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Shake and pack

US scientists have announced that the only way to answer one of the oldest questions in physics -- how many frozen peas can you get in a bag -- is to shake it and see. But is it the right question anyway, asks Philip Ball?

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PHILIP BALL

How many frozen peas can you get in a bag? Or how many powder grains can you get in a tank? The answer, a group of US scientists have announced, is that there is no unique answer. There is no mathematically exact way of deciding how densely a disorderly collection of identical spheres can be packed, they explain in the journal *Physical Review Letters*[1].

The puzzle is an old one, and the connection to peas not entirely spurious. In the eighteenth century, the British clergyman Stephen Hales made one of the earliest attempts to understand how spheres may be randomly packed by experimenting with peas.

If the packing is not random but orderly, the problem looks considerably simpler. In 1611 the astronomer Johannes Kepler proposed that identical spheres could never be packed any more densely than in the usual 'greengrocer stall' manner: in layers with each sphere surrounded by a hexagon of six others. This 'face-centred cubic packing' squeezes spheres into 74% of the total available space. Though not seriously doubted throughout the following centuries, this proposal was only rigorously proved in 1998, by the mathematician Thomas Hales (apparently no relation).

Spheres packed at random cannot occupy space so efficiently: typically they fill only about 60% of it. So precisely *how* densely can spheres be packed at random? The problem is that the possible configurations of random packings are endless, and (unlike regular, face-centred cubic packing) there is no neat mathematical way to describe them. So it has been very hard to even pose the question in a mathematical way.

Instead, many have resorted to experiments. In 1969, G. D. Scott and D. M. Kilgour shook ball bearings in a container until they occupied 63.7% of the space. Three years later one commentator remarked that "ball bearings have been shaken, settled in oil, stuck with enamel paint, kneaded inside rubber balloons -- and all with no denser a result".

A density of about 64% seemed to be the limit. But computer simulations, exploring many configurations rapidly, have since achieved random 'packing fractions' of up to 68%. Much depends, it seems, on the 'pouring' and 'shaking' of the balls.

Now Sal Torquato and colleagues of Princeton University in New Jersey say that we have been asking the wrong question all along: a random, closest packing of spheres is an 'ill-defined' state -- a will o'the wisp, something that can never be pinned down. In its place, they propose a new idea: a 'maximally random jammed' (or 'MRJ') state.

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Torquato's team announce that a sphere is jammed if it cannot be moved when all the other spheres are held fixed. The whole system of spheres is said to be jammed if all its components are jammed. They suggest that, close to the densest randomly packed states, there are a whole range of jammed states, which merge eventually into the ordered, jammed state of face-centred cubic packing. But there is a unique one of these states that has the greatest degree of disorder: the MRJ state.

The difficult part is deciding how to define disorder; but Torquato's group offer a way. Applying their criteria to computer simulations, they say that the packing fraction for the maximally random jammed state of identical spheres is roughly 64% -- about the same as that found by Scott and Kilgour. The researchers claim to have transformed a very fuzzy problem -- albeit one with considerable technological importance, given how many materials are processed and handled as powders of roughly spherical grains -- into a mathematically precise question. Phew.

References

1. Torquato, S., Truskett, T. M. & Debenedetti, P. G. Is Random Close Packing of Spheres Well Defined? ***Physical Review Letters*** **84**, 2064 - 2067 (2000).