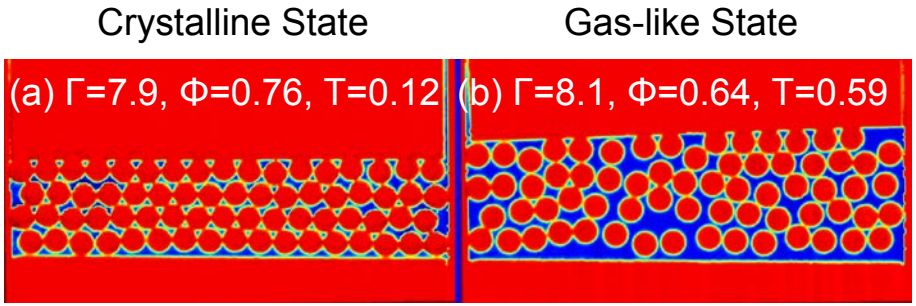
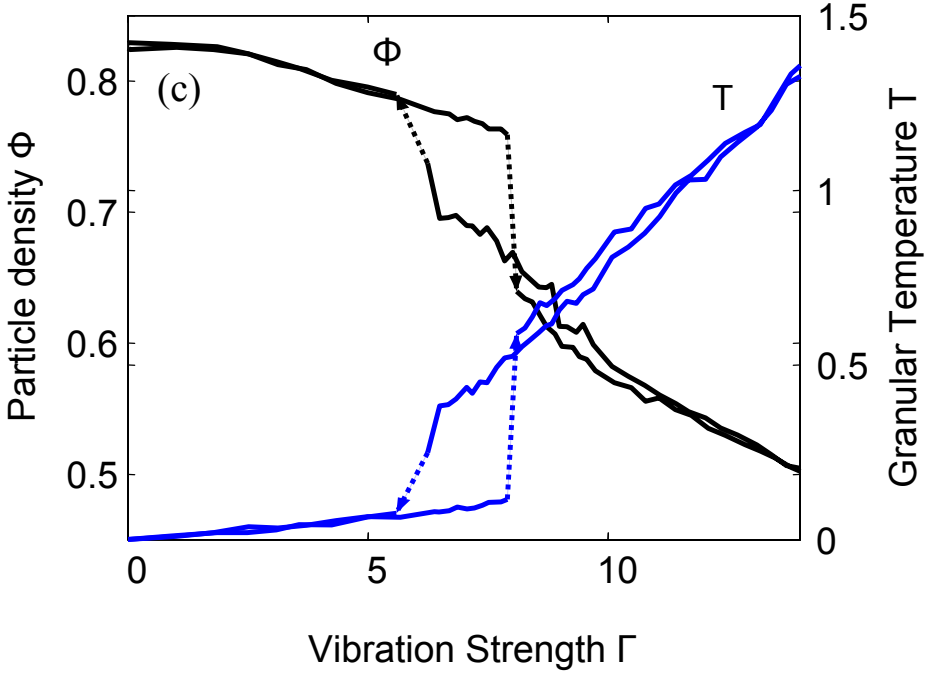
CAREER: Granular Media: Experimental Kinetic Theory I

Mark D. Shattuck, City College of New York, DMR-0134837

First-order phase transition in a vibrated 2D granular fluid: From pharmaceutical powder mixers to the rings of Saturn, granular materials are an integral part of our universe. We investigate granular flows to determine the validity of statistical descriptions analogous to ordinary fluids. We have experimentally discovered a first-order phase transition in a 2D granular fluid excited by vibration from below and confined by a floating plate above. The steady-state transition occurs between a crystal(a) and a gas(b) and is characterized by a discontinuous change in both density and temperature(c). It shows rate-dependent hysteresis, and obeys the Lindemann criterion for melting. Granular systems do not conserve energy and the concept of free energy is not establish, even under steady state situations since there is a constant flow energy through the system. The idea of applying thermodynamic ideas to a non-equilibrium-steady-state (NESS) is at the forefront of current statistical physics. The demonstration of experimental systems which undergo first-order phase transitions under NESS conditions points to the universality of entropy-production and free-energy concepts even in the absence of energy conservation.





