several molecular components should undergo phase separation and form intramembrane domains. If the membrane is under low tension, these domains tend to form spherical membrane buds, a theoretical prediction[7] that has been recently confirmed by optical microscopy[1,7]. Where direct observation by optical microscopy is not possible, a variety of coarse-grain membrane models (Fig. 1) can be used to study bilayers containing several lipid or diblock copolymer components, or even mixtures of lipids and diblocks.

Computer simulations are also beginning to shed light on the fusion of bilayer membranes — a topological transformation that is crucial for intracellular transport and communication. In this process, one starts from two separate nano- or microcompartments simulating two unilamellar vesicles. These compartments adhere to each other, and the adjacent bilayers within the adhesion zone then undergo molecular reorganization leading to the formation of a fusion pore: a smooth neck-like connection between the two bilayers. However, in spite of a lot of experimental work, both on biological and on biomimetic membranes, some basic properties of membrane fusion are still unknown. One such property is the timescale for the formation of the fusion pore. So far, the most sensitive experimental techniques applied to this formation process are patch clamp methods from which one concludes that the fusion pore is formed within less than 100 μs (ref. 8). In contrast, recent computer simulations of coarse-grain models indicate that this process is much faster and can be completed in about 200 ns (J. Shillcock and R. Lipowsky, unpublished work). Thus, there is still a relatively large gap between the length and timescales that are accessible to computer simulations and experimental probes of membrane processes. This gap is shrinking, however, and will eventually vanish as we further develop both types of research tools.

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MATERIAL WITNESS

A blast from the past

Sometimes you never know when a material will come into its own. Fifty years ago there was a small flurry of work on a rather obscure class of metal oxides, manganites with a perovskite structure. These materials had interesting magnetic properties: they exhibited a phenomenon dubbed double exchange, wherein electron spins on adjacent mixed-valence metal ions are coupled by delocalization of an electron between them.

This process, explained by Clarence Zener (of Zener diode fame) in 1951, posed a nice theoretical challenge, and it drew the attention of two future Nobel laureates (Philip Anderson and Pierre-Gilles de Gennes) as well as John Goodenough, now arguably the world's leading expert on the behaviour of metal oxides. But despite the calibre of the researchers, no one would have guessed that papers with titles like 'Interaction between *d*-shells in transition metals. II. Ferromagnetic compounds of manganese with perovskite structure.' were destined for great things.

Yet this, Zener's original paper on double exchange in manganites (*Physical Review* 82, 403–405; 1951), has just been ranked as the paper with the sixth highest impact among all the publications in the *Physical Review* (*PR*) journals since 1893. A publication on the subject by Anderson ranks at number 19, de Gennes' at 21, and Goodenough's at 37.

Even more remarkably, all four papers, along with one by E. O. Wollan and W. C. Koehler on neutron diffraction from manganites (published in 1955, ranked 37), made very little impact at the time of publication. They were cited just a few times a year, if at all, until the mid-1990s, when the citation statistics for all of them soared. In 2000, Zener's paper was cited over 100 times within the *PR* journals alone.

They were classic 'sleepers'. These papers suddenly became hot when it was discovered in 1993 that thin films of manganite materials exhibit so-called colossal magnetoresistance: their electrical resistance changes dramatically in the presence of a magnetic field. This is the crucial characteristic of readout heads for magnetic data storage, and the manganites were suddenly of vast technological interest.

This history of the early work on manganites emerges from a fascinating analysis by Sidney Redner of Boston University of the citation statistics of all the papers published in the *PR* journals since they began 111 years ago (xxx.arvix.org/abs/physics/0407137). The extraordinary burst of citations of the manganite studies, 40 years after their first appearance, is 'unique in the entire history of *PR* journals', Redner says.

Nonetheless, the significance of that work fits within the general consensus from Redner's list of highest-impact papers in *PR* journals, which is to say that twentieth-century physics was largely about condensed matter, and more specifically about the quantum-mechanical theory of electronic and magnetic properties in the solid state. The top two papers, both co-authored by future Nobel laureate Walter Kohn, established the density-functional theory by which means electronic band structures are typically calculated. The story Redner's study tells is one of physics' persistent engagement with materials and technology.

Philip Ball