much more conservative than those of Tuljapurkar *et al.*[1]. In the past, national governments, as well as international organizations and academic researchers, have almost invariably underpredicted life expectancy in industrialized market-economy countries. For example, in 1984 the United Nations prepared international population projections based on the assumption that the maximal life expectancy in human populations is 75 years for males and 82.5 years for females. The assumption soon proved wrong: in Japan, for instance, the figures in 1998 were 77.2 years and 84 years respectively. The reason for the underestimates is partly because forecasters regard conservative prospects as less controversial and so 'safe'; and partly because they have often extrapolated past trends in death rates by cause of death or age (or both), missing future transitions in the cause-of-death pattern and age pattern of mortality reduction. It looks as if the same error is still being made. ■

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Fluid dynamics

Smart polymer solutions

Jacob Klein

The proverbial water stays off a duck's back because the duck has waxy water-repellent layers on its feathers. Similarly hydrophobic layers on the surface of most leaves ensure that raindrops bounce or roll off them[1]. This is sometimes known as the Lotus effect — after the leaves of the Lotus flower, which are particularly hydrophobic — and makes it easier for rain to wash away dust and dirt and keep the foliage healthy[2]. But these same waxy layers can have less desirable consequences: for example, they cause droplets of herbicide and pesticide sprays to bounce off plants[3]. As a consequence, over 50% of these toxic sprays are wasted, making it difficult to protect crops and meet environmental regulations.

On page 772 of this issue, Bergeron and co-workers[4] show that by adding low concentrations of long, flexible polymers to water droplets, they can prevent the droplets from bouncing off hydrophobic surfaces. As well as showing how plants could be more effectively sprayed, the work has applications in other areas, such as the efficiency of water-based inks or paints to coat water-repellent surfaces. In this case, polymer additives would eliminate the unwanted side effects associated with the use of noxious organic solvents, which wet such surfaces more readily.

Liquid drops hitting a flat, solid surface expand and flatten, because of their momentum. Most studies to date[5,6] — driven by the need to coat surfaces with liquids as efficiently as possible — have focused on the behaviour

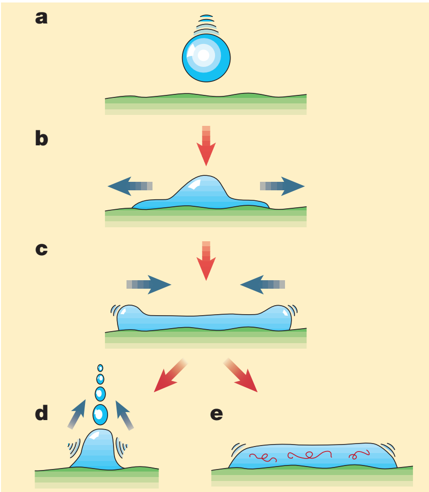

Figure 1 **How to save on weedkiller.** a–c, **The progressive flattening of a water drop hitting a solid surface.** c, **The drop has reached its maximum radius and begins to retract from the hydrophobic surface.** d, **Pure water then retracts rapidly enough to be ejected from the surface.** e, **Bergeron *et al.*[4] show that adding a low concentration of long, flexible polymers slows down retraction — as a result of increasing elongational viscosity — to the extent that ejection does not occur.**

of so-called newtonian fluids[7], such as water, whose viscosity is essentially unchanged by most rates of deformation or 'shear'. In the case of water hitting a hydrophobic material, the drops retract after flattening to minimize their contact with the surface; this retraction may be so rapid that part of the drop is ejected and lost from the surface (Fig. 1). Bergeron *et al.*[4] found that a small concentration of a long, flexible polymer added to the water dramatically slows down the retraction rate of the flattened drop on a hydrophobic surface. This prevents it from reaching 'escape velocity', ensuring that the drop — and anything delivered within it — remains on the surface.

