

ROUNDTABLE: PHYSICS IN TRANSITION

Recent scientific developments, new research instruments and different political and economic demands caused by the end of the cold war and the instability of corporate America are making changes in physics increasingly apparent. Roundtable participants discuss the immediate future of physics.

Roundtable Participants

Judith L. Bostock, executive director of the South Carolina Universities Research and Education Foundation and former science policy analyst at the White House Office of Management and Budget

D. Allan Bromley, assistant to President Bush for science and technology and director of the Office of Science and Technology Policy, now Henry Ford II Professor of Physics at Yale University

Ralph E. Gomory, president of the Alfred P. Sloan Foundation and former senior vice president for science and technology at IBM

Daniel Kleppner, Lester Wolfe Professor of Physics at MIT and chairman of the American Physical Society's Physics Planning Committee

Albert J. Libchaber, professor of physics at Princeton University and a fellow at the NEC Research Institute in Princeton, New Jersey

Walter E. Massey, director of the National Science Foundation and former vice president for research and Argonne National Laboratory at the University of Chicago

Alan Schriesheim, director of Argonne National Laboratory

Richard N. Zare, Marguerite Blake Wilbur Professor of Chemistry at Stanford University and member of the National Science Board

Gloria B. Lubkin, editor of PHYSICS TODAY

Irwin Goodwin, senior associate editor of PHYSICS TODAY

Lubkin: The question before us can be stated simply: Where do we go from here? The "we" is the physics community, though it's our hope that the discussion will range more widely into science and technology, so we'll be able to comment on the changes likely to take place in research universities, national laboratories and private industry. Our subject is physics in transition to the 21st century. Some say physics has been in a state of transition for well over a century—certainly since James Clerk Maxwell in the 19th century. In every decade of the 20th century, physics has experienced momentous turning points. In this last decade of the century we seem to have reached another turning point with the end of nuclear weapons rivalry that was given the name of cold war and the increase of global industrial competitiveness. In the past year, pressures by the Federal government and by commercial companies have increased to make physics and the rest of science more relevant to business and to society. We are already witnessing the reduction of physics research at some major corporate laboratories and sensing a shakeup for physics facilities at some national labs. So this discussion of the future of physics is timely.

Let's start our talks today by asking: How do you expect physics to change in the next decade?

Kleppner: I submit that physics is either going to flourish or to decay in the next decade. It certainly can't go on as it is right now. The situation must improve or physics will take a nosedive. We're at a critical point for our scientific future as well as for our economic future.

Bromley: I would put it differently. We physicists are on the edge of a vital new period. If we consider all that's been happening in physics over the last five or ten



Future of physics is discussed by participants in the roundtable discussion held on 17 November in the library of the Optical Society of America in Washington, DC. Seated around table, clockwise from left: Walter Massey (with back to camera), Daniel Kleppner, Albert Libchaber, Judith Bostock, Allan Bromley, Gloria Lubkin, Richard Zare, Ralph Gomory, Irwin Goodwin and Alan Schriesheim.

years, I am not a bit pessimistic about the future. We've been increasing our know-how; we've been increasing our technology; we've been increasing our experience; we've been increasing our understanding of natural phenomena. Just think: Almost every week we learn about discoveries in astrophysics that give rise to new perceptions and new possibilities. In nuclear and particle physics, we're constructing facilities that have been on the table for two decades and we're at last within reach of achieving an unprecedented ability to attack some of the fundamental questions about the origin of the universe. In atomic physics and in condensed matter we now have the ability for the first time to manipulate single atoms, and that opens up a whole new set of questions. The fact that we have single-electron electronic devices seems to me to be typical of a new wave of developments. There are, as we all know, the usual problems, but physicists have always been ingenious in getting around those and in doing what they want to do. I venture to say the future will be a lot more exciting than the past.

Goodwin: Is that because physicists are better trained than in the past or because their instruments are now better or because the questions are yielding to more systematic attacks?

Bromley: It's all that and more. It's also because physicists are now planning better than they did in the past. They have taken a leading role in laying out for people like me in government what they really want, and they've been doing all this in a consistent fashion for several decades. That is very important. Of all scientists, only the astrophysicists seem to do it better, and, of course, they are physicists too.

Kleppner: Allan, I share your optimism about what's happening in physics and more generally in science. But when one looks at the problems young people face in starting their careers in science, there is reason for concern. The number of new start-up projects has dropped to a danger point. Young people know this, and some of our best young people are no longer seeking careers in university research. They're turning away because they sense that the probability of leading a satisfying life in basic research is low. That gives cause for concern.

Gomory: I certainly think that you're accurately describing some of the problems, but my own guess is that we will work our way out of those problems. My remarks are in the nature of a commentary on all of basic science not only on physics. I think the rationale for basic science is now evolving and solidifying so that in the end we will develop a more realistic picture of the functions and values of basic science. As we do that—which I expect will be in the next few years—scientific careers will become more stable and satisfying. Careers in science will no longer be subject to the boom-and-bust cycles that we've known and to the ill-defined level of how many scientists are enough in any particular field. I am confident that it will be possible again, as it was for some small groups in bygone years, to have a life in science that doesn't consist of an endless scrambling for grants and all the negatives that go with that. I think we'll look back on these years as a time of troubles, followed by something much better.

Kleppner: I like your scenario. Your operative word seems to be "work." You say we are going to work ourselves into a favorable situation. How are we going to do that? Right now things are drifting.

Zare: With a sense of humility when one speaks about the future, let me suggest something about what might be happening in terms of science and physics. We have made great progress on the few-body problem. If a system has a small enough number of particles or can be divided up, we've found a lot of the laws that govern what happens. We have made great progress on the many-body problem in the sense that if there are many particles involved, we can turn to statistics of one sort or another and we've made great generalizations. Where we suffer is the some-body problem in between. This is normally referred to as somebody else's problem. [Laughter] I think the somebody problem will be taken up increasingly in the next decade and into the next century, and that we have the tools to deal with it. The tools we look to are not only experimental new tools, which are fantastic, but the ability to use computers to hone our thinking and to test it out in ways that stimulate us to think about things we never considered before. So, I agree, it's a most exciting time in science and in physics.

