Study shows how granular materials get themselves out of a jam

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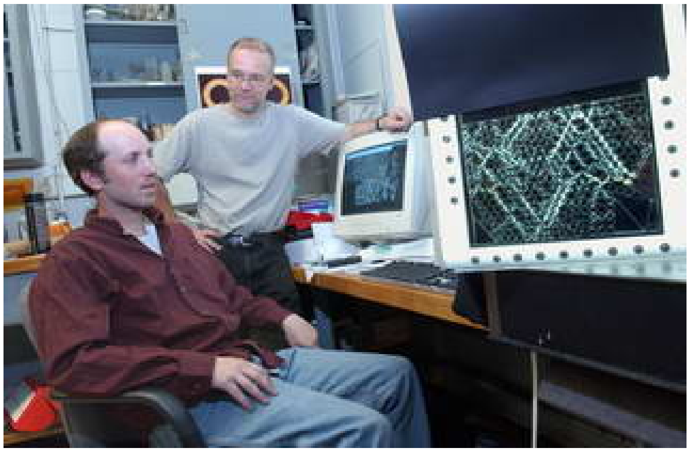

Scientists probe complicated issues of seemingly simple phenomena

University of Chicago physicists have made careful measurements of flowing sand that can help resolve longstanding questions regarding how glasses differ from liquids at the atomic level, the scientists report in the Thursday, June 23 issue of the journal *Nature*.

Image: Eric Corwin (seated), a graduate student in physics, and Heinrich Jaeger, Professor in Physics, both at the University of Chicago, review data from their new study on how the behavior of granular materials changes from a jammed to a flowing state. The study, which will be *published in the June 23 issue of the journal Nature, has implications for solving long-standing questions about how glasses differ from liquids at the atomic level. The device in the foreground displays lines of force as they are transmitted through polymer discs in response to the application of force from above.*

Glass flows just like liquids do, but at such a super-sluggish pace that for all practical purposes it takes on the appearance of a solid at room temperature. Yet after years of experiments, scientists still have failed to determine if atoms arrange themselves differently in glass than in liquids.

Now a team of physicists at the University of Chicago has measured the forces exerted between granular particles as they switched from a static to a flowing condition that probably correspond to changes that occur at the atomic level in glass as it becomes liquid under increasing temperatures. The finding has no known applications, but it addresses a problem that scientists have puzzled over for decades.

"This is something that has been speculated about. It's something that has been simulated, but something that has not been measured directly," said Heinrich Jaeger, a Professor in Physics at the University of Chicago. Jaeger is a co-author of the Nature paper, along with Eric Corwin, a graduate student in Physics, and Sidney Nagel, the Stein-Freiler Distinguished Service Professor in Physics, both at the University of Chicago.

Sand-or tiny glass beads in the case of the Chicago experiments-in theory corresponds to atoms in glasses under certain circumstances, Jaeger said. Glasses behave like a frozen liquid at room temperature, while sand and other granular materials experience a similar frozen state, called jamming, when compressed by gravity.

"Glass doesn't flow at all on even enormous time scales and really is jammed," Corwin said. But under certain conditions, both glasses and granular materials begin flowing like liquids.

The Chicago scientists have now, for what they believe is the first time, measured the forces acting between individual particles in granular materials as they undergo their transition from a jammed state to a flowing state. Computer simulations at the University of Chicago and elsewhere show that this transition resembles the one that atoms experience in melting glass.

It is very hard to measure forces between individual atoms except on a computer. But Corwin's measurements of these forces in granular materials serve as a sort of magnifying glass, Jaeger said, allowing him to more easily read the jamming transition left by the flowing beads in his experiment.

"We can actually see what happens as you go from a jammed state to an unjammed state," Jaeger said.

The experimental apparatus includes a cylinder filled with 50,000 to 100,000 glass beads. A motor-driven rotating piston compresses the beads from above. Shear stress applied by the rotating piston travels through the beads and lights up a spot in a specially prepared surface at the bottom of the cylinder. A video camera then records images of the spots over the course of an hour-long period of data collection.

Adam Bushmaker began developing the optics associated with the experiment during the summer of 2001 while participating in the National Science Foundation's Research Experiences for Undergraduates program. Bushmaker completed his bachelor's degree in engineering physics at the University of Wisconsin, Platteville, in 2004. Corwin then took over the project, building the final apparatus and doing the data analysis with additional support from the NSF and the U.S. Department of Energy.

"Eric was able to push this particular force measurement technique to a new level," Jaeger said.

Corwin's statistical analysis of the data shows a distinct difference in the way grains transmit forces depending on whether they are flowing or jammed.

In glass, flow begins when heat rises to a certain temperature. Similarly, the Chicago study shows that granular systems have what scientists call an "effective temperature," one caused by the application of force instead of heat.

"A pile of sand at room temperature would not have sufficient energy to rearrange," Nagel explained. "However, if you were to shake the container with the sand, for example, the energy provided by the shakes would be enough to rearrange the particles. This shaking should act in some ways like a temperature."

Another way to create an effective temperature in grains is to apply a shear force, as the Chicago scientists did in their experiment, which forced the particles to move around and continually rearrange.

"Can one associate an 'effective temperature' with the energy provided, or random motion caused, by the shear stresses in a flowing granular material?" Nagel asked. "We have shown that according to one strict measure, we can."

Designing the experiment and bringing it to a successful conclusion required countless hours of time-consuming adjustments and calibrations. "The whole thing with all its tribulations took us several years, but when a nice result like this comes out, it's really worthwhile," Jaeger said.

Source: University of Chicago

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