What's Inside a Planet: Density and Differentiation

Grade Range: 5-8

Teaching Time: four to five, 45-minute periods

Module: Interiors

Lesson: What's Inside a Planet: Density and Differentiation

Activities:

I. What do we know about the interiors of Earth and Jupiter
II. Demonstration: Layered Liquids
III. Determining Density and Composition
IV. Recipe for a Planet

Lessons Recommended to Precede this Lesson:

- What's Inside a Planet: Inferring Interiors

Advanced Planning

1. 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.
2. Collect and organize materials
3. Copy student pages

Materials

Teacher Materials

- Computer with Internet access and the ability to project images and multimedia
- Access to presentation software such as PowerPoint or Keynote and QuickTime or RealPlayer
- Slideshow: *What's Inside a Planet: Density and Differentiation*
- Overhead transparency of the graphic organizer, *What We Know about the Interiors of Earth and Jupiter* or poster paper

Materials for Demonstration

- Large transparent graduated cylinder
- (1 cup) Water plus food coloring
- (1 cup) Light corn syrup
- (1 cup) Vegetable oil
- (Optional) grape, coins, plastic beads

Student Materials

- Student Pages: *Drawing the Interiors of Earth and Jupiter, Interior of Earth vs. Jupiter Two Column Chart, Determining Density and Composition, Recipe for a Planet*

- Several ounces of Plasticine™ or other modeling clay of varying colors
- Ruler
- Digital scale or balance
- Steel ball bearings, plastic beads, glass marbles, dried peas or beans

Learning Outcomes

As a result of this lesson students will:

- List their current beliefs about the structure and composition of the interiors of Earth and Jupiter
- Make a simple diagram to visually represent, compare and contrast their current understanding about the structure and composition of the interiors of Earth and Jupiter
- Calculate the densities of various materials and mixtures
- Use data about the density of various elements and compounds to model the compositions of Earth and Jupiter

Prior Knowledge and Skills

- Ability to find the mass and volume of regular shaped objects
- Basic understanding density
- Ability to perform multiplication and division

What Students Do

The Juno Mission Interior Module engages students in a comparison of the composition and structure of the interiors of Earth and Jupiter. The first lesson consists of several activities that address ***the role of inference in scientific investigation***. The second lesson addresses the contrasts between the composition and structure of terrestrial planets and gas giants. Much of our knowledge about the interiors of gas giants comes from inferences made by observing them from a distance, through indirect measurements, and computer simulations and modeling.

The lesson, *What's Inside a Planet: Density and Differentiation* is composed of several activities designed to address the difference in the composition and structure of terrestrial planets and gas giants. In Activity I students brainstorm their current knowledge and understanding about the interiors of Earth and Jupiter. The whole class participates in a discussion and the development of a graphic organizer designed to activate students thinking about the composition and structure of the interiors of terrestrial planets and gas giants. Students then draw an image of the interior of Earth and Jupiter to visually represent their initial beliefs and knowledge. Following this, the teacher presents a slideshow that compares and contrasts the interiors of Earth and Jupiter. From discussion and the slideshow, students summarize their knowledge by creating a Two Column Chart that compares and contrasts the interiors of Earth and Jupiter. Activity II, Layered Liquids involves a discussion around a teacher demonstration of liquids with varying density and object that float or sink within the column of liquids. In Activity III students calculate the density known and unknown substances. Using data students compare the density of a known substance (modeling clay) to an unknown clay mixture to infer the composition of the additional materials in the clay. In Activity IV, students compare the densities of Earth and Jupiter (5.5 g/cm^3 versus 1.3 g/cm^3) and use a table of elements and their densities to create a "recipe" for each planet.

Rationale

Earth is heterogeneous, varied in composition, and layered. In contrast, Jupiter is homogenous, composed primarily of hydrogen and helium, and whether or not and to what degree it is layered remains one of the outstanding questions and a focal point of the Juno mission.

Geologists, especially geophysicists and seismologists, have examined and described the layered nature of the Earth from crust to core. The composition and structure of the interior of Earth is known and inferred based upon the direct and indirect investigations of our planet and the study of the composition of the Universe and the solar system. The ultimate composition and structure of the interior of Jupiter remains a significant mystery, one which data from Juno will help to reveal.

The solar system contains two types of planets: terrestrial and gas giants. As the solar system developed, terrestrial and gas giants evolved along different lines. The composition of gas giants more closely resembles that of stars, primarily hydrogen and helium, with potentially some dense, rocky material at the core. The distribution of materials in both terrestrial planets and gas giants reflects the differentiation of matter based upon density. From the surface inward, the density of each planet increases. For example, Earth's crust has a density under 3 g/cm^3 whereas research suggests that the core of Earth has a density over 13 g/cm^3. This lesson engages students in the study and application of density to infer the composition of Earth and Jupiter. *It is important to note that density is one of several factors that informs our knowledge and inferences of the composition of a planet.*

Curriculum Connections

The structure of Jupiter's interior remains a significant mystery. Much of what we know about Jupiter's interior is based upon inference. In this module, students compare and contrast the composition and nature of the interiors of Earth and Jupiter. They participate in activities that emphasize and address the value of inference to scientific knowledge. The module consists of two lessons. The first lesson, *Jupiter, the Fuzzy Planet: Inferring Interiors*, addresses inference and direct observation, exploring how scientists use each to better understand the natural world. The second lesson, *What's Inside a Planet: Density and Differentiation*, applies inference as a habit of mind in the context of comparing and contrasting the structures of the interiors of terrestrial and gas giants. The solar system is comprised of two planet types, terrestrial and gas giants. Their structure and composition vary as a result of processes associated with the origins of the solar system (See Origins Module). Earth is composed of denser material and is structurally heterogeneous whereas Jupiter is composed of less dense materials and appears to be homogenous in structure.

Juno Mission Connection

Theories about solar system formation all begin with the collapse of a giant cloud of gas and dust, or nebula, most of which formed the infant sun. Like the sun, Jupiter is mostly hydrogen and helium, so it must have formed early, capturing most of the material left after our star came to be. How this happened, however, is unclear. Did a massive planetary core form first and gravitationally capture all that gas, or did an unstable region collapse inside the nebula, triggering the planet's formation? Differences between these scenarios are profound.

Even more importantly, the composition and role of icy planetesimals, or small proto-planets, in planetary formation hangs in the balance – and with them, the origin of Earth and other terrestrial planets. Icy planetesimals likely were the carriers of materials like water and carbon compounds that are the fundamental building blocks of life.

Unlike Earth, Jupiter's giant mass allowed it to hold onto its original composition, providing us with a way of tracing our solar system's history. Juno will measure the amount of water and ammonia in Jupiter's atmosphere and determine if the planet actually has a solid core, directly resolving the origin of this giant planet and thereby the solar system. By mapping Jupiter's gravitational and magnetic fields, Juno will reveal the planet's interior structure and measure the mass of the core.

Instruments and Data

Juno has two instruments onboard that will help scientists infer the interior: the Magnetic Field Investigation – the MAG instrument – and the Gravity Science Experiment – the GSE.

