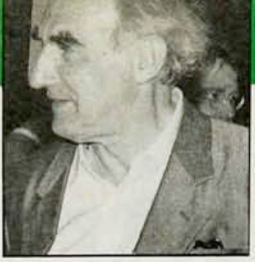

HIGH-TEMPERATURE SUPERCONDUCTIVITY: PAST, PRESENT AND FUTURE

Vitaly L. Ginzburg

I am writing this note in California, and being here reminds me how 20 years ago, in September 1969, Felix Bloch and I traveled from here to Honolulu, where William Little had organized a conference devoted to organic and high-temperature superconductors.[1] At the time, one well-known specialist characterized the conference as something almost absurd because not only did organic superconductors not exist, neither did layered or high-temperature superconductors. However, soon after, in 1971, investigations of intercalated layered compounds began. Organic superconductors were synthesized in 1980, and finally in 1986–87 stable and reproducible high-temperature superconductors were discovered. With the present boom in high-temperature superconductivity, previous developments in the field have practically been forgotten and frantic competition has begun among experimenters and among theorists. I have no intention, however, of discussing here the history of high-temperature superconductivity research, since I have done so recently.[2] I permit myself only to quote, as I did in reference 2, from one of my papers, published in 1984, *before the boom*: "It somehow happened that research in high-temperature superconductivity became unfashionable (there is good reason to speak of fashion in this context, since fashion sometimes plays a significant part in research work and in the scientific community). It is hard to achieve anything by making admonitions. Typically it is some obvious success (or reports of success, even if erroneous) that can radically and rapidly reverse attitudes. When they sense a 'rich strike' the former doubters, and even dedicated critics, are capable of turning coat and becoming ardent supporters of the new work. But this subject belongs to the psychology and sociology of science and technology, and I shall not dwell on it here. In short, the search for high-temperature superconductivity can readily lead to unexpected results and discoveries, especially since the predictions of the existing theory are rather vague." I think that, beginning in 1986, events have moved in just the manner I anticipated.

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Two years has not been long enough for the physical properties of the high-temperature superconductors to be clarified, for the mechanism of their superconductivity to be determined or for the applications to be realized. Naturally, there are quite different opinions concerning these issues.

According to one extreme point of view, the mechanism by which superconductivity occurs in the known high-temperature superconductors is quite different from that in the previously known, "conventional" superconductors. It has been suggested (in the resonating-valence-bond model of Philip W. Anderson and similar models) that high-temperature superconductivity is superconductivity of a spin liquid; in conventional superconductors it is the electronic Fermi liquid that becomes superconducting. Spin-liquid models are undoubtedly very interesting, and they might even be able to behave like high-temperature superconductors. However, as far as I can judge, this possibility has not been proved theoretically, nor has it been confirmed by experiments. Consider, for instance, the linear temperature dependence of the specific heat predicted at $T \ll T_c$ in spin-liquid models. Several new measurements testify against the existence of such a linear term in some high-temperature superconductors; in other cases, a linear specific heat can be connected with impurities in the samples. Furthermore, in the high-temperature superconductor $Ba_{0.6}K_{0.4}BiO_3$ there apparently are no magnetic moments, and so no spin liquid could exist. I do not know of any convincing argument in favor of spin-liquid models of high-temperature superconductivity.

At the other extreme is the view that superconductivity in the known high-temperature superconductors is very like that in conventional superconductors: Both are described by models of the type developed by John Bardeen, Leon Cooper and J. Robert Schrieffer, with weak coupling and, furthermore, with the pairs in s states. High values of T_c appear to be due to an excitonic mechanism of attraction—that is, to result from the exchange of electronic excitations that are not connected with spin effects. Such a model can be called the "simplest" one. In this simplicity lies the model's beauty. Little has recently summarized the arguments in favor of this simplest model.[3]

The simplest model may be correct, but it has not yet been verified. The model does not contradict general principles connected with metal stability requirements.[2,4] Confirmation for high-temperature superconductivity of the BCS relation $2\Delta(0) = 3.52kT_c$ connecting the gap width at $T = 0$ with T_c would provide strong, though not sufficient, evidence for the simplest model. (I mean, of course, confirming this relation for the bulk of the high-temperature superconductor specimen, not at its surface.)