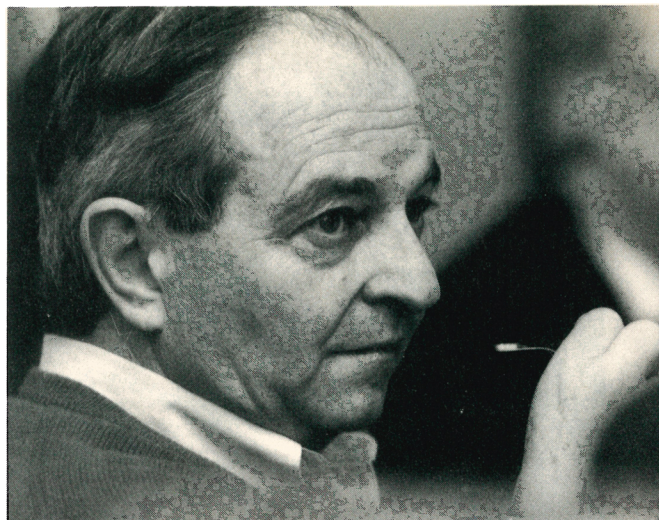
Libchaber: In this connection I would say that outside of physics, which is, for me, an extension of the field from the beginning of the 20th century, the important developments today are related to the science of complex systems. Do we comprehend the world we see around us? Can we grasp what's being revealed in geophysics? Can we make some headway in biophysics? Can we understand what lies between the many-body and the few-body problems? In answering these questions, physics will find itself linked to many other disciplines, which is already the case—less in America and more in Europe. Indeed, I find America backward in this regard.

Lubkin: Would you care to amplify your remark?

Libchaber: Well, you know, I come from France, from the Ecole Normale, a school where many of our bright young graduate students are attracted to your style of physics research, but also to biophysics and to the evolving science of complex systems and to the use of powerful computers. To my surprise I find that academic physics in the US is more conservative than the physics culture that we have in France. American physics seems even now to be a child of the bomb and the transistor. I find it very hard for a new field or subfield of physics to emerge and expand in your country.

Bromley: I want to go back to Dan's comment about the difficulties that young people are experiencing. I think he's absolutely right: They are in tough times. This past summer I spent a lot of time visiting universities across the nation, and I came back to Washington depressed about this problem because so many times—most frequently at the more prestigious universities—I was told by postdocs, graduate students and undergraduates that the only really satisfying career was a clone of their professor's career. In fact, one of them told me quite bluntly, "My God, if my grant doesn't come through, I might have to consider going into industry." There's a very low survival potential in today's world with that attitude. We owe it to young people to give them a better understanding of the challenges and the opportunities that lie outside an academic career. If we don't do that, we're going to have terrible problems. Even with our best efforts, we're going to have a lot more very bright young people than we can place. What I also want to emphasize is that we're not going to have more young Americans in science than we need because of the problems with our elementary education—something scandalous and something we should urgently fix.

Schriesheim: Being a chemist, I don't have the temerity to talk about the future of physics. But when I think about physics and other sciences, I wonder how the



'...physics will find itself linked to many other disciplines, which is already the case—less in America and more in Europe. I find America backward in this regard.'

Albert Libchaber

sciences will cope with the obvious issue of the increased societal demand for both basic and applied research that satisfies the needs of the country. I wonder how physics will fare under the rubric of meeting society's needs? I wonder how the physics community, once so clearly identified with the atomic bomb and weapons of all sorts, and still envied by the rest of science for its ability to plan ahead, will convince the people who do the actual funding that, with the cold war over, it is necessary to continue supporting the community?

Gomory: I think we've raised a welter of issues we now need to deal with, so I will unhesitatingly give you my picture of the situation. I will speak about all science, since I am not a physicist, except perhaps an honorary one. In my own experience I have found that there is such a thing as good basic research and there is good applied research—with a cloud of things in between that are neither. The existence of this third state of research is very confusing. Notwithstanding, I don't find this a hard problem. Clearly, basic research, at least in the areas I know well, is best left to chart its own course. In applied science that is really applied and not in the fuzzy third state, it's always the case that a user is eager to have it. So the researcher works for the user or works with the user. In Alan Schriesheim's example, physicists did the basic research that made the atomic bomb possible, and then they worked for the industry that needed it, which happened to be the US Army. So it is not difficult to understand that people who do basic research can also do applied research. That's true for industry, where the smart practice is to have people with a basic research background working toward an agreed goal, whether the goal is the atomic bomb, say, or a new type of computer or something to improve the environment. Academic physics can very well evolve this way, but—and this comes back to an important point made by Allan Bromley—not if students are longing to be clones of their professors. You

'We know that science can't work the miracles that are promised. The day Congress figures that out for itself, we are in deep trouble.'

Judith Bostock



don't get physicists to work for the user if their only dream in life is to be their professor over again.

Massey: We seem to be pursuing several threads here. I agree with the statements about the current excitement in science, with physics contributing much of the excitement to many other disciplines—though perhaps not as much as it should or could. Still, it seems to me there are, if not contradictory threads, at least some that are not so easy to reconcile. One is the degree of excitement in the field as seen by the rest of science. Another is the perceived quality of life for the scientists themselves, and especially for younger scientists. Still another is the public support, as Alan Schriesheim observed, for the exciting research. I think the future of physics in the next 10 years is going to depend a great deal on how the community and the rest of us who are concerned about the future reconcile those three things. I don't think the three are easily compatible in the sense that the excitement in science is not necessarily going to be the rationale for convincing our supporters to heap the amount of resources on us to make the quality of life better and to attract creative young people into the field. Then, too, I think we need to look at history perhaps a little more carefully. We use examples in the past to predict the future of physics. We start with World War II as if there was no science in the world or in America before that period. We also argue that the only standards we have for the quality of life are derived from the way things were in the past 40 years. I'm more pessimistic than some of you. I don't see an easy solution to our problems that will allow us to be excited by the science we're doing, that will attract all the best people we want and that will provide the quality of life that scientists have come to expect, given the resources that I see, realistically, on the horizon.

