Chapter 11 Jupiter

Orbital and Physical Properties

Jupiter is named for the Roman king of the gods. It is the largest planet in the solar system.

The View from Earth

Jupiter is the 3rd brightest object in the night sky after the Moon and Venus. Jupiter has around 60+ moons and has no solid surface. The 4 largest of these are called the *Galilean Moons* because they were first seen by Galileo. When you look at Jupiter you will see banding that goes across the planet. These are alternating cloud bands moving in different directions and at different speeds.

Mass and Radius

After watching the Galilean Moons, we have been able to determine the mass of Jupiter. It is about 318 times more massive that the Earth. In fact, Jupiter has more than twice the mass of all of the other planets combined. Many scientists regard the solar system as having 2 important objects: the Sun and Jupiter. These 2 objects exert a huge gravitational influence on everything else in the solar system. The radius o Jupiter is about 71,500 km or about 11.2 Earths in diameter. It would take 1400 Earths to fill the volume of Jupiter. The density appears to be about 1300 kg/m^3. Our studies of Jupiter show that it must be made up primarily of hydrogen and helium.

Rotation Rate

So far to determine the rotation rate all we really needed to do was look at the planet and watch features. Jupiter is much different. The bands on Jupiter don't all move at the same rate. This is called *differential rotation*. This can't happen in solid bodies, but since Jupiter is a gas giant we get this effect. To really calculate the rotation period we used the magnetosphere of Jupiter. Jupiter has a strong magnetic field so it was easy to track. Our careful measurements show that Jupiter rotates in 9hours 55 minutes. This is the fastest rotation rate in the solar system. Due to the fast rotation, Jupiter bulges along the equator and is somewhat flattened in the polar direction. The equatorial radius is 71,500 km while the polar radius is 66,900 km. This also tells us something about the interior. If Jupiter were strictly hydrogen and helium it would be flattened much more than it is. This says that there must be an object about 5 – 10 times the mass of the Earth at the center of Jupiter.

The Atmosphere of Jupiter

The thing that you will notice about Jupiter is that the bands are ever-changing and that there is a disturbance called the *Great Red Spot*. In photographs you can see that the bands show many colors to us. The Red Spot is a hurricane that is about 2 times the size of the Earth. It has been visible since first being seen in the 17th century.

Atmospheric Composition

Astronomers first studied the composition of the clouds by looking at the spectra of reflected sunlight off the clouds. Later more advanced techniques gave us a better understanding of Jupiter. The clouds are made up of molecular hydrogen, 86.1%, and helium, 13.8%. That is over 99% of all material. Since Jupiter is so massive, it is thought that very little of its original atmosphere has ever escaped out into space.

Atmospheric Bands

The Jovian worlds are usually described as having a series of bright *zones* and dark *belts* crossing the surface. The bright zones are thought to be the upwelling of material from convection currents and the dark belts are the areas that are falling back down into Jupiter. This means that the zones are areas of high pressure and the belts are areas of low pressure. The differences in temperature and chemical composition are the reasons for the different colors. There are underlying bands of very stable air flow called *zonal flow*. The equatorial region has material flowing faster due to the higher rotation rate at the equator. It is about 300 km/hr. This is very similar to our jet streams on Earth. Jupiter has no seasons (Why?) so the zones and belts remain pretty much intact even though they can vary in their size.

Atmospheric Structure and Color

Scientists suspect that the variety of colors is due to complex chemical reactions that are taking place in the atmosphere because things like ammonia and water vapor and others wouldn't produce the many colors we see. Figure 11.6 is our best guess due to available data and mathematical models. The troposphere is considered to be at 0 km, which means we can have negative altitudes on the drawing. The clouds which are the result of convection currents are all at negative altitudes. Just above the troposphere is a thin layer of haze caused by *photochemical effects*. These are reactions that occur due to light. The temperature here is about 110 K and it increases as you go up due to the absorption of UV.

There are 3 main layers in the atmosphere. At – 40 km you will find a layer of white wispy clouds of ammonia ice. The temperature here is about 125 – 150 K. Below the clouds the temperature is around 200 K and the clouds are probably made of drops of ammonium hydrosulfide. Below that you have clouds of water vapor or water ice. The lowest cloud layer is found at about -80 km. In the middle layer you find the color is tawny. This is where the atmospheric chemistry begins to occur. Many planetary scientists think this is where sulfur plays an important part in color, especially the reds, browns, and yellows.

