Chapter 12 Saturn

Orbital and Physical Properties

Overall Properties

In ancient times, Saturn was the farthest planet that they knew about. In Roman mythology, Saturn was the father of Jupiter. Saturn takes 29.4 years to go around the Sun and it is about 9.5 AU from the Sun. Even though Saturn is the second largest planet behind Jupiter, it only has 1/3rd the mass of Jupiter. Saturn's moons allowed for accurate measurements of the mass. The average density is about 700 kg/m^3 while water is 1000 kg/m^3. That means that it would float in water. It is composed of hydrogen and helium just like Jupiter.

Rotation Rate

Saturn rotates quite rapidly, just like Jupiter. The rotational; period is 10 hours 40 minutes. Because of the lower density than Jupiter it means that Saturn is more flattened than Jupiter is. Saturn's equatorial radius is about 60,000 km while the polar radius is only 54,000 km. From all of this it has been calculated that Saturn has a rocky core about 15 times the mass of the Earth.

Rings

The most obvious feature of Saturn are the rings. Because of their position at the equator of Saturn, the rings appear to flatten out as the angle of the tilt changes over time as seen by us. When this happens the rings simple disappear from sight.

Saturn's Atmosphere

Saturn is much less colorful than Jupiter. It is mainly yellows and browns, or as some say butterscotch. Saturn doesn't appear to have any of the storms or ovals like Jupiter has.

Color and Composition

Methane was discovered on Saturn in the 1930's by reflected light, but it wasn't until the 1960's when better instruments were available that we detected ammonia. In the upper atmosphere the ammonia is in the solid form with very little gas. We also determined the hydrogen and helium content of Saturn. The atmosphere is molecular hydrogen (92.4%), helium (7.4%), methane (.2%) and ammonia (.02%). The hydrogen and helium are there because of the low temperatures and high gravity. But the amount of helium is much less than what is found on Jupiter. Why? It is thought that in the past that the helium started to settle into the interior of Saturn.

The atmospheric structure is quite similar to Jupiter's except that the temperatures are a little lower than Jupiter. This is due to Saturn's distance from the Sun and because it's clouds are thicker. Like Jupiter, when we look at Saturn's atmosphere, we set the troposphere to 0km. The tops of the clouds that we see lies about 50 km below the troposphere. Above the clouds lies a layer of haze formed by the action of the sunlight with the upper atmosphere. The cloud layers in Saturn is much thicker that the cloud layers in Jupiter because of the weaker gravity on Saturn. It doesn't compress them like on Jupiter. Because of the thicker clouds on Saturn, we can't see into the interior and see the colorful layers that we can see on Jupiter.

Weather

Saturn has a wind pattern very similar to Jupiter. The flow is east-west and apparently quite stable. If we enhance the image of Saturn we bring out the detail of the clouds on Saturn as well as oval storms and turbulent patterns. Like Jupiter it is thought that these bands and storms are caused by convective motion in Saturn's interior and rapid rotation. The movement is similar to Jupiter only much faster. On Jupiter the equatorial band moves at 400 km/hr while on Saturn it moves at 1500 km/hr. This flow is eastward and not until 40° N and 40° S do we find westward moving bands. In September 1990 an amateur astronomer discovered a large white spot on Saturn. By November when they imaged the planet with the Hubble Space Telescope the spot had developed into a band of clouds encircling the planet. It was thought that this was a case where an upwelling of warm material pushed through the cooler clouds. It was probably ammonia ice. WE have seen spots and storms every so often. Before 1990 the last one was in 1933. Scientists think that these are long lived storm systems and keep watching to learn more about the interior of Saturn.

Saturn's Interior and Magnetosphere: Interior Structure and Internal Heating

Saturn and Jupiter have the same basic internal structure just not in the same proportion. Saturn's layer of metallic hydrogen is thinner but it has a core that is larger than Jupiter. The internal pressure of Saturn would be very similar to the pressure at the center of the Earth. Saturn radiates about 3 times more energy than it receives. So just like Jupiter it has an internal heat source. The mode of producing the energy is not the same as Jupiter though. Jupiter is the leftover heat from the formation while Saturn is too small to have kept that heat. So what causes it? The explanation also explains why Saturn seems to be deficient in helium. In Jupiter the helium dissolves into hydrogen due to the extreme heat and pressure. In Saturn the temperature is lower and the helium doesn't dissolve. It eventually condenses out and falls like rain into the interior. As it does, it is compressed and it heats up. Thus the energy is gravitational energy from the falling helium.