Magnetic Field Investigation

Where does a planet's magnetic field come from? A bar magnet or a refrigerator magnet has been permanently magnetized, so their magnetic fields are 'frozen in' to the material itself. Another way of creating a magnetic field is to have moving charges, like an electromagnet. A planetary magnetic field is thought to arise from the liquid metal core and the spin of the planet. The spin of the planet spins the liquid metallic (highly conductive) core, which causes flows of charged particles in the planet's interior, thus creating a magnetic field. (This is an extreme simplification of the dynamo theory. The physics is very complicated!) If scientists can measure the magnetic field of a planet and all the small variations in the magnetic field, they can make inferences about those flows in the interior of the planet. The MAG instrument on Juno is going to make a complete, detailed, and sensitive map of Jupiter's magnetic field. This map, along with theoretical and computer models, will help scientists understand the flows responsible for the magnetic field and infer the properties of Jupiter's core.

Jupiter's magnetic field rotates with the planet, and measuring that magnetic field has helped us determine Jupiter's interior rotation rate.

Gravity Science Experiment

A gravitational field is determined by the amount of matter (material, stuff) and how that matter is spatially distributed. On Earth, we basically always feel the same gravitational pull. But gravity is not exactly the same everywhere on our planet. There are locations where the gravitational force is a little stronger or a little weaker, depending on the local properties of the interior. These differences are small and require sensitive instruments to detect. But measuring them helps us infer what the interior of Earth is like.

The GSE will measure all the gravitational forces on Juno and keep precise tracking of Juno's position. This will provide scientists with a detailed map of Jupiter's gravitational field and its variations. In turn, this will help scientists infer matter distribution throughout Jupiter's interior.

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

Earth and Space Science, Content Standard D:

- Structure of the earth system
- Earth's history
- 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
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

F. Motion

9. 10. Historical Perspectives

A. Displacing the Earth from the Center of the Universe

11. Common Themes

A. Systems

B. Models

12. Habits of Mind

A. Values and Attitudes

C. Manipulation and Observation

D. Communication Skills

E. Critical-Response 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

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
- Benchmark 8: Evaluates the results of scientific investigations, experiments, observations, theoretical and mathematical models and explanations proposed by other scientists
- Benchmark 9: Knows possible outcomes of scientific investigations

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

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
- Connections

McREL Compendium of Standards and Benchmarks

Mathematics

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 (e.g., mental, paper and pencil, calculator, computer) for a given situation
- Benchmark: 5. Understands the correct order of operations for performing arithmetic computations
- Benchmark: 6. Uses proportional reasoning to solve mathematical and real-world problems (e.g., involving equivalent fractions, equal ratios, constant rate of change, proportions, percents)
- 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: 2. Solves problems involving perimeter (circumference) and area of various shapes (e.g., parallelograms, triangles, circles)
- Benchmark: 3. Understands the relationships among linear dimensions, area, and volume and the corresponding uses of units, square units, and cubic units of measure

- Benchmark: 4. Solves problems involving units of measurement and converts answers to a larger or smaller unit within the same system (i.e., standard or metric)
- Benchmark: 5. Understands the concepts of precision and significant digits as they relate to measurement (e.g., how units indicate precision)
- Benchmark: 7. Understands formulas for finding measures (e.g., area, volume, surface area)
- Benchmark: 8. Selects and uses appropriate estimation techniques (e.g., overestimate, underestimate, range of estimates) to solve real-world problems

Common Core State Standards for Mathematics

Grade 6

Ratios and Proportional Relationships

- Understand ratio concepts and use ratio reasoning to solve problems.

The Number System

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

Grade 7

Expressions and Equations

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

Note to the Teacher

The lesson guide parallels the slideshow, *What's Inside a Planet: Density and Differentiation*. 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.

What's Inside a Planet?: Density and Differentiation

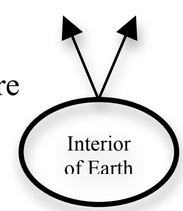
Introducing the Lesson

Explain to students that in this lesson they will learn about the nature and composition of the interior of Jupiter as compared to Earth. Explain that terrestrial planets, like Earth, are more differentiated whereas gas giants, such as Jupiter, are more homogeneous.

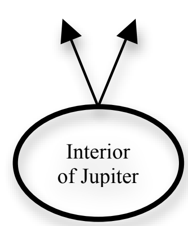
Activity Ia: What We Know about the Interiors of Earth and Jupiter

Use this activity to activate student thinking about existing knowledge and understanding of the composition and nature of the interiors of Earth and Jupiter.

1. Explain to students that they will brainstorm their ideas and then draw images of the interiors of Earth and Jupiter.
2. Project the graphic organizer (page 23), *What We Know about the Interiors of Earth and Jupiter* on the screen or draw it on poster paper.
3. As a class, complete the graphic organizer. Ask students to brainstorm words, phrases, or ideas that they associate with the composition and nature of the interior of Earth and Jupiter. Working from the familiar (Earth) to the less familiar (Jupiter) prompt student discussion by posing questions such as:



   - What do you think is beneath the ground we stand upon?
   - What is under the crust of the Earth?
   - What is at the center of Earth/Jupiter?
   - Imagine you could fly from outside the atmosphere of Earth/Jupiter right to the center of the planet, what would you travel through?
   - What is Earth/Jupiter made of?
   - How do you think Jupiter is similar to or different from Earth?



4. Post the completed graphic organizer in a location for all to see.
5. Following the brainstorming process, distribute and review the student page, *Drawing the Interiors of Earth and Jupiter*. Allow students time to draw their image of the nature and composition of the interiors of Earth and Jupiter. Remind students to refer to the graphic organizer, *What We Know about the Interiors of Earth and Jupiter* as they work on their images.

6. Review student drawings using one of the following strategies
   - Ask students to volunteer their ideas and explain their drawings to the class.
   - Use a “pair share” approach. Ask each student to explain his or her ideas to a partner.
   - Line the walls of the classroom with the drawings. Ask students to walk past each image to see and reflect upon the ideas of their peers and the ways that the interiors of Earth and Jupiter were portrayed. In this scenario, the classroom briefly becomes a museum or art gallery.

Activity Ib: Slideshow

Following the review of student work, present the slideshow, *What’s Inside a Planet: Density and Differentiation*.

On Earth the boundaries between the lithosphere, hydrosphere, and atmosphere appear well defined. These layers have been further classified based upon observations of such things as processes, composition, and forms of life. Unlike terrestrial planets, gas giants present challenges when assigning boundaries such as the one between the interior and the atmosphere. Astronomers differ in their definition of the boundary between the atmosphere and interior of Jupiter. In part, this results from a lack of information. Also, it is difficult to create a boundary within a fluid (gas or liquid). Scientists separate the interior based on temperature variation rather than on states of matter.

