of nicked DNA substrates. This finding could be of therapeutic importance.

Dideoxynucleoside drugs and their analogues — such as ddC, ddI, AZT, D4T and T3C — are not usually incorporated into genomic DNA in large amounts. But they do get into our genome through the action of polymerase b, which can incorporate them into repair patches during base excision repair[8], and through another polymerase (g), which inserts them into mitochondrial DNA[9]. Both of these events should cause problems, as incorporating these substances into DNA generates strand breaks that cannot be joined. Thus, by removing them from genomic DNA, APE1 helps our cells to survive.

In contrast, because DNA synthesis by HIV takes place in the cytoplasm, where there is no APE1, chain terminators incorporated into the proviral DNA by the HIV enzyme reverse transcriptase are not removed. As a result, synthesis of full-length HIV DNA can be inhibited. So, by improving the efficiency of APE1-mediated removal of chain terminators from genomic and mitochondrial DNA, it should be possible to reduce the side effects of HIV therapy.

The APE1-catalysed removal of nucleoside analogues from DNA termini is also interesting from the structural point of view. All of these substances form standard Watson–Crick pairs with the nucleosides in the complementary strand. This implies that, rather than seeing the mispairs as such, APE1 may be detecting subtle distortions of the double helix at the nick, characterized by misalignments of the strand ends that make it impossible to rejoin them.

Gorillas that have learned to use sign language remain a rarity, even though they pop up on television from time to time. The newly discovered proofreading APEs, by contrast, are clearly commonplace and, in contrast to signing gorillas, likely to be of considerable clinical importance. ■

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Granular materials

Taking the temperature

Bob Behringer

The 'temperature' of a granular material depends on its entropy, but is hard to measure in the laboratory. So a theory that ties temperature to grain mobility and diffusion is welcome.

Granular materials are collections of solid, macroscopic particles, characterized by a loss of energy whenever the particles interact[1] (for instance, through friction when grains collide). On page 614 of this issue[2], Makse and Kurchan offer new insight into the statistical properties of granular materials. In particular, their simulations suggest ways of determining a granular 'temperature', defined by the kinetic motion of the grains in much the same way that the random motion of molecules in a gas defines its temperature[3].

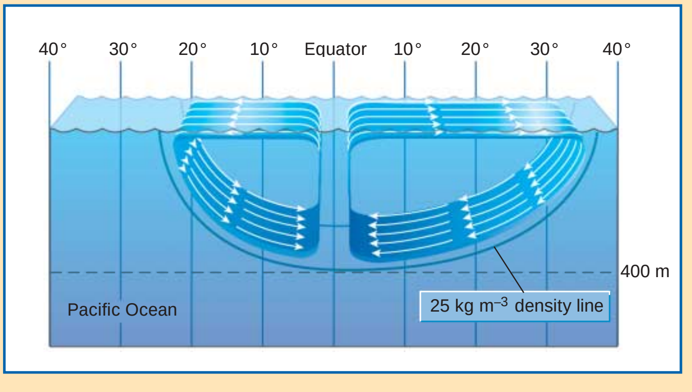
Typical granular materials include coal,

Oceanography

A slower flow

The deep 'overturning' circulation in the North Atlantic, in which northward-flowing surface water sinks at high latitudes and flows back at depth, may not be fully understood, but its existence has long been public knowledge. The Pacific has held on to some of its secrets for longer. Only in the 1990s were two shallow overturning circulation cells discovered, lying on either side of the Equator. As they describe elsewhere in this issue (*Nature* **415**, 603–608; 2002), M. J. McPhaden and D. Zhang have now produced an analysis of historical data to show that both cells have been slowing since the 1970s.

The circulation loops occur because winds produce surface currents away from the Equator. Water masses then flow along surfaces of constant water density (the figure shows the 25 kg m1 3 surface as an example) from subtropical regions towards the Equator, at depths of 100–400 m. Near the Equator, upwelling water replaces that lost at the surface to wind action.



McPhaden and Zhang have looked at data for the Pacific between 20° S and 50° N for the years 1950 to 1999. The calculated volumes of water transported in both circulation loops were much the same for 1956–65 and 1970–77, but declined rapidly in ensuing years. In the period 1990–99, the circulation volume was 25% less than at the earlier times.

This slowdown could help account for other changes that occurred in the past couple of decades. For instance, sea surface temperatures in the tropical Pacific Ocean have risen by about 0.8 °C since the 1970s, despite increasing cloudiness. And the amount of carbon dioxide released into the atmosphere from that part of the ocean has declined. Both observations can be explained by a reduction in the delivery of relatively cool, CO_2-rich subtropical water to the equatorial ocean.

Perhaps the most intriguing question is whether there is any connection here with the El Niño/Southern Oscillation (ENSO), which occurs on shorter timescales. A shift towards stronger and more frequent El Niño events occurred in 1976–77, just when the decadal decline in the circulation began. But it is not clear whether the longer-term variation in circulation is a consequence of the increasing number of El Niño years, or whether the circulation slowdown provided the background for the change in ENSO cycles.

