large asteroid hit Earth?

- Asteroid Belt

1. How many asteroids 1/2 mile or larger are in Earth crossing orbit?
2. When will a catastrophic asteroid impact happen?
3. What happened when Shoemaker-Levy 9 hit Jupiter?
4. What could we do if an asteroid were headed toward us?

Practice Answers

- Rogue Asteroids

1. Most are locked into orbit around the Sun far from Earth, but some are on a more rogue path that may bring them near Earth.
2. The enormous gravitational tug of Jupiter draws them into near-Earth orbit.
3. Near the impact site everything would vaporize.

- Asteroid Belt

1. 500
2. No one knows but it will happen.
3. A tremendous amount of energy and an Earth-size dust cloud.
4. We might be able to change the orbit so that the asteroid misses Earth rather than hits Earth.

Review

1. What is the reason there is a belt of asteroids between Mars and Jupiter?
2. Why do scientists look for asteroids that might strike our planet?
3. What do scientists hope to learn from missions to visit asteroids?

Review Answers

1. These asteroids may have been a planet that was pulled apart by Jupiter's gravity.
2. An asteroid caused the extinction at the end of the Cretaceous and if one that size hit again humans would almost certainly die out so they want to try to find a threat and see if something can be done about it.
3. They are remnants from the early solar system. They also could collide with Earth so knowing more about them could help us avoid that.

1.17 Comets

- Describe the characteristics of comets and explain where they come from.

Why do comets have tails?

The ball of white in the lower left portion of the image is a comet, Comet Holmes. Comets do not have tails out in space, only when they are close to the Sun. The spiral shaped light in the image is the Andromeda Galaxy.

Comets

Comets are small, icy objects that have very elliptical orbits around the Sun. Their orbits carry them from the outer solar system to the inner solar system, close to the Sun. Early in Earth's history, comets may have brought water and other substances to Earth during collisions.

Comet tails form the outer layers of ice melt and evaporate as the comet flies close to the Sun. The ice from the comet vaporizes and forms a glowing coma, which reflects light from the Sun. Radiation and particles streaming

from the Sun push this gas and dust into a long tail that always points away from the Sun (**Figure** 1.46). Comets appear for only a short time when they are near the Sun, then seem to disappear again as they move back to the outer solar system.

FIGURE 1.46

Comet Hale-Bopp, also called the Great Comet of 1997, shone brightly for several months in 1997. The comet has two visible tails: a bright, curved dust tail and a fainter, straight tail of ions (charged atoms) pointing directly away from the Sun.

The time between one appearance of a comet and the next is called the comet's period. Halley's comet, with a period of 75 years, will next be seen in 2061. The first mention of the comet in historical records may go back as much as two millennia.

Where Comets Come From

Short-period comets, with periods of about 200 years or less, come from a region beyond the orbit of Neptune called the **Kuiper belt** (pronounced "KI-per"). It contains not only comets, but also asteroids and at least two dwarf planets.

Comets with periods as long as thousands or even millions of years come from a very distant region of the solar system called the Oort cloud, about 50,000 —100,000 AU from the Sun (50,000 –100,000 times the distance from the Sun to Earth).

Summary

- Comets are icy objects that have very elliptical orbits around the Sun.
- Comet tails form as ice vaporizes and glows in the Sun's light.

- Short-period comets come from the Kuiper belt beyond Neptune, and long-period comets come from the Oort cloud far out away from the Sun.

Practice

Use these resources to answer the questions that follow.

https://www.windows2universe.org/comets/comets.html&edu=high

1. What are comets?
2. What happens to comets when they get close to the Sun?
3. What happened to comet Shoemaker-Levy?
4. Why is Hale-Bopp unique?

http://www.windows2universe.org/comets/comet_model_interactive.html

1. What do you observe about the comet at it orbits around the Sun?

Practice Answers

1. Comets are lumps of ice and dust that sometimes make their way from the outer solar system into the inner solar system.
2. When comets get close to the Sun the heats makes the nucleus sublimate and a cloud of gas and dust forms. This creates the jets of dust and gas tails.
3. Shoemaker-Levy plunged into Jupiter in 1994 with astronomers watching.
4. Hale-Bopp is unique because it is very bright.
5. The comet has a much more elliptical orbit than the planets. It takes a long time for it to go around the sun once relative to the inner planets, but it is much faster than Jupiter.

Review

1. Why do comets only have tails when they are near the Sun?
2. Where is the Kuiper belt and what is found in it?
3. Why does Halley's comet appear to earthlings every 75 years?

