Lesson Labs

Quick Labs
• Gravity's Effect
• Gravity and the Orbit of a Planet
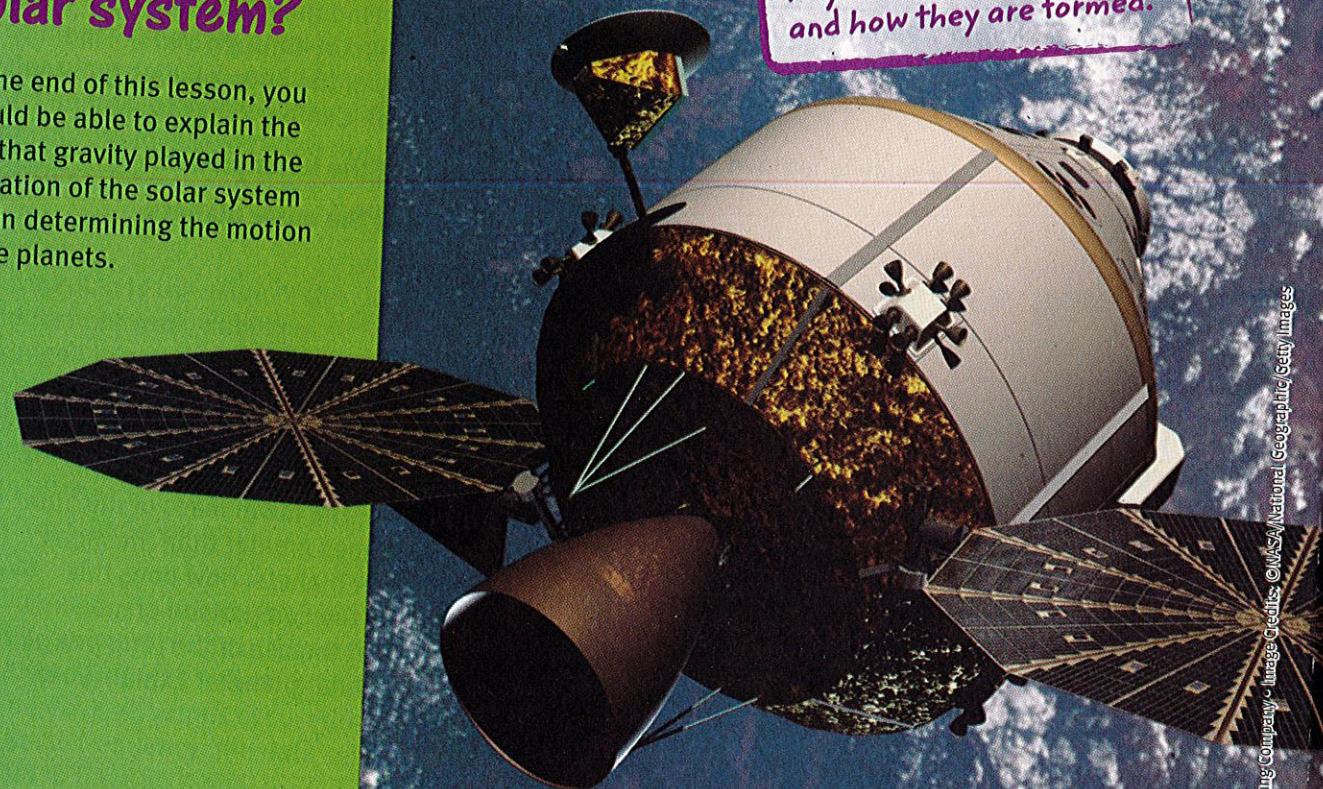**Exploration Lab**
• Weights on Different Celestial Bodies

Gravity and the Solar System

ESSENTIAL QUESTION

Why is gravity important in the solar system?

By the end of this lesson, you should be able to explain the role that gravity played in the formation of the solar system and in determining the motion of the planets.

Gravity keeps objects, such as these satellites, in orbit around Earth. Gravity also affects the way in which planets move and how they are formed.