In the North Atlantic, changes in atmospheric conditions (the so-called North Atlantic Oscillation index) have brought milder and stormier winters to Northern Europe. As with the events documented by McPhaden and Zhang, this is a change that occurs over a period of several decades. There may in both cases be a connection with human-induced climate change, but for the moment that possibility remains speculative. **Heike Langenberg**

BILL BACHMAN/SPL

Figure 1 **New work[2] clarifies the thermodynamics of granular materials, such as sand.**

wheat, sand (Fig. 1) and all sorts of powders. The study of such materials has a long history dating back to at least the time of Coulomb[4], whose friction law was actually derived for these materials rather than for blocks moving on planes. It was Reynolds[5] who first showed that compacted materials must first expand (dilate) if they are to deform. And Faraday's observation[6] of convection in a shaken powder provided an insight into the role played by the surrounding air. More recently, investigations of granular materials have been driven by commercial applications. Vast sums of money are expended in handling these materials for applications that range from energy production or extraction to food supplies and pharmaceuticals.

In the past few years, researchers have taken up the issue of the statistical properties of granular materials. Because these materials have flow characteristics that roughly resemble those of ordinary, newtonian fluids, it is tempting to look in that direction for useful analogies. But these analogies should not be pursued too closely: granular systems dissipate energy quickly, so ordinary techniques of statistical mechanics that depend on energy conservation break down.

Undeterred, several groups have worked towards understanding the true statistical properties of granular materials. Such work includes studies of gas-like granular states[7], investigations of fluctuations and stress variability in dense systems[8], and, perhaps most importantly here, proposed new versions of statistical mechanics that would apply in a granular system where energy is not conserved[9–12].

This issue of energy conservation was addressed early on by Edwards and co-workers[9,10]. They introduced a new way of calculating the entropy (the degree of disorder) and temperature for a granular system. Entropy depends on the number of states available to a system. Edwards *et al.* counted the number of configurations possible for fixed volume and energy, and defined the 'Edwards temperature' in terms of the volume derivative of this entropy.

The problem with the Edwards approach is that it is difficult to test directly in real systems. Some experiments have achieved at least a flavour of the Edwards picture, such as studies of granular compaction[12,13] that showed very slow increases in the density of a granular column that is tapped repeatedly. But, as with many granular experiments, their interpretation is complicated because there is a non-uniform rate of energy injection and non-uniform density — the key control parameter.

In Makse and Kurchan's numerical model[2] of a granular system subject to a gentle shearing force, the rate of energy input is uniform (over a reasonable time scale), and a uniform density is maintained. The authors use a tried and tested means to extract a temperature for the system: a comparison of diffusivity and mobility, whose ratio yields the temperature in conventional fluids. They then show that, for their model granular system, this ratio is identical for different particle sizes, just as one would expect in a fluid. The temperature extracted from their observations of diffusion and mobility is also consistent with the predicted value of the Edwards temperature.

So this work shows that, at least in a model system, it is possible to relate temperatures obtained from transport measurements, such as diffusion and mobility, to the Edwards picture. If similar transport measurements are performed in real granular systems, we would have, arguably for the first time, a measurement of a key statistical property that could be matched, in principle, to a theoretical prescription.

But there is a caveat: when real granular systems are sheared or shaken, they tend to become inhomogeneous often in both space and time. Although, to a certain extent, inhomogeneities can be avoided or accounted for, the link to the theoretical picture would be broken. Nonetheless, this work[2] leads us towards a clearer understanding of the statistical properties of real dense granular materials. ■

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Daedalus

Perfect perforations

Birds have feathery porous wings, and engineers are pondering the reason, with a view to applying it to aircraft wings. One idea is to riddle aircraft wings with tiny holes. Any solid wing has a boundary layer of air. A porous wing can remove this layer by suction, or displace it by blowing. To optimize these effects, says Daedalus, we need a wing that is dense with little holes, but not at 90° to the wing surface. The wing should suck at the front, with each inlet hole pointing forwards to accept air from ahead. It should blow at the rear, with exit holes angled steeply to eject air backwards. The two effects would counterbalance each other, but need not cancel out. The ideal combination would optimize the wing as a lifting device of low drag.

Modern passenger aircraft need to provide cabin air for their passengers. The wings might draw on the plane's air budget, or alternatively might help to supply it; any supply from or drain to the wings must be taken into account. Even so, Daedalus reckons that porous wings must have good physics behind them, or rather beneath them. Nature knows her business.

Daedalus does not intend to power his aircraft from the air extracted ahead and ejected behind by its porous wings, though this should make a useful contribution. His idea is simply to make artificial porous wings as efficient as possible, and with the lowest feasible drag.

So DREADCO engineers are flying blown and sucked wings in a wind tunnel, and comparing the results with those obtained with naturally feathered wings. Both natural and artificially porous wings should have lower drag and higher lift than the standard solid variety. Further, sucking in air at the front while ejecting it at the back should improve the wings both as lifters and thrusters.

One problem will be ice, which at high altitudes grows on even the best wings. But conventional engines are only about 25% efficient, so 75% of their energy is wasted as heat. A distributed cooling system would warm the wings, helping to keep ice away. It could heat the rear-ejected air as well, increasing the thrust of blown wings by a sort of afterburner effect. A plane with cylinder engines could even release its exhaust gases through the rear-facing holes in a blown wing. This would neatly capture energy that would otherwise be lost, and raise the thrust of the wings. Sadly, it would disfigure the usual tasteless painted-on colour scheme.

David Jones