and then tested at the restrictive temperature, memory retention was impaired.

So, memory acquisition and retrieval can be dissociated by interfering with neurotransmission in the mushroom body. The acquisition and early processing of memories are known to depend on a signalling cascade in the mushroom body that involves cyclic AMP[9]. This cascade seems to be driven by simultaneous input from olfactory interneurons and unknown modulatory neurons that are activated by the shock. This neural circuit, including input to the mushroom body and the mushroom body itself, might be a site for associative learning and memory storage. The sites of output from the mushroom body, however, are required for memory retrieval[3] (at least for the early stages of memory tested here).

These results lead to several broad conclusions, as well as some questions. First, continuous neural activity at chemical synapses — often considered to be the basis of early memory phases — is not required in the mushroom body. So it seems unlikely that early memory formation requires any feedback from the mushroom body to input neurons, or to the mushroom body itself (that is, if electrical synapses are also not involved, a possibility not testable with the methods used here).

Second, the parts of mushroom-body neurons that are involved in memory acquisition and retrieval are clearly separate. But there must be some sort of signal that coordinates these processes. The signal probably includes the transport of molecules along mushroom-body neurons, and other, more rapid processes[10]. Dynamin is involved in protein transport as well as neurotransmission, so the memory-retrieval defects seen in the mutant flies might also reflect defects in coordination signals.

Third, a common feature of memory is its progression through different phases. The period tested by Dubnau *et al.*[3] may represent a phase during which the formation of memories at mushroom bodies can be clearly dissociated from retrieval. But it is not known whether this separation also exists in later memory phases.

Finally, most memory traces in large brains are distributed over much greater distances than in fruitflies, and involve several areas of the brain[11]. In the tiny fly brain, the memory trace of a rather simple, odour-guided behaviour is instead distributed between different sites in the same neuron, and these sites are specialized for the formation and retrieval of acquired information. Is this a design principle of a small brain, or of a simple type of memory, or both? The answers to these questions will help to show whether there is a general difference in how small and large brains cope with learning and remembering. ■

Randolf Menzel and Uli Müller are at the Institut für Biologie–Neurobiologie, Freie Universität Berlin, Königin-Luise-Strasse 28-30, D-14195 Berlin, Germany.
e-mail: menzel@neurobiologie.fu-berlin.de

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Condensed-matter physics

Why vortices matter

Peter Gammel

In a magnetic field, a superconductor is threaded by swirling whirlpools of electric current. Understanding these magnetic vortices is important because they control the flow of current through the superconductor.

The defining property of a superconductor is the ability to carry an electrical current without resistance when cooled below a transition temperature, typically a few degrees above absolute zero. But below this temperature, most of the superconductor's useful properties are governed by its response to external magnetic fields. Under certain conditions magnetic field lines can permeate some superconductors, leading to the creation of magnetic vortices. Vortices have non-superconducting cores, which carry the magnetic field lines, surrounded by swirling 'supercurrents'. The behaviour of these magnetic vortices determines the physical properties of superconductors, including the maximum electrical current the superconductor can support. The movement of vortices is particularly damaging because it creates electrical resistance, thereby destroying the superconducting state.

In 1986, a new class of high-temperature superconductor was discovered with unprecedented transition temperatures above 77 K. Magnetic vortices usually form stable and regular patterns, such as a triangular lattice, but in the high-temperature superconductors they appear in exotic and frequently less stable patterns. Two papers by Avraham *et al.*[1] and Bouquet *et al.*[2] (starting on page 448 of this issue) examine the response of vortices to changing temperatures and fields, and reveal some of their unusual behaviour in the high-temperature superconductors.

When a current flows in a high-temperature superconductor, it exerts a force on the magnetic vortices. If the vortices move in response to this force they dissipate energy and produce a non-zero resistance. But the vortices can also be fixed or 'pinned' to defects in the material, so they don't move. Practical applications of superconductors require zero resistance and therefore pinning. A solid hexagonal lattice was thought to be the only stable vortex state until it was discovered that the vortex lattice can melt into a 'liquid' phase[3]. In the liquid phase it is more difficult to prevent vortex motion (and, hence, electrical resistance), which restricts applications of superconductivity to the vortex solid phases.