Engage Your Brain

1 Predict Check T or F to show whether you think each statement is true or false.

T	F	
☐	☐	Gravity keeps the planets in orbit around the sun.
☐	☐	The planets follow circular paths around the sun.
☐	☐	Sir Isaac Newton was the first scientist to describe how the force of gravity behaved.
☐	☐	The sun formed in the center of the solar system.
☐	☐	The terrestrial planets and the gas giant planets formed from the same material.

2 Draw In the space below, draw what you think the solar system looked like before the planets formed.

Active Reading

3 Synthesize You can often define an unknown word if you know the meaning of its word parts. Use the word parts and sentence below to make an educated guess about the meaning of the word *protostellar*.

Word part	Meaning
proto-	first
-stellar	of or having to do with a star or stars

Example sentence
The protostellar disk formed after the collapse of the solar nebula.

protostellar:

Vocabulary Terms

• gravity	• centripetal force
• orbit	• solar nebula
• aphelion	• planetesimal
• perihelion	

4 Apply This list contains the key terms you'll learn in this section. As you read, circle the definition of each term.

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Gravity

What is gravity?

Gravity is a force of attraction between objects that is due to their masses and the distances between them. Every object in the universe pulls on every other object. Objects with greater masses have a greater force of attraction than objects with lesser masses have. Objects that are close together have a greater force of attraction than objects that are far apart have.

Gravity is the weakest force in nature. A toy magnet can overcome the gravitational force acting on a paperclip by the entire mass of Earth. Yet, gravity is one of the most important forces in the universe. It accounts for the formation of planets, stars, and galaxies. It also keeps smaller bodies in orbit around larger bodies. An **orbit** is the path that a body follows as it travels around another body in space. For example, the moon orbits Earth, and Earth orbits the sun.

When astronauts are in orbit, Earth's gravity still pulls them downward toward the planet. However, they appear to be weightless and floating. They "float" because everything around them is falling at the same speed.

What are Kepler's laws?

The 16th-century Polish astronomer Nicolaus Copernicus (nik•uh•LAY•uhs koh•PER•nuh•kuhs) (1473–1543) changed our view of the solar system. He discovered that the motions of the planets could be best explained if the planets orbited the sun. But, like astronomers who came before him, Copernicus thought the planets followed circular paths around the sun.

Danish astronomer Tycho Brahe (TY•koh BRAH) (1546–1601) built what was at the time the world's largest observatory. Tycho used special instruments to measure the motions of the planets. His measurements were made over a period of 20 years and were very accurate. Using Tycho's data, Johannes Kepler (yoh•HAH•nuhs KEP•luhr) (1571–1630) made discoveries about the motions of the planets. We call these *Kepler's laws of planetary motion.*
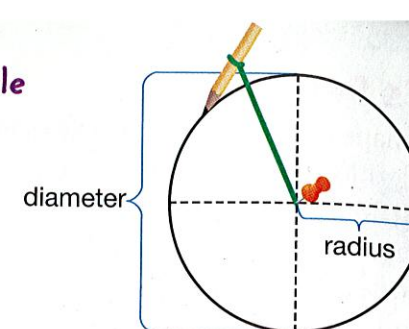
Kepler found that objects that orbit the sun follow elliptical orbits. When an object follows an elliptical orbit around the sun, there is one point, called **aphelion** (uh•FEE•lee•uhn), where the object is farthest from the sun. There is also a point, called **perihelion** (perh•uh•HEE•lee•uhn), where the object is closest to the sun. Today, we know that the orbits of the planets are only slightly elliptical. However, the orbits of objects such as Pluto and comets are highly elliptical.

Circle

diameter
radius

Ellipse

semiminor axis
minor axis
focus   focus
semimajor axis
major axis

Visualize It!

6 **Compare** How is a circle different from an ellipse?
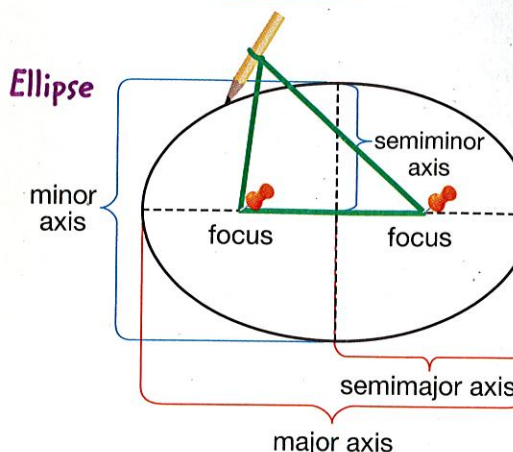
Kepler's First Law

Kepler's careful plotting of the orbit of Mars kept showing Mars's orbit to be a deformed circle. It took Kepler eight years to realize that this shape was an ellipse. This clue led Kepler to propose elliptical orbits for the planets. Kepler placed the sun at one of the foci of the ellipse. This is Kepler's first law.

