



## New Gels for Mixing Immiscible Liquids

Philippe Poulin  
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about  $N = 10^6$  spin-3/2 nuclei. There are some subtle quantum-mechanical aspects to the interaction of the electron with these nuclei (4), but one obvious, large, essentially classical effect has been evident in several recent experiments: At any instant in time, each nuclear spin has a projection along the direction of the external magnetic field, adding or subtracting to the total effective field. The value of this Overhauser field can be enormous: If all Ga and As nuclei were maximally aligned with the external field, they would add about 5 T to it. The actual value in the experiment is much smaller, because the direction of each nuclear spin is essentially random (the temperature of the experiment, 100 mK, is “high” as far as the nuclei are concerned). But each dot has a random statistical excess or deficit of Overhauser field, which scales as  $\sqrt{N}$ , seen by the electrons as a  $\approx 2$ -mT, slowly fluctuating field. These variations cause the observed decoherence time of the electron spin to be very short, about 10 ns.

Reenter SWAP, to erase the effect of this slowly fluctuating field, and greatly extend the coherence times of the two-spin states in the double-dot system. In the experiment, at time  $t = 0$ , the system can be set in the S state.

But over time it acquires a random admixture of a triplet state T owing to the difference of Overhauser fields on the two dots. A SWAP is applied at  $t = \tau$ , interchanging the two spin states. When time  $2\tau$  has elapsed, each spin state has effectively spent an equal time in both dots, so that the average Overhauser field seen by both is the same. But S and T do not mix when the effective field is equal in the two dots. What is seen in practice is that, at time  $2\tau$ , the random admixture with T is completely undone, and the state becomes again pure S. There is a “singlet echo,” in complete analogy to “spin echo” in magnetic resonance. This echo can be seen for  $2\tau$  exceeding 1  $\mu$ s, proving that the actual spin coherence time is at least 100 times that of the originally observed value.

This experiment opens up the real prospect of using the two states, S and T, as a coded qubit, a possibility anticipated and thoroughly analyzed by Levy (5) some years ago. He showed that with a fixed magnetic field gradient between the two dots, the SWAP operation alone suffices to execute a quantum computation. The field gradient may itself be produced by differential Overhauser fields obtainable in these kinds of experiment (6, 7). Again, there is a  $\sqrt{N}$

fluctuation of these fields; but given the slowness of these fluctuations, there are more magnetic resonance tricks, like the spin echo, for using sequences of SWAPs to erase the effects of these fluctuations.

The remarkable thing about this experiment is that it can make use of all the tricks for reliable operations that are available in magnetic resonance, even though the controls are not magnetic at all—SWAP is controlled by a purely electric pulse. Real magnetic resonance manipulations of spins in this system would be orders of magnitude slower, and none of the results observed would have been possible. It appears now a real possibility that all-electrical control of spins in semiconductors may be a practicable route to real quantum computation.

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#### CHEMISTRY

## New Gels for Mixing Immiscible Liquids

Philippe Poulin

**S**ynthetic or natural porous media with a single continuous connected pore space are common. These materials are used in research laboratories as supports for catalysts, as well as in filters for automobile engines and coffee makers. But these classical solid porous media cannot be used to separate two different fluids, nor to keep two distinct liquids in contact for later separation. To achieve these aims, one needs a bicontinuous structure with two continuous media that are intimately combined but separated by porous walls. Such a novel compartmented structure could be of great interest for liquid purification and cleaning, for accurately enriching a liquid with another component dissolved in another liquid, for controlling chemical reactions between immiscible fluids, and for sorting the reaction products afterward. On page 2198 of this issue, Stratford *et al.* at the University of

Edinburgh (1) report computer simulations of just such a material.

An ideal bicontinuous structure would be made of a rigid self-supporting scaffold with open and continuous walls so that gases, liquids, living cells, biomolecules, or particles can travel through the open spaces. But how can we make such a structure? Bicontinuous liquid phases do exist at thermal equilibrium (2). Some oil and water combinations can indeed form bicontinuous phases in the presence of surfactants in well-defined temperature and concentration ranges. Unfortunately, the intrinsic liquid nature and thermodynamically determined structures of these mixtures make the use of such phases for separation or filtration impossible.

Designing materials beyond thermal equilibrium could be a far more versatile way to create a variety of structures. For example, it has been shown that phase separations of fluids (3, 4) can be used to create various structures including gels, droplets, and cellular systems. Fluid demixing thus

seems to be an interesting approach to achieve complex morphologies. Consider a mixture of two fluids that are miscible at high temperature. By quenching the system at low temperature, the two fluids undergo phase separation. If the fractions of the two fluids are nearly equal, a bicontinuous structure forms. In the initial stages of the phase separation, the characteristic size (that is, the typical size of the separating domains) of the system is very small. It grows over time until a macroscopic phase separation occurs. If we perform such a simple experiment, we see a bicontinuous structure that spontaneously evolves with time.