Like the melting of an ordinary solid, the melting of vortices is described as a first-order phase transition because it is accompanied by abrupt changes in physical

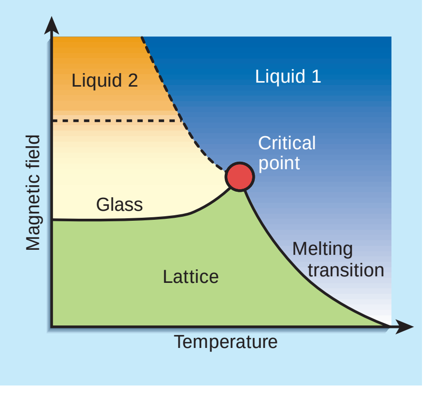

Figure 1 **Phase diagram for magnetic vortices in a superconductor as a function of magnetic field strength and temperature. In the lattice and glass states, the superconductor will have zero electrical resistance. Motion of the vortices in the liquid states will generally lead to finite resistance. Taming the vortices is crucial for practical applications of superconductivity. Avraham *et al.*[1] show that the lattice–glass transition includes a region of 'inverse melting' just below the critical point. The critical point is where the solid, liquid and glass phases become indistinguishable. Bouquet *et al.*[2] have investigated the behaviour of vortices above the critical point, and identify a second transition between two distinct vortex liquids. These studies highlight the unusual properties of vortices in the high-temperature superconductors.**

properties, such as magnetization. The properties of the vortices as a function of temperature and magnetic field can be summarized in a conventional phase diagram (Fig. 1). Detailed understanding of this phase diagram is essential for designing superconducting materials that have the properties needed for applications in microwave filters, magnetic field sensors and current-carrying cables.

The first-order melting transition from the vortex lattice to liquid 1 is well understood[4] (solid line; Fig. 1). But the other parts of the phase diagram have remained a mystery, and this is where Avraham *et al.* and Bouquet *et al.* come in. Avraham *et al.*[1] study the first-order melting transition in the high-temperature superconductor $Bi_2Sr_2CaCu_2O_8$ (BSCCO), using microscopic Hall sensors to probe the changing magnetization. Previous studies of this transition in BSCCO were restricted to below the 'critical point' in Fig. 1, which occurs around a temperature of 40 K and a magnetic field of 25 millitesla (mT). The critical point is where the solid and liquid vortex phases become indistinguishable. Further exploration of the phase diagram above the critical point was hindered by the slow response of the lattice and glass (disordered solid) phases to changes in temperature and field.

Avraham *et al.* overcame this problem by applying a small alternating current (a.c.) field perpendicular to the existing magnetic field, to 'shake' the vortices into their new equilibrium state. They show that the first-order transition from lattice to glass is a continuation of the first-order vortex melting line. The slight upturn near the critical point in Fig. 1 means that the transition becomes 'inverse' — as the temperature increases, the disordered glass 'melts' into an ordered lattice. Inverse melting is a rare and counter-intuitive phenomenon[5]. For example, if melting of ice were inverse, an ice cube in a drink would actually grow as it cooled the surrounding liquid. Inverse melting cannot be a thermal process, because thermally driven transitions always proceed from less disorder at low temperature to increasing disorder at higher temperature.

Avraham *et al.*[1] suggest that the transition from the lattice to the glass phase is driven by pinning of the flux lines to impurities and disorder in the crystal. Such a transition would be almost temperature independent, but competition between thermal fluctuations and pinning disorder leads to the inverse melting near the critical point. This is a highly plausible explanation, but questions remain about the nature of the 'shaken' equilibrium compared to a real thermodynamic equilibrium. The unique properties of shaken equilibrium, for example in experiments with metal balls[6], can lead to phase diagrams determined by the shaking itself, rather than by a thermodynamic variable such as temperature.