Slideshow Key Concepts

Earth	Jupiter
• **Multiple layers:** lithosphere, hydrosphere, atmosphere and differentiation within these layers • **Composition**: Varied composition both between layers (lithosphere, hydrosphere, atmosphere) and within layers (e.g., crust vs. core of lithosphere). Over 90 elements exist on Earth. • **Energy Source**: Radiation from the interior of Earth drives convection within the lithosphere; solar radiation drives most processes within the atmosphere of Earth; internal heat drives geologic processes.	• **Layers**: Unknown. It is assumed that Jupiter has a core of liquid metal hydrogen. The layers within the atmosphere have yet to be studied in detail. Jupiter may also have a solid rocky core about the size of Earth • **Composition**: Hydrogen and helium with trace amounts of water, ammonia, and methane. • **Energy Source**: Energy from the interior of Jupiter far exceeds energy absorbed from the Sun. Thus, most processes within and throughout Jupiter are driven by internal heat radiated outward from the core.

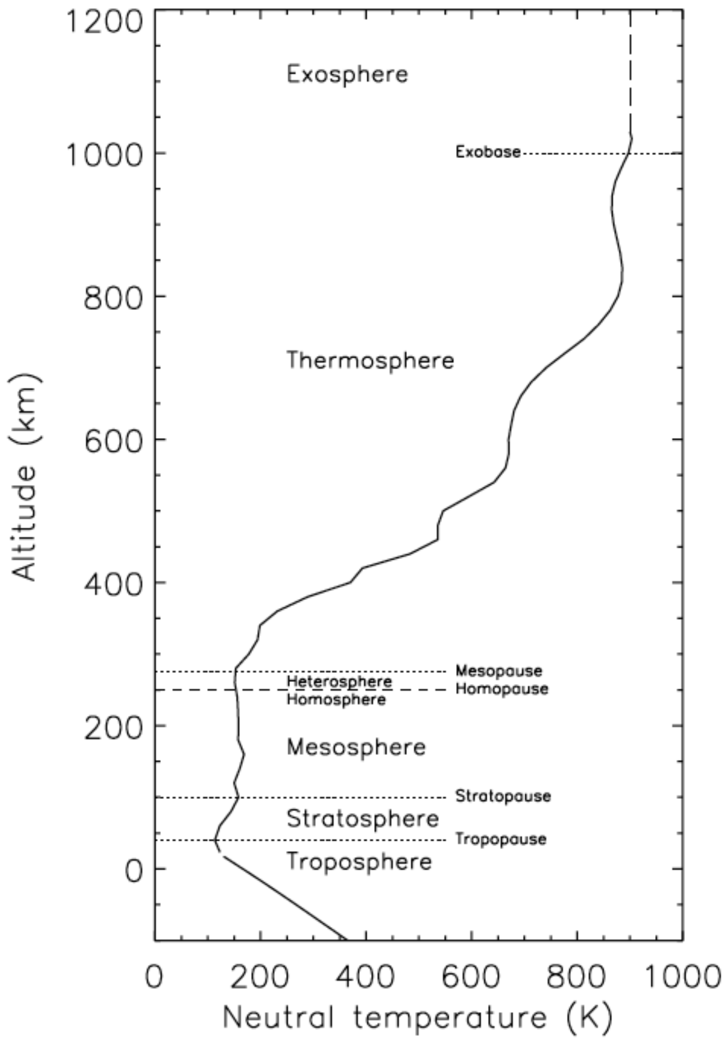


Figure 1: Temperature profile of Jupiter; Source: Chris Smith

Orienting Students to Images of Planets from Space

If your students are not familiar with the images of planets from afar, prompt them by explaining that these are photographs taken of objects in space (Slide #2). Direct their attention to the image A (Earth) and ask questions such as:

- Look at picture A, describe some of the colors you see? What might the different colors represent?
- Look at picture A, what are some shapes you see? What could the shapes represent?
- Look at picture A, what are some of the patterns you see? What might these patterns represent?

Corresponding Slide Number	Instructional Steps
1-3	1. Project the ***unlabeled*** images of Earth and Jupiter using the slideshow, *What's Inside a Planet: Density and Differentiation*. Ask students to examine each image briefly and then turn to their neighbor and using a "Pair Share" approach, explain what he or she thinks these images represent ***and*** why. 2. Next, ask volunteers to share what they heard their partner say and the reasoning the partner gave for his/her beliefs. 3. Point out to students that they have drawn conclusions from their observations of photos and that scientists make similar inferences as part of their work.
1-3	4. Confirm that these are images of Earth and Jupiter. Project the ***labeled*** images of each planet on a screen and point out some of the features. Some examples include: • The various mediums: land, water, ice, atmosphere • Earth has land whereas Jupiter does not • Features: continents, clouds, bodies of water for Earth; storm systems, cloud bands for Jupiter
4-6	5. Briefly review basic atmospheric and meteorological features of Jupiter and compare its size to that of Earth. To notice: • Bands: Jupiter's cloud pattern results from differences in internal temperatures and its rapid spin • Spots: These features represent storm systems • Jupiter is much larger than Earth; some storms on Jupiter are larger than Earth • For a more detailed study of Jupiter's atmosphere, refer to the Atmosphere Module
7	6. Explain to students that we know much about the composition and layers of Earth based upon understanding planet formation and seismic studies. We know little about the interior of Jupiter. What we do know we infer from the behavior and composition of the upper layers of atmosphere.
8-9	7. Review the property of density. Explain its role in the

	formation of the layers of Earth.
9-10	8. Slides 9 and 10 compare and contrast the composition and structure of Earth and Jupiter. We know little about the interior of Jupiter. NASA's Juno Mission will help answer many questions about Jupiter's composition and structure.
11	9. Distribute and review the student page, *Interior of Earth vs. Jupiter Two Column Chart*. Ask students to complete the two column charts in pairs and share their work.

Summarize and Reflect

Use the two column chart to have students summarize and reflect upon the composition and structure of Earth versus Jupiter.

Teacher Answer Key

Interior of Earth vs. Jupiter Two Column Chart

Interior of Earth	Interior of Jupiter
Solid core of iron, nickel	*Possibly - Solid core of dense materials most likely iron/nickel*
Clear layers and boundaries-heterogeneous	*Unknown to what degree the interior is differentiated-homogeneous*
Semi-solid, solid	*Liquid, gas*
Mixture of many elements, average density of 5.5 g/cm^3	*Primarily hydrogen and helium, average density of 1.3 g/cm^3*
Composition and structure inferred from understanding of planet formation and seismology	*Composition and structure inferred from understanding of planetary formation and behavior of outer most layers of atmosphere*

Activity I Assessment Opportunities

Collect student pages, *Drawing the Interiors of Earth and Jupiter* and *Interior of Earth vs. Jupiter Two Column Chart*. Use these pages to evaluate student ability to compare and contrast the composition and structure of Earth and Jupiter.

Activity II: Demonstration: Layered Liquids

To Do and To Notice

Do: Mix the water and the food coloring. Slowly add equal measures of water, light corn syrup, and vegetable oil to the graduate cylinder. Let stand prior to students' arrival in class.
Do: Ask students to observe the graduate cylinder and its contents.
Discuss: Ask students to describe their observations; draw their attention to the number of layers visible. Point out that all are in the same state - liquid. Name the liquid in each layer.
Ask and discuss the following questions:

- How many layers do you observe? (*Answer: three*)
- What do you think explains why these liquids appear as separate layers? (*Answers may vary. These layers are separate due to differences in densities of the liquids.*)
- Based upon our discussion of the composition and interiors of Earth and Jupiter, what might explain the layered liquids? (*Answers may vary. Some students may make the connection between density, the layered nature of planets and the layered liquids on display.*)

Do: Predict what will occur when we drop (a grape, a coin, a plastic bead) into the cylinder. (*Answers will vary.*)
Do: Drop various objects into the cylinder. Observe the level at which each comes to rest.
Discuss: Discuss the following questions:

- How do your predictions compare to your observations?
- Which objects came to rest at which elevations and within or between which fluids?
- What does the location of the object tell us about its' density relative to the densities of the liquids?

