magnetic flux is completely expelled from the sample when the applied field is less than the lower critical field H_{c1} and partially expelled when the applied field is larger than H_{c1}. As before, the sample stops being a superconductor when the applied field is greater than H_{c2}. Quantized magnetic vortices appear in the intermediate region when the applied field is between H_{c1} and H_{c2}.

The vortices can be thought of as long filaments of concentrated magnetic flux, surrounded by a flux-free region of circulating 'supercurrents'. Because the supercurrents do not dissipate energy, the quantized vortices are stable (in contrast to vortices formed by vigorously stirring a bucket of water, which eventually dissipate because of viscous effects). If there are no significant thermal fluctuations or sample imperfections, the vortices arrange themselves into a stable pattern. Because the vortices repel each other, the minimum energy configuration for the vortices is one in which they are as far away from each other as possible. The favoured configuration is a triangular lattice. The characteristics of high-temperature superconductors, such as the maximum superconducting current they can support, are limited by the behaviour of this vortex lattice. So a lot of effort has gone into understanding the patterns of vortices, or controlling them by introducing defects into the superconductor.

So far we have only discussed the bulk properties of superconductors. But what happens when the sample is small and the surfaces or edges play a significant role? A flat surface parallel to the applied magnetic field tends to enhance the superconductivity[2], so that superconductivity persists near the sample's surface for fields above H_{c2}, and is finally destroyed at a field $H_{c3} = 1.69H_{c2}$. More complex behaviour might be expected to occur for samples with dimensions that compare to the vortex spacing (a micrometre or less).

Advances in nanotechnology over the past ten years mean that it is possible to make such mesoscopic devices and measure their properties. For example, Geim and collaborators[3–5] have uncovered a great deal of exotic behaviour in micrometre-sized discs; and Bolle *et al.*[6] have used micromechanical oscillators to detect the motion of single vortices in mesoscopic samples. This experimental work has spawned a great number of theoretical studies of vortex nucleation in small superconducting discs and rings[7,8]. There has also been great interest in using these mesoscopic superconductors as logic elements in a quantum computer[9]. If such a 'qubit' were operated in a magnetic field its maximum superconducting current would depend on the arrangement of vortices, just as in a macroscopic superconductor, so understanding vortex behaviour would be crucial to the operation of the qubit.

The work of Chibotaru *et al.*[1] is different because they have studied magnetic vortices in square superconducting samples. This geometry produces a much richer set of phenomena than the more simple disc geometry studied previously. The group measured the critical temperature (below which the sample becomes superconducting) as a function of magnetic flux in square (2 μm by 2 μm) aluminium samples. (Bulk aluminium is a type-I superconductor, but a thin sample can behave as a type-II superconductor.) The resulting curve has oscillations characteristic of vortex creation (see Fig. 1b on page 833).

To interpret their results the researchers solved the equations that describe the onset of superconductivity in the square geometry, and got a surprising result: the vortices respect the sample's symmetry by organizing themselves into a square with a fifth vortex at the centre. The nature of this central vortex changes as the magnetic flux is increased, from a vortex, to a giant vortex (which carries a double, rather than a single, quantum of magnetic flux), to an antivortex (responsible for the expulsion of magnetic fields). The theoretical results agree nicely with the researchers' measurements, and the picture they propose for vortex creation is compelling. But imaging the vortices (perhaps using a scanning tunnelling microscope) would provide a more direct and dramatic confirmation.

The results of Chibotaru *et al.* highlight geometry's influence on the patterns of vortices in superconductors, and raise several questions. For instance, what are the dynamics of the vortex nucleation process[10]? How do the vortices enter the sample, and what are the barriers[8] to nucleation? What about other sample shapes — do five vortices in a triangular sample form a hexagon with an antivortex at the centre, or a triangle with a giant vortex at the centre?

It is also possible that the findings of Chibotaru *et al.* might apply to materials that show 'super-behaviour' such as superfluid helium or Bose–Einstein condensates[11]. These can also flow without resistance and generate stable vortices when rotated in a container. Earlier this year[12], giant vortices were generated for the first time in superfluid helium-3. Chibotaru *et al.* suggest that superfluid helium, rotated in a triangular or square vessel, might generate antivortices. Similarly, the laser fields used to confine Bose–Einstein condensates could be arranged to encourage the production of antivortices in triangular or square traps. ■

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Daedalus

David Jones

David Jones, author of the Daedalus column, is indisposed.

Plant biology

Volatile defence

Plants can't run away from trouble and have developed sophisticated chemical defences instead. Maize, for example, releases a cocktail of volatile indole and terpenoid compounds when attacked by the beet armyworm caterpillar (*Spodoptera exigua*, pictured). These compounds attract a parasitic wasp, which deposits its eggs in the caterpillar; the wasp larvae then devour the caterpillar.

Writing in *Proceedings of the National Academy of Sciences USA* (online early edition, 5 December), two groups describe their investigations of how maize produces the substances. Monika Frey and colleagues have identified a gene, *Igl*, that is involved in the synthesis of indole. And Binzhang Shen and co-workers show that another gene, *stc1*, is required for maize to make a sesquiterpene compound (a terpenoid).

Maize releases the compounds only when under attack, so it seemed likely that the genes are activated only temporarily. Using techniques such as treating maize plants with volicitin, an 'elicitor' substance in the caterpillar's saliva, both groups show that each gene is indeed switched on only in response to damage.

HOLT

Finally, Shen *et al.* look at maize plants in which the *stc1* gene is mutated, and discover that they do not produce a major volatile compound seen in the normal plants. **Amanda Tromans**