

## Jovian Planet Systems (Chapter 11)

Jupiter and Saturn are mostly hydrogen, with layers of gas, liquid, and metallic hydrogen above a small rock/ice (water, methane, ammonia) core. Uranus and Neptune have a thinner outer layer of hydrogen gas, a thick ice mantle, and a core. All four planets contain about 10 Earth masses of ice, rock, and metal. The nebular theory of solar system formation can explain why Jupiter is heavier than Saturn, and Saturn heavier than Uranus/Neptune. Jupiter and Saturn have similar chemical compositions, yet Jupiter is much denser. Jupiter's greater mass makes its internal pressure greater, which compresses its hydrogen/helium making it more dense. Jovian planets rotate rapidly, which makes them bulge out at the equator. Their rotations are measured using their magnetic fields. Jupiter, Saturn, and Neptune emit more heat than they receive from the Sun, but Uranus does not. Internal heat sources for Jupiter and Saturn are known, but not for Neptune. Nor is it clear why Uranus and Neptune are different.

Jupiter has three cloud layers, an upper layer of ammonia, an intermediate layer of a compound of ammonia and water, and a lower layer of water. The causes of its colours are unclear. Saturn has similar cloud layers to Jupiter. The blue appearances of Uranus and Neptune are caused by methane clouds. The rapid rotation of jovian planets splits their convection cells into many narrow bands, where air alternately rises and falls. Storms such as the Great Red Spot are also common. All four jovian planets have magnetic fields. Jupiter's and Saturn's are generated within their layer of metallic hydrogen, which can flow like a liquid and conduct electricity like a metal. Those of Uranus and Neptune, which are not parallel to their rotational axes, are generated within their thick layer of water, methane, and ammonia.

All jovian planets have many moons, typically 50% ice and 50% rock, unlike the rock/metal composition of the terrestrial planets. Most large moons have well-behaved orbits and rotations, just like the planets orbiting the Sun, suggesting that large moons of jovian planets formed in mini-nebulas around their planet. Large moons (>1500 km diameter) are geologically active. Jupiter has four large moons, Io, Europa, Ganymede, and Callisto. Io, which is squeezed and heated by Jupiter's tides, has active volcanoes. Europa has a liquid water ocean beneath a crust of water ice. Saturn has one large moon, Titan, which has a thick nitrogen atmosphere with methane clouds and lots of chemical interactions between the surface and atmosphere. Neptune has one large moon, Triton, that was probably captured by Neptune. Medium-sized moons generally show evidence of past geological activity, but have now lost most of their interior heat. Icy moons are more geologically active than rocky bodies of the same size because ice deforms, flows, and melts at lower temperatures than rock does. Many icy moons are also tidally heated.

Jovian planet rings are <100 m wide and contain many metre-sized and smaller pieces of ice. Ring particles have circular orbits in the planet's equatorial plane. Gravitational interactions with nearby small moons, more distant large moons, and between ring particles create intricate patterns in the rings. Ring particles are destroyed over millions of years, so rings need a steady source of fresh ring particles. Impacts onto the planet's small moons continually blast fragments into space to replenish the rings.