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EXPLORING PLANETARY SYSTEMS
UNIT OVERVIEW

Students of all ages have an innate curiosity about our solar system with its planets, their moons, and asteroids, comets, and meteoroids. Exploring Planetary Systems taps this curiosity by helping students clarify what they already know about the solar system and Earth as a planet, and by giving them the opportunity to perform a series of engaging hands-on activities through which they extend and enrich this knowledge.

Each lesson in this unit builds on skills and concepts presented in previous lessons. As students progress through the unit, they take increasing responsibility for their own learning. Eventually, students plan and conduct their own procedures, devise their own data tables, and analyze the results they obtain. Therefore, Exploring Planetary Systems should be taught as a complete unit. It should not be used as a sourcebook for occasional experiments.

Exploring Planetary Systems addresses the skills and concepts deemed appropriate for grades 5 through 8 by the National Science Education Standards. It allows students to experience phenomena that they find fascinating and exciting and that often make headline news. By completing this unit, students and teachers alike will develop a better understanding of the relationships among the solar system bodies and how our study of the solar system helps improve our own understanding of Earth’s history and future as a planet.

LESSON-BY-LESSON SUMMARY

Lesson 1 is a pre-assessment. Students share what they already know about the solar system and then list questions they may have about it. Students then answer a set of 10 questions (each with a matching photograph) to generate a discussion about their understanding of the solar system. This allows them to examine their own preconceptions about the solar system, and gives them an opportunity to revisit their ideas throughout the unit.

In Lesson 2, students use a set of objects to demonstrate what they know and want to know about the order, size, and relative distance between each of the planets. They learn how to apply their math skills to determine the relative sizes and distances of the planets and to build a model that represents the size and distance relations of the planets in the solar system.

Lesson 2 also introduces students to the Mission series, a collection of reading selections in which they will read about space exploration throughout Exploring Planetary Systems. The Mission series provides students with information about missions to each of our solar system’s planets. Each selection in the series outlines information about the planet and provides images collected from its missions. Each reading selection includes a graphically organized planetary facts page that details information on the planet’s relative size compared with Earth’s, relative distance from the Sun, composition of the atmosphere, internal structure, and overall characteristics. These characteristics include, for example, the planet’s average surface temperature, mass, length of day and year, and number of moons.

NOTE
The planets are not presented in their order from the Sun in the Mission series. They are, instead, discussed in reference to a lesson and to how the concepts of that lesson relate to the planet. For example, in Lesson 2, which focuses on scaling and relative sizes, you will find the Mission reading selection about Jupiter, the fifth planet from the Sun, since it is the largest planet. On the other hand, the Mission selection about Mars, the fourth planet from the Sun, is in Lesson 6 because the surface features investigated in that lesson are found on Mars.
Students record information about each planet on a student sheet throughout the unit. This enables them to analyze and compare planetary data to determine patterns. They use this information as part of their research for the Exploration Activity, which they begin in **Lesson 4**.

During **Lesson 3**, students focus on surface gravity and the relationship between the mass and weight of an object. Students make general observations about a model that simulates the weight of an object on the surface of each of the planets. Students analyze planetary data to consider why weight at the surface varies from planet to planet, and draw conclusions about the relationship between planetary mass and size and the weight of an object at a planet’s surface.

**Lesson 4** introduces students to the Exploration Activity, which focuses on solar system explorations and missions. This activity challenges students to think about space science from historical and technological perspectives. The Exploration Activity is a research project during which students work individually to gather information about a particular planet or other object in the solar system, organize their findings into a travel brochure, and present them to the class near the close of the unit. Students also work in teams to develop a planetary mission design using the data that they have learned about their chosen solar system object.

**Lessons 5 and 6** focus on the surface features of the terrestrial planets. Students examine photographs of Earth and are asked to analyze whether the landforms visible on Earth exist on other planets. **Lesson 5** focuses on impact craters; students investigate the variables that affect impact cratering and model impact cratering. In **Lesson 6**, students use the jigsaw method to investigate four different planetary processes—wind erosion, water erosion, tectonics, and volcanism—and their effects on Earth as well as on a variety of terrestrial planets and moons.

In **Lesson 7**, students revisit gravity and investigate its effects on orbital motion. They complete four inquiries that focus on how gravity affects the motion of objects. Students use a stretched elastic sheet and water balloon to model how mass curves space and how the Sun’s gravity makes the planets and other solar system objects orbit it in elliptical paths.

**Lesson 8** serves as an assessment of students’ current knowledge about the history of Earth as a planet. Based on their knowledge of the solar system, students look at ways in which asteroids, comets, and meteoroids have contributed to changes in Earth’s history as a planet. Students watch a short video about dinosaur extinction and read about a comet striking Jupiter.

In **Lesson 9**, students explore how fossils reveal the history of possible asteroid and comet impact on Earth. They examine samples of fossiliferous limestone and brainstorm about fossils, and read about how an asteroid impact may have caused the demise of the dinosaurs. Students complete three inquiries to investigate the excavation, identification, and formation of fossils.

The unit ends with a three-part summative assessment in **Lesson 10**. Students analyze an investigation to describe the relationship between distance and orbital period of orbiting bodies, and complete a series of multiple-choice and short-answer questions. Students also revisit the 10 questions they answered in **Lesson 1** to see how much they have learned over the course of the unit. By comparing students’ post-unit thinking with their ideas from **Lesson 1**, teachers can assess each student’s growth in understanding our solar system.

**SCIENCE NOTEBOOKS**

Students should have a science notebook in which to record their observations, data, conclusions, and answers to questions as well as their own ideas and thoughts as they progress through the inquiries in the unit. Students should come to view their notebook as a resource that they can use throughout the unit. Reviewing observations, data, and information will help them refine their understanding of key concepts and conceptual models. Teachers will find the science notebook to be a valuable assessment tool in tracking student progress in both content knowledge and inquiry skills.
READING SELECTIONS

The STC Program™ incorporates two types of reading selections into each unit to enhance and extend the lesson material. The first type is embedded directly into the procedure of the lesson. Called “Building Your Understanding,” these reading selections provide background information or further explanation of concepts that are critical to a student’s understanding of the inquiry at hand. A second type, “Extending Your Knowledge,” appears at the end of the lessons, extending the concepts of the lesson to the real world, highlighting the application of the concepts in such contexts as science and technology careers, current events, and the history of science and technology. Each of these reading selections is followed by two open-ended questions designed to help students apply the information from the text and extend their thinking.

USING THE ANNOTATED TEACHER’S EDITION FOR STC®SECONDARY

The Teacher’s Edition for STC–Secondary was developed to support the teacher in every aspect of the unit. Imagine having everything right at your fingertips, yet in an organized and intuitive design. In each lesson, you will find two types of content—pages that support the teacher, and pages that help the teacher support the students.

Teacher-only Content Pages: These pages have no Student Guide correlation, and appear at the beginning and end of each lesson. Here you will find overview and background information, planning and preparation, common misconceptions, homework and extension activities, and assessment guidelines. These pages guide teachers to obtain and prepare materials and highlight the concepts of the lesson.

Annotated Student Pages: These pages include inset full-color Student Guide pages right in the Teacher’s Edition. This way, you’ll always have the student instructions and reading selections right in front of you. The step numbers for each inquiry correspond one-to-one between the Student Guide step and the annotated wrap of the Teacher's Edition. The notes in the wrap provide anticipated or best responses, guide teachers in informal assessment, and offer classroom management tips. It is important to remember that the Student Guide explains the procedure while the annotation in the Teacher's Edition wrap-around supports what is presented there.

TEACHER’S TOOLS CD

The CD included with the kit includes PDF files of all the reproducible sheets needed to teach this unit. Blackline masters are grouped by lesson, so finding exactly what you need is fast and simple. If your unit uses chemicals, you’ll also find PDFs of all the Material Safety Data Sheets (MSDS) to print and have on hand in your classroom or the main office. Additional items include English and Spanish versions of the safety contract and any images or diagrams that need to be printed for use with overhead projectors or document cameras.

GLOSSARY

A glossary is included at the back of the Student Guide. It expresses scientific terms and concepts in a more formal language than students may initially use when they talk about or reflect on the inquiries and their observations. Before you introduce students to and have them use the more formal scientific terms, allow them to develop explanations and express their understanding in their own words.
Concept Storyline: *Exploring Planetary Systems*

### UNIFYING THEME
- The Sun, planets, moons, comets, asteroids, and meteoroids in our solar system comprise a system of interacting bodies.

### UNIT CONCEPTS
- The Sun is at the center of the solar system.
- Planets, asteroids, comets, and meteoroids orbit the Sun.
- Gravity is the force that keeps the planets in orbit around the Sun and governs the rest of the motion in the solar system.

### GRADE-LEVEL CONCEPTS
- Earth is part of a system that includes the Moon, seven other planets, and smaller objects, such as asteroids and comets.
- Geological and atmospheric processes that occur on Earth also occur on other planets.
- Earth's history is occasionally influenced by catastrophes, such as the impact of a comet or asteroid.
- Fossils provide evidence of how life and environmental conditions have changed.

#### SUBCONCEPT 1
Students have preconceived ideas and questions about our solar system.
**Lesson 1: Thinking About Our Solar System**
Students answer a set of 10 questions about the solar system and discuss what they know and what they want to know about it.

#### SUBCONCEPT 2
Scale modeling is one way of working with large distances and sizes and other properties of planets.

#### SUBCONCEPT 3
Scientists send robotic probes on missions to visit other planets and objects and to send information about them back to Earth.
**Lesson 2: The Solar System: Designing a Scale Model**
Students use different objects to represent the planets and build a scale model of the solar system. Students read about missions to Jupiter.

