National Institute of Health), used a different strategy to produce a similar chimaera. They constructed a mutagenesis cartridge using a naturally occurring and an artificially constructed restriction site in the infectious complementary DNA clone of the Mahoney strain of type 1 poliovirus which can accept synthetic double-stranded DNA fragments. Using this strategy, they produced a chimaeric virus in which residues 88–102 of VP1 of the Mahoney strain of type 1 poliovirus are replaced by the corresponding amino acids from the Sabin strain of type 3 poliovirus. This chimaera is neutralized by antisera against both type 1 and type 3 poliovirus, and induces a significant neutralizing response to both type 1 and type 3 poliovirus in rabbits and monkeys.

Girard, Martin, Couderc, Crainic and Wychowski (Pasteur Institute) used a similar mutagenesis cartridge, in this case with two artificially generated restriction sites, to replace residues 94–102 of VP1 of the Mahoney strain of type 1 poliovirus with the corresponding residues from the mouse-adapted Lansing strain of type 2 poliovirus. This chimaera is neutralized by both type 1 and type 2 antisera and generates a neutralizing response to both serotypes in rabbits. Moreover, although most strains of poliovirus (including the Mahoney strain of type 1 poliovirus) are specific for primates, the substitution of residues 94–102 from the Lansing strain of type 2 poliovirus confers on the chimaera the ability to cause paralytic poliomyelitis in mice. Earlier work by Racaniello and colleagues (Columbia University) shows that mouse-adaptation in the Lansing strain of type 2 poliovirus maps to the capsid region of the genome[6], and that mutations in the 94–104 loop of VP1 significantly diminish the virulence of the Lansing strain in mice[7]. The mouse-virulence of the chimaera demonstrates conclusively that the 94–104 loop of VP1 is in itself an important determinant of the host range of poliovirus, and indicates that this highly exposed loop (see figure) may be involved in receptor binding, at least in the mouse central nervous system.

The success of these three groups in producing viable intertypic chimaeras of poliovirus demonstrates the feasibility of this approach for producing improved poliovirus vaccines. As a practical matter, however, the efficacy and safety of the existing poliovirus vaccines may make the large-scale testing of any new polio vaccine difficult. Nevertheless, the results do allow considerable optimism that similar approaches may permit the easily grown and (relatively) genetically stable Sabin 1 strain to act as a carrier of antigenic determinants of other viruses, such as hepatitis A virus, which do not have vaccines and which are sufficiently difficult to grow to inhibit attempts to produce a vaccine by conventional methods. Finally, the exciting demonstration that the Lansing–Mahoney chimaera is mouse-adapted is a poignant reminder that the usefulness of these chimaeras extends well beyond their immediate implications for vaccine development, as they are very accurate probes of the roles of specific amino-acid sequences in determining virus structure and biological functions. ☐

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Superconducting ceramics

Rare-earth elements redundant

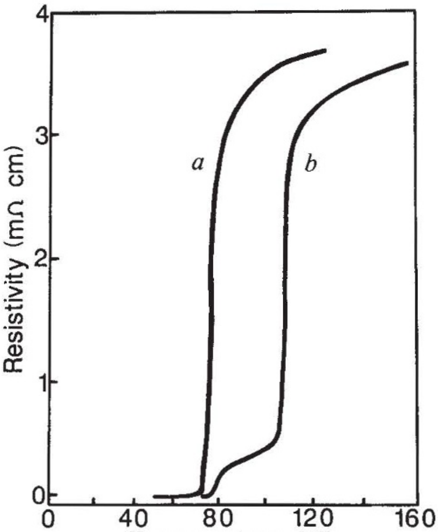
Ted Forgan and Colin Greaves

DESPITE the legions of researchers now studying high-temperature superconductors, there have been no reproducible measurements of superconductivity at temperatures above 93 K, the record established with YBa$_2$Cu$_3$O$_{7-x}$ (YBCO) a year ago. This situation now seems set to change. On page 55 of this issue[1], Sheng and Hermann report that Tl–Ba–Cu–O becomes superconducting below 85 K, and their forthcoming results[2] indicate that partial substitution of calcium for barium increases the transition temperature (T_c) to around 115 K. Also, Maeda *et al.* can now observe[3] superconductivity at 105 K in Bi–Sr–Ca–Cu–O. This increase in T_c above 93 K, although modest, is nevertheless important because it doubles the operating margin between T_c and 77 K, the boiling point of liquid nitrogen. Moreover, unlike the ceramics previously reported to have higher transition temperatures, the materials seem to be stable and, for the bismuth system at least, the results have been confirmed in many laboratories. In addition, the high-T_c phenomenon is no longer constrained to compounds of the rare-earth elements, so that a wider spectrum of possibilities for research now exists.

