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Chain reaction

In the 1950s J. Desmond Bernal sought to understand the structure of liquids by considering them as random packings of incompressible spheres, which he modelled using steel ball bearings. Bernal's model raised the question of how far the behaviour of a molecular system, agitated by thermal fluctuations, can be considered analogous to a collection of macroscopic particles in static equilibrium at zero effective temperature.

In the ensuing decades, Sam Edwards at Cambridge took that idea further by developing explicit analogies between the statistical mechanics of matter at the microscopic scale and the behaviour of granular media. Edwards and Oakeshott suggested that the volume for a granular material can play a role analogous to energy in statistical mechanics, and that a quantity called the compactivity, related to the packing fraction, is the analogue of temperature¹.

This hypothesis is still debated. It implies a definition of an effective entropy for granular media that seems to hold at least at the special point where a granular pile becomes 'jammed' into immobility². This jamming transition has been proposed as the analogue of the transition from a liquid to a glass.

Much of Edwards's focus, however, was not simple liquids but polymers. Here the equivalent of a granular system of hard spheres is a chain of beads. The mechanical behaviour of such a system is complicated by the fact that, while the beads may still

jam against one another by friction, their motion is also restricted by the bonds between beads. Does Edwards's correspondence of macro and micro work for polymers too?

It does indeed, according to Zou et al., who showed that metal bead chains of the kind commonly used for window-shade pulls, when shaken in a container to produce dense packing, exhibit jamming in a manner that supports an equivalence between the final (maximal) random-packing density and the inverse of a polymer's glass transition temperature³. As those authors pointed out, this implies that condensed matter may be governed by geometry and symmetry beyond any details of microscopic interaction.

Dumont et al. have now taken this comparison further⁴. Using similar shaken bead chains of varying length, they explored how the resistance to indentation for chains packed within soft-sided containers (to allow for dilation and reduce the formation of load-bearing 'arches') varies with the number of beads per chain. This enabled them to investigate the changes in behaviour from Bernal-style 'ball-bearing liquids' to analogues of long-chain polymer melts.

Using ideas from polymer physics, the researchers predict that the resistance force due to friction is self-amplifying, increasing exponentially with the applied load, and that the exponent is proportional to the square root of the chain length. That's a relationship closely borne out by the data using a mechanical indenter.



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They also consider the case of a 'dilute polymer' in a solvent of single beads, where, by analogy with real polymer solutions, the chains are expected to be more or less self-avoiding, blob-like random coils. Again, polymer theory suggests a dependence of the exponent on the volume fraction of chain beads to the power 11/8, which is close to the measured value.

As well as lending further credence to the correspondence between microscopic molecules and macroscopic grains and chains, the work suggests that powders might be given greater mechanical integrity by interspersing a low concentration of chain-like structures, which may help to bind the grains together purely by friction. □

Published online: 26 March 2018
<https://doi.org/10.1038/s41563-018-0048-y>

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