**Lesson 3: Surface Gravity**
Students use differently weighted cans to investigate how surface gravity affects the weight of an object on different planets. Students read about missions to Venus.

#### SUBCONCEPT 4
Different solar system objects have features that make them interesting places to explore and potentially visit.
**Lesson 4: Exploration Activity: Solar System Explorations**
Individual students select a solar system object and design a travel brochure for the object. Students researching the same object work collaboratively to design a mission to visit it. Students read about exploring Earth from space.

#### SUBCONCEPT 5
Surface features seen on planets, moons, and asteroids reveal how processes that occur on Earth also occur on other planets.
**Lesson 5: Impact Craters**
Students investigate the features of impact craters and design an investigation to find out what factors affect the formation of impact craters. Students read about missions to Mercury.

**Lesson 6: Other Surface Features**
Students investigate how wind erosion, plate tectonics, water, and volcanoes produce surface features seen on planets and moons. Students read about missions to Mars.

#### SUBCONCEPT 6
Gravity governs motion in the solar system.
**Lesson 7: Gravity and Orbital Motion**
Students revisit gravity and investigate how the Sun's gravity holds the planets and other objects in orbit around it. Students read about missions to Saturn, Uranus, and Neptune.

#### SUBCONCEPT 7
Life on Earth is influenced by collisions with asteroids and comets.
**Lesson 8: Asteroids, Comets, and Meteoroids**
Students investigate asteroids, comets, and meteoroids and how these objects can collide with planets.

**Lesson 9: Fossils As Evidence of Asteroid Impact**
Students excavate and examine fossils and make molds and casts of objects. Students learn about asteroid impacts and their effect on life on Earth.

**Lesson 10: Solar System Assessment**
Students complete a three-part assessment that consists of an experiment analysis, short-answer and multiple-choice questions, and a self-assessment about what they have learned in this unit.

*Pacing Guide is based on 40- to 50-minute class periods.*

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# EXPLORING PLANETARY SYSTEMS UNIT GOALS

In this unit, students investigate planets and other objects in the solar system. Their experiences introduce them to the following concepts, skills, and attitudes:

## CONCEPTS

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<th>The solar system is made up of a number of different objects, including planets, moons, the Sun, asteroids, comets, and meteoroids.</th>
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<tr>
<td>The solar system is mostly empty space but does contain the Sun, the Earth with its moon, and seven other planets with their moons.</td>
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<tr>
<td>Scale is a ratio between two sets of measurements.</td>
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<tr>
<td>When the scale factor is known, scale measurements can be calculated from true measurements, and vice versa.</td>
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<tr>
<td>A model is a representation that helps demonstrate how complex processes, systems, and devices look and act.</td>
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<tr>
<td>Mathematics is an important tool for scientific inquiry.</td>
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<tr>
<td>A scale model is one way of working with measurements that are too large to see firsthand, such as the sizes of and distances between planets in our solar system.</td>
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<tr>
<td>Gravitation refers to a force that attracts objects to each other.</td>
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<tr>
<td>Surface gravity refers to the gravitational attraction exerted by a planet (or other solar system object) on objects near its surface.</td>
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<tr>
<td>Surface gravity depends on the mass and radius of the planet.</td>
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<tr>
<td>Earth is the third planet from the Sun in a solar system that includes the Sun, planets, and moons, and smaller objects such as asteroids, comets, and dwarf planets.</td>
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<tr>
<td>Space exploration has provided information about variations in the features and properties of the bodies in our solar system.</td>
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<tr>
<td>Science and technology have advanced through the contributions of many different people at different times in history.</td>
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<tr>
<td>Sharing knowledge is an important aspect of science.</td>
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<tr>
<td>Science and technology cannot answer all questions, solve all human problems, or meet all human needs.</td>
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<tr>
<td>Planets, moons, and asteroids have a variety of surface features. The surfaces of some planets, moons, and asteroids are heavily cratered.</td>
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<tr>
<td>Impact craters are bowl-shaped holes in solid, rocky surfaces that are formed when large meteoroids, asteroids, or comets smash into the surface of a terrestrial planet, asteroid, or moon.</td>
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<td>Rays of ejected material radiate outward from an impact crater in all directions.</td>
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<td>Older surfaces generally contain more craters than newer surfaces.</td>
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<tr>
<td>Many craters on Earth have been eroded by wind and water and destroyed by tectonics and volcanism.</td>
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<tr>
<td>The character of an impact crater depends on the size of the impacting object and the speed at which it strikes the surface.</td>
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<tr>
<td>Planetary processes that exist on Earth also may exist on other planets, moons, and asteroids.</td>
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<tr>
<td>Planetary processes include wind erosion, water erosion, tectonics, volcanism, and impact cratering.</td>
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<tr>
<td>The relative locations of lava flows and craters help indicate the age of the surface of a planet, a moon, or an asteroid.</td>
</tr>
<tr>
<td>The planets close to the Sun travel faster in their orbits than the planets farther from the Sun.</td>
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</tbody>
</table>
Any two objects, from the largest galaxy to the smallest particle, attract each other with a force called gravity.

Unbalanced forces, including gravity, can change the speed and/or direction of an object’s motion.

Gravity keeps planets in orbit around the Sun and governs all motion in the solar system.

Most objects in the solar system are in regular and predictable motion.

In addition to the Sun, planets, and moons, the solar system includes smaller objects, such as asteroids, comets, meteoroids, and dwarf planets.

Asteroids are rocky and metallic objects that orbit the Sun but are too small to be considered planets; the majority of asteroids move between Jupiter and Mars in an area known as the “asteroid belt.”

Meteoroids are space matter too small to be called asteroids or comets; meteors are streaks of light produced when meteoroids burn up as they fall into Earth’s atmosphere.

Some meteoroids are the result of collisions of asteroids.

Comets are relatively small solar system bodies made of ice, rock, and dust; each is in an independent elliptical orbit around the Sun, often outside of the solar system.

Some meteoroids are the dust released from comets as they near the Sun and heat up.

Earth experiences occasional catastrophes, such as asteroid impact, which can change or destroy human and wildlife habitats, damage property, and harm or kill humans.

Fossils are found in limestone.

During Earth’s history, asteroids have struck it with devastating results.

Fossils represent the remains of once-living organisms.

Fossils provide important evidence of how life and environmental conditions have changed on Earth over time.

Molds and casts are examples of two fossilizing mechanisms.
## SKILLS

- Developing an interest in investigating the solar system.
- Recognizing the unique nature of the solar system.
- Recognizing how models can be used to explain observed phenomena.
- Understanding the nature of scientific inquiry.
- Using scaling to represent distance and size relationships among objects in the solar system.
- Using modeling to understand phenomena observed in the solar system.
- Designing and performing experiments about the solar system.
- Analyzing data from investigations about the solar system.
- Writing evidence-based conclusions for experiments related to the solar system.
- Comparing and discussing ideas about the solar system.
- Communicating results through writings, tables, and graphs.
- Reflecting on experiences with solar system topics through writing and discussion.
- Applying previously learned concepts and skills to understand relationships within the solar system.
- Reading to obtain more information about the solar system.

## ATTITUDES

- Developing an interest in investigating the solar system.
- Recognizing the unique nature of the solar system.
- Recognizing how models can be used to explain observed phenomena.
- Understanding the nature of scientific inquiry.
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## Lesson 7: Gravity and Orbital Motion

### Getting Started

**Objectives**
- Analyze patterns in planetary motion.
- Prepare for the inquiries in this lesson.

### Inquiry 7.1: Gravity’s Effect on Objects in Motion

- Analyze patterns in planetary motion.
- Observe the motion of a marble when acted upon by different forces.

### Inquiry 7.2: Testing Balanced and Unbalanced Forces

- Observe the motion of a marble when acted upon by different forces.

### Concepts

**The planets close to the Sun travel faster in their orbits than the planets farther from the Sun.**

- Any two objects, from the largest galaxy to the smallest particle, attract each other with a force called gravity.

- Unbalanced forces, including gravity, can change the speed and/or direction of an object’s motion.

### Overview

- Students view a computer simulation of the planets orbiting the Sun and review the procedures for the four inquiries in this lesson.
- Students investigate how gravity affects the motion of a marble rolled off a ruler.
- Students investigate the motion of a marble rolled around the inside of a metal ring and the motion of the marble when the ring is lifted.

### Key Terms

<table>
<thead>
<tr>
<th>Orbital motion</th>
<th>Balanced force</th>
<th>Balanced force</th>
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<tbody>
<tr>
<td></td>
<td>Gravity</td>
<td>Inertia</td>
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<tr>
<td></td>
<td>Unbalanced force</td>
<td>Unbalanced force</td>
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</table>

### Time

- 1.0 period
- 0.5 period
- 0.5 period

### Correlation to National Science Standards

- Content Standard A
  - Abilities necessary to do scientific inquiry
- Content Standard B
  - Motion and forces

- Content Standard A
  - Abilities necessary to do scientific inquiry
- Content Standard B
  - Motion and forces
### Inquiry 7.3
Observing Planetary Motion

Relate the observed behavior of a marble and sphere to the motion of moons and planets.

### Inquiry 7.4
Investigating the Effect of Planetary Mass on a Moon’s Orbit

Investigate the effect of a pulling force on the orbital period of a sphere. Summarize, organize, and compare information about Saturn, Uranus, and Neptune.

### Reading Selections

**Stars Wobble** Read about how the wobble of stars can help astronomers discover exoplanets.

**Heavy Thoughts** Read about Isaac Newton and the law of universal gravitation.

**Mission: Saturn** Read about the Voyager 2 and Cassini missions to Saturn.

**Mission: On to Uranus and Neptune** Read about the discoveries that Voyager 2 made as it flew by Uranus and Neptune.

Gravity keeps planets in orbit around the Sun and governs all motion in the solar system.