Why does the addition of such small amounts of polymer (typically 0.1 g of polymer per litre of water) have such a large effect? One way that very low concentrations of polymer additives could produce a large surface effect is through adsorption, by which the polymers adhere to the solid surface. Indeed, studies have shown that polymers attached to non-wetting surfaces can stabilize liquid films and prevent 'dewetting'[8,9]. A simple calculation suggests that the duration of the droplet spreading in the experiments of Bergeron *et al.*[4] is sufficient for a polymer layer to adsorb onto the surface. But the authors report that the surfaces remain similarly hydrophobic both before and after the polymer solution has made contact with them.

From this, they conclude that adsorption of the polymer — which would reduce the water repellency and would therefore slow down the drop retraction — is negligible and is unlikely to provide the answer. In fact, they suggest a different origin for the slowing down of the retraction phase. They propose that the flexible polymer coils provide a large resistance to being stretched in the rapidly deforming drop as it retracts after spreading. Such resistance results in a drag on the flowing liquid that is known as elongational or extensional viscosity[7], and it is this, they suggest, that is responsible for the sluggish retraction rate and that stops the drop from bouncing off. The initial flattening is dominated by the drop's momentum, and is much less affected by the elongational viscosity. But the retraction is driven by hydrophobicity, a weaker driving force, which is therefore more affected.

Elongational viscosity in polymer solutions is a non-newtonian effect that comes into play only at deformation rates comparable to or larger than the molecular relaxation rates of the polymer molecules. It can then be orders of magnitude larger than the more familiar shear viscosity, which arises from the drag of the solvent on the undistorted polymer coils and manifests itself at all deformation rates. Elongational viscosity has long been exploited in firefighting, where a tiny concentration of dissolved polymers can dramatically increase the range of the water jet emerging from the hose.

This effect, known as turbulent drag reduction[10], is thought to result mainly from an increase in elongational viscosity, which suppresses the spread of turbulence and so ensures that the flow within the pipe remains streamlined and rapid (an extra benefit is suppression of the jet break-up as it leaves the nozzle). This is one of the few known practical applications of elongational viscosity, as opposed to the widespread use of polymers to increase shear viscosity, such as the thickening of foodstuffs by starch, a naturally occurring polymer. So it is intriguing, as noted by Bergeron *et al.*, that the same elongational viscosity should act to reduce rather than increase flow, thereby suppressing the rebound of water droplets.

To confirm their theory, Bergeron and co-workers[4] show that drops of a polymer solution with a high extensional viscosity retract at the same speed as drops of polymer-free water thickened to the same high viscosity by mixing with glycerol. Such evidence is circumstantial but persuasive: the implication is a new and unexpected demonstration of extensional viscosity, and may find applications in other areas where rapidly deforming thin films are involved. An extra bonus of this system, as the authors point out, is that the shear viscosity of their dilute solutions remains almost indistinguishable from that of pure water, ensuring that little viscous friction is encountered while handling and pumping the liquids. The high elongational viscosity becomes important only when it is needed — during the rapid deformation of the retracting drop. Not an intelligent liquid, perhaps, in view of its simplicity, but certainly a smart one. ■

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Neurobiology

Nervous engineering

Melitta Schachner

The ability to repair damaged tissue in the human nervous system has long been a goal of neurobiologists. Writing in *Proceedings of the National Academy of Sciences*, Todd Holmes and colleagues[1] describe a promising biomaterial for this purpose. It consists of a peptide scaffold that can act as a substrate for the attachment of neurons, and allows the growth of nerve fibres and the formation of synapses — the specialized connections between neurons. It is early days as yet, but the idea is that such artificially grown tissue could be transplanted into patients.

Repairing nervous tissue is no easy task. Cell replenishment happens in many other adult mammalian tissues, but very few new neurons are produced in the adult central nervous system. Moreover, the outgrowth of fibres from regenerating neurons into damaged areas is controlled by various molecules that can promote or inhibit the process; and neurons that lack an appropriate substrate cannot regrow and are vulnerable to self-destruction through apoptosis. An ideal transplantable substrate for repairing damaged tissue in the nervous system should support neuronal attachment, fibre outgrowth, and survival and formation of active synapses. Such a substrate should be well tolerated *in vivo*.