Bostock: I agree with Albert Libchaber. We still pigeonhole our physics graduates—that is, the bright and creative ones—into narrow specialties. You can't bring

physics to bear on environmental problems like waste management, for instance, if you know absolutely nothing about chemistry and biology. So although we are devoting a lot of resources in training little kids in science and math, we still have a lot to do to teach college students to comprehend many fields before they specialize. To be a physicist is not like being a statistician. Those who work in condensed matter physics—because they're looking for different kinds of materials for different kinds of uses—often get a much broader training than those who will end up in high-energy physics, say, or in single atoms. We tell young people that if you're excellent, you'll be an academic, and if you're not, you have second-rate skills that industry can use. At our research universities we don't suggest the true excitement of working in that wide domain between the basic and applied that Ralph Gomory talks about. It's our fault that we don't put together teams of young physicists to work on problems that are neither basic nor ready for application. Nor do we farm out our physics graduates to industry for a year or so. If we did this, I think there would be excitement all over the place.

Libchaber: I'm listening to you talk about excitement in science and I'm puzzled. I live at Princeton and I was at the University of Chicago before that, and I see physics students who are quite depressed. They don't appear excited. They are worried. During your election campaign, I heard stunning speeches about America being at war over world markets and about America needing to change its ways and its priorities. Now I hear at this table that America is unable to attract good scientists to industry. That is strange to my ears. For at least 20 years, I was told in France that there is only one country that is able to train scientists for industry. That country was the United States. It was always the example that France and Europe tried to follow. So my question is, what is happening? Why is there such pessimism? Why, suddenly, what used to work doesn't work so well any more? Why are you so concerned about the future of physics and the rest of science? Why is it that at a time when the cold war is over we talk about a new war—over technology? I don't understand this gloom.

Bromley: Those questions deserve answers. Probably one of the most important answers is that in periods of generous Federal funding—which many people now believe to be the norm but in fact were anomalous periods—we allowed the universities and the non-university community to grow apart. I think one of the most important things we can do is arrange for much more frequent exchanges of people between the private industrial sector and the universities. I don't mean just sending somebody you're trying to get rid of at some company to work at a university for six months or vice versa. It should be recognized that spending time in the other place is important to improving your institution and your career. The stereotypes about industrial research need to be discarded. The notion that physicists outside academia are second rate is flat wrong. On the other hand, the feeling in some industrial offices and labs is that universities are filled with a bunch of wild-eyed dreamers who aren't very practical and have never had to make the bottom line come out right. The other pertinent thing here is that over the years we have allowed the compact between the universities and the Federal government, as drawn up right after World War II by Vannevar Bush in his *Science—the Endless Frontier*, to come apart. That agreement called for the Federal government to make a continuing investment in higher education and in scientific research; in return, academic research promised results that would pay off handsomely for everyone. We've let this idea of investment in the future drift into one of

procurement for the present. So now agencies write a contract with university X as if they were buying a submarine or a subway system. The paperwork is just about as extensive for grants and for procurements.

Zare: I want to return to the first point made by Bromley and say that we need a two-way street whereby university people can spend some time in research labs in industry doing exciting things and people from industry can spend some time in university labs. This is, to me, the most meaningful form of the buzzwords "technology transfer." It involves people interacting with other people to make something happen. Some of that is happening but much more is needed.

Goodwin: Aren't there already signs that academic physics is being reinvented in the way you are suggesting? Isn't that happening in the field of superconductivity at MIT with Bell Labs and IBM and in biotechnology at Washington University of St. Louis with Monsanto and at other institutions with other companies?

Bromley: Those are isolated examples. Those instances should be multiplied many times over.

Gomory: I'd like to try and roll some of these thoughts together. Walter made a very important point, which we ought to face up to. It is that science isn't going to be funded for its excitement. It certainly isn't going to receive many billions of dollars for either personal thrills or entertainment values or even new knowledge. For those purposes, it might be funded at a level of several hundred million, which is the largess that the arts and humanities receive from the Federal government. Science undoubtedly is funded today because of the belief that it contributes to America's defense or to America's prosperity. Now that happens to be a correct view, but we need to add the details. We shouldn't create the illusion that science alone brings these enormous benefits. Solid-state physics alone did not create the computer industry, though there wouldn't be a computer industry without solid-state physics. We have to develop a convincing and accurate picture of the role of science in our society, that it is part of a complex process that ends up with products and prosperity. We need to instill a realistic picture of cause and effect, not a picture that science does it all. So to go back to Walter's question about what I meant: 40 years is hardly long enough, as Walter rightly says. When I first started in science the perspective on a scientific career was totally different from today's. A career in science then did not depend on ever-accelerating growth in the field. There was a more or less stable number of scientists, and it never would have crossed our minds that we couldn't have a decent life if the size of the scientific population wasn't growing all the time. Now, to go back to Albert's conundrum: How come this country, relative to others, was once so good at sending people into industry and then became so poor at this? I think Allan Bromley had the answer: He said that after the war there was a stream of money from the government, so people's eyes turned naturally in that direction, and scientists became divorced from the rest of society. Now, when I say I'm optimistic about the future, it's because I think there is a compelling rationale for science in practical terms. I believe the absence of perpetual growth will be healthy for science. It forces us to confront our true role in society.

Schriesheim: I would like to voice something that concerns me: That is the issue that has to do with the training of physicists and other scientists so that they are acquainted with the prospects and the problems in other fields. Of course, we have to be sure that we train talented people in the core competencies that enable them to have a firm foothold someplace. We shouldn't confuse the importance of core competency with the need to become

relevant to society by taking on the problems associated with health care delivery or environmental purity or transportation safety. I think we don't do such a good job educating scientists because none of us has a clear idea of how the problems of society can be approached scientifically or technically. I don't think our schools are particularly adept at that, and I don't think we can achieve solutions to our societal problems by transferring people back and forth between universities and industry.

