Experimental Study on the Coefficient of Restitution and Rotation in Low-Velocity Oblique Impacts of Ice Spheres onto Solid Targets

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In protoplanetary disks, μm-sized dust particles are thought to grow through low-velocity collisions and sticking, forming highly porous aggregates. However, when the aggregates grow to approximately cm size, bouncing may occur because of increasing collision velocity and decreasing porosity. This bouncing can prevent further growth of the aggregates. Understanding low-velocity collisions of aggregates composed of water-ice dust particles is, therefore, important for elucidating the formation process of icy planetesimals beyond the snow line.

Previous laboratory experiments have investigated dust collisions, but low-velocity collision experiments under low-temperature conditions are technically difficult. In particular, the effect of impact angle on collision outcomes has not been sufficiently studied. In this study, we aim to investigate the dependence of the coefficient of restitution and rotational motion on collision velocity and impact angle by conducting low-velocity oblique impact experiments on cm-sized aggregates composed of water-ice dust particles.

As a first step toward this goal, we developed a free-fall oblique impact system and an analysis method using a two-dimensional laser displacement sensor. In this presentation, we report the results of our preliminary experiments using non-porous ice spheres impacting on a granite plate.

The ice spheres were prepared by pouring boiled tap water into silicone molds and freezing them in a freezer at -20°C. A commercially available granite plate with a mirror-polished surface was used as the target plate. The ice spheres were dropped freely onto the granite plate. The impact velocity was controlled by changing the height of the granite plate (v_i ~ 16–161 cm s^{-1}). The impact angle was controlled by changing the inclination angle of the granite plate (θ_i = 15°, 30°, 45°, 60°, 75°, and 90°).

To observe horizontal motion, vertical motion, and rotational motion during oblique impacts, we used a two-dimensional laser displacement sensor with a sampling frequency of 1 or 2 kHz. We measured the sphere's position and the angle of the reference surface over time, both before and after the collision. All experiments were conducted in a cold room at -15°C.

The results show that the coefficient of restitution decreases with increasing impact velocity and impact angle. This suggests that energy dissipation occurred because of crack formation caused by impact stress. In contrast, the tangential coefficient of restitution was approximately 1, suggesting that frictional energy dissipation was negligibly small for collisions between smooth ice spheres and the mirror-polished granite plate.

We also found that the change in angular velocity before and after collisions increases with increasing impact velocity. We attribute this rotational change to the torque induced by a slight misalignment between the geometric center and the center of mass of the sphere.