

simplicity, the mini-domain V1/V2 epitope designed by McLellan *et al.* may well be a more straightforward target for re-eliciting potent neutralizing antibodies by active vaccination.

However, uncertainties remain. First, does the scaffolded V1/V2 mimic reported here accurately represent the respective molecular architecture of the actual gp120 trimer? The answer would come with the structure of the trimeric envelope glycoprotein, although the reduced affinity of PG9 for the scaffolded mimic³ compared with that estimated for the trimeric glycoproteins suggests differences.

Second, it is not clear how common this type of interaction between antibodies and glycopeptide antigens is. But there is reason to be optimistic. McLellan *et al.* propose³ that the epitopes of two other related, but distinct, neutralizing antibodies (CH04 and PGT145) have similar structures. Moreover, another potent neutralizing antibody, PGT128, binds a remarkably similar type of glycopeptide

structure in a different region of gp120 called the V3 loop¹¹. This suggests that the production of glycopeptide-reactive, broadly neutralizing antibodies may not be a particularly rare event during HIV-1 infection. The convergent evolution in antibody recognition also suggests that the immune system is rising to the challenge of generating antibodies with appropriate shapes to fit the structural constraints required to pierce the gp120 glycan shield and interact with protein surfaces beneath.

Vaccination relies on triggering the immune system's B cells to produce antibodies. Will vaccination with appropriately designed antigen mimics such as that described in this paper³ elicit equivalent antibody responses to those seen during HIV-1 infection? This cannot be answered yet. What we do know is that B cells from some individuals infected with HIV-1 recognize this type of glycopeptide epitope after stringent selection and a substantial degree of mutational evolution to

increase antibody binding strength for antigen. Whether vaccination can select the appropriate B-cell specificities and drive sufficient antibody evolution remains to be seen, but this is likely to be the major remaining hurdle on the way to an antibody-based HIV-1 vaccine. ■

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SOFT MATERIALS

Marginal matters

Most soft materials, such as sand, can be in either a solid-like or a liquid-like state. New experiments probe the surprisingly rich nonlinear physics that can occur in between these two states. SEE LETTER P.355

VINCENZO VITELLI & MARTIN VAN HECKE

All around us, things are falling apart. The foam on our cappuccinos looks solid, but gentle stirring irreversibly changes its shape. Sand, a granular material, mimics a solid when we walk on the beach but a liquid when we pour it out of our shoes. Such examples suggest that we can think of the mechanics of soft disordered materials as either jammed (solid-like) or unjammed (freely flowing). On page 355 of this issue, however, Bi *et al.*¹ describe experiments showing that such materials come in more than just these two flavours.

The hybrid behaviour of sand and foams has fascinated physicists for decades, and lies at the heart of Liu and Nagel's jamming diagram² (see Fig. 1a of the paper¹). The idea behind this diagram is that the mechanical state of a whole range of soft materials — such as granular media, pastes, foams and emulsions — is controlled by how densely their constituents (grains, bubbles or droplets) are packed. Dense packings are jammed, loose packings are unjammed, and when the constituent particles just touch, the material is said to be marginal. Think of mayonnaise, an emulsion of oil droplets in water: only when a sufficient amount of oil is added to the mixture do the oil droplets start to touch and the

mayonnaise acquires its solid-like consistency.

Bi and colleagues' experiments¹ suggest that the jamming diagram should be revisited to describe a broader variety of states than the strictly jammed and unjammed ones. The authors placed a granular material consisting of small plastic discs in a box whose side walls could be moved in order to compress or shear (deform without compression) the material. The discs were photoelastic and so permitted direct visualization of the forces operating

between them when the material was subjected to deformation: the more incident light that went through the material, the larger the forces³.

The first question Bi *et al.* addressed was, what happens when such granular material is sheared? Typically, when we spread mayonnaise on a sandwich, smear foam on our skin or kick a sandcastle, we unjam these materials. By contrast, the authors¹ find that, when sheared under constant volume, collections of loose, unjammed discs build up pressure and resist further deformation — they become rigid. This phenomenon is reminiscent of Reynolds' dilatancy, in which granular materials expand when sheared under constant pressure. A familiar manifestation of this is how footprints on a wet beach tend to become dry as the deformed sand expands and sucks in water.

The second question Bi *et al.* tackled was, what is the nature of the novel states in which mechanical rigidity is generated by

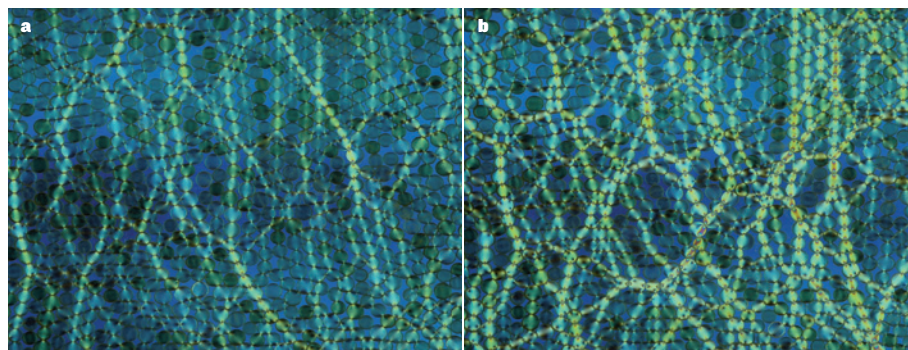


Figure 1 | Fragile and shear-jammed states. Bi and colleagues¹ prepared a granular material consisting of a mixture of plastic discs of diameter 0.74 and 0.86 centimetres and subjected it to shear deformation. **a**, For small applied shear deformation, the material becomes fragile: the discs come into contact with each other mostly in one direction (here, vertical). **b**, For large applied shear deformation, the material is said to be shear-jammed: the discs come into contact with each other in more than one direction. The intensity of light seen on each grain is proportional to the amount of force it experiences.

