100 YEARS AGO

As a general rule, the pitch of a musical note does not in any way depend upon its intensity, but solely upon the wave-length. It appears probable, however, that any wave motion of very great intensity produces distorted effects. Thus we find that a very loud sound may so affect the ear of the observer as to appear flatter than it really is. This is a purely subjective effect… If a C tuning-fork (middle C, 256 vibrations per second) be *strongly* bowed, and then be quickly brought near the ear, before its loud note has had time to die away, the sound will appear flattened to about Bb_1, or even A_1, the amount of the effect being different to different ears… The amount of the subjective effect differs with different individuals, both in pitch and in intensity. What to one person appears a flattening of a minor 3rd , to another auditor appears a flattening of only a major 2nd, but in every case it appears to be a flattening and not a sharpening. Also the loudness of the subjective note appears different, even to the different ears of the same person… Much of my own musical work has been done amongst male voices, and I have frequently noticed that a singer of good concert-room power may, if practising in a small room, seemingly sing with flat intonation.

From *Nature* 30 May 1901.

50 YEARS AGO

The leading article in *Nature* of April 28 on "Biologists in the Modern State" draws attention once more to the need for biologists with sound basic training in one of the physical sciences. The Agricultural Research Council is seriously concerned about the shortage of plant and animal physiologists with an adequate knowledge of chemistry and physics and of biochemists with biological experience. Posts in these subjects have remained unfilled for long periods owing to lack of suitable applicants. It is recognized by the Council that it is rarely possible in the course of study for a first degree to include adequate training in both biological and physical sciences; and hence applications for the Council's studentships from candidates wishing to study biology after graduating in a physical science, or to study a physical science more thoroughly after training in biology with a physical science as a subsidiary subject, are given very sympathetic consideration.

From *Nature* 2 June 1951.

in temperate regions, is tossing many global-warming coins. Each population might live on different plants (or perhaps suites of them), across landscapes with different structures of habitat patches, and in range centres or at range margins. And each population will make different trade-offs between its ability to disperse and other essential biological functions. In aggregate, among widespread species, there will be winners and losers, but there will always be survivors.

In the tropics, each of the many more participants in the global-warming gamble plays a far riskier game. Each outcome will be as idiosyncratic and biologically fascinating as those uncovered by Thomas and co-workers. But, because tropical species typically have smaller geographical ranges[5], each species bets its existence on far fewer tosses. Human actions have forced small ranges on many species, while others are born this way. The broad lesson from Thomas and colleagues' results should not be awe at how quickly a few species benefit from global change, but concern with how rapidly many may be harmed by it. ■

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Superconductivity

Rehearsals for prime time

Paul Grant

Superconductivity seems to have been forever waiting in the wings. Although superconducting power cables are about to go live, will the newest material, magnesium diboride, become the class act of the future?

Practical superconductors made their debut in the early 1960s. This followed the discovery of intermetallic compounds that promised high-performance electromagnets cooled by liquid helium to temperatures of about 4 K. But it took 20 years for one of the players, niobium–titanium (NbTi), to become the material of choice for superconducting wires in real applications, such as magnetic resonance imaging and high-energy physics. In 1986, a new family of high-temperature superconductors burst on the scene, based on complex copper-oxide materials. This time the potential lay in electric power applications using refrigeration technologies spanning 20 to 100 K. Despite the brittleness of the copper oxides, a viable, albeit expensive, wire technology was in place by 1992 and 'street performances' in the form of power cables are currently in production.

Then, this January, in what perhaps was the briefest billing given a modern physics discovery, *Nature* published a paper[1] reporting superconductivity at 39 K in magnesium diboride (MgB_2), an unexpected new talent for such a simple compound, which has been around since the 1950s. Now, barely five months later, some 35 physicists report in three acts[2–4] (starting on page 558 of this issue) substantial progress towards improving the properties of MgB_2 that are vital to applications requiring high electric current and magnetic field. Superconductivity, like other players in the theatre of science, moves faster these days.

Whether or not a material is superconducting depends not only on its temperature but also on the strength of the ambient magnetic field, arising either from current flow or an applied field. In addition to having zero electrical resistance, an ordinary 'type-I' superconductor has the ability to shield itself completely from magnetic fields. But above a critical field, H_C, the superconductivity is destroyed. However, in the 1930s it was noticed that an applied magnetic field could partially penetrate some materials, eventually called 'type-II' superconductors, and the sample would remain superconducting. The magnetic flux flows through magnetic vortices, whose cores behave as simple metallic conductors, surrounded by superconducting regions. When the field is high enough the number of vortices occupies the total volume of the sample, and all superconductivity is lost. All practical superconductors are type II.

These magnetic vortices are the source of another operating limit on superconductors — the maximum superconducting current they can support. When a current flows in a type-II superconductor it produces a force on the magnetic vortices, causing them to move and creating electrical resistance through friction with the atomic lattice. But, thankfully, defects in the material can fix or 'pin' enough vortices such that they remain motionless, at least until the current and field become sufficiently strong that the vortices are 'unpinned' and so generate resistance. The behaviour of vortices therefore defines the maximum current, J_C, and magnetic field, H^*, for a given temperature and material. It is common for J_C and H^* to start out fairly low for newly discovered superconductors, and MgB_2 was no exception[5,6]. These quantities can be improved by introducing 'pinning defects' into type-II superconductors, but here success is based more on 'black art' than science.