Kepler's First Law

Sun lies at one focus
Nothing lies at the other focus
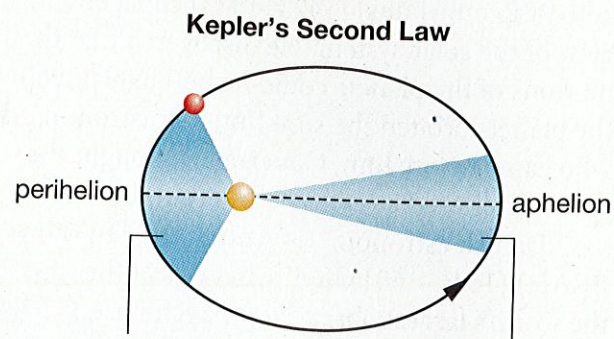perihelion
aphelion
semimajor axis

Each planet orbits the sun in an ellipse with the sun at one focus. (For clarity, the ellipse is exaggerated here.)

Kepler's Second Law

Using the shape of an ellipse, Kepler searched for other regularities in Tycho's data. He found that an amazing thing happens when a line is drawn from a planet to the sun's focus on the ellipse. At aphelion, its speed is slower. So, it sweeps out a narrow sector on the ellipse. At perihelion, the planet is moving faster. It sweeps out a thick sector on the ellipse. In the illustration, the areas of both the thin blue sector and the thick blue sector are exactly the same. Kepler found that this relationship is true for all of the planets. This is Kepler's second law.

Active Reading 8 Analyze At which point does a planet move most slowly in its orbit, at aphelion or perihelion?

As a planet moves around its orbit, it sweeps out equal areas in equal times.

Kepler's Second Law

Near perihelion, a planet sweeps out an area that is short but wide.

Near aphelion, in an equal amount of time, a planet sweeps out an area that is long but narrow.

Kepler's Third Law

When Kepler looked at how long it took for the planets to orbit the sun and at the sizes of their orbits, he found another relationship. Kepler calculated the orbital period and the distance from the sun for the planets using Tycho's data. He discovered that the square of the orbital period was proportional to the cube of the planet's average distance from the sun. This law is true for each planet. This principle is Kepler's third law. When the units are years for the period and AU for the distance, the law can be written:

$$(\text{orbital period in years})^2 = (\text{average distance from the sun in astronomical units [AU]})^3$$

The square of the orbital period is proportional to the cube of the planet's average distance from the sun.

Kepler's Third Law

$$p^2 \text{ yrs} = a^3 \text{ AU}$$
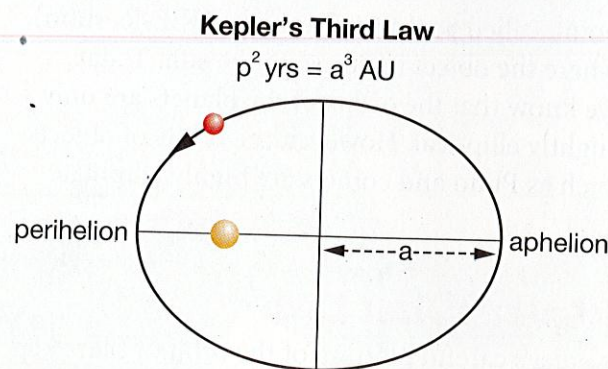
9 Summarize In the table below, summarize each of Kepler's three laws in your own words.

First law	Second law	Third law

What is the law of universal gravitation?

Using Kepler's laws, Sir Isaac Newton (EYE•zuhk NOOT'n) became the first scientist to mathematically describe how the force of gravity behaved. How could Newton do this in the 1600s before the force could be measured in a laboratory? He reasoned that gravity was the same force that accounted for both the fall of an apple from a tree and the movement of the moon around Earth.

