

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 issue²⁻⁴ 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 significant⁸. 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 March⁹, it may yet win plaudits in applied superconductivity. Still, we will have to await a few more sequels to this new work²⁻⁴ 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 Turing¹ 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 issue², 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

that any of them act as a morphogen has been a matter of debate. Several of these molecules have been studied during the induction of mesoderm, from which tissues such as muscle develop, in the African clawed toad (*Xenopus laevis*). In this process, a signal emanates from the vegetal pole of the embryo to induce certain cells to produce mesoderm. In many respects, the TGF- β protein Activin can act like a morphogen in mesoderm induction. A high concentration of Activin induces the formation of the type of mesoderm from which the notochord will develop, whereas a low concentration induces muscle-producing mesoderm⁵. Moreover, Activin can cross a field of unresponsive cells that have been treated to block the synthesis of a possible intermediate signal⁶.

But several results have thrown into jeopardy the view that Activin behaves like a morphogen. In particular, it is unclear whether Activin really has a role in mesoderm induction. In addition, a version of Activin, tagged so its movements could be traced, was not found to diffuse from its source⁷. Meanwhile, another member of the TGF- β family, TGF- β 1, activates its receptor only on neighbouring cells, and not at a distance.

Now, Chen and Schier² provide conclusive evidence that the TGF- β family member Squint does indeed function as a morphogen in zebrafish (*Danio rerio*) embryos. Squint and a relative called Cyclops are known as Nodal signals, because they are highly related to the mouse TGF- β protein Nodal, which is involved in mesoderm induction. First, Chen and Schier injected RNA encoding Squint or Cyclops into a single cell of zebrafish embryos. They then investigated which mesodermal 'markers' — genes that are expressed specifically in particular parts of the mesoderm — were turned on at various distances from the source of Squint or Cyclops. The authors found that both proteins can, depending on their concentration, induce the expression of two sets of target genes. However, Squint and Cyclops act over different ranges, with only Squint being able to activate target genes several cells away from its source (Fig. 1). The authors then showed that no relay mechanism is required for this long-range action of Squint (Fig. 2).

So, Squint appears to act as a morphogen, but the related protein Cyclops does not. To try to understand the difference in the range of action of these molecules, the authors swapped the 'prodomains' of the two proteins. In some TGF- β molecules these regions are required as 'chaperones', to enable the proteins to fold accurately and to form intramolecular disulphide bonds. Exchanging the prodomains did not affect the ability of Squint to act over long distances, so this property must reside in the core protein. Defining the molecular basis of this ability will help us to understand how morphogens travel through tissues.

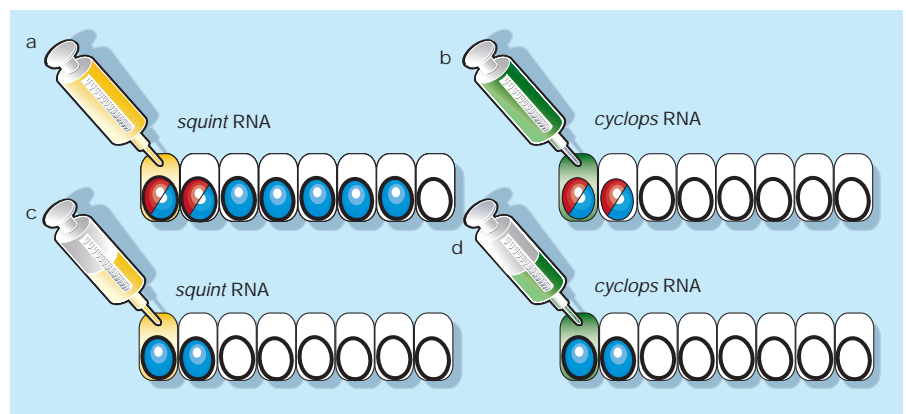


Figure 1 The Squint protein acts over long distances. To determine whether the zebrafish Squint and Cyclops proteins act as morphogens, Chen and Schier² first determined their range of action. Using zebrafish embryos consisting of 128–256 cells, the authors injected either *squint* (yellow) or *cyclops* (green) RNA into one cell and monitored the expression of target genes such as *gooseoid* (*gsc*, red) and *no tail* (*ntl*, blue). a, b, High doses of RNA injected; c, d, low doses injected. The results show that *gsc* and *ntl* are expressed in response to different levels of inducer. Moreover, at high concentrations, only Squint can induce the expression of *ntl* in distant cells. Squint therefore fulfils one requirement for a morphogen: it acts over long distances and in a graded manner.

