Interlayer effects in high- T_c superconductors

SIR—A striking feature of the known high-transition-temperature superconductors is the presence of square-planar Cu–O layers. In the newly discovered thallium¹ and bismuth² families, one, two or three of these Cu–O layers are sandwiched between layers of thallium or bismuth oxide³ and the superconducting transition temperature (T_c) increases with the number of layers in the sandwich. This points to an interlayer mechanism such as the one we have recently discussed⁴.

The basic ingredient in our model is the coherent hopping of valence-bond pairs⁵ between Cu–O planes. T_c is set principally by the values of the parameters $\Lambda = t_l^2/J$, where t_l is the interlayer hopping matrix element and J is the intralayer exchange constant. It is believed that phase coherence between valence bonds can be achieved by pairing the holons, which are bose-like in the background of resonating valence bonds. In this way it is hoped that the essential physics of the isolated layer (strong correlations and pre-formed pairs) can be handled correctly both above and below T_c . Of course it is not clear *a priori* whether there might exist a stronger purely in-plane pairing effect; one must appeal to experiment to settle this issue.

Let n be the number of Cu–O sublayers. The superconducting amplitude $F_l = \sum_k \langle e_{-k} e_k - k_l \rangle$ (where e is the holon destruction operator) must be the same in all layers (l) for $n = 1$ and $n = 2$, as in these cases all layers are equivalent. For $n = 1$ and $n = 2$, we find $T_c = 2\Lambda/p\delta$ and $T_c = (\Lambda_o + \Lambda_m)p\delta$, respectively, where p is a model-dependent number of order unity and δ is the doping away from nominal valence Cu^{2+} . The couplings are defined in the figure, and their values derived from the observed T_c are given in the table legend.

In contrast, when $n = 3$ or 4 there are inequivalent outer (o) and middle (m)

sublayers; nevertheless, all layers must go superconducting at a single temperature. T_c is given in these cases by the eigenvalue equations

$$\frac{T_c}{p\delta} \begin{pmatrix} F_m \\ F_o \end{pmatrix} = \begin{pmatrix} 0 & 2\Lambda_m \\ \Lambda_m & \Lambda_o \end{pmatrix} \begin{pmatrix} F_m \\ F_o \end{pmatrix} \quad n=3$$

$$\frac{T_c}{p\delta} \begin{pmatrix} F_m \\ F_o \end{pmatrix} = \begin{pmatrix} \Lambda_m & \Lambda_m \\ \Lambda_m & \Lambda_o \end{pmatrix} \begin{pmatrix} F_m \\ F_o \end{pmatrix} \quad n=4$$

The predicted T_c s for the $n = 3$ bismuth and thallium materials, shown in the table, are in good agreement with experimental values.

At $T = 0$ another clear test of the interlayer mechanism emerges. It is easily shown that the superconducting amplitudes F are equal on all layers at $T = 0$.

Cu–O sublayers and definition of the pair-hopping parameters, Λ_o and Λ_m .

This implies distinct order parameters $\Delta_m/\Delta_o = 2\Lambda_m/(\Lambda_m + \Lambda_o)$ for inequivalent planes when $n \geq 3$. $\Lambda \approx \Lambda F$ determines the change spectrum in superconducting state. A purely in-plane mechanism necessarily leads to a single Δ .

Finally we comment on the couplings found. The Λ_m s for the bismuth and thallium compounds are similar, as is expected from their structure. Λ_o for Bi is small compared with that of Tl, perhaps because the Tl p -band is closer to Cu levels than is the case for Bi. (There is also the cleavage difference, as noted in ref. 3.) Note, however, that the simple numerology above assumes that the doping is the same in all layers, and that the doping is roughly the same for the Bi and Tl compounds for the quoted T_c s.

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Observed ($n=1,2$) and predicted ($n=3,4$) transition temperatures for bismuth and thallium superconductors

n	Formula*	T_c (K)	
		Bi	Tl
1	2021	10	80
2	2122	85	105
3	2223	116	114
4	2324	131	119

The observed T_c s for the 2012 and 2122 compounds (ref. 6 and J.B. Torrance *et al.*, personal communication) yield $\delta\Lambda_o = 5$ K for Bi, 40 K for Tl; $p\delta\Lambda_m = 80$ K for Bi, 65 K for Tl. The predicted T_c s for the 2223 and (hypothetical) 2324 compounds are then calculated from these parameters.

* The four digits represent the number of cations in the unit cell, in the order Bi(Tl), Ca, Sr(Ba), Cu.

Solar cycle 22 to be one of the largest on record?

SIR—It now seems virtually certain that the value of 12.3 for the smoothed monthly mean sunspot number for September 1986 defines the minimum of solar cycle number 21, and hence the conventional beginning of cycle 22. Since then, activity has increased unusually steeply. Because it has generally been found that rapid initial rises in sunspot activity have been followed by large maxima, there is already wide interest in the development of cycle 22.

Given the comparative regularity of the solar cycle period, the prediction of the timing of a subsequent sunspot maximum does not pose such a problem as the prediction of its magnitude. The consensus seems to be that cycle 22 will peak in 1990 ± 1 . Magnitude predictions are based on a variety of techniques¹, which generally give a large spread of values. Recent predictions^{2–5} for cycle 22 have all been at the top end of the range (International Sunspot Number as great as 190), compared with tentative earlier anticipations of a very small maximum (even as low as 36).

One prediction technique which has a broad scientific basis, and which generally gave near-correct forecasts for the previous cycle¹, makes use of experimentally observed 'precursors'. According to the dynamo theory, a given solar cycle is generated in the Sun by the gradual conversion of a poloidal magnetic field into one of toroidal form, powered by the Sun's differential rotation during most of the declining phase of the preceding cycle. If this is so, then solar or geophysical data obtained during this phase might be expected to contain clues about the forthcoming activity. One such precursor method^{6–8} is based on the occurrence of so-called geomagnetic abnormal quiet days (AQD)⁹ determined from the form of the diurnal variation of the magnetic horizontal component on international quiet days at a temperate latitude station, such as Hartland (51° N, 4° W geographic).

The annual number of AQDs (n) varies inversely with the solar cycle, and the peak number that occurs near a sunspot minimum anticipates the size of the subsequent sunspot maximum. This relationship holds good back to 1885, the earliest year for which data are available⁷. To illustrate the relationship, Fig. 1 shows an example of the variation of n over the last few solar cycles. Due to the necessary smoothing of the data, n is always around two years in arrears, so that it is only possible to locate the maximum with confidence some three years after it occurred. It is clear that the peak value of n that anticipates cycle 22 may now be identified fairly confidently. Fortunately for prediction purposes, this maximum has occurred