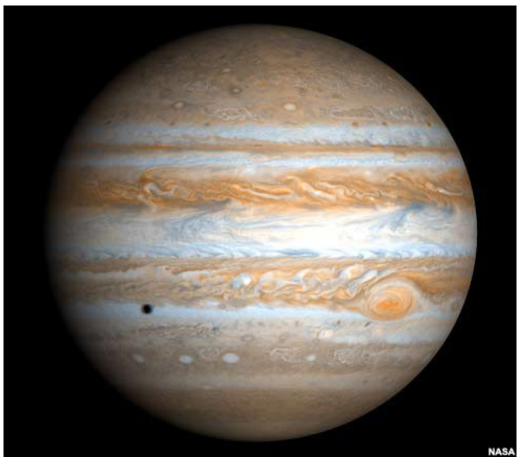
Dowling College

Student name: ____________________________________

Lab 8: Jovian Planets

The second major family of planets is the Jovian, or Giant, Planets. As noted in Lab 6 and in class, Jovian planets include the group's namesake, Jupiter, as well as Saturn, Uranus, and Neptune. All are comprised primarily of hydrogen and helium, with fractional percentages of other constituents. The Jovian planets do not have solid surfaces. Instead, their gaseous material simply gets denser with depth. What we see when looking at these planets is the tops of clouds high in their atmospheres. Other qualities shared by the four giant planets include their great distance from the Sun, their rapid rotation (all rotate in less than 11 hours), and their large diameters. All four are also encircled by many natural satellites as well as ring systems.

Jupiter



Jupiter is the fifth planet from the Sun and by far the largest. To the eye, Jupiter appears as the fourth brightest object in the sky (after the Sun, the Moon and Venus). It has been known since prehistoric times as a bright "wandering star". But in 1610 when Galileo first pointed a telescope at the sky he discovered Jupiter's four large moons Io, Europa, Ganymede and Callisto and recorded their motions back and forth around Jupiter. This was the first discovery of a center of motion not apparently centered on the Earth. It was a major point in favor of Copernicus's heliocentric theory of the motions of the planets.

Jupiter is about 90% hydrogen and 10% helium (by numbers of atoms, 75/25% by mass) with traces of methane, water, ammonia and "rock". This is very close to the composition of the primordial Solar Nebula from which the entire solar system was formed. Saturn has a similar composition, but Uranus and Neptune have much less hydrogen and helium.

Our knowledge of the interior of Jupiter (and the other Jovian planets) is highly indirect and likely to remain so for some time. Jupiter probably has a core of rocky material amounting to something like 10 to 15 Earth-masses.

Above the core lies the main bulk of the planet in the form of liquid metallic hydrogen. This exotic form of the most common of elements is possible only at pressures exceeding 4 million bars, as is the case in the interior of Jupiter (and Saturn).

The outermost layer is composed primarily of ordinary molecular hydrogen and helium which is liquid in the interior and gaseous further out. The atmosphere we see is just the very top of this deep layer. Water, carbon dioxide, methane and other simple molecules are also present in tiny amounts. The vivid colors are probably the result of subtle chemical reactions of the trace elements in Jupiter's atmosphere, perhaps involving sulfur whose compounds take on a wide variety of colors, but the details are unknown.

Jupiter and the other giant planets have high velocity winds that are confined in wide bands of latitude. The winds blow in opposite directions in adjacent bands. Slight chemical and temperature differences between these bands are responsible for the colored bands that dominate the planet's appearance. The light colored bands are called zones; the dark ones belts. The bands have been known for some time on Jupiter, but the complex vortices in the boundary regions between the bands were first seen by Voyager. Jupiter's atmosphere was also found to be quite turbulent. This indicates that Jupiter's winds are driven in large part by its internal heat rather than from solar input as on Earth.

The Great Red Spot (GRS), seen by Earthly observers for more than 300 years, is believed to be a cyclonic storm system. Infrared observations and the direction of its rotation indicate that the GRS is a high-pressure region whose cloud tops are significantly higher and colder than the surrounding regions.

Jupiter also has rings like Saturn's, but much fainter and smaller.

Calculate the mass of Jupiter, using the motions of its moons

1. For this first exercise, we are going to calculate the mass of Jupiter by using Kepler's 3rd Law and information gathered from the appendices in the back of the textbook.

