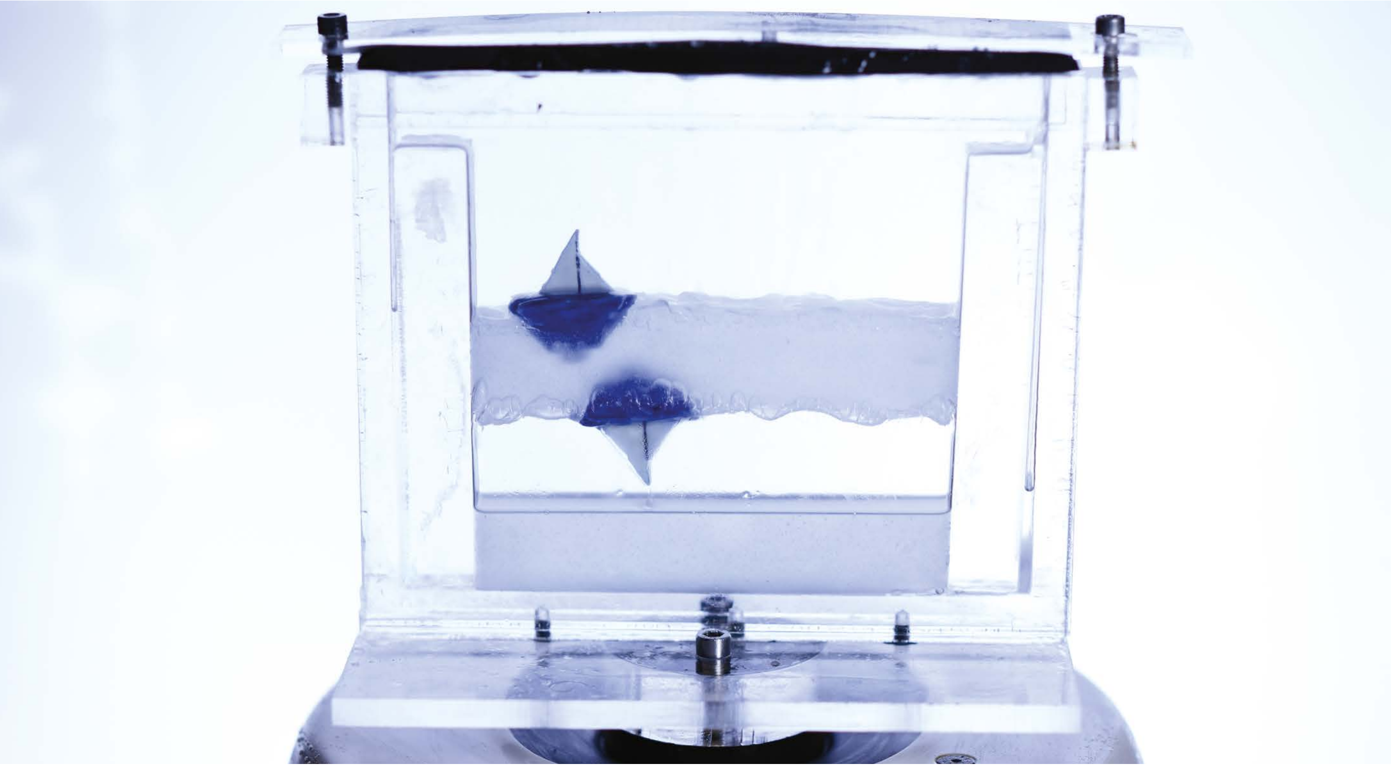

BENJAMIN APFFEL

Figure 1 | Inverse floating. Apffel *et al.*[5] levitated a liquid above a layer of air in a container by vertically shaking the container. They observed that objects can float upside down from the lower side of the air–liquid interface.

Fluid dynamics

Vibration overcomes gravity on a levitating fluid

Vladislav Sorokin & Iliya I. Blekhman

Volumes of fluid have previously been made to float above air by vibrating the air–fluid system vertically. It now emerges that an ‘antigravity’ effect enables objects to float upside down on the air–fluid interface. **See p.48**

Counter-intuitive phenomena that arise in fluids under the action of vibration have attracted considerable research interest since the 1950s. For example, in a vibrating volume of fluid, gas bubbles can sink and heavy particles can rise[1–3]. Moreover, a layer of fluid can be levitated above a layer of air by shaking the system vertically at a relatively high frequency (of the order of 100 hertz or more)[4]. On page 48, Apffel *et al.*[5] report another remarkable phenomenon associated with a vibrating, levitated layer of fluid: objects can float upside down on the lower interface of the fluid, as if gravity were inverted (Fig. 1). These phenomena have strong potential for practical use[3], for example in systems that involve gas bubbles suspended in fluids (such as bubble column reactors used for gas–liquid reactions), and for the segregation and transport of material inclusions in fluids (as used in mineral processing and waste-water treatment).

The extraordinary behaviours of vibrating fluids are just a small fraction of the surprising phenomena that arise as a result of high-frequency vibrations more generally. Probably the most well-documented examples are the Stephenson–Kapitza pendulum[6], in which a rigid pendulum balances upside down from a vibrating point of suspension, and the Chelomei pendulum[2], in which a washer that can slide along a rod seems to ‘float’ when the rod is vibrated vertically.

Special branches of the fields of mechanics and rheology have long been established to study the physical effects of high-frequency vibrations[7]. Such studies have revealed that time-averaged forces, known as vibrational forces, occur in vibrating systems in addition to the forces that apply in analogous non-vibrating systems. It is these vibrational forces that lead to seemingly paradoxical phenomena, including the sinking of gas bubbles in vibrating liquids, and the levitation of fluid layers above air[2,3]. Vibrational forces have been used in practical applications, for example to enable the self-synchronization of the rotation of several bodies, and to separate and transport materials[7].

