Status of U.S. Solid State Chemistry

Arthur W. Sleight

The state of the U.S. effort in solid state chemistry has been much lamented. Many national committees have concluded that the weakest aspect of materials research in this country has been the lack of strong university programs in the synthesis of new inorganic solids. This problem becomes even more critical at a time when U.S. corporate laboratories tend to be abandoning such undirected research. There is reason to believe, however, that the U.S. problem with solid state chemistry is finally on the verge of being solved.

The current interest in oxide superconductors has served to spotlight the U.S. weakness in exploratory solid state chemistry. The main lesson to be learned from the discovery of high temperature superconductors is that we are, in general, not yet clever enough to produce breakthrough compounds by design. Therefore, we must conduct exploratory synthesis of new compounds in order to discover their unexpected properties. The copper-oxide-based superconductors have their roots primarily in exploratory solid state chemistry carried out in Europe. French universities, in particular, have had very strong programs in this area. To the extent that one can find roots to high temperature superconductivity in the United States, it would be superconductors based on $BaBiO_3$, but this research was in U.S. industry rather than university laboratories.

Several sectors are helping to bring about the transformation we are currently undergoing to ensure the future health of the U.S. solid state chemistry effort. They include funding agencies, universities, private companies, and the scientific community.

Funding Agencies

Those administrating government support of research have generally favored increased funding for exploratory synthesis of inorganic solids, and we have good reason to expect that an increased funding level for this area will become a reality. The sentiment that good scientists should be supported to do what they want has faded. Some of this country's most notable scientists have changed their research area in response to funding realities. Thus, funding agencies play a key role in bringing about improvement in neglected research areas. However, they cannot bring about the desired changes without help. For example, agency program directors require information so that special initiatives can be proposed within the agency in a timely and efficient manner.

The typical defense of the funding agencies in the area of solid state chemistry has been that they could not find many good people to fund and that many university chemistry departments were not sympathetic to adding a solid state chemist to their department. These were legitimate excuses in the past, but they do not apply today. The role of the funding agencies will be particularly critical in the next few years. There are now an increased number of deserving individuals to fund, and many chemistry departments are anxious to initiate or expand programs in solid state chemistry.

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A program sponsored by the National Science Foundation deserves special mention in terms of helping to solve the problem of neglect of solid state chemistry in the United States. For the past several summers, this program has exposed both undergraduate chemistry students and teachers of undergraduate chemistry to solid state chemistry. Students become familiar with solid state chemistry before they decide on graduate school, and the professors enrolled in this program introduce more solid state chemistry into their undergraduate teaching.

Universities

Most chemistry departments in the United States do not have research programs in solid state chemistry. Where such programs do exist, the solid state chemist frequently feels isolated from the rest of the department. There can be blame on both sides for this feeling of isolation.

Certainly, it is true that chemists of this country are usually poorly educated in the chemistry of solids. To many chemists, solid state chemistry isn't really chemistry. Instead it is something like ceramics or physics—in any case, something they don't readily relate with. This is a most unfortunate attitude—which is not shared by some of our greatest chemists, e.g., Linus Pauling.

Some blame for the isolation also lies with solid state chemists, who have looked to physics for leadership in the understanding of solids. Although the physics view of solids is important, solids can be understood very well based on chemistry concepts. Solid state chemists should not feel obliged to adopt the jargon of solid state physics. When they adopt this jargon, they naturally isolate themselves from other chemists. On the other hand, solid state chemists have learned that they must use the jargon of physics if they are to communicate effectively with a physics community which has come to believe that its jargon is the universal language for describing solid state phenomena.

Another problem has frequently existed with this country's few university-based solid state chemistry programs. These programs have tended to ignore the exploratory synthesis of new compounds. Many programs have instead been based on measuring and understanding the physical properties of known compounds. So, having a solid state chemistry program at a university doesn't necessarily mean that new compounds are being synthesized, and it doesn't necessarily mean that students are being well trained in the synthesis of inorganic solids.

