POWDER PROCESSING

Size segregation mechanisms

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PEBBLED beaches, industrial powders and jars of mixed nuts have this in common: when shaken or agitated, the larger particles rise to the top. But the microscopic mechanisms underlying this segregation and the salient features of the 'shaking' processes that drive it are far from clear. Knight and co-workers have now put forward a new idea: that the formation of convective rolls in a shaken powder provides a mechanism for size segregation[1].

Much of the modern interest in segregation mechanisms was stimulated by two-dimensional computer simulations of shaking by Rosato *et al.*[2]. In their picture, each cycle of applied vibrations causes all the grains to rise from the base of the container, so that the granular bed becomes dilated. Then, during settling, the smaller particles can fall more freely; larger grains require larger voids to fall into, and these can be generated only by the collective motion of many small grains, which is statistically unlikely. The large grains therefore appear to rise through the bed. There is no size threshold below which the segregation ceases, but an isolated impurity will rise only intermittently if the size ratio of large to small particles is low (at least in finite-sized computer simulations). For large particle size ratios, the segregation is a continuous process.

The key feature of low-temperature Monte Carlo simulation techniques, such as the one used by Rosato *et al.*, is that they include simultaneous and cooperative grain movements (known as 'non-sequential' particle dynamics). Nonsequential elements are an essential feature of granular dynamics[3]. Crudely speaking, this is because granular configurations are not subject to the constant jostling of brownian motion, and therefore clusters of grains, once formed, are frozen in. The competition between the motion of these clusters and the motion of independent grains is crucial for size segregation.

The confusion raised by a simple model of shaking that omitted collective motion illustrates this point. The simulations made by Jullien and co-workers[4] predicted a size threshold for segregation and provided no role for the shaking amplitude, two features which run contrary to most of the experimental evidence[5–7]. The origin of these discrepancies can be traced to the purely sequential and deterministic granular dynamics used by Jullien *et al.* to drive segregation; more realistic behaviour is recovered only if collective effects and complex coupling of the granular assembly to the driving force are included[8]. This coupling reflects the complex fashion in which the driving force is transmitted to an interior grain through inelastic collisions, variable interparticle interactions and friction, if any; that is, the effect of tapping a tray, a jar or a conveyor belt will not be felt by all grains alike.

The experiments of Knight and co-workers add another ingredient to this complicated picture: convective motion. Using cylinders filled with glass beads 2 millimetres in diameter and also containing one or two larger beads of the same composition, they have demonstrated that, under conditions of low amplitude and high acceleration, convective motion causes size segregation in a vibrated bed.

They monitored the progress of selected (dyed) beads — the large beads, and the layer of small beads in which they originally nested. Both large and small particles were borne upwards along the middle of the cell, they found, but while the smaller particles were transported

Windows open onto Titan's surface

WRAPPED in a mystery inside an enigma, Saturn's moon Titan is cloaked by a dense atmosphere, making its surface the largest unexplored area in the Solar System. At visible wavelengths a thick stratospheric haze hides the surface from view, and Voyager images such as this one show virtually no features. Infrared imaging is difficult because of the large atmospheric concentrations of methane, nitrogen and hydrogen. But in the near-infrared, extinction by the haze is not such a problem, and there are a few narrow spectral 'windows' in which the atmosphere absorbs only weakly.

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Caitlin Griffith, on page 511 of this issue, uses these windows to explore Titan's surface; she presents Earth-based measurements of the respective albedos when Titan is at eastern and western elongation relative to Saturn. (Although Titan's rotational period is unknown, Griffith assumes that its rotation is synchronous with its orbit around Saturn, so that opposite hemispheres face the Earth when Titan is at opposite elongations.) She shows that the albedo at eastern elongation is larger than that at western elongation for two different orbital cycles.

In a separate paper, Lemmon *et al.* (*Icarus* 103, 329–332; 1993) detect a similar variation in albedos for a single orbit, and suggest that they may be observing some kind of surface feature. But as they have results from only one orbital cycle, it is hard to rule out the possible influence of the transient clouds that can sweep across the surface. Griffith's observations for two additional cycles place the interpretation beyond doubt — Titan's surface is clearly heterogeneous.

This poses a problem for current theories about the surface composition. It is widely believed that the surface is coated with liquid methane and ethane, partly because methane has a very short lifetime in the atmosphere, so the high atmospheric concentration of methane implies a readily available source such as a surface ocean. Also, atmospheric methane photolyses to form ethane, which is a liquid at Titan's cold surface temperature. But Titan's large orbital eccentricity means that if there is an ocean, it should be global and more than 400 metres deep, which is hard to reconcile with the heterogeneity seen by Griffith. In fact, Griffith suggests that her observations are consistent with a water-ice feature on the surface. More information should be forthcoming if the Cassini mission manages to map the surface in more detail using the same near-infrared windows.

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