tion they use was initially proposed for the analysis of a model describing interacting relativistic particles in two-dimensional spacetime (*10*). The theory now operates in a different world of particles: Phonons, which are normal modes of the entire system, are replaced by weakly interacting soliton-like particles that are fermions traveling through the system. The new theory cannot be renormalized, which should be expected given that it is the old one in disguise. However, if residual weak interactions between the new soliton-like particles are neglected, the theory can be treated exactly, and the interactions between the prototype particles—the phonons—remain practically unchanged. These interactions are encoded in the nonlinear transformation rules from one theory to the other and allow any hydrodynamic observable to be calculated explicitly.

The beauty of Imambekov and Glazman's work is that it provides an example of a meaningful quantum field theory for a problem lacking a consistent perturbative formulation. The mathematics of this theory is not only interesting—it describes real systems with rich phenomenology, and should allow for further explorations. For example, it should be possible to develop a theory of quantum wave breaking and quantum shock waves.

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10.1126/science.1168389

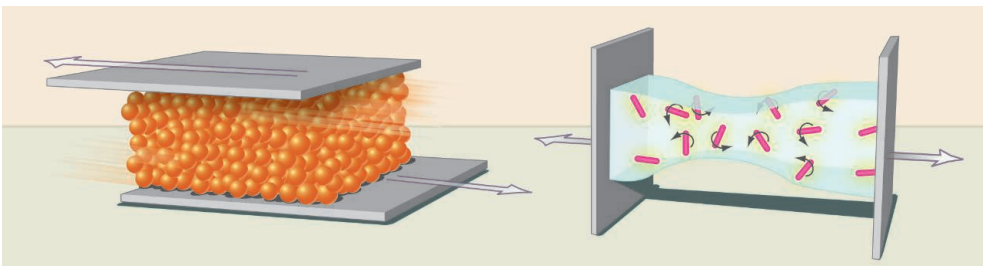
MATERIALS SCIENCE

Unjamming a Polymer Glass

Small probes reveal that glass can melt in different ways.

David A. Weitz

When a glass is heated, it melts and begins to flow. This transition from an elastic solid to a flowing fluid is a distinguishing feature of the glass transition, one of the most widely studied, yet incompletely understood, phase transitions (*1*). The application of stress can also make a glass flow; softer glasses, including many polymers, yield when subjected to sufficiently large stresses (*2*). The equivalence of these two routes to flow is a basic tenet of jamming, a conceptual means of unifying glassy behavior with that of granular materials such as sand (*3*). The shear-induced flow of sand, or other granular materials, is well studied. On page 231 of this issue, Lee *et al*. (*4*) show that the nature of shear-induced flow in molecular glasses can now be probed. By measuring the motion of small probe molecules in a polymer glass, they find fluidlike properties when the glass is sheared; however, the route to melting the glass is different from that followed when it is heated.



Shear flow. Schematics comparing shear-induced flow in a granular material (**left**) and a glassy polymer (**right**).

Lee *et al.* use an optical method to measure the rate of rotation of small dye molecules embedded within thin slabs of lightly cross-linked poly(methyl methcrylate) (PMMA). These probe molecules provide a direct, local measure of the fluidity of the polymer. As the temperature is increased and the polymer glass starts to flow, the structural relaxation rate of the polymer, as determined by the motion of the probe molecules, becomes measurable and begins to increase with temperature, adopting the characteristic stretched exponential form of a fluid very close to the glass transition (*5*). Moreover, the structural relaxation exhibits the strong spatial heterogeneity commonly observed in a fluid very close to the glass transition (*5*, *6*). The new experiments investigate the behavior of the probe molecules when the polymer is subjected to an external uniaxial tension; the sample is pulled apart by its two ends. Initially, when the strain is small, the structural relaxation rate increases slightly, and can be described by a theory that incorporates the effects of the induced strain energy, which lowers the activation barriers for the relaxation of the probe molecules due to their shear-induced rotation (*7*). The shape of the decay retains the characteristic stretched exponential form. However, as both the strain and strain rate increase, the relaxation rate of the probe molecules increases by several orders of magnitude, and the shape of the relaxation becomes nearly exponential. At this point, the sample undergoes plastic flow, and at the molecular scale, the glass melts due to the induced strain.

