Jupiter and Saturn

- Observations from Earth
- Different rotation
- Storms on Jupiter and Saturn
- Internal heat
- Jupiter's atmosphere
- Cores of Jupiter and Saturn
- Metallic Hydrogen & Magnetic fields
- Saturn's rings
- Makeup of Saturn's rings
- Intricate structure of the rings
- Small moons affected the rings

http://physics.wm.edu/~hancock/171/
Jupiter is the largest planet in the Solar system.

**TABLE 12-1** Jupiter Data

- Average distance from the Sun: 5.203 AU = 7.783 × 10^8 km
- Maximum distance from the Sun: 5.455 AU = 8.160 × 10^8 km
- Minimum distance from the Sun: 4.950 AU = 7.406 × 10^8 km
- Eccentricity of orbit: 0.048
- Average orbital speed: 13.1 km/s
- Orbital period: 11.86 years
- Rotation period: 9h 50m 28s (equatorial)
  - 9h 55m 29s (internal)
- Inclination of equator to orbit: 3.12°
- Inclination of orbit to ecliptic: 1.30°
- Diameter: 142,984 km = 11.209 Earth diameters (equatorial)
  - 133,708 km = 10.482 Earth diameters (polar)
- Mass: 1.899 × 10^27 kg = 317.8 Earth masses
- Average density: 1326 kg/m³
- Escape speed: 60.2 km/s
- Surface gravity (Earth = 1): 2.36
- Albedo: 0.44
- Average temperature at cloudtops: -108°C = -162°F = 165 K
- Atmosphere composition: 86.2% hydrogen (H₂), 13.6% helium (He), 0.2% methane (CH₄), ammonia (NH₃), water vapor (H₂O), and other gases

*Table 12-1*
*Universe*, Tenth Edition
© 2014 W. H. Freeman and Company
Saturn

**TABLE 12-2  Saturn Data**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average distance from the Sun</td>
<td>$9.572\text{ AU } = 1.432 \times 10^9\text{ km}$</td>
</tr>
<tr>
<td>Maximum distance from the Sun</td>
<td>$10.081\text{ AU } = 1.508 \times 10^9\text{ km}$</td>
</tr>
<tr>
<td>Minimum distance from the Sun</td>
<td>$9.063\text{ AU } = 1.356 \times 10^9\text{ km}$</td>
</tr>
<tr>
<td>Eccentricity of orbit</td>
<td>0.053</td>
</tr>
<tr>
<td>Average orbital speed</td>
<td>9.64 km/s</td>
</tr>
<tr>
<td>Orbital period</td>
<td>29.37 years</td>
</tr>
<tr>
<td>Rotation period</td>
<td>$10^\text{h }13^\text{m }59^\text{s}$ (equatorial) $10^\text{h }39^\text{m }25^\text{s}$ (internal)</td>
</tr>
<tr>
<td>Inclination of equator to orbit</td>
<td>26.73°</td>
</tr>
<tr>
<td>Inclination of orbit to ecliptic</td>
<td>2.48°</td>
</tr>
<tr>
<td>Diameter</td>
<td>120,536 km = 9.449 Earth diameters (equatorial) 108,728 km = 8.523 Earth diameters (polar)</td>
</tr>
<tr>
<td>Mass</td>
<td>$5.685 \times 10^{26}\text{ kg } = 95.16\text{ Earth masses}$</td>
</tr>
<tr>
<td>Average density</td>
<td>687 kg/m³</td>
</tr>
<tr>
<td>Escape speed</td>
<td>35.5 km/s</td>
</tr>
<tr>
<td>Surface gravity (Earth = 1)</td>
<td>0.92</td>
</tr>
<tr>
<td>Albedo</td>
<td>0.46</td>
</tr>
<tr>
<td>Average temperature at cloudtops</td>
<td>$-180^\circ\text{C } = -292^\circ\text{F } = 93\text{ K}$</td>
</tr>
<tr>
<td>Atmosphere composition (by number of molecules)</td>
<td>96.3% hydrogen ($\text{H}_2$), 3.3% helium ($\text{He}$), 0.4%, methane ($\text{CH}_4$), ammonia ($\text{NH}_3$), water vapor ($\text{H}_2\text{O}$), and other gases</td>
</tr>
</tbody>
</table>