Whatever the fate of the simplest model turns out to be, it is especially important now to establish the type of pairing in high-temperature superconductors and in this connection the character of the order parameter that governs their behavior. Even the macroscopic behavior of superconductors depends on the type of order parameter and so on the type of pairing: A material with s pairing behaves differently from one with, let's say, p or d pairing. If it is s

pairing that occurs in high-temperature superconductors, the order parameter will be a complex scalar function, and then the macroscopic theory of high-temperature superconductivity, even taking into account fluctuations, could be considered established.[5] Little has mentioned several methods for determining the character of the pairs[3]; other approaches include investigating fluctuation effects near T_c and, in particular, measuring the fluctuation part of the specific heat. According to reference 6, measurements of this type made so far contradict s pairing. However, other explanations of these results exist that retain s pairing but take into account the existence of twinning in the crystal structure.[7] Observation of thermoelectric effects in the superconducting state could also clarify the character of the pairs.[8]

Even if the known high-temperature superconductors are not described by the simplest model, they could nevertheless be analogous to conventional superconductors—as I am inclined to believe. There would then be no grounds for thinking that only metal oxides can be high-temperature superconductors. In particular, I know of no general restrictions[4] that limit the T_c at which a Fermi liquid undergoes the superconducting transition. Several families of superconductors with T_c's of 30–125 K have already been discovered, not to mention unstable and nonreproducible materials with apparently even higher T_c values. This demonstrates that general restrictions on T_c not only are unknown but do not exist, at least for $T_c \sim 100$ K and probably even for $T_c \leqslant 300$–400 K. So we can conclude that every reason exists for looking for new kinds of high-temperature superconductors. As I have said in the past,[4] it seems to me that the best candidates are organic superconductors and inorganic layered compounds, particularly intercalated ones.

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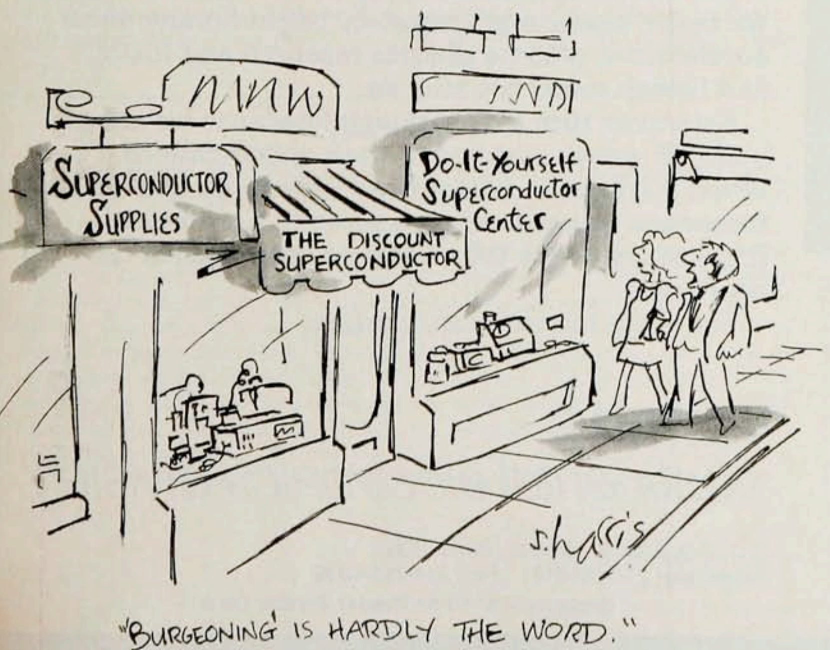

"BURGEONING" IS HARDLY THE WORD."