

Remarks to the 2001 Pittsburgh Conference & Exposition

"Analytical Chemistry, Just Look at You Now"

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It is with the warmest pleasure that I participate in this symposium on Electrochemistry in the 21st Century, which is intended to frame the presentation of the 2001 Pittsburgh Analytical Chemistry Award to Allen J. Bard, my teacher, mentor, colleague, coauthor, and friend of 35 years. Four of the capacities that I have just named--teacher, mentor, colleague, and friend--are roles that Al has also fulfilled in the lives of countless other scientists active in the last half century of remarkable progress. Many present in this room would say so on their own behalf. No small number of colleagues can further claim a link to him in that fifth role: coauthor. What a remarkable impact he has had.

Breathtaking is the word that I would apply to the scale and quality of Al's contributions: to individual scientists and to science as a whole, to the literature of science and to the venues of literature that set standards used by scientists everywhere, to the health of science as a social enterprise and to the effectiveness of science in promoting the health of the larger society, to science as a calling and to science as an inspiration. The Society for Analytical Chemists of Pittsburgh has chosen wisely, not only because Allen Bard merits the Award, but also because the Award merits Allen Bard.

Al, I join everyone here in extending congratulations. When I joined your group in the fall of 1966 little did I know that you would become a legend in your own lifetime, and little did I know that we would form a relationship that would flourish so richly over so many years. I am grateful to you and I honor you.

This occasion combines ceremony with serious science. When Al suggested some months ago that I participate, I knew that I could handle the ceremony, but I was not so sure about the serious science. After all, it has now been about seven years since I closed my laboratory, and it has been three since I delivered what I declared to be my last scientific presentation here in New Orleans in 1998. What could I offer now that might have value to an audience of active scientists working on the leading edge?

Well, it's certainly not a new body of experimental results.

Probably my best shot is to offer some perspectives. Those that I present are based partly on age and partly on the reality that I now spend my days talking with a very broad range of people, including those who set agendas in business, government, private foundations, education, the media, and other aspects of American life. I'd like to offer a look at where analytical chemistry has been and where it might go.

"Analytical Chemistry, Just Look at You Now," I say in the title for this talk. We have all heard this kind of phrase from an older person speaking to a child grown up. It bespeaks

wonder and pride at the changes suddenly realized by the beholder. These are my reactions now when I behold our field.

It's unnerving to realize that my career in science reaches back almost four decades, but it's true.

In the middle 1960s, analytical chemistry was near death. Despite ideas in common circulation at that time, the surviving analytical chemists were not actually paranoid. As everyone knows, it's not paranoia when they really are out to get you. On the academic side, chemistry department after chemistry department was eliminating faculty and curricula altogether in analytical chemistry. On the industrial side, the practice of analytical chemistry continued out of practical value, but there were very few industrial organizations that could or would host the kind of creative activity and network building that must furnish vitality to any genuine field of science. Analytical chemistry seemed to have burned out. It seemed to be producing neither new scientific concepts nor new tools that the rest of science found valuable. Advances in what we now recognize as analytical chemistry were being made, but mostly by others outside the field.

Then everything changed. In the decade of the 1970s, the field rose from its ashes like the phoenix, vastly more powerful than ever before. In retrospect, it was a marvel. In real time, it was tremendously exciting. How did it happen? I think these were very important factors:

- the rapid success of the environmental movement
- the very broad impact of the quality movement
- advances in chemically-based health care
- the explosion of the microelectronics industry
- the development of information technology based on microprocessors

Serious environmental concerns gave rise to a demand for information of diagnostic value, most of it chemical, and by the middle of the 1970s, essentially all major industries were facing a regulatory environment where sophisticated analytical information was of critical importance.

The quality movement was born of intense competitive pressures, but it gave rise to a culture where diagnostic measurement became deeply embedded in product improvement and product development cycles. In any industry dealing with substances of any kind, the diagnostic measurements of value are very often chemical.

Many advances in health care since the 1960s have rested on the much-enlarged use of clinical diagnostics, many based on analytical chemistry, and pharmaceutical treatment working hand-in-hand with continued clinical monitoring.