shearing? The authors show that these states are anisotropic, as evidenced by the patterns formed by the bright, load-bearing discs. For moderate anisotropies, the states seem to be fully jammed: they are rigid enough to resist deformation in any direction. These are shear-jammed states. However, in the case of strong anisotropy, the packings become fragile: the discs come into contact with each other mostly in one direction (Fig. 1). Such fragile packings⁴ can resist deformation in some directions but not in others. These packings are thus neither fully jammed nor fully unjammed.

To account for their findings, Bi *et al.* suggest a modification to the jamming diagram: in addition to the areas describing the jammed and unjammed states, there should be an in-between region for the fragile and shear-jammed states (see Fig. 1b of the paper¹). All of these states should meet near a point known as the marginal or jamming point, at which the rigidity vanishes.

This proposed diagram is specifically geared towards frictional granular media. But the idea of fragile states⁵, which are extremely susceptible to perturbation and emerge from the marginal point, is more general. Many soft materials — including granular media, emulsions, foams and polymer networks — can be prepared in a state of vanishing rigidity and thus become marginal materials. Several examples are emerging^{6–10} that show precisely how the mechanical response of such marginal materials becomes strongly nonlinear. The closer they come to the marginal point, the lower the driving force needed to access this fully nonlinear regime. At the marginal point, even the tiniest perturbation produces an extremely nonlinear mechanical response.

One example of the nonlinear behaviour of fragile matter is the mechanics of networks of randomly arranged springs. These reach a marginal state when the average number of springs equals twice the number of network nodes. Such networks are floppy if fewer springs are present and become rigid when extra springs are added, provided that they are under relatively weak stress. Between these two regimes, there is a window of extreme response: when the spring network is near its marginal state, its response becomes completely nonlinear⁶.

A second example is the flow of foams and soft colloidal suspensions. Under low stress, these exhibit a liquid-like state for low densities and a solid-like state for high densities. In between these two states, an intermediate regime of nonlinear flow arises^{7,8}.

A third example is waves in granular media. Under large pressure, linear elastic waves occur. However, at low pressures the material approaches its marginal point, and even a gentle touch can generate strongly nonlinear shock waves^{9,10}.

Bi and colleagues' work¹ underscores the surprisingly rich nonlinear physics that governs marginal soft matter. The simplest

manifestation of this nonlinear behaviour can be found near the marginal point. In many cases, it is unclear exactly what happens when such fragile materials are subjected to stress. But what is clear is that being marginal matters. ■

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SUPRAMOLECULAR CHEMISTRY

Molecular wires get connected

A long-standing issue in nanotechnology is how to connect molecular electronic devices. A method for splicing nanoscale wires made from different materials paves the way for a solution to this problem.

DARIO M. BASSANI

What could be easier than joining two wires together? Just about anything, if the wires in question are only 14 nanometres thick. Such nanowires are the future of miniaturization for electronics, but are so small that they cannot be handled with tweezers or through other mechanical means. Another problem is that, so far, such wires have been composed of only one type of molecule, which has limited their potential as components of future electronic devices¹. Reporting in *Science*, Zhang *et al.*² now describe an approach for making nanowires in which tubular sections made from different molecular building blocks are connected together. Developing methods for joining materials that have different electronic properties is an essential step towards building nanometre-scale electronic devices such as diodes and transistors.

To achieve their aims, Zhang *et al.* built disc-shaped molecules fitted with long hydrocarbon chains on one side and a metal-binding site on the other. When the authors allowed a solution of the molecules to mix slowly with methanol, the molecules spontaneously assembled into tubes (Fig. 1). This happens because the molecules do not dissolve well in methanol — as the concentration of the methanol in the mixture increases, the disc-shaped molecules stick together to avoid being in contact with it. As they aggregate, the molecules partly overlap one another in a way that forms tubular nanowires.

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Zhang *et al.* constructed the central disc of the molecules from carbon atoms with the same electronic configuration as graphene sheets³ — that is, with atoms that form an aromatic, hexagonal network of alternating single and double bonds. This makes the molecules especially good at transporting charges when they are 'doped' (mixed with small quantities of another compound that partly ionizes the molecules) or illuminated with light. The authors also prepared similar molecules in which some of the hydrogen atoms on the periphery of the central disc were replaced by fluorine. This reduces the electron density in the disc, making the molecules better electron acceptors than the non-fluorinated analogues. Zhang *et al.* then used molecular wires made from the non-fluorinated molecules as 'seeds' that promoted the deposition of the fluorinated molecules from solution as new tubular segments at the ends of the seed wires (Fig. 1).

The authors designed their system so that the molecules in the different segments of the wires do not scramble after they are mixed. Such behaviour is highly unusual because it seems to undermine a fundamental premise of molecular self-assembly: electron-rich molecules prefer to mix with electron-poor ones to form alternating layers of each, analogous to the way that small magnets spontaneously align with their magnetic poles opposed. To understand why no scrambling occurs, we need to consider the basics of self-assembly processes.

Molecular self-assembly is driven by a