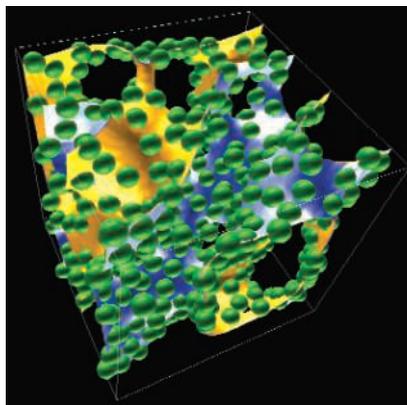
At some point, when our ideal imaginary system reaches a characteristic size that would suit the bicontinuous material, we would like to stop the process and solidify the system right away. Unfortunately, the liquid system will just continue coarsening, driven by the unavoidable minimization of energy. Indeed, the growth of the characteristic size of the bicontinuous structure minimizes the amount of interface area between the two separating liquids. Because this interface costs a lot of energy, the characteristic size of the system keeps increasing. Stratford *et al.* (1) have proposed a very elegant approach to stop the coarsening at will. In numerical simulations, they have accomplished this by adding small particles that remain trapped at the interface between the two demixing

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fluids. The wetting of the particles by the two phases is neutral, meaning that the particles exhibit the same affinity for the two fluids.

Under these conditions, the particles remain strongly and irreversibly stuck at the interface between the two fluids. In the initial stages of the phase separation, there is a large amount of interface area and the particles can freely move even if their motion is restricted in two dimensions at the interface between the fluids. Nothing prevents the coarsening from proceeding. But the particles become more and more concentrated as time elapses because the interface area is decreasing. At some point, the concentration of the particles confined at the interfaces is so high that the system becomes jammed. In other words, the particles cannot move anymore and they form a continuous self-supporting gel delimited by the interfaces between the fluids.

An important finding of Stratford *et al.* (1) is that the particles are not expelled from the walls. They can sustain a sufficient stress to preserve the walls and keep the three-dimensional gel intact. The authors call this new material a fluid bicontinuous particle-stabilized gel. In this state, the jamming of the particles has a dramatic consequence because the phase separation is suddenly arrested. The beauty of this new concept is the versatility and almost infinite tunability it allows. The system is no longer restricted to a single state imposed by thermal equilibrium and a solid structure can be achieved. Two critical challenges are solved in one shot. One can in principle use many kinds of organic or inorganic particles as long as they exhibit neutral or near-neutral wetting. By simply controlling the concentration of the particles, one can accurately select the characteristic size of the bicontinuous gel. The more particles added, the smaller the characteristic size of the compartmented media. If the gel is too weak to be directly used as a bicontinuous material for various applications, the particles can be fused or bound to each other via chemical reactions to make the material stiffer. Or subsequent additives can reinforce the walls. Because the system is frozen, a range of approaches to functionalize and adapt the system becomes possible. Also, even if the particles are jammed, there remains room between them so that two liquids in each continuous compartment can interact, chemically react, or exchange components through the pores of the walls. The size of these pores can be directly controlled by the size of the added particles. As a result, the liquids are in intimate contact with a huge amount of interface between them without being continuously mixed or emulsified.



**Gel jamming.** Three-dimensional view of colloidal particles (green) trapped at the interface between two fluids during a phase separation. The liquids are not shown. The interface delimits two continuous media, which will ultimately form the pores of the bicontinuous gel.

This concept has been validated by Stratford *et al.* (1) using extensive computer simulations. Such simulations are extremely difficult because they must be undertaken on a large scale. But the efforts are worthwhile because the authors are presenting experimentalists with a particularly exciting challenge. Moreover, Stratford *et al.* provide an example of a potential application in the form of a unique simulation of cross-flow microfiltration.

The main difficulty for experimentalists will consist in finding particles and fluids to achieve neutral or near-neutral wetting conditions. However, this seems feasible. For example, Binks and colleagues at the University of Hull (5) have already shown that different kinds of emulsion droplets could be stabilized by controlling the wettability of particles at

the interface between two fluids. By functionalizing mineral particles, Binks and his group have shown that the wetting of small particles by aqueous or oily fluids can be accurately controlled.

By combining experimental knowledge acquired in other studies (3–5), it is conceivable that the predictions of Stratford *et al.* will soon be validated on a laboratory bench. Clegg *et al.* (6) have been independently developing an experimental system that seems to be ideally suited for such an application. This system has been used to create emulsions, but small changes in the experimental conditions could lead to bicontinuous gels.

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#### CELL BIOLOGY

## A Fungal Achilles' Heel

Joseph Heitman

**T**he emergence of drug resistance in pathogenic microbes provides a resounding validation of Darwinian evolution and yet forces a sobering realization that we share this planet with organisms whose long-term survival threatens our own.

This threat is particularly poignant with eukaryotic pathogenic microbes whose cellular machinery is similar to that of our own cells, making drug target identification and development of antimicrobial agents all the more challenging. And with the development of drug resistance in pathogenic fungi and parasites—such as resistance to azole drugs that target ergosterol (a unique membrane sterol in fungi such as *Candida albicans*) synthesis, or resistance to

chloroquine and mefloquine in the malaria parasite *Plasmodium falciparum*—we are often only one step ahead of disaster. The study by Cowen and Lindquist on page 2185 of this issue begins with a basic interest in molecular events that presage microbial drug resistance (1) and unveils a role for a heat shock protein called Hsp90 in enabling pathogenic fungi to rapidly develop drug resistance. Hsp90 is best known as a molecular chaperone that allows cells and organisms to cope with protein folding defects that arise from insults including mutations and environmental stress. Cowen and Lindquist show that Hsp90 enables the evolution of phenotypic diversity in fungi in response to evolutionarily selective forces. The work also implicates Hsp90 as an Achilles' heel of pathogenic fungi that could be harnessed by small-molecule ligands to improve and extend the armamentarium of antimicrobial agents.

Resistance of fungi to antifungal agents can emerge by the overexpression of multidrug transporters that extrude toxic com-

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