The Dynamics of Granular Flows

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How can we understand and predict the behavior of materials composed of particles, which can flow like fluids? These "Granular Materials" include sand in dunes, snow (or rocks) in avalanches, sediments on the sea floor, and powders from which many commercial products, including pharmaceuticals, are made. We normally describe fluids by "differential equations" that predict how the velocity at different places in the fluid will change with time in response to external forces. Often these equations allow the flow of a fluid to be predicted quite accurately, while in other cases only statistical prediction is possible, for example in turbulent flows.

However, the possibility of reliable prediction for the flow of granular materials is still unclear. One problem is that large changes in velocities and forces occur over short distances. Another problem is that in some regions of the flow, collisions may be rare, while in other regions, the particles are always in contact. These flows also dissipate energy in ways that are hard to model.

In the talk, I discuss some recent experiments that illustrate the striking flow behavior of granular materials, and raise questions about how to make progress. One experiment shows that when sheared, random granular matter can sometimes crystallize into an ordered array of particles, dramatically affecting its flow properties. In some cases both ordered and disordered states coexist, with the history of the material affecting its current behavior. These and other experiments raise interesting questions about how the history of granular packings can be recorded in their internal structure. Other questions concern how the flow is confined to narrow regions of the material called shear bands, what happens when the direction of shear is reversed so that the material becomes anomalously mobile, and how the behavior of a sheared granular material depends on the degree of uniformity of the particle size.

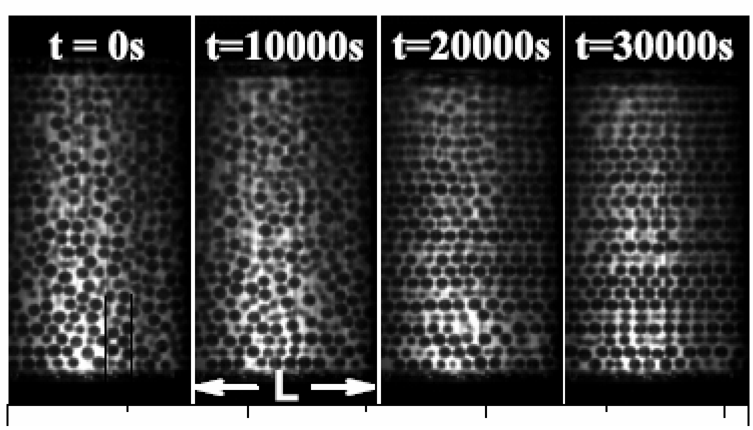

Figure: Shearing of a disordered granular material transforms it into an ordered crystal whose flow properties are dramatically different.

In other experiments, many interesting phenomena are found. For example, excited particles that are immersed in a fluid can attract each other indirectly through their effect on the surrounding fluid. Granular materials can sustain waves or ripples, or even supersonic shock waves, and much effort has gone into explaining the great variety of patterns that are produced. Even when the waves are untable, they fluctuate in a transient fashion. Avalanches on an inclined slope can propagate both downhill and uphill, surprisingly.

Granular particles that are chiral (lacking in mirror symmetry) are found to rotate spontaneously when excited, extracting angular momentum from a heat bath and sharing it with each other. Particles can diffuse in a granular flow, but the diffusion is anomalous and anisotropic, quite different from that in ordinary fluids.

When a hard object impacts on a bed of granular matter, it forms craters, and recent studies of this process may give insight into the origins of craters on planetary bodies. Other recent studies are directed at understanding the motion of sand dunes, which has direct bearing on the process of desertification that is so important in some areas of the world.

Finally, recent studies of the erosion of granular beds by water show promise in contributing to our understanding of the origin of the diverse landforms that compose the earth's surface, both above and below sea level.

These striking experiments demonstrate how important it is to develop quantitative explanations for the flow of granular matter. This research involves scientists in various disciplines, including condensed matter physics, mechanical engineering, and applied mathematics. It involves an intimate interplay between theory, experiment, and computation.