The growth of the microelectronics industry reinforced the success of analytical chemistry in two distinct ways. First, this industry was itself an important arena for challenging new analytical measurements involving spatial resolution of chemical

information on unprecedented distance scales. Thus, like the environment, industrial process control, and the world of health care, the microelectronics industry became a large domain for innovation in analytical measurement and application. But it also gave rise to reliable, versatile electronics that enabled invention after invention in the area of chemical instrumentation and gave rise to a much larger industrial base supporting instrumentation itself.

I separate information technology based on microprocessors from the microelectronics industry, because I see the qualitative effects as different, even though the information technology itself rests on progress in the microelectronics industry. The microprocessor and the information technology that flowed from it made possible, even by the late 1970s, whole new approaches to chemical measurement via instruments packaged in small, affordable units. Techniques resting on the use of mathematical transforms, methods requiring immediate access to databases, protocols involving precise, multistep sample handling, the automation of complex measurements, or the management of large numbers of samples suddenly became practical.

As scientists, we have a tendency to look at this history in terms of the demand for capabilities and methodologies, just as I have done here. But let me cast things another way by pointing to social impact. Over the past four decades, advances in analytical chemistry have become critical to huge movements in social affairs, business and industry, politics, and international relations. The evolution and expansion of health care, environmental protection and remediation, international competitiveness in manufacturing, and the prevention of terrorism are just four fields in the forefront of public concern where the pace of history and the likelihood of future progress rest on analytical instruments and methods. Business and government leaders, and even the public at large, have come to understand that analytical measurements are indispensable to the modern management of individual commercial enterprises or social issues of huge scale. None of this seems likely to fade. It's satisfying indeed to see such impact for a field that seemed to have such poor prospects not so very long ago.

As I mentioned earlier, analytical chemistry was practically moribund in the middle 60s. The fact that it rose so powerfully so soon thereafter was, as I have argued here, in large measure the result of social necessities of enormous importance. But even in the 60s there were leaders who laid a foundation for a radically modernized field of analytical chemistry. I would like to credit a few:

- Fred Findeis, Program Director for Analytical Chemistry at the National Science Foundation in the 1960s and 1970s, was a public servant of extraordinary effectiveness and vision, who understood that the analytical chemistry of the future would need to draw from a strong scientific base and that it would need to include people interested in a wide range of measurements not traditionally part of analytical chemistry. He put the Foundation's money where his thoughts were, and his efforts helped to redefine field and to foster new talent committed to it.
- Herbert Laitinen, Editor of *Analytical Chemistry* throughout the 1960s, was a man of considerable vision who understood the importance of linking the existing field

with related science and engineering outside the field. Laitinen also appreciated the great importance that environmental measurements would come to hold.

- Howard Malmstadt, Professor of Chemistry at the University of Illinois, was at least a decade ahead of others in understanding the great qualitative changes that could occur in analytical chemistry by taking advantage, first, of the advances in microelectronics and, later, by the new technology resting on microprocessors. Malmstadt also anticipated the explosive growth that would occur in clinical analytical chemistry.
- Charles Reilley, Professor of Chemistry at the University of North Carolina, had a catholic mind and remarkable chemical insight. He understood that analytical chemistry beyond his time would draw from unexploited chemical concepts, from processes in new media, and from the newer techniques of physics and physical chemistry. He encouraged younger colleagues to redefine the boundaries of the field, and his inclusive attitude became important to the explosive growth in subsequent decades.

An old adage says that success has many fathers. That is certainly true of any success on the scale that analytical chemistry has enjoyed. The few whom I have mentioned were joined by others around the world in forging the modern field. It is not possible for me to give particular credit to all who deserve it. These four were leaders whose genius I was able to experience personally, and it's simply my liberty to credit them by name here.

Among those many fathers were members of a remarkable crop of top-flight electroanalytical chemists who began their independent careers in the 50s and 60s. One of them was Al Bard himself; others are speaking in this very symposium. Their imagination and energy transformed electroanalytical chemistry and expanded its horizons vastly. They connected to physical chemistry, inorganic chemistry, organic chemistry, biochemistry, physics, surface science, neurobiology, kinetics, optical spectroscopy, separations, and many other active areas of research.

