CHEMISTRY OF SUPERCONDUCTOR MATERIALS

Preparation, Chemistry, Characterization and Theory

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Foreword

The word "Chemistry" in the title of this book just radiates a host of associations, questions, and relations. What role is there for the science of molecules in the study of a phenomenon that is basically physical? Why were these remarkable compounds not made before? Do we need to understand a physical property to make advances with it?

You cannot investigate the properties of a molecule before making it. Oh, some theoretical colleagues of mine would argue otherwise, and they do have a case for some small molecules in the interstellar medium, and a few other isolated successes as well. But for molecules of reasonable size one needs the beast in hand before one can tame it. And who are the experienced designers of molecules? Chemists, of course. Not all of them, mind you. Physical chemists have a lot of trouble making molecules, and physicists--well, they're just not supposed to be good at this archetypical chemical enterprise, the transformation of recalcitrant matter from one bonding arrangement to another.

So here is the first surprise of the new developments of the eighties in superconductivity. Complex materials, compounds of as many as seven elements, were (and are) made by people who weren't supposed to be good at making them, physicists in particular. To some chemists this came as a shock. And to say that it was easy, that this solid state synthesis, the "shake-and-bake" methodology, is trivial, only allows the question to form in our minds, "If so, why did chemists not discover them earlier?"

Perhaps they did, or could have, come close, except that they didn't possess the capability to make the crucial measurements indicating superconductivity. You might think "never again," that given what we have learned of the high T_c materials, no chemist could possibly avoid searching for superconductivity in newly synthesized conducting materials. But that is not so. About 90% of the interesting materials that I, as a theoretician, have picked up from the literature of the last three years, remain untested. Only their synthesis and structure are reported, perhaps the briefest indication of electric and magnetic properties. Obviously the community has been sensitized, but lags behind in exploring the richness it itself wrought. Either the instruments are not available, or people do not have friends cooperative enough to do the measurements, compartmentalized as our specialized disciplines often are. Or they, the synthesizers, remain content in the paradigmatic exercise of their molecular trade, unwilling to be bothered by Brillouin zones or the art of attaching leads. And, just to set the balance right, many of their more progressive friends, the fortunate ones to whom those measurements come easy, intellectually and instrumentally, would rather spend their time making a tiny stoichiometric wrinkle of a perturbation than look at a phase that bears no resemblance to known successes.

Did we really understand superconductivity before 1985? And, does one need to understand the physics and chemistry of the phenomenon today, before making new, better materials? I think the answer to *both* these questions is "no and yes." And the questions and answers addressed in this new chemistry of superconductivity, in this book, are revealing, probing what we mean by "understanding."

The scientific community at large has bought into reductionism as the ideology of understanding. A phenomenon in chemistry is said to be understood when it is reduced to the underlying physics, when we know the physical mechanism(s) contributing to it, how they vary with macroscopic or microscopic perturbations. In that sense the BCS theory *did* provide a detailed understanding of the physics of superconductivity. But in another sense we should have known all along that we did not really understand the phenomenon. For we could never predict whether a given material would be superconducting or not, not to speak of its T_c. "Oh," we would say–"if only we could calculate the electron-phonon coupling exactly," and some day, in that millennium of the clever theoretical chemist coupled to whatever will come beyond the supercomputer, we would indeed be able to do so. But until then, well, we had to make do with the intuition of people such as the late Bernd Mattias.

I think we didn't understand superconductivity, in the sense of being able to use the physics to build a molecule with predictable properties. Our understanding was deconstructive or analytical rather than constructive or synthetic. I think there is a difference between these modes of understanding.

Do we need to understand superconductivity to make better superconductors? Well, I think we do need to have (a) the systematic experimental experience requisite for intuition to develop; (b) a set of theoretical frameworks, none necessarily entirely logical or consistent, to provide us with the psychological incentive to do the next experiment; (c) a free exchange of results; (d) people wishing to prove others wrong as well as themselves right; (e) the material resources to investigate what needs investigating. Together these criteria make up the working *system* of science, not the catechism of how science should work. Note that understanding, in the reductionist sense, enters only in (b), and even there not in a controlling way. The frameworks of understanding that will move us forward can be simplistic chemical ones, just as much as fancy couplings in some weirdly truncated Hamiltonian. Let's take a look, ten years from now, at what principles will have guided the discoverers, chemists and physicists, of the materials that may make this book obsolete.

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