A Spin Around Jupiter: Understanding the Effects of Rotation on Atmosphere

Grade Range: 6-8

Teaching Time: three to four, 45-minute periods

Module: Atmosphere

Lesson: A Spin Around Jupiter: Understanding the Effects of Rotation on Atmosphere

Activities

I. How Long is a Day?
II. What does Spin do to the Atmosphere of a Planet?
III. What more can we learn by comparing the atmospheres of Earth and Jupiter?

Lessons Recommended to Precede this Lesson

- Giants in Our Neighborhood: Exploring the Atmospheres of Earth & Jupiter
- (Optional) Kinesthetic Magnetosphere

Advanced Planning

1. Copy student pages
2. Ensure that you have access to a computer with the ability to project multimedia and images using presentation and video software such as PowerPoint, KeyNote, and Quicktime.

Materials

Teacher Materials

- Computer with Internet access and ability to project images and multimedia
- Access to presentation software such as PowerPoint or Keynote
- Access to video presentation software such as QuickTime or RealPlayer
- Slideshow: *A Spin Around Jupiter*
- Videos: Nor'easter Blizzards (also listed as Nor'easter Parade), Jupiter Cloud Sequence from Cassini, Voyager 1 Jupiter Cloud Time-lapse animation
- Globe of Earth or sphere
- Flashlight to represent the Sun as a source of light
- Calculator

Student Materials

- Student pages: *How Long is a Day?*, *What does Spin do to the Atmosphere of a Planet?, What more can we learn by comparing the atmospheres of Earth and Jupiter?*
- Pencil
- Calculator
- Metric Ruler
- Lined paper

Learning Outcomes

As a result of this lesson students will:

- Use mathematics to calculate the rate of spin (period of rotation at the equator) for planets in our Solar System
- Use qualitative and quantitative data to describe the effects of the period of rotation on the atmosphere of a planet
- Measure the size and describe the appearance of several atmospheric features on Jupiter.
- Use the Internet and text sources to research scientific information about selected atmospheric features of Jupiter.

Prior Knowledge & Skills

Students should have a basic knowledge, understanding, or skills:

- Ability to use division, multiplication, and estimation
- Mathematical terms: circumference, radius
- Experience describing and interpreting images
- Ability to use the Internet to source appropriate information
- Understanding of basic meteorology
- The cause of night and day
- Basic knowledge of heat transfer: radiation, conduction, convection
- Causes of cloud formation

What Students Do

The Juno Atmosphere Module engages students in a comparison of the nature and features of the atmospheres of Earth and Jupiter. The Atmosphere Module consists of two lessons. One lesson, *A Spin Around Jupiter: Understanding the Effects of Rotation on Atmosphere* compares and contrasts global atmospheric patterns and rates of rotation. The other lesson, *Giants in Our Neighborhood: Understanding the Effects of Rotation on Atmosphere* compares and contrasts the scale of atmospheric events on Earth to those on Jupiter. Students use an array of information (data, images, and multimedia resources) to learn about the features, composition, and processes of the atmospheres of Earth and Jupiter. The data sets provide students the opportunity to perform comparative planetology using information captured by remote sensing devices.

This lesson, *A Spin Around Jupiter*, compares the rotation of the planets in our solar system to the rotation of Earth. The lesson then explores the effects of spin on planetary atmospheres. In Activity I, students ***review*** the cause of day and night. They address the question, "Do other planets have day and night?" Students calculate the length of day for each planet in the solar system in "Earth-days". Next, students compare the number of degrees other planets turn in one hour with respect to the rotation of Earth. In Activity II, students explore the effects of the rate of spin on the number and width of cloud bands for the atmospheres of several planets. After comparing global scale impacts of spin on the atmospheres of planets, Activity III engages students in the study of storms on Earth and Jupiter.

Rationale

Comparative planetology and our understanding of Jupiter rely heavily on data and images collected by remote sensing devices. We study other planets from afar and compare them to our own. The activities in this lesson explore the relationship between period of rotation (rate of spin) and the nature and structure of planetary atmospheres. The lesson begins with a discussion about the cause of day and night, asking students to consider if other planets experience day and night. This discussion provides teachers an initial, embedded assessment of student understanding of planetary rotation. Following this, students apply mathematics to calculate and compare the period of rotation for planets in our solar system. The integration of mathematics in this lesson provides students with quantitative data along with qualitative information (images of each planet) to identify and interpret a pattern of atmospheric structure—atmospheric bands increase in number and decrease in width with increased rate of planetary spin. Finally, students compare specific atmospheric features and phenomena of Earth and Jupiter. Their detailed investigations reveal significant differences in the nature of atmospheric phenomena that result from the fundamental differences in the composition and structure of rocky and gaseous planets.

Curriculum Connections

The Juno Atmosphere Module engages students in a comparison of the nature and features of the atmospheres of Earth and Jupiter. The Atmosphere Module consists of two lessons, focused on key concepts associated with the study of the atmosphere of Jupiter. Students use an array of information (data, images, and multimedia resources) to learn about the features, composition, and processes of the atmospheres of Earth and Jupiter. The data sets provide students the opportunity to perform comparative planetology using information captured by remote sensing devices. In the lesson, *Giants in Our Neighborhood: Scale and the Atmospheres of Earth and Jupiter*, students investigate the size of atmospheric features and phenomena on Earth and Jupiter after calculating the scale factor between the planets. In *A Spin Around Jupiter* students compare global atmospheric patterns to rates of spin the planets in our solar system that have atmospheres.

Juno Mission Connection

How deep Jupiter's colorful zones, belts, and other features penetrate is one of the most outstanding fundamental questions about the giant planet. Juno will determine the global structure and motions of the planet's atmosphere below the cloud tops for the first time, mapping variations in the atmosphere's composition, temperature, clouds and patterns of movement down to unprecedented depths.

Instruments and Data

Juno will observe the atmosphere of Jupiter at infrared wavelengths with the Juno InfraRed Auroral Mapper – JIRAM – instrument. JIRAM will observe Jupiter at a few very specific wavelengths of infrared light and produce maps or images of Jupiter's atmosphere at each of those specific wavelengths. A team of researchers in Italy built JIRAM.

Currently, scientists observe Jupiter's atmosphere with telescopes on Earth. Juno will orbit around the poles of Jupiter producing the first complete observations of the planet. At its closest, Juno will be about 4,000 km above the cloud tops. This means we will have the most detailed infrared pictures available to date.

Observing Jupiter's deep atmosphere is a challenge. The Microwave Radiometer will allow scientists to probe the deep atmosphere at wavelengths from 1.3 cm - 50 cm. The data will help determine the depth of the atmospheric circulation. The wavelengths of 1.3 cm – 50 cm allow Juno to collect data about the atmosphere while avoiding radiation at other wavelengths, especially strong signals of processes produced by the magnetosphere. To create a complete picture of the variation in temperature with altitude in Jupiter's atmosphere, MWR collects data from six different wavelengths.

National Standards and Benchmarks

This lesson has been mapped to middle school grade level mathematics and science content standards, benchmarks, and common core state standards as defined by:

- National Science Education Standards (National Research Council, National Academy Press, Washington, D.C., 1996); http://www.nap.edu/html/nses/html
- Benchmarks for Science Literacy (American Association for the Advancement of Science, Project 2061, Oxford University Press, New York, 1993, revised in 2009); http://www.project2061.org/publications/bsl/online.
- Principles and Standards for School Mathematics (2000-2004 by the National Council of Teachers of Mathematics); http://www.nctm.org/standards
- Mid-continent Research for Education and Learning compendium of standards and benchmarks for K-12 education; http://www.mcrel.org/standards-benchmarks/index.asp.
- Common Core State Standards for Mathematics (National Governors Association Center for Best Practices and the Council of Chief State School Officers, 2010); http://www.corestandards.org

National Science Education Standards

Science as Inquiry, Content Standard A:

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Physical Science, Content Standard B:

- Properties and changes of properties in matter
- Motions and forces
- Transfer of energy

Earth and Space Science, Content Standard D:

- Structure of the earth system
- Earth in the solar system

Science and Technology, Content Standard E:

- Understandings about science and technology

Science in Personal and Social Perspectives, Content Standard F:

- Science and technology in society

History and Nature of Science, Content Standard G:

- Science as a human endeavor
- Nature of science

AAAS Benchmarks for Science Literacy

1. The Nature of Science
   A. The Scientific Worldview
   B. Scientific Inquiry
   C. The Scientific Enterprise
2. The Nature of Mathematics
   A. Patterns and Relationships
   B. Mathematics, Science, and Technology

   C. Mathematical Inquiry
3. The Nature of Technology
   A. Technology and Science
4. The Physical Setting
   A. The Universe
   B. The Earth
   C. Processes that Shape the Earth
   D. The Structure of Matter
   E. Energy Transformations
   F. Motions
   G. Forces of Nature
9. The Mathematical World
   A. Numbers
   B. Symbolic Relationships
   E. Reasoning
10. Historical Perspectives
   A. Displacing the Earth from the Center of the Universe
11. Common Themes
   A. Systems
   B. Models
   C. Constancy and Change
   D. Scale
12. Habits of Mind
   A. Values and Attitudes
   B. Computation and Estimation
   C. Manipulation and Observation
   D. Communication Skills