Most objects in the solar system are in regular and predictable motion.

When a planet orbits a star, it exerts a gravitational force that makes the star wobble.

Space probes have revealed interesting information about Saturn, Uranus, and Neptune.

Stars pull on planets that orbit them, and planets pull on the stars they orbit.

Every object in the universe attracts every other object in the universe with a force that is directly proportional to the masses, and inversely proportional to the distance between the masses.

An object will move in a straight line at a constant speed if no unbalanced forces act on it.

Students observe and describe the motion of a marble as it rolls on a stretched elastic sheet that has a water-filled balloon at the center.

Students investigate how the amount of mass at the center of an orbit affects the motion of an object orbiting the mass.

“Stars Wobble” explains how a star’s motion is influenced by an orbiting planet.

“Heavy Thoughts” highlights the theories of gravity and motion proposed by Isaac Newton and Albert Einstein.

“Mission: Saturn” discusses the findings of the Voyager 2 and Cassini missions to Saturn and the landing of the Huygens probe on Titan.

“Mission: On to Uranus and Neptune” is about the continuation of the Voyager 2 mission to Uranus and Neptune and what Voyager discovered about these outer planets.

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<thead>
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<th>Alignment</th>
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<tr>
<td>Gravity</td>
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<td>Gravitational field</td>
</tr>
<tr>
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<td>Exoplanet</td>
<td>Plutonium</td>
</tr>
<tr>
<td>0.5 period</td>
<td>Fragment</td>
<td>Triton</td>
</tr>
<tr>
<td>0.5 period</td>
<td>Magnetic field</td>
<td>Voyager 1</td>
</tr>
<tr>
<td>2.0 periods</td>
<td>Ring</td>
<td>Voyager 2</td>
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**Content Standard A**
- Abilities necessary to do scientific inquiry

**Content Standard D**
- Earth in the solar system

**Content Standard G**
- History of science

STC Earth Science Strand: Earth’s Dynamic Systems
**Gravity and Orbital Motion**

**Overview**

During Lesson 3, students investigated surface gravity and the effect of mass on weight as a measure of this force. During this lesson, students investigate the force of gravity and its effect on the orbits of planets and moons. To begin, students observe a computer animation that demonstrates how the planets and asteroids move around the Sun. They review what they know about the Sun and Earth and consider patterns in the rotation and orbit of bodies within the solar system. Students then engage in four short inquiries that focus on orbital motion and read to learn more about gravity and its effect on the orbits of planets and moons. The lesson ends as students continue reading the Mission series to learn more about the journey of Voyager 2 to Saturn, Uranus, and Neptune.

**Background**

Just as a planet exerts a gravitational force on objects at its surface, the Sun and planets exert a gravitational force on each other. The enormous mass of the Sun produces the gravitational attraction that keeps the bodies in the solar system in orbit around it—eight planets (including Earth), and thousands of asteroids, comets, and dwarf planets. Gravity also keeps moons in orbit around planets.

**Orbital Motion**

How does gravity govern orbital motion in the solar system? The Sun's gravity continuously pulls the planets toward the Sun. But the planets also have a natural tendency to move forward in their orbits at a constant speed and in a straight line until acted upon by an outside force. These two motions—forward motion and motion toward the Sun under the influence of gravity—keep the planets traveling in closed, curved paths that are elliptical orbits around the Sun (see Figure 7.1). The greater the gravitational force pulling on a planet, the greater its orbital velocity must be to maintain a stable, closed orbit. Without the Sun's gravity, these solar system bodies would each move out through space in a straight line.

**The Two Motions That Keep a Planet Traveling in Orbit**

The planets orbit the Sun in a counterclockwise direction (as seen from Earth's North Pole) with those planets closest to the Sun traveling the shortest distances. Because the planets and the Sun were formed from the same rotating disk of dust and gas, it is logical that the counterclockwise direction of planetary revolution coincides with the Sun's counterclockwise rotation. Most of the planets also rotate in a counterclockwise direction. Venus is an exception because it is tilted nearly 180 degrees on its axis. This means that from Earth's North Pole, Venus appears to rotate in a clockwise, or retrograde, direction.

**Laws of Planetary Motion**

German astronomer Johannes Kepler (1571–1630) created a simple, precise description of planetary motion using records from Tycho Brahe (1546–1601), a Danish astronomer who had recorded the position of the stars and planets with unprecedented accuracy. Kepler stated that each planet moves around the Sun in an elliptical orbit. He also stated that a planet moves slowest when it is farthest from the Sun, and fastest when it is closest to the Sun.

Kepler observed that each planet moves in such a way that if an imaginary line were drawn between the Sun and a particular planet, the planet “sweeps out” equal areas in equal times (see Figure 7.2). This means that no matter where a planet is in its orbit around the Sun, the area of its triangular “sweep” remains the same for the same interval of time. Therefore, when a planet...
or satellite travels in an elliptical orbit, its orbital velocity is fastest when it is closest to the body it is orbiting, since the distance the planet “sweeps out” or covers in a given time is greatest. Its orbital velocity is slowest when it is farthest from the body it is orbiting, since the distance the planet covers in a given time is less.

The speed at which a planet travels in its orbit is called its orbital velocity. The amount of time required by a planet to complete one solar orbit is called its orbital period (or period of revolution). Both are affected by a planet’s distance from the Sun. Students will investigate the relationship between a planet’s orbital period and its distance from the Sun in their final performance-based assessment during Lesson 10.

Newton’s Law of Gravitation

While Kepler explained how the planets move, English physicist and mathematician Sir Isaac Newton (1642–1727) explained why the planets move as they do. Newton proposed a law of universal gravitation to explain the motions of the planets as described by the laws of Kepler. The law of universal gravitation states that any two objects, from the largest galaxy down to the smallest particle, attract each other with a force called gravity. Newton stated that the force of gravity is directly proportional to the product of the mass of two bodies, and inversely proportional to the square of the distance between them. (See “Background,” Lesson 3, for more information.) Simply put, Newton’s law states the following:

- **Mass:** More massive objects will attract each other with a greater gravitational force than less massive objects. As the mass of either object increases, the force of gravitational attraction between them also increases. If the mass of one of the objects is doubled, then the force of gravity between them is doubled. If the mass of one of the objects is tripled, then the force of gravity between them is tripled. If the mass of both of the objects is doubled, then the force of gravity between them is quadrupled, and so on.

- **Distance:** As the distance between two orbiting solar system bodies increases, the gravitational force between them decreases. This means that if Earth were 300,000,000 km away from the Sun (approximately twice its actual distance) the Sun's pull on it would only be one-quarter as strong. If Earth were three times farther away than it is now, the gravitational attraction between the Sun and Earth would be just one-ninth as strong. Planets closest to the Sun feel a stronger gravitational pull from the Sun than planets farther away from the Sun.
Newton’s Laws of Motion

To understand how gravity governs the planets' orbit around the Sun, it is important to understand some basic facts about how bodies move in general. Newton proposed the following three laws to describe and explain the motion of objects:

• Newton’s first law of motion, called the law of inertia, states that a body remains in a state of rest or uniform motion until an unbalanced force acts on it. This means an object will not change its speed or direction unless an outside force causes the object to change its motion. Newton used the term “inertia” to describe this tendency for a body to remain either at rest or in motion until acted upon by an outside force. (See “Heavy Thoughts” on pages 136–141 for more information on the law of inertia.) For example, a person in a moving car continues to move forward if the car comes to a sudden stop. The more mass an object has, the more inertia it exhibits.

• Newton’s second law of motion states that the acceleration (a) of an object is directly related to the force (F) exerted on an object and indirectly related to the mass (m) of the object:

\[ a = \frac{F}{m} \]

Acceleration is the rate at which an object changes its velocity. The velocity of an object describes not only how fast an object is moving but in what direction. This means that an object is accelerating if it is changing its speed and/or direction of motion over time. An object will move with an acceleration directly proportional to the force applied to it and indirectly proportional to its mass. Therefore, the greater the force, the more the object will accelerate, and the greater the mass, the less the object will accelerate when the other two values are held constant.

• In his third law of motion, Newton described how bodies interact. The third law is often stated as, “for every action there is an equal and opposite reaction.”

Gravity and Planetary Motion

Newton’s laws provide an explanation for the motions of planets around the Sun and of moons around planets. A simple analogy of how gravity controls the motion of a moon around a planet is demonstrated during Inquiry 7.4 when students twirl a sphere at the end of a string. According to Newton’s first law, the natural motion of an object, such as the sphere, is to move at a constant speed in a straight line. However, the sphere twirled on the end of a string travels in a circular path, which indicates that there is an unbalanced force holding it in a circular orbit and directed toward the center of the orbit. As the sphere moves in its circular path, it moves with constant speed but continually changes the direction of its motion. (Remember that an object whose direction of motion is changing is accelerating.) Similarly, a moon moves in a nearly circular orbit around a planet because there is a force that pulls it toward the center of its orbit. That force is the gravitational pull of the planet at the center of the moon’s orbit.