Bromley: Just to pick up on that: While the exchange of people goes a long way to at least exposing the opportunities and the challenges, I agree that in some areas—biophysics, for instance—it may not work. Biophysics is a membrane through which physicists move into biology and do some remarkable things. We must encourage young physicists to risk moving through those non-traditional interfaces more frequently than they've done before. This is the point Albert made. Physicists are likely to bring something unique to most fields. They bring a reductionist approach that can peel away a lot of the extraneous detail and focus on something that can be modeled mathematically. They can apply what they've learned to the model, make some predictions and check them out. The advantage of this will not accrue to physics per se, as exciting as it is to the individual physicist, but to those interfaces between physics and just about any field.

Libchaber: Once more I must express my surprise. I have heard here that physicists should go into industry. In my time—and I once worked at Bell Labs—the dream of almost every young physicist was to be hired by Bell Labs or IBM or Xerox or Exxon. There were plenty of great research labs. Now it is suggested that we need to reconstruct something that stands as a monument to physics. The problem is not that young physicists don't want to work in industry but that the great labs are shutting down.

Bromley: I don't believe that. The labs you cite are not closing.

Kleppner: They may not be closing, but they're not hiring physicists. The interests of these labs are changing. They are moving away from the physical sciences. So our discussion of young scientists who don't want to go into industry is somewhat unrealistic in these times when corporations have altered their priorities as well as their products. Opportunities are diminishing for young scientists in an industrial setting. There was talk about young scientists who sought to be clones of their professors. I don't think that's true either. Many young people are eager to leave the universities in search of other jobs. But those jobs just aren't there right now. My concern is that too few graduate students want to clone their professors, because they don't see academic careers as satisfying.

Bostock: I'm not sure the reason grad students shun academic careers is because their professors are spending most of their time writing grant proposals. It may be that the thrill is gone from academic physics. Yet, there are subjects that are fun. Nanophysics—I don't do this—has young physicists making nanoscale devices a hair in width and 900 to 1000 angstroms long. There is no practical use at the moment, but there are many predicted uses if we can learn to apply physics on another scale. Now, I disagree with Albert Libchaber on the value of an exchange program for academic and industrial scientists. The exchange cannot be *pro forma*. It requires nothing less than scientists and engineers at Bell Labs or GE or Motorola working at universities with grad students and, in turn, grad students doing their thesis at the labs. The purpose is renewal, a turn-on for both.

Libchaber: This is already happening.

Bostock: But not on a large scale and only at



'It isn't enough to support science for new knowledge. Science must be coupled with societal benefits.'

Richard Zare

'I believe that the absence of perpetual growth will be healthy for science. It will force us to confront our true role in society.'

Ralph Gomory



prestigious universities.

Gomory: I think we need to sort out two things about this business of exchange. It's hard to see how students can get to the heart of complex technical problems in a school year and how industrial scientists can get out front of applied science during the year. The second dimension is the importance of learning the problems of corporate research and learning there's a way of life out there that some students want to be part of. In graduate school, a student learns about the academic life. But the industrial research culture is alien to all but a very few students.

Massey: Ralph makes a salient point about the culture of industrial research being very different from university research. Each involves different expectations and different approaches to doing research. One of the eye-openers that I had during my visits to the foundation's science and technology centers over the past year came in speaking with graduate students who work in those places. Students are working with more than one faculty member on a research problem, so they have more than one model. And it's not just that the professors come from different fields and have different approaches to research, but that the students work alongside other students in different fields with other contributions to make to the common problem. There's an excitement at these centers that I don't see when I visit the customary university science department or the research group doing a slice of a problem that's been laid out by a professor. I don't want to comment on whether there's excitement for individuals in a group of 300 or so engaged in a high-energy physics experiment, but seeing the many different ways of research is important for young students.

I also want to say something about the messages we are sending to the next generation of physicists and all

other scientists by the way we teach them and the things we tell them. We do them a disservice by leading them to believe that the public will support their work if it's exciting to scientists. Students really believe that. It's almost heart-rending to hear them speak of their expectations as scientists. I hear much too often such statements as "Walter, tell Congress how exciting this is!" They believe that's all that's necessary. Another message we seem to be sending is that winning grants has a symbolic—maybe even mythic—importance that carries more weight than actually doing research or carrying out a satisfying career in an academic institution. We need to change such messages.

Bostock: You don't get ahead in academia if you don't get grants.

Massey: So, we may have to change the reward system in academia.

Bostock: Let me cite a case on the academic research dilemma: At Clemson University the College of Sciences has 39 vacancies coming up in the next year and a half. If you talk with the people who are going to hire young scientists, they claim it costs about \$200 000 just to launch one position. For the most part, science research at Clemson is sponsored by government agencies, not by some industrial company because the work is usually of no interest to industry. But when the time comes for a decision on tenure, the scientist will not get it if he or she is not good at getting grants and writing lots of papers. That's the way it is.

Bromley: That's true if we continue the university model of individual grants. When David Packard [chairman of Hewlett-Packard] and I studied research universities in the mid-1980s [for the White House Office of Science and Technology Policy], we found that even in some of our

best universities the push on individual assistant professors was such that they were spending up to a third of their time writing proposals or writing reports on their proposals. That's insane. What I have been arguing for is the kind of system where senior faculty members get block grants to provide the facilities and support the research. This arrangement will free investigators and their students to devote themselves to doing what they really do best: research. Everybody would benefit.

Libchaber: I agree completely. I am amazed by the immense quantity of paperwork at universities. I don't understand why students are not paid to teach. They should not be paid out of grants. I like to be in the lab and I can assure you that at the two institutions I have been associated with, professors are not in their labs anymore, because they have no time for their labs. It's not that they're lazy. They're always writing proposals. I personally never write grant proposals and I find it possible to survive. [Laughter] I am puzzled that everybody is paralyzed by the system. They talk about grants all the time. They have nightmares about grants.

Kleppner: The academic research system has simply broken down. It's in disarray. If young professors do not get grants, they can't get their research done. Graduate students know that when their professors have their grants cut the implications for their own careers are unmistakable. Someone mentioned a hot new field—nanophysics or mesoscopic physics. This area represents a wonderful interface of theory and experiment. In the background one can see devices. Despite this, one leader in the field recently had his grants cut, not because the work isn't first rate but because there just isn't enough money to go around.