Review Answers

1. Comet tails form when the outer layers of ice sublimate and reflect sunlight. It must be near the Sun for it to be warm enough for this to happen.
2. The Kuiper belt is located beyond the orbit of Neptune. It contains comets, asteroids and dwarf planets.
3. Halley's Comet has an elliptical orbit and passes near enough to Earth for earthlings to see every 75 years.

1.18 Meteors

- Define and describe meteors, meteoroids, and meteorites.

Is a shooting star really a star flying across the sky?

When a meteor shoots through the atmosphere it burns and glows. When we look up and see one, we call it a shooting star. When Earth travels through the debris left by a comet's tail, we see a meteor shower.

Meteors

A **meteor**, such as in **Figure** 1.47, is a streak of light across the sky. People call them shooting stars but they are actually small pieces of matter burning up as they enter Earth's atmosphere from space.

Meteors are called **meteoroids** before they reach Earth's atmosphere. Meteoroids are smaller than asteroids and range from the size of boulders down to the size of tiny sand grains. Still smaller objects are called interplanetary dust. When Earth passes through a cluster of meteoroids, there is a **meteor shower**. These clusters are often remnants left behind by comet tails.

Meteorites

Although most meteors burn up in the atmosphere, larger meteoroids may strike the Earth's surface to create a **meteorite**. Meteorites are valuable to scientists because they provide clues about our solar system. Many meteorites are from asteroids that formed when the solar system formed (**Figure** 1.48). A few meteorites are made of rocky material that is thought to have come from Mars when an asteroid impact shot material off the Martian surface and into space.

FIGURE 1.47
A meteor streaks across the sky.

FIGURE 1.48
A lunar meteorite originates on the Moon and strikes Earth.

Summary

- A meteor that strikes Earth's surface is a meteorite.
- Many meteorites are remnants of the earliest material that formed in the solar system.
- Shooting stars are meteors that burn up in Earth's atmosphere.

Making Connections

MEDIA

Click image to the left for use the URL below.

URL: http://gamma.ck12.org/flx/render/embeddedobject/64667

Practice

Use these resources to answer the questions that follow.

http://www.windows2universe.org/our_solar_system/meteors/meteors.html&edu=high

1. What are meteors?
2. What happens to most meteors?
3. What are fireballs?
4. Explain the difference between meteors, meteoroids, and meteorites.

http://stardate.org/nightsky/meteors

1. When is the next meteor shower?
2. What causes a meteor shower?

Practice Answers

- Meteors

1. Meteors are rocks that fall through the atmosphere.
2. Most burn up in the atmosphere.
3. Fireballs are shooting stars that light up aas they experience friction in the atmosphere.
4. Meteors are the rocks as they light up in Earth's atmosphere; meteoroids include all categories of these rocks; the ones that strike Earth become meteorites.

- Stardate

1. Answers will vary.
2. Most occur as Earth travels through the stream of debris left by a comet.

Review

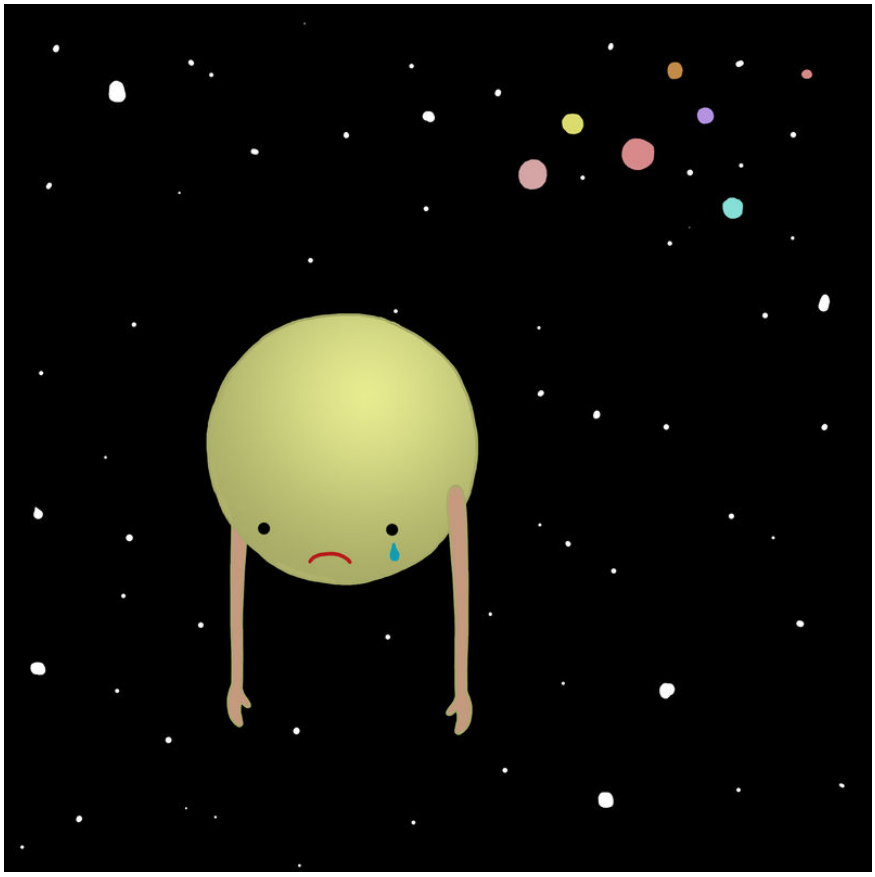
1. The Perseid meteor shower appears every August. Why is the shower so regular in its appearance?
2. What are the similarities and differences between meteors, meteoroids, and meteorites?
3. Why are meteors known as shooting stars?