During Inquiry 7.4, students change the mass of the central force pulling on the sphere by adding washers to a cylinder. The more mass that students add to the cylinder, the faster the sphere must move to remain in orbit. This is in accordance with Newton’s second law of motion, which states that a moon will have greater
In this lesson students read “Stars Wobble,” which describes how planets exert a gravitational force on the stars they orbit and how scientists can detect the presence of planets around other stars from the wobble that the pull produces on the star’s motion. “Heavy Thoughts” highlights the theories of gravity and motion proposed by Isaac Newton and Albert Einstein. Students also read about the Voyager 2 and Cassini missions in “Mission: Saturn,” and about Voyager 2’s exploration of Uranus and Neptune in “Mission: On to Uranus and Neptune” in the Mission series.
GRAVITY AND ORBITAL MOTION

INTRODUCTION

How does a manmade satellite get into orbit? A satellite is launched by a rocket to a height (or altitude) at which Earth’s gravitational force keeps the satellite in orbit around Earth. A satellite, like the Moon, must travel at just the right speed to stay in Earth’s orbit. If the satellite moves too slowly, gravity might pull it back down to Earth. If the satellite moves too fast, it might escape Earth’s gravitational pull and zoom out into space.

In Lesson 3, you investigated the effects of surface gravity on weight. In this lesson, you will conduct four inquiries that focus on gravity and its effects on the orbits of moons and planets. What part does gravity play in keeping the planets in orbit around the Sun? How do the moons stay in orbit around each planet? In this lesson, you will investigate these and other questions. You will also read to learn more about missions to Saturn, Uranus, and Neptune.

NOTE

As an option, students can use a plastic box filled only with sand for Inquiry 7.1.

PREPARATION

1. Prepare eight areas of your room in which you can set up eight stations—two for each inquiry. Allow plenty of room between stations. Groups will rotate through these stations over a two-day period.

2. Make two copies of each inquiry card and laminate them (or put them into protective sheets) so that they can be reused throughout the day at the appropriate inquiry stations. (These are provided on the Teacher’s Tools CD.)

3. For Inquiry 7.1, use two plastic boxes filled with sand, flour, and cocoa from Lesson 6 and place two sets of the other materials for Inquiry 7.1 each in a resealable bag. For Inquiry 7.2, prepare two sets of materials each in an empty plastic box or resealable plastic bag. Use an index card to label each station with the appropriate inquiry number, and set out the materials.

4. For Inquiry 7.3, assemble two Planetary Motion Models™, one for each station, by doing the following:

   A. Separate the inner and outer rings of the quilting hoops.

   B. Lay the outer ring of the hoop on a large flat surface.

   C. Lay one 68.6-cm × 68.6-cm latex sheet across the outer ring of the hoop.

   D. Lay the inner ring of the hoop onto the latex sheet. Push the inner ring down into the outer ring so that the latex sheet is now between the two rings.

   E. Pull the opposing corners of the excess latex tightly together toward the center to tighten the latex sheet. As you pull on the excess latex, seal the two rings of the hoop together by tightening the wing nut. (You may need to work with a partner.)

   F. Repeat Steps A–E to assemble a second Planetary Motion Model.

   G. Support each model on four boxes of equal height. The models should sit about 30 cm above the table or floor (see SG Figure 7.3 on page 129). Make sure that the edge of the latex sheet hangs down as much as possible (as opposed to resting on the boxes) to help keep the center of the sheet taut.

   H. Fill two yellow round balloons with water to around 12 cm in diameter. Securely tie the neck of each balloon.
I. Place one water-filled balloon in the center of each elevated Planetary Motion Model. Press down on the balloon. If the latex beneath the balloon touches the tabletop or ground, raise the model using taller boxes. Remove the balloons for now.

J. Place one marble, the water-filled balloon, and a grooved plastic ruler in a resealable bag next to each model.

K. Label both stations “Inquiry 7.3.”

5. Cut the nylon fishing line. You will need two pieces that are 1 m in length.

6. For Inquiry 7.4, you will need to assemble two Moon Orbiters™, one for each of the two stations. To build each Moon Orbiter, do the following:

A. Place a few drops of glue along the threads of the screw eye.

B. Thread the screw into the sphere. Allow the glue to dry.

C. Punch two opposing holes approximately 1 cm from the top of the plastic cylinder (see Figure 7.3). Be careful not to punch the holes too high or the plastic will rip.

D. Thread the nylon line through the eye of the screw, then knot it. Make sure that it is very secure.

E. Thread the other end of the nylon line through the narrow plastic tubing, through the two opposing holes in the plastic cylinder, and then back up through the narrow plastic tubing. Knot the end of the nylon in the eye of the screw.

F. Repeat Steps A–E to assemble the second Moon Orbiter.

G. Place one Moon Orbiter, one student timer, and 25 large steel washers in each of two empty plastic boxes (or large resealable bags) for Inquiry 7.4.

H. Label the two stations “Inquiry 7.4.”

7. Place one copy of the appropriate laminated inquiry card at each station so students can refer to those directions instead of their Student Guides.

8. Set up the computer and its projector. Preview the Introduction in the software program Explore the Planets (see “Getting Started,” Step 1). You will use slides 1–14 in that program to introduce the lesson.

9. Make a copy of Student Sheet 8: Bode’s Law for each student. This will be completed as homework.
MATERIALS FOR LESSON 7

For the teacher
8 index cards, 3 × 5 in.*
1 marker*
1 pair of scissors*
1 pair of indirectly vented goggles*
1 hole punch
Question F folder (from Lesson 1)*
Question G folder (from Lesson 1)*
1 Explore the Planets CD-ROM
Access to a computer lab or computer LCD projector and screen*
Access to water*
White glue

For each student
1 working copy of Student Sheet 2.3c: Solar System Chart*
1 copy of Student Sheet 8: Bode’s Law* (see Homework)
1 pair of indirectly vented goggles*
*Needed but not supplied

NOTE
Set up two stations for each inquiry.

MATERIALS FOR INQUIRY 7.1

For each station
1 copy of Inquiry Card 7.1: Gravity’s Effect on Objects in Motion*
1 plastic box from Lesson 5 (filled with sand, flour, and cocoa)
1 large resealable plastic bag* containing the following:
  1 metric ruler, 30 cm (12 in)
  1 marble
  1 metric measuring tape
*Needed but not supplied

MATERIALS FOR INQUIRY 7.2

For each station
1 copy of Inquiry Card 7.2: Testing Balanced and Unbalanced Forces*
1 plastic box (empty)
1 metal canning jar ring
1 marble
1 sheet of white paper, 8.5 × 11 in*
*Needed but not supplied

MATERIALS FOR INQUIRY 7.3

For each station
1 copy of Inquiry Card 7.3: Observing Planetary Motion*
1 Planetary Motion Model™ (made up of the following):
  1 quilting hoop
  1 latex sheet
4 boxes of the same height*
1 large resealable plastic bag* containing the following:
  1 yellow balloon (filled with water)
  1 metric ruler, 30 cm (12 in)
  1 marble
*Needed but not supplied

MATERIALS FOR INQUIRY 7.4

For each station
1 copy of Inquiry Card 7.4: Investigating the Effect of Planetary Mass on a Moon’s Orbit*
1 large resealable plastic bag* containing the following:
  1 pre-assembled Moon Orbiter™ (made of the following):
    1 sphere, 7.5 cm
    1 m nylon fishing line
    1 screw eye
    1 piece of plastic tubing, 0.6 cm × 10 cm
    1 plastic cylinder, 2.5 cm × 15 cm
  25 large metal washers, %s in OD
1 student timer*
*Needed but not supplied
MATERIALS FOR LESSON 7

For you
1. working copy of Student Sheet 2.3c: Solar System Chart
2. pair of goggles

For the class
1. Inquiry Card Set
2. plastic box from Lesson 5 (filled with sand, flour, and cocoa)
3. metric rulers, 30 cm (12 in)
4. marbles
5. metric measuring tape
6. plastic box (empty)
7. metal canning jar ring
8. sheet of white paper
9. Planetary Motion Model™
10. plastic boxes or boxes of the same height
11. yellow balloon, filled with water
12. pre-assembled Moon Orbiter™
13. 25 large steel washers
14. student timer
GETTING STARTED

1. Show students the Introduction from Explore the Planets. Open the application file on the program and select <Help>. Place an X in the box marked <Sound (on/off)> Be sure the screen reads <Narration Active>. If not, click to activate. Return to the main menu, and select <Introduction>. Go through the first 14 slides with students. (You can stop before calculating weight based on gravitational force.)

2. Ask students to make general observations about the movements of the planets around the Sun. They may want to record their observations in their science notebooks. Discuss them as a class. Responses may include the following:

- The planets orbit counterclockwise around the Sun. The counterclockwise orbit of the planets matches the counterclockwise rotation of Earth (and the Sun).
- The planets are not in line with each other when they orbit the Sun.

- The inner planets appear to move in faster orbits than the outer planets. (Note that this difference is particularly evident between Mercury and Neptune.)
- Pluto’s orbit is greatly elliptical and is at an angle with the plane of the ecliptic (the orbital plane of the Sun and other planets). Pluto’s orbit crosses Neptune’s orbit.

NOTE

Point out that Pluto is no longer considered a major planet and has been reclassified as a dwarf planet. Pluto is now recognized as a member of a group of objects beyond Neptune that scientists have recently discovered.

NOTE

If you have a planetarium program, such as Starry Night Enthusiast™, use it to show the orbits and motions of the planets around the Sun. Some Internet sites also simulate the solar system and may be suitable for demonstrating the motions of objects in it.

NOTE

If your classes are 45 minutes long, this may be a good stopping point.
**PROCEDURE FOR THE CIRCUIT OF INQUIRIES**

**PROCEDURE**

1. Inform students that they will complete this lesson in a circuit format. They will work at four different stations and move from one station to the next to complete the four inquiries in this lesson. Show students how the inquiries have been set up around the room in stations. Inform groups that they will visit a total of four inquiries, each for a limited period of time (for example, 20 minutes) before moving on to the next inquiry. Establish a time period for the station visits.