Studying this is difficult because the chemicals are sensitive to changes in pressure and temperature. It is a place that is constantly churning which constantly mixes different chemicals together. That means that the conditions change hour to hour. The source of energy is from internal heat, solar UV, and lightning in the clouds of Jupiter. IN 1995 we checked our models when Galileo dropped a probe into the atmosphere. It showed that most of our ideas about Jupiter were good. The probe was dropped into an equatorial band which happened to be void of high clouds. One of the things that were unexpected was the fact that the winds continued down into Jupiter. This says that heat within Jupiter not the Sun drives Jupiter's weather patterns. Simple carbon-carbon molecules were detected, but nothing more significant.

Weather on Jupiter

There are many small-scale weather patterns on Jupiter. The Great Red Spot is one example. Robert Hooke first saw this in the 17th century and it has existed ever since. When did it start? We have no idea. It is very much like a whirlpool or hurricane. The winds swirl around. The size of the spot varies over time, but at present it is about 25,000 km x 15,000 km. It lies at about 20°S latitude. It is unknown why the spot is the color it is. It rotates counterclockwise in about 6 days. There are many storms smaller than the Great Red Spot that occur as well. On the dark side of Jupiter we have seen what appears to be lightning. Also on Jupiter we have seen small white ovals that have appeared and disappeared. There has also been a brown oval that only appears at 20°N latitude. We don't know why. These spots can exist for years or decades.

Internal Structure

At its distance from the Sun astronomers thought that the temperature at the cloud tops should be about 105K, but when we got there we found the temperature to be about 125K. This means that Jupiter releases about 2 times as much energy as it receives. Where does the extra energy come from? It is thought to be coming from the escape of gravitational energy or in other words, the energy of contraction. As the planet contracted, the molecules bumped into each other causing friction and producing heat. It is that heat that is slowly leaking out through the atmosphere. It has been calculated that Jupiter loses a millionth of a K per year.

Jupiter's clouds are probably only about 200 km thick. Below them the temperature and pressure increases. We have very little evidence about the interior of Jupiter. But since it is made up of hydrogen and helium, 2 gases that we understand well, we believe that our model of the interior is accurate.

As you deeper inside Jupiter, the gas becomes more compressed. At a depth of a few thousand km the gas slowly becomes a liquid. Below about 20,000 km the pressure is thought to be about 3 million times the Earths pressure. Here the liquid hydrogen is compressed so much that it takes on the properties of being a metal. This is called liquid metallic hydrogen. This is why Jupiter has such a large magnetic field.

Since the Galileo spacecraft went to Jupiter we now believe that the core in Jupiter may be as small as 5 times the mass of the Earth. It is believed to be a rocky core, one that is similar for all of the Jovian planets. The pressure at the center of Jupiter is about 50 million times greater than Earths. The core must be extremely dense. It is thought to be 20,000 km in diameter and have a temperature of about 40,000 K.

Jupiter's Magnetosphere

Fro years we knew that Jupiter had a magnetic field, but it wasn't until Voyager and Galileo did we realize just how large it was. Jupiter is surrounded by a large number of charged particles, mainly electrons and protons. The radiation that we could detect on the Earth was due to the particles being accelerated to high speeds- near the speed of light- by the magnetic field. The radiation is several thousand times more intense than produced by the Earth's magnetic field. This means that spacecraft we put into orbit around Jupiter needs to be protected from the particles. The magnetosphere is about 30 million km across (remember the Earth's magnetosphere is about 120,000 km across). The size and shape of the magnetosphere is determined by the solar wind. Just like on the Earth, Jupiter's magnetic field can cause aurora on Jupiter. The axis of the magnetic field is 10° off from the rotational axis. Observations have determined that it is probably 20,000 times stronger than the Earths magnetic field.

The Moons of Jupiter

The number of moons around Jupiter stands at 61 as of early 2004. Give it time. We are finding small moons still, but now comes in the problem of how small you call it a moon. The Voyager spacecraft discovered 3 of the 4 small moons that lie closer than Io does. The largest is only 300 km across. Then you come to the Galilean moons and just beyond them you see 8 small moons, 4 of which move in eccentric, inclined orbits and the other 4 have orbits that are fairly eccentric, but orbit in a retrograde motion. These are all thought to be captured bodies. They were probably from 2 objects that broke up due to Jupiter's gravity into 4 pieces each.

The Galilean Moons as a Model of the Solar System

The Galilean Moons are very similar to the terrestrial planets. The orbits are roughly circular and lie close to the equatorial plane. Their sizes range from just smaller than our Moon to larger than Mercury. Like the inner solar system, the densities decrease as you move away from Jupiter. Many scientists think that the Galilean moon system may have mimicked the formation of the solar system. This could give us valuable insights to the formation of our solar system.

