BEHAVIOR OF DUST IN THE SOLAR NEBULA. S.J. Weidenschilling, Planetary Science Institute, Tucson, Arizona 85719.

A solar nebula of mass $\lesssim 0.1M_\odot$ has a gas density distribution $\rho(z) = \rho_0 \exp(-z^2/h^2)$, where z = distance from the central plane, and the "scale height" $h = (\pi r^3/4GM_\odot)^{1/2}\bar{v}$, where r = helocentric distance and $\bar{v}$ = mean thermal velocity of the gas (1). Typically, $h \sim 0.1r$. The initial distribution of dust should be similar. In order for planetesimals to form, the dust must be concentrated in the central plane. Gravitational instability will occur if the dust forms a layer of thickness $\sim 10^{-6}r$ (2).

If particles do not stick together, settling is homologous and essentially all of the dust reaches the central plane at one time. The e-folding time scale $\tau = z/\dot{z}$ is $\sim 10^2/s$ yr at 1 AU ($10^3/s$ yr at 30 AU), where s = particle radius in cm. The presence of <μm-sized grains in meteorites would imply a delay $\sim 10^7$-10^8 yr before planetesimals formed, in the absence of sticking mechanisms.

Coagulation allows more rapid settling. If relative velocities are assumed due only to thermal Brownian motion, settling is homologous, on a time scale $\sim 10^5$-10^6 yr (3). However, for particle sizes larger than a few μm, settling velocities exceed thermal velocities. The z-component of solar gravity produces vertical motion. Also, a radial pressure gradient in the gas causes non-Keplerian rotation of the nebula and radial motion of grains (4). Terminal velocity is proportional to particle size (Epstein drag law). Particles which are initially larger than those surrounding them grow by sweeping up smaller ones, in a process analogous to rain production in terrestrial clouds.

Van der Waals forces appear sufficient to cause sticking. Dahneke (5,6) has developed a model for coagulation of aerosol particles. Sticking occurs if particles collide below a critical relative velocity which depends on their sizes, mechanical properties, and coefficient of restitution. The simultaneous settling and growth of individual particles has been computed by numerical integration. During descent to the central plane, cm-sized aggregates form; their velocities are low enough to allow coagulation by Dahneke's criterion, for reasonable mechanical properties. Radial velocities become too large for van der Waals sticking when particle sizes $\gtrsim$ 1 cm (Figure 1). Further growth may require another mechanism, e.g., mechanical interlocking of aggregates.

Aggregates first reach the central plane in $\sim 10^3$ yr at 1 AU (10^4 yr at 30 AU). These are lower limits on settling times; they are independent of nebular mass, assumed particle density, or initial size. During descent, r decreases by ~10%. Aggregates do not overshoot the central plane. Settling is non-homologous; small particles which are not swept up by descending aggregates remain suspended. The opacity of the nebula can remain high after planetesimal formation. A quantitative settling model requires numerical simulation of growth in a system of competing particles; this effort is currently underway.

Dust fractionation mechanisms involving Coulomb forces (7) are ineffective. The expected equilibrium surface potential of a grain is $\sim kT$. Since settling velocities exceed thermal velocities for sizes >~1μm, any Coulomb barrier to coagulation is easily overcome.

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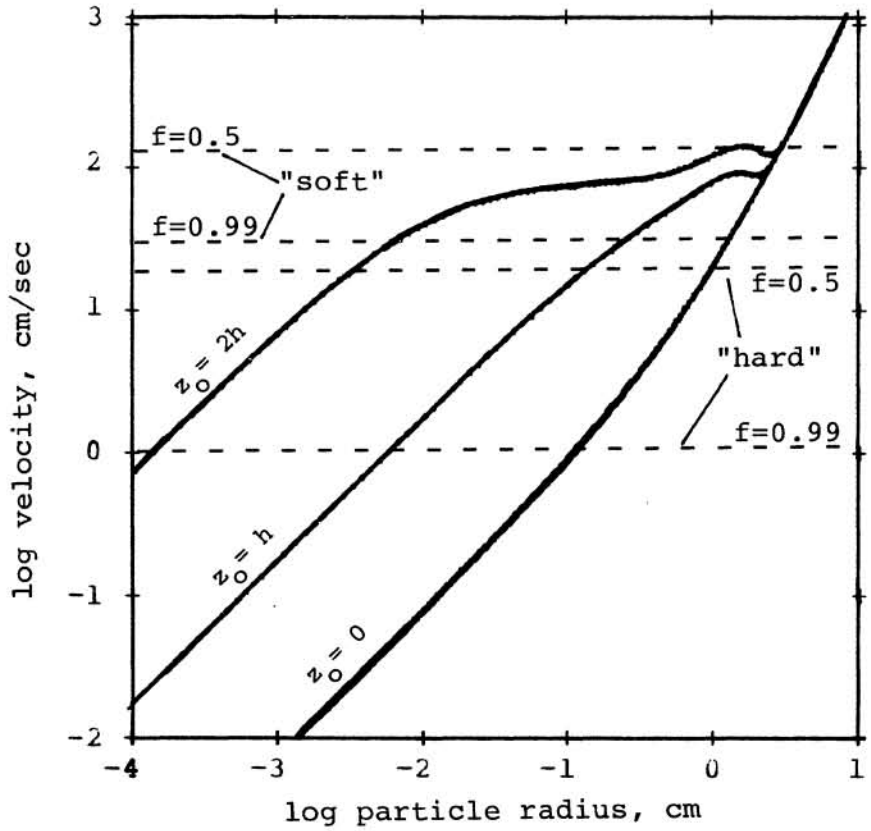

Figure 1: Velocity vs. particle radius for simultaneous settling and growth (solid lines). Nebular mass = 0.5 $M_\odot$; T = 600 K @ 1 AU; h = .07 AU. Initial r = 1 AU, initial z in units of h. Dashed lines: critical velocity for sticking of 1 μm particle to hard surface by van der Waals force. "Hard" material has Young's modulus Y = 5 x 10^{11} dyme cm^{-2}, "soft" has Y = 5 x 10^{10} dyne cm^{-2}; f = coefficient of restitution.