What is Going On?

The three liquids each have a different density. They separate into distinct layers. The corn syrup (1.4 g/cm3) rests on the bottom. Water (1 g/cm3) resides in the middle, and vegetable oil (0.9 g/cm3) sits above the water. Depending upon the items selected, some will sink. Others will float, suspended in or between the liquids based upon their densities. One can use knowledge of the densities of the liquids to estimate the densities of other substances.

Activity III: Determining Density and Composition

In this activity students determine the density of cubes of known and unknown composition. First, all students find the density of modeling clay (Plasticine™). Next, each team creates a cube of clay that contains a foreign object. They find the density of their mystery cube. Teams swap mystery cubes. The receiving team must determine the density of the cube and infer the composition of the foreign object embedded in the cube.

> **Volume of an Irregular Shape**
>
> Extend or modify this activity to have students find the volume of an irregular shape using the displacement method.

> **Density**
>
> Mass per unit volume

1. Explain to students that they will find the density of a cube of clay, with and without foreign objects inside. Explain that based upon a comparison of densities (pure clay to clay containing foreign objects) they will infer the composition of the material added to the cube.
2. Explain or review the definition of density.
3. Hold up a cube of clay, 5 cm on a side. Ask for volunteers to suggest ways to find the volume and mass of the cube. Review methods for finding volume and mass of objects as necessary.
    - Demonstrate how to find the volume and mass of the cube.
    - Model calculating density from mass and volume.
4. Distribute and review the student pages, *Determining Density and Composition*
5. Create student pairs. As teams work, circulate throughout the class to support their efforts to make clay cubes, measure mass and length, and calculate volume and density.
6. Once most teams have found the density of ***pure clay***, reconvene class and review the results. List the densities teams calculated on the board or overhead. ***Find the mean density for pure clay based on student data.***
7. Before students return to work:
    - Remind teams that after finding the density of a cube of clay combined with other material, they need to give it to another team.
    - As a class, discuss how teams will determine the composition of the material embedded in the clay. If students do not suggest comparing the densities of various materials, point out that the densities of clay, steel, glass, and plastic differ and that a combination of clay and other materials will differ in density from any of the source materials.
8. Allow teams to return to work. Support the process of making and swapping clay cubes. Help students respond to the follow-up questions (1-6) that accompany this activity. Once most individuals have completed their work, reconvene class as a whole and review results.

> **Average Density**
>
> Clay = use class average
>
> Steel = 7.9 g/cm^3
>
> Glass = 2.4 to 2.8 g/cm^3
>
> Plastic = 0.9 to 1.4 g/cm^3

Summarize and Reflect

As a class, review student responses to questions 1-6 on the final student page of this activity, *What is Inside: Steel, Glass, or Plastic?*

Ask teams to share their results. Ask teams to compare the density of their cubes to the density of the source materials and explain their conclusions. Also, ask teams to reveal the contents of their cubes to the investigating team. Did the recipients correctly infer the composition of the cubes?

Activity III Assessment Opportunities

Collect student pages. Use student work to evaluate the abilities of individuals to measure mass and length and to calculate volume and density. Use written responses to assess students' abilities to record data and communicate their ideas in writing. Based upon class discussion, evaluate student ability to articulate their ideas verbally.

Challenge students to determine the density and composition of one or more mystery cubes that you have prepared.

Activity IV: Recipe for a Planet

In this activity, students infer the composition of Earth and Jupiter based upon knowledge of the density of each planet and the densities of common elements and compounds. Their work takes place in two stages. First, they examine and select elements to include in the recipe. Next, they add compounds and additional materials to the recipe. ***Note that it is OKAY for students to struggle to create the correct recipe.*** The goals of this activity are to help students understand that:

- Knowing the density of a planet helps one infer its composition
- Although the majority of the matter in the Universe is hydrogen and helium, the vast amounts of material needed to create a planet result in concentrations of other substances
- Elements combine to form compounds that also play a role in planetary formation
- Density is only one source of information needed to infer composition of a planet

Corresponding Slide Number	Instructional Steps
12 and (Optional slides 21, 22)	1. Explain to students that since ancient times scientists and mathematicians have calculated the volume and mass of Earth. 2. Ask students to compare the mass of Earth to the mass of Jupiter. They should note that the mass of Jupiter is much greater than the mass of Earth. *Jupiter is 318 times more massive than Earth.* 3. Ask students to compare the volume of Earth to the volume of Jupiter. They should note that Jupiter's volume far exceeds Earth's. *The volume of Jupiter is 1321 times that of Earth.* 4. (Optional) As a class or in pairs, ask students to calculate the densities of Earth and Jupiter. Density = Mass/Volume
13	5. Compare the density of Earth to the density of Jupiter. Earth's density is greater than Jupiter's density. Until students are comfortable with the concept of density, it may be counterintuitive that the density of Jupiter is less than that of Earth. Ask students: a. If Jupiter is more massive and has a greater volume than Earth, how can it be denser? *Answer: Density is a ratio of mass to volume.* b. Can we use the density of a planet to infer its composition? *Answer: Possibly; denser planets are composed of denser elements and compounds.*

Historical Perspective

250 B.C. Eratosthenes calculates of the circumference of Earth. More: NOAA, The History of Geodesy

1666 A.D. Sir Isaac Newton demonstrated the relationship between mass and acceleration. By finding the gravitational acceleration of an object on the surface of Earth we can estimate its' mass.

$$\textbf{Acceleration} = \mathbf{G \times M_E/R_E^2}$$

G = Gravitational Constant
M_E = Mass of Earth
R_E = Radius of Earth

The Astronomer's Periodic Table

Slides 14-17 provide a review of the periodic table for students familiar with the elements. The slides next introduce how an astronomer might revise the periodic table to reflect the abundance of elements in the Universe. In order to develop a recipe for a planet one needs to understand the abundance of ingredients and, in this activity, their densities.

Is this recipe misleading?

The average density of all the elements on the table equals 2.4 g/cm^3. This number exceeds the density of Jupiter (1.3 g/cm^3) and approximates the density of Earth's crust. The activity does not ask students to suggest proportions for each ingredient, which ***might*** resolve disparities.

The activity is intentionally oversimplified. The disparities help students recognize that Jupiter cannot be pure hydrogen and helium (densities: 0.1 and 0.2 g/cm^3) and Earth must be a mix of substances–as we know from experience and from an average density of 5.5 g/cm^3. Even Part II, adding compounds and rocks, does not result in densities that approximate the averages for each planet.

