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Early metal–silicate differentiation of accreting planetesimals and planetary embryos

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In early Solar System during the runaway growth stage of planetary planetary formation, the distribution of planetary bodies progressively evolved from a large number of planetesimals to a smaller number of objects with a few dominant planetary embryos. Over a few millions years after the condensation of the first solids in the solar nebula, the growing planetesimals were heated by the radioactive decay of now extinct isotopes, in particular ^{26}Al and ^{60}Fe. Another source of heating was provided to the planetary embryos by the deposition of gravitational energy by the impactors as the embryo increased in size. These two sources of thermal energy may have not necessarily overlapped in time for a given body, as the gravitational energy heating only becomes important when a sufficient mass is reached, corresponding to a radius of roughly 1000 km. Both these heat sources were probably sufficient to reach the melting temperature of the metal and possibly even the silicate component, thus generating partially molten regions and fully molten magma oceans. Given the timing of the heating and depending on the accretion rate, there may have been several episodes of melting both at the surface and in the interior regions of a planetesimal, where separation of the heavier metal from the lighter silicates could readily occur. To test these ideas, we develop a simple model of accreting spherical body to study its thermal and dynamic evolution during its growth from a small planetesimal up to a Moon-size planetary embryo. The model includes short-lived radioactivity as well as a parametrization of the impact heating. In partially molten regions the heavier molten iron can separate from the deforming solid silicates by Darcy-type two-phase flow. In completely molten regions a very fast metal–silicate separation is assumed. We present a series of simulations to discuss the effects of the assumed accretion law and the rate of accretion on the final thermal and compositional state of the planetary embryo.