ROUNDTABLE: PHYSICS RESEARCH IN INDUSTRY

Three weeks before the stock market crash on Black Monday, 19 October, PHYSICS TODAY conducted a roundtable discussion on the current state of US industrial research. The eight participants who gathered at the Washington office of the American Institute of Physics on 29 September included the heads of research at four prominent manufacturing companies, a former research minister of France, the deputy director of a national laboratory that often collaborates with major corporations, an administrator at a leading technical university, and the only member of Congress who holds a DSc. Questions were posed by PHYSICS TODAY editors. As the following excerpts from the two-hour discussion reveal, the participants spoke candidly about problems and practices, ranging over such matters as technological competitiveness, research management, physics education, technology transfer from industrial and national laboratories, and government R&D policies.

Roundtable Participants

Pierre R. Aigrain, scientific adviser to the president, Thomson Group; former scientific director of Ministry of Defense, director of higher education of Ministry of Education, Secretary of State for Research, Republic of France

Daniel Berg, Institute Professor of Science and Technology and former president, Rensselaer Polytechnic Institute

Peter Cannon, vice president for research and chief scientist, Rockwell International

Praveen Chaudhari, director of physical sciences department, IBM Corp

Robert A. Frosch, vice president of research laboratories, General Motors Corp; former deputy director of Advanced Research Projects Agency in the Department of Defense, assistant secretary of the Navy for R&D and administrator of NASA

Donald L. Ritter, member of Congress for 15th District of Pennsylvania; former faculty member in materials science department, Lehigh University

Robert Stratton, vice president and corporate staff director of central research laboratory, Texas Instruments Inc

Alexander Zucker, associate director, Oak Ridge National Laboratory

Gloria B. Lubkin, editor, PHYSICS TODAY
Irwin Goodwin, senior associate editor, PHYSICS TODAY
William Sweet, associate editor, PHYSICS TODAY

Goodwin: Let's begin this discussion by looking at the big picture. Whether we are conscious of it or not, the terrible truth is that many Americans are haunted by the fear of the nation's scientific and technological decline. That thought pervades much of our industrial, academic and governmental enterprise. It is rather symbolic of the state of things that President Reagan addressed a technical meeting of scientists and engineers last July—perhaps the first time a US Pesident has ever done this. The topic of the conference was high-temperature superconductivity. Earlier, last February, he was called on to understand the principles and prospects of a gigantic particle accelerator, the Superconducting Super Collider—the largest scientific instrument ever conceived and something no previous President has ever had to learn about. The President applauds research in superconductivity and the SSC because they are championed in terms of improving the country's competitiveness—in the sense of reasserting the nation's hegemony in science, technology and world trade.

The country seems obsessed right now with competitiveness—possibly because US industrial leadership has been challenged, some would say humiliated, by foreign technology. On the best sellers' list are titles like *The Reckoning*, a book examining what Japan's car companies did right and US firms did wrong, and *The Great Depression of 1990*, which depicts the state of economic life to come if the US doesn't make some immediate changes and commitments in its R&D and in society. It's com-

ALL PHOTOS: DOUGLAS GORALSKI FOR PHYSICS TODAY

Managers of some leading industrial centers discuss their knottiest problems with PHYSICS TODAY editors. Around table, clockwise from top: Gloria Lubkin, Praveen Chaudhari, Robert Frosch, Robert Stratton, William Sweet, Alex Zucker, Peter Cannon, Irwin Goodwin, Pierre Aigrain, Daniel Berg and Don Ritter.

monplace for prominent economists and corporate executives to speak and write about America's industrial disease and America's technological sickness. Is this a correct diagnosis?

Back in 1941, Henry Luce, writing in his magazine *Fortune*, proclaimed this the American Century. His declaration was based on the nation's scientific and industrial success, as well as on the vitality and creativity of its people. To hear some tell it, the American Century has been short-lived. Is it wrongheaded to conclude that US business is in decline, that our dominance, based for so long on science and technology, is passing into other hands in a global marketplace? Does physics have a part to play? Would anyone like to comment?

Frosch: I'll comment. I think there is a problem: a decline of American business that is not closely connected with the question of a decline of American science and engineering. I think what has happened is that American business has gradually become more and more incompetent on its own technological terms, by which I mean not the question of whether it does physics or it doesn't do physics, but whether it does business in an intelligent way. Business is increasingly becoming a national financial lottery. The pressures on those who run the large businesses do not allow them to have the span of attention of more than a three year old. They are continually looking over their shoulders to see whether somebody is going to manipulate the finances in such a way that they can't run the business anymore.

I don't know whether my colleagues see this. I see it in the industry I am in, although it has lots of problems of its own that have to do with technological questions such as whether it adopts innovation or doesn't. But these are seriously compounded by the financial problem.