14-17	6. Introduce or review the periodic table of the elements. Explain that elements are pure chemical substances consisting of only one type of atom. 7. Review or introduce the astronomer's periodic table of the elements. Explain that astronomers might rearrange the periodic table to demonstrate that in the Universe, hydrogen and helium are the most abundant elements. 8. Explain that during the formation of the solar system heavier elements were concentrated closer to the Sun and lighter elements further from the Sun.
18-19	9. Distribute and review the student page, *Recipe for a Planet: Part I Selecting Elements*. Explain to students that they will compare and contrast the densities of various elements to create a list of materials that when combined, ***might*** represent the compositions of Earth and Jupiter. Remind students that they should use the following information to select the elements for their recipe:

	• Densities of Earth and Jupiter • Densities of various elements • The Astronomer's Periodic Table 10. As students work, circulate throughout the room. Engage students in a discussion about their choice of elements. Ask students to explain which elements they selected for each planet and why. 11. Allow time for students to complete their recipe and answer questions 1-5. 12. Reconvene class as a whole. Ask volunteers to share their recipe and responses to the related questions. Note that the combination of elements students select will most likely ***not reflect*** the composition of Earth or Jupiter or lead to their average densities. This is ***OKAY***. It is important for students to realize that this is a complicated task and that they are ***INFERRING*** composition from density only. 13. Emphasize comparing student's calculations of average density to the average densities of Earth and Jupiter. What might account for discrepancies or similarities?
20	14. Explain to students that the processes and ingredients for planet formation are much more complex than simply mixing together elements. 15. The elements do not reflect all the substances that are available for creating a terrestrial or gas giant. For example, Jupiter contains ammonia, methane, and water. The Earth's crust is composed of rocks of many types with densities that range from about 2.0-3.0 g/cm^3. 16. Distribute and review the student page, *Recipe for a Planet: Part II Adding Compounds and Rocks*. Remind students that they are ***INFERRING*** the ingredients of each planet based upon density. 17. Repeat steps 10-13, above, having students revise their selection of ingredients and reflect upon their decisions. Have students answer questions 6-11 as related to Part II.

Summarize and Reflect

Use the review of student answers to questions 1-11 to reflect on how knowing the density of an object allows one to infer its composition. Pay close attention to student responses to questions 1, 4, 5, 10, and 11, having students elaborate upon their answers. Help students to understand that this exercise was an oversimplification of the process and designed to help them understand the role of inference in scientific investigations and that astronomers have a very different view of the composition of the Universe. Scientists use a variety of data, not just density, to infer the composition of Jupiter and other planets.

Corresponding Slide Number	Instructional Steps
21-22	Summarize the discussion of Earth and Jupiter's composition and density by explaining that the Earth's density varies with depth and that the Juno mission will provide scientists with new information to better understand the composition and density of Jupiter.

Return students' original two-column charts. Have students use a contrasting color pen or pencil to update their two-column chart or distribute blank charts and have students create a new one based upon the series of activities.

Activity IV Assessment Opportunities

Collect student work to evaluate their ability to calculate an average and to evaluate their critical thinking skills with respect to inferring the compositions of Earth and Jupiter. Use class discussion to assess student ability to articulate complex concepts.

Extensions

1. Modify Activity II to address finding volume for irregular shapes. Have students shape the clay irregularly and use the displacement method to find volume, mass, and density of an equal volume of water.

Resources

NASA: Interactive model of the structure of the Earth, http://scign.jpl.nasa.gov/learn/plate1.htm, The Southern California Integrated GPS Network Education Module

Background Information for the Teacher

How Scientists Use Evidence and Inference to Understand Jupiter

Scientists use evidence (observations from telescopes and space missions) and their knowledge of physics and chemistry to make computer programs that model or simulate Jupiter's atmosphere and interior. This enables them to make hypotheses. It also helps them to determine additional evidence to collect to verify hypotheses. Missions like Juno gather that evidence so that inferences can be made or existing hypotheses confirmed or not.

For example, Juno will collect information about Jupiter's mass, pressure, density, radius, composition, spin, temperature, magnetic field variations, etc. This information – along with fundamental physics and chemistry – will be used to develop or modify models of Jupiter's interior. These models make predictions; that is, they suggest other properties of the planet that could be measured in order to test the hypotheses. Then experimenters can go out and look for that evidence, whether that's through remote sensing or in situ observing.

As planets rotate, they flatten. Earth is not exactly spherical – it flattens a little as it spins. Jupiter is a gas planet, and flattens as it spins, too. Scientists understand a great deal about gravity and rotation, so they can infer the type of flattening that occurs for different materials. Jupiter would flatten differently if it were all gas versus if it was mostly gas with a rocky interior. Observations of Jupiter's flattening lead scientists to infer that there is a small, dense core. As planets spin, they also wobble on their axis – this is called "precession". This precession can help scientists determine the size of a core and whether it is likely solid or liquid.

Another clue to the interior of a planet is its temperature structure. Temperature in a planet changes with altitude or depth. Temperature changes deeper in the interior are due to heat flows from the hot core. The nature and structure of these heat flows can help scientists infer the nature of the core.

The Interior of Juno

Source: *Jupiter: The Planet, Satellites, and Magnetosphere*, Edited by Fran Bagenal, Timothy Dowling, and William McKinnon, Cambridge Planetary Science, Cambridge University Press, 2004 (page 35)

Jupiter, owing to its large mass and rapid formation, played a crucial role in shaping the solar system as we know it today. Jupiter mostly contains hydrogen and helium (more than 87% by mass), and as such bears a close resemblance to the Sun. However, the Sun has only 2% of its mass in elements other than hydrogen and helium (the *heavy elements*), whereas Jupiter has between 3 and 13%. The exact amount of these heavy elements in the planet and their distribution are keys to understanding how the solar system formed.