Apffel and colleagues now add inverse floating to the list of what vibrational forces can do. In their experiments, the authors filled a container with a viscous liquid, and used a shaking device to vibrate the liquid vertically at high frequency. Air bubbles added to the liquid below a critical depth sank to the bottom of the container. The authors inflated sunken bubbles to produce a stable air layer with the liquid levitating on top. The maximum volume of levitating liquid studied was 0.5 litres, and the maximum width was 20 centimetres. Remarkably, Apffel *et al.* observed that small objects (up to 7 grams in mass and 2.5 cm in length or diameter) floated upside down on the lower side of the air–liquid interface (Fig. 1).

To explain their observations, the authors suggest that the effective gravity exerted on the fluid – the apparent gravitational force that acts on a vertically accelerating system – as well as that exerted on submerged and floating bodies, oscillates with time when the system is vibrated vertically. The immersed volume of the body floating on the lower interface of the fluid also oscillates with time. Apffel and co-workers propose that this causes a time-averaged force to be applied to the body. This force has an 'antigravity' effect that, for vertical vibrations of frequencies of 80 Hz or above, enables the body to float on the lower interface of the fluid. As is the case for the Stephenson–Kapitza pendulum[6] and the Chelomei pendulum[2], the stable states of Apffel and colleagues' vibrating system correspond to potential-energy maxima, rather than minima.

The authors suggest a relatively simple mathematical description of the inverse-floating phenomenon. This description involves some simplifying assumptions, for example by supposing that the relationship between the pressure in the air layer and the height of the layer is linear. The simplifications somewhat limit the accuracy with which the authors' theory describes the behaviour of the experimental system, leading to minor discrepancies with the observations.

It is also worth noting that the speed of sound in gas-saturated fluids is surprisingly low for a wide range of volumetric gas concentrations, and this has also been observed to produce antigravity effects[3]. For example, for air concentrations of 30–70%, the speed of sound is only 20 metres per second (ref. 3); this compares with about 340 m s^{-1} in air, and about 1,450 m s^{-1} in water. When the speed of sound is this low, one or even several longitudinal (compression) standing waves can fit into a vibrating volume 1 m in height at frequencies of the order of 50 Hz. Heavy, rigid particles and gas bubbles are attracted to the points of minimum and maximum amplitude of these standing waves, leading to gravity-countering effects.

Apffel and colleagues' work suggests that many remarkable phenomena arising in vibrating mechanical systems are yet to be revealed and explained, particularly at interfaces between gases and fluids, implying great potential for future research. More broadly, the analysis of the effects of high-frequency excitations on systems from other fields of science, such as chemistry, physics and biology, is another promising research topic[8]. In these systems, the excitation can be any periodic change in a property of the environment or medium in which a process is taking place. It will be exciting to discover what counter-intuitive phenomena can be induced by high-frequency excitations in non-mechanical systems – is there a chemical or biological counterpart of inverse gravity?

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Cell biology

Connections that couple brain activity to blood flow

Chiara Zurzolo

Structures similar to closed-ended tunnelling nanotubes have now been seen connecting pericyte cells in the mouse retina. The structures enable pericytes to coordinate their responses to neural activity, thereby modulating blood flow. **See p.91**

The discovery of membrane protrusions that form open-ended channels between cells has revolutionized our understanding of cell-to-cell communication. These tunnelling nanotubes (TNTs) enable the exchange of compounds, including organelles, pathogens and genetic material[1–3], and have been reported – mainly on the basis of *in vitro* and *ex vivo* cultures – to participate in a range of cell behaviours, from differentiation to neurodegeneration and immune responses[4]. However, the lack of markers for TNTs has made their identification *in vivo* particularly challenging[3]. Consequently, there has been debate over whether they actually exist, how to define bona fide TNTs *in vivo*, and how many types there might be[3,4]. On page 91, Alarcon-Martinez *et al.*[5] now provide perhaps the first *in vivo* evidence for the existence of a type of TNT-like protrusion that is closed at one end, in the retina of living mice.

The authors set out to investigate a process called neurovascular coupling[6], in which signalling between neurons and non-neuronal cells leads to altered blood flow in response to changes in neural activity – thereby ensuring that more blood flows towards more-active brain regions. One cell type that might be involved is the pericyte, which surrounds capillaries throughout the body. Pericytes regulate microcirculatory blood flow by contracting and relaxing, but whether and how this process is synchronized with neurovascular coupling has been unknown.

Empty, thin, long projections extending from and between pericytes have been seen before[7,8]. Alarcon-Martinez *et al.* show that, in the mouse retina, these interpericyte connections are not open bridges, but have one closed end: the protrusion extends from one cell (dubbed the proximal cell) to make contact with the other (the distal cell), and the tip of the protrusion is closed by a structure called a gap junction (Fig. 1). Small particles, such as ions, can pass through this junction, but larger objects, such as organelles, cannot. This type of closed-ended TNT has been shown to aid electrical coupling between cells *in vitro*[9].

The authors found that, rather than being empty shells, these interpericyte TNTs (IP-TNTs) mediate communication between distant pericytes in separate capillary systems, through bidirectional transfer of calcium ions (Ca^{2+}). Closed-ended TNTs are mainly formed from a network of the structural protein actin, but lack another structural protein, tubulin[9] – and the authors found actin, but not tubulin, in their IP-TNTs. In support of the supposition that IP-TNTs derive from