The three articles published in this issue[2–4] pursue several traditional routes to improving pinning used successfully in both low- and high-temperature superconductors. Eom *et al.*[2] explore the effects on J_C and H^* of making thin films of MgB_2, in addition to what appears to be unintentional substitution of some of the boron by oxygen atoms. Thin films of almost all forms of superconductors, even single crystals, have higher values of J_C and H^* than their bulk counterparts. It is generally believed that the interface discontinuity between the film and substrate alone creates pinning defects. The authors present data on three film samples, all of which yielded values of J_C and H^* higher than bulk MgB_2, the greatest increase being obtained in the 'accidentally' oxygen-doped sample. It will be interesting to see the results of more controlled attempts to affect oxygen content. In the meantime, Eom *et al.* have given us proof that the performance of MgB_2, at least in the laboratory, can rival and perhaps eventually surpass that of existing superconducting wires.

Bugoslavsky *et al.*[3], on the other hand, use proton irradiation to induce crystalline disorder in bulk samples of MgB_2, an effect that is known to result in vortex pinning in many type-II superconductors. Such treatment can also reduce the temperature below which a material is superconducting, T_C, and there is some evidence of that in their data. But at a temperature of 20 K (roughly 50% of T_C) the reduction of J_C with applied field is much slower than in untreated samples, whereas H^* doubles on irradiation, about the same improvement observed by Eom *et al.* in their thin films. Bugoslavsky *et al.* used proton energies up to 2 mega-electron volts (MeV), as high as they had available, with penetration depths of about 50 micrometres in MgB_2. In 1997, Krusin-Elbaum *et al.*[7] reported huge increases in H^* in a mercury/copper oxide superconductor due to proton-induced fission of the mercury atoms. At a lower energy of 580 keV, protons colliding with ^{11}B (the most abundant natural isotope of boron) should result in fission and the emission of three 8.7 MeV alpha-particles — presumably creating more defects. Perhaps this would be an interesting 'sequel' plot for the authors to consider.

Some readers may wonder why there is all the fuss over a superconductor with a T_C of 'only' 39 K when we already have wire made from copper oxides that operate at liquid nitrogen temperatures (77 K). One good reason is cost. High-T_C wires in use today are 70% silver by volume. Even if a silver-free technology can be developed using so-called coated conductors — thin films of superconductor deposited on metal tapes — manufacturing capital costs could be significant[8]. Moreover, a liquid cryogen, like nitrogen, is really only necessary for long lengths of alternating current (a.c.) cables, owing to large a.c. losses in both the superconductor and surrounding metallic casing. By developing lower-temperature but cost-effective MgB_2 wires, one could imagine a complete and relatively inexpensive energy-delivery system based on electricity transmitted over direct current cables (which do not have the above intrinsic losses) and cooled just by hydrogen gas at 25 K. The gas itself can be usefully consumed or stored by the end user. We could use something like this in California right now.

That is why for me the third paper, in which Jin *et al.*[4] report a high J_C in iron-clad MgB_2 wires at 25 K and in 1 tesla fields, deserves the most applause of all. A J_C of 30,000 A cm^{-2} is already almost high enough for power transmission cables. Magnesium, boron and iron are commodity elements, and the method used to produce the wires is the well-tested powder-in-a-tube technique which was developed for low-temperature superconductors, such as NbTi, and which can be readily scaled up to high-volume manufacturing. The source of vortex pinning leading to such a high J_C is unclear at present, but is probably due to damage induced by the crushing and rolling processes used in drawing the wire (remember, I said this was a black art).

Although the dream that MgB_2 was just the first of a whole new family of materials was probably already over by the time the curtain came down at midnight at a special session of the American Physical Society meeting in March[9], it may yet win plaudits in applied superconductivity. Still, we will have to await a few more sequels to this new work[2–4] before we can predict whether and when MgB_2 will be ready to power the bright lights of Broadway and Piccadilly. ■

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Developmental biology

Fishing for morphogens

Stephane Vincent and Norbert Perrimon

Morphogens are long-range signalling molecules that are proposed to organize tissue patterning in animals. But their existence in vertebrates has been controversial. One suspect is now shown to fit the bill.

Throughout development, extracellular molecules tell cells where they are in the embryo, thereby guiding the formation of elaborate tissues. Fifty years ago, Alan Turing[1] proposed the 'morphogen' concept to explain how a molecule can provide spatial information. The idea is that a morphogen ('form-giving molecule') is secreted from a group of cells called an organizing centre, and then moves away. The activity of the morphogen decreases gradually as a function of its distance from the source. In this way, cells can detect where they are with respect to the organizing centre. The morphogen induces the cells to take on different fates according to their position. The existence of morphogens in vertebrates has been controversial, in part because it is difficult to prove that a given signalling molecule travels across a field of cells, instead of acting through intermediate signals. But, on page 607 of this issue[2], Chen and Schier confirm that Squint — a member of the transforming growth factor-β (TGF-β) protein family — is, as suspected, a bona fide morphogen.

For some time now, members of the TGF-β family of growth factors have been prime candidates for morphogens. Indeed, studies of fruitflies (*Drosophila melanogaster*) have provided conclusive evidence that Decapentaplegic (Dpp) — a protein in the TGF-β family that controls the growth and patterning of the imaginal discs — is a morphogen. For example, in the type of imaginal disc from which wings will form, Dpp regulates the expression of two genes (*spalt* and *optomotor-blind*) differently according to the magnitude of its activity[3,4]. Moreover, the cellular response to Dpp does not depend on interactions with other cells, and cannot propagate itself from cell to cell[4,5]. So, Dpp acts directly on target cells, rather than by a relay mechanism through other cells, and it works in a graded manner — so fulfilling the requirements of a morphogen.

In vertebrates, a myriad of TGF-β molecules has been identified. But the evidence