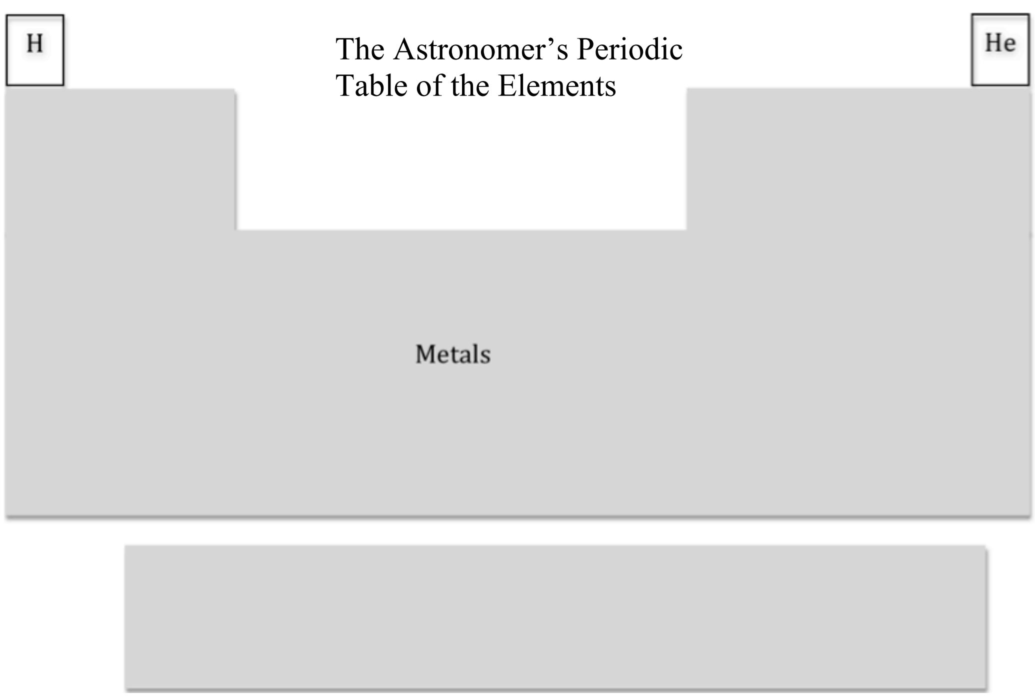
Yet, it would seem that since the first Jupiter book was published, more than twenty five years ago, there has been little qualitative change to our vision of the interior of Jupiter, as a planet with a central dense core and surrounding hydrogen and helium envelope (Stevenson and Salpteter 1976, Hubbard and Slattery 1976). Fortunately, several factors have led to significant quantitative improvements to that picture. Jupiter's gravity field has been measured with a better accuracy by the *Voyager* flybys in 1979, thereby yielding stronger constraints on the interior models. Our understanding of its atmosphere has been steadily improved, in particular by the in situ measurements of the *Galileo* probe in 1995, but also by the *Galileo* and *Cassini* missions, and by more accurate ground-based observations. On the experimental side, hydrogen (actually deuterium) has been successfully compressed to pressures up to several Mbar. Although the latest experiments remain controversial, this has generally led to the calculation of improved equations of state, a crucial ingredient for the calculation of interior models of the giant planet. Last but not least, the discovery of giant planets in orbit around other stars and of the related *brown dwarfs* has motivated more detailed studies of the evolution of substellar objects with direct applications to Jupiter.

To first order, Jupiter's interior can be described by simple arguments. Jupiter is a hydrogen-helium planet in hydrostatic equilibrium. Its interior is warm (~20000 K) because it formed from an extended gas cloud whose gravitational energy was converted into heat upon contraction. (It is still contracting at the rate of ~3 cm per year while its interior cools by ~1 K per million year.) This has several important consequences: The relatively warm conditions imply that Jupiter's interior is *fluid*, not solid. The cooling and contraction yield a significant intrinsic energy flux (revealed by the fact that Jupiter emits more energy than it receives from the Sun) that drives convection in most parts of the interior. Convection ensures the planet's homogeneity and generates the observed magnetic field through a dynamo mechanism.

Were the above description entirely true, one would be able to derive the planet's composition directly from the determination of the atmospheric abundances. However, several factors contribute to a more complex picture of Jupiter's interior. As discussed in Section 3.2, the observation of the planet's atmosphere indicates that several major chemical species (such as helium, neon and water) are partly sequestered into the interior. In the interior, the degenerated nature of the electrons and the Coulomb interactions between ions can be responsible for phase transitions and/or phase separations, synonymous with chemical inhomogeneities (Section 3.3). Energy transport is complicated by the possibility of radiative transport of the intrinsic heat flux in some regions, while convection itself is complicated by the presence of molecular weight gradients and by the intricate coupling with rotation and magnetic fields (Section 3.4). Finally, interior models based on the measurements of the planet's gravity field generally (but not always) require the presents of a central, dense core of uncertain mass and composition (Section 3.5). As shown in Section 3.6, this has major consequences for the planet's evolution and our understanding of its formation. Answering the most fundamental questions concerning Jupiter's origin (and by extension, the origin of the solar system) requires a renewed exploration of this planet.

The Astronomer's Periodic Table

Given the opportunity, astronomers might reorganize the periodic table of elements to reflect their observations of space. Approximately 99% of the ***volume*** of the Universe is composed of hydrogen. The next most abundant element, helium, comprises less than 1% of the Universe by volume. The remaining elements in the Universe occur in trace amounts. Some astronomers might even lump all elements other than hydrogen and helium into one group, the metals. The elements hydrogen and helium were created during the Big Bang. All other elements result from astrophysical events associated with stellar evolution.



It is difficult to convey the relative abundance of the ten most common elements in the Universe. It is hard for many to grasp a Universe composed of 99% hydrogen. Our reference point, the composition of Earth, complicates the situation. The Earth and its combination of solids, liquids, and gases composed of a variety of elements and compounds provides us with a very different experience than we would have elsewhere in space.

Composition of the Universe, Jupiter, and Earth

The tables and charts below provide several ways to express the proportion of hydrogen and helium to the other elements. All elements, helium through sulfur, are compared to hydrogen, the most abundant element in the Universe.

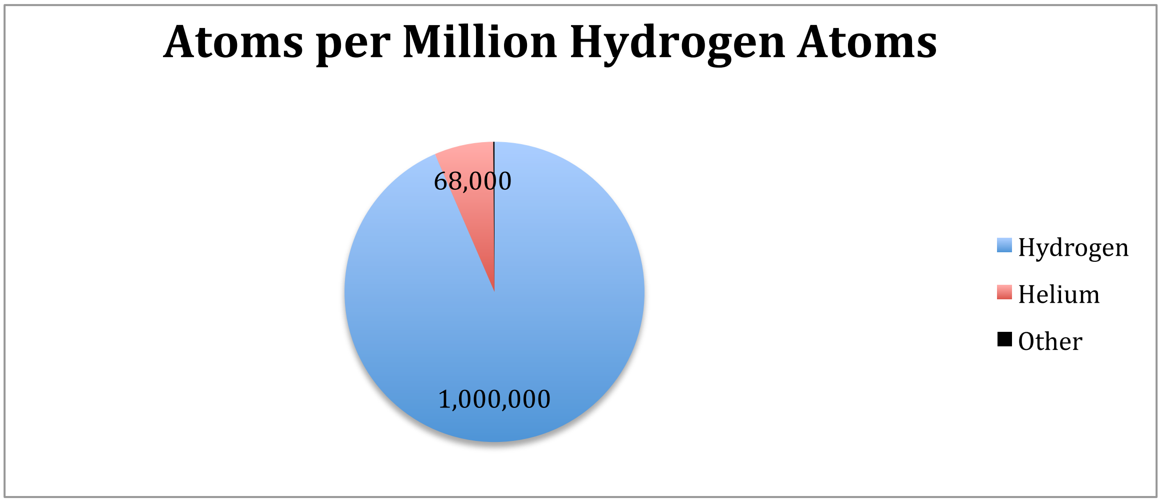
The Ten Most Abundant Elements in the Universe*

Element	**Symbol**	**Atomic Number**	**Number of Atoms per Million Hydrogen Atoms**	**Number of Hydrogen atoms for each 1 atom of other elements**
Hydrogen	H	1	1,000,000	
Helium	He	2	68,000	15
Oxygen	O	8	690	1,449
Carbon	C	6	420	2,381
Neon	Ne	10	98	10,204
Nitrogen	N	7	87	11,494
Magnesium	Mg	12	40	25,000
Silicon	Si	14	38	26,315
Iron	Fe	26	34	29,412
Sulfur	S	16	19	52,632