McREL Compendium of Standards and Benchmarks

Science

Standard 2: Understands Earth's composition and structure

- Benchmark 1: Knows that the Earth is comprised of layers including a core, mantle, lithosphere, hydrosphere, and atmosphere

Standard 3: Understands the composition and structure of the universe and the Earth's place in it

- Benchmark 1: Knows characteristics and movement patterns of the planets in our Solar System
- Benchmark 2: Knows how the regular and predictable motions of the Earth and Moon explain phenomena on Earth

Standard 11: Understands the nature of scientific knowledge

- Benchmark 1: Understands the nature of scientific explanations
- Benchmark 2: Knows that all scientific ideas are tentative and subject to change and improvement in principle, but for most core ideas in science, there is much experimental and observational confirmation
- Benchmark 3: Knows that different models can be used to represent the same thing and the same model can represent different things; the kind and complexity of the model should depend on its purpose

- Benchmark 4: Knows that models are often used to think about things that cannot be observed or investigated directly

Standard 12: Understands the nature of scientific inquiry

- Benchmark 1: Knows that there is no fixed procedure called "the scientific method," but that investigations involve systematic observations, carefully collected, relevant evidence, logical reasoning, and some imagination in developing hypotheses and explanations
- Benchmark 2. Understands that questioning, response to criticism, and open communication are integral to the process of science
- Benchmark 6. Uses appropriate tools (including computer hardware and software) and techniques to gather, analyze, and interpret scientific
- Benchmark 7. Establishes relationships based on evidence and logical argument

Standard 13: Understands the scientific enterprise

- Benchmark 1. Knows that people of all backgrounds and with diverse interests, talents, qualities, and motivations engage in fields of science and engineering; some of these people work in teams and others work alone, but all communicate extensively with others
- Benchmark 2. Knows that the work of science requires a variety of human abilities, qualities, and habits of mind
- Benchmark 3. Knows various settings in which scientists and engineers may work
- Benchmark 6. Knows ways in which science and society influence one another

NCTM Principles and Standards for School Mathematics

Number & Operations

- Work flexibly with fractions, decimals, and percents to solve problems
- Understand and use ratios and proportions to represent quantitative relationships

Algebra

- Represent, analyze, and generalize a variety of patterns with tables, graphs, words, and, when possible, symbolic rules

Measurement

- Understand both metric and customary systems of measurement
- Understand relationships among units and convert from one unit to another within the same system

Data Analysis & Probability

- Formulate questions, design studies, and collect data about a characteristic shared by two populations or different characteristics within one population

Process Standards

- Problem Solving
- Communication
- Connection
- Representation

McREL Compendium of Standards and Benchmarks

Mathematics

Standard 2: Understands and applies basic and advanced properties of the concepts of numbers

- Benchmark 1. Understands the relationships among equivalent number representations
- Benchmark 2. Understands the characteristics and properties of the set of rational numbers and its subsets
- Benchmark 3. Understands the role of positive and negative integers in the number system
- Benchmark 7. Understands the concepts of ratio, proportion, and percent and the relationships among them

Standard 3: Uses basic and advanced procedures while performing the processes of computation

- Benchmark 1: Adds, subtracts, multiplies, and divides integers, and rational numbers.
- Benchmark 4. Selects and uses appropriate computational methods for a given situation
- Benchmark 5. Understands the correct order of operations for performing arithmetic computations
- Benchmark 8. Knows when an estimate is more appropriate than an exact answer for a variety of problem situations

Standard 4: Understands and applies basic and advanced properties of the concepts of measurement

- Benchmark 1. Understands the basic concept of rate as a measure
- Benchmark 5. Understands the concepts of precision and significant digits as they relate to measurement
- Benchmark 6. Selects and uses appropriate units and tools, depending on degree of accuracy required, to find measurements for real-world problems
- Benchmark 8. Selects and uses appropriate estimation techniques to solve real-world problems

Standard 5: Understands and applies basic and advanced properties of the concepts of geometry

- Benchmark 6. Understands the mathematical concepts of similarity

Standard 6: Understands and applies basic and advanced concepts of statistics and data analysis

- Benchmark 4. Reads and interprets data in charts, tables, and plots

Common Core State Standards for Mathematics

Grade 6

The Number System

- Compute fluently with multi-digit numbers and find common factors and multiples.

Grade 7

Ratios and Proportional Relationships

- Analyze proportional relationships and use them to solve real-world and mathematical problems.

Expressions and Equations

- Solve real-life and mathematical problems using numerical and algebraic expressions and equations

A Spin Around Jupiter: Understanding the Effects of Rotation on Atmosphere

Note to the Teacher
This lesson guide parallels the slideshow, *A Spin Around Jupiter*. For those without the ability to project the presentation, it is recommended that you print hard copies of each slide and distribute them to students.

Introducing the Lesson

Explain to students that in this lesson they will perform a number of activities using data sets (data, images, and multimedia resources) to compare and contrast the effect of the period of

Orienting Students to Images of Planets
If your students are not familiar with the images of planets from afar, take the time to orient them to the images on slides 1-3. The notes included with each slide provide an explanation of the image and features to notice.

Activity I: How Long is a Day?

Use this activity to review student understanding of the cause of day and night on Earth and to calculate and compare the length of day on other planets to the length of day on Earth. Astronomers measure length of day in different ways as described in greater detail on page 19.

Corresponding Slide Numbers	**Instructional Steps**
1-3	1. Use slides 2 and 3 to assess student understanding of day and night. Ask students to turn to a classmate and briefly explain their understanding of the cause of day and night using a "Share Pair" approach. 2. Ask volunteers to share their partner's explanation of day and night. Allow students use of a sphere/globe to represent a planet and a flashlight to represent the Sun as tools to explain their ideas. 3. As a class, discuss student responses to the question, "Do other planets have day and night?"
4	4. Review the definition of a "day". *A day is the time it takes a planet to rotate once on its axis.* We compare the length of day of other planets to Earth's day of 24 hours.
5-6	5. Distribute and review the student page, "How Long is a Day?" Distribute calculators or explain your expectations for performing division without a calculator. 6. Explain that students will calculate the number of Earth

	days it takes each planet in the solar system to make one rotation. 7. Pair students or have them work individually to complete the data table and answer the questions. 8. Reconvene the class as a whole or pair students with others to review calculations and responses to the questions.
7	9. (Optional) Review the rate and direction of rotation for each planet.
8-9	10. Explain that scientists measure the rate of rotation of planets in degrees per hour. Explain that Earth rotates 360 degrees in 24 hours or 15 degrees/hour. Using a sphere, model rotating the planet in 24 segments of 15 degrees. Next, have students estimate the number of degrees each of the other planets rotates in one hour. Ask students: • Based upon this table (Slide #8) which planets rotate more degrees per hour than Earth? Which planets rotate fewer degrees per hour than Earth? *Answer: Mars spins at about the same rate as Earth. Mercury and Venus fewer degrees per hour, and the gas giants spin more degrees per hour than Earth.*

Summarize and Reflect

As a class, review the length of day and the amount of rotation (in degrees) for the various planets. Ask students to consider what this information might allow them to infer about the conditions on other planets. Asks questions such as:

- To which planet would you travel if you wanted to spend the most continuous number of Earth days in sunlight? *Answer: Venus. Day lasts for 2802 hours or 117 days.*
- To which planet would you travel if you wanted to see the Sun rise and set the most often in an Earth day? *Answer: Jupiter. A resident of Jupiter would experience 2.5 days (2 sunrises and sunsets, plus) in the time an observer of Earth would experience one sunrise and sunset.*
- On which planet would you *feel* like you were spinning the fastest/slowest? *Answer: **This is a trick question**. If it were possible to survive on other planets, we would not notice the speed at which the planet spins any more than we notice that the Earth is spinning. We would notice the rate of sunrise and sunset for different planets. The concept of day (and year) is relative to the planet on which the observer is located.*

Activity I Assessment Opportunities

Collect and review student work to assess their ability to perform division and classify planets based upon length of day. Use student responses to questions to evaluate their critical thinking skills.

Activity II: What does Spin do to the Atmosphere of a Planet?

Explain to students that they compare the effects of spin on the atmospheres of planets in our solar system.

Corresponding Slide Numbers	**Instructional Steps**
10	1. Ask students to brainstrom a list of responses to the question: *What does Spin do to the Atmosphere of a Planet?* Record and save student responses for later reference. • If students find it difficult to imagine the effects of spin on a planet, suggest that they recall the effects of amusement park rides on their bodies.
11	2. Next, distribute and review the student page, *What does Spin do to the Atmosphere of a Planet?* Project the images of the planets on the screen. Model esitmating the number and relative width of the bands for one of the planets. (**Note that images are *NOT to SCALE*.**) 3. Have students examine the images, specifically looking for a relationship between the length of day/degrees of rotation per hour and the relative number and width of the cloud bands. As students work, help them to ***estimate*** the number of cloud bands visible for each planet and the relative widths of the bands. Note that the images are ***NOT to SCALE*** so cloud band width will be relative to planet size.
12-16	4. Once the majority of individuals have completed the work, review student responses to the questions. Have students explain their observations and any patterns they found. 5. Use slides 13-16 to review student responses and to visualize the continumn.