This shear-induced melting is exactly what is expected within the jamming picture. The basic concepts of jamming can be understood from the perspective of a granular material, such as a bucket of sand. Normally, the sand in the bucket is a solid; it does not flow and it supports a stress, as easily proven by stepping on it—the sand supports your weight. However, if you tip the bucket, the sand flows, much like a fluid. Here, gravity provides the shear stress that causes the sand to change from a solid to a fluid. To make the analogy between granular sand and a glass requires a second route to fluidizing the sand—by increasing its effective temperature. This can be accomplished by gently shaking it, or by blowing air slowly up through the sand, to slightly suspend all the grains in the flow of air (*8*). In this case, the grains are rapidly moving, but are trapped in place by all their neighbors. This rapid random motion of the grains is akin to an increased effective temperature. To complete the jamming picture, there is a third means of fluidizing a solid, and that is to

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decrease the volume fraction. This may be difficult to comprehend for sand in air, so imagine instead immersing the sand in a fluid to provide buoyancy. Then, if you decrease the number of grains per unit volume, you will eventually have so few grains that they will no longer be self-supporting, and thus the solid will be fluidized. Any of these three routes can take the system through the solid-to-fluid transition, and much work has been devoted to explore the generality of this concept for granular systems. By contrast, there have been fewer attempts to explore the same concept of jamming for molecular glasses.

The importance of the experiments by Lee *et al.* is that they establish that shear does induce melting of the glass, and that the resultant flowing material has many features of a liquid, particularly as evidenced by the relaxation of the probe molecules. However, these experiments also establish that the nature of the solid-to-fluid transition is different when it is shear-induced as compared with thermally induced melting. The sheared sample lacks the large spatial heterogeneities that characterize a melting sample.

Moreover, in a sheared sample, there is a narrower distribution of barriers to relaxation than in a sample that has melted. Instead, it is tempting to think that the imposed shear rate sets the scale for all the relaxations, resulting in a much narrower range of rates. Moreover, flow occurs in localized regions, in agreement with the picture of shear transformation zones (*9*), and the volume of these regions is consistent with that found in computer simulations (*9*) and in measurements of a colloidal glass (*10*), a material that straddles a granular system and a molecular glass.

The comparison between a granular system and a molecular glass, as originally postulated by the jamming concept, remains an intriguing and appealing hypothesis. These experiments provide strong evidence for the merit of this perspective, suggesting that computer simulations of jammed granular systems under shear may also provide new insight into the behavior of sheared molecular glasses. However, a detailed understanding of the true extent of the analogy must await confirmation by further studies. The approach of Lee *et al.* should help make this possible.

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11. This work was supported by the NSF (grant DMR-0602684) and the Harvard Materials Science Research and Engineering Center (grant DMR-0820484).

10.1126/science.1168304

BEHAVIOR

Surprising Emotions

Why are our predictions of how we'll feel or act sometimes wrong?

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Imagine that you are a white student waiting with two other students, one black and one white, for a psychology experiment to begin. The black student steps out of the room for a moment, lightly bumping against the white student on his way out. While he is out of earshot, the white student comments, "Typical, I hate it when black people do that." How would you feel? And if you later had the choice, with which of the other students would you prefer to work? If you anticipate being upset and avoiding the fellow who made the racist remark, you are like most "forecaster" participants in a study by Kawakami *et al.* (*1*) on page 276 in this issue. These were students, self-identified as members of racial groups other than black, who predicted how they would react after reading about or viewing a videotaped enactment of these events.

Other participants in the study, from the same student population as the forecasters, actually experienced this event, with actors portraying the white and black students in the scenario. Surprisingly, when asked during the experiment how they felt, these "experiencers" did not report feeling any more upset when the racist comment was made than when the same event occurred without any comment being made at all. Nor did the experiencers tend to avoid the originator of the racist comment.

These findings are an example of what social psychologists call a failure of affective forecasting: People often mispredict how they would feel (and therefore act) in imagined or future situations (*2*, *3*). In other words, our emotional reactions (or lack of them) often surprise us. Indeed, if our emotions never surprised us, they would fail to perform one of their most important functions: to call our attention to important aspects of a situation that we otherwise might not have consciously noted. For example, one reason for poor emotion forecasting is that experiencers react to a much wider range of cues in a situation, whereas forecasters focus more narrowly on its most salient features (such as the racist remark in the study by Kawakami *et al.*) (*4*).

Who would be in this situation? Depending on the identity (such as egalitarian or racist) that is activated in a given situation, people can experience different emotions and behave in different ways. But people often fail to predict accurately their identity and emotions in a future or imagined situation.

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One thing emotions can inform us about, sometimes to our surprise, is who we are in a given situation. This happens because emotions can arise from our identification with social groups and not only from our individual self (*5*, *6*). For example, imagine you are a woman in an organization, learning that a female colleague has won promotion to upper management. You may feel disappointment and envy if you are taking an individual perspective. But if you are thinking of yourself instead primarily as a woman, you may feel pride and happiness at this blow to the "glass ceiling" (*7*). Thus, feeling happy rather than envious may tell you, perhaps to your surprise, what group membership defines you in the specific situation.

What identities and corresponding emotional and behavioral reactions are possible in

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