2. Let students know that the procedures are summarized on inquiry cards at each station as well as in the Student Guide. Point out that students will use the plastic box of sand, flour, and cocoa for Inquiry 7.1 and that the sand, flour, and cocoa will keep the marble from rolling after it lands in the plastic box. Tell students to ignore the crater that the marble makes in the flour and to pay attention to the way the marble moves before it lands in the box. Review the Safety Tips.

3. Discuss how students will record their observations. Have students divide their notebook page into quadrants and label the quadrants 7.1, 7.2, 7.3, and 7.4, as shown in Figure 7.4 on page 124-B. Students should include the following in each quadrant:

   - The date of the entry and the inquiry number (and/or title)
   - What they observed during the inquiry (using words, labeled diagrams, and/or a data table)
   - Why they think this happened

4. Assign each group to a different station. Inform groups of the order in which they will complete the inquiries. Remind them that copies of the procedure for each inquiry are at each inquiry station.

5. Allow students time to rotate through all four inquiries. Remind them to return their equipment and inquiry card to its plastic box or bag before moving to the next station.

**SAFETY TIPS**

Wear safety goggles at all times.
Work in a well-ventilated area to reduce the level of dust in the air.
Be careful working with the balloon. It can be a choking hazard.
Be advised that the latex in the sheeting may cause an immediate or a delayed allergic reaction in certain sensitive individuals.

Do not swing the Moon Orbiter™ (Inquiry 7.4) at other students. Make sure that other students are not nearby when you orbit the large white sphere.
Always swing the Moon Orbiter above your head.
SAMPLE NOTEBOOK PAGES DIVIDED INTO QUADRANTS, ONE PER INQUIRY

FIGURE 7.4
INQUIRY 7.1

GRAVITY’S EFFECT ON OBJECTS IN MOTION

SAFETY TIPS
Wear safety goggles at all times.
Work in a well-ventilated area to minimize the level of dust in the air.

PROCEDURE

1. Hold the marble 40 cm above the plastic box. With the marble in your hand, decide what two forces are acting on the marble. Are the forces balanced (both pulling equally) or unbalanced (one is pulling more than the other)? Discuss your ideas with your group.

2. What will happen if you release the marble from your hand into the box? Discuss your predictions with your group.

3. Let go of the marble. Discuss your observations of the marble’s motion with your group. (Do not be concerned about the crater that the marble makes. The sand and flour keep the marble from moving once it lands in the box.) Compare your observations to your predictions.

4. Repeat Procedure Steps 1–3. Does the marble move the same way each time? Discuss your observations and record them in quadrant 7.1 in your science notebook.

5. Use the ruler as a ramp to gently roll the marble into the plastic box, as shown in Figure 7.1. Keep the ruler nearly flat. Discuss your observations. How did the marble move once it left the ruler?

STC Earth Science Strand: Earth’s Dynamic Systems 125

CURVED PATH OF BALLS TRAVELING AT DIFFERENT SPEEDS WHEN LEAVING A TABLETOP
FIGURE 7.5

High speeds Low speed

INQUIRY 7.1

PROCEDURE

1. Help students see that the two forces on the marble are gravity pulling down on the marble and the force of the hand which exerts an upward force that opposes the force of gravity. The forces are balanced. The marble is at rest and remains at rest.

2. From their experiences with impact craters in Lesson 5, most students will predict that the marble will fall down and hit the sand and make a crater.

3. Make sure students record in their science notebooks what happens when they release the marble. When released, the marble accelerates as it falls down and then comes to rest in the sand.

4. Encourage different students to repeat Steps 1–3.

5. Students should hold the ruler so that it is nearly flat (horizontal) and give the marble a gentle push so that it rolls a short distance off the ruler and then lands in the box. This time, the marble moves forward after it is pushed. Because of inertia, the marble continues its forward motion after the student’s hand has pushed it. When the marble leaves the end of the ruler, the marble moves forward and down at the same time. The marble drops into the box because gravity pulls it down as it continues its forward motion. The path of the marble is a curved path.
6. As the speed of the marble on the ruler increases, the marble will travel a greater distance across the box before it lands each time. Students can use the ruler to measure the distance the marble travels each time.

NOTE: In each trial, the marble drops the same distance each time it leaves the ruler; so, the time to fall is the same in each trial. However, if the speed of the marble on the ruler is increased, the marble will travel a greater distance across the box before it lands in the sand. See Figure 7.5 on page 125.

7. A. Gravity acts on the marble at all times, even when students are holding it in their hands, which balances the force of gravity.

B. The marble drops straight down into the box.

C. The marble is dropping the entire time once it leaves the ruler, but it has momentum when students push it along the ruler. This means that momentum carries the marble forward while it is also dropping. The harder students push the marble, the more momentum it has and therefore the faster the marble’s speed. The faster its speed, the farther out in the box it moves before it hits the bottom. If the marble could move fast enough, it would keep moving in an orbit around Earth, unless it traveled so fast that it could escape Earth’s gravity.

D. Its path would curve. For example, the Sun’s force of gravity continuously pulls each planet toward it. But the planets also have a natural tendency to move forward in their orbits at a constant speed and in a straight line. The tendency for a body to remain either at rest or in motion until acted upon by an outside force is called inertia. The force of gravity from the Sun makes the planets accelerate toward the Sun, which causes the planets’ path to curve.

8. Remind students to leave their stations as they found them.
Trace an outline of the ring onto the paper. Remove the metal ring from the paper. Mark four points at equal distances around the circle. Number the marks 1 to 4 going clockwise, as shown in Figure 7.2.

Place the metal ring on the circle, again with the lip up. Place the marble inside the metal ring. Without moving the metal ring, describe the motion of the marble. Record your observations in quadrant 7.2 in your science notebook.

**INQUIRY 7.2**

**PROCEDURE**

1–2. Check to see that students trace the ring and label the points correctly.

3. Students should observe that the marble does not move. Although gravity pulls down on the marble, the surface on which the marble rests exerts a force that is equal and opposite to that of gravity. These two forces balance each other and the marble remains at rest. No other forces act on the marble.
4. By moving the ring in a circular fashion, students give the marble a forward speed. The ring then exerts an unbalanced force on the marble that pushes the marble toward the center of circle. The unbalanced force that the ring exerts on the marble makes the marble move in a circular path.

5. Predictions will vary. Many students may think that the marble will move in a curved path once the ring is lifted.

6. When the ring is lifted, students should see the marble move in a straight line tangent to the circle at the point where the ring was lifted.

7. A. The marble moves in a curved path toward the center of the ring, instead of in a straight path.

   B. The marble leaves the ring tangent to the point at which the ring was lifted and then moves in a straight path.

   C. See Figure 7.6.

   D. See Figure 7.6.

   E. The unbalanced force that keeps the planets in orbit is the Sun's gravity. Without the Sun's gravity, the planets would move off into space in a straight path.

8. Remind students to leave their stations as they found them.
INQUIRY 7.3

OBSERVING PLANETARY MOTION

PROCEDURE
1. Check the setup of the Planetary Motion Model™. The lip of the hoop should be facing up to prevent the marble from falling off the latex sheet, as shown in Figure 7.3. Allow any extra sheeting to hang down under the hoop. Make sure the hoop rests on the edges of the boxes so they do not interfere with the marble once it is on the sheet.

SAFETY TIPS
Wear safety goggles at all times.
Be careful working with the balloon. It can be a choking hazard.
The latex in the rubber sheeting may cause either an immediate or delayed allergic reaction in certain sensitive individuals.

THE PLANETARY MOTION MODEL™ SHOULD BE SET UP AS SHOWN. (A) FACE THE LIP OF THE HOOP UP. (B) HANG THE EXTRA SHEETING UNDER THE HOOP. (C) PLACE THE HOOP ON THE EDGE OF EACH BOX.

FIGURE 7.3

THE MARBLE LEAVES THE RING TANGENT TO THE POINT AT WHICH THE RING WAS LIFTED AND THEN moveS IN A STRAIGHT PATH.

FIGURE 7.6

1. Check the setup of the Planetary Motion Model™. See SG Figure 7.3.
2. Encourage students to share and discuss their predictions of what will happen if they roll a marble onto the latex sheet.

3. Have students do several trials of rolling the marble on the flat sheet, trying different speeds. The marble follows a nearly straight path across the sheet each time before coming to rest.

4. The balloon makes the sheet stretch and sag in the middle. This is analogous to the Sun's mass curving the space around it (which is Einstein’s model of how gravity works). Because the space around the balloon is curved, there will now be an unbalanced force on the marble, pulling it toward the balloon as it rolls on the sheet. The marble should orbit a few times before it crashes into the Sun (balloon) at the center of the sheet. The path of the marble will probably be very elliptical. The speed of the marble will change as it moves around the sheet. The marble will move slowly near the outer edge of the sheet, and as it falls toward the balloon, its speed will noticeably increase. The marble will have its greatest speed when it is closest to the balloon. As the marble moves outward, away from the balloon, its speed will decrease.

5. Pushing the balloon down simulates a more massive Sun at the center of the solar system.

6. Predictions will vary.

**NOTE**

This motion simulates the path of a comet and shows how the speed of a comet changes dramatically as it falls from the outer solar system and passes close to the Sun. The planets' orbits are almost circular. To simulate a planet, try to release the marble so that its path is close to that of a circle around the sheet.

Because of friction between the marble and the sheet, the marble will lose its energy, slow down, and fall into the balloon after a few orbits. The balloon will wobble a bit as the marble orbits. Careful observation may reveal that the balloon's center and the marble's center are on opposite sides of the center of the circular sheet as the marble orbits the balloon.
7. Test the motion of the marble several times and observe its motion carefully. Let everyone take a turn. How does the motion of the marble change as it nears the balloon?