In 1687, Newton formulated the *law of universal gravitation*. The law of universal gravitation states that all objects in the universe attract each other through gravitational force. The strength of this force depends on the product of the masses of the objects. Therefore, the gravity between objects increases as the masses of the objects increase. Gravitational force is also inversely proportional to the square of the distance between the objects. Stated another way this means that as the distance between two objects increases, the force of gravity decreases.
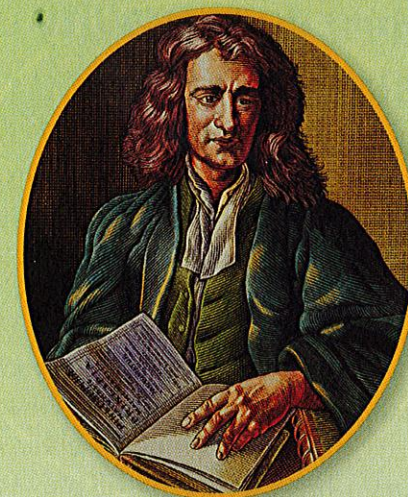
Sir Isaac Newton (1642–1727)

📲 Do the Math

Newton's law of universal gravitation says that the force of gravity:
- increases as the masses of the objects increase and
- decreases as the distance between the objects increases

In these examples, M = mass, d = distance, and F = the force of gravity exerted by two bodies.

Sample Problems

A. In the example below, when two balls have masses of M and the distance between them is d, then the force of gravity is F. If the mass of each ball is increased to 2M (to the right) and the distance stays the same, then the force of gravity increases to 4F.


B. In this example, we start out again with a distance of d and masses of M, and the force of gravity is F. If the distance is decreased to ½ d, then the force of gravity increases to 4F.
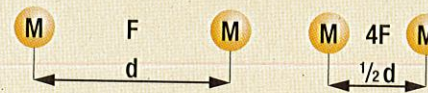
You Try It

Recall that M = mass, d = distance, and F = the force of gravity exerted by two bodies.

10 Calculate Compare the example below to the sample problems. What would the force of gravity be in the example below? Explain your answer.
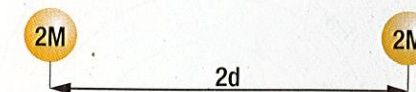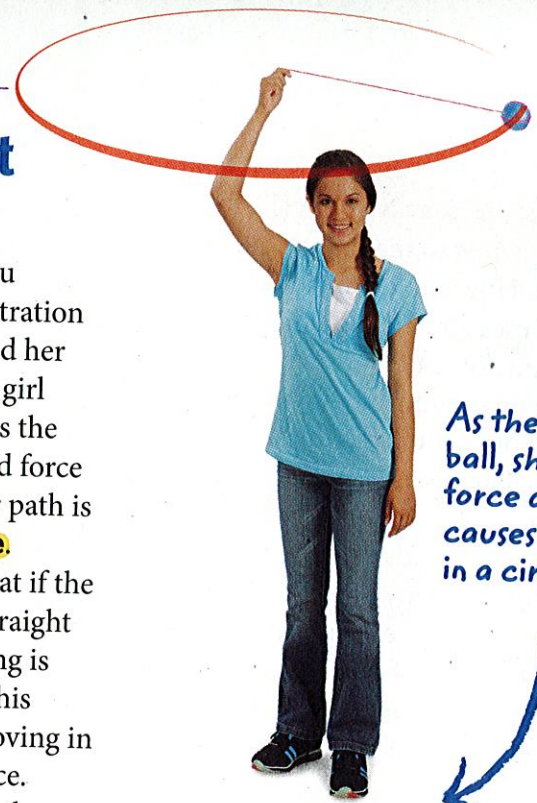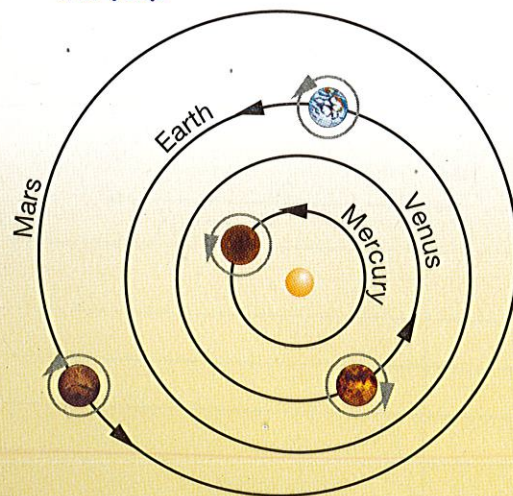
How does gravity affect planetary motion?