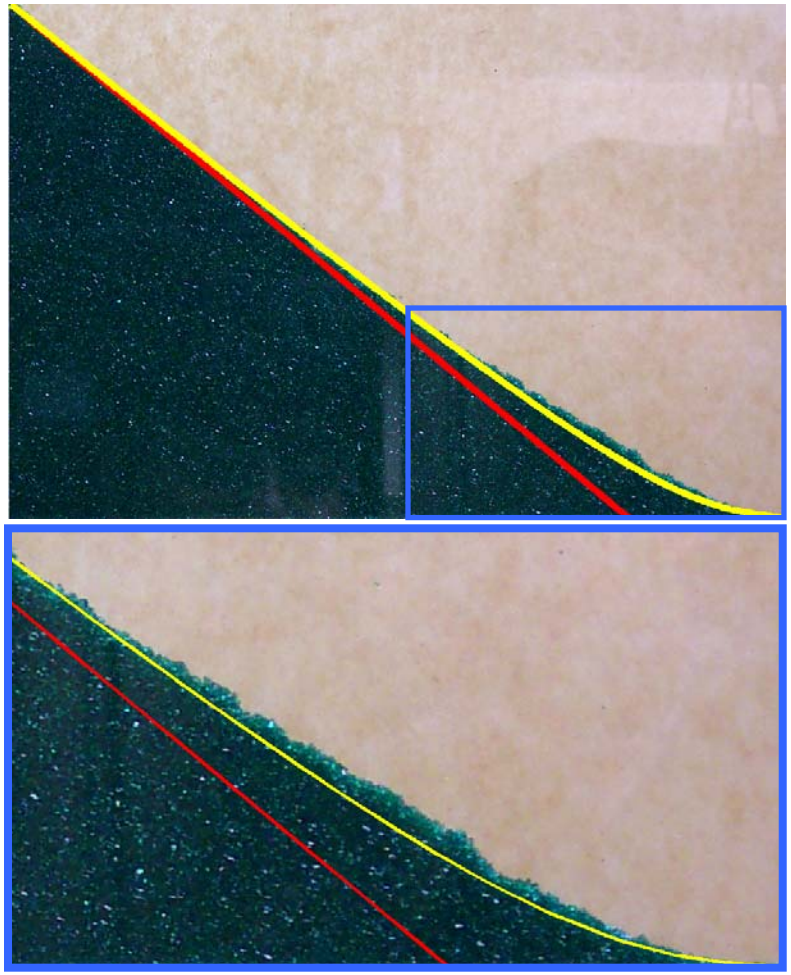
Granular materials, like sand and salt, can behave like fluids or solids, just like ordinary materials. Unlike ordinary materials they can change between fluid and solid very easily. When sand is shaken or stirred it acts like a fluid, but in a pile or on the beach it acts like a solid, and it will support the weight of a person. If you want to freeze water the temperature must be lowered below the freezing point. In general, the state of an ordinary material depends on the pressure, temperature, and the density. For example, water can be frozen at room temperature if it is under enough pressure. For sand, density and pressure are easily defined by analogy with water, but temperature is more difficult. In water, the temperature is determined by the average speed or energy of the molecules, and the same definition can be used for sand by imagining that the grains are molecules. The key difference is that sand grains lose energy every time they collide and molecules do not. In a closed, insulated container water will remain at the same temperature indefinitely, but moving grain will quickly come to rest and therefore to zero temperature.

In our experiments we try to push the analogy between ordinary material and sand as far as possible. We continually shake the particle from below to maintain a constant temperature and place a floating top on the container to maintain a constant pressure. At low shaking strength the particles order to form a crystal, as seen in figure (a), at high shaking strength a gas-like state is formed (b). We find that just as in ordinary materials there is a sharp transition between the crystal and gas-like state. For example when carbon-dioxide is frozen the density decreases dramatically. In our experiment the density changes by 15% when the shaking is changed by only 2.5%; see figure (c). This type of evidence suggest that the analogy between ordinary materials and granular materials is very strong. It also allows us to use granular materials to better understand ordinary materials on the scale of molecules and to explore how systems which can lose energy behave.