Magnetospheric Activity

Saturn has a strong magnetosphere due to the liquid metallic hydrogen and the rapid rotation. Due to the hydrogen layer being smaller it is only about $1/20^{th}$ of Jupiter's magnetic field or about 1000 x greater than ours. The magnetic field at the cloud tops is roughly the same as at the Earth's surface. The magnetic field of Saturn is not inclined with respect to axis of rotation. Like Jupiter the magnetic field is oriented opposite the Earths—a compass would point towards the South Pole.

The magnetosphere extends out about 1 million km. The moon Titan lies at 1.2 million km from Saturn, so it lies just outside and sometimes inside the magnetosphere depending on the distortions caused by the solar wind. Saturn also emits radio waves, but as luck would have it they are in the AM band and reflected by the ionosphere. They were discovered by Voyager.

Saturn's Spectacular Ring System

The View from Earth

When looking at Saturn, the most obvious feature is the ring system. All of the Jovian planets have rings, but none are as spectacular as Saturn's rings. Galileo saw them in 1610, but he thought that it was some kind of triple planet or something. By 1616 Galileo realized that they were not round, but rather elongated. In 1655 Christian Huygens realized that what it was was a thin, flat ring encircling the planet. In 1675 Giovanni Cassini discovered the first ring feature: a dark band about 2/3rds of the way out from the inner edge. From Earth this band looks like a gap in the material. It is called the Cassini division. There were 3 rings seen from Earth called the A, B, and C rings. In the A ring you will find a narrow gap called the Enke gap which is just like the Cassini division. The B ring is the brightest that we can see.

What are Saturn's Rings?

An obvious question was what are the rings made of? There were many ideas, but in 1857 James Clerk Maxwell concluded that the rings couldn't be solid or else they would break up. Therefore the rings must be made up of small particles that are in orbit around Saturn. This was verified in 1895 at Lick observatory by doing a Doppler shift on the particles. What are the particles made up of? Since they reflect most of the light that strikes them (80%), many astronomers thought that they were made of ice. It was later confirmed that ice was a main part of the rings. Radar and Voyager showed that the particles are pieces between fractions of a millimeter to boulders that are 10's of meters across with most particles being the same size and composition as a snowball on Earth. The rings are thin, a few tens of meters in places. Why? Apparently the collisions between ring particles keep them moving in circular orbits. If they move out of their orbit they end up in another part of the ring and have collisions there and are put into orbit there.

Roche Limit

Why do we have a ring of particles? As a moon comes closer to the planet it starts to be stretched by the planets gravity. A bulge forms. As it gets closer still, eventually the force of gravity of the planet overcomes the force that is holding the moon together and it is torn apart. When that happens, each particle finds its own orbit, eventually spreading out around the planet. That critical distance away from the planet where it will be torn apart is called the *tidal stability limit* or the *Roche limit*. A rule of thumb is if the moon is held together by its own gravity and its composition is similar to the parent planet, then the critical distance is 2.4 times the radius of the planet. That means that no moon could survive within a distance of 144,000 km of the center of Saturn. Small moons can survive inside the Roche limit because they are held together by interatomic forces, not gravity.

The View from Voyager

When Voyager approached Saturn, it became obvious that the main rings were composed of thousands of individual *ringlets*. Apparently the mutual gravity of the particles allows the particles to form waves of matter that move in the plane of the rings. This would be like ripples on the surface of a pond. The wave crests wrap around the rings, called a *spiral density wave*, much like the groove on a record. There are about 20 gaps in the rings and these are most likely swept clear by small moonlets that are imbedded in the rings. They simply sweep up material found in the rings through collisions as they go. One of the unusual features on the rings was a series of spokes. It was very small particles that were held above the rings by electrostatic forces caused by collisions. Eventually the charge wore off and the particles dispersed.

Orbital Resonance and Shepherd Moons

The Cassini division is the result of *orbital resonances*. This is between the particles and the moon Mimas. If a particle is in the Cassini division, then it is in a 2:1 resonance with Mimas. That means that the particles receive a gravitational tug at exactly the same point in its orbit every 2 orbits. These tugs will add up The orbit becomes an ellipse which puts it into another ring where you have collisions and it ends up in a circular orbit in that ring. Mimas and other moon tug on non-resonance particles but the tug is spread out throughout the orbit, so there is no real change in their orbit.

Outside the A ring you will find the F ring. Pioneer first saw it then Voyager studied it more closely. It is a thin ring which appears to be made up of several braided rings. This caused quite a stir about how this could be. It is now thought that the structure is due to the 2 shepherd moons that lie on each side of the ring. This explains why the ring is there, but not why it has a braided look.

