ICE AS A GRANULAR MATERIAL

Barbara Turnbull*[1], Michael Swift[2], and Richard Hill[3]
[1]*Faculty of Engineering, University of Nottingham, University Park, Nottingham, UK*
[2]*School of Physics & Astronomy, University of Nottingham, University Park, Nottingham, UK*
[3]*School of Physics & Astronomy, University of Nottingham, University Park, Nottingham, UK*

Summary Ice is a unique material, fundamental to vital processes on earth, in the atmosphere [1] and as planets and comets form [2]. In this work, we introduce two experiments investigating ice as a granular material, to provide snippets of insight into those processes. Initial investigations of ice particles in a granular flow show that the energy spent in collisions can generate localised surface wetting, even below the melting point [3]. This wetting reduces friction between granules, leading to acceleration of the bulk flow and in turn more wetting. The experiments described here are designed to show how even wetting invisible to an observer, can fundamentally alter the flow. The experiments also use the diamagnetic properties of ice to investigate how the outcome of high speed binary collisions, energetic enough to generate some melting, depends on this wetting.

Here we describe the development of two experiments: one investigating high speed binary collisions of ice in microgravity, the second creating a vibrating bed of ice particles to observe the transition from ostensibly dry granular behaviour to that of wetted granules.

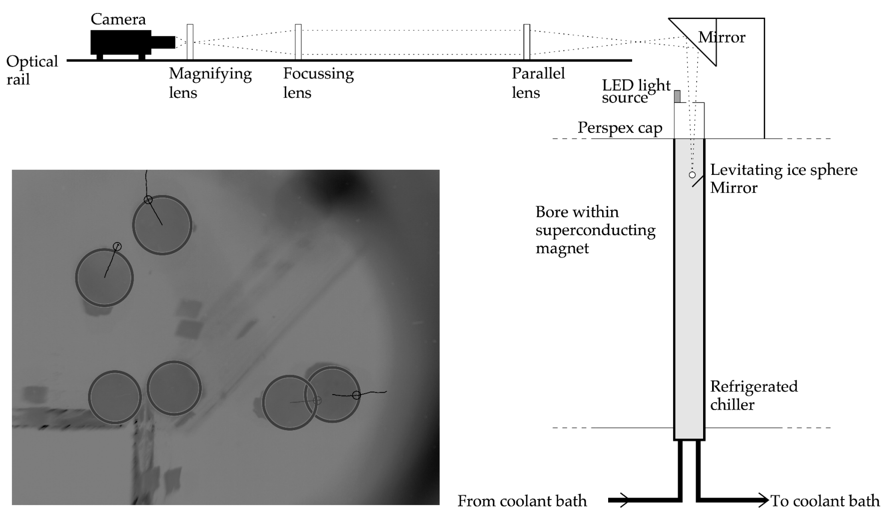

Figure 1: The configuration of an experiment with a single ice sphere levitated within the magnet bore. A combination of mirrors and lenses allows the trajectory of the levitated particle and any colliding particle to be recorded. A collision is created by dropping a second particle through a small hole in the top of the Perspex cap. Inset: Camera view after the collision of a dropped ice particle with a levitated ice particle. Centroid positions at collision are shown as circular markers, and centroid trajectory as lines. Here you see images of the pair of colliding particles, and their two perpendicular mirror images.

EXPERIMENTS

If we are to understand ice particle interactions in a variety of ambient conditions and with different particle geometries we need to be able to create a large number of binary collisions in a controllable environment. Here we introduce diamagnetic levitation [4] as a technique to investigate high speed ice collisions, where ambient conditions within the bore of a superconducting magnet can be controlled and the logistical constraints of parabolic flight or a drop tower [2], the chief alternatives, are removed. A refrigerated cylinder was inserted into the bore of a 19 Tesla superconducting magnet, cooled to -12°C. Ice particles were manufactured by dripping water from a syringe into a liquid nitrogen bath to form beads with diameters between 3 and 4 mm [3]. A single bead was placed at the levitation point in the magnet (fig. 1). A Perspex cap was placed over the magnet bore to stabilise the temperature within it and prevent convection. A 6 kHz camera was triggered to record as a second particle was dropped using tweezers through a small hole in the Perspex cap, vertically above the levitating particle. Since the