What about Mercury and Mars?

Mercury and Mars are not part of this comparison because they lack significant atmospheres.

Mercury's position near the Sun creates what is known as an exosphere, a thin layer of atoms "blasted off the surface by the solar wind and micrometeoroid impacts." These atoms escape into space forming a comet-like tail behind the planet.

Several theories explain the thin atmosphere of Mars. The atmosphere may have been blown away from the planet due to a massive collision with another object. The atmosphere may be gradually eroded due to either the solar wind or interactions between the electromagnetic field and the solar wind.

Source: NASA, solarsystem.nasa.gov/planets

Summarize and Reflect

Refer to slides 11-15 and the student page, *What does Spin do to the Atmosphere of a Planet* as you review student estimates and responses to the questions. Refer to their initial responses to the question as brainstormed at the beginning of the activity. Ask students the following question:

- Has their work, comparing the rate of spin to images of the atmospheres of planets, changed their response to the question: *What does Spin do to the Atmosphere of a Planet*?
- Have students use specific examples from their work to revise their responses to the question.

Ask for volunteers to concisely summarize their answers to the follow-up questions posed on the student page, *What does Spin do to the Atmosphere of a Planet?*

Ask students to look at their original responses, listed during the brainstorming, and make any changes now that they have compared quantitative and qualitative information about the atmospheres of planets.

Activity II Assessment Opportunities

Collect and evaluate student work for their ability to use estimation and to identify and articulate the relationship between the period of rotation of a planet and the number and relative width of cloud bands. Use student contributions to class discussion to evaluate their ability to verbally communicate complex mathematical and scientific concepts.

Activity III: What more can we Learn by Comparing the Atmospheres of Earth and Jupiter?

Explain to students that in the previous activity they looked at patterns on a global scale. In this activity they will focus their attention on regional scale features and phenomena of Earth and Jupiter to better compare and contrast the atmospheres of each planet.

<table>
<tr><th>Corresponding Slide Numbers</th><th>Instrucitonal Steps</th></tr>
<tr><td>17-18</td><td>1. Distribute and review the student page, What more can we Learn by Comparing the Atmospheres of Earth and Jupiter?
2. If students are not familiar with a T-chart, explain that it is used to compare the attributes of two objects or events, in this case, images of storms on each planet.</td></tr>
<tr><td>19 (optional)</td><td>(Optional) Using Time Series Photography to Observe Atmospheric Patterns on Earth and Jupiter
1. Pause the slideshow and have students pause in their examination of the images of storms on Earth and Jupiter.
2. Explain to students that they will now observe video footage of the movement of the atmopsheres of both planets.
3. Introduce each video to help students anticipate and prepare for what they will see.
• The video of the Earth shows the movement of storms over the east coast of the U.S. in the winter of 2010.
• The video of Jupiter shows the movement of the bands of clouds and storms in the upper atmosphere of the planet.
4. Play the video footage for storms on Earth and the atmosphere of Jupiter. Ask students to observe the videos and be prepared to compare and contrast the motions of the clouds and cloud bands for each.
5. As needed, pause or repeat the video to allow students additional time to look for patterns. Ask students the following questions to prompt their thinking.
Earth: Nor’easter Parade
• How much time is represented by this video? Answer: 16 days on Earth
• Where on Earth are we looking? Answer: East cost of the U.S
• What is the general pattern of cloud movement? Answer: West to East, South to North
• Why do you think the name, “Nor’easter” applies to the storms shown in this video? Answer: The storms travel from south to north along the east coast of the U.S.
Jupiter:
• What are we looking at? Answer: The planet Jupiter.
• Notice the Great Red Spot, which way does it rotate? Answer: Counter-clockwise.
• Notice the smaller spots/storms, how are they moving? Answer:</td></tr>
</table>

	Most appear to move from west to east while spinning. • Notice the bands (zones and belts) how do they appear to move? *Answer: They appear to move in opposite directions.* 6. Have students add the results of this discussion and watching the videos to their T-Chart.

Summarize and Reflect

Review students' T-Charts. Have several individuals or pairs recreate their T-Chart responses on the board for all students. As a class, discuss entries in student T-Charts. Compare and contrast attributes students listed. Show slide 20 as needed.

T-Chart discussion questions. Based upon the attributes students identified and described, ask students some or all of the following questons:

Size

- How did students estimate the size of the storms on each planet? What tools did the image provide? *Answer: Each image contains a scale.*
- How do the size of the storms on Earth and Jupiter compare? *Answer: Storms pictured on Earth range in diameter from 400-600 km. The storms pictured on Jupiter range in diameter from 8000-30,000 km.*

Shape

- What are some similarities and differences in the shapes of the storms on Earth and Jupiter? *Answers will vary. Students should notice that the storms on Earth appear as pinwheels whereas the storms on Jupiter appear more circular or oval. Both images show turbulent flow around the storms.*

Color

- How do the colors of the storms on Earth and Jupiter compare? *Answer: Storms on Earth appear white whereas on Jupiter the color of the storms varies from white, to red, to brown. Current scientific research suggests that storms on Jupiter vary in color because they vary with depth. The different colors represent different source materials located at different depths.*

Location

- Where are these storms located on Earth and Jupiter? *Answer: In this case, the images represent storms located in the norther and southern hemispheres of Earth and Jupiter, respectively. Storms occur at all latitudes on both planets.*

Apparent Motion

- The images suggest motion. What direction are the storms spinning and moving? *Answer: The storms are spinning counter-clockwise on both planets. The storms on Earth are moving West whereas the storms on Jupiter are moving East.*

Age

- What are the ages of the storms on both planets? How do they compare? *Answer: Storms on Earth last upto a week whereas storms on Jupiter last from years to centuries. The life of a storm is much longer on Jupiter because there are no continents for it to pass over and thus lose energy to friction with the surface.*

Activity III Assessment Opportunities

Collect and review student T-Charts to assess their ability to analyze and communicate visual resources (images and multimedia) for metorological patterns apparent in the atmospheres of Earth and Jupiter. Use student contributions to class discussion to evaluate their ability to verbally communicate complex scientific concepts.

Summary and Reflection

This lesson uses images and data to help students compare and contrast the atmospheres of most of the planets and specifically Earth and Jupiter. Bring closure to the lesson by having students review the main concepts addressed in this series of activities:

- The rate of spin varies for the planets. Terrestrial planets spin much slower than the Gas Giants.
- As spin increases the number of bands increases
- As spin increases the width of the bands decreases
- Earth and Jupiter have storms.
- Storms on Earth are brief events.
- Storms on Jupiter last for years, decades, and centuries
- Storms are similar in that they rotate and travel.
- Careful observation of images, even of very distant objects, allows us to form some conclusions about the atmospheres of planets that we can then attempt to confirm by sending instruments to collect additional information.

Extensions

1. Use the topics in this lesson to introduce and study the Coriolis force.

Assessment Options

This lesson offers multiple opportunities to formally and informally evaluate student performance. Look for opportunities to assess student participation in discussion and their ability to communicate complex scientific and mathematics. The lesson relies heavily on student ability to interpret visual data in the form of images. Use this opportunity to assess student abilities for observation and description. Check student work for their ability to calculate speed, their ability to identify patterns in data (the relationships between rate of rotation and cloud band number and width), and their ability to estimate the number and width of the cloud bands. Review T-charts to assess student ability to organize their ideas and compare and contrast attributes of Earth and Jupiter's atmospheres.

Resources

EarthKAM (Earth Knowledge Acquired by Middle school students) is a NASA educational outreach program enabling students, teachers and the public to learn about Earth from the unique perspective of space.

MicroObservatory (also known as *Observing with NASA*) is a network of automated telescopes that can be controlled over the Internet. The telescopes were developed by scientists and educators at the Harvard-Smithsonian Center for Astrophysics and were designed to enable youth nationwide to investigate the wonders of the deep sky from their classrooms or after-school centers.

NASA Earth Observatory: The Earth Observatory's mission is to share with the public the images, stories, and discoveries about climate and the environment that emerge from NASA research, including its satellite missions, in-the-field research, and climate models.

The Gateway to Astronaut Photography: Earth Sciences and Image Analysis at NASA's Lyndon B. Johnson Space Center

Jules Verne Voyager is a precision interactive map tool for the World Wide Web, developed at the UNAVCO Boulder, CO Facility. It was originally developed to better visualize the inter-relationships of geophysical and geologic processes, structures, and measurements with high-precision GPS monument data and solutions on Earth. ***Voyager works equally well for visualizing other planets and moons, and we are collecting a set of data for most major bodies of the Solar System.***

- Earth Exploration Toolbook familiarizes users with **Jules Verne Voyager**, a freely available online map tool that includes data for Earth as well as 19 other planets and moons. Users create a variety of map images then save and import the images into a presentation or a word-processing document.

- Using Satellite Images to Understand Earth's Atmosphere, Earth Exploration Toolbook. Users select, explore, and analyze satellite imagery in the context of a case study of the origins of atmospheric carbon monoxide - a harmful gaseous pollutant, and aerosols - tiny solid airborne particles such as smoke from forest fires and dust from desert windstorms. They use images to animate a year of monthly samples of aerosol data and then compare the animation to one created for monthly images of carbon monoxide data.