Some insights into the mechanisms that might underlie the movement of TGF- β -like molecules have emerged from studies of *Drosophila*. Two groups^{8,9} looked at the behaviour of the Dpp protein fused with green fluorescent protein. The authors followed the distribution of the fused protein in imaginal discs, and showed that it is organized in a concentration gradient. This gradient formed quickly, was unstable, and was much steeper than the gradient of Dpp activity. Both groups concluded that the target cells help to shape the gradient. Entchev *et al.*⁹ also showed that mutations that compromise endocytosis — a process by which cells take up extracellular molecules — affect the establishment of the range of Dpp activity. These authors propose that the

long-range distribution occurs by 'planar transcytosis', in which molecules are imported into a cell, transported across it and exported on the other side.

Proteins of the Wnt and Hedgehog families have also been proposed to act as morphogens, and this has been confirmed in *Drosophila*^{10,11}. It will be important to find out how these molecules, too, might move through fields of cells. Do they travel by simple diffusion, or are they actively transported? Are extracellular cofactors involved, such as heparan-sulphate proteoglycans, which have been implicated in receiving TGF- β , Wnt and Hedgehog¹² signals at target cells? Finally, on a different note, how do cells translate quantitative information about the level of a signal into a qualitative

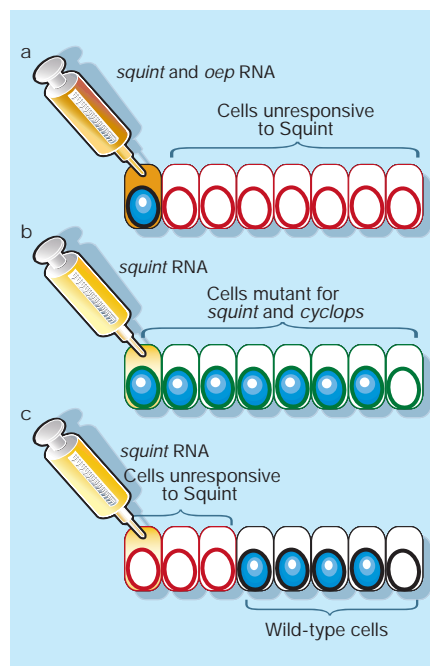


Figure 2 The Squint protein directly induces the expression of the *ntl* gene in distant cells. a, Chen and Schier² first used zebrafish embryos with mutations in the *one-eyed pinhead* (*oep*) gene. These embryos do not respond to Squint. When the authors injected both *squint* and *oep* RNA into one cell in a mutant embryo, that cell was induced to express *ntl*, but the adjacent cells (which did not express *oep*) did not. Thus, a relay mechanism that is independent of *oep* is not involved in the induction process. b, The authors injected *squint* RNA into one cell in an embryo with mutations in both *squint* and *cyclops*. Only the injected cell then expressed *ntl*. So Squint does not induce its own expression, or that of Cyclops, in neighbouring cells. c, The authors injected *squint* RNA into *oep* mutant embryos, and grafted normal cells at a distance. The intervening cells, which did not respond to Squint, did not inhibit *ntl* expression in the normal cells. So, no secondary signal is required for the long-range activity of Squint. Squint therefore fulfils the second criterion of a bona fide morphogen.

output? This fascinating problem in signal transduction must be solved before we can fully appreciate how morphogens pattern fields of cells. ■

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Earth science

Mantle cookbook calibration

Craig R. Bina

Doubts about a fundamental model of the chemistry of Earth's deep interior have now been transmuted into doubts about a standard used to calibrate these studies — gold's equation of state.

