

Study reveals mysterious equality with which grains pack it in

June 26 2017



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At the moment they come together, the individual grains in materials like sand and snow appear to have exactly the same probability of combining into any one of their many billions of possible arrangements,

researchers have shown.

The finding, by an international team of academics at the University of Cambridge, UK, and Brandeis University in the US, appears to confirm a decades-old mathematical theory which has never been proven, but provides the basis for better understanding granular materials - one of the most industrially significant classes of material on the planet.

A granular material is anything that comprises solid particles that can be seen individually with the naked eye. Examples include sand, gravel, snow, coal, coffee, and rice.

If correct, the theory demonstrated in the new study points to a fact of remarkable - and rather mysterious - mathematical symmetry. It means, for example, that every single possible arrangement of the [grains](#) of sand within a sand dune is exactly as probable as any another.

The study was led by Stefano Martiniani, who is based at New York University but undertook the research while completing his PhD at St John's College, University of Cambridge.

"Granular materials are so widely-used that understanding their physics is very important," Martiniani said. "This theory gives us a very simple and elegant way to describe their behaviour. Clearly, something very special is happening in their physics at the moment when grains pack together in this way."

The conjecture that Martiniani tested was first proposed in 1989 by the Cambridge physicist Sir Sam F. Edwards, in an effort to better understand the physical properties of granular materials.

Globally, these are the second-most processed type of material in industry (after water) and staples of sectors such as energy, food and

pharmaceuticals. In the natural world, vast granular assemblies, such as sand dunes, interact directly with wind, water and vegetation. Yet the physical laws that determine how they behave in different conditions are still poorly understood. Sand, for example, behaves like a solid when jammed together, but flows like a liquid when loose.

Understanding more about the mechanics of granular materials is of huge practical importance. When they jam during industrial processing, for example, it can cause significant disruption and damage. Equally, the potential for granular materials to "unjam" can be disastrous, such as when soil or snow suddenly loosens, causing a landslide or avalanche.

At the heart of Edwards' proposal was a simple hypothesis: If one does not explicitly add a bias when preparing a jammed packing of granular materials - for example by pouring sand into a container - then any possible arrangement of the grains within a certain volume will occur with the same probability.

This is the analogue of the assumption that is at the heart of equilibrium statistical mechanics - that all states with the same energy occur with equal probability. As a result the Edwards hypothesis offered a way for researchers to develop a statistical mechanics framework for granular materials, which has been an area of intense activity in the last couple of decades.

But the hypothesis was impossible to test - not least because above a handful of grains, the number of possible arrangements becomes unfathomably huge. Edwards himself died in 2015, with his theory still the subject of heated scientific debate.

Now, Martiniani and colleagues have been able to put his conjecture to a direct test, and to their surprise they found that it broadly holds true. Provided that the grains are at the point where they have just jammed

together (or are just about to separate), all possible configurations are indeed equally likely.

Helpfully, this critical point - known as the jamming transition - is also the point of practical significance for many of the granular materials used in industry. Although Martiniani modelled a system comprising soft spheres, a bit like sponge tennis balls, many granular materials are hard grains that cannot be compressed further once in a packed state.

"Apart from being a very beautiful theory, this study gives us the confidence that Edwards' framework was correct," Martiniani said.

"That means that we can use it as a lens through which to look at a whole range of related problems."

Aside from informing existing processes that involve granular materials, there is a wider significance to better understanding their mechanics. In physics, a "system" is anything that involves discrete particles operating as part of a wider network. Although bigger in scale, the way in which icebergs function as part of an ice floe, or the way that individual vehicles move within a flow of traffic (and indeed sometimes jam), can be studied using a similar theoretical basis.

Martiniani's study was undertaken during his PhD under the supervision of Professor Daan Frenkel. It built on earlier research in which he developed new methods for calculating the probability of granular systems packing into different configurations, despite the vast numbers involved. In work published last year, for example, he and colleagues used computer modelling to work out how many ways a system containing 128 tennis balls could potentially be arranged. The answer turned out to be ten unquadragintilliard - a number so huge that it vastly exceeds the total number of particles in the universe.

In the new study, the researchers employed a sampling technique which

attempts to compute the probability of different arrangements of grains without actually looking at the frequency with which these arrangements occur. Rather than taking an average from random samples, the method involves calculating the limits of the possibility of specific arrangements, and then calculates the overall probability from this.

The team applied this to a computer model of 64 soft spheres - an imaginary system which could therefore be "over-compressed" after reaching the jamming transition point. In an over-compressed state, the different arrangements were found to have different probabilities of occurrence. But as the system decompressed to the point of the jamming transition, at which the grains were effectively just touching, the researchers found that all probabilities became equal - exactly as Edwards predicted.

"In 1989, we didn't really have the means of studying whether Edwards was right or not," Martiniani added. "Now that we do, we can understand more about how granular [materials](#) work; how they flow, why they get stuck, and how we can use and manage them better in a whole range of different situations."

The study, Numerical test of the Edwards conjecture shows that all packings become equally probable at jamming is published in the journal *Nature Physics*.

More information: Numerical test of the Edwards conjecture shows that all packings become equally probable at jamming, *Nature Physics* (2017). [DOI: 10.1038/nphys4168](https://doi.org/10.1038/nphys4168)

Provided by University of Cambridge

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