Granular flows : fluidization and anisotropy

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Summary

This dissertation is dedicated to the physics of the flow of granular materials. A granular material, such as sand, is a material that consists of a conglomeration of discrete particles. Even though a single particle is a simple object, the collective behavior of billions of particles can be very complex. In a surprisingly large amount of cases, it is not exactly known how a granular material behaves, and this while these kinds of materials are omnipresent in everyday life, industry, and nature.

Similar to materials such as water, which can occur as ice, liquid water and vapor, sand can also exist in different phases of matter. If you for instance walk on the beach, sand behaves like a solid, but if you pour it out of your shoes afterwards, it flows like a liquid. The main part of this thesis is dedicated to experiments where we investigate what happens when you try to "liquefy" sand by weakly vibrating it.

If two layers of sand flow past each other, there is a relatively thin *shear zone* where the particles actually scrape past each other. It was found that sand flow can be understood relatively well if you consider this shear zone as two surfaces sliding past each other with a certain friction. Surprisingly, the required force does not depend on the flow rate, because the force is mostly used to overcome the friction. In chapter 3, we investigate whether this picture remains valid when the sand is weakly vibrated. We find that the behavior of weakly vibrated sand is also determined by friction. However, the frictional resistance now does depend on the amount of vibrations *and* on the flow rate. If you shake more vigorously, something completely different happens. The sand now becomes soft to the extent that you need different physics, namely that of fluids, to describe the sand flow.

If you increasingly tilt a plank with sand, for a certain angle, the sand will rapidly slide down. It is impossible to make the sand slide down the

plank slowly. But, if the grains are weakly vibrated, slow flow *is* possible. However, the sand is only “fluid” enough to sustain very slow flow, and there remain intermediate flow rates that are impossible to induce. The more you vibrate the sand, the fewer rates are impossible. Above a certain critical vibration intensity, all rates are allowed. In chapter 4 we investigate the slow and fast flow, and the transition between these two flow regimes. We consider this from the perspective of the important, *critical* point where the two kinds of flow meet.

If sand has flowed in a certain way, this direction is built into the packing. As a result, if you want to make the system flow more, it requires more force to do this in the same direction than in the opposite. We say the packing is *anisotropic*. In chapter 5 we show that this anisotropy can be measured by looking how it disappears from the packing when the system is vibrated. We find a relation between how much force was exerted during the flow, and the resulting anisotropy. This tells us that anisotropy is a crucial ingredient for the understanding of sand flow.

In chapter 6 we study the flow of rod-shaped particles. An important difference between rod-shaped and spherical particles is that, for rods, it is important in which direction they are oriented. Granular materials typically expand when they are sheared. However, rods can order, thereby reaching a very high density. From our flow experiments, where we see a heap arising from the surface when we shear rods, we know that the expansion dominates over the ordering. From measurements in a CT-scanner, where we can also see the particles below the surface, we know that there is an additional continuous upwards flow of particles in the center of the system. At the edge of the heap, the particles avalanche down its slope. This secondary flow is a good example of the influence of the shape of the particles on their flow properties.