Many universities are now anxious to add faculty in solid state chemistry, at both

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junior and senior levels. This has occurred partly because of the interest in superconductors, but the interest had been growing for several years. There are clearly not enough well-qualified candidates to fill the current demand. Chemistry departments have been negligent for many years in the teaching of solid state chemistry, so there is no easy way to quickly add many faculty in this area. Nonetheless, recent additions have been significant, and enough solid state chemists are on the faculties of U.S. universities that we can be optimistic that solid state chemistry will flourish, *if the students and funding are available.*

Companies

The value of solid state chemistry has long been recognized by the U.S. private sector. Historically, there was a special interest in the synthesis of new compounds because this could easily lead to breakthroughs with good patent protection. Many technologically important inorganic solids have been discovered through such exploratory programs. For example, CrO_2 was discovered at Du Pont in an exploratory synthesis program that did not have ferromagnetism as a goal. However, the value placed on solid state chemistry by U.S. industry has actually contributed to the problem of weak university programs in this area. The best jobs for the few U.S. solid state chemists were in the large corporate laboratories. There is no less appreciation today for solid state chemistry in the U.S. industrial sector; however, this sector has become less interested generally in supporting undirected research. Furthermore, the university situation has improved to the point where there is now little reason for the best solid state chemists to prefer an industrial laboratory for exploratory research. Today some U.S. companies are actually helping to solve the university problem through their failure to attract the best solid state chemists, as they once did.

Scientific Community

Ironically, the biggest problem that remains to be faced for exploratory synthesis may lie within the scientific community. The exploratory synthesis of new materials is frequently not well understood and appreciated by scientists outside the area. This lack of understanding is a particular problem when such scientists are reviewing programs in exploratory synthesis. The exploratory synthesis of new compounds is certainly appreciated—when a new compound has dramatically different, unanticipated properties—but even then the science of exploratory synthesis is generally not well understood. If we consider the ultimate goal of exploratory synthesis to be the production of new compounds with properties we haven't seen before, or even previously anticipated, the odds of success are extremely small. Many hundreds of new compounds are prepared before there is one "success." Those working in this area also know that for every new compound prepared, there are many attempts which produce nothing new.

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Many in the scientific community have charged that chemists synthesizing new compounds are simply "synthesizing new compounds for the sake of synthesizing new compounds"—i.e., their work has no real goal. Sometimes this is a legitimate criticism, but more often it reflects an ignorance of exploratory synthesis. All those who excel at synthesizing new compounds have goals or themes for their work. They may not, however, be attempting to prepare compounds with certain physical properties. After all, we must remember that the ultimate goal for exploratory synthesis is to prepare compounds with unanticipated properties. This area can still be scientifically rewarding, even if no such compounds are prepared. For example, a chemist may succeed in preparing a new compound with just the properties he is seeking. It's always comforting to find that we can occasionally produce, by design, new compounds with predicted properties. Maybe a new compound will not have physical properties perceived to be interesting, but it will have an intriguing structure or will exhibit some interesting chemical bonding. Science can be significantly enriched even if a new compound does not have interesting physical properties.

Frequently, the chemist synthesizing new compounds is not the one who recognizes the potential for some interesting property. Many people in the world scan the literature for new compounds, hoping to find features which would motivate them to investigate certain physical properties. It is extremely important that the catalog of synthesized compounds continue to expand—even if the new compounds are not considered interesting the day they are added to the catalog. Someone in the world may be looking for just such a combination of elements in that particular structure. Many important discoveries occur precisely this way. More often than not, an unusual property or an application for a new compound is not found by the individual who first synthesized the compound.

Concluding Remarks

Before the discovery of high temperature superconductors, there was widespread belief that from this point forward new materials with unique properties would not be single phase. Instead, such new materials would be composites or artificially structured materials. Certainly, the design and synthesis of new multiphase materials with properties which could not exist for a single phase remains one of today's most exciting synthesis areas. However, we now have renewed faith that we can continue to discover remarkable properties in single-phase compounds, even such well-studied compounds as oxides.

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There are many aspects to solid state chemistry, and I have focused here on the primary problem the United States has faced with this discipline, i.e., the meager university effort in the exploratory synthesis of new compounds. However, other areas of solid state chemistry have also been neglected in the United States. Very few students, for example, are trained in crystal growth or phase diagram studies.

We can be optimistic that the problem the United States has faced with solid state chemistry is finally being solved. However, the next few years will be critical and questions remain. Will there be adequate funding? Will we be able to attract enough good students to the area? Will we have the patience required for exploratory synthesis to flourish, or will we quickly forget the basic lesson to be learned from the discovery of high temperature superconductors?

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