Development of the new peptide-scaffold biomaterials[1] started with a serendipitous observation by Holmes and Shuguang Zhang, another of the authors on the paper. Holmes was testing the neurotoxicity of peptides in neuronal cultures, and Zhang provided him with the so-called EAK16 peptide for the purpose. As its name implies, EAK16 is 16 amino acids long, and it is made up of repeating units of negatively charged glutamate residues (E in single-letter amino-acid code) and positively charged lysines (K), separated by hydrophobic alanines (A). This arrangement gives EAK16 two distinct polar and non-polar surfaces.

Much to their surprise, Holmes and Zhang observed the formation of macroscopically well-ordered, thin-sheet structures in the neuronal cultures into which EAK16 was introduced; moreover, there was no measurable neurotoxicity in the cultures exposed to the peptide. They went on to find out that the formation of the macroscopic sheet structures from EAK16 depended on millimolar levels of monovalent salts. Scanning electron microscopy of the sheet structures revealed a fibrous assembly of the EAK16 material. The openings between the microscopic fibrils were small enough to exclude cells, but large enough to allow the passage of macromolecules. Holmes, Zhang and colleagues devised a molecular model for the salt-induced formation of the EAK16 material and published their findings in 1993 (ref. 2).

The sequence of EAK16 has some similarity to the RGD (arginine-glycine-aspartate) sequence that is characteristic of some integrin receptors, molecules that are central players in cell adhesion and nerve-fibre outgrowth. On making the EAK16 derivatives RGD16 and RAD16, Holmes and Zhang found that the RAD16 peptide formed stable macroscopic sheets in solutions containing salt at physiological levels. In contrast, no macroscopic materials were formed from the RGD peptides. With the help of Michael DiPersio, they tested the hypothesis that cells would attach and grow on the RAD16 peptide biomaterials in an integrin-dependent fashion. They found, however, that both EAK16 and RAD16 peptide biomaterials robustly supported the attachment and growth of many types of non-neural primary

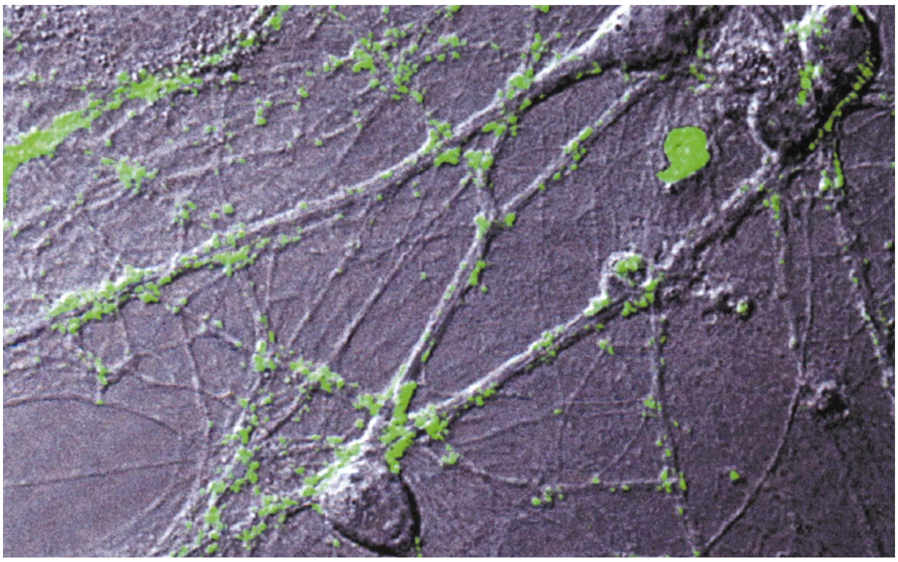

Figure 1 **Synaptic activity of neurons grown by Holmes *et al.*[1] on their peptide scaffolds. The neurons concerned come from rat hippocampus; the fluorescent dye is indicative of neurotransmitter release. (Reproduced from ref. 1.)**