DUST ACCRETION ONTO PLANETESIMALS IN THE SOLAR NEBULA. M. N. Simon[1] and F. J. Ciesla.[2] [1,2]Department of Geophysical Science, The University of Chicago, 5734 S. Ellis Avenue, Chicago, IL 60637 (msimon3@uchicago.edu)

Introduction: Once planetesimals formed in the solar nebula, they would continue to move through the gas-dust suspension on their orbits for up to millions of years until the disk was dissipated. This allows for the possibility that, regardless of how the planetesimals originally formed, they continued to grow in mass by overrunning dust that remained suspended in the solar nebula. This accretion of dust could have an important effect on the subsequent thermal evolution of the planetesimal; in fact, this continued growth is thought to be a necessary to explain the remnant magnetism observed in CV chondrites if due to a core dynamo [1,2].

The extent to which newly formed planetesimals will accrete solids in the nebula, however, remains uncertain. Large particles are likely to be accreted readily by planetesimals, but small particles may be swept around the planetesimal as the gas flows around the body. The exact outcome will depend on a number of factors: the size-distribution of dust in the nebula, the relative velocity of the planetesimal with respect to the nebular gas, the density of the gas, as well as the impact parameter of the encounter. Here we begin to address this issue by creating a model to determine under what conditions particles will be accreted by the planetesimal. We focus on the case in which the potentially accreted particle is much smaller than the planetesimal, such that the planetesimal can be considered to be at rest ($M_{plan} >> m_{particle}$). These findings will help develop an understanding of the mechanism by which planetesimals grow in the early Solar System and what implications that has for the materials accreted onto the planetesimals.

Model Approach: In the absence of gas, the motion of a dust particle in the presence of a planetesimal will be determined by gravity, with the small dust particle constantly accelerating toward the planetesimal until it hits the surface. In the presence of gas, however, the motions of the dust particle become more complicated because of the drag force that develops as a result of the particle moving with a velocity that is different than the gas. This is particularly important as the planetesimal itself will move with some velocity with respect to the gas either due to the gas orbiting at slightly sub-Keplerian rates [3] or because the planetesimals acquire non-zero eccentricities and thus develop radial components to their velocity which the gas does not [4,5].

To quantify how these forces combine to determine the dynamics of the small particle, we consider a planetesimal of radius R_p at rest, centered at the origin of our coordinate system, with the gas flowing around it. Far upstream from the planetesimal (in the x-direction), the gas velocity is undisturbed and flows at a constant speed of U. As the gas approaches the planetesimal, its flow is disturbed in a way that can be calculated [e.g. 6]. As a result, the gas develops some component of velocity perpendicular to its original velocity (y-direction; we assume cylindrical symmetry). For our purposes, we assume steady flow such that the x- and y- velocities of the gas remain constant throughout the time of interest.

We consider the motions of the dust particles released upstream of the planetesimal at some point $(-x_0, y_0)$, with $x_0 >> R_p$. The particle is assumed initially to have the same velocity of the gas with respect to the planetesimal. The acceleration of the particle due to the gravity of the planetesimal and due to gas drag (when non-zero relative velocities exist) in both the x and y directions are then calculated. The new velocity and position of the particle are calculated after a timestep, Δt, and the calculations are repeated until the particle hits the surface of the planetesimal or until the planetesimal passes the x=0 plane.

Results: In the first case that we considered, we explored how the position and velocity of a micron-sized particle changed over one-second intervals as it approached a planetesimal with R_p=100 km embedded in a gas with density 10^{-9} g/cm^3, and moving with a relative velocity of 50 m/s far upstream toward the planetesimal. The particle started 600 km from the planetesimal in the x-direction. We considered various impact parameters for the dust particle by changing its initial y-position from 80 km to 10 km in 10 km intervals, and included an additional case with y_0 = 5 km. The results can be seen in Figure 1 below.

Particles that approach the planetesimal with high impact parameters (y_0>30 km) are swept around the planetesimal by the gas, whereas those with smaller impact parameters are accreted onto the planetesimal (though with greater values of y than the initial value).

In our second trial, we used the same conditions for a centimeter-sized particle, considering the same initial locations as with the micron-sized particles. Due to the larger masses of these particles, and greater inertia, the particles are less affected by the flow of gas around the planetesimal. These particles travel on nearly straight lines, hitting the planetesimal at a y-location very near their initial location.