In a paper published[4] at the end of 1987 (but submitted in May), Michel *et al.* reported superconductivity in Bi–Sr–Cu–O, although the transition temperatures were disappointingly low: 7–22 K. The apparent relationship between this system and the previously reported high-T_c mixed copper oxides stimulated Maeda and co-workers at Tsukuba in Japan to try other substitutions, which resulted in superconducting transitions near liquid-nitrogen temperatures in a Bi–Sr–Ca–Cu oxide sample prepared on 23 December 1987. This result was revealed to the Japanese press on 22 January 1988 and was confirmed within days in several Japanese laboratories. On 25 January, Chu and co-workers in Houston announced similar results, but with Bi–Sr–Ca–Cu–Al–O.

The work by Sheng and Hermann reported[1] in this issue follows a different path: they attempted to replace Y^{3+} in YBCO by another trivalent cation, and on 22 January, reported 85 K superconductivity in Tl–Ba–Cu oxides, and a few weeks later they announced superconducting behaviour at around 115 K in the similar Tl–Ba–Ca–Cu oxides. Once again, the importance of chemical intuition and knowledge of the periodic table in synthesizing new high-T_c materials is evident. Interestingly, however, attempts to substitute cations have often resulted in new phases rather than the intended doped versions of the parent phase.

It appears that the Bi–Sr–Ca–Cu–O samples are multiphasic with two significant superconducting phases; the one with the lower T_c, around 80 K, is dominant in most samples synthesized so far and its complete characterization is probably imminent. Our X-ray diffraction patterns reveal a close structural relationship to the Aurivillius phases[5], which were



Resistivity curves for BiSrCaCu$_2$O$_x$ showing both the single phase sample (*a*) with T_c=75 K and a multiphase sample (*b*) with higher T_c = 105 K. (From ref. 3.)

previously used as a model for the Bi–Sr–Cu–O superconductor[4]. In these phases, $Bi_2O_2^{2+}$ layers separate up to four perovskite-like layers (three in the 80 K phase) in which copper ions occupy at least some of the small octahedral sites. Related Cu–O layers are responsible for the two-dimensional planes and one-dimensional chains which appear to be of fundamental importance in the previously discovered high-T_c superconductors. It is therefore fairly certain that similar structural features are present in the new materials. Electron-, X-ray- and neutron-diffraction studies should soon give a much clearer picture (W. I. F. David and D. McK. Paul, personal communication; R. M. Hazen *et al.*, preprint). The thallium-containing materials seem to have a different structure (A. M. Hermann, personal communication) and confirmation of structural data for this class is eagerly awaited.

A frustrating feature of the YBCO superconductor family is that almost every effective substitution results in a decrease in T_c: YBCO seems to represent a 'local peak' of T_c in the range of readily adjustable parameters. To discover new high-T_c families, it has been necessary to descend into a valley before finding a new area of high ground. We are now experiencing a return of the old excitement as researchers cast around to see if there are new, undiscovered peaks. In this respect, note that the new bismuth-containing materials seem to be very tolerant of variations in composition, and the thallium-based materials also seem to belong to an extended family.

One aspect of the new broad field of investigation is the vital need for optimization of preparative conditions. Lower temperatures are certainly required than for YBCO, and this in itself is an attractive feature. Also of potential significance is the apparent stability of the new materials, especially the resistance of the bismuth-based phases to degradation by water. The importance of the recent discoveries is further underlined by the fact that the increase in T_c could be very helpful in enhancing the critical currents so far achieved with ceramic superconductors. Finally, because the new T_c is above the boiling point of liquid methane (110 K), one new application immediately suggests itself: the measurement of resistance as a level detector in tanks of liquefied natural gas. □

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Biological optics

Paradoxical superposition

Michael F. Land

THE discovery of a new type of imaging system in an eye is always an event worth celebrating. By my count there were only about eight such systems until today, and now there are nine, thanks to D.-E. Nilsson's careful study of the eye of the crab *Macropipus* on page 76 of this issue. I cannot claim to like this eye, however. It is quite the most complicated optical system known in biology, and resentably difficult to understand. It was even hard to find a name for it, and although "parabolic superposition" finally won over "peculiar superposition" and "problematic superposition", those of us who watched, impressed, as Nilsson struggled with this eye felt that so straightforward and informative a name failed to do justice to its real deviousness. The feature of the eye that makes it particularly alarming for biologists, although intriguing for optical technologists, is that the mechanism of bending light is quite different in different planes.