*Corresponding author. Email: barbara.turnbull@nottingham.ac.uk

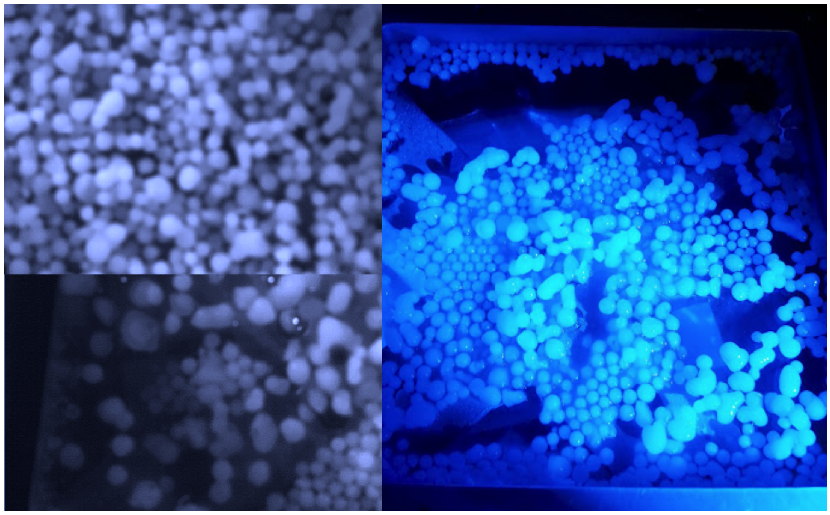

Figure 2: Ice granules in a closed glass cassette vibrated by an electromagnetic shaker, in a temperature controlled chamber at -3°C. Top left: A dry granular gas, after 5 minutes of shaking. Bottom left: After 20 minutes of shaking, larger coalesced particles appear alongside pockets of close packed particles. Right: Once all of the granules stopped moving after 65 minutes of shaking, the cassette was opened.

collision occurs along the camera axis, it was not possible to use the actual particle images to track collision trajectories and a pair of perpendicular mirrors were placed just below the levitation point allowing the full three-dimensional velocity field to be resolved (fig. 1 insert).

In a second experiment, ice particles (manufactured as previously described) were placed in a glass cassette (15 cm square, with a gap between base and top of 1.8 cm) that was shaken at $\omega = 50\,\mathrm{Hz}$ with an amplitude $A = 0.87\,\mathrm{mm}$, providing a dimensionless peak acceleration $\tau = A\omega^2/g = 8.8$ [5]. The experiment was placed in a temperature controlled chamber at -3°C. Image sequences of the shaking ice particles were captured every 10 minutes, to identify changes to the bulk behaviour of the flow.

RESULTS

In a short space of time, 50 ice collisions were generated in the magnet bore, of which 22 were on-axis (thereby not generating spin). This compares with previous methods where only a few ice collisions have been possible under one set of conditions. Thus, large numbers of collisions can be created using diamagnetic levitation to generate statistically meaningful data on binary collisions, where we can control conditions such as impact speed and ambient temperature, and thus surface wetting, alongside additional parameters such as electrostatic charge and particle shape.

When ice was shaken at -3°C, the particles adopted an ostensibly dry granular flow (fig. 2). After 15 minutes, small changes could be observed, where some particles started to coalesce, and other small pockets of particles close to the centre of the cassette became clustered in a close packing formation. These patches of particles numbered up to approximately 10 until, after circa 65 minutes of shaking, all particles became spontaneously immobile. The majority, including the new larger, coalesced particles, clustering to the small patches of close packed pockets. At the end of the experiment, the granules still appeared dry. This spontaneous clustering behaviour is qualitatively very reminiscent of predictions from recent numerical simulations of wetted granular gases [5]. With enhanced diagnostics through e.g. capacitive liquid volume fraction measurements, this system should be capable of providing detailed verification of wetted materials that can currently only be explored numerically.

References

[1] Dash J. G., Rempel A. W., Wettlaufer J. S.: The physics of premelted ice and its geophysical consequences. Rev. Mod. Phys. 78(3):695, 2006.

[2] Heißelmann D., Blum J., Fraser H., Wolling K.: Microgravity experiments on the collisional behaviour of surturnian ring particles. Icarus 206(2):424–430, 2010.

[3] Turnbull B.: Scaling laws for melting ice avalanches. Phys. Rev. Lett. 107(25):258001, 2011.

[4] Hill R. J. A., Eaves, L.: Vibrations of a diamagnetically levitated water droplet. Phys. Rev. E 81(5):056312, 2010.

[5] Strauch S., Herminghaus, S.: Wet granular matter: a truly complex fluid. Soft Matter 8(32):8271-8280, 2012.