

Formation of the Solar System (Chapter 8)

The formation of the solar system began 4.5 billions years ago when a cloud of gas collapsed inwards due to its own gravitational attraction. Conservation of energy and angular momentum heated the cloud and made it spin faster. Collisions between particles flattened the spherical cloud into a flat disk. Mass was concentrated at the centre of the disk, where temperatures were hottest. Young stars are often observed in clouds of gas and hot disks of gas, giving support for this nebular theory of solar system formation.

The nebula was mostly hydrogen and helium. Ice-forming elements, oxygen, carbon, and nitrogen, which form water, methane, and ammonia when they combine with hydrogen, were the next abundant. Rock-forming elements and metals were far less abundant. Colliding atoms are more likely to stick together to form molecules, and colliding molecules are more likely to stick together to form solid particles, if the temperature is low. Only metals and rock could condense close to the Sun. Beyond a line somewhere between the present orbits of Mars and Jupiter, ices could condense as well. This “frost line” was responsible for the division between terrestrial and jovian planets.

Specks of metal, rock, and ice became planets through a two-step process called accretion. Inside the frost line, small specks collide gently, then stick together due to static electricity, eventually becoming boulder-sized. Gravity is not important in this first step. Gravitational forces between large boulders alter their orbits, making collisional speeds faster. Small boulders shatter easily during collisions, whereas larger ones do not. Series of collisions cause large boulders to grow in size very rapidly, so a small number of boulders become much larger than the average size, eventually consuming all the other boulders and becoming terrestrial planets. The same process occurs beyond the frost-line, but the baby planets become larger here due to the vast amounts of condensed ices. They become large enough to capture gas from the nebula, forming their own mini-nebulas and eventually forming the jovian planets. Moons around the jovian planets were formed in the mini-nebula just like the planets formed in the nebula around the Sun.

When the Sun first grew large enough to start shining, it had a very strong wind of protons and electrons blowing off it. This wind swept the remaining gas out of the solar system, stopping the growth of the jovian planets. Asteroids are leftover rock planetesimals that Jupiter’s gravity prevented from accreting into a planet. Icy planetesimals that formed beyond Neptune’s orbit remain there today as the Kuiper Belt. Icy planetesimals that formed between Jupiter and Neptune were scattered in all directions by Jupiter’s gravity, forming the Oort Cloud. Comets come from the Kuiper Belt and Oort Cloud. Solar system formation ended with a period of many large impacts, called the heavy bombardment. A giant impact on Earth formed the Moon. Similar giant impacts may also have affected Uranus’s rotation and formed Pluto’s moon, Charon.

Radioactive dating is used to study when these events happened. A radioactive isotope is one that will spontaneously change into another isotope, either by nuclear fission, by a proton and electron merging into a neutron, or some other process. Each radioactive decay process has a characteristic timescale, or half-life.