Among the most important reasons for the success of analytical chemistry, as we know it today, was that it was able to reject the insularity that was killing it in the 60s, to embrace new science, and eventually to recruit large new communities of scientists who had developed extremely valuable analytical technologies but had no previous identification with analytical chemistry. It did not have to be that way. The subfields could have remained islands, and there could have been no successful joint development of the new discipline. The four leaders whom I named helped greatly to create the receptive, welcoming attitude that engendered success. The electroanalytical leadership that I mentioned were also important in this regard.

But we all must give great credit to the Society for Analytical Chemists of Pittsburgh and to their offspring, the Pittsburgh Conference, which began as an instrument show, but grew into the powerfully integrating forum that it has become today. It has perhaps been the most important vehicle for analytical chemistry to expand its boundaries and its community, and yet to maintain coherence, over the past four decades. It was fortunate that the Pittsburgh Conference was already a sizable enterprise by the latter 60s and was

ready to accept this essential role during the subsequent decades of tremendous expansion and elaboration of our field.

What can we draw from all of this as we consider the future? Here are four thoughts that have been on my mind:

First, analytical chemistry is already intimately coupled with three themes that will remain indefinitely in the forefront of public concern: health care, environmental protection, and economic competitiveness. This triad will constitute a huge, firm base of application far into the future and will shape the character of much of our developing enterprise.

- Health-care costs will continue to exert tremendous pressure on individuals, businesses, and governments because of changing demographics, broadened options for treatment, and rising global standards for care. All scenarios that I can conceive involve increasing demands for analytical information, whether health-care policies in any particular time or place are focused on cost control, improved quality of delivery, or broadened access.
- Environmental concerns are here to stay. There are serious, real concerns in both global and local contexts; but we remain grossly ignorant about causes and effects and about degrees of threat. We do not really know what we need to control or what we need to fix. There is no way to address any of these concerns--diagnostically, protectively, or remedially--without analytical information. This will be a growth area for fifty years, in my judgment.
- Economic competitiveness rests on many factors, but in any business involving manufacturing or production, it depends at least on the optimization of processes, and it may depend on the speed and effectiveness of cycles leading to innovation or product improvement. Globalization of the economy will make these dependencies even greater, so I foresee increasing requirements for analytical information relevant to these needs.

By the way, it is significant that the last presidential campaign in the United States focused on these three core areas: health care, environmental protection, and economic competitiveness. It's very clear just from that fact that our field is well coupled to central themes of public concern in the United States. The same concerns exist in societies around the world. We can count ourselves fortunate that they will not be passing fads and that analytical information is essential to progress in all of them, regardless of policy. We are even more fortunate that we do not have to take responsibility for the policies themselves.

My second thought is that nanostructures, nanomaterials and nanodevices have the potential for revolutionary technological and economic impact, quite analogous with what we have already seen from microelectronics. In some respects, nanotechnology is an extension of microelectronic technology, but this new sphere of human activity could become even more powerful, not least because it has a broad interface with biology, which is intrinsically nanostructural. An economic impact of nanotechnology on a

massive scale is not just around the corner, but a decade or more away, in my view. But the opportunities are there, and realizing them will require a new facet of analytical chemistry. The premium will be on sensitivity to particular spatial relationships among moieties, to supramolecular configurations, and sometimes to small numbers. This is a research area with exciting challenges. Having beaten the drum for it for about 20 years, I am sorry that I can only watch from the sidelines. The difference in the present situation relative to 20 years ago is that synthetic possibilities are much better developed, and economic impact, an invaluable driver of progress, is much closer. It should be fun to watch.

A third idea in this series is that the analytical community should keep a close eye on developments in information technology. I have already listed historical progress in this domain as a major enabler of the great advances in our field in recent decades. Analytical chemistry is itself a form of information technology. Analytical chemistry enables action by the way it informs. My point here is that our field has natural connections to the sciences of information management and human-machine interaction. Tremendous things are happening in those fields, and we should expect to make use of them to gain greater value from the information that we produce and to produce even more powerful instrumentation.