8. Now wobble the balloon very slightly as the marble orbits it. What happens? Try to use a gentle wobble on the balloon to keep the marble in motion. Discuss your observations. Then let go of the balloon. Does the balloon wobble on its own as the marble orbits it?

9. Record your answers to these questions:
   A. Describe how the marble moved when the mass in the center (the balloon) was not present.
   B. Describe how the marble moved when the mass in the center was present.
   C. As the distance between the balloon and marble decreased, what happened to the marble's speed?
   D. Based on your observations, which planet do you think would have the fastest orbital speed? What evidence do you have to support your answer?
   E. What force keeps the planets in their orbits around the Sun?
   F. Read “Stars Wobble.” Why does a star’s "wobble" indicate that a planet is nearby?

10. Clean up. Return all materials to their original condition.

---

**STARS WOBBLE**

There are many stars like our Sun. Some of these other stars may also have planets that orbit them. In 2008, the Hubble Space Telescope took the first picture of an exoplanet (a planet orbiting another star). The exoplanet is three times more massive than Jupiter. But most planets around other stars cannot be seen directly. So how do astronomers know that there are planets around other stars?

One way is to observe a star’s motion. When a planet orbits a star, it makes the star wobble. The wobble will make the star move toward us and away from us. Astronomers can detect this motion using spectroscopes attached to their telescopes.

It all begins with gravity. The law of gravity tells us that all objects pull on each other. The Sun pulls on the planets, but it also means that the planets pull on the Sun. (And moons and planets tug at each other.) An orbiting planet exerts a gravitational force that makes the star wobble in a tiny circular or oval path. The star’s wobbly path mirrors in miniature the planet’s orbit. It’s like two twirling dancers tugging each other in circles.

From the size of the wobble, astronomers can figure out how big, how massive, and how far away the planet is from the star. This method has been very successful for finding exoplanets. In 1995, astronomers confirmed the discovery of the first exoplanet. By 2007, more than 200 planets had been found. How many exoplanets have astronomers found now? See if you can find out.

C. The marble’s speed increased as the distance between the marble and balloon decreased.

D. Mercury has the fastest orbital speed because it is closest to the Sun. The motion of the marble was fastest when it was closest to the balloon.

E. The Sun’s gravitational pull is the force that keeps the planets in orbit around the Sun.

F. A planet exerts a gravitational force on the star it orbits (and vice versa), causing the star to wobble.
INQUIRY 7.4

INVESTIGATING THE EFFECT OF PLANETARY MASS ON A MOON’S ORBIT

PROCEDURE

1. Give students a couple of minutes to discuss how they think the orbiter works.
2. Make sure students check the knots on the string to be sure everything is secure.
3. Students will need to practice using the orbiter before they can get data. Some students will be able to twirl the sphere better than others. Encourage groups to find out who does this best and have that student twirl the sphere. Make sure everyone gets a chance to twirl the sphere of the orbiter even though some students will be more successful at twirling it than others.

SAFETY TIPS

Wear safety goggles at all times.
Do not swing the Moon Orbiter at other students. Make sure that other students are not nearby when you swing the white sphere.
Always swing the Moon Orbiter above your head.

PROEDURE

1. Examine the Moon Orbiter™. Discuss with your group how you think the Moon Orbiter might work.
2. Move to an area in the classroom where no other groups are working. Check to see that all nylon knots are secured to the large white sphere.
3. Hold the narrow plastic tubing of the Moon Orbiter in your hand like a handle. Practice holding the Moon Orbiter over your head and moving your hand in circles to get the white sphere to orbit your hand. Use a steady and regular motion. When the sphere is in full orbit, the bottom of the tube should nearly touch the cylinder. Let everyone in your group try to swing the Moon Orbiter. Remember, when the sphere is in full orbit, the tube should nearly touch the cylinder.

NOTE

The bottom of the tube and the cylinder should not touch when the student is twirling the sphere. If the cylinder touches the tube, students may not get the intended results for this inquiry.
Increase the mass of the Moon Orbiter by adding five washers to the cylinder. Move your hand in circles over your head to get the white sphere to orbit your hand, as shown in Figure 7.5. Describe how fast the sphere has to move to stay in orbit around your hand with a mass of five washers pulling on it. (If possible, calculate its orbital period—the time it takes the sphere to orbit your hand. For example, count the number of seconds it takes the sphere to orbit your hand 10 times. To get the orbital period, divide the number of seconds by 10.) Record your observations and data in quadrant 7.4 in your science notebook.

Predict what will happen if you increase the mass of the Moon Orbiter’s cylinder to 25 washers.

Fill the cylinder of the Moon Orbiter with 25 washers. Repeat Procedure Step 4 and discuss your observations. Describe how fast the sphere has to move to stay in orbit around your hand with 25 washers pulling on it. (Try calculating the sphere’s orbital period.) Record your observations.

Period = \( \frac{\text{time for 10 revolutions}}{10} \)

Predictions will vary.

Make sure students stand clear of the moving sphere. As they repeat Step 4, encourage students to keep their method of twirling as consistent as possible.

**NOTE**

During Inquiry 7.4, students will observe that the sphere orbits their hand faster when the cylinder contains more mass. This qualitative observation is sufficient. Although timing the motion of the sphere may not be easy, you may also want students to quantify their observations by calculating the orbital period of the sphere, as described in SG Procedure Step 4. Students will calculate the orbital period of a washer during the Lesson 10 assessment. Inquiry 7.4 can serve as a prerequisite.
Record your answers to these questions:

A. How does the mass of the cylinder affect how fast or slow the sphere orbits your hand?

B. Examine Table 7.1. Compare the mass of Jupiter with the mass of Earth. Which planet has more mass?

C. Examine Table 7.1. Compare Jupiter’s moon Io with Earth’s moon. How are they alike? How are they different?

D. Compare Io and the Moon. Which planetary satellite travels faster (has a greater orbital speed)? Given your results from the inquiry, why do you think this is?

E. Orbital period is the time it takes a revolving object to orbit a central object. Which planetary satellite has a shorter orbital period? What is the relationship between orbital speed and orbital period?

F. In Lesson 3, you learned the approximate mass of each planet. How do you think scientists determine the mass of the planets?

**TABLE 7.1 PLANETARY MASS VERSUS MOON’S ORBITAL PERIOD**

<table>
<thead>
<tr>
<th>SOLAR SYSTEM BODY</th>
<th>MASS (kg)</th>
<th>DIAMETER (km)</th>
<th>DISTANCE FROM PLANET (km)</th>
<th>ORBITAL SPEED (km/sec)</th>
<th>ORBITAL PERIOD (DAYS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JUPITER</td>
<td>$1.898 \times 10^{22}$</td>
<td>139,822</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EARTH</td>
<td>$5.97 \times 10^{24}$</td>
<td>12,742</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IO</td>
<td>$9 \times 10^{21}$</td>
<td>3643</td>
<td>421,800</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>MOON</td>
<td>$7 \times 10^{22}$</td>
<td>3475</td>
<td>384,400</td>
<td>1</td>
<td>27</td>
</tr>
</tbody>
</table>

Source: http://solarsystem.nasa.gov

This question is a conceptual leap for many students. To determine a planet’s mass, scientists observe the orbital periods of the planet’s moon or moons. For planets without natural satellites, such as Mercury, scientists may observe the orbital period of an artificial orbiter. The faster the satellite or orbiter’s orbital speed, the more massive the planet it is orbiting. Other factors, such as the mass of the orbiting satellite and its distance from the planet, are also taken into consideration.
Clean up. Return all materials to their original condition.

REFLECTING ON WHAT YOU’VE DONE

1. Share your answers to the inquiry questions with the class.
2. Read “Heavy Thoughts” on pages 136–141. Be prepared to discuss the questions at the end of the reading selection.
3. With your class, return to the Question F (What is gravity? Where is gravity strongest? Where is it weakest? Why?) and Question G (What keeps the planets in orbit around the Sun?) folders from Lesson 1. Is there anything you would now change or add? Discuss your ideas with the class.
4. Return to your list of ideas about gravity from Lesson 3. What new information about gravity do you want to add to your list?

8. Remind students to leave their stations as they found them.
**Period 3**

Have students read “Mission: Saturn” (pages 142–148) and “Mission: On to Uranus and Neptune” (pages 149–155). Remind them to add information to Student Sheet 2.3c: Solar System Chart and, if applicable, to their travel brochures.

**Period 5**

On the last day of this lesson, copy and distribute Student Sheet 8: Bode’s Law from Lesson 8 and have students complete this for homework. They will use this sheet in “Getting Started,” Lesson 8.

**EXTENSIONS**

**Science**

1. Have students experiment with the effects of orbital motion. Place a penny inside a 12-inch round balloon and a quarter in another balloon of the same size, and inflate the balloons. How much work do students have to do to get the penny to “orbit” the inside of the balloon? Have students describe the motion of the penny. How does this compare with the motion of the quarter? Making sure to control variables, students can experiment with different coins and different size balloons. Have students think about how the movements of the coins relate to planetary motion.

**Science/Mathematics**

2. Have students adapt Inquiry 7.4 by adding small washers to the hook of the white sphere to determine the effects of different masses of an orbiting object on the orbital period. Remind students to wear safety goggles at all times.

