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Granular materials not so puzzling after all, physicists find

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Understanding the physics of granular materials is important in industries that handle and process large amounts of the materials, such as pills and powders in the pharmaceutical and food industries and sand in the construction business.

But the problem of how to model granular materials has perplexed physicists. In particular, they'd like to better understand how the temperature within an assemblage of granular material affects the system's dynamics. That understanding will help scientists determine whether the same thermodynamic principles that apply to systems at equilibrium also apply to systems that are far from equilibrium, such as living organisms.

In a paper to be published in the Aug. 21 issue of the journal Nature, a multinational team that includes University of Michigan physicist Franco Nori describes experiments in which the team devised an unusual "thermometer" and used it to test the soundness of the temperature concept in a continuously shaken container of tiny beads.

Temperature measurements actually are a reflection of how excited individual particles in a material are, be they molecules of air or grains of sand. In a gas, for instance, molecules vibrate and constantly collide with one another like extremely bouncy rubber balls. If the gas was trapped in a box, the microscopic motion would never stop and the temperature would remain constant. This so-called equilibrium state is possible because no loss of energy occurs in the molecules' chaotic dancing.

In the work described in the Nature paper, the researchers explored the question of whether temperature can be similarly defined for systems that are not at equilibrium, especially those in which energy is dissipated during collisions. If it can, that means that equilibrium thermodynamic concepts can be generalized to far-from-equilibrium situations.

The question has practical implications for understanding natural phenomena such as the formation of order from disorder (a process known as pattern formation) and the extraction of motion out of randomness (biological Brownian motors). For these non-equilibrium situations, the lack of a definition of temperature and related parameters has prevented scientists from completely understanding the systems involved.

The researchers used an experimental set-up that they compare to a pinball machine, with balls moving around in a closed space. In a standard pinball machine, however, the balls are launched one at a time and bounce from one obstacle to the next. In the experimental system, thousands of tiny beads move almost imperceptibly due to the gentle shaking of the container in which they are held, colliding with each other and with the container walls. Because the beads are not perfectly elastic, energy is dissipated during these collisions. Only the external vibration of the container maintains the beads' chaotic motion;

if the container isn't constantly shaken, the beads quickly stop moving.

In this experimental model of a non-equilibrium system, the researchers used a device called a torsion oscillator to act as a thermometer. The torsion oscillator---a wire with a cone-shaped probe at the end---was immersed in the container of beads. When the container was shaken, the beads bombarded the probe, causing the wire to oscillate back and forth like a clock spring.

By looking at the resulting motion of the wire, the scientists were able to determine whether the measured "temperature" followed the rules one would expect in an equilibrium energy conserving system---a system in which energy is not dissipated in collisions. To their surprise, they found that temperature did follow the expected rules, leading them to conclude that even for a dissipative system, a few parameters---such as temperature---can be used to extract essential information concealed in the disordered motion of billions of particles.

In addition to Nori of the Institute of Physical and Chemical Research (RIKEN) in Japan and the Center for Theoretical Physics at the University of Michigan, the research team included: Gianfranco D'Anna and Patrick Mayor of the Ecole Polytechnique Federale de Lausanne in Lausanne, Switzerland; Alain Barrat of the Universite de Paris-Sud in Paris, France; Vittorio Loreto of the Center for Statistical Mechanics and Complexity in Rome, Italy; and Franco Nori of the Institute of Physical and Chemical Research (RIKEN) in Japan and the.

The researchers hope their results will stimulate new ideas in the description of non-equilibrium physics.

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