or large reductions (Forsberg *et al.*) in one of these mediators, mouse mast-cell protease-6 (mMCP-6). Because the many different mast-cell proteases have distinct substrate specificities[7], these findings have clear implications for potential mast-cell functions.

But regulating the enzyme content of cytoplasmic granules may not be all that heparin does in mast cells. Given its extraordinarily negative charge[2,10], heparin has long been thought to be a storage site in the mast-cell granule for the positively charged amines histamine and serotonin[13]. In accord with this view, Forsberg *et al.*[5] report that the peritoneal mast cells in their NDST-2-deficient mice show a large — roughly 94% — reduction in cell-associated histamine. Humphries *et al.*[4], however, report a more modest reduction of about 30%.

How can we explain this apparent discrepancy? One reason could be the ages of the mice studied. Mast cells can be long-lived, and, in both rats and mice, the volume of the cytoplasmic granules and histamine content of the peritoneal mast cells increase with age[14]. This may lead to progressively larger differences in the histamine (or mMCP-6) content of the NDST-2-deficient cells compared with normal cells. Another reason could be technical differences in the methods used to quantify mast cells. Finally, the two strains of NDST-2-deficient mice could have phenotypic differences owing to, for example, differences in the two targeting vectors, effects of the targeting on nearby genes, or the genetic backgrounds of the mice.

The functions of heparin stored in resting mast cells and that released into the tissues by activated mast cells are probably distinct. However, given that the consequences of mast-cell activation examined by Humphries *et al.*[4] and Forsberg *et al.*[5] — enhanced vascular permeability and recruitment of white blood cells (leukocytes) — were not substantially influenced by heparin, which mast-cell functions might be? First, activation of mast cells has been shown to lead to clotting in the adjacent connective tissue, where mast cells normally mature[15] (Fig. 1b). Perhaps such clotting is enhanced in the NDST-2-deficient mice. Second, as well as being an anti-coagulant, heparin can bind certain cytokines, chemokines and growth factors, many of which are produced by mast cells[6,7,16]. Finally, depending on the circumstances, heparin can either promote or suppress the proliferation and migration of cells involved in vascular development, atherosclerosis, wound healing and tissue remodelling[2]. Heparin also regulates the distribution and enzymatic activity of certain mast-cell proteases[7,17].

Heparin may, then, have many functions beyond regulating the storage of other mediators in the mast-cell cytoplasmic granule. In other words, the production and initial characterization of NDST-2-deficient mice is not the end of the heparin story, but the beginning of an exciting new chapter in our attempts to understand the biology of this fascinating, clinically useful — and still enigmatic — natural product. □

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Condensed-matter physics

Real metals, 2D or not 2D?

Michelle Y. Simmons and Alex R. Hamilton

The distinction between metals and insulators appears simple — metals conduct electricity whereas insulators do not. Yet, for the past 25 years, arguments have raged over whether a two-dimensional (2D) system can be regarded as a real metal or not. In a 2D system — such as a very thin metal film, or the active region of many semiconductor transistors — the electrons are constrained to move in a plane of negligible thickness. Although these structures may conduct at room temperature, it was generally accepted that as the temperature (T) is reduced to absolute zero they would become insulating. The celebrated discovery of the quantum Hall effect in 1980 demonstrated that it is possible to have metallic states in a 2D system that persist to $T=0$ by applying a strong magnetic field[1]. But it has never been clear what happens to these states when the magnetic field is turned off, and the existence of a 2D metal without a magnetic field (that is, $B=0$) is still strongly debated. Recently, new evidence emerged indicating a transition from insulating to metallic behaviour at $B=0$ in extremely pure 2D semiconductors. On page 735 of this issue[2], Hanein *et al.* report an experiment that suggests a link between this

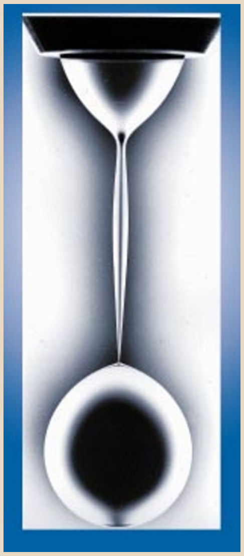
Fluid dynamics

Lights, camera, drip

Scientists at the University of Chicago have been focusing a high-speed camera on dripping glycerine in the hope of catching the moment when the fluid drop breaks off. By taking 10,000 frames per second of a glycerine and water mixture dripping through a nozzle, they have captured images, such as the one shown here, of a drop at the point of snap-off.

According to an analysis of these images published in *Physical Review Letters* (83, 1147–1150; 1999), drops about to break free are self-similar — that is, the shape of the drop just before breaking looks the same at different times, if you rescale the axes. Understanding such fractal behaviour is important for the physics of mixing, because the quality of a dispersion — crucial when spray-painting cars, for example — depends on the way it breaks into drops.

Getting to grips with the mathematics of this problem may be relevant to other areas of physics, such as theoretical studies into the gravity around black holes. When a fluid drop is about to break, a singularity develops, rather like the space–time singularity of a black hole. Simulating the infinite character of gravitational collapse remains a mathematical headache, and so studying a dripping tap may be an attractive alternative.



Sarah Tomlin

new metallic behaviour at $B=0$ and the quantum Hall metal, and raises the possibility that both share a common physical origin.