**Mathematics**

3. Have students calculate the circumference of the orbits of the Moon and Io and use this distance to calculate the speed of each.

\[
\text{Speed} = \frac{\text{distance}}{\text{time}} = \frac{\text{circumference of orbit}}{\text{period}}
\]

Have them calculate the speed of other moons and compare the speeds.
Check students’ notebooks for completion of the questions for the four inquiries. In Inquiry 7.1, students should have identified gravity as an unbalanced downward force on the marble as it traveled off the ruler and landed in the sand. In Inquiry 7.2, students should recognize that the marble travels in a straight line when the roll of tape is lifted because the unbalanced force is removed and because of its inertia, the steel moves off along a straight line path. In Inquiry 7.3, check to see that students correctly described that path of the marble as elliptical as it moved across the stretched latex sheet, and that the planets and other objects in orbit around the Sun follow elliptical orbits. Check also to see that they related the mass of the Sun (water-filled balloon) as the controlling factor in making the marble travel along an elliptical orbit around it, just as planets follow elliptical orbits around the Sun. In Inquiry 7.4, students should have related the amount of hanging mass in the cylinder pulling on the orbiting stopper to the speed needed to keep the stopper in a steady motion as it was swung. Check to see that they concluded that as the mass of the cylinder increases, the speed needed to stay in orbit also increases.
NEWTON’S APPLE
According to a well-known story, a brilliant 23-year-old English scientist named Isaac Newton was sitting under an apple tree one afternoon in 1666, when he saw an apple fall to the ground. Newton began thinking about the force that pulled the apple from the tree.

After careful experimentation, Newton concluded that there must be a single, invisible force responsible for these motions. The force we know as gravity is like the one you can feel when you place a magnet near a metal object (although gravity is not as strong as electromagnetic forces). Gravity makes apples fall from trees and it holds planets and moons in their orbits.
### WHAT IS AN UNBALANCED FORCE?

If two individual forces are of equal magnitude (size) and opposite direction, then the forces are balanced. Think of the marble you held in your hand during Inquiry 7.1. One force—Earth’s gravitational pull—exerts a downward force on the marble. The other force—your hand—pulls upward on the marble. The forces acting on the marble are balanced; as a result, the marble is at rest. Its motion does not change; it does not slow down or speed up or change direction. But if the two forces are not balanced, the marble will change its motion. It will change its speed or direction or both. For example, when you let go of the marble, the unbalanced force of gravity disturbs the marble’s motion and the marble falls into the box. As it falls, its speed constantly increases. Unbalanced forces cause objects to accelerate (change their speed or direction).
NEWTON’S LAW OF UNIVERSAL GRAVITATION

Newton’s Law of Universal Gravitation states that any two objects in the universe have gravity and will attract each other. Just how much those objects attract each other depends on two things—the mass of each object, and the distance between the objects.

The more mass a star (like our Sun) has, and the closer a planet is to that star, the greater the star’s ability to hold the planet in its orbit. Mercury, for instance is very close to the Sun, and it’s unlikely to drift away. Also, the more massive a planetary object, the better it is at pulling faraway objects into orbit. Jupiter, a planet with a lot of mass, has 62 known moons in orbit around it.

NEWTON’S LAWS OF MOTION

Newton described three famous laws of motion that help us understand how forces, like gravity, affect the motion of bodies.

The first of Newton’s three laws of motion is called the Law of Inertia. It says that a body in motion tends to travel at a constant speed in a straight line unless it is disturbed by an unbalanced force (a force that isn’t canceled out by another force). The Law of Inertia explains why you don’t keep rising when you jump up in the air. The unbalanced force of gravity disturbs your motion and pulls you back down. The Law of Inertia governs the motion of the planets and moons. If they weren’t affected by gravity, they would leave the solar system immediately, traveling in straight lines like a key you’ve been twirling when you let its cord fly off your finger. Gravity holds all the planets in orbit around the Sun, and each planet’s gravity captures and holds its moon(s) in orbit.

Newton’s Second Law of Motion tells how unbalanced forces affect the motion of objects. It says that unbalanced forces will change the motion of an object.

MUTUAL ATTRACTION

An object with a large amount of mass can exert a huge gravitational pull even on objects that are quite distant and massive. The Sun’s gravitational pull is so enormous that it easily hangs onto Jupiter, which has a mass two-and-a-half times as much as all the other planets combined. The Sun also exerts a gravitational hold over dwarf planets like Pluto. But, tiny Pluto also exerts a small gravitational pull on the Sun, even though they are more than 4.5 billion kilometers apart!

ACTION AND REACTION

Newton’s Third Law of Motion tells us that objects exert equal and opposite forces on one another. The Sun pulls on the planets and the planets pull on the Sun. The planets pull on the moons that orbit them and the moons pull on the planets. The same thing happens between you and Earth. If you jump up, Earth’s gravity pulls you back down and your gravity also pulls Earth toward you.

ORBITAL VELOCITY

The farther a planet is from the Sun, the more slowly it travels in its orbit. The closer a planet is to the Sun, the faster it travels in its orbit. Mercury, the planet closest to the Sun, travels at about 48 kilometers (30 miles) per second. But Neptune, the planet farthest from the Sun, is quite a different story. Look at Table 7.2: Orbital Velocity of Planets on page 141 and compare the orbital velocity of the planets. Do you notice patterns in the data? If so, what are they?

The attraction between two objects decreases as the distance between them increases. The
The great mass of Jupiter helps hold its many moons in orbit around the giant planet.

PHOTO: NASA Jet Propulsion Laboratory
HOW MATTER AFFECTS SPACE

Is gravity a force, or is it something else? About 250 years after Newton, another genius started thinking about gravity: Albert Einstein. Einstein’s theories changed the way we think about the universe.

Einstein came to believe that gravity isn’t really a force, but simply the way that matter affects space. According to Einstein, wherever there’s a chunk of matter—an apple, a person, a planet, or a star—the matter curves the space around it. The bigger the matter, the more that space is curved. And when space is curved, anything traveling through that space must follow those curves.

According to Einstein, the planets are caught in the curved space around the Sun. Our moon is caught in the curved space around Earth. If you were far enough away from the gravitational force of Earth or the Sun, small objects would become caught in the curved space around you!

MODELING CURVED SPACE

Einstein believed that the more massive the object, the more it curved the space around it. Think back to the inquiry in which you placed a water-filled balloon in the center of a rubber sheet. The balloon curved the rubber sheet around it. A marble placed on the sheet rolled toward the balloon, but not in a straight line. Instead, the marble followed the curves of the sheet and “orbited” the water-filled balloon in the center. The closer the marble got to the balloon in the center, the faster the marble rolled. Something similar happens with stars such as the Sun. Space curves around the star’s mass and helps to keep other objects, such as planets, “rolling” around them.
Sun’s pull on distant Neptune is much less than its pull on nearby Mercury. As a result, Neptune orbits the Sun at a much slower speed.

Newton and other scientists made important discoveries that describe how gravity works not just on Earth, but throughout the universe. Newton’s laws of motion and universal gravitation enable us to predict how planets, moons, and other bodies in our solar system move. That’s made it possible to send probes and spacecraft to planets, moons, comets, and asteroids. After all, if you can’t predict where Mars will be when your spacecraft reaches its orbit, your chances of landing on the planet are not so good.

### TABLE 7.2 ORBITAL VELOCITY OF PLANETS

<table>
<thead>
<tr>
<th>PLANET</th>
<th>ORBITAL VELOCITY (km/s)</th>
<th>APPROXIMATE DISTANCE FROM SUN (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MERCURY</td>
<td>47</td>
<td>57,900,000</td>
</tr>
<tr>
<td>VENUS</td>
<td>35</td>
<td>108,200,000</td>
</tr>
<tr>
<td>EARTH</td>
<td>30</td>
<td>149,600,000</td>
</tr>
<tr>
<td>MARS</td>
<td>24</td>
<td>227,900,000</td>
</tr>
<tr>
<td>JUPITER</td>
<td>13</td>
<td>778,300,000</td>
</tr>
<tr>
<td>SATURN</td>
<td>10</td>
<td>1,426,700,000</td>
</tr>
<tr>
<td>URANUS</td>
<td>7</td>
<td>2,870,700,000</td>
</tr>
<tr>
<td>NEPTUNE</td>
<td>5</td>
<td>4,498,400,000</td>
</tr>
</tbody>
</table>

Source: http://solarsystem.nasa.gov

### DISCUSSION QUESTIONS

1. What would happen to the planets if there were no gravitational influences from the Sun?
2. In baseball, why does a curve ball curve? Explain using Newton’s laws of motion.
Mission: SATURN
**VOYAGERS 1 AND 2**


The *Voyager* probes gave us a new, sharper view of Saturn, its rings, and its moons. The rings are like a brilliant, vivid necklace with 10,000 strands, and they proved to be more beautiful and strange than once thought.

Evidence indicates that Saturn's rings formed from large moons that were shattered by comets and meteoroids that struck them, exploding into huge clouds of debris. The resulting ice and rock fragments—some as small as a speck of sand and others as large as houses—went on orbiting Saturn, gathering in a broad plane around the planet. The rings themselves are very thin, but together they are 171,000 kilometers in width! (That’s more than 10 times Earth’s diameter.)

The irregular shapes of Saturn’s eight smallest moons indicate that they, too, are fragments of larger bodies. Two of these small moons—Prometheus and Pandora—are located in one of Saturn's many rings.

*Voyager 2* showed something even more dramatic: a gravitational tug of war among Saturn, its 60+ moons and moonlets, and the ring fragments. This struggle has caused variations in the thickness of the rings. Some particles are even rising above the ring band as if they might escape.
THE CASSINI MISSION

In October 1997, NASA launched a probe on a new mission to explore Saturn. The probe was named Cassini, in honor of the seventeenth century Italian astronomer who observed Saturn and discovered a gap in Saturn's ring system, and its launch generated worldwide excitement. In order to save fuel, the Cassini probe used gravity assists from Venus, Earth, and Jupiter along its journey to the distant ringed planet. Cassini arrived at Saturn in 2004 and went into an elliptical orbit around the planet.