Background Information

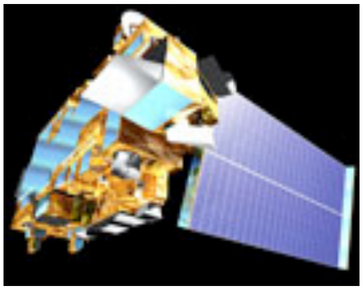
Understanding How We Study Jupiter's Atmosphere

When we want to know something about the Earth's atmosphere, we have a number of tools at our fingertips. We can step outside and directly experience current atmospheric conditions for our location. We can check the weather forecast for regional conditions and larger patterns. And, if we want to take a global perspective, we analyze data and images produced from instruments mounted on orbiting satellites.

To study the atmosphere in detail, we can take samples at different altitudes and measure the composition, temperature, density, etc. If we want to study the "big picture" of the atmosphere, we can send a satellite into space to monitor the atmosphere over large parts of Earth. In either case, we can make many measurements over time to study weather patterns and to see how the atmosphere is changing over time. By taking data in different wavelengths of light – infrared, visible, ultraviolet, or radio, for example – we can explore different aspects of the atmosphere. Different processes and different components of the atmosphere give off light at different wavelengths. By making studies at all wavelengths, we get a complete picture of the atmosphere, beyond what just our eyes can see.

But how do we explore a planet like Jupiter, more than 360 million miles away? To study Jupiter's atmosphere, we can in theory use the same methods we use to study Earth. But getting to Jupiter to take samples of the atmosphere is very difficult. And getting samples back to a lab on Earth would be even harder! Because we can't get to Jupiter very often, much of our data on Jupiter's atmosphere comes from telescopes on and orbiting Earth that observe Jupiter at various wavelengths. Therefore, the Juno Mission represents a unique opportunity to gather data about the solar system's largest planet.

Artists' depiction of the Juno spacecraft fully deployed with Jupiter in the background. Source: NASA



Terra (formerly EOS AM-1) is the flagship satellite of NASA's Earth observing systems. Terra is the first EOS (Earth Observing System) platform and provides global data on the state of the atmosphere, land, and oceans, as well as their interactions with solar radiation and with one another. Source: NASA

Sunset shot of the 70m antenna at Goldstone, California. The Goldstone Deep Space Communications Complex, located in the Mojave Desert in California, is one of three complexes which comprise NASA's Deep Space Network (DSN). The DSN provides radio communications for all of NASA's interplanetary spacecraft and is also utilized for radio astronomy and radar observations of the solar system and the universe. Source: NASA

Understanding the Length of a Day on Other Planets

To help us comprehend the nature of events and conditions on other planets, we often compare them to events and conditions on Earth. Our experience of Earth provides the context for understanding other worlds. Although the definitions of day and year appear simple upon first impression, complexities arise when one takes a closer look.

Keep it Simple for Students
"Day" is the time it takes a planet to spin once on its axis of rotation. This is the simplest definition and the one most appropriate for middle school students. Likewise, the simplest definition of "year" is the time it takes a planet to orbit the Sun, once.

There are actually two ways we can think about the length of a day. One method of measuring length of day uses the apparent motion of the Sun in the sky. For example, it takes the Sun one day (24 hours) to move from sunrise to sunrise on Earth. On Jupiter a day dawns every 0.4 earth-days (10 hours) and on Mercury sunrise occurs once in 176-earth days. There are several names for this measure of day: ***synodic day, solar day***, and simply ***length of day***.

A second measure of the length of day compares the spin of the planet to a fixed background of stars (not the Sun). This is called a ***sidereal day*** or ***period of rotation***. The period of rotation for Earth is one day (24 hours), Jupiter's period of rotation equals 0.4 earth-days (10 hours) and Mercury's period of rotation lasts 58 earth-days.

One way to think of this is that the length of a day can be calculated either by measuring how long it takes for the Sun to return to the same position in the sky (synodic) or how long it takes a star to return to the same position in the sky (sidereal). While a planet spins, it also orbits the Sun, so the position of the Sun compared to the stars changes; the Sun moves around the sky in a different period of time than the stars.

For many planets, the length of day and period of rotation are nearly equal. But for planets that spin slowly, like Mercury and Venus, there is a large difference between the length of day and period of rotation (see table below).

Two Methods for Calculating Length of Day

Planet	**Length of Day (in Earth days)**	**Period of Rotation (in Earth days)**	**Year (in Earth days)**	**Comments**
Mercury	176	58	88	
Venus	117	-243	225	Retrograde spin
Earth	1	1	365	
Mars	1	0.99	687	
Jupiter	0.4	0.4	4,331	
Saturn	0.45	0.45	10,747	
Uranus	0.72	-0.72	30,589	Retrograde spin
Neptune	0.67	0.67	59,800	

Source: NASA

Planet	**Length of Day (hours)**	**Degrees of Rotation/Hour**
Mercury	4223	0.09
Venus	2802	0.13
Earth	24	15
Mars	24.6	14.6
Jupiter	9.9	36.4
Saturn	10.7	33.6
Uranus	17	21.2
Neptune	16	22.5

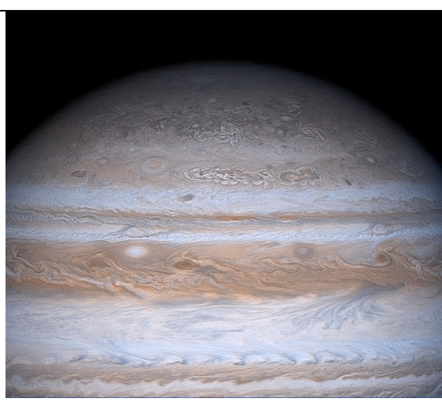
Jupiter’s Family Secrets

The Juno Mission Will Unlock Jupiter’s Family Secrets

Cassini image of Jupiter. Credit: NASA/JPL/Space Science Institute.

At more than twice the mass of all the other planets combined, Jupiter is the patriarch of our planet family. It grew large enough to capture and hold onto the materials of the solar nebula, so its mixture of about 90% hydrogen and 10% helium by percent volume (with some methane, water, and ammonia mixed in) reflects the composition of the primordial mixture that produced all the planets. Yet, its composition is not *exactly* like the primordial mixture, leaving scientists uncertain about how exactly Jupiter, and by extension, the solar system, formed. Better understanding Jupiter’s traces of methane, water, and ammonia will help scientists piece together exactly how a collection of gas and dust came to form the planets we see today.

Juno will use a special set of “eyes,” called microwave radiometers, to spy deep into Jupiter’s atmosphere in wavelengths of light invisible to the human eye, and gather information about the trace components water and ammonia. By measuring how its orbit is very slightly altered by the gravity of the planet, Juno will infer just how massive Jupiter’s core is to provide additional clues about how Jupiter captured heavy enough materials in its infancy to grow so large. The very stuff of Jupiter holds clues to understanding the story of our solar system’s birth!

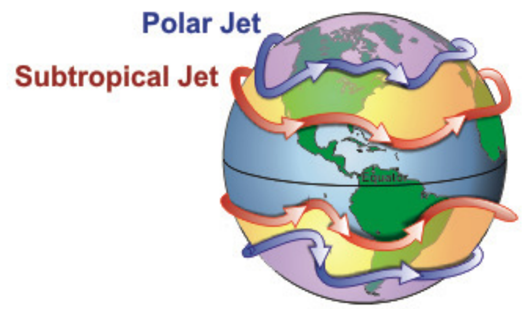


Convection drives violent weather on Jupiter. Heat leaks outward from the planet’s interior, causing atmospheric gases boil up from the warm bottom layers to the cooler upper layers.

Credit: NASA.

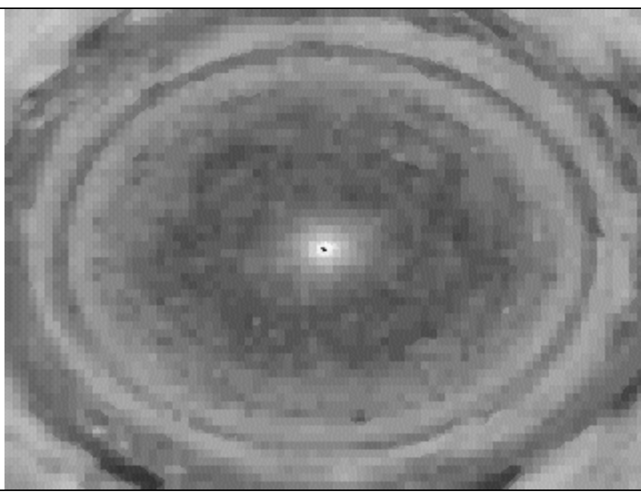
Jupiter’s Atmosphere - Jupiter’s clouds shroud a very turbulent place. The immense pressure of the planet’s bulk crushed the interior as it formed (and possibly still does as Jupiter continues to contract) and the resulting heat is still leaking from the planet. Jupiter is far from the Sun, so this internal heat warms the planet and plays a major role in its weather. Jupiter radiates twice as much infrared energy as it receives from the Sun! Its core temperature may be about 43,000ºF (24,000ºC) — hotter than the surface of the Sun. This heat leaks up through the liquid metallic hydrogen and liquid hydrogen layers to supply energy to the atmosphere. Like a pot of soup on a hot stove, atmospheric gases boil up from the warm bottom layers to the cooler upper layers; temperatures are –261ºF (–163ºC) at the top of the atmosphere. Juno's microwave radiometer will map the atmosphere's temperature at different depths.