Bouquet *et al.*[2] focus on the part of the phase diagram above the critical point, which corresponds to high magnetic fields. They measure both heat capacity and magnetization for defect-free crystals of the high-temperature superconductor $YBa_2Cu_3O_7$ (YBCO). In YBCO, superconductivity extends to much higher temperatures and fields than in BSCCO, so that the critical point is at a temperature of 75 K and a magnetic field of 11 T. The purity of the crystal used by Bouquet *et al.* is shown by the nature of the first-order melting transition below the critical point. Below 5 T, the vortex melting is sharp (first order), and the heat capacity and magnetization are precisely related. The melting transition remains first order up to 11 T, although between 5 T and 11 T thermal fluctuations and disorder start to compete. At fields above the critical point, up to 26 T, Bouquet *et al.* identify a second-order transition between two distinct types of vortex liquid (liquid 1 and liquid 2 in Fig. 1). A second-order transition is less sharp, such that disorder and other properties change continuously across the transition.

To understand the distinction between these two vortex liquids, Bouquet *et al.* measured their heat capacity. Their data agree with a theory[7] in which the magnetic field lines in the low-temperature vortex liquid are thought of as having 'line tension', as if they were rubber bands. In this picture, liquid 1 has line tension, whereas liquid 2 does not. This means that the flux lines in liquid 1 can be pulled, elongated and twisted without losing energy.

The work of Avraham *et al.* and Bouquet *et al.* gives us a more comprehensive view of the vortex phase diagram. Exactly how the pieces of the phase diagram they explore join together at the critical point is still uncertain and is likely to depend on the detailed structural disorder of the materials[8]. Away from the critical point, and armed with the insight provided by these experiments, we can hope to control the vortices in both the glass and liquid phases. This will eventually allow superconducting devices to operate at much higher temperatures and magnetic fields than before. ■

Peter Gammel is in the Electronic Devices Research Laboratory, Agere Systems, Murray Hill, New Jersey 07974, USA.
e-mail: plg@agere.com

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Daedalus

Gas is for burning

Combustion, says Daedalus, is the most fundamental reaction for disposing of human rubbish. And yet modern civilization uses it very badly. A generation or two ago, the universal coal or coke fire automatically got rid of old newspapers and scrap food; today it would easily remove waste plastics as well. Yet these all go to fill our dustbins. The contents are then incinerated, which is highly unpopular, and finally as landfill they evolve combustible methane gas, a useful product we cannot collect and use safely. There must be a better way.

The better way which DREADCO engineers are studying is the 'Burnall', a device designed to burn to gas, waste and anything else that comes its way. It was inspired by Daedalus' memory of the gas poker, which one placed in the coke to start a fire. The idea is that gas is burned in a normal grate; immediately below this is a tray on which is placed the shredded paper waste, food waste or other waste. Heat radiated downwards gasifies these unwanted items, and their vapour burns in the gas stream; their carbon goes more slowly to one of the oxides. All the skill of domestic engineering will be needed to make this consumer durable effective and acceptable; but the thing seems feasible. Many of the problems have already been solved on a large scale, in hospital incinerators for example.

A steady stream of unfortunate people gas themselves by cooling a gas flame in a water-coil (thus producing deadly carbon monoxide); so the Burnall will be topped by a mesh of appropriate catalyst to convert all such nasties to harmless carbon dioxide and nitrogen. The output stream of gas, maybe at 400 °C, will traverse water coils to transfer its heat to a central heating unit. If it is worth it, a second condensation stage will capture the latent heat of condensation of steam, and pass the water to a drain.

The DREADCO Burnall will effortlessly solve many of the problems of modern living. All the smelly troublesome wastes will now escape the dustbin, and will go up the flue to reduce the heating bill. All the tedious paper and card, plastic wrappings, soiled infants' disposable nappies, and so on, will be reclaimed for their heat and saved from the binman. Sadly, bottletops, buttons and other objects containing PVC and related plastics will liberate unwanted chlorine. A controllable feed of lime, converting this into calcium chloride in the white and harmless ash, may be necessary.

David Jones