Steps:

- Go to Appendix 8 and pick one of Jupiter's four major (Galilean) moons.
- Record the following information in the spaces below:
  - o Name of the moon: ______________________
  - o Orbital period (days):_____________________
  - o Semimajor axis (km): ____________________
- Convert the moon's orbital period into seconds. How many seconds are there in a day? 60x60x24 = 86,400 Record your answer here: P = ______________
- Convert the size of that moon's orbit into centimeters. Record your answer here: R = _________
- Use Kepler's Third Law, as formulated by Newton to determine the mass of the planet Jupiter
  - o Solve the equation $P^2 = (4\pi^2R^3/GM)$ for the mass (M). Hint: You will need to cross multiply to get the equation in the correct order.
  - o Plug in the values of the constants ($G = 6.67 \times 10^{-8}$ and $\pi = 3.14159$) as well as the semimajor axis and period.
  - o Calculate the mass in grams and convert to Earth masses (the mass of the Earth is 6×10^{27} grams). Show calculations below:

Answers: The mass of Jupiter (in grams): __________ The mass of Jupiter (in Earth masses): ________

2. a. If Jupiter's diameter is 142,800 km, what is its volume in cubic kilometers (km^3)? [Hint: Volume = $(4/3)\pi r^3$]

b. Convert your answer into cubic centimeters. [Hint: There are $1x10^4$ cm^3 in 1 km^3]

3. Calculate the density of Jupiter (in gm/cm^3) by dividing its mass by its volume. Is Jupiter heavier or lighter than water (D_{water} = 1 gm/cm^3)?

When we look at the Jovian planets, we are not looking at solid surfaces. Rather, we are looking at the tops of impenetrable atmospheres. Of the four Jovian worlds, Jupiter shows the most varied atmospheric structure. Gigantic storms punctuate a turbulent atmosphere. The photo below shows the largest storm on Jupiter. Because of its prominent color in photographs, it has been christened the Great Red Spot (often abbreviated GRS).

4. Just how great is the Great Red Spot? Based on the photo above and given that the equatorial diameter of Jupiter is 143,000 km, determine the dimensions of the GRS's major and minor axes.

Answer: major axis = ________________km minor axis = ________________km

5. How many planet Earths would fit across the GRS's major axis, assuming Earth is 12,800 km in diameter?

6. The Sun is often cited as a "typical" star. Stars emit their own energy (light, heat, etc.) from a thermonuclear fusion reaction that occurs deep within their interiors. Some astronomers have said that Jupiter resembles stars in many ways. List two traits of Jupiter that are similar to stars.

7. Why didn't Jupiter turn into a star when it first formed?

Saturn

Without a doubt, one of the most beautiful sights in the sky is the planet Saturn and its famous ring system. Saturn is the sixth planet from the Sun and the second largest. Galileo was the first to observe it with a telescope in 1610, although it was not until 1659 that Christian Huygens correctly identified the planet's famous rings.

Saturn was first visited by Pioneer 11 in 1979 and later by Voyager 1 and Voyager 2. Cassini arrived on July 1, 2004 and will orbit Saturn for at least four years.

Saturn is the least dense of the planets; its specific gravity (0.7) is less than that of water. Like Jupiter, Saturn is about 75% hydrogen and 25% helium with traces of water, methane, ammonia and "rock", similar to the composition of the primordial Solar Nebula from which the solar system was formed. Saturn's interior is similar to Jupiter's consisting of a rocky core, a liquid metallic hydrogen layer and a molecular hydrogen layer. Traces of various ices are also present.

The bands so prominent on Jupiter are much fainter on Saturn. They are also much wider near the equator. Details in the cloud tops are invisible from Earth so it was not until spacecraft encounters that any detail of Saturn's atmospheric circulation could be studied.

Saturn's rings, unlike the rings of the other planets, are very bright. Two prominent rings (A and B) and one faint ring (C) can be seen from the Earth. The gap between the A and B rings is known as the Cassini division. Though they look continuous from the Earth, the rings are actually composed of innumerable small particles each in an independent orbit. They range in size from a centimeter or so to several meters. A few kilometer-sized objects are also likely.

Saturn's rings are extraordinarily thin, less than one kilometer thick. Despite their impressive appearance, there's really very little material in the rings -- if the rings were compressed into a single body it would be no more than 100 km across.

Use the photo above, showing Saturn as photographed by the Cassini spacecraft as it was making its way out to the planet in March 2004, to answer question 8.

8. If the equatorial diameter of Saturn is 121,000 km, what is the outer diameter of Saturn's rings?

Answer: ____________________

9. The Voyager 2 photo below shows part of Saturn's rings silhouetted against the limb of the planet. Examine the photo closely. What observational evidence can you find that suggests the ring system is not very dense?

10. Calculate how Earths would fit into the volume of Saturn.

Uranus

Uranus is the seventh planet from the Sun and the third largest (by diameter). Uranus is larger in diameter but smaller in mass than Neptune. Uranus, the first planet discovered in modern times, was discovered by William Herschel while systematically searching the sky with his telescope on March 13, 1781. It had actually been seen many times before but ignored as simply another star (the earliest recorded sighting was in 1690).

Uranus has been visited by only one spacecraft, Voyager 2 in January 1986.