Review Answers

1. Every August Earth goes through the debris left by a comet so we get the Perseid meteor shower.
2. It depends on where they are. A meteoroid is a rock in space; a meteor enters the atmosphere and a meteorite strikes the surface.
3. When a meteor enters the atmosphere, friction causes it to burn up so it appears as if a star were burning across the sky.

1.19 Dwarf Planets

- Identify our solar system's five dwarf planets.
- Describe the characteristics of dwarf planets.
- Compare and contrast planets and dwarf planets.



What is, and what is not, a planet?

Pluto just didn't fit the criteria for a planet, so it was placed in a new category with others of its kind, dwarf planets. So what is a planet, and what is Pluto?

What is a Planet?

In 2006, the International Astronomical Union decided that there were too many questions surrounding what could be called a planet, and so refined the definition of a planet.

According to the new definition, a planet must:

- Orbit a star.
- Be big enough that its own gravity causes it to be shaped as a sphere.
- Be small enough that it isn't a star itself.
- Have cleared the area of its orbit of smaller objects.

Dwarf Planets

The **dwarf planets** of our solar system are exciting proof of how much we are learning about our solar system. With the discovery of many new objects in our solar system, astronomers refined the definition of a dwarf planet in 2006.

According to the IAU, a dwarf planet must:

- Orbit a star.
- Have enough mass to be nearly spherical.
- Not have cleared the area around its orbit of smaller objects.
- Not be a moon.

Pluto

The reclassification of Pluto to the new category dwarf planet stirred up a great deal of controversy. How the classification of Pluto has evolved is an interesting story in science.

From the time it was discovered in 1930 until the early 2000s, Pluto was considered the ninth planet. When astronomers first located Pluto, the telescopes were not as good, so Pluto and its moon, Charon, were seen as one much larger object (**Figure** 1.49). With better telescopes, astronomers realized that Pluto was much smaller than they had thought.