The illustrations on this page will help you understand planetary motion. In the illustration at the right, a girl is swinging a ball around her head. The ball is attached to a string. The girl is exerting a force on the string that causes the ball to move in a circular path. The inward force that causes an object to move in a circular path is called centripetal (sehn•TRIP•ih•tuhl) force.

In the illustration at center, we see that if the string breaks, the ball will move off in a straight line. This fact indicates that when the string is intact, a force is pulling the ball inward. This force keeps the ball from flying off and moving in a straight line. This force is centripetal force.

In the illustration below, you see that the planets orbit the sun. A force must be preventing the planets from moving out of their orbits and into a straight line. The sun's gravity is the force that keeps the planets moving in orbit around the sun.

As the girl swings the ball, she is exerting a force on the string that causes the ball to move in a circular path.

Centripetal force pulls the ball inward, which causes the ball to move in a curved path.

direction ball would move if string broke

direction centripetal force pulls the ball

Center of rotation

String

path ball takes when moving around the center of rotation

Just as the string is pulling the ball inward, gravity is keeping the planets in orbit around the sun.

Earth
Mars
Venus
Mercury
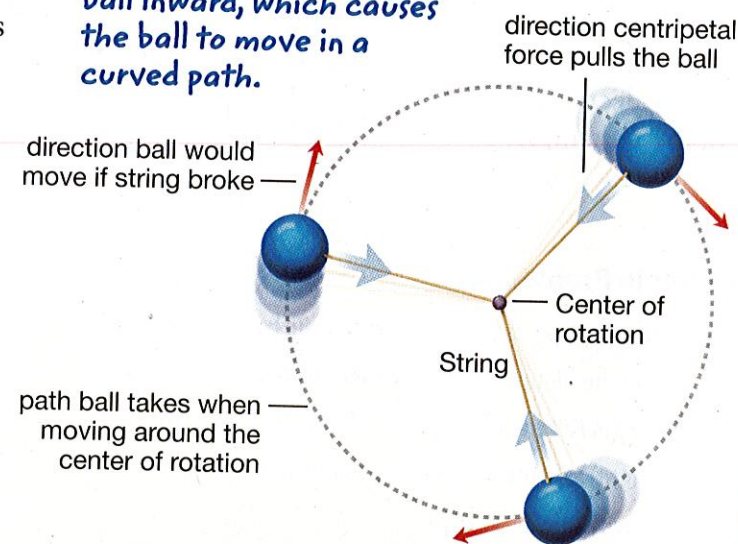
11 Explain In the illustration at the top of the page, what does the hand represent, the ball represent, and the string represent? (Hint: Think of the sun, a planet, and the force of gravity.)

_____
_____
_____

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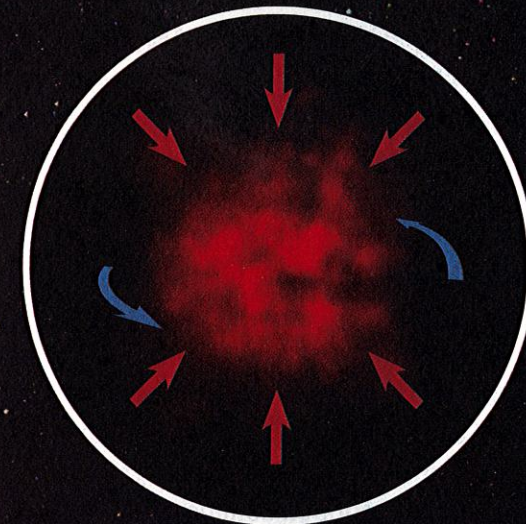
Collapse

How did the solar system form?