CAREER: Granular Media: Experimental Kinetic Theory II

Mark D. Shattuck, City College of New York, DMR-0134837

Education: We developed and taught a graduate level course focusing on statistical and continuum approaches to both rapid and slow granular dynamics. Too often students never get to see current research topics. Therefore, the course is designed to incorporate research-level ideas into the curriculum. The course was given once at the Graduate Center of the City University of New York and once at the City College campus. Both times 9 students took the course and presented both experimental and theoretical research projects at the end of the term on a variety of subject related to granular flows. The results from one project are shown to the right. The shape of a granular pile is deduced from a simple nonlinear theory and compared to an actual pile of green colored sugar crystals. The yellow line is the nonlinear correction to the linear theory in red.



Training:

2 undergraduates students,
1 graduates student,
1 post-doctoral researcher.

CAREER: Granular Media: Experimental Kinetic Theory I

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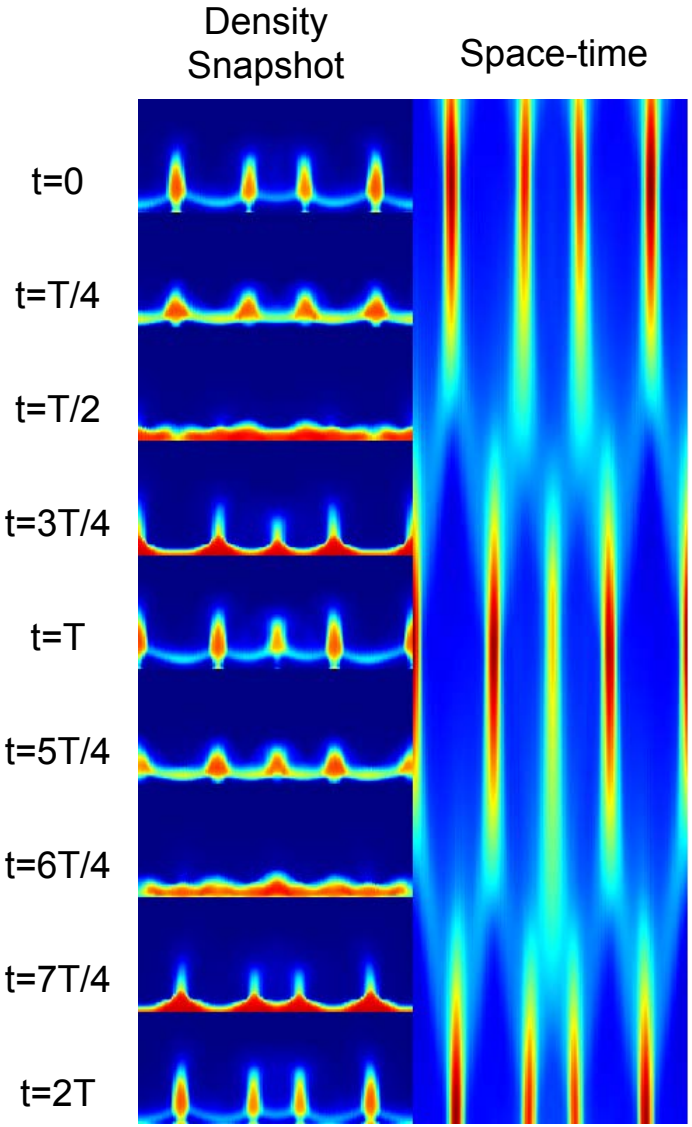
From coal mines to grain silos to the rings of Saturn and the granular mixers of the pharmaceutical industry, granular materials are an integral part of our universe. We investigate granular flows to determine the validity of statistical descriptions analogous to the kinetic theory of ordinary molecular fluids. A vertically vibrated granular layer spontaneously develops a wave pattern when the maximum vibration acceleration is greater than 2.5 times gravity. The wave pattern repeats every two periods T of the applied vibration, as seen in the density snapshot taken every quarter period. These snapshots are the results of the numeric integration of continuum equations developed using kinetic theory. The equations capture all of the main features of this complicated granular flow, including the period doubling, decrease of the pattern wavelength with increasing drive frequency, and a critical acceleration to create the pattern. We are currently designing 2D experiments to look at quantitative comparisons. The space-time plot shows a more detailed view of the temporal behavior.