While it orbits the Sun only once every 12 years, Jupiter spins on its axis once every 10 hours. The rapidly spinning planet generates five jet streams in each hemisphere that produce Jupiter's unique banded appearance. Earth has only about four dynamic jet streams, two — sometimes three — in each hemisphere, which all travel from west to east. Wind speeds are high, up to 330 miles per hour (530 kilometers) per hour, and alternate direction from eastward to westward with latitude. Lightening, produced as ice particles within storms rub past each other, is frequent. The Great Red Spot is a massive storm system larger than the diameter of Earth that has been raging for at least several hundred years.



Like on Jupiter, Earth's rotation generates jet streams that influence weather patterns. However, Earth has only about four dynamic jet streams, two — sometimes three — in each hemisphere, which all travel from west to east.

Credit: National Weather Service.



This movie, made up of Cassini spacecraft images, shows bands of eastward and westward winds on Jupiter from the perspective of looking down at Jupiter's north pole. Long-lasting storms are seen to drift in opposite directions inside alternating bands.

Credit: NASA/JPL/Southwest Research Institute.

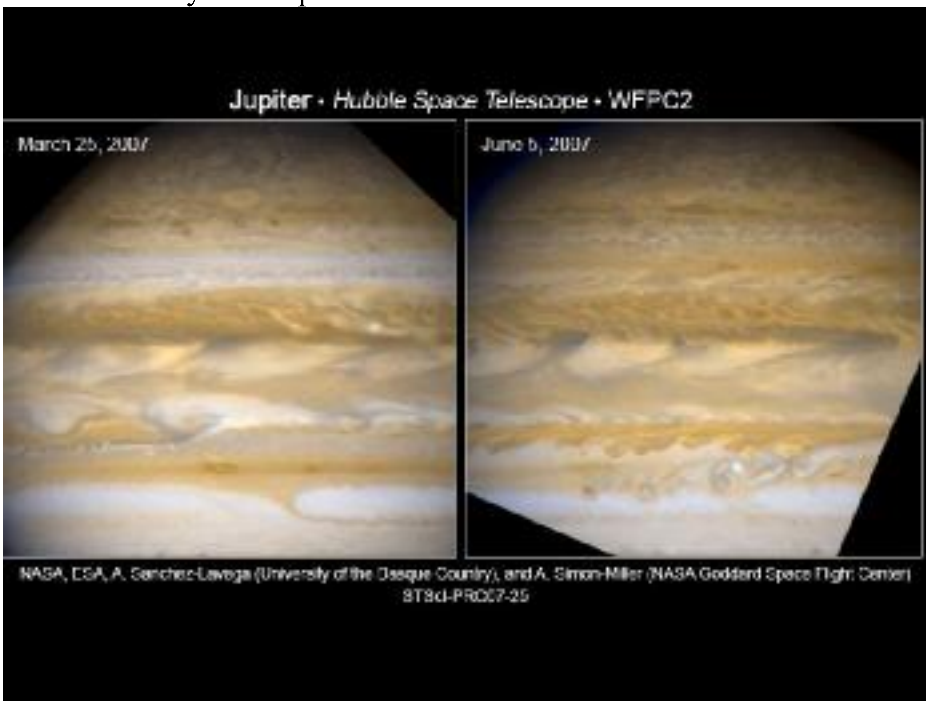
Storms, such as the persistent Great Red Spot, rage throughout the atmosphere. The Great Red Spot is a massive storm system larger than the diameter of Earth that has been raging for at least several hundred years.

Credit: NASA.

Where Did You Get Those Stripes?

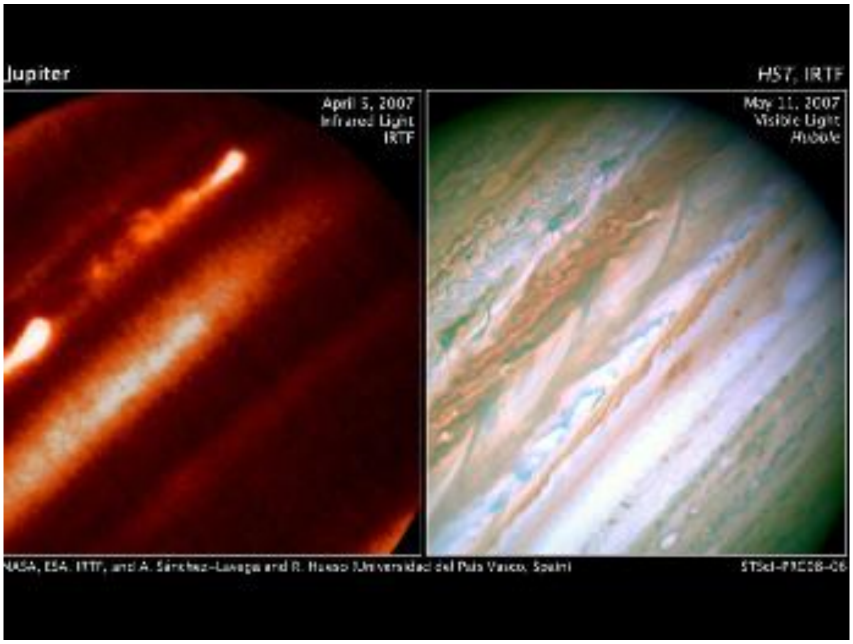
Source: NASA

The most obvious features on Jupiter are the alternating bands of white and colored clouds, zones and belts. As of yet, no one knows what gives the clouds the colors they have, but scientists have theories on why the stripes exist.



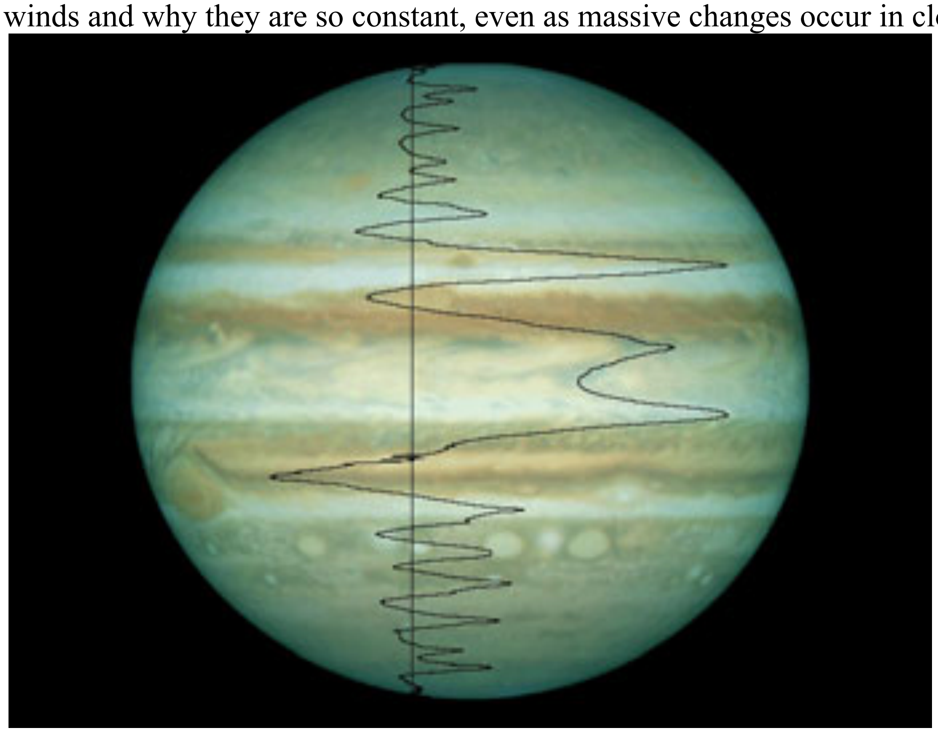
Jupiter's turbulent clouds are always changing as they encounter atmospheric disturbances while sweeping around the planet at hundreds of miles per hour. Notice in these Hubble Space Telescope images the changes in the shape and color of Jupiter's clouds near the equator.

Analysis of data at many wavelengths shows that the white regions have higher thicker, clouds than the redder regions. This may mean there is active cloud formation in those regions, producing fresh white clouds. The clouds in the reddish brown "belts" are deeper, covered by thick smog-like haze.



As seen in the infrared and visible images above, two continent-sized storms erupted in Jupiter's atmosphere in March 2007. Internal heat drives Jupiter storms.

These belts and zones are also lined up with Jupiter's strong wind field, which may drive the cloud formation. The winds alternate from eastward to westward with latitude and can top 150 m/s (325 mph). An interesting aspect is that the winds are extraordinarily constant: the wind speed at a given latitude varies very little over time. Scientists are still studying what drives the winds and why they are so constant, even as massive changes occur in cloud color and structure.



The wind velocity measurements on Jupiter have been added to this image of the planet.
The vertical black line equals zero wind speed.
The highest velocities exceed 150m/s (~325mpg).

