Engineering

A quirky fluid that has robotic capabilities

P.-T. Brun

Scientists have designed a liquid that behaves as both a solid and a fluid owing to the presence of tiny gas-filled capsules. An unusual relationship between pressure and volume enables this material to grasp fragile objects. **See p.545**

Solids, gases and liquids are states of matter with well-established — albeit dissimilar — properties. For instance, gases can be compressed, whereas liquids cannot; solids have a definite shape, but gases and liquids conform easily to a container. On page 545, Djellouli *et al.*[1] blur the lines between these states by developing a 'metafluid' with intriguing properties.

Metafluids are part of an ever-increasing library of systems known as mechanical metamaterials. These materials are structured in a way that gives rise to behaviours that differ from those of their individual constituents[2]. Djellouli and colleagues' metafluid is a conventional liquid that contains a suspension of gas-filled elastic capsules. The authors engineered these capsules to collapse when the pressure in the medium surpasses a threshold value, thereby inducing an appreciable change in the volume of the metafluid. In this sense, the metafluid behaves similarly to a gas, in that it can be compressed. However, its changes in volume are mediated by the catastrophic failure of solid structures — the capsules implode in the same way that the beams of a bridge would collapse if overloaded[3] (Fig. 1).

This working principle confers a solid-like character on the authors' metafluid. But the metafluid is also closely related to the liquid that makes up the bulk of its mass. For instance, when 30% of its volume consists of microcapsules, the metafluid flows with a viscosity that is twice that of the carrier liquid. The viscosity changes when the capsules in suspension are collapsed, becoming similar to that expected of a normal suspension[4]. Yet the mix of gas-, fluid- and solid-like properties sets metafluids apart from other suspensions, and from other types of matter, and this inherent versatility makes them ideal candidates for use in engineering applications.

Djellouli *et al.* investigated the broad applicability of their metafluid. This required them to understand the properties of the capsules, and to be able to tune the capsules' behaviour across various length scales. The authors showed that, for centimetre-scale capsules, the relationship between pressure and volume in the system could be engineered merely by modifying the number of capsules. By design, the pressure in the medium remains roughly constant when many capsules start to snap. Adding more capsules simply makes this pressure plateau for longer. And the process is hysteretic, meaning that the way in which the pressure increases when the fluid is compressed differs from how it decreases when the fluid expands.

The authors made use of this hysteresis to build a system capable of gripping and holding onto objects as heavy and stiff as a glass bottle, as small as a blueberry or as fragile as an egg (see Fig. 3a in ref. 1). Achieving such a feat is challenging for conventional robots, which are not typically designed to interact with soft bodies[5]. One day, metafluids such as the one designed by Djellouli *et al.* could be an integral part of sophisticated robotic systems whose programming is embedded in the material properties of the fluid. These systems could be miniaturized because the authors' capsules can be made microscopically small.

The prototype for Djellouli and colleagues' capsules had an outer radius of one centimetre. The authors then used lab-on-a-chip techniques[6] to fabricate capsules with an outer radius of just 250 micrometres. The working principle of these microcapsules follows that of their larger counterparts. However, on this length scale, the state of the capsules affects the metafluid's optical properties. Suspensions that contain spherical capsules act like the microdroplets of oil that form when the French liqueur Pastis is poured into water[7]. These droplets scatter light, making the liquid cloudy. However, when the metafluid is put under sufficient pressure, each particle in suspension is forced to snap shut. In this collapsed configuration, light scattering is reduced, and it is possible to see clearly through the metafluid.

Djellouli and colleagues' metafluid is thus largely tunable and has properties that differ from those of its constituents, justifying the 'meta' prefix in the name — it is more than the sum of its parts[2]. Mechanical metamaterials typically make use of buckling and other complex mechanical processes to generate functional materials. Scientists are applying these principles to develop and program materials[8] that are inert but have functionalities reminiscent of features of living creatures — for example, shape-changing abilities that mimic strategies used by plants. Attention is now