The formation of the solar system is thought to have begun 4.6 billion years ago when a cloud of dust and gas collapsed. This cloud, from which the solar system formed, is called the solar nebula (SOH•ler NEB•yuh•luh). In a nebula, the inward pull of gravity is balanced by the outward push of gas pressure in the cloud. Scientists think that an outside force, perhaps the explosion of a nearby star, caused the solar nebula to compress and then to contract under its own gravity. It was in a single region of the nebula, which was perhaps several light-years across, that the solar system formed. The sun probably formed from a region that had a mass that was slightly greater than today's mass of the sun and planets.

Active Reading **12 Define** What is the solar nebula?

_____
_____

A Protostellar Disk Formed from the Collapsed Solar Nebula

As a region of the solar nebula collapsed, gravity pulled most of the mass toward the center of the nebula. As the nebula contracted, it began to rotate. As the rotation grew faster, the nebula flattened out into a disk. This disk, which is called a *protostellar disk* (PROH•toh•stehl•er DISK), is where the central star, our sun, formed.

A cloud of dust and gas collapsed 4.6 billion years ago, then began to spin. It may have spun around its axis of rotation once every million years.

As a region of the solar nebula collapsed, it formed a slowly rotating protostellar disk.

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the Protostellar Disk

As the protostellar disk continued to contract, most of the matter ended up in the center of the disk. Friction from matter that fell into the disk heated up its center to millions of degrees, eventually reaching its current temperature of 15,000,000 °C. This intense heat in a densely packed space caused the fusion of hydrogen atoms into helium atoms. The process of fusion released large amounts of energy. This release of energy caused outward pressure that again balanced the inward pull of gravity. As the gas and dust stopped collapsing, a star was born. In the case of the solar system, this star was the sun.

Active Reading **13 Identify** How did the sun form?

_____

_____

_____

_____

This is an artist's conception of what the protoplanetary disk in which the planets formed might have looked like.
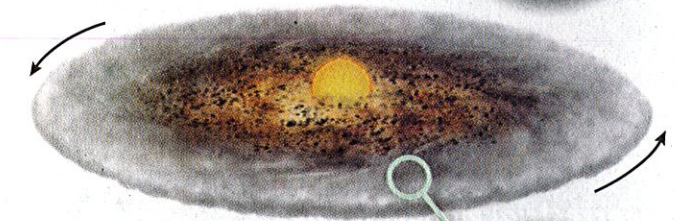
Visualize It!

14 Describe Use the terms *planetesimal* and *protoplanetary disk* to describe the illustration above.

_____

_____

_____

_____

_____

Planetesimals formed from the collisions of meter-sized bodies.