Discussion: Under the same initial conditions, it is evident that smaller particles are more greatly affected by the motion of the gas around the planetesimal. Micron-sized particles are not accreted by the planetesimal unless their initial position in the y-direction relative to the planetesimal is inward of 30 km. Centimeter-sized particles are accreted by the planetesimal even when their initial position in the y-direction is essentially equivalent to the radius of the planetesimal. This suggests that the accretion efficiency of micron particles is roughly 9%; that is, assuming a uniform distribution of micron-sized grains, less than 1 in 10 will be accreted by a planetesimal under the conditions assumed here. At the same time, centimeter-sized particles will have an accretion efficiency of 100% as any particle that is in the path of the planetesimal will hit its surface.

Additionally, the velocity in the x-direction (*Vx*) calculated for both particles at initial distances of x_0 = 600 km and y_0 = 5 km from the planetesimal varied greatly between the centimeter and micron-sized particles. The micron-sized particle collided with the planetesimal at *Vx* = 15.77 m/s while the centimeter-sized particle collided with the planetesimal at a much faster velocity, *Vx* = 125 m/s (essentially the escape velocity of the planetesimal). The corresponding energy per unit mass for these collisions was $\sim 10^6$ and 8×10^7 erg/g respectively. The micron-sized particle would accrete onto the surface without incident, whereas the specific energy of the larger particle is comparable to its internal strength [7], suggesting it would fragment on impact. Such energetic collisions may pose a challenge for chondritic meteorites with unfragmented chondrules coming from the mantling of pre-existing planetesimals [1,2]. We continue to explore this issue.

In order to acquire a more extensive range of results, we will analyze different parameters that are applicable to the early Solar System, such as how changes in velocity and position vary with different relative velocities between the gas and planetesimals. We will also change the gas densities in the model, and change the particle's initial x and y-distances from the planetesimal to determine the fate of small particles as they are overrun by planetesimals in the solar nebula.

5. References

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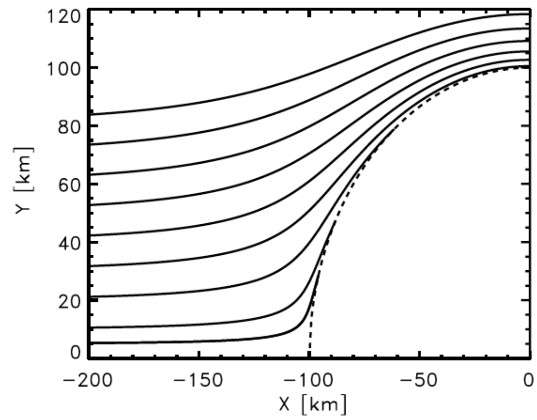

Figure 1: Trajectories of a 1 micron dust particles as they approach a planetesimal in the solar nebula. The semicircular cross section (dashed line) represents the planetesimal. The micron-sized particle is accreted by the planetesimal if the impact parameter is <30 km. Outward of 30 km the particle does not come in contact with the surface of the planetesimal. At a distance of y_0 = 5km, the dust particle collides with the planetesimal at a velocity in the x-direction of 15.77 m/s.

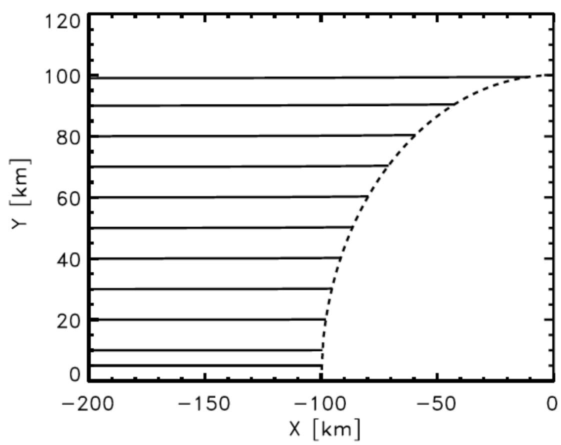

Figure 2: Trajectories of 1 cm dust particles as they approach the same planetesimal in Figure 1. The centimeter sized-particle is accreted by the planetesimal at distances inward of 99 km in the y-direction. This indicates that at any impact parameter <100 km, a particle will be accreted by the planetesimal. At a distance of y_0 = 5 km, the dust particle collides with the planetesimal at a velocity in the x-direction of 125 m/s.