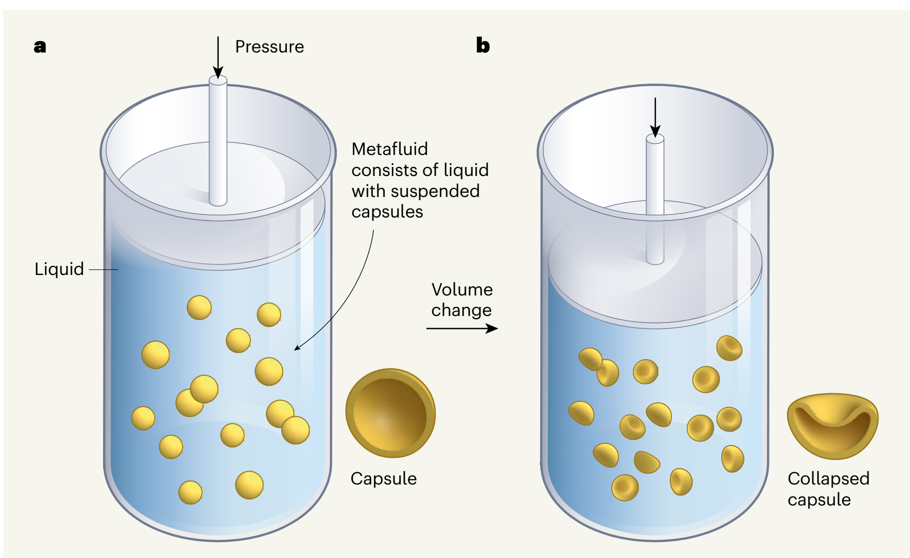

Figure 1 | A material with both solid- and fluid-like properties. Djellouli *et al.*[1] designed a 'metafluid' by combining a conventional liquid with a suspension of gas-filled elastic capsules. The capsules were engineered to collapse under pressure, so compressing the metafluid past a certain point induces a change in its volume, while the pressure remains roughly constant. The material is therefore compressible, but, unlike a gas, its volume changes in response to the failure of solid structures. These unusual properties can be used to build sophisticated robotic systems.

turning to materials that draw inspiration from complex animals, such as octopuses, which are capable of sensing, decision-making and remarkable adaptability using a decentralized nervous system. To get there, transformative work is needed, and innovations such as the authors' metafluid are a step in the right direction.

Most achievements in mechanical metamaterials have been fuelled by progress in solid mechanics, paired with key advances in computing and digital fabrication (for example, 3D printing[9]). Fluids[10] and fluid mechanics[11] have yet to be considered substantial contributors to research in this field. The authors' metafluid provides an opportunity to transfer the now-mature ideas of solid metamaterials to the world of fluids. Many researchers will surely take inspiration from this study, and will work to better understand — and ultimately make use of — the characteristics of metafluids. This path is challenging, but future investigations will be able to draw on a long and rich history of research in fluid dynamics.

It's crucial to understand that metafluids do not flow in the same way as normal liquids. For example, when water flows through a small tube, its rate of flow is determined by the difference in pressure between two points, not by the magnitude of this pressure. For Djellouli and colleagues' metafluid, the magnitude also matters: a pressure difference across a system with spherical capsules will induce a behaviour that differs from that elicited by the same pressure difference across a fully collapsed suspension. In turn, this state will affect the viscosity and, thus, the flow.

This result is not surprising to anyone trained in fluid mechanics. However, the authors' ingenuity and profound understanding and control of the capsules' mechanics casts such flows in a new light — as versatile and tunable. Their metafluid is as multifunctional as a Swiss army knife. It could easily be integrated into robotics to form logic gates, but might also be applied in optics, thermodynamics and acoustics — metafluids can do it all.

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Cell biology

The race to find factors for organelle fission heats up

Shilpa Gopan & Thomas J. Pucadyil

Organelles called lysosomes fuse with cargo-carrying vesicles and degrade the cargo molecules. How lysosomes maintain their size despite constant vesicle fusion was unclear, but now factors that aid organelle fission have been found. **See p.630**

Lysosomes are acidic organelles that are involved in the degradation of molecules and proteins. They also represent a signalling hub for the maintenance and quality control of cellular functions[1–4]. Many of these functions are attributed to the delivery of specific molecular cargo to the lysosome by fusion of cargo-containing vesicles with the organelle. Although a lot is known about fusion[5], the pathways and mechanisms that enable the release of membrane-bound material through fission from the lysosome, which balances the size of the organelle, have remained elusive[6] until now. On page 630, Li *et al.*[7] reveal components that mediate lysosomal fission.

Li and colleagues examined the worm *Caenorhabditis elegans* and found that mutations in the gene *hpo-27* caused lysosomes to become extensively tubular. Such shape changes coincided with a decrease in acidity and degradative capacity of the organelle. This indicates that the shape of a lysosome is

From the archive

Early progress in predicting how proteins fold up, and Isaac Newton's use of the word 'axiom'.

50 years ago

In the right conditions, many proteins spontaneously and reversibly fold into their biologically active conformation … Such observations have appropriately been interpreted as evidence that the linear sequence of amino acid residues … carries all the necessary information for directing the folding process, and it is just a short step to speculation that artificial synthesis or genetic engineering of novel sequences will lead to conformations with novel catalytic and control functions. But which sequences will lead to the desired conformation, and achieve it in reasonable time? … What does seem clear is that the final stages of folding will be the most difficult to … predict … [S]uccess will owe as much to the size and speed of future generations of computers as it does to the programs and data fed to them. But it is remarkable that one can now discuss the difficulty of predicting the final stages of folding, not the folding as a whole.
From *Nature* 19 April 1974

150 years ago

In reference to the controversy … about Sir I. Newton's calling his laws of motion "axioms," it is to be observed that there is a certain ambiguity in the word … Whatever may be considered the ground of Euclid's "axioms" so called, Euclid himself did not apply that name to them; but the first nine he called "common notions," and the last three … he placed among the postulates … and heads them with "let it be granted." Now it is clear, from Newton's own words, that in calling his Leges motûs "axioms," he does not imply that they are *necessary* judgments, but that … they are postulates, like Euclid's last three "axioms." In our modern use of the words "axiom," "axiomatic," there is always implied the *ground* why a proposition is demanded as granted, viz., because its necessity is self evident; but this wider use is not required by etymology, or (I think) in interpreting all ancient writings.
From *Nature* 16 April 1874