For four years, Cassini sent back fascinating images of Saturn's rings and moons. Saturn's rings look smooth and orderly as seen from Earth, but the Cassini images showed that the ring system around Saturn is complex. Small moons and ring particles collide within the ring system and waves form within the rings as well.
Cassini spacecraft firing main engine to insert itself into Saturn’s orbit (artist conception)

PHOTO: NASA Jet Propulsion Laboratory

Cassini also looked closely at the cloud patterns in Saturn’s atmosphere to learn about weather on the planet. Cassini found that Saturn has rain and snow and storms with lightning.

Images of Saturn’s moons revealed fantastic features, such as ice plumes that contain carbon-backbone chemicals like those found on Earth, and rings around some moons, as well as puzzling surface features like an unusual bulge in one moon’s dark-side shadow. Cassini found that the moon, Iapetus, has a white side, a black side, and a mountainous bulge around its equator. Cassini also discovered previously unseen moons orbiting Saturn; more than 60 moons have now been counted.
WORKERS GETTING THE HUYGENS PROBE READY FOR ITS MISSION.

PHOTO: NASA Kennedy Space Center
Cassini carried another probe inside itself. The probe was named Huygens, in honor of Christian Huygens, who discovered Saturn's largest moon, Titan, in 1655. The Huygens probe was built by the European Space Agency and its mission was to descend through the atmosphere of Titan and send back data. It successfully completed that mission on January 14, 2005. Huygens survived the trip through the atmosphere and landed on the surface of Titan. Huygens found huge methane lakes, regions of wind-driven hydrocarbon sand dunes, and ice boulders on Titan.

The original Cassini mission ended in 2008, but it not only answered questions about Saturn and its rings and moons, it generated many new questions—much to the excitement of astronomers! The Cassini mission was extended and renamed the Saturn Equinox mission. The new mission has given us more time to learn more about this fascinating system.

DISCUSSION QUESTIONS

1. Compare and contrast the characteristics of Saturn with those of other gaseous giants.

2. Given what you know about requirements for life, would it be possible for life to exist on Saturn? Is it likely? Explain your ideas.
SATURN: QUICK FACTS*

- Diameter: 116,464 km
- Average distance from the Sun: 1,426,666,422 km
- Mass: 56,832 \times 10^{22} \text{ kg}
- Surface gravity (Earth = 1): 1.06
- Average temperature: \(-140^\circ\text{C}\)
- Length of sidereal day: 10.66 hours
- Length of year: 29.45 Earth years
- Number of observed moons: 62

DID YOU KNOW?

- If there were an ocean big enough to plop Saturn into, the planet would float—just like an iceberg does on planet Earth! That’s because of Saturn’s low density. Saturn is the only planet that is lighter than the same volume of water.
- Saturn’s winds reach 1800 km/hour. (The strongest tornadoes on Earth have wind speeds of only 350 km/hour.)

* Source: Data from NASA as of 2011
Beginning in 1977, the Voyager mission became quite a scientific odyssey! After flying past Saturn, *Voyager 1* left the plane of the solar system, as planned. (If you imagine the planets laid out on a flat disc around the Sun, you can see what’s meant by “the plane of the solar system.”) *Voyager 2* was supposed to take the same course. But the
spacecraft was performing so well, scientists and engineers on Earth decided to send it on to Uranus and Neptune for a closer look. Saturn, Neptune, and Pluto were lined up near each other in their orbits, and a similar alignment of the outer planets would not occur again until the year 2157. Never before had we had a close-up view of the outer solar system.

Saturn’s huge gravitational field pulled Voyager 2’s path toward Saturn, then flung the spacecraft toward Uranus. A similar boost from giant Uranus would send Voyager 2 to Neptune. This maneuver, called a gravity assist, took decades off Voyager’s flying time.

Unfortunately, the grand tour of the solar system conducted by Voyager couldn’t include Pluto because Pluto’s orbit took it far from the spacecraft’s path. Still, the remarkable journey of Voyager 2 yielded many insights.

**URANUS**

After its push from Saturn’s gravitational field, Voyager 2 arrived at Uranus in 1986, and on arrival found 10 moons never seen by Earth’s telescopes. That brought the count of Uranus’s moons to 20. Scientists had believed that there might have been several more tiny moons within the rings, and they were right!

The Voyager cameras also found that Uranus had more rings than had been seen from Earth, and showed that rings of fine dust surrounded the planet’s nine major rings.

According to data, Uranus’s rings probably formed after the planet itself. Like Saturn’s rings, Uranus’s appeared to be the remnants of a moon destroyed in a collision.

Voyager 2 made another major discovery at Uranus. It turns out that the planet has a magnetic field as strong as Earth’s. The cause of this field isn’t clear, but it’s shaped like a long corkscrew. And, according to Voyager’s measurements, it reaches 10 million kilometers (more than 6 million miles) behind the planet! How far is that? Earth’s magnetic field extends just tens of thousands of kilometers, so this is a couple of orders of magnitude greater.

**NEPTUNE**

Thanks to the gravity assist from Uranus, Voyager reached Neptune just three years later, in 1989. Until that time, scientists had believed that the planet had arcs, or partial rings. But Voyager showed that Neptune has complete rings with bright clumps; it was the clumps that had been noticed from Earth. Voyager also discovered six new moons.

> This view of Uranus was acquired by Voyager 2 in January 1986. The greenish color of its atmosphere is due to methane and smog. Methane absorbs red light and reflects blue-green light.

PHOTO: NASA Jet Propulsion Laboratory
THIS 1998 IMAGE SHOWS THE GREAT DARK SPOT ON NEPTUNE, A STORM RAGING IN THE NORTHERN HEMISPHERE. THE WHITE SLASH BELOW IT IS A GROUP OF CLOUDS, SIMILAR IN APPEARANCE TO CIRRUS CLOUDS ON EARTH, BUT MADE FROM CRYSTALS OF FROZEN METHANE RATHER THAN ICE. THESE STORMS COME AND GO; A PREVIOUS GREAT DARK SPOT IN THE SOUTHERN HEMISPHERE DISAPPEARED IN 1994.

PHOTO: NASA Jet Propulsion Laboratory
Voyager flew within 5000 kilometers (3107 miles) of Neptune's long, bright clouds, which resemble cirrus clouds on Earth. Instruments aboard Voyager measured winds up to 2000 kilometers (1243 miles) an hour—the strongest winds on any planet. Tornado-strength winds on Earth's surface are only a tenth that fast.

Triton, Neptune's largest moon, is one of the most fascinating (and coldest) satellites in the solar system. Imaging from Voyager 2 revealed “ice volcanoes” spewing frozen nitrogen and dust particles several kilometers into the atmosphere!

In 1990, Voyager 2 left Neptune and headed south onto a course that has taken it, like Voyager 1, to the edge of our solar system and beyond, almost past the reaches of the Sun's winds. This is where interstellar space begins. The spacecraft—fueled by the radioactive decay of plutonium—is expected to continue operating until about 2030.

Voyager carries not just scientific equipment, but a message for any intelligent life forms it might meet. On a golden record, the kind of record made for old-fashioned record players, it carries the following symbols, as well as several kinds of recordings, all aimed at telling the alien about Earth, Earthlings, and the space mission. Can you guess what the symbols mean?

The record carried music from around the world; Earth sounds like wind, whales, and a kiss; the brainwaves of the wife of astronomer Carl Sagan; and a printed message from President Jimmy Carter. It said: “This is a present from a small, distant world, a token of our sounds, our science, our images, our music, our thoughts, and our feelings. We are attempting to survive our time so we may live into yours.”
Although its cameras have been shut down to save fuel, Voyager 2 is still sending fascinating data. Recently it discovered a powerful magnetic field just beyond the solar system. NASA scientists say that hundreds of thousands of years from now, that magnetic field could actually squeeze the area around the solar system, and bring interstellar space closer to Earth.
**URANUS: QUICK FACTS**

- Diameter: 50,724 km
- Average distance from the Sun: 2,870,658,186 km
- Mass: $8.681 \times 10^{22}$ kg
- Surface gravity (Earth = 1): 0.90
- Average temperature: -195°C
- Length of sidereal day: 17.24 hours (retrograde)
- Length of year: 84.02 Earth years
- Number of observed moons: 27

**COMPOSITION**

- Ring system
- Gas and ice mantle
- Solid rock core

**RELATIVE SIZE**

**DID YOU KNOW?**

- The poles of Uranus are in the same position as the equators on other planets. That’s because Uranus rotates on its side.
- It takes nearly 2½ hours for light from the Sun to reach Uranus. (It only takes about eight minutes for the Sun’s light to reach Earth!)

**ATMOSPHERE**

- Hydrogen (83%)
- Helium (15%)
- Methane and traces of other compounds (2%)

*Source: Data from NASA as of 2011*
**NEPTUNE: QUICK FACTS**

- **Diameter**: 49,244 km
- **Average distance from the Sun**: 4,498,396,441 km
- **Mass**: $10,241 \times 10^{22}$ kg
- **Surface gravity (Earth = 1)**: 1.14
- **Average temperature**: -200°C
- **Length of sidereal day**: 16.11 hours
- **Length of year**: 164.79 Earth years
- **Number of observed moons**: 13

**COMPOSITION**

- Solid rock core
- Gas and ice mantle
- Ring system

**ATMOSPHERE**

- Hydrogen (80%)
- Helium (19%)
- Methane and traces of other compounds (0.5%)

**DID YOU KNOW?**

- Neptune was named after the Roman god of the sea, probably because of its blue color.
- Neptune gives off more heat than it receives from the Sun. This means it probably has its own heat source.

*Source: Data from NASA as of 2011*