The Coriolis Force

Wednesday, March 1, 1995

by Neil deGrasse Tyson
From *Natural History* Magazine, March 1995

I am often asked by students whether their toilet bowl will flush clockwise or counterclockwise in the southern hemisphere, or whether it will flush straight down in Ecuador. This would, of course, be important information if you were ever kidnapped and blindfolded and dropped off in a strange land. If we assume a commode of conventional size, then this toilet bowl test will fail because the answer lies in the manufacturer's design. But if your northern hemisphere toilet bowl were a few hundred miles in diameter then the Coriolis force of the rotating Earth would easily overcome the random water currents, and force the bowl to empty its contents in a counter clockwise swirl. If you have southern hemisphere friends with an equally large toilet, then theirs would indeed empty in the opposite (clockwise) direction.

The circulation within oversized flush toilets is a natural consequence of motion on the surface of an object that rotates. We owe our detailed understanding of the effect to the work of Gaspard Gustave de Coriolis who, in 1831, presented details of the laws of mechanics in a rotating reference frame to the Academie des Sciences in Paris. Earth's surface provides an excellent place to demonstrate why the origin of the Coriolis force is relatively simple. Our planet rotates on its axis approximately once every 24 hours. In that 24 hour period, objects on Earth's equator travel a circle with a circumference of nearly 25,000 miles, which corresponds to a speed of a more than 1,000 miles per hour. By 41 degrees north, the latitude of New York City and the American Museum of Natural History, the circumference traveled is only about 19,000 miles. The west-to-east speed is now approximately 800 miles per hour. As you continue to increase in Earth latitude (north or south of the equator) your west-to-east speed decreases until it hits exactly zero miles per hour at the poles. (For this reason, most satellites are launched as close to the equator as possible, which enables them to get a good running start in their eastward orbits.

Imagine a puffy cloud in the northern hemisphere and a meteorological low pressure system directly to its north. The cloud will tend to move toward the low. But during the journey its greater eastward speed will enable the cloud to overtake the low, which is itself in motion, and end up east of its destination. Another puffy cloud that is north of the low will also tend to move toward the low, but will naturally lag behind and end up west of its destination. To an unsuspecting person on Earth's surface, these curved north-south paths would appear to be the effects of a mysterious force (the Coriolis force) yet no true force was ever at work.

When many puffy clouds approach a low pressure system from all directions you get a merry-go-round of counter-clockwise motion, which is better known as a cyclone. In extreme cases you get a monstrous hurricane with wind speeds upwards of a hundred miles per hour. For the southern hemisphere the same arguments will create a cyclone that spirals clockwise. The military normally knows all about the Coriolis force and thus introduces the appropriate correction to all missile trajectories. But in 1914, from the annals of embarrassing military moments, there was a World War I naval battle between the English and the Germans near the Falklands Islands off

Argentina (52 degrees south latitude). The English battle cruisers *Invincible* and *Inflexible* engaged the German war ships *Gneisenau* and *Scharnhorst* at a range of nearly ten miles. Among other gunnery problems encountered, the English forgot to reverse the direction of their Coriolis correction. Their tables had been calculated for northern hemisphere projectiles, so they missed their targets by even more than if no correction had been applied. They ultimately won the battle against the Germans with about sixty direct hits, but it was not before over a thousand missile shells had fallen in the ocean.

In high school I knew all about the Coriolis force, but I never had the opportunity to test it on something as large as a swimming pool until the summer after my junior year when I worked as a lifeguard. At the mid-summer cleaning, I opened the drain valve to the pool and carefully observed the circulation. The water funneled in the wrong direction—clockwise. The last I had checked, I was life-guarding in Earth's northern hemisphere so I was tempted to declare Coriolis forces to be a hoax. But a fast back of the envelope calculation verified that the difference in Coriolis velocity across the pool was a mere 1/2 inch per minute. This is slow. The water currents from somebody just climbing out of the pool, or even a gentle breeze across the water's surface would easily swamp the effect and I would end up with clockwise one half the time and counterclockwise the other half of the time. A proper experiment to demonstrate the insignificance of the Coriolis forces would require that I empty and refill the pool dozens of times. But each try would dump 15,000 cubic feet of water and diminish my job security. So I didn't.

The air circulation near a high pressure systems, which are inelegantly known as anticyclones, is a reverse picture of our cyclone. On Earth, these high pressure systems are the astronomer's best friend because they are typically devoid of clouds. The surrounding air still circulates, but it does so without the benefit of clouds as tracers of the air flow. The circulation around low and high pressure systems, known as geostrophic winds presents us with the paradox that Coriolis forces tend to move air along lines of constant pressure (isobars) rather than across them.

Now imagine, if you will, a place that is not only fourteen hundred times larger than Earth, but has an equatorial speed that is about twenty-five times as fast, and has a deep, thick, colorful atmosphere. That place is the planet Jupiter, where a day lasts just 9 hours and 56 minutes. It is a cosmic garden of atmospheric dynamics where all rotationally induced cloud and weather patterns are correspondingly enhanced. In the most striking display of the Coriolis force in the entire solar system, Jupiter lays claim to the largest, most energetic, and longest-lived storm ever observed. It is an anticyclone that looks like a great red spot in Jupiter's upper atmosphere. We call it Jupiter's Great Red Spot. Discovered in the mid 1660s by the English physicist Robert Hooke and separately by the Italian astronomer Giovanni Cassini, the feature has persisted for over 300 years. It was not until the twentieth century when the Dutch-born, American astronomer Gerard Kuiper was the first to supply the modern interpretation of the Spot as a raging storm.

The Great Red Spot, by the way, is bigger than Earth, although its size and shape has varied over the years. It lives in Jupiter's southern hemisphere and rotates counterclockwise, which immediately tells us we have a high pressure system. The coloration, from orange-red to a barely visible pale cream, is generally attributed to various concentrations of phosphorus and sulfur compounds. Close-up images from the Voyager flyby missions of the late 1970s revealed a maelstrom of colorful curlicues at the interface of the Great Red Spot and the surrounding atmosphere. There were also strikingly resolved horizontal belts and zones interlaced with countless smaller cyclones and anticyclones that give Jupiter the appearance of an archaeological cross section of a Big Mac hamburger from McDonald's, bun included. Above all else, however, the Voyager data posed renewed theoretical challenges. It resolved Jovian features down to twenty miles in diameter—astonishingly small when one remembers Jupiter's size relative to Earth. Models of cosmic phenomena are often clean and tidy until they are tested outside of the limits in which they were formulated. Higher image resolution is one such example. When this happens, many models are discarded, others are modified, while some are freshly invented, but jumps in resolution have always been followed by a deeper understanding of the universe.

Whatever else a model of Jupiter's atmosphere is designed to explain, it should as a minimum, account for basic properties of the Great Red Spot such as its longevity, and perhaps its distinguished size, and that it is an anticyclone. An ideal model would be able to account for all atmospheric motion on Jupiter. The tools available to the theorist are Newton's laws of motion as adapted to the properties of gases and liquids—otherwise known as fluid mechanics.

Contemporary models do capture the basic features of the Great Red Spot, but very little is known about the structure of Jupiter's under-layers. Jupiter radiates more heat than it receives from the Sun, and there are enormous thermal reservoirs in Jupiter's interior that can drive atmospheric flow patterns. One source is the radioactive decay of trace elements while another is the left-over heat form Jupiter's initial contraction from a proto-planetary cloud to a planet in the early solar system. The sustaining source of energy for the Spot could also (or instead) be tapped from other sources. On Earth, hurricanes are partially driven by the latent heat released to the atmosphere when rain drops condenses out of the air. A similar mechanism may dominate in Jupiter's atmosphere as its gases condense toward its liquid interior. The Spot has also been observed (and successfully modeled) to dine upon smaller turbulent eddies in its vicinity. This cannibalistic behavior is yet another source of energy. Clues to the deeper cloud layers will almost certainly be gained when the spacecraft Galileo passes Jupiter (in December 1995) and parachutes a mini-probe that will measure temperature, density, composition, wind speeds, and lightning events as it descends through the outer atmosphere.

For now, there is no reasonable hope of describing every one of Jupiter's surface features in detail. A more realistic approach is to construct an atmospheric model that provides a statistically equivalent picture of Jupiter's surface features. In other words, a model of a Big Mac can approximate all Big Macs even though it may not look like any one in particular.

One nagging problem with models that always produce a single, sustained anticyclone is the blunt reality that Jupiter's northern hemisphere is devoid of a twin Great Red Spot. Clearly, if models show that big spots are inevitable, then the north ought to have one too. Elsewhere in the solar system, the Coriolis force has given rise to a great dark spot on Neptune. We call it Neptune's Great Dark Spot. Like Jupiter's Great Red Spot, it is an anticyclone of epic proportions in Neptune's southern hemisphere that appears without a twin in the north. This is a problem that may require an as yet unexplored north-south asymmetry in both Jupiter's and Neptune's internal structure. One way to induce such an asymmetry would be to survive a cosmic collision in one of your two hemispheres. The July 1994 encounter between Jupiter and the dozens of crumbled comet parts from Shoemaker-Levy 9 left visible and sustained scars on Jupiter's outer gaseous surface. The long-term effects of this impulse of deposited energy remains to be seen. Will the scars form stable new structures among the cloud-tops? Or will the scars dissipate completely into the atmosphere? For the moment, feel free to consider the new blemishes to be extra ingredients in your hamburger.