Table 12-2
*Universe, Tenth Edition*
© 2014 W. H. Freeman and Company

Saturn is the second largest planet in the solar system
Jupiter and Saturn from Earth

Jupiter is a superior planet that orbits the Sun \(\sim 12\) years. It is the brightest object in the night sky except for the Moon and Venus. Jupiter is 318 more massive than the Earth.

Saturn is also a superior planet with a period of \(\sim 29\) years. It is about \(1/7\) as bright as Jupiter. Saturn is 95 times the mass of Earth. Its most conspicuous feature are its rings.
Both Jupiter and Saturn have light colored areas called zones. The darker colored areas are called belts. The zones and belts on Saturn are much less pronounced.

A notable feature is a giant storm called the 'Great Red Spot' which has persisted for hundred of years. Saturn's rings are its most notable feature.
Differential Rotation

Jupiter and Saturn exhibit differential rotation. Because they are not solid but gas giants different parts of the planet rotate at different rates. On Jupiter the polar regions rotate slower than the equator by about 5 minutes (9 hours, 55 minutes vs 9 hours 50 minutes). On Saturn the polar regions rotate 25 minutes slower than the equator. This is evidence that both planets are not solid like the terrestrial planets but partially fluid.
The compositions of Jupiter and Saturn have been difficult to measure from Earth. Spectroscopy of reflected sunlight does not reveal the lines He and H$_2$ in the UV. Almost all UV is absorbed by the Earth's atmosphere. He and H$_2$ were conclusively detected by spacecraft in the 1970s.

The composition of Jupiter's atmosphere is 86.2% H$_2$, 13.6% He and 0.2% other gases (CH$_4$, NH$_3$, and H$_2$O). In terms of mass Jupiter is 75% H$_2$, 24% He and 1% other gases. This is similar to the Sun's makeup.

Jupiter and Saturn are thought to have a large rocky core made of heavy elements.
Composition of Jupiter and Saturn Atmospheres

The makeup of Saturn's atmosphere is made up of 93.6% H$_2$, 3.3% He and 0.4% other gases. By mass Saturn is composed of 92% H$_2$, 6% He and 1% other. Since Jupiter and Saturn are thought to have formed in the same way from the solar nebula. Why does Saturn have less He than Jupiter?

One idea is that the smaller Saturn cooled more quickly which resulted in the He condensing into droplets (He rain!) and fell deeper into the planet. Jupiter's upper atmosphere was warmer and the He could not condense to a liquid. In this scenario both planets have about the same composition. Saturn is about 1/3 the mass of Jupiter so the gravitation force on Saturn can not compress its H and He. This results is Saturn having the lowest density of all the planets (687 kg/m$^3$)
Pioneer 11 (1974) and the two Voyagers (1979) flew past Jupiter. They showed an active atmosphere. In 1975 the Great Red Spot is completely in a white zone of Jupiter's atmosphere. In 1979, a dark belt has encroached on the Great Red Spot.
In 1995, this Hubble telescope image show the Great Red Spot completely back in a white zone.

The Great Red Spot has been observed from Earth for over 400 years. It has changed in size from 40,000 to 14,000 km. At times it has almost faded away.
The Great Red Spot

The Great Red Spot has been observed from Earth for over 400 years. It has changed in size from 40,000 to 14,000 km. At times it has almost faded away. The Great Red Spot rotates counterclockwise. The winds to the north flow westward while the winds to the south flow eastward. Note the turbulence to the northeast. The clouds of the Great Red spot are at relatively high altitudes surrounded by a collar of very low level clouds.
Another feature of Jupiter's atmosphere are white orals. White ovals rotate counterclockwise like the Great Red Spot. They are thought to be storms like the Great Red Spot. They are a persistent feature with some existing for decades. White ovals are high cold clouds. Most white ovals are in the southern hemisphere.
From 1998-2000 three white ovals merged into one white oval. Each separate oval had existed for 60 years. The merged oval is about ½ the size of the Great Red Spot.
In 2009-2010 a dark belt completely faded away in the southern hemisphere of Jupiter.
Brown Ovals

Brown ovals appear mainly in the northern hemisphere. They are dark in the visible spectrum but appear bright in the infrared, which implies brown orals are holes in the upper cloud layer.

