FAST, REPEATABLE CLUMPING OF SOLID PARTICLES IN MICROGRAVITY. S. G. Love[1] and D. R. Pettit[2], [1]Mail Code CB, NASA - Johnson Space Center, 2101 NASA Road 1, Houston, TX 77058; stanley.g.love@nasa.gov; [2]Mail Code CB, NASA - Johnson Space Center, 2101 NASA Road 1, Houston, TX 77058; donald.r.pettit@nasa.gov.

Introduction: A crucial step in planet formation is the growth of solid bodies in the sub-millimeter to meter size range: too large to condense directly from the gas phase and too small to interact meaningfully through mutual gravitation. The existence of planets in our solar system demands that some growth process once operated in that size regime, but the mechanism has not been positively identified. Whatever it was, it worked despite nebular turbulence [1,2] that was probably strong enough to break dust structures cohering by weak surface forces and to disrupt small-scale gravitational collapse via the Goldreich-Ward [3] mechanism. Recent work on this topic, reviewed in [4], has focussed on ice and frost in the laboratory [5, 6, 7], silicate dust in drop-tower and orbital microgravity environments [8, 9, 10, 11], and numerically modelled magnetic particles [12, 13].

Here we present a series of informal experiments carried out in microgravity on board the International Space Station. Despite their simplicity, they illustrate the counterintuitive sticking behavior of solid particles in gas without the influence of gravity. We hope that these results will aid future investigations of small particle agglomeration in protoplanetary nebulae.

Method: The granular solids used in this work were limited to those readily available aboard the Space Station: table salt (NaCl) crystals 0.5-1.0 mm in size, NaCl crystals ~1-6 mm in size, sugar crystals ~1 mm in size, powdered coffee particles ~0.1 mm in size, and mica flakes ~5 μm in diameter. These specific materials are obviously not important in planet formation, but they do represent a crystalline ionic solid, two different organic substances, and a hydrated silicate. A sample of each material, with a mass of a few grams, was placed in an inflated plastic bag of ~ 4 liters volume. Once sealed, the bag was shaken strongly to separate the particles and destroy any pre-existing clumps. The role of air drag in these experiments was probably minor, since the stopping distance of the particles was much larger than the bag. The dielectric container material should have had minimal impact on the electrostatic forces that apparently dominated the observed phenomena. At the same time, the container did affect the experiment by keeping particles confined at high density (~ 10^3 g/m^3), thus increasing collision frequency. Each experiment was filmed with a hand-held video camera; frames from the recordings are shown in the Figures below.

Results and Discussion: The most important result of these experiments is that the mm-sized solid particles coalesced into 1-5 cm fractal-like clumps within a few seconds (Figures 1, 2, and 3). The clumps broke up into individual particles when shaken vigorously, but new clumps quickly formed when the shaking stopped. The material properties of the solids appeared to have little effect on the observed behavior. The spontaneity, speed, and repeatability of the process suggests that it is energetically favorable.

In the real nebula [1], the mass of solids per unit volume of gas was much lower than in these experiments: 10^{-5} g/m^3 for a 10^{-5} atm, 300 K solar composition nebula with solids making up 1% of the total mass. It is plausible that clump formation time varies inversely with the square of particle number density, implying that analogous structures would require an unreasonably long time (~ 10^{16} s, or ~ 300 Ma) to form in the nebula. But turbulent concentration is thought to be capable of enhancing local densities by factors of 10^5 to 10^7 [14], which would speed the aggregation process by a factor of 10^{10} to 10^{14} and permit formation of clumps within days, hours, or minutes.

Once formed, the clumps could likely endure plausible nebula conditions. Our aggregates were observed to withstand gentle shaking (~ 5 cm travel at ~ 2 cycles per second, implying accelerations of a few tens of cm/s^2 or perhaps 1/10 g; and peak velocities ~ 10 cm/s relative to the gas) and survive impacts against the wall of the bag with minor deformation. Similar structures could have survived the gas drag forces encountered in a ~ 10^{-5} atm nebula with ~ 100 m/s turbulent velocities. Smaller aggregates, with greater surface-area-to-mass ratios, may have been stronger. In a turbulent environment, bombardment by small particles better coupled to the gas might have threatened a clump's structural integrity, but the assemblages' significant porosity would have helped them resist impact damage [15].

One trial used mica flakes suspended in water rather than air (Figure 4). In this case, the much greater density and viscosity of the fluid led to the same general clumping behavior, but over a period of days rather than seconds. This observation suggests that our model system is a robust analog of a wide range of fluid viscosity, density, and drag conditions.

Although these experiments lacked formal controls to identify the precise clumping mechanism, it is apparently electrostatic. Some charge exchange evidently occurs: sometimes when a clump accretes a particle or collides with the container wall, a particle elsewhere on the clump is forcibly ejected.

Conclusion: In the future, we hope to try similar experiments using cosmogenically realistic materials: rock dust or ground-up chondrite. Controlling the electrical properties of the particles and the container may illuminate the physical clumping mechanism. It may be possible to use lower gas pressures, further improving the analog to protoplanetary nebula conditions.

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Figure 1. Clumps of 1- to 6-mm salt (NaCl) particles in air. The scale is approximately 1:1.

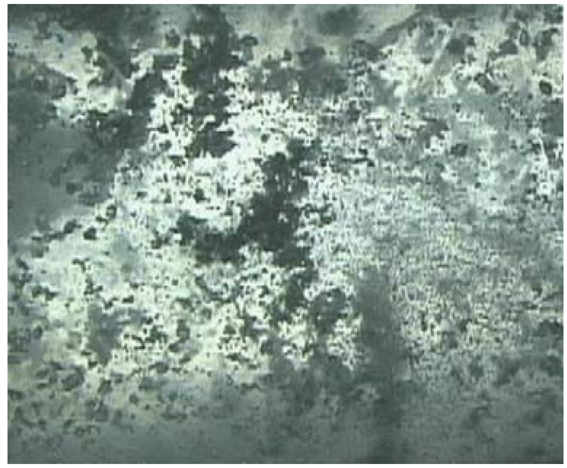

Figure 2. Clumps of 0.5- to 1.5-mm sugar (sucrose) particles in air. The scale is approximately 1:1.

Figure 3. Clumps of ~ 0.1 mm coffee particles in air. The scale is approximately 1:1.

Figure 4. Clumps of ~ 5 μm mica particles in water. The scale is approximately 1:1.