Researchers make sand that flows uphill

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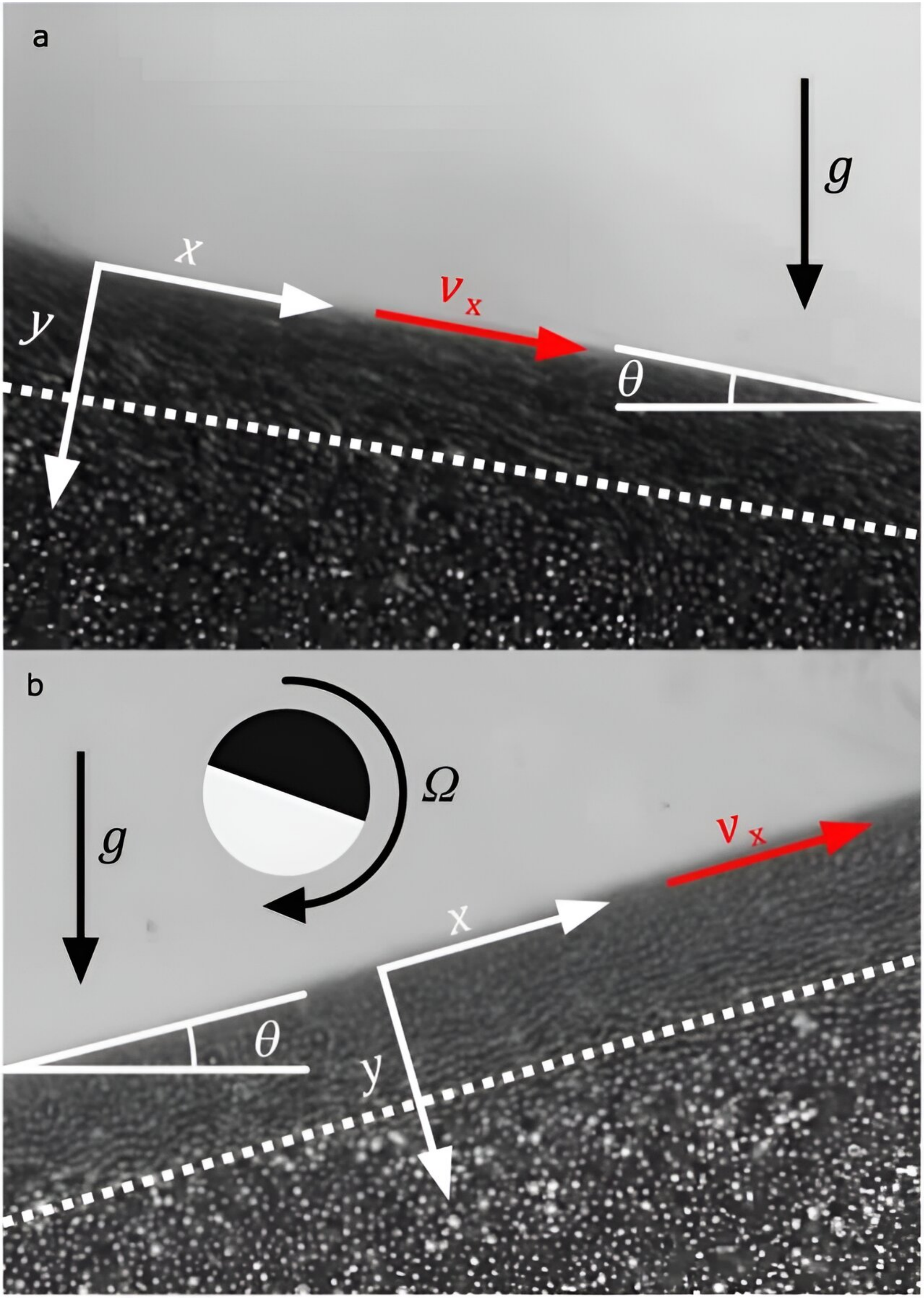
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Gravity-driven and magnetically-driven flowing layer of ferromagnetic Janus particles. Intensity average images of (a) a gravity driven flow in a granular heap of unactuated Janus particles and, in contrast, (b) an uphill flow of the Janus microrollers driven by magnetic actuation, including an illustration of the direction of particle rotation. Movies of uphill granular flow are available (see Supplementary Information in paper). The relative magnetic field strength is $(\beta/\beta 0)^2 = 3.5$ and the granular bed depth is $\Delta/2a = 26.0$. The dotted white line is an approximate representation of the flowing layer. Credit: *Nature Communications* (2023). DOI: 10.1038/s41467-023-41327-1

Engineering researchers at Lehigh University have discovered that sand can actually flow uphill.

The team's findings were published today in the journal *Nature Communications*. A corresponding video shows what happens when torque and an attractive force is applied to each grain—the grains flow uphill, up walls, and up and down stairs.

"After using equations that describe the flow of granular materials," says James Gilchrist, the Ruth H. and Sam Madrid Professor of Chemical and Biomolecular Engineering in Lehigh's P.C. Rossin College of Engineering and Applied Science and one of the authors of the paper, "we were able to conclusively show that these particles were indeed moving like a granular material, except they were flowing uphill."

The researchers say the highly unusual discovery could unlock many more lines of inquiry that could lead to a vast range of applications, from health care to material transport and agriculture.

The paper's lead author, Dr. Samuel Wilson-Whitford, a former postdoctoral research associate in Gilchrist's Laboratory of Particle Mixing and Self-Organization, captured the movement entirely by serendipity in the course of his research into microencapsulation. When he rotated a magnet beneath a vial of iron oxide-coated polymer particles called microrollers, the grains began to heap uphill.

Wilson-Whitford and Gilchrist began studying how the material reacted to the magnet under different conditions. When they poured the microrollers without activating them with the magnet, they flowed downhill. But when they applied torque using the magnets, each particle began to rotate, creating temporary doublets that quickly formed and broke up. The result, says Gilchrist, is cohesion that generates a negative angle of repose due to a negative coefficient of friction.

"Up until now, no one would have used these terms," he says. "They didn't exist. But to understand how these grains are flowing uphill, we calculated what the stresses are that cause them to move in that direction. If you have a negative angle of repose, then you must have cohesion to give a negative coefficient of friction. These granular flow equations were never derived to consider these things, but after calculating it, what came out is an apparent coefficient of friction that is negative."

Increasing the magnetic force increases the cohesion, which gives the grains more traction and the ability to move faster. The collective motion of all those grains, and their ability to stick to each other, allows a pile of sand particles to essentially work together to do counterintuitive things—like flow up walls, and climb stairs. The team is now using a laser cutter to build tiny staircases, and is taking videos of the material ascending one side and descending the other. A single microroller couldn't overcome the height of each step, says Gilchrist. But working together, they can.

"This first paper just focuses on how the material flows uphill, but our next several papers will look at applications, and part of that exploration is answering the question, can these microrollers climb obstacles? And the answer is yes."

Potential applications could be far ranging. The microrollers could be used to mix things, segregate materials, or move objects. Because these researchers have discovered a new way to think about how the particles essentially swarm and work collectively, future uses could be in microrobotics, which in turn could have applications in health care. Gilchrist recently submitted a paper exploring their use on soil as a means of delivering nutrients through a porous material.

"We're studying these particles to death," he says, "experimenting with different rotation rates, and different amounts of magnetic force to better understand their collective motion. I basically know the titles of the next 14 papers we're going to publish."

More information: Samuel R. Wilson-Whitford et al, Microrollers flow uphill as granular media, *Nature Communications* (2023). DOI: 10.1038/s41467-023-41327-1

Provided by Lehigh University