The Origin of the Rings

There are 2 scenarios as to where the rings came from. One theory is that it was a moon that was inside the Roche limit. It has been calculated that the material in the rings could make up a moon about 250 km across and that it got torn apart. The other theory is that the rings are material that is left over from the formation of the outer solar system and that it never accreted into a moon. It has been suggested that the rings are very young, maybe only 50 million years old, and a ring system like this couldn't have remained stable for billions of years. So it seems that the idea of a moon being destroyed is the current winner.

The Moons of Saturn

General Features

The moons of Saturn are the most complex and extensive system of natural satellites in the solar system. Most are covered with ice, probably water ice. They are very curious and scientists eagerly await the Cassini data. They fall into 3 basic groups. There are the small moons, less than 400 km across. They are irregularly shaped and have fascinating orbits. There are 6 medium sized moons that range from 400 to 1500 km in diameter. They offer clues to the past and present state of the environment. Finally we have 1 large moon, Titan which is 5150 km across. Titan has an atmosphere that is 1.5 times thicker than the Earth's atmosphere. Jupiter has no medium sized moons. The Hubble Space Telescope in 1995 discovered 2 more moon of Saturn. Since then other observatories have discovered more bringing the total to 31 moons. These moons are similar to Jupiter's small outer moons.

Titan

Titan was discovered in 1655. Using spectroscopic data we knew that Titan had an atmosphere. Voyager 1 was programmed to pass close to Titan even though it meant that Saturn could not be used to go to Uranus and Neptune. It is thought that Titan has an internal composition and structure similar to Ganymeade and Callisto. In 2005 Cassini will release a probe and lander to land on Titan to study the atmosphere and gravitational pull of the moon. The moon is covered in a haze that we can't see through. The atmosphere is mainly nitrogen (90%) and argon (~10 %) with a small amount of methane. Titan's atmosphere is a chemistry lab, making new compounds in the atmosphere with the energy from the Sun. In 2003 it was discovered that Titan may have liquid lakes of hydrocarbons. Regardless of the moon's size the pressure on Titan is probably 60 % higher than on Earth. The top of the haze layer lies about 200 km above the surface of Titan. Below the haze it is clear, but gloomy since the haze block the sunlight. The surface temperature is about 94 K which is chilly. At those temperatures you would find that methane and ethane would be like water on Titan. The reason Titan has an atmosphere is because of its distance from the Sun. The colder temperature enhanced the ability of the water ice to absorb methane and ammonia.

Saturn's Medium Sized Moons

All 6 of these moons were known from Earth observation. The inner 5 moons all have synchronous rotation (like our Moon) and move on circular trajectories. These 6 moons have a density of between 1000 – 1400 kg/m^3. They are thought to be composed mainly of rock and water ice. The largest is Rhea which has $1/30^{th}$ of the Moons mass and is covered in ice. This ice is so hard that it acts like rock which is why the craters on Rhea look like those on the Moon. The only riddle is the *wispy streaks* found on the surface. One idea is that it may be water released from the interior that was laid down on the surface. One of the moons is Enceladus, which lies just beyond Mimas, is quite reflective. In fact it reflects almost 100 % of the light striking it. It is thought that it is covered in small ice crystals. There are very few craters so it must have been resurfaced in the near past. There is strong circumstantial evidence for volcanism on Enceladus. No one can explain why a small moon like this has so much activity.

The Small Satellites

The dozen or so small satellites of Saturn are probably similar to Jupiter's moons. Only 2 were discovered in the 19^{th} century and the rest were discovered in the second half of the 20^{th} century. Just beyond the F ring there are 2 satellites that are *co-orbital satellites*. Janus and Epimetheus are 2 satellites that share an orbit. At any moment they are in circular orbits around Saturn. Once every 4 years the inner moon overtakes the outer moon. As the inner one gets close enough the outer moon feels the gravity of the inner one and visa versa. They switch orbits at this point. The inner moon pulls away from the outer one. Two small moons, Telesto and Calypso, are in orbit in front of and behind the moon Tethys. They are found at an angle of 60° in front of and behind Tethys. These points are called the Lagrangian point.

One other moon that is different is Hyperion. It is between Titan and Iapetus. The tug of Titan means that Hyperion doesn't have synchronous rotation. Rather it has *chaotic rotation* which means that it changes its rotation and its axis of rotation. It tumbles randomly, never repeating itself.