The properties of the Earth's mantle change abruptly 660 km below the surface, with sharp rises in both density and the transmission speed of seismic waves created by earthquakes. But in 1998 it was announced that highly sophisticated laboratory experiments¹ had failed to confirm this 660 km transition — instead, seeming to place the mineral transformation concerned at 600 km. Elsewhere in this issue, Chudinovskikh and Boehler², and Shim *et al.*³, describe how they have revisited the ques-

tion. The news they report is both reassuring and disturbing.

For decades, the global 660-km seismic discontinuity has been thought to coincide with the chemical reaction $\gamma \rightarrow \text{pv} + \text{mw}$, in which the mineral γ -(Mg,Fe)₂SiO₄ (also called ringwoodite or silicate spinel) breaks down to a mixture of pv-(Mg,Fe)SiO₃ (silicate perovskite) and mw-(Mg,Fe)O (magnesiowüstite, also called ferropericlae) at high pressures. This view was supported by experiments in which the reaction occurred

at pressures and temperatures believed to be appropriate to 660 km depth^{4–6}. In these experiments, samples were subjected to high pressures and temperatures inside diamond-anvil and multi-anvil devices, and were then cooled quickly and removed for analysis — a bit like looking at one's baking after removing it from the oven and allowing it to cool.

In 1998 Irifune *et al.*¹ used synchrotron X-rays to peer through the oven door and observe the baking *in situ*. But consternation greeted their report that the $\gamma \rightarrow \text{pv} + \text{mw}$ transition took place at pressures about 2 gigapascals (GPa) lower than expected, equivalent to a depth of 600 km rather than 660 km. Irifune *et al.* gave two possible explanations for this result: either their state-of-the-art pressure measurements were in error, or the common model of Earth's deep chemistry was wrong.

The two new papers^{2,3} describe experiments aimed at resolving the equilibrium pressure of the $\gamma \rightarrow \text{pv} + \text{mw}$ reaction. Using diamond-anvil devices, Chudinovskikh and Boehler² (page 574) subjected samples of Mg₂SiO₄ to high pressures and temperatures, swiftly cooled them to room temperature, and examined them using Raman spectroscopy while still at high pressures. Shim *et al.*³ (page 571) do precisely what Chudinovskikh and Boehler suggest in their closing sentence: they examined such samples *in situ*, at high pressures and temperatures, using synchrotron X-rays. The two groups used different methods of pressure calibration,

Behavioural ecology

Down on fungal farm



Leaf-cutting ants of the tribe Attini do not eat the vegetation they gather. Rather they use it to grow fungi, and then feed off the fungi. The ants' vast nests, containing

up to eight million individuals, have chambers devoted to fungus cultivation. But like all farmers, the ants face competition for the crop in the form of pathogens —

in this case other fungi, which threaten to destroy the fruits of their labours.

A couple of years ago, Cameron Currie and colleagues showed how the ants use antibiotic-producing bacteria for pest control. From observations of the species *Atta colombica* (pictured), he and Alison Stuart now describe other strategies to that end (*Proc. R. Soc. Lond. B* **268**, 1033–1039; 2001). One is simple cleanliness: the ants lick the surfaces of both the nest itself and new leaf material to keep them clear of contaminants.

The authors also sprayed fungal-cultivation chambers with spores of two pest fungi, *Trichoderma viride* and *Escovopsis*, to see the reaction. When rogue spores were found by the inhabitants, large numbers of workers congregated at the infected

site to gather up spores in their mouthparts and cart them away. If the spores reached the stage of germination, the ants turned to weeding by removing chunks of leaf along with crop and pest fungi.

The ants seem to be able to tell the difference between the two invading fungi. The specialist pathogen *Escovopsis* triggered more ants to take up cleaning duties, and their efforts went on much longer, than those directed against *Trichoderma*. But the ant farmers don't have everything their own way. Although *Trichoderma* was eliminated rapidly, *Escovopsis* hung on in the nests. It may be that this pathogen grows too quickly for the ants to keep up, or that the stickiness of the spores makes it impossible for the ants to remove 100% of them from a nest.

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