Neil de Grasse Tyson is an astrophysicist with a joint appointment at the Hayden Planetarium and Princeton University. His recent book *Universe Down to Earth* is available from Columbia University Press.

Teacher Answer Key

How Long is a Day?

Each morning the Sun appears to rise in the east and set in the west. The Earth spins around once in 24 hours giving us day and night. Other planets in our Solar System experience day and night, too. But other the other planets turn at different rates. So, how many Earth days does it take to make one day on other planets in our solar system?

Question

How long is a day on other planets in our solar system? On Earth we see the Sun rise every 24 hours. We call the time from sunrise to sunrise, “one day”. How does our day compare to the day on other planets?

Calculate

Planet	Length of Day (hours)*	Earth Day in Hours	Calculation	Number of Earth Days for 1 Day on Planet
Mercury	4223	24	*4223/24*	*176*
Venus	2802	24	*2802/24*	*117*
Earth	24	24	*24 /24*	*1 day*
Mars	24.6	24	*24.6/24*	*1.025*
Jupiter	9.9	24	*9.9/24*	*0.4*
Saturn	10.7	24	*10.7/24*	*0.45*
Uranus	17	24	*17/24*	*0.7*
Neptune	16	24	*16/24*	*0.67*

* Sunrise to sunrise

Teacher Answer Key

How Long is a Day?

Complete the Table

Planets with Longer Days than Earth	**Planets with Shorter Days than Earth**
Mercury *Venus* *Mars*	*Jupiter* *Saturn* *Uranus* *Neptune*

1. Look at the two groups of planets in your table. What is similar about the planets that have longer days than Earth? Make a list of their similarities. *Answers will vary. The terrestrial planets all have days nearly equal or longer than a day on Earth. Therefore, students may list attributes such as terrestrial, rocky, small (relative to gas giants), closer to the Sun, and more.*

2. Look at the two groups of planets in your table. What is similar about the planets that have shorter days? Make a list of their similarities. *Answers will vary. The gas giants all have days that are shorter than a day on Earth. Therefore, students may list attributes such as gas giant, mostly hydrogen and helium, no surface, large, distant from the Sun, and more.*

Name
Date

How Long is a Day?

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Saturn	10.7	24		
Uranus	17	24		
Neptune	16	24		

Name
Date

How Long is a Day?

Complete the Table

Planets with Longer Days than Earth	Planets with Shorter Days than Earth

1. Look at the two groups of planets in your table. What is similar about the planets that have longer days than Earth? Make a list of their similarities.

2. Look at the two groups of planets in your table. What is similar about the planets that have shorter days? Make a list of their similarities.

Teacher Answer Key

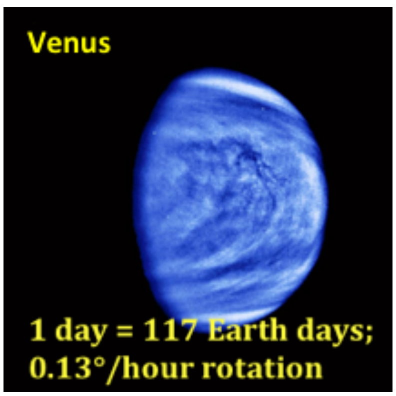
What does Spin do to the Atmosphere of a Planet?

The atmosphere of a planet is influenced by the spin of the planet. As the planet spins, it causes the atmosphere to rotate, too. In this activity, you will compare the rate of spin to the appearance of the atmosphere.

Question

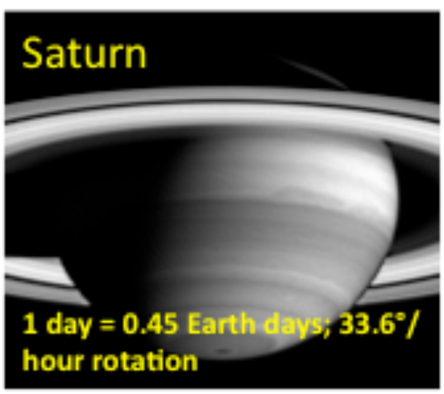
How does the number and width of the bands of clouds change as the rate of spin of the planet increases? *Answer: The number of cloud bands visible in the atmosphere of a planet increases and their relative width decreases as the rate of spin increases.*

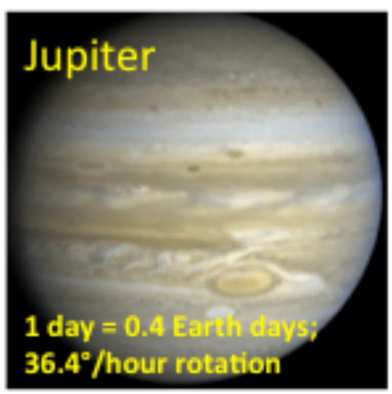
Estimate the number of cloud bands on each planet and ***compare*** their widths.



Why does Spin Affect Atmosphere?

Atmospheres experience viscous (frictional) forces, which 'drag' the atmosphere with the rotation of the planet. At the same time, this creates turbulence. Frictional forces and turbulence increase with speed.





Teacher Answer Key

Answer the following questions on a separate sheet of paper. Use complete sentences and restate the question as part of your answer.

What did you decide?

1. How does the number of bands change as the rate of spin changes for each planet? Explain your answer and give examples from your work above. *Answer: As the rate of spin increases, the number of bands of clouds in the atmosphere increases.*
2. How does the width of the cloud bands change as the rate of the spin changes for each planet? *Answer: As the rate of spin increases, the relative width of the cloud bands decreases.*
3. Review your table for the rate of spin for Uranus and Neptune. Do you think that these planets would have ***equal, fewer***, or ***more*** bands of clouds than Earth? Explain your reasoning. *Answer: By interpolation, the number of bands in the atmospheres of Uranus and Neptune would be greater than the number for Earth but less than Jupiter or Saturn.*
4. How would the width of cloud bands on Uranus and Neptune compare to the width of cloud bands on Earth? *Answer: By interpolation, the width of cloud bands for Uranus and Neptune would be narrower than the cloud bands on Earth but wider than those found on Jupiter or Saturn.*
5. Why do you think that spin affects the atmosphere of a planet? Brainstorm a list of reasons. *Answer: Atmospheres experience viscous (frictional) forces, which 'drag' the atmosphere with the rotation of the planet. At the same time, this creates turbulence. Frictional forces and turbulence increase with speed.*

Name:
Date:

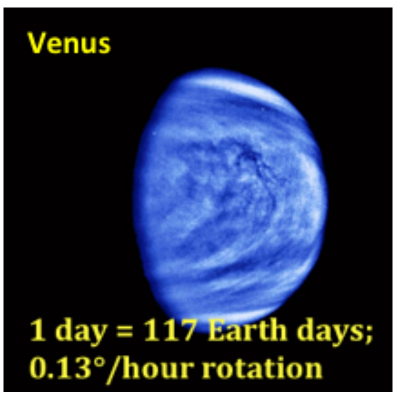
What does Spin do to the Atmosphere of a Planet?

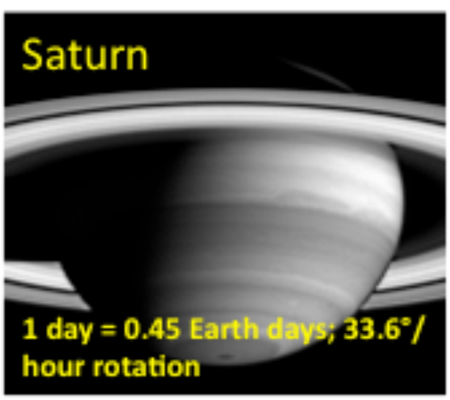
The atmosphere of a planet is influenced by the spin of the planet. As the planet spins, it causes the atmosphere to rotate, too. In this activity, you will compare the rate of rotation to the appearance of the atmosphere.

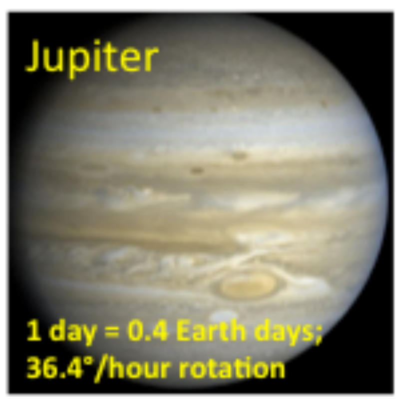
Question

How does the number and width of the bands of clouds change as the rate of spin of the planet increases?

Estimate the number of cloud bands on each planet and ***compare*** their widths.







Name:
Date:

What does Spin do to the Atmosphere of a Planet?

Answer the following questions. Use complete sentences and restate the question as part of your answer.
What did you decide?

1. How does the number of bands change as the rate of spin changes for each planet? Explain your answer and give examples from your work above.

2. How does the width of the cloud bands change as the rate of spin changes for each planet?

3. Review your table for the rate of spin for Uranus and Neptune. Do you think that these planets would have equal, fewer, or more bands of clouds than Earth? Explain your reasoning.