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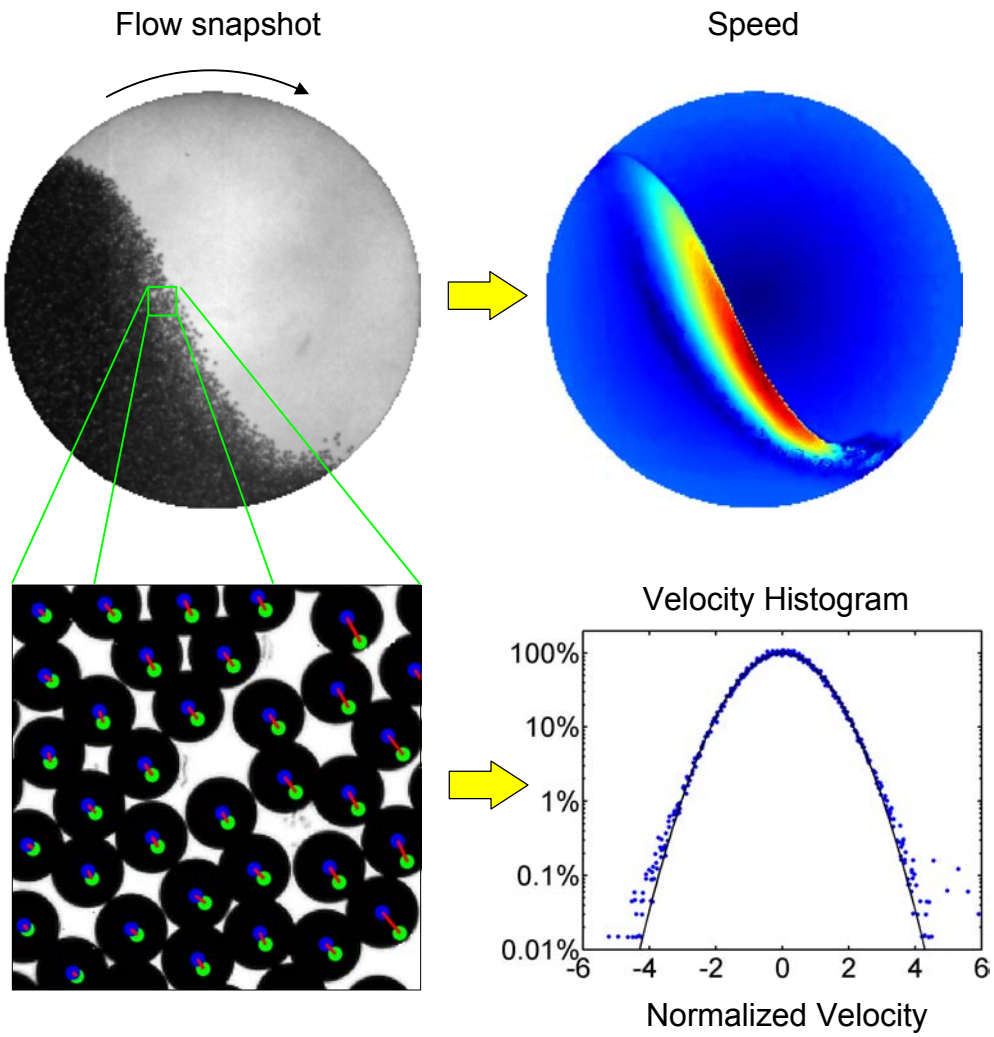
From coal mines to grain silos to the rings of Saturn and the granular mixers of the pharmaceutical industry, granular materials are an integral part of our universe. We investigate granular flows to determine the validity of statistical descriptions analogous to the kinetic theory of ordinary molecular fluids. From snap shots of a rotating layer of spheres trapped between two glass plates, we extract the velocity field using a temporal cross-correlation technique we developed for granular flows. The result is shown to the right as a speed field. We measure the local statistical properties of the grains from close-up high-speed digital photography shown in the lower image. We developed highly adaptable particle tracking software to extract the velocities of individual particles. The blue and green dots are the centers of the particles in successive frames. From this data, we extract a histogram of the velocities (small blue dots) that shows excellent agreement with kinetic theory (solid black curve).