After stress comes relax(ation)

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Abstract
Viscoelastic materials take a finite time to relax and dissipate stress and this time scale is directly connected to the microstructure of the material itself. In their paper, Gomez-Solano and Bechinger (2015 New J. Phys. 17 103032) perform ‘miniaturized’ mechanical tests on a range of viscoelastic materials by dragging a micron-sized bead across them using optical tweezers. Upon switching off all the external forces, they watch the bead recoil to its original position and by tracking its motion they pinpoint the relaxation time of the material. These experiments open up a new range of possibilities to characterize stress relaxation at the microscale just by watching it.

Perspective
We all like to relax after being stressed. Materials are like us, they also relax after a stress has been applied to them and, similarly to humans, different materials show different responses to stress. There are the limiting cases, those ideal fellows who relax immediately (Newtonian fluids) and those other ones who keep it all in until the stress is released externally (Hookean solids). And then there is everyone else in between. Most of us take some time to relax and how long it takes can tell you something about the person and their current state. For materials, a finite relaxation time is a signature of viscoelasticity, a mixed, complex response to stress that combines the reactions of an ideal viscous fluid and of an ideal elastic solid. The time associated to stress (or strain) relaxation is directly connected to the internal structure of the material and to the interactions amongst its constituents. This is of particular importance for soft materials, e.g. suspensions, emulsions, foams, polymers and biological matter, for which transitions between viscous and elastic response happen at stress (and frequency) scales easily accessible in a lab [2].

Relaxation experiments are typically carried out in a rheometer, a macroscopic instrument where the material to be studied is confined between two walls and is subjected to a Heaviside step strain, during which internal stress builds up, followed by a period of time during which the relaxation of the stress is measured (figure 1(a)). In recent years there has been a continuing strive to miniaturize rheometers, for the following reasons, among others. First, performing rheological measurements on soft and biological materials often poses severe restrictions in terms of available material quantity or requires the option to do the measurements in specific environments, e.g. in protein solutions, inside cells or living tissue. Secondly, there is a clear interest in studying the response of materials at different length scales, from the macroscopic scale all the way down to the characteristic microscopic length scale of the internal structure of the material. These measurements can be performed via active microrheology, a technique where localized strains and stresses are applied by dragging a micrometric sphere through a material by means of an external force, e.g. optical or magnetic, and where by monitoring the position of the sphere as a function of time the mechanical response of the material can be inferred [3, 4]. Most of the literature up to date has focused on the use of active microrheology for steady-state measurements, e.g. where the probe is dragged at a constant velocity [5–7], or for linear-response studies, e.g. where the probe applies small-amplitude oscillatory deformations [8–10].

In their paper, Gomez-Solano and Bechinger [1] extend significantly the scope of active microrheological measurements by showing that they can be indeed employed also for stress-relaxation studies analogous to...
macroscopic experiments. In their work, they use optical tweezers to drag micron-sized beads and apply localized and controlled strains to a range of complex viscoelastic fluids, i.e. micellar, polymeric and DNA solutions.

They subject the material to a controlled strain protocol (see figure 1(b)) and measure material relaxation after turning off the optical trap by monitoring how the bead moves back towards its original position as the internal stress in the material is dissipated (see figure 1(c)). Interestingly, they find that relaxation proceeds through a double-exponential decay, with two distinct time scales. There is a first, fast relaxation, which is ascribed to viscous damping as the bead moves back in the fluid, and a second, slower relaxation, which is the stress-relaxation time scale of the viscoelastic material.

There are two main features that make these experiments appealing: their conceptual simplicity and the generality of the findings. Macroscopic relaxation experiments in a rheometer are tricky. This is particularly true for weak materials that show a very narrow linear regime and for which very small strains and very long relaxation times need to be probed, challenging the stability and sensitivity of the instruments. Performing the same experiments with an optical trap shows that all of the rheological information can be extracted simply by tracking the position of the probe over time after cessation of the stress. By playing with bead size, strain amplitude and rate, a broad range of material responses may be elicited and collected in a series of conceptually very straightforward experiments. In this fashion, linear and non-linear properties may be measured. The systems tested by the Gomez-Solano and Bechinger showed shear thinning (a viscosity reduction upon increasing strain rate), but other materials can be studied in the future e.g. glassy materials, shear-thinning fluids, i.e. micellar, polymeric and DNA exhibiting a similar rheological behavior that can be generalized by a simple model. This is a common feature in soft materials, where systems with very different details in their chemical formulations show nonetheless similar structures, dynamical and mechanical responses. Therefore, the possibility of continuously drawing analogies and working in ‘boxes’ (e.g. glassy materials, shear-thinning materials, yield-stress materials, etc) populates the soft matter world with wonderful model systems, where new experiments keep shedding light on their potential.

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