Bromley: The unvarnished fact is that more money is available to support individual investigators in American universities than ever before in history. Government spending for academic research went up by 10% last year. It went up 10% the year before. I am optimistic that it's going to continue to grow at a rate far greater than almost anything else in the Federal budget. Nevertheless, the fact is that the number of young applicants is growing even faster.

Kleppner: Those figures just do not make sense to me. I know the funding figures for the mathematics and physical sciences directorate at NSF, which is, after all, the biggest single player in the physical sciences in this country. In terms of constant dollars those funds have changed little. The total may have gone up in the past year because of some large initiatives, but in fact the number of new starts is simply a trickle.

Bromley: NSF, with apologies to Walter, is not the only patron of physicists. NASA, the Energy Department and the Defense Department provide support as well.

Gomory: Look, you cannot address this problem, in my opinion, in terms of financial levels. If you don't have an adequate picture of the system, there's no point in talking about the levels. I would guess that in the system as it now stands, the more money you put into it, the more researchers you have. So if we pour in money forever at 10% per year, we will continue in all likelihood to scramble desperately for grants and, in fact, it may get worse. The issue is simply this: If we're going to produce more graduates with higher degrees in physics and other sciences, they've got to go somewhere to do what they want to do or else you better stop creating them.

Massey: One thing that bothers me whenever we have conversations about these problems is that we always recognize the issue and then the typical response goes something like this: "Well, that's the way it is." The grant system is not necessarily the only way the world of

research can work. As important as it is, it's not written anywhere that that's the way the system has to be. I think we really should step back and look at the structural troubles that underlie the science enterprise. Is it possible for someone to go into physics at a good university and graduate to a satisfying career in teaching and research without having to write proposals all the time? If that's not possible, then people shouldn't go into physics, because the grants are not going to keep coming at the rate that physicists enjoyed in the past. I don't expect physics to return to its period of plenty.

Zare: I think we can all agree that we're in the midst of a paradigm change in terms of the support of science. Some people call this paradigm change simply a reaction to the excess of the cold war, but I think there's another element involved. That element is our country's current economic woes. Allan Bromley invoked the name of Vannevar Bush earlier in this discussion, and I would like to quote a line from Bush's little monograph, written in 1945. Here it is: "New products, new industries, and more jobs require continuous additions to knowledge of the laws of nature." That's true but it's not sufficient. It isn't enough to support science for new knowledge. Science must be coupled with societal benefits, whether in health or in manufacturing or in defense.

Goodwin: The next Administration, under Bill Clinton, has vowed to shift the R&D budget away from defense, perhaps by \$7.5 billion over the next three years. Some of that amount may be destined for civilian R&D.

Zare: Defense was a rationale that served us well in the past. It is less important now, though that doesn't mean military security should be forgotten. We need to be aware that science is coupled to the rest of society, including the nation's military and economic security. As scientists we are excited about the future of science, but we need to consider the fractured economy and our horrible budget deficits. As scientists we have to find our role in this society. We will continue to be in partnership with society but we may not be able to grow when the country's gross domestic product isn't growing the way it once did.

Bromley: I want to pick up on Dick's citation of Vannevar Bush. Bush's paper served as a blueprint for the way we've done research for the last half of the 20th Century. But it's far from obvious that the blueprint is appropriate for the first half of the 21st Century or even for the 1990s when you stop to think that the cold war is over. The European Community and the Western Pacific rim have emerged as economic superpowers. Our own society has experienced some important cultural and demographic changes. Walter hit the key point: We've got to examine the rationale for research and development in our country, as well as the structure of our R&D enterprise, the way it's going to be supported and the way its results are going to be effectively utilized. We have assumed for a long time a model where research produced in the university flowed out by some magical process and was found useful by somebody—we didn't much care by whom—so that research was seen as important enough that funds came back to the university. That model simply isn't working nearly as well as it has to work if we're going to remain economically competitive. So we've got to think of a new structure, a new approach, a new rationale. The Vannevar Bush model is no longer applicable to our times. If I were going to stay around for another year at the White House and the Office of Science and Technology Policy, my highest priority would be to design a new model.

Kleppner: Do you see a strategy for the rationale and reorganization you call for?

Bromley: Yes, I do. First of all, there is a fairly firm



'If we fail to contribute to economic competitiveness, we are not likely to survive in the style to which we have grown accustomed.'

Alan Schriesheim

foundation built on the bipartisan consensus in the Reagan-Bush Administrations and in the Congress that as a nation we are underinvesting in research and development. What all these people want is some rational argument and some coherent strategic plan for where we're heading and why they should support what we propose to do. We've just finished a careful look at the interface between research universities and government agencies from both the outside and the inside. We need a similar diagnostic examination for the Federal labs. We also need the industrial perspective for the strategic plan. The real challenge is to put this all together into a package that makes sense to Congress. When I testify before Congress, I'm often asked: "Why should I support this project? Only a trivial fraction of the money you're asking for will ever go to my district or my state." We need to make compelling arguments for our budgets, and we're not making these now.

Gomory: I guess some might be baffled by all this, but I think the picture is fairly clear, at least to me. [Laughter] Look, the thing is, as Walter and others have already said, we're never going to rationalize science on the basis of excitement. So what is really the connection between science and, let us say, economic progress? Allan alluded to the notion that if we just do basic research, it will trickle down to innovative industrialists. That is true in part. Few concepts are more basic than quantum



'I think one of the most important things we can do is arrange for more frequent exchanges of people between the industrial sector and the universities.'

Allan Bromley

mechanics. Out of that came an understanding of solids that led to the transistor and to the computer industry as we know it today. So quantum mechanics transformed the world. We're going through the same thing again with biotechnology. So the trickle-down process of research to technology does work, but it's only half the story or perhaps less than half the story. Another part of the tale may be illustrated by the auto industry, which does not live from trickle-down R&D. Nor does the semiconductor industry once it was well established. Semiconductors live on incremental improvements. The semiconductor industry was born at the universities, but its parents, the research professors and their grad students, who were at the conception and delivery, soon left to live on their own for better or worse.

So you have to look realistically at the connection between universities, their research and their people, and the nation's economic enterprise. The connection occurs sometimes: New industries sometimes spring from basic research. Semiconductors, computers and biotechnology are three spectacular examples. Those industries make a compelling case for supporting academic R&D.