Protoplanetary Disk

As the sun was forming, dust grains collided and stuck together. The resulting *dust granules* grew in size and increased in number. Over time, dust granules increased in size until they became roughly meter-sized bodies. Trillions of these bodies occurred in the protostellar disk. Collisions between these bodies formed larger bodies that were kilometers across. These larger bodies, from which planets formed, are called **planetesimals** (plan•ih•TES•ih•muhls). The protostellar disk had become the *protoplanetary disk*. The protoplanetary disk was the disk in which the planets formed.
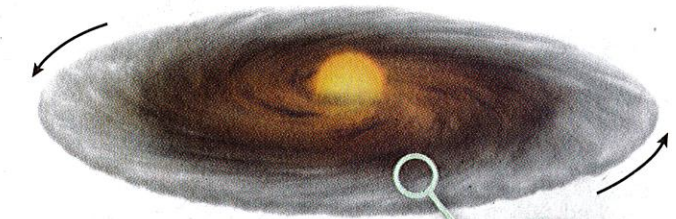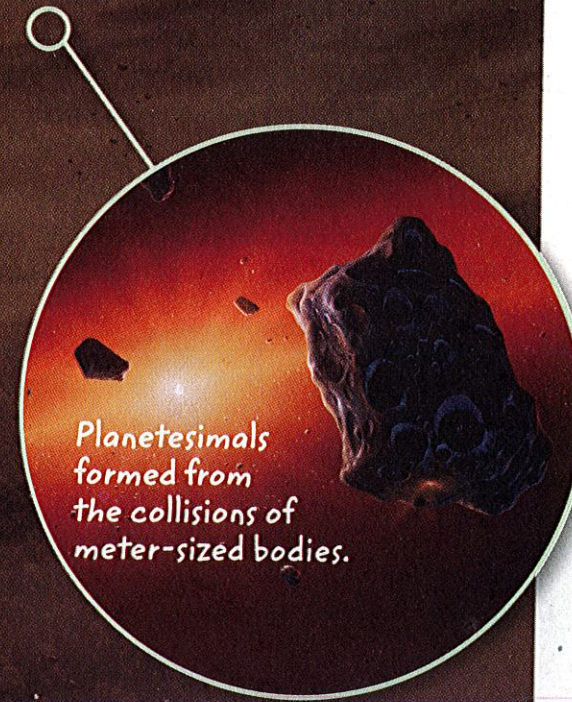
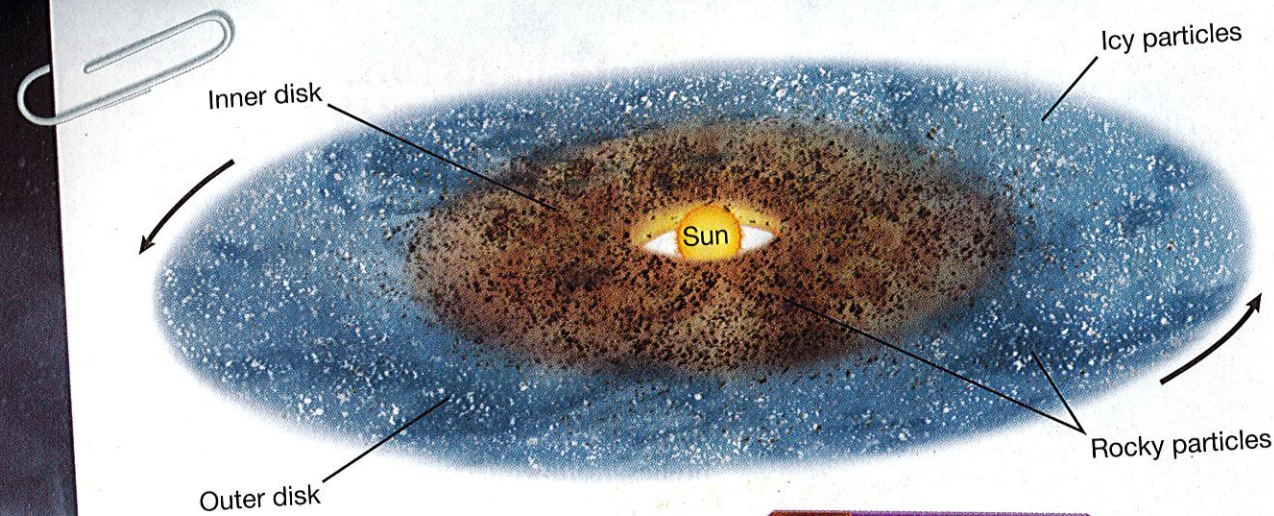Dust grains collided and stuck together.

Over time, dust granules grew to become meter-sized bodies.

Visualize It! **Inquiry**

15 Explain How can objects as small as dust grains become the building blocks of planets?

_____

_____

_____

_____

Inner disk

Icy particles

Sun

Outer disk

Rocky particles

Temperatures in the protoplanetary disk controlled the formation of the planets.

16 Analyze Where did planets made mostly of gas and ice form within the protoplanetary disk?

_____
_____
_____

The Planets Formed from Planetesimals

The inner part of the protoplanetary disk was so hot that only rocks and metals were in solid form. Therefore, rocky, metallic planets formed in the inner disk. These planets formed from the collisions and mergers of rocky planetesimals. We call these inner planets the *terrestrial planets*.

In the cold outer disk, ices, gases, rocks, and metals were all found. At first, massive planets made of icy and rocky planetesimals may have formed. The gravity of these planets was so strong that they captured gas and other matter as they grew. Therefore, planets that formed in the outer disk have rocky or metallic cores and deep atmospheres of gas and ice. We call these outer planets the *gas giant planets*.

Terrestrial planets formed when rocky planetesimals collided.

Gas giant planets captured gas and other matter in the area of their orbits.

