

Core-Mantle Differentiation in Planets

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Planets have a different elemental composition in their central regions from their outer regions, either because of the way they formed (the least volatile material aggregating to form an embryo and gas accumulating on top,, as is likely for gas giants and ice giants) or because of immiscibility (separation of chemically distinct materials because of thermodynamics, as in terrestrial planets and large icy satellites). The role of gravity is secondary (an often misunderstood point) but it preserves a stable structure (less dense over more dense). A homogeneous mixture (emulsion) of materials of different densities will not form a layered structure (e.g., core and mantle) unless there is mobility. In primarily solid bodies this means at least one component (and often both components) was melted during or after formation. If one volumetrically dominant component stays solid then transport is initially by percolation or cracks. If most everything is liquid (a magma ocean) then rainfall or hail arises. The magma ocean scenario is popular and favored by giant impacts (sudden delivery of accretional energy) but not an obvious physical state. The need for mobility (a liquid) argues for the importance of size unless one can use very early radiogenic heating (Al-26). Later radiogenic heating may not suffice though that depends on the phase diagram (sulfur may help differentiation of a core at low pressure; Ganymede may be an example).

In terrestrial bodies (Mercury, Venus, Earth, Moon, Mars, perhaps Io) the result is a silicate/oxide mantle, usually solid now, and a metallic iron-dominated liquid core, part of which may solidify. In large icy satellites (Ganymede, Callisto, Titan) the separation of ice from "rock" (silicates and iron) may arise during accretion but subsequent separation of metallic iron from the silicates/oxides must have involved radiogenic or tidal heating (and we only know that this happened for sure in Ganymede). Smaller bodies may encounter difficulty differentiating unless tidal heating was large (Enceladus, presumably Mimas) or very volatile rich (Pluto?) Differentiation affects the planetary (including mantle) chemistry, the heat flow, the existence of a magnetic field and rotational dynamics.