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Three-Dimensional Shapes of Cosmic spherules: Deformation of Dust Particles Molten in the Earth Atmosphere

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Cosmic spherules are extraterrestrial-origin round-shaped dust particles collected from the stratosphere, polar ice, and ocean floor sediments. When extraterrestrial dust particles enter the Earth atmosphere, they are heated by the gas friction and melted. Because of the surface tension, the molten particles become spherical and form cosmic spherules when they solidify.

Tsuchiyama et al. (2004) have examined 3-D structures of cosmic spherules and found that there are both prolate and oblate shapes. The ram pressure, the surface tension, and the centrifugal force acting on the particles deform the shape when they are molten. Thus, it seems natural to consider that the variation of the observed cosmic spherule shapes may originate from the shape of dust particles when they solidified.

When a molten dust particle does not rotate, it forms oblate shape due to the ram pressure from one direction (Sekiya et al. 2003). On the contrary, when a molten dust particle rotates fast, it forms prolate shape. In this study, we define the magnitude of the deformation of the molten particle as $X= \{(1\text{-}B/A)^2 + (1\text{-}C/B)^2\}^{1/2}$, where A, B, and C are axial radii approximated as three-axial ellipsoid. To calculate X, we use the analytic solutions both for the fast rotating molten particles and for the no rotating molten particles.

We calculate the velocity, temperature, and the radius of the dust particle. In our model, the effect of evaporation is also taken into account. We examine the cases with a wide variety of entry parameters: the initial radius (from 0.1 mm to 2 mm), the entry velocity (from 11.2 km/s to 20 km/s), and the entry angle (from 0 to 90 degrees, the angle 0 corresponds to the entry from the zenith direction).

We measure three axial radii of once molten stony cosmic spherules, which are collected from Antarctica, in a radius range between 40 micron and 120 micron. After shape parameter measurement, each spherule was polished to have flat surface and analyzed for major element concentrations using an electron microprobe analyzer.

As a result, we found that the X calculated in cases both fast rotation and no rotation is less than 0.1 in the radius range between 40 micron and 120 micron, while the measured X distributes up to X = 0.3.

We discuss three possibilities that may cause such a large deformation. (1) A low surface tension: We calculated X with different surface tension coefficients and found that if it is as low as 50 dyn cm-1, X becomes almost 0.3 in the radius range between 40 micron and 120 micron. However, the chemical composition of the measured cosmic spherules does not show a large variation. So, it seems difficult to assume that the surface tension is significantly different among samples. (2) A very high viscosity: If the viscosity of the molten particle is very high, the timescale of the deformation is longer than a period when the particle is molten. Then the shape of the particle may be determined by the ram pressure at the moment earlier than the solidification. Since the ram pressure at that moment is higher, the deformation may be large. However, we cannot expect such a large difference of the viscosity among samples because of the chemical homogeneity. (3) Crystallization generally elongates the particle in a certain direction. But we do not see a prominent crystalline structure in large-deformed spherules. Therefore, it is hard to consider that such a large deformation is caused by possibilities discussed above.

We have to look for yet other reasons that cause such a large deformation. For example, fragments of a meteorite entering the Earth atmosphere may collide with each other to form a large-deformed cosmic spherule. Or a bubbling in a liquid may deform the molten particle.

The rotation axis parallel to gas flow or a large dust particle entering the Earth atmosphere with high speed may cause the large deformation. Details of these effects should be investigated in a future work.