Just as you can't have a growing scientific enterprise in a country that isn't growing, you can't have a growing basic research unit in a company that isn't growing. That is the case at IBM, for instance. The company is getting smaller. So is its basic research unit. But the commitment to science and technology and their use is not in any way diminished. R&D goes up and down with the fate of the company. So do the careers of scientists and engineers. Therefore, I think we have to think in the following terms: Basic research must continue because it is the precursor to whole new industries. Education at universities must also continue in order to train people for more basic research and for work in industry.

Bromley: I agree with all that, Ralph. I think your

remarks emphasize that things can change. We've tended over the past few decades to focus almost exclusively on revolutionary discoveries. Our reward structure is such that we give rewards and recognition to the revolutionary discovery or development that gets a Nobel Prize and is a new paradigm or contributes to a new industry, and we've tended to forget the evolutionary discovery or development that is made on a production line that gets a product out the door a little faster, a little more cheaply, a little more reliably, and gets the company more market share. That's what our friends in Europe and Japan have learned to do extraordinarily well, and they reward people for that. I think that a reward change and a structural change could be enormously beneficial, because it applies to situations where we have been losers, in the transformation of our technology into manufacturing products. We have had a breakdown in a domain we once dominated.

Gomory: We're getting away from questions of science, and I say that not as criticism of this group, but because of the general tendency of scientists and technologists to imagine, first, that they are the solution, and second, that if there is a problem, they caused it. [Laughter] That is not the case. I think you have to be quite egocentric to imagine that science and technology have caused the problems at General Motors, for instance. They haven't. There are other sources of corporate problems than science and technology.

Schriesheim: Still, there are expectations in Washington and in the rest of the country that science and technology can make contributions to solving the problems of American industry. If we fail to contribute to economic competitiveness we are not likely to survive in the style to which we have grown accustomed. So how do we in the communities do what I think society expects? As I see it, society—and that includes Congress—expects us to fix the problems at General Motors and at dozens of other companies.

Gomory: There are realistic expectations and unrealistic ones. Whatever the fix may be in the short run, in the long run I think all of us need to deal with the realities. If it turns out that society believes that we can do everything, by some magical act or art, then part of our task is to convince society that we are unable to do everything. Still, we can do some damn important things, such as inventing semiconductors, computers and biotechnology. It's also important that we not be given blame for problems in the automobile industry. There are significant contributions we can make—particularly in training people for new and existing industries.

Massey: I always find it interesting whenever a group like this discusses problems in the science community that the talk switches from universities and research to the problems in industry and management. The discussion moves right away from such matters as start-up money for young faculty, the tenure system, the role of grants and so forth. I was at a conference last week in Cincinnati, one of the most fascinating conferences I have ever attended. It brought together about 200 people—mostly CEOs of some of the most dynamic US corporations, including Motorola, Xerox and Hewlett-Packard, along with some university presidents, faculty and deans. The industrial people convened this conference to try to get universities to think about how to manage themselves and how to deal with the kinds of issues we're talking about here. I don't see this kind of introspection applied to our science enterprise. So as we look at the future of physics, I would like to encourage all of us to look inward at our own enterprise to determine what we're doing right and what we're doing wrong.

Libchaber: We have been raised to admire Ameri-

can universities as the only university system in the world that works well in the 20th century. So I would suggest that the first thing is to be sure that the research universities retain their preeminence. Another thing is that science in America before the Second World War was in its adolescence. During and after that war, American science came of age. The rest of the scientific world was in ruins. So America became the scientific superpower, just as it also became the military and economic superpower almost by default. To all these remarks about responding to society's demand, I say: If you want to respond to society's demand, the only way is to keep our universities at the highest quality.

Zare: As we speak about the future of American physics, we see that it's embedded in the future of American society. It's obvious. I would like to return to the automobile, about which I am a well-known non-expert. What can we physicists contribute to the revival of America's auto industry? We could learn from different disciplines coming together how to make a non-polluting engine. We could devise cars to run on batteries. We know that whoever contributes these developments will have a major say in the future of the industry and in the shape of our society. Most of the improvements will be incremental, not revolutionary.

Among the other improvements we can contribute to society is scientific literacy. It hurts me to see someone with a physics degree unable to teach science at a high school level. Here's a national problem we can come to grips with and do our part. It requires action on our part.

Gomory: What I think Dick is talking about is the contribution that physicists and other scientists can make to society outside of their own specialty. At this roundtable we have heard two extreme positions, both of which we should reject. One I caricature as saying that somehow science is responsible for everything. I think the scientific community projected that view for many years. The other is that we don't need to know anything about the outside world, we should just do our thing well. I don't believe either is workable.

Massey: Perhaps our slogan ought to be "Physician, heal thyself."

Gomory: Okay. But we have got to understand the setting. In my own experience at IBM, I had the problem of justifying basic science in a different, difficult world. I was able to do this but it wasn't always easy. Science can make tremendous contributions, both of the breakthrough and the incremental types, if you're organized to do it. So we should not just curl up and say our own purpose and contribution is to be excellent. Neither should we go to the other extreme and say, "We can do everything and we're going to save the country. Just double our budget." We have to be realistic.

Bostock: I want to lay out two major themes. The first is that we all agree that we are not going to continue to increase the funding of science. The second is that we need to talk about the things we can do. I agree with Walter. We can help change the culture of academia. Now, that's a difficult chore for the simple reason that we have the best universities in the world—particularly the research universities. Can we right the wrongs at these universities while maintaining or improving their excellence? We might emulate the European or Canadian systems in which faculty members get a certain amount of research money, without writing for grants and without any strings.

Bromley: Even in those lands the science faculties spend time griping.

Bostock: But we need to remember that in most of Europe and Asia, young people get an excellent K-12



'I don't see any solution to our problems...given the resources that I see, realistically, on the horizon.'

Walter Massey

education in science and math. Our kids do not get that. So our first-year college students have no thoughts about physics other than it is a tough subject, few people do it and you have to slog along for years before you are going to enjoy it. We can help change that, but it will take years to do it. As for adopting the system used in Canada or France for awarding research grants, I take no stand, but it is an option that ought to be considered.