Fourth, I would like to make a special pitch concerning opportunities in clinical analysis. I believe that the improvement of health care worldwide will be a major social goal in the decades ahead. But to achieve it, serious reductions in the cost of the most basic clinical diagnostics will be important. Another area where fine opportunities seem to exist is in devices that are sophisticated, simple, and reliable enough for people to provide their own monitoring of important diagnostics. This could be a key to both improved health care and cost control. Great contributions could be made if some imagination could be applied in these directions.

In my abstract, I promised that the last section of this talk would touch upon possibilities for evolution of American research institutions over the next half century in the face of scientific opportunities and public pressures. This subject is too large for there to be value in my dedicating much time to it in this forum, but let me mention a couple of things: one scientific opportunity and one public pressure.

Nanoscience is the scientific driver that I will highlight. This theme is causing a sizable shift of focus, not only in chemistry, but also in biology, physics, materials science, and various parts of engineering. Over the next decade or two, it will register a substantial impact on the organization of research and teaching in major universities. Many of those same institutions have already manifested something similar in the reorganizations that have taken place in the life sciences. The classic divisions of biology, including botany, zoology, and microbiology, are now disappearing. We may see similar effects in the physical sciences and engineering as the focus on nanoscience becomes more pervasive.

The public pressure that I mention comes from the broadly held perception that undergraduate education is becoming indispensable to the economic and social success of

the next generation. Parents, young people, and, policymakers across the land increasingly believe that this is true. In public life in America, if something is essential to success, it becomes a right; if a right, then undeniable. Particularly in the public sector over the past 15 years, we have seen a tremendous increase in concern over undergraduate programs. Legislatures, governing boards, state-level coordinating boards, and accrediting agencies have taken a sharp interest in the cost of education, admissions policies, student access, freshman retention rates, graduation rates, teaching loads, and post-tenure review. There is now a growing movement to develop outcomes-based methods for curricular accountability.

The consequence is a phenomenon that I sometimes call the "commodification of undergraduate education." In this era, institutional boards, administrations, and faculties are under tremendous public pressure to see that students succeed in an activity deemed essential to their future and that the institutions themselves demonstrably deliver their essential social service as efficiently as possible. This operating environment differs fundamentally from the traditional one based on the dual idea of the faculty as a professional, self-accountable body and the university as a place where the student bears the primary responsibility, by far, for his or her own success. Private institutions are not immune from this shift in concept, because their governing boards and accrediting agencies transmit broader social concerns, and because there is another form of accountability driven by the high tuition charges at private schools.

My purpose in setting out this issue is to suggest that a consequence may be the gradual restructuring of graduate education and research. In America, the combination of research and teaching in powerful universities has been a brilliant success in so many ways, and I do not see the nation abandoning it. However, it will be increasingly difficult to use a unified organizational structure for both functions together, given the change in operating environment for undergraduate education that I have just discussed, and the additional important fact that different sources pay for teaching and research, so that the accountability for success in each sphere is to different people and organizations. Still another factor driving organizational change is that so much of the emerging research agenda deals with intrinsically interdisciplinary topics, which need broad-based institutes and centers to foster the collegial interchange essential to progress. Accordingly, I see American research universities evolving toward a structure in which research is carried out within such organizations in much larger measure. I also expect that professional research staff having long-term employment will become much more common in universities. The result might be something like the French model, featuring strong research institutes funded by CNRS or other national agencies, within universities whose departmental structure is more aligned with the teaching function.

Let me close now by congratulating Al Bard one more time. I surely speak for this whole audience in saying that we are proud of what you have achieved and we are grateful for your personal support of so many of us.

The title of this symposium is "Electrochemistry in the 21st Century," yet I now find myself not having spoken about electrochemistry specifically. The topic that I chose

seemed more appropriate to the contribution that I could offer; moreover it seemed well matched to the particular award at hand and to the Pittsburgh Conference more generally. But let me declare that I am confident in the future of electrochemistry, if only because we have found out so little about it in 200 years of study! Just remember that there is no life without electrons.