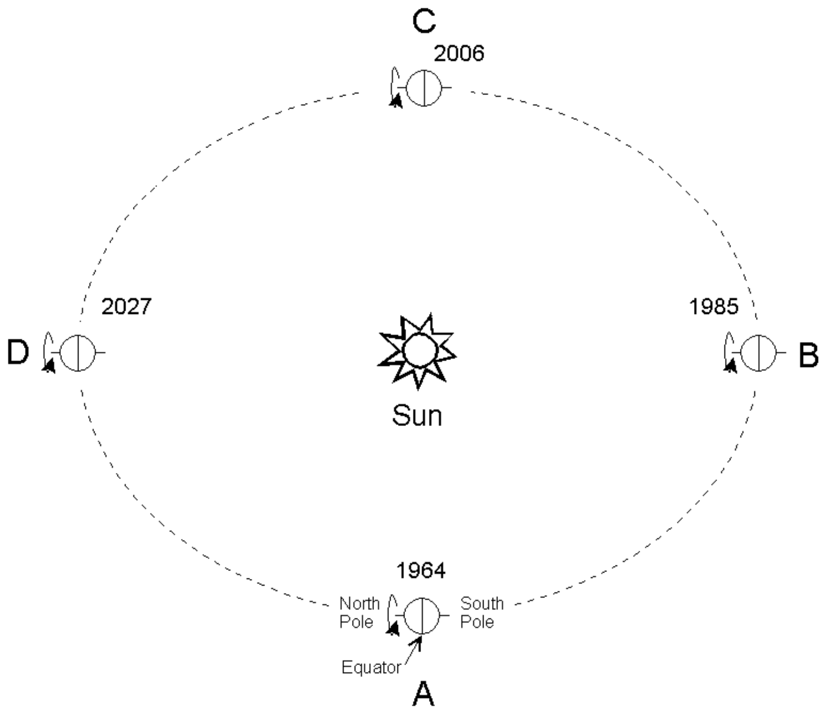
Uranus' atmosphere is about 83% hydrogen, 15% helium and 2% methane. In many ways, the planet (and Neptune) resembles the cores of Jupiter and Saturn minus the massive liquid metallic hydrogen envelope. It appears that Uranus does not have a rocky core like Jupiter and Saturn. Rather, its material is more or less uniformly distributed. Uranus' blue color seen prominently in color photos is the result of absorption of red light by methane in the upper atmosphere. There may be colored bands like Jupiter's but they are hidden from view by the overlaying methane layer.

Like the other giant planets, Uranus has bands of clouds that blow around rapidly, although they are extremely faint. Recent observations with the Hubble Space Telescope show large, pronounced streaks in the planet's atmosphere. Based on these images versus the bland images returned by Voyager 2 in 1986, it now seems clear that the differences are due to seasonal effects. The Sun is now at a lower Uranian latitude than in 1986, which may cause more pronounced day/night weather effects. By 2006, the Sun will be directly over Uranus's equator.

Uranus is unique among the planets for its unusually tilted orbit. Unlike the other planets, which effectively spin around the Sun like toy tops, Uranus is tilted on its side, rolling around the Sun in its 84-year orbit. At the time of Voyager 2's passage, Uranus' south pole was pointed almost directly at the Sun. This results in the odd fact that Uranus' polar regions receive more energy input from the Sun than do its equatorial regions. Uranus is nevertheless hotter at its equator than at its poles. The mechanism underlying this is unknown.

Like the other giant planets, Uranus has rings.

Uranus is shown at four orbital positions (labeled A, B, C, and D) in the diagram below. Each also shows the planet's north pole, south pole, and equator, as well as the year that the planet was or will be in that position. Complete the questions below based on this diagram.

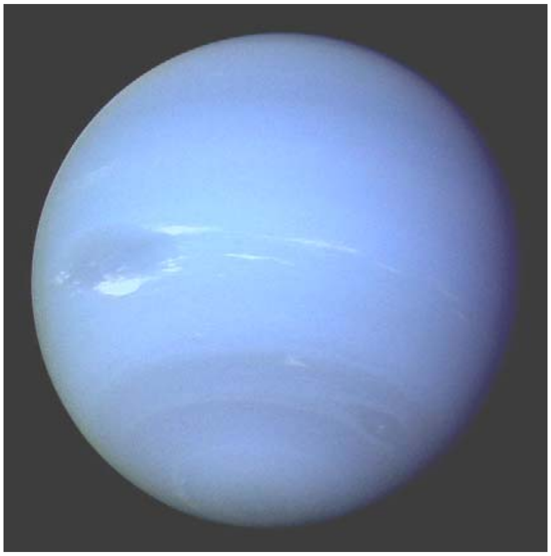


11. Complete the following table, indicating whether each of the planet's three regions will receive direct sunlight, indirect sunlight (that is, at a narrow angle), or no sunlight when Uranus is at each of the four orbital positions. Position A has been completed as an example.