HST, February 1995

Figure 12-4c
Universe, Tenth Edition
Reta Beebe and Amy Simon, New Mexico State University, and NASA
Storms and Patterns on Saturn

The Cassini Saturn orbiter has observed storms on Saturn. While they are not as long lived on Saturn as Jupiter's Great Red Spot, storms on Saturn can last of months.

First Voyager in 1980 and then Cassini observed the hexagon at the north pole of Saturn. The pattern has been reproduced in computer simulations and laboratory experiments.
Internal heat of Jupiter and Saturn

- Jupiter and Saturn emit twice the heat they receive from the Sun!
  - They are possibly still gradually contracting (Jupiter)
  - Or differentiating (helium sinking in Saturn) and converting gravitational energy to thermal energy
Fast Winds

The rapid rotation and outflow of heat on Jupiter and Saturn creates global patterns of eastward and westward zonal winds. On Jupiter these winds can exceed 500 km/hr. The winds are strongest at the boundaries between zones and belts.

Saturn rotates about as fast as Jupiter but receives less heat from the Sun and release less heat from its interior. But the winds on Saturn are faster. At the equator of Saturn have been measured at ~1800 km/hr. This is 2/3 the speed of sound in Saturn's atmosphere. These are the fastest winds in the solar system. Why the winds on Saturn are faster than the winds on Jupiter is not completely understood.
Cloud Layers on Jupiter and Saturn

Both planets have three main layers of upper clouds. The top layer is NH$_3$ frozen crystals. The middle layer is NH$_4$SH (ammonium hydrosulfide) formed from NH$_3$ and H$_2$S. The lower level is ice crystals (H$_2$O).

Saturn's cloud layers are 300 km thick while Jupiter's are 75km because of Jupiter's larger gravity.
White clouds form in the middle layer with red at the tops. The Great Red Spot are among the highest clouds on Jupiter. The zones and belts on Jupiter were believed to be regions of rising and descending gases. However, the Cassini flyby of Jupiter has called this into question. Saturn's colors are less visible because they are obscured by high hazy clouds.
Galileo Probe of Jupiter's Atmosphere

In 1995, a probe (separate form the orbiter) entered Jupiter's atmosphere on a parachute. The probe radioed back information about the atmosphere down to 200 km below the cloud tops. The basic findings were:

- The winds were nearly constant at ~ 650 km/hr showing the energy source is internal heating and not solar.
- The probe measured only traces of NH$_3$ and NH$_4$SH and almost no H$_2$O. (It may have entered an warm area with few clouds.)
- The probe found noble (inert) gases Ar, Kr and Xe in amounts three times what is found in the Sun. These elements do not solidify at this distance from the Sun. It is unclear how so much of these noble gases were accumulated in Jupiter's atmosphere.
Rocky Cores of Jupiter and Saturn

Both Jupiter and Saturn are oblate. The diameter through the poles are less than the diameter through the equator. The ratio or oblateness is 6.5% for Jupiter and 9.8% for Saturn. Since both planets rotate so fast, this is not surprising. But models of oblateness suggest both planets have solid highly compressed rocky cores. Jupiter's core is about 8 time the mass of the Earth (2.6% of Jupiter's total mass) but compressed to 11,000 km. Saturn's rocky core is about 10% of Saturn's mass but because of the lower gravity is not compressed as much.
The metallic hydrogen layer (56,000 km thick) in the interior of Jupiter combined with its rapid rotation creates an enormous magnetic field and magnetosphere. The magnetic field of Jupiter is 20,000 times the Earth's magnetic field.