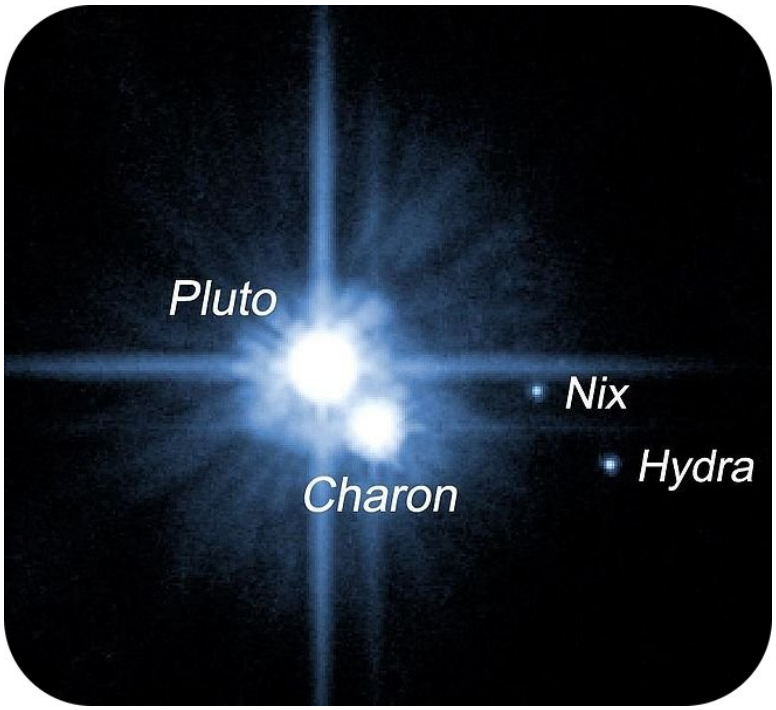


FIGURE 1.49
Pluto and its moon, Charon, are actually two objects.

Better technology also allowed astronomers to discover many smaller objects like Pluto that orbit the Sun. One of them, Eris, discovered in 2005, is even larger than Pluto.

Even when it was considered a planet, Pluto was an oddball. Unlike the other outer planets in the solar system, which are all gas giants, it is small, icy, and rocky. With a diameter of about 2,400 km, it is only about one-fifth the mass of Earth's Moon. Pluto's orbit is tilted relative to the other planets and is shaped like a long, narrow ellipse. Pluto's orbit sometimes even passes inside Neptune's orbit.

In 1992, Pluto's orbit was recognized to be part of the Kuiper belt. With more than 200 million Kuiper belt objects, Pluto has failed the test of clearing other bodies out its orbit.

From what you've read above, do you think Pluto should be called a planet? Why are people hesitant to take away Pluto's planetary status? Is Pluto a dwarf planet?

A video showing why Pluto isn't a planet any more: http://www.youtube.com/watch?v=FqX2YdnwtRc .

Pluto has three moons of its own. The largest, Charon, is big enough that the Pluto-Charon system is sometimes considered to be a double dwarf planet (**Figure** 1.49). Two smaller moons, Nix and Hydra, were discovered in 2005. But having moons is not enough to make an object a planet.

Pluto and the other dwarf planets, besides Ceres, are found orbiting out beyond Neptune.

Ceres

Ceres is by far the closest dwarf planet to the Sun; it resides between Mars and Jupiter. Ceres is the largest object in the asteroid belt (**Figure** 1.50). Before 2006, Ceres was considered the largest of the asteroids, with only about 1.3% of the mass of the Earth's Moon. But unlike the asteroids, Ceres has enough mass that its gravity causes it to be shaped like a sphere. Like Pluto, Ceres is rocky.

Is Ceres a planet? How does it match the criteria above? Ceres orbits the Sun, is round, and is not a moon. As part of the asteroid belt, its orbit is full of other smaller bodies, so Ceres fails the fourth criterion for being a planet.

FIGURE 1.50

This composite image compares the size of the dwarf planet Ceres to Earth and the Moon.

Makemake

Makemake is the third largest and second brightest dwarf planet we have discovered so far (**Figure** 1.51). With a diameter estimated to be between 1,300 and 1,900 km, it is about three-quarters the size of Pluto. Makemake orbits the Sun in 310 years at a distance between 38.5 to 53 AU. It is thought to be made of methane, ethane, and nitrogen ices.

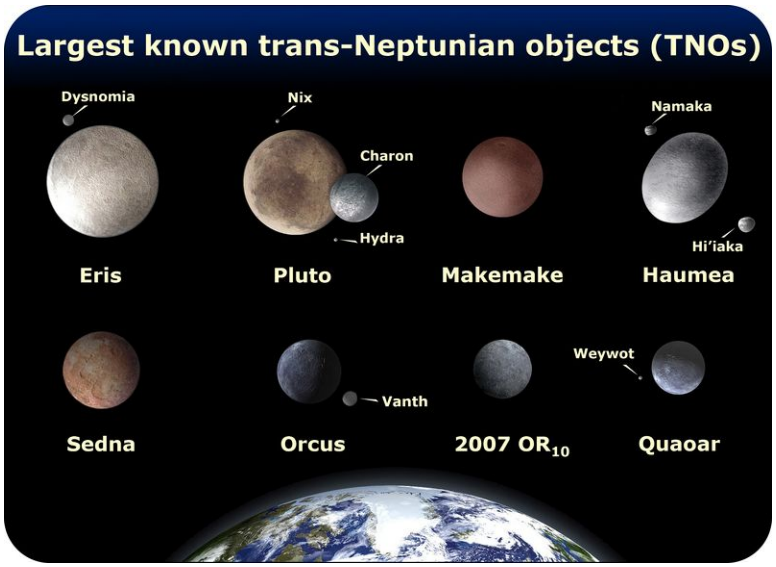


FIGURE 1.51

Largest Known Trans-Neptunian Objects. Makemake is named after the deity that created humanity in the mythology of the people of Easter Island.