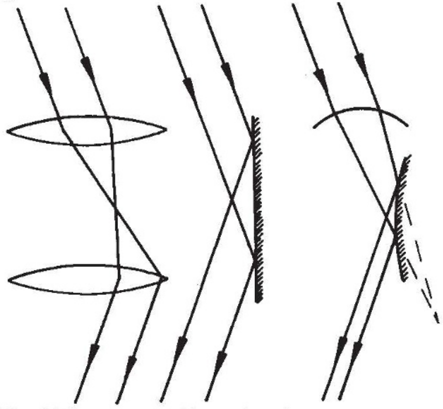

Fig. 1 Three ways of inverting the direction of a light beam, corresponding to the three types of superposition eye. *a*, Refracting; *b*, reflecting; *c*, parabolic.

These eyes are a variant of the superposition type of compound eye, in which many facets contribute ray-bundles to a single erect image on the deep-lying retina. The essential feature of the optical components of these eyes is that they redirect light-beams across their axes, and the way they do this defines the type of eye (Fig. 1). Until today two kinds of superposition eye have been recognized. The first, found in moths and krill, relies on lenses arranged in pairs as an array of tiny inverting telescopes (Land, M. F. *Nature* **287**, 681–686; 1980). The second, found in shrimp and crayfish, uses a square array of plane mirrors to achieve the same inversion. The mirror type was actually the last natural optical system to be discovered, by Klaus Vogt (*Z. Naturforsch.* **30**c, 691; 1985). I remember wondering at that time whether intermediates were possible — whether some combination of a single lens and half a mirror could be persuaded to do the same job — but I abandoned the speculation because nothing I could think of corresponded to the half-mirror. Confident the laws of physics were on my side, I concluded that intermediates could not exist.

The upshot of Nilsson's study is that my confidence was misplaced. There is at least one, and possibly many solutions to the problem. In the version reported here, the crab *Macropipus* makes use of a single lens and of a mirror surface with a unique form, cylindrical in cross-section but a convex parabola in profile (Fig. 2). The parabola straightens out the converging beam from the lens (Fig. 1*c*), so that the combination behaves much like a plane mirror. The tricky bit comes when the beam is viewed from along the axis of the element. The mirror surface is now not parabolic and convex but circular and concave, and the body of the element itself behaves as a cylindrical lens. The result is an optical system that as before produces a parallel emergent beam, but using a lens–mirror–lens combination, not a lens and parabolic mirror.

Why should some crabs use this complicated mechanism? The answer seems to be that it gives them two alternative types of eye. Under bright conditions, dark pigment intercepts the reflected rays, leaving only those that are focused by the corneal lens onto the rear surface of each element. Here a light-guiding structure conveys the focused light down to the

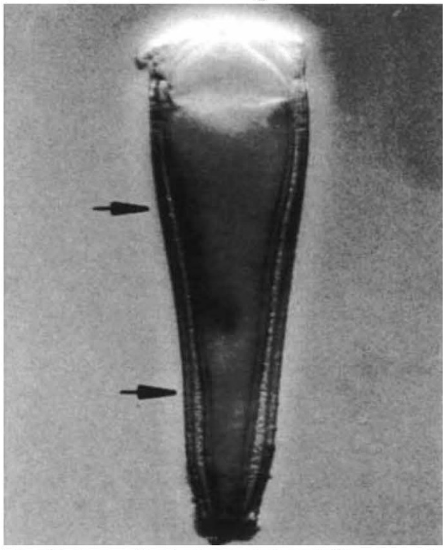

Fig. 2 An optical element (crystalline cone) from the crab *Macropipus* showing the region of parabolic curvature (arrows). (Photograph by D.-E. Nilsson.)