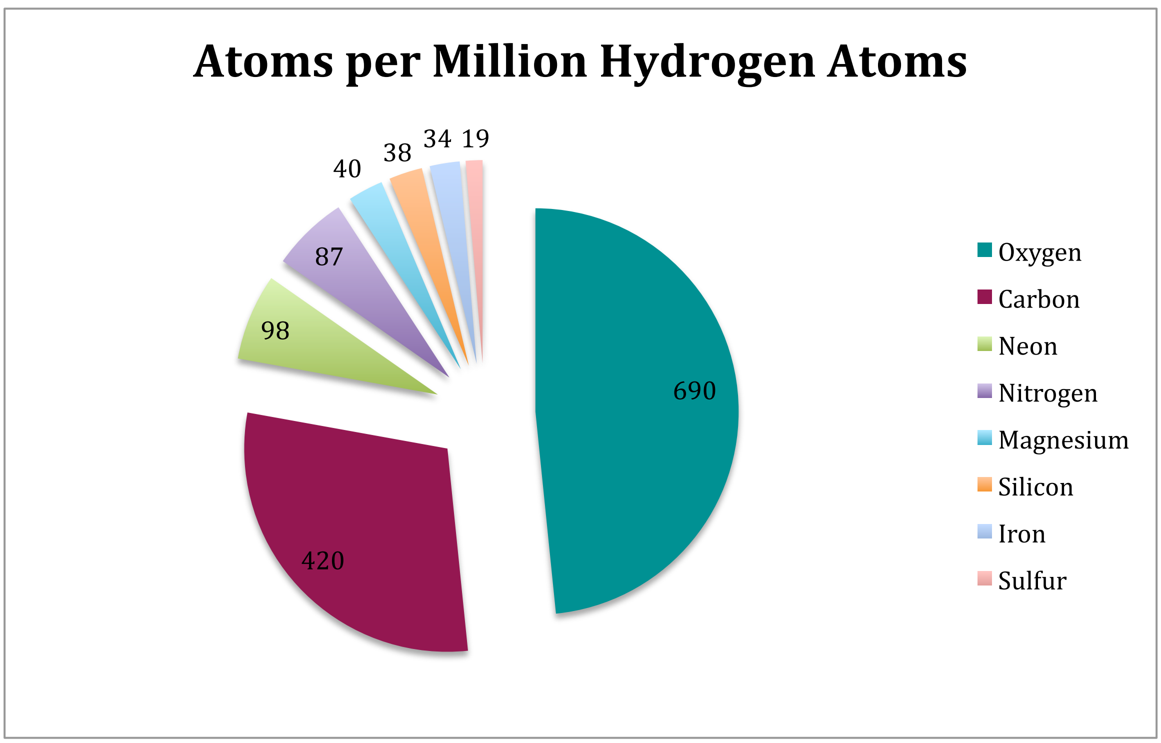
*Abundance by mole-fraction.

The table above lists the ten most abundant elements. One column compares the number of atoms of each element to 1,000,000 atoms of hydrogen, or ***parts per million***. The table also shows the number of atoms of hydrogen for each one atom of other elements. For example, for every 1,000,000 atoms of hydrogen there are 68,000 atoms of helium. The ratio of hydrogen to helium is 15:1. There are nineteen atoms of sulfur for each million atoms of hydrogen; a ratio of 52,632:1.

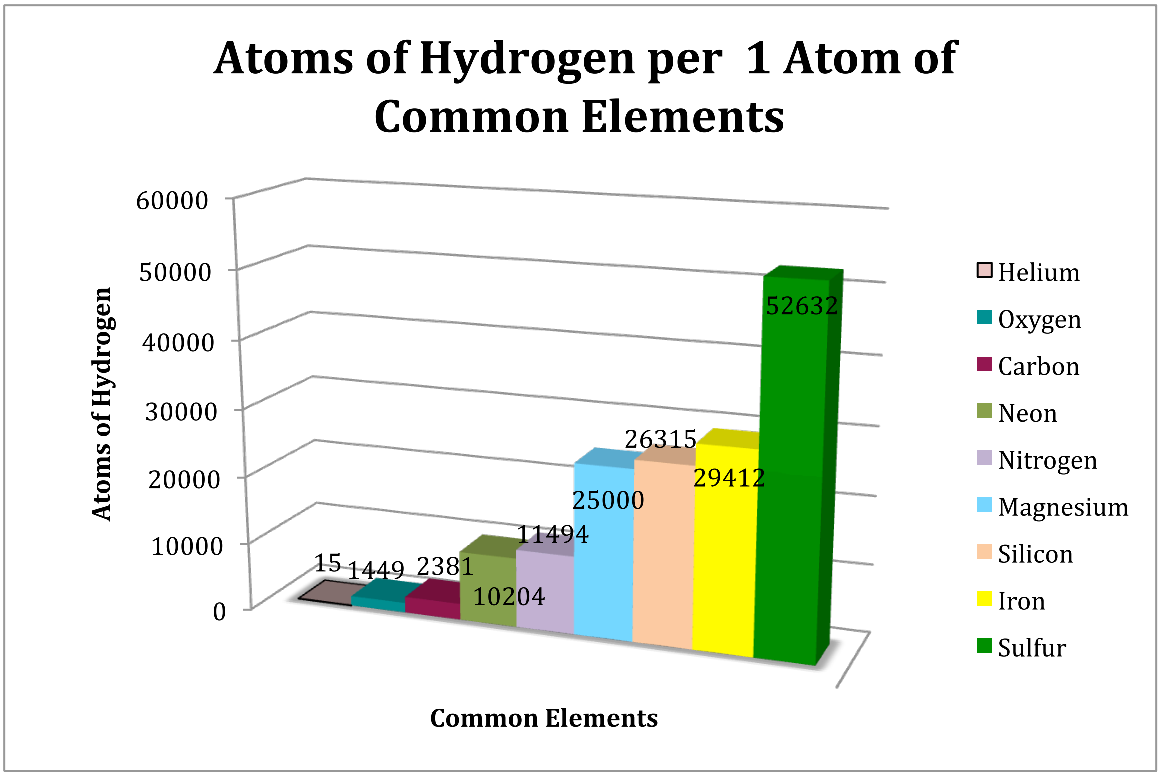
Charts provide a visual method for comparing the abundance of elements in the Universe. Different visual representations may help students to grasp the surprising lack of diversity in the composition of the Universe.



The above chart compares the number of atoms of helium (68,000) to 1,000,000 atoms of hydrogen. The remaining elements combined, listed as "other" are so few that the wedge that represents their portion of the chart appears as a line.



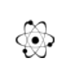
Here the "other" eight elements in the top ten appear in their own pie chart. As you can see, oxygen atoms while the third most abundant element in the Universe occur 690 times for every 1,000,000 atoms of hydrogen.



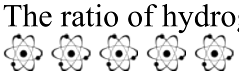
This chart compares one atom of each element to a corresponding number of atoms for hydrogen. There are 15 atoms of hydrogen to every one atom of helium. The ratio for hydrogen to sulfur is 52,632:1.