4. How would the width of cloud bands on Uranus and Neptune compare to the width of cloud bands on Earth?

5. Why do you think that spin affects the atmosphere of a planet? Brainstorm a list of reasons.

Teacher Answer Key

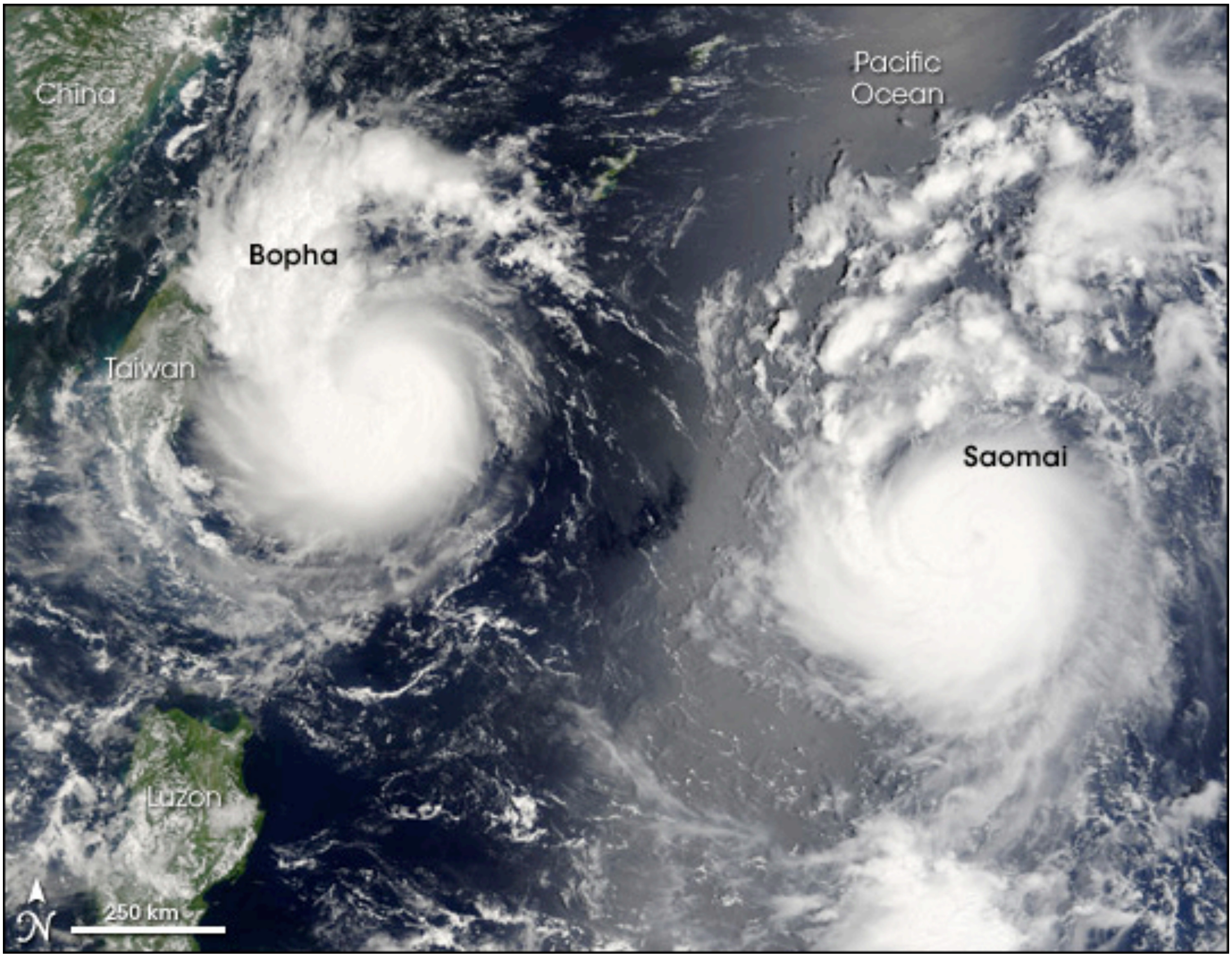
What can we learn by comparing the atmospheres of Earth and Jupiter?

Attribute	Earth	Jupiter
Size	~400-600 km across	~8000-30,000 km across
Shape	Round, pin-wheel	Round, oval
Color	White	Red, brown, white
Location	In this case, above the equator, but all over planet	In this case, below the equator, but all over planet
Apparent Motion	Still Image: The storms are spinning counter-clockwise and moving to the west (Optional) Video: Complex. Cloud and storm systems sweep from west to east and then northeast and wrap west and then south	Still Image: The storms/spots are spinning counter-clockwise and moving east. (Optional) Video: The belts and zones appear to move in opposite directions. The spots rotate and appear to move west to east. The Great Red Spot just rotates.
Age	Hours, days	Years to centuries

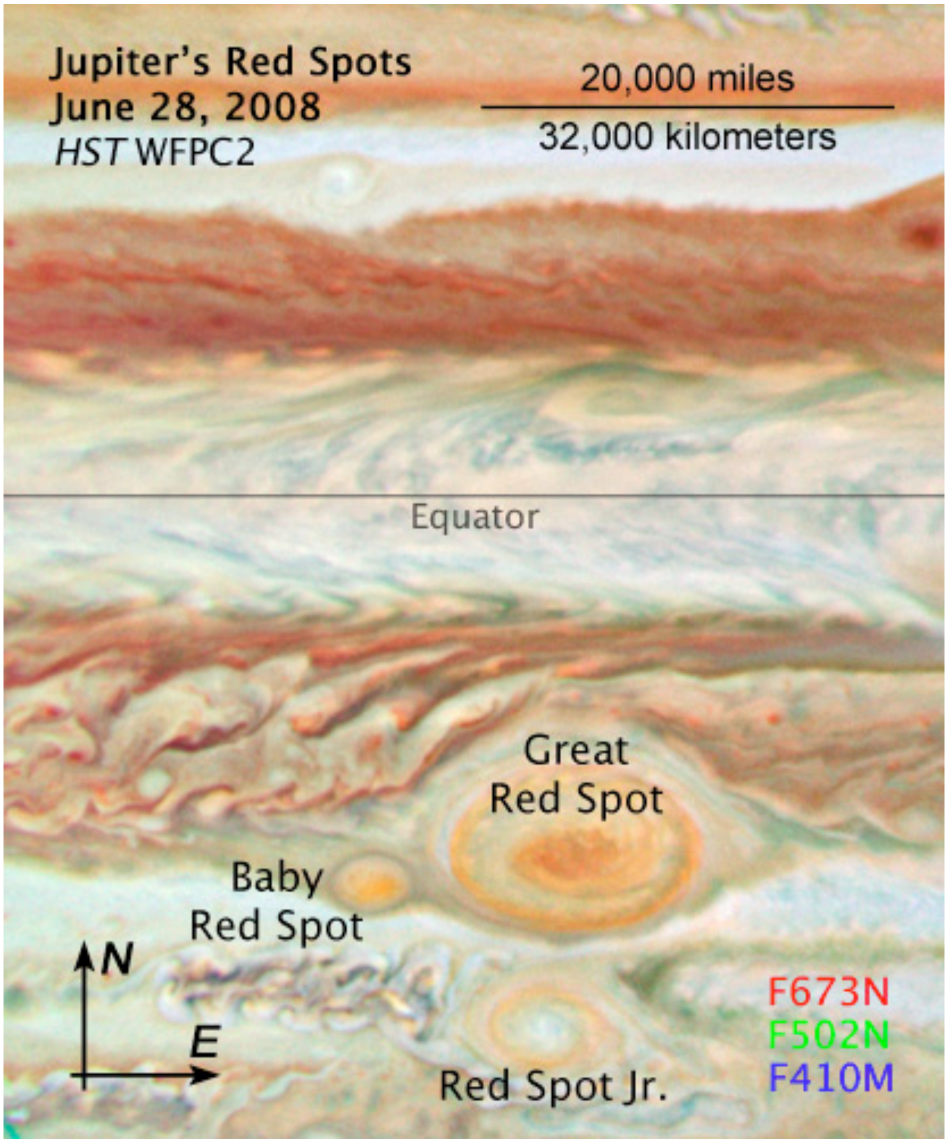
Name:
Date:

What can we learn by comparing the atmospheres of Earth and Jupiter?

You have already learned a lot about the atmospheres of Earth and Jupiter from comparing the rate of spin, length of day for the planets and cloud bands. Now, let's take a closer look.



Earth
Main Features: Two storms, Bopha and Saomai, located off the eastern coast of China
Location: The Pacific Ocean, north of the equator
Date: The storms began on August 4, and lasted until August 11, 2006



Jupiter
Main Features: Cloud bands and spots of Jupiter
Location: Jupiter, south of the equator
Date: The Great Red Spot was first observed by in 1655, Red Spot Jr. formed in 2000, Baby Red Spot formed and combined with the Great Red Spot in 2008

What do you see?

- Look closely at the images of Earth and Jupiter.
- Use a “T-Chart” to list some of the similarities and differences you see in these pictures.
- Use the information below each image to help you complete the chart.

Earth	Jupiter