PERSPECTIVES: GRANULAR MATERIALS

Mixing and De-mixing

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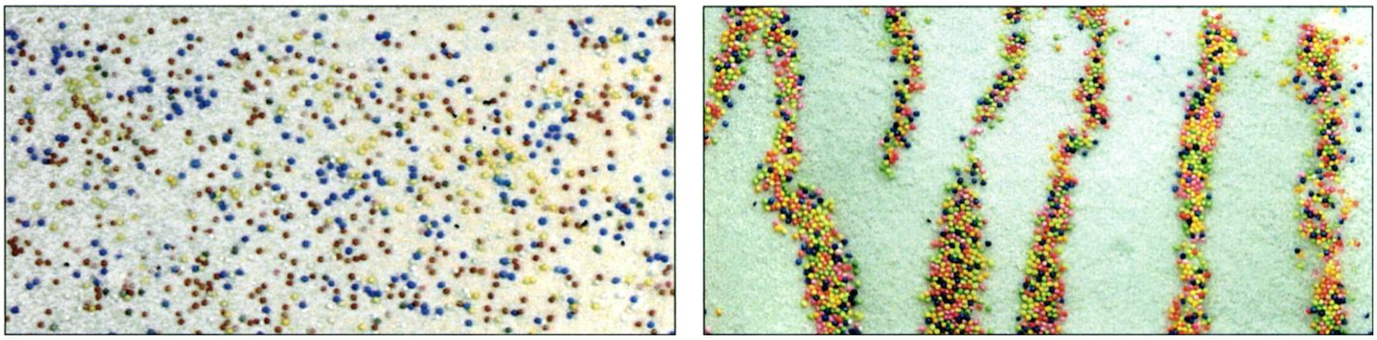
If you take a pack of playing cards and shuffle it many times, it is reasonable to expect this action to randomize the cards, allowing a fair game to ensue. It would surely come as a surprise if the pack were turned over to reveal that the red and black cards had separated out with the 26 red cards in one half of the deck. The probability of this event is finite but vanishingly small.

It is similarly counterintuitive that shaking a box containing a mixture of two similar dry granular powders will separate the constituent components so that a completely de-mixed state is formed. But on page 1877 of this issue, Burtally *et al.* (*1*) provide evidence for just such a behavior. They show that when a dry powder mixture consisting of particles of equal size but different density is vibrated up and down, it can completely separate out with probability of one.



Size segregation of a polystyrene sphere/"sprinkles" mixture. The colored sugar balls lie in a layer of beads that is two particles deep. Initially, the balls are distributed randomly (**left**); when horizontal vibration is applied, they form ordered patterns (**right**).

The phenomenon of de-mixing has been known to engineers for a very long time and is considered a nuisance in many technological processes (*2*). In almost all cases, the particles are of different sizes, and one cannot always predict whether this phenomenon, known as "size segregation," will occur. Segregation is made possible by the gaps that open up around particles when they are shaken or made to flow, allowing percolation to occur. Large particles tend to move toward less dense regions of smaller particles, and this is why large heavy objects can rise to the top of vertically shaken layers of granular materials. You can exploit this phenomenon by shaking a box of muesli up and down before serving. In this way, you can select some of the best bits, much to the annoyance of the rest of the household.

In recent years, it has become clear that dry powders not only segregate but that they can also spontaneously form patterns in the process. In other words, in the playing card analogy, the cards will be sorted into their respective suits by shuffling. An example of a pattern in a dry granular mixture is shown in the figure. An originally uniform mixture of polystyrene spheres and cake decorations ("sprinkles") has been oscillated from side to side (*3*). The striped pattern forms after a few minutes of excitation, and its behavior follows simple systematic rules.

Patterns such as those in the figure share features with the geological phenomenon of "stone striping," where loose rocks form line patterns naturally on the dirt surfaces of Alpine slopes subjected to solar heating cycles (*4*). Spontaneous pattern-forming processes such as these have received increasing interest in recent years because of developments in the mathematics of nonlinear dynamical systems.

On a more practical level, the results of Burtally *et al.* raise some serious questions about the mixing of powders. The manufacture of pharmaceutical pills necessarily involves agitation of dry granular powders, often with two or more components. The first difficulty is to form a uniform mixture of the dry powders because induced flow may encourage them to demix. Various methods have been developed to blend dry materials, but these are often empirical and laborious. Even if a perfect mixture can be formed, it still has to be transported and put into dyes to make the pills. Both of these actions will involve flow and hence the possibility of segregation.

As in any aspect of processing, practical solutions to these problems need to be economically viable for low-cost products. There is a limit to the progress that can be made with an empirical approach. There is therefore a great need for an improved understanding of the fundamental processes underlying segregation.

Many of the advances made in the theory of granular processes rely on relatively simple mathematical modeling, which is itself often ad hoc in form. Computer simulations can describe the motion of individual particles subject to the laws of classical mechanics. However, these microscopic descriptions are necessarily limited in scope and are not yet able to replicate some aspects of experiments. An alternative approach could be to simulate the motion of the particles as if they collectively acted as a fluid. But this may not capture all aspects of their behavior. For example, Burtally *et al.* point out that the interstitial air between the powder particles has a substantial effect on the observed segregation.

One way ahead is to seek universal properties in the detailed experimental information on relatively simple dry flow systems that has become available in the past few years. Granular flow shares features with other pattern-forming systems in fluid flows, chemical reactions, and nonlinear optics. Simple, controlled studies such as that of Burtally *et al.* provide severe tests for such theoretical models.

Granular materials are of substantial scientific importance. They are ubiquitous in nature, ranging in scale from grains of sand to polar ice floes. They are also of tremendous industrial relevance: The processing of granular materials consumes an estimated 10% of the planet's energy budget. Burtally *et al.* have brought us one step closer to understanding their motion, but many challenges remain before we can predict their behaviors.

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