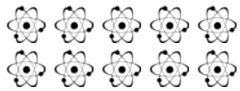
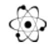
Students readily compare large numbers to small numbers when they manage money. Point out that they compare pennies to dollars. They know that there are 100 pennies for every 1 dollar. Can they calculate the number of pennies to a single, $100 dollar bill?

There are 100 pennies for each single dollar.
There are 100 single dollar bills for each $100 dollar bill.
Therefore, 100 pennies X 100 single dollars equals 10,000 pennies for a $100 bill; a ratio of 10,000:1

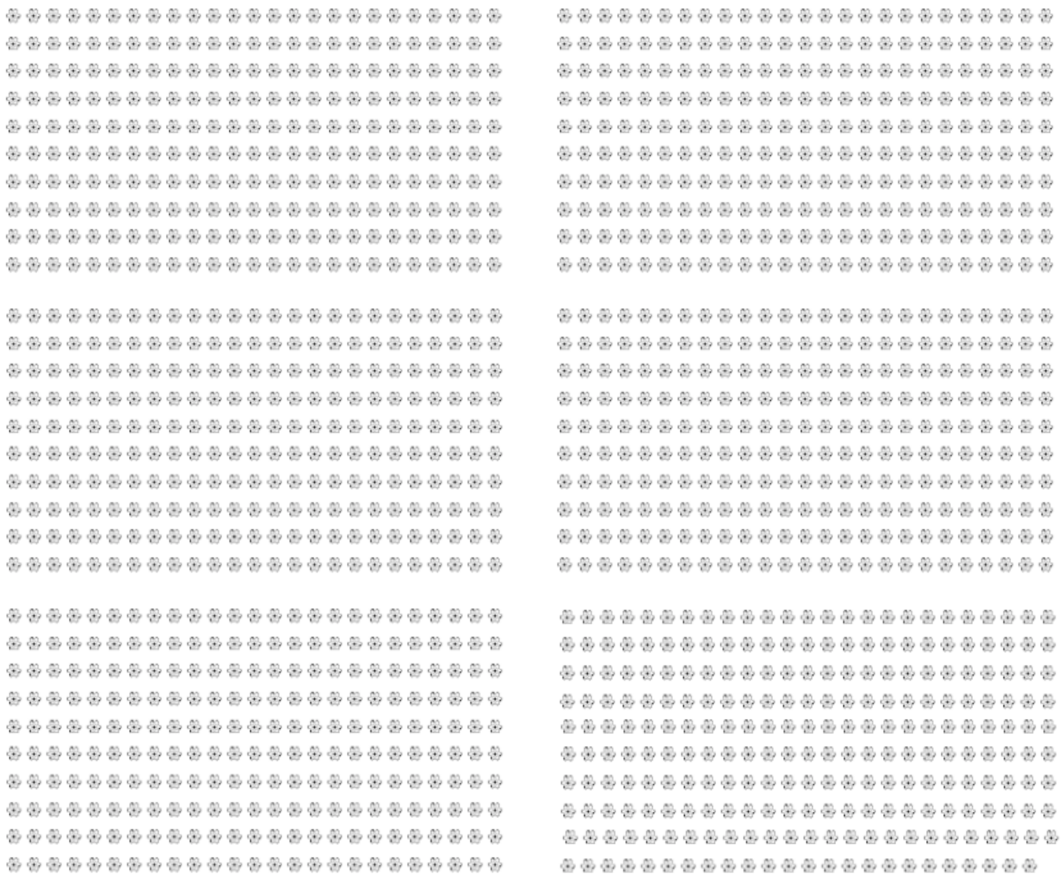
If students find it easier, have them draw the comparisons. In the images below, each  represents a single atom.

The ratio of hydrogen to helium appears as:



 to 

The Universe contains1,449 hydrogen atoms for each atom of oxygen:

 to 

The composition of Earth is significantly different that that of Jupiter and the Universe. The similarity of compositions of Jupiter and the Universe suggest that Jupiter formed early in the evolution of the system and retained a composition more comparable to that of the nebula from which our solar system arose. Earth, located closer to the Sun and within the frost line, lost its more volatile compounds, creating a higher concentration of heavier elements and compounds.

Composition of Earth, Jupiter, and the Universe by *Mass*

Element	Earth	Jupiter	Universe
Hydrogen		75.00%	75.00%
Helium		24.00%	23.00%
Oxygen	30%		1.00%
Nitrogen			0.10%
Iron	32%		0.11%
Sulfur	3%		0.05%
Aluminum	1%		
Calcium	2%		
Nickel	2%		
Silicon	15%		0.07%
Magnesium	14%		0.06%
Carbon			0.50%
Neon			0.13%
Argon			0.02%
Other	1%		
Compound			
Water		0.30%	
Ammonia		0.30%	
Methane		0.30%	
Other		0.10%	

How Much?: Describing Abundance

The abundance of an element (throughout the Universe) may be described in several ways: by mass, by volume, or relative to hydrogen. For example, helium:

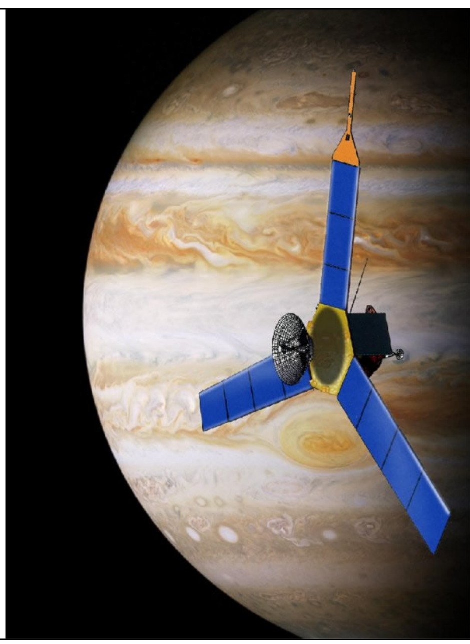
24% by Mass
1% by Volume
68,000 atoms He to 1,000,000 atoms H (parts per million)

Jupiter’s Family Secrets

Our solar system is a family of planets, dwarf planets, comets, and asteroids orbiting our Sun, each harboring clues of our common origins, with their disparate compositions and characteristics.

How do scientists discover those secrets? Ancient civilizations studied the skies and noted the strange travelings of “wanderers,” or “*planetes*” in Greek, which seemed to move against the background of familiar constellations. Telescopes allowed astronomers to view the *surfaces* of planets; spacecraft instruments now allow us to infer information about the *interiors* of planets. Instruments like radar, sophisticated compasses, orbital mapping devices, and others that detect wavelengths of light invisible to the human eye are some of the tools that allow spacecraft to explore other worlds.

NASA’s Juno mission to Jupiter is scheduled to launch in 2011 and will investigate not only the deepest mysteries of its unique personality, but it also will plumb the secrets of our solar system’s origins.



NASA’s Juno mission to will investigate Jupiter’s interior, atmosphere, magnetosphere, and origins. By discovering clues about Jupiter’s unique personality, the Juno mission will reveal answers about our solar system's birth. This artist's rendering shows the Juno spacecraft in front of Jupiter, where it will arrive in 2016.

Credit: NASA.

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!