Are plasmons the key to superconducting oxides?

SIR—Recently, Sir Nevill Mott addressed the issue of distinguishing viable explanations for the high-temperature superconductors¹. His discussion of polaron effects represents a novel approach to superconductivity in addition to the highly original suggestion proposed by Anderson on the basis of resonating valence bonds². Another approach to creating room-temperature superconductors relies on the plasma oscillations of electrons (or holes). In view of the reported experimental evidence for plasmon anomalies in the cuprates, it seems appropriate to indicate the limitations as well as the promising features of this electronic mechanism for superconductivity.

Traditional explanations of superconductivity based on phonon-mediated interactions (Bardeen–Cooper–Schrieffer (BCS) theory) provide the somewhat modernized formula for the superconducting transition temperature

$$T_c = 0.7 \theta \exp \left[-\frac{1+\lambda}{\lambda-\mu^*} \right]$$

where θ represents a typical temperature for the sound wave of the lattice vibrations, λ is the electron–phonon coupling and μ^* is the modified Coulomb repulsion between electrons. But in the case of phonon-mediated interactions, $\mu^* \approx 0.1$, $\lambda \approx 1$, and a value of $\theta \approx 300$ K yields superconducting temperatures up to 25 K. The case of Y–Ba–Cu–O has become more mysterious with the measurements where the ¹⁸O isotope is substituted for the normal ¹⁶O atoms. The Raman scattering shifts of the oxygen vibrations predict a change in T_c by 4 K according to the BCS formula, but the actual measurements rule out changes in excess of 0.2 K. In other words the evidence suggests minimal involvement by the oxygen-related phonons in the high-temperature superconductivity^{3,4}.

The original discovery⁵ of the La–Ba–Cu–O alloys showed that their T_c was unusually sensitive to the alloy content: for example, if 5% of the La is substituted by Ba, no benefit is produced, whereas 15% Ba triggers a superconducting state, with $T_c \approx 40$ K. Later, Chu and his colleagues showed that this can be improved by substituting yttrium for La, giving the Y–Ba–Cu–O series of 90 K superconductors⁶.

One interpretation of the concentration dependence of T_c is that a low frequency plasmon mode is created only in those alloys where the Fermi energy may intersect a narrow band of electrons (or holes), which then participate, in addition to the majority carriers. This suggestion⁷ is compatible with both recent electronic structure calculations for the Y–Ba–Cu–O compounds and photoemission data.

Moreover, the nature of the two component plasmons may resemble acoustic waves, with a corresponding ‘sound’ velocity much higher than ordinary phonon velocities.

The allure of plasmons as candidates for the mediation of the electron–electron pairing is obvious from the T_c formula. If the prefactor $\theta \sim 100,000$ K is substituted, the resulting T_c enhancement would indicate that room-temperature superconductors should be readily available. Unfortunately, this optimistic glance must contend with a disagreeable fact; namely, the existence of plasmons in metals is commonplace, yet ordinary metals are usually not very good superconductors, and some are not superconducting at all.

A plausible solution to this dilemma may be the existence of two plasmon modes: the first high-energy excitation, say $\Omega \sim 1$ eV, simply represents the majority of electrons or holes that carry electrical current, while a second branch at lower energies, say $\theta \sim 0.1$ eV, may occur under exceptional circumstances and meet the stringent requirements for an electron pairing interaction. The existence of an acoustic plasmon in metals was originally proposed by Pines, and applied

to superconductivity by Radhakrishnan⁸, Fröhlich and others⁹.

Infrared absorption experiments should provide a test of the plasmon models proposed to date. The two-component acoustic plasmons⁷ in the Cu–O plane should be very responsive to alloy composition and the interlayer plasmon¹⁰ should exhibit a selective response to polarized light. The single-component, two-dimensional plasmon invoked by Kresin¹¹ should be examined as well. The first evidence for a two-dimensional acoustic plasmon in a metal has just been reported for La₂NiO₄ (ref. 12).

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Extraordinary non-spreading light beams

SIR—The non-spreading light beam of Durnin *et al.*¹ mentioned in a recent News and Views article² is much like that produced by passing plane waves through a piece of glass flat on one side and conical on the other³. Both go on to form a circle at infinity. In getting there, the light passes through the axis, where it creates a region of high intensity. This region is a caustic, not a focus: in any transverse plane, only a minute fraction of the energy in the beam passes through the central bright spot. Because the caustic is straight, the conical lens and other ‘axicons’ (from axial icon = axial image) have been used as aligning devices. The device of Durnin *et al.* differs from every other axicon I know of in producing a diffraction pattern that ideally varies neither in form nor intensity with position along the caustic.

The caustic is limited in length to the portion of the axis crossed by the conical beam on its way to infinity. In the experiment of Durnin *et al.* this was about 0.8 m. It can be increased by narrowing the cone angle of the beam — but the central maximum will then be broader — or by increasing the diameter of the axicon. Fourier still rules the photon shooting gallery.

To hit a target with photons, there is still no better way than launching spherical waves, with the target as centre, from a spotlight of the largest possible diameter. Depending on how errors are penalized, it helps to vary the amplitude across the

launched wavefronts in one way or another. The root-mean-square miss distance is minimized if the amplitude falls off with distance from the axis as the J_0 Bessel function, scaled so its first zero falls at the edge of the beam (ref. 4 — in equation 4 of which the number 2.405 should be replaced by 2.405²). For uniform amplitude, the root-mean-square error is infinite in paraxial theory.

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Prospects for life in Lake Nyos?

SIR—The active interest of the international scientific community in the disaster in the vicinity of Lake Nyos in Cameroon on 21 August 1986 is very encouraging. It is important to know the cause and mechanisms of this event so that it can be determined if others are likely to occur at Lake Nyos or other lakes of volcanic origin. I have, however, been struck by the lack of mention in the reports that I have seen in *Nature* and other science journals of the animal life in the lake.

For example, I am aware that the volcanic lakes of western Cameroon are well known to biologists as a natural evolutionary laboratory for fishes, mostly of the