The notion that 2D metals cannot exist in the absence of a magnetic field dates back 20 years, when powerful 'scaling' theories indicated that any amount of disorder would trap electrons, so preventing conduction and the existence of a metallic state[3]. These arguments are based on the quantum-wave nature of the electrons, whereby a travelling electron wave can be scattered from impurities back to its starting point. If these returning waves interfere constructively, the electrons become localized in one place and are less able to diffuse through the solid. At high temperatures this effect is weak and the sample *appears* metallic. As the temperature is reduced quantum interference becomes more important, so that at absolute zero all the electrons are localized and completely unable to move. Low-temperature experiments with both thin-metal films[4] and 2D sheets of electrons in field-effect transistors[5,6] confirmed these theoretical predictions, and for nearly two decades it was generally accepted that there can be no 2D metal at $B=0$.

It is a historical coincidence that at about the same time as a consensus was being reached that no metallic states could exist in 2D systems, the quantum Hall effect was discovered. The classical Hall effect occurs when a current-carrying conductor is placed in a perpendicular magnetic field. This produces a Hall voltage across the conductor, which rises linearly as the magnetic field is increased. In contrast, the Hall voltage measured in 2D semiconductors at extremely low temperatures rises in steps with a series of abrupt transitions between well-defined plateaux at which the Hall voltage is precisely quantized. It is only possible to explain this quantization of the Hall voltage by the existence of both localized (insulating) and extended (metallic) electron states that persist to $T=0$. So, increasing the magnetic field reveals a series of insulator–metal transitions as the current-carrying electrons alternately find themselves in localized and extended states. Despite many years of intense study, it is still not clear what happens to these extended states as the magnetic field goes to zero. Some argue that, below some non-universal magnetic field, the extended states simply disappear; others suggest that, at low magnetic fields, they 'float' up to higher energies, becoming inaccessible to electrons at low temperatures[7].

In 1994, strong evidence for a $B=0$ phase transition from an insulator to a metal was found in extremely low-disorder silicon field-effect transistors[8], in apparent contradiction with the prevailing scaling theory. Similar behaviour was subsequently observed in other material systems, independent of the sign of the charge carriers, indicating that the metallic state is a universal property of all low-disorder 2D systems. At present there is no theoretical consensus as to the nature of this unusual metallic phase, but experiments suggest that strong interactions between the charge carriers (not considered in the original scaling theory) and the spin of the electron (or positively charged hole) both play a role[9].

Hanein and co-workers[2] have now carried out an experiment that relates the $B=0$ and quantum Hall metal–insulator transitions. By tuning the carrier density in a high-quality 2D GaAs hole system, they are able to alter the magnetic field at which the quantum Hall metal–insulator transitions occur. Their results are unique because they followed these transitions to much lower magnetic fields than in previous studies[10]. They find that the transition associated with the quantum Hall effect at high magnetic fields evolves continuously into the $B=0$ metal–insulator transition. This implies that the extended states in the quantum Hall regime do not simply disappear as the magnetic field is reduced, nor float up indefinitely in energy, but continue to $B=0$ with some finite energy.

These results are intriguing because they link the quantum Hall effect, which can be understood without considering electron–electron interactions, with $B=0$ metallic behaviour that is only found in strongly interacting systems. A number of questions remain. If the two metals share a common physical origin, it is difficult to reconcile the fact that the $B=0$ metal is destroyed by applying a magnetic field *parallel* to the 2D plane[11,12], whereas the extended states in the quantum Hall regime are not. Furthermore, although some theories attribute the $B=0$ metal to a new, many-body ground state, certain experiments suggest that it may simply be a finite-temperature spin-related scattering effect[13]. If this is the case, then other effects, such as phase-coherent localization, may reappear at even lower temperatures. A great deal of work remains to be done before we can finally answer the simple question: is it possible for a 2D system to be a real metal at $B=0$? □

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Marine biology

No hibernation for basking sharks

Daniel Weihs

The phrase 'gentle giants' and the word sharks do not usually appear in the same sentence — sharks normally evoke the image of a bloody, tooth-filled mouth as in the film *Jaws*. But the biggest species of selachians (sharks) are, in fact, placid, slowly moving grazers that feed by filtering plankton. They swim with a widely opened mouth, engulfing small prey and the water they are in, and using long, bristle-like projections on the gill arches to remove the prey.

The only species of shark that uses this method of feeding — known as ram filter feeding — exclusively is the basking shark (*Cetorhinus maximus*). Because these sharks have to swim with a wide gape (Fig. 1, overleaf) that increases drag and, hence, the energetic cost of feeding, a long-standing theory has been that they may migrate (and even hibernate[1]) during winter, when the concentration of plankton falls below a relatively high threshold[2]. But in *Proceedings of the Royal Society*, David Sims[3] combines behavioural observations and theoretical calculations to show that the threshold for gainful filter feeding is probably much lower for the basking shark, implying that hibernation and migration are not necessary.

Actually, what Sims shows is that we probably do not need complicated explanations such as hibernation. These complex models came about because original investigators assumed the energy content of copepods (the main constituent of the planktonic soup ingested by basking sharks) to be three orders of magnitude larger than currently accepted values. This large overestimation did not result in absurd conclusions (which, presumably, would have alerted previous investigators to the error) because initial estimates of the energy cost of swimming were also between one and two orders of magnitude too big.