Regions analogous to Earth's Van Allen belts trap ions. Io's is within this region. Io has volcanoes which eject tons of material which form ion. Europa also contributes a belt of ions around Jupiter.
Saturn also rotates rapidly and has a metallic hydrogen shell although not as large as Jupiter's. Saturn also has a magnetosphere but the number of trapped ions is small. There are no moons like Io or Europa to provide the ions and the ions that do get trapped are absorbed by the rings.

The trapped ions on Jupiter (upper image) create circular aurora near the poles of the planet. Even with few trapped ions, Saturn (lower image) also has aurora near the poles of the planets.
Galileo first observed 'lumps' on the sides of Saturn that are now known to be the rings of Saturn. Huygens later identified the 'lumps' as a thin flattened ring. In 1675, Cassini discovered a gap in the rings system know as the 'Cassini division'.
The rings of Saturn are around its equator. Because of the 27° tilt of Saturn's axis of rotation to its orbital plane, we see both the top and bottom of the rings from Earth at different times.
Saturn's Rings

James Maxwell showed theoretically in 1857 the rings could not be solid because of the varying pull of Saturn's gravity. In 1895, Keeler measured the Doppler shift of the approaching and receding edges of the ring. The result was in agreement with Kepler's laws. The rings are made of small particles each circling Saturn.

The rings are highly reflective (80% compared to Saturn itself at 46%). The rings are made mainly of water ice particles at -180°C to -200°C. Spacecraft radio beam passing through the rings show the particles range in size from 1 cm to 5 m. The amount of material in Saturn's rings is quite small. Collected together, the rings would make a moon only 100 km in diameter.
The Roche limit is a radius around a planet where tidal forces will break up a gravitationally bound together satellite or moon. It does not break up rocks and particles that are chemically bound together. Particles closer to the planet orbit faster by Kepler's law than particles that are further from the planet.
The Roche limit is about 2.4 times the radius of the planet. All of the outer planets have ring systems. Voyager discovered rings around Jupiter but they are composed of small particles (1 μm) and reflect on average 5% of the light. The amount of material in Jupiter's rings is only $10^{-5}$ of the material in Saturn's rings.
Pioneer 11, Voyager 1 & 2 all flew by Saturn. Cassini went into orbit around Saturn in 2004. Pioneer 11 discovered the F ring. The Voyager images showed the broad A, B and C were not uniform but consisted of hundreds of closely spaced bands or ringlets.
Images from the Cassini orbiter showed that the Cassini division is not empty but contains tiny dust sized particles. The lower image show the true color of the rings. The main components of the rings are ice but trace amounts of other chemical are probably responsible for the different colors.
Only the A, B and C rings are visible from Earth. Spacecraft flybys have discovered the D, E and G rings. Note the location of the smaller moons that orbit Saturn.
Spacecraft Views of Saturn's Rings

The image from Cassini as Saturn eclipsed the Sun show the G and E rings.
When one orbiting object has twice the period as another (or some ratio of small integers) a **orbital resonance** exist. The maximum amount of energy can be transferred with an orbital resonance. One of Saturn's moon (Mimas) orbits with a period of 22.6 hours. According to Kepler's law, any particles in the Cassini division would have a period of 11.3 hours. Every 22.6 hours the particle in the Cassini division would find itself between Mimas and Saturn. Because of the resonant orbit of the particle, it would be sweep out of the Casaini division.
Other moons can herd particles together. Pandora moves around Saturn slower than particles in the F ring. As the particles move past Pandora they experience a small gravitational tug and lose a little energy sending them closer to Saturn. Prometheus orbits faster and gives the particles a gravitational pull that speeds them up into a slightly larger orbit. The two moons together 'shepherd' the F ring into a narrow band.
In 2005 the Cassini spacecraft found a small moon (Daphnis) orbiting in a small gap in the A ring. The 'shepherd' moon effect creates the Keeler gap. Daphnis is only 7 km in diameter be maintains a gap that is 42 km. The moon Pan maintains the 270 km Encke gap although Pan in only 20 km in diameter.