Massey: You know, we're still on the first question: What can physicists or the physics community do to maximize the probability that the next 10 years are going to be healthy for physics, for science and for our society? Let me modify the question slightly. What should physicists be thinking about when they read this in *PHYSICS TODAY*? Could some shout out loud, "Aha, here's something I can do that is going to make a difference in the enterprise over the next 10 years" or "At last, these blokes have come up with an answer to our dilemma."

Bromley: I suggest a few simple political things that I think are important. First of all—and the physics community has been rather good at this in most sub-fields—physicists can get their own priorities in order and be up front in making them public. Second, physicists have led the way in connecting the scientific community with the political community ever since the war. That's now changing. Biologists are going to be much more important in the years ahead—to society and to government policy. But physicists can still play an important role if they were somewhat less arrogant. The impression many people in the Congress have is that we are just a terribly self-centered lot. We honestly don't do much to correct the impression. We're also a terrible political constituency. Please bear in mind that over the last four years, in order to get any increase at all for the sciences, we've had to postpone or kill other parts of the discretionary domestic program that had, in many cases, very vocal, needy constituencies. What was done for science was done simply because the President and the Congress thought that investment in science was important.

I think the most important thing we can do is to work within our own scientific community, not just physics, to come up with something that we can all agree on as a strategic plan that is appropriate for the next few decades and

then to help Congress and the public accept the distillation of our best thinking on such a plan. Just as we no longer divorce ourselves from the practical applications or the social implications of what we do, we can no longer be divorced from the political aspects of what we do.

Kleppner: At present there is no single body that one can address with a strategic plan. The lines of authority for the support of science in Congress are so diffuse that it's difficult to put together a strategic plan for physics, much less all of science. Do you have thoughts on how one might address that task?

Bromley: My successor would love to get a strategic plan for physics that is agreed to by the entire physics community, as well as a plan for chemistry and another one for biology. These would be enormously helpful in working with the Office of Management and Budget to put together a coherent budget for the White House.

Goodwin: You have often said, Allan, that if the scientific communities don't get their act together and set their priorities, others will do it for them.

Bromley: The politicians and bureaucrats will surely do it for them, that's right. Budget decisions will be made by people with far less expertise. Let me add a caveat: Physicists tend to believe that once they have pulled together their priority listing, then, by God, they should get their wishes in the precise order of their list. They fail to recognize that when you're putting together a President's budget, there are a lot of other inputs—political, strategic, international, you name it. The input of the scientific community is only one of those. And so it may turn out, for any number of reasons, that in a particular year one can't hew exactly to the recommendations. But over a period of years, physics and astrophysics have been remarkably successful in getting what they want.

Kleppner: In its last budget cycle, Congress seems to show no understanding or appreciation of NSF's mission, let alone concerns for the priorities set by scientists. The American Physical Society has issued resolutions about support for the Superconducting Super Collider and the space station that were ignored by Congress. In the end both got funded again at the expense of support for individual investigators.

Bromley: Walter and I have spent many hours

'My concern is that too few graduate students want to be clones of their professors because they don't see academic careers as satisfying.'

Daniel Kleppner

talking about that and how to try and fix it. We're on your side when it comes to NSF's mission for basic research and individual investigators.

Kleppner: The scientific community worries about the signal Congress sent to NSF—that to get an increase in Federal funds, research needs to be transferable to technologies. It looks like Congress is no longer our ally and that the covenant between science and Congress is now broken.

Massey: First, I don't think simply because you don't win every political battle that the effort is wasted. Second, it is true that you take a risk any time you recommend a facility. That's the practical politics of this place. It doesn't do any good to say we'll only take the facility if we can be guaranteed you won't be taking money from somewhere else in the science budget that we also badly want. Politics just doesn't work that way. Once the site for the facility is decided, the political dynamics change altogether. The project takes on a life of its own that removes it outside the realm of science.

Gomory: I am troubled by the statement that Congress is sending a signal that it is no longer the friend of science. I used to visit various Congressmen and Senators in one of my earlier lives. I can remember walking into their offices and talking to these guys, and they'd say things like, "I believe in science." My blood would run cold because, I'll tell you, when they say "I believe in science," that position will collapse someday because they don't know why they are believers. So I think we need to explain to them why science works for the country. As long as we're going to rely on some quasi-religious belief, science is in a very exposed position. I speak from some experience, because when I became the director of research of IBM in 1970, I felt greatly exposed. A lot of people in IBM supported research, but they didn't know why. In fact, a lot of research in the United States was founded on that premise: Science is good and if we have it in our company it will work for us and we will prosper. Science doesn't work that way. I spent almost 20 years transforming that myth into a realistic understanding that the research units could contribute to the company and produce basic science at the same time.

Bostock: Two things come to mind: A lot of people see strategic planning as having only downside risks. They argue that a strategic plan provides a guide for what to pare two or three years down the road. Unlike Ralph, I think that members of Congress still hold to the idea that science is good and the more the better. That is why Congress has become so adept at carving up university pork and for attempting to double NSF's budget in five or six years. Congress believes what scientists say they can do. We know that science can't work the miracles that are promised. The day Congress figures that out for itself, we are in deep trouble.

I believe there is a sense, as Allan Bromley said earlier, that science has gone from an investment to a procurement. So when the APS states publicly that it backs the SSC all the way, then cautions "but not if it will cause any money to be diverted from individual researchers," what is the message to Congress? It is saying that



Congress has the right to rank order the appropriations process. You may recall that the year the SSC was introduced in the Energy Department budget, the machine was the beloved son. Now people speak about it eating their lunch.

The Clinton Administration has made it clear that it plans to shift money in the science budget from fundamental research to applied research as a way of stimulating industrial innovation and productivity. Academic scientists will have to live under such strictures. It is unrealistic to think that scientists will be able to say, as they did in the past, "Just give us the funds and let us decide what to do."

Zare: Judy, when you talk about productive physics or chemistry or whatever, are you talking about just end results, like finding the Higgs particle with the SSC, or are you talking about relevance to society?