Eris

Eris is the largest known dwarf planet in the solar system —it has about 27% more mass than Pluto (**Figure** 1.51). The object was not discovered until 2003 because it is about three times farther from the Sun than Pluto, and almost 100 times farther from the Sun than Earth is. For a short time Eris was considered the "tenth planet" in the solar system, but its discovery helped to prompt astronomers to better define planets and dwarf planets in 2006. Eris also has a small moon, Dysnomia, that orbits it once about every 16 days.

Astronomers know there may be other dwarf planets in the outer reaches of the solar system. Haumea was made a dwarf planet in 2008, so the total number of dwarf planets is now five. Quaoar, Varuna, and Orcus may be added to the list of dwarf planets in the future. We still have a lot to discover and explore.

Summary

- There are currently five dwarf planets in our solar system: Pluto, Eris, Haumea, Makemake, and Ceres.
- Most dwarf planets are similar to planets, except that they haven't cleared their space of debris.
- Pluto was thought to be larger than it is because its large moon made the dwarf planet look bigger than it is.

Practice

Use these resources to answer the questions that follow.

https://www.youtube.com/watch?v=D9FGePDvwjA

1. What is found in the outer solar system?
2. What characteristics must a planet have?
3. Which characteristic did Pluto fail? Why?
4. What are the characteristics of Eris and what is it?
5. What is Pluto made of? What is its surface?
6. Why is Pluto so cold?
7. What is Charon?

Practice Answers

1. Pluto and many similar objects some even larger.
2. It must orbit the Sun; it must have enough gravity to keep a spherical shape; it must have cleared other objects from its neighborhood.
3. Pluto has not cleared its orbit of other objects. Pluto is in the Kuiper belt and there are 1,000 objects there.
4. Eris is a dwarf planet in the Kuiper belt that is 25% larger than Pluto.
5. Pluto is made of frozen rock and ice. It's surface is frozen nitrogen, methane and carbon monoxide.
6. It is very far from the Sun, it doesn't have any internal heat and it has little atmosphere so no greenhouse effect.
7. It is a large moon of Pluto or it is a co-dwarf planet with Pluto.

Review

1. Why isn't Pluto still a planet?
2. Why did people think that Pluto was a planet in the decades after its discovery?
3. If Pluto is a dwarf planet, are any other of the eight planets in our solar system at risk of losing their planetary status?
4. Why do some people still insist that Pluto is a planet?

Review Answers

1. Pluto doesn't meet one of the criteria for a planet; it has not cleared its space of debris. It is very similar to other objects ot in space that are also not planets.
2. One reason is that Pluto and Charon appeared as one body in older telescopes and so that body looked much larger. As telescopes got better, astronomers also discovered many objects that were similar to Pluto so they all needed to be planets or none of them should be planets.
3. All of the existing eight planets meet the IAU criteria for a planet so they are safe.
4. People grew up with nine planets and Pluto has the same name as a cartoon character. People don't understand what dwarf planets are.

Summary

At the center of the solar system is our star, the Sun. Solar energy is the result of the fusion of hydrogen and helium. The Sun is not just a featureless ball of gas, but has three internal layers and an atmosphere. We see the surface features, like sunspots, which have an affect on Earth. Eight planets orbit the Sun; the small, dense, rocky four nearer the Sun, and the large, gaseous four further away. Mercury is the smallest planet; it is closest to the Sun so it is extremely hot in most locations. Venus, the second planet out and the closest to Earth, has a thick, carbon dioxide-rich atmosphere with a large greenhouse effect and so is also very hot. Earth, the third rock from the Sun, is the only one of the inner planets with a large moon. The red planet, Mars, is the most earth-like, with channels where water once flowed and large volcanoes. The four gas planets —Jupiter, Saturn, Uranus, and Neptune —are composed of hydrogen, helium, and some methane and other gases. All have rings and moons. The other objects in the solar system are the five dwarf planets, which include Pluto, plus the asteroids, and comets. An object that strikes Earth is a meteorite. Increasing numbers of planets are now being found in other solar systems; they are called extrasolar planets or exoplanets.

1.20 References

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