Io: the Most Active Moon

Io is the most active moon in the solar system. It is similar in size and mass as our Moon, but that's where it ends. Io has active volcanoes. There have been over 80 active volcanoes identified on Io. The largest is Loki which is bigger than Maryland and emits more energy than all of the volcanoes on Earth. The lava at some volcanoes have temperatures of 2000 K which makes it hotter than any volcano on Earth. The orange color you see on Io is due to the sulfur compounds in the ejecta. Except for the volcanoes, there really isn't any other features because they have been filled in by the lava.

The volcanoes on Io affect the magnetosphere of Jupiter. Io is releasing many charged particles and they are being trapped by the magnetosphere. The particles are swept up and accelerated. This gives rise to the *Io plasma torus*. Studies of the torus show that sulfur is a major part of the torus. This torus would be lethal to humans. Why is a world as small as Io so active? There are tremendous tidal forces tugging at Io. Jupiter pulls on Io while the other 3 Galilean Moons tug on Io in the opposite direction, The inside of Io is being pulled and tugged by gravity which makes the inside of Io extremely hot. Because of this the inside of Io remains hot constantly so that you have volcanoes erupting constantly. This means that the surface of Io is the youngest surface in the solar system.

Europa: Liquid Water Locked in Ice

Europa is very different from Io. Io is a volcanic world while Europa is covered in ice. There are very few craters on Europa which suggests that some sort of geologic activity has taken place. This means that the surface is probably only a few million years old.

There are lines that run across the surface of Europa that resemble pressure ridges that develop in the ice floes at the Earth's poles. It is thought that Europa has an ocean that is covered by a thin layer of ice. It is due to the tidal forces of Jupiter and the other Galilean moons that these cracks have formed. The ice layer is thought to be several kilometers thick and the ocean may be 100 km thick. There are many areas that show what looks to be localized flooding of the region. The moon has been found to have a small magnetic field. It apparently has developed because the magnetic field produced by Jupiter is acting on an electrically conducting fluid about 100 km under the ice- specifically the salty layer of liquid water. This causes the field to change strength and direction. The possibly of liquid water brings up the possibility of life on Europa. The Earth is the only world that we know of that has liquid water. If Europa has liquid water it may have more water than the Earth! But remember that it is still a very hostile environment compared to the Earth.

Ganymeade and Callisto: Fraternal Twins

The last 2 Galilean moons are Ganymeade and Callisto. Their density is only about 2000 kg/m^3. This says that they must contain a significant amount of ice. Ganymeade is the largest moon in the solar system. It is even bigger than Mercury and Pluto. It has many craters and areas of light and dark just like on the Moon. The dark areas are the oldest parts of Ganymeade. It is covered by micrometeorite dust which darkens the surface. The light areas are much younger. These areas may have formed when intense meteoric activity caused liquid water to well up from below and flood the area. There are grooves and cracks that appear to be some type of tectonic activity, much as Earth's surface undergoes mountain building and faulting at plate boundaries. Ganymeade appears to have had plate tectonics early in its history, ending abut 3 billion years ago. The Galileo spacecraft in 1996 detected a weak magnetic field around Ganymeade. This implies that Ganymeade has a modest iron rich core. The magnetic field is about 1% of the Earth's. In 2000 the field was seen to show fluctuations just like Europa, so maybe Ganymeade has a layer of slushy water under its surface.

Callisto is similar to Ganymeade in appearance. It has 2 large basins, the largest of which is 3000 km across. Callisto apparently froze before any plate tectonics occurred. Callisto's surface is probably about 4 billion years old, making it the oldest of the 4 Galilean moons. There are hints from Galileo's magnetometers that there may be a thin layer of water or slush deep below the surface. Unlike Ganymeade that was differentiated in the past, Callisto has not differentiated. Scientists are uncertain why 2 such similar bodies have evolved so differently. It is thought the heating and melting on Ganymeade occurred in the last billion years since it may still be slightly warm inside. Ganymeade may have been much closer to Jupiter and the tidal forces heated the insides. What happened? One idea is that Ganymeade's orbit has changed due to interactions with the other moons about a billion years ago. This would explain why it is still warm.

Jupiter's Rings

In 1979 Voyager discovered that Jupiter has a series of faint rings around it. They lie about 50,000 km above the planet. The rings are perpendicular to the equatorial plane of Jupiter. The rings are dark and may be due to pieces chipped of 2 small moons that are nearby.