Bostock: Relevant to society. That is what Congress is beginning to define as productive science.

Kleppner: What you're talking about is directed science.

Bostock: Yes.

Libchaber: What should I tell a young university scientist after our discussion today? I would tell him first, "Don't get polarized about grants." "Convince your students to teach." "Free yourself from the organization as much as you can." Another thing I would tell a young physicist is that astrophysics and high-energy physics are well organized because their goals are well defined. Physics now is spreading into all the other disciplines and, it seems to me, doing that in a very useful way. Some of my friends are taking positions in mathematics, others in biology. So this is something I would encourage them to do and to look around and try to ally themselves to other disciplines. Then the final thing they would learn from our discussion is that NSF is very rigid and inflexible. If your work falls between the definitions of NSF, you are

lost. So something NSF should do in order to help the physics community is to open itself to cross-disciplines and multi-disciplines. In France if you get the Nobel Prize because you work on superglue, that subfield attracts the best students. That doesn't happen here. Unless this attitude changes, unless there is a realization that physics is much more diverse than the traditional 1900 discipline, America will lose something important. In France, physicists and chemists work together in many places. I don't see this in the US.

Massey: I don't think we are getting anywhere when we debate whether Congress loves physicists or not. I've learned a number of lessons from proposing the commission to look at the future of NSF. We've received more than 800 letters and e-mail responses. Actually the total represents many more individuals because some of the letters and faxes come from scientific societies and industrial groups. Unfortunately, a number of the responses from the physics community fall into the category of "Don't bother us. We have nothing to contribute to this discussion. And make sure whatever is done doesn't harm us." After a while we began to get letters, many from well-known physicists— theorists, not practical people doing applied research—saying, in effect, "You know, we shouldn't do directed research, Walter, but here are some things that really make sense and here are some things that I think could really make a difference and be productive for physics research as well as some points that you could tell our supporters in Congress that would answer their concerns." The problem is that Congress wants us to do something for society and the economy. The Senate appropriations committee and Congressman [George] Brown's report really are a plea to the scientific community that says: "The country is in economic trouble. What can you, some of the best scientists in the world, do to help in the country's hour of need?" Is "Nothing" our best answer?

Goodwin: The reaction, for the most part, is one of kicking and screaming at the suggestion that NSF may support more applied research.

Massey: That's less than saying "Nothing." The science community could be saying to Congress: "Look, the way you're going about it is not going to work. But there are ways to make it work right, and here's how we can make a difference." I find it difficult to move the science community beyond thinking of Congress as our patron and protector to a point where we can demonstrate what we can do to make a legitimate contribution to solving some of the country's problems.

Gomory: I'm extremely optimistic. I think we will evolve toward a sensible arrangement. Put in very simple terms, universities should do basic research and industry should do the implementation. Each should help the other whenever possible. I think we should guard against trying to transform basic research into applied research without a user, which I think is quite tempting. Applied research without a user is usually bad by any standard, and we shouldn't encourage this. That does not mean that the universities cannot contribute to this country. They have done so in the past, and they can do so better in the future.

Kleppner: Walter's Commission on the Future of NSF provides an excellent mechanism for opening a dialogue with the science community. I've felt for a long time that the National Science Board has operated in isolation from the science community. There has been little interaction between the board and ordinary scientists. If there is to be a restructuring of science, as has been suggested, it will require a lot of discussion. Apparently this process has already started.

Goodwin: What are your thoughts about the cre-

ation of some form of technology agency in the Federal government to augment the NSF in its mission to support basic research?

Bromley: Congressman George Brown is planning to reintroduce his bill to set up a National Technology Foundation. He is not happy with just inserting the word "engineering" into the organic act of NSF.

Gomory: I don't think you can tell whether producing technology in itself is a good thing or a bad thing. Technology does not exist in a vacuum. But if there is to be a government agency closely tied to industry, then it could make a contribution. There must always be a user.

Goodwin: Is the paradigm for a technology foundation something akin to a civilian Defense Advanced Research Projects Agency, a non-defense DARPA?

Gomory: There are really two DARPAs—the DARPA that's visible to the academic community, funding advanced artificial intelligence, building ARPANET and things like that, and the other DARPA that helps bring advanced weapons in to a customer of their own agency. DARPA funded basic research, which can be done without a customer, and also funded weapons for the Defense Department. So DARPA fit my paradigm both ways.

Bromley: I will certainly watch with great interest the different solutions that are proposed. The implication is that our existing institutions are sick or that our existing institutions are incapable of modifying themselves to come to grips with the problems of the country. I admit to a certain bias about introducing new institutions or agencies. We ought to spend the time first to examine the existing institutions and agencies from the standpoint of how they can become more effective. I'm concerned that in the rush to do something, Congress or the Administration will set up other institutions that will inevitably drain money from existing institutions. In the end, I fear we'll wind up not with new stronger institutions, but with existing weaker institutions.

Massey: There are several versions of bills floating around for civilian technology agencies or civilian DARPAs. I find it somewhat anachronistic, however, to have a National Science Foundation and a National Technology Foundation. Maybe the names won't be indicative of what they actually do, but if they imply that science and technology should be separate, then, to me, it's just going against the grain of what's happening naturally and the way things are coming together. I agree with Allan that simply creating new mechanisms or institutions, unless you expect a major growth in financial resources, is unlikely to solve the problem. However, what I've learned very quickly since I've been in Washington is that perhaps the only way members of Congress can express their will is through the introduction of legislation, the preparation of reports and op-ed articles and the passage of budgets. I'll come back to a point I made earlier. I view the actions of Congress, when they do these things, not so much as their conviction that they know the best way of doing things, but their only way of getting the attention of the science community to find a better way. The members are saying, "I'm doing this knowing you're not going to approve, but nobody's shown me a better way."

Bostock: As someone who comes from academic science at MIT, no less, and spent a decade in the executive branch in Washington, I think Walter has issued the marching order for mobilizing the physics community and the rest of the science communities. We need to defend what is good in basic science and oppose the easy and untried solutions that are proposed for improving the industrial capabilities of the country.

Lubkin: That's probably a good note on which to end this discussion. ■