Position	**North Pole**	**Equator**	**South Pole**
A	INDIRECT	DIRECT	INDIRECT
B			
C			
D			

12. On the diagram, put an X where Uranus is presently in its orbit. What year will it have returned to this same orbital position?

Neptune



Neptune is the eighth planet from the Sun and the fourth largest (by diameter). Neptune is smaller in diameter but larger in mass than Uranus.

After the discovery of Uranus, it was noticed that its orbit was not as it should be in accordance with Newton's laws. It was therefore predicted that another more distant planet must be perturbing Uranus' orbit. Neptune was first observed by Galle and d'Arrest on 1846 Sept 23 very near to the locations independently predicted by Adams and Le Verrier from calculations based on the observed positions of Jupiter, Saturn and Uranus. An international dispute arose between the English and French (though not, apparently between Adams and Le Verrier personally) over priority and the right to name the new planet; they are now jointly credited with Neptune's discovery. Subsequent observations have shown that the orbits calculated by Adams and Le Verrier diverge from Neptune's actual orbit fairly quickly. Had the search for the planet taken place a few years earlier or later it would not have been found anywhere near the predicted location.

More than two centuries earlier, in 1613, Galileo observed Neptune when it happened to be very near Jupiter, but he thought it was just a star. On two successive nights he actually noticed that it moved slightly with respect to another nearby star. But on the subsequent nights it was out of his field of view. Had he seen it on the previous few nights Neptune's motion would have been obvious to him. But, alas, cloudy skies prevented observations on those few critical days.

Neptune has been visited by only one spacecraft, Voyager 2, in August 1989. Much of we know about Neptune comes from this single encounter. But fortunately, recent observations with ground-based telescopes and the Hubble Space Telescope have added a great deal of additional information.

Neptune's composition is probably similar to Uranus'. Like Uranus, but unlike Jupiter and Saturn, it may not have a distinct internal layering but rather to be more or less uniform in composition. But there is most likely a small core (about the mass of the Earth) of rocky material. Its atmosphere is mostly hydrogen and helium with a small amount of methane.

Neptune's blue color is largely the result of absorption of red light by methane in the atmosphere but there is some additional as-yet-unidentified chromophore which gives the clouds their rich blue tint.

Like a typical giant planet, Neptune has rapid winds confined to bands of latitude and large storms or vortices. Neptune's winds are the fastest in the solar system, reaching 2,000 km/hour.

Like Jupiter and Saturn, Neptune has an internal heat source -- it radiates more than twice as much energy as it receives from the Sun.

At the time of the Voyager encounter, Neptune's most prominent feature was the Great Dark Spot in the southern hemisphere. It was about half the size as Jupiter's Great Red Spot. Neptune's winds blew the Great Dark Spot westward at 300 meters/second (700 mph). Voyager 2 also saw a smaller dark spot in the southern hemisphere and a small irregular white cloud that zips around Neptune every 16 hours or so.

However, Hubble Space Telescope observations of Neptune in 1994 showed that the Great Dark Spot had disappeared! It had either simply dissipated or was being masked by other aspects of the atmosphere. A few months later, HST discovered a new dark spot in Neptune's northern hemisphere. This indicates that Neptune's atmosphere changes rapidly, perhaps due to slight changes in the temperature differences between the tops and bottoms of the clouds.

Neptune also has rings. Like Uranus and Jupiter, Neptune's rings are very dark. Their exact composition is unknown.

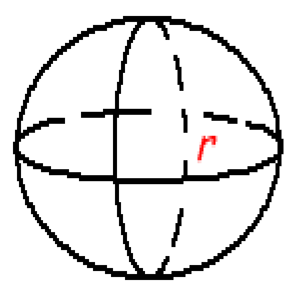
13. The wind speeds in circular storm systems can be formidable on both Earth and the giant planets. First think of our big terrestrial hurricanes. If you watch their behavior in satellite images shown on the weather channels, you will see that they require about one day to rotate. If a storm has a diameter of 400 km and rotates once in 24 hours, what is the wind speed? Speed equals distance divided by time. The distance in this case is storm's circumference (π x diameter), or approximately 1,200 km. Since we know the time period is 24 hours, the wind speed at the edge of the storm is 50 km/hour (1,200÷24 = 50), or about 35 miles per hour. Of course, wind speed jumps dramatically as you move in toward the center of the storm.

    Using the above methodology and example, calculate the wind speed at the edge of Neptune's Great Dark Spot, which had a diameter of 2,500 km and rotated in 17 days. Please show all work in the space below.

    Answer: ___________________________

14. Based on the diameters listed in Appendix 7 (page 718), calculate how many Earths could fit inside the volume of Neptune. Remember that the formula for calculating volume is:

$$\text{Volume} = 4/3\pi r^3$$



Answer: _________________________