17 Describe In the spaces on the left, describe Steps 2 and 4 in the formation of the solar system. In the spaces on the right, draw the last two steps in the formation of the solar system.
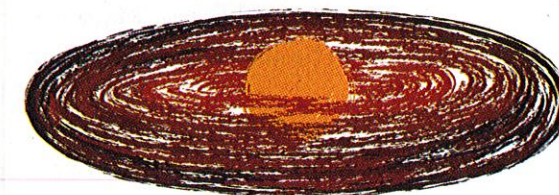
Steps in the Formation of the Solar System

Step 1 The Solar Nebula Collapses

A cloud of dust and gas collapses. The balance between the inward pull of gravity and the outward push of pressure in the cloud is upset. The collapsing cloud forms a rotating protostellar disk.
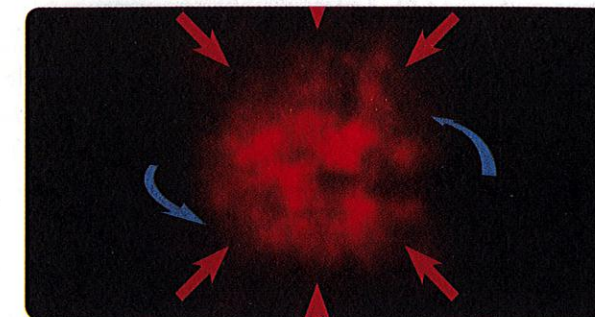
Step 2 The Sun Forms

_____
_____
_____
_____

Step 3 Planetesimals Form

Dust grains stick together and form dust granules. Dust granules slowly increase in size until they become meter-sized objects. These meter-sized objects collide to form kilometer-sized objects called *planetesimals*.

Step 4 Planets Form

_____
_____
_____
_____

Visual Summary

To complete this summary, fill in the blank with the correct word or phrase. Then use the key below to check your answers. You can use this page to review the main concepts of the lesson.

The Law of Universal Gravitation

Mass affects the force of gravity.

18 The strength of the force of gravity depends on the product of the _____ of two objects. Therefore, as the masses of two objects increase, the force that the objects exert on one another _____.

Distance affects the force of gravity.

19 Gravitational force is inversely proportional to the square of the _____ between two objects. Therefore, as the distance between two objects increases, the force of gravity between them _____.

Gravity affects planetary motion.

20 The sun exerts a _____, indicated by line B, on a planet so that at point C it is moving around the sun in orbit instead of moving off in a _____ as shown at line A.
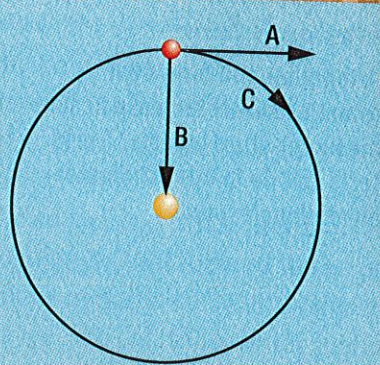
Answers: 18 masses, increases; 19 distance, decreases; 20 gravitational force or centripetal force, straight line

21 Explain In your own words, explain Newton's law of universal gravitation.

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Lesson Review

2

Vocabulary

Fill in the blank with the term that best completes the following sentences.

1 Small bodies from which the planets formed are called _____

2 The path that a body follows as it travels around another body in space is its _____

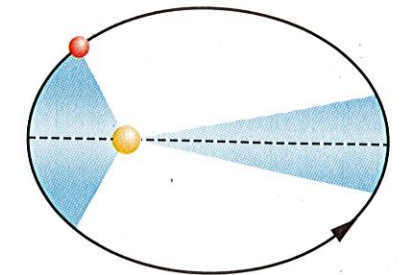**3** The _____ is the cloud of gas and dust from which our solar system formed.

Key Concepts

4 Define In your own words, define the word *gravity*.

_____

_____

5 Describe How did the sun form?

_____

_____

_____

_____

_____

6 Describe How did planetesimals form?

_____

_____

_____

_____

_____

Critical Thinking

Use the illustration below to answer the following question.

7 Identify What law is illustrated in this diagram?

_____

_____

8 Analyze How does gravity keep the planets in orbit around the sun?

_____

_____

_____

_____

9 Explain How do temperature differences in the protoplanetary disk explain the arrangement of the planets in the solar system?

_____

_____

_____

_____

_____

_____

_____

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