We usually say that the strength of American innovation is in the creation of small businesses. I think there is a good deal to that. But increasingly I see situations in which the small businesses are created, and the people who create them stay with them long enough so that they can be sold to somebody else and then go on to start another company. Whether this is, in fact, the economic ferment that leads to more innovation or whether it is merely the degradation of intellectual ferment into another financial manipulation isn't clear to me.

I see the barriers rising to commercial use of innovative technology. The barriers are rising because of the increasing inability of businessmen to understand what they are doing in terms of long-term cost structures, as well as organizational problems and short-term pressures. Businesses no longer seem to understand technological research, which is really the underpinning of modern corporations. The problem of technological innovation is at bottom the difficulty of running a business in the current short-term climate.

Lubkin: Should scientists—physicists, say—start teaching in the business schools of Harvard and Stanford?

Cannon: Perhaps they should be teaching in Michigan! There is a difference between the situation Frosch describes, which I think is a fairly accurate representation of the struggle to manage a large-scale manufacturing enterprise over the long term, and the dynamics of the situation in small business, which can move in a period of, say, 100 days to create a brand new economic entity and bring in good people. In the whole nation we have seen an increase of 13.2 million jobs—the number is just astonishing—in the past seven years. I haven't made up that number. It comes from the Bureau of Labor Statistics.

Goodwin: Are those new jobs mainly in the service industry?

Cannon: No, that is not so. If you go to California, to the Santa Clara Valley or to Los Angeles, you will find lots of new jobs filled with PhDs—physicists, mathematicians, bioengineers. The area I live in, Ventura County in California, was once dominated by agricultural and oil extraction industries. Today, within two miles of our laboratory in Thousand Oaks, which was the first laboratory in an otherwise undeveloped valley, there are 6000 technical jobs. These are not service jobs in the sense of slinging hamburgers. They are service industry jobs in the sense of practicing and applying physics and electrical engineering. In the last ten years, the technological sector has become the largest component of our local economy.

Goodwin: But isn't California's Silicon Valley experience really an anomaly?

Cannon: If it is an anomaly, then so is Route 128 and the DC Beltway and so is San Diego. I have lived in this environment for so long that it looks real to me. To me the gray skies over the great steel mills are the anomaly.

Frosch: I am worried about the staying power of all of this. I see a lot of things start, such as semiconductors, in which we did beautifully for a while and now is troubled. I see how well we did in computer products, but now I don't quite know where we are going. I see a lot of turbulence—uncertainty.

Stratton: I would like to return to Goodwin's opening question about whether there is, in fact, a decline of science and technology in American business. Because business covers a large collection of different activities. I would like to confine my comments, initially at least, to the electronics industry, with which I am familiar, and the dependent downstream industries, like the computer industry. Yes, we are in trouble. We are in trouble primarily because the environment we operated in during the 1950s, 1960s and early 1970s allowed us to succeed and prosper using approaches that are not good enough in the 1980s because of the very intense competition, primarily from Japan and from Western Europe.

If you look at the numbers, like market share of leading components, you have to say that the American electronics industry is in trouble. The problems in my opinion are to a first order financial. The financial structure didn't hurt us while the competition wasn't very smart. The competition has now become smart and enjoys a superior financial structure. That enables our competitors to have a strong impact in international markets.

Let me make a broad statement: I don't see a decline in American science. I see a decline in American technology, in that our ability to translate science and the results of research and development into innovative products is inferior to the capabilities of our rivals, particularly the Japanese. This is a contributing factor to our business decline. It is directly related to the financial structure. Japanese companies are able to apply a lot more dollars to R&D per sales dollar than American companies, and as a result are much more effective in bringing their products to the marketplace early. So, yes, we have got difficulties.

Robert A. Frosch
Businesses no longer seem to understand technological research, which is the underpinning of modern corporations

Zucker: I see the industrial question from the sidelines. I see a general loss of nerve when it comes to research, which has to do partly with the fact that corporations have to look for the bottom line every year. Just yesterday I saw in the paper that Allied–Signal is in financial trouble. So what are they going to do? They are going to cut R&D. That's a perfect example. What they are doing will place them in deeper trouble in five years. You can guarantee that.

Let me give you another example, from ceramics. The US ceramic industry used to be preeminent, the only one in the world for a while. It is now pressed hard by the Germans, the Japanese and others. So, the ceramic industry got together and decided that what it needed was a

Peter Cannon

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concerted effort in processing research—that is, from the powder to the ceramic body. Everybody agreed that was a good idea. Now, we are trying to put together a consortium of these companies to essentially develop a processing R&D center at Oak Ridge National Laboratory. To that end we have created a nonprofit corporation, and we are now asking each of about a dozen ceramic companies to join. The cost of joining for each company is $250 00. You would not believe how difficult it is for a director of R&D in the ceramic industry to come up with that amount of money. These are industries with sales of $20 million, $50 million, $100 million a year. To obtain $250 00 for research is a decision that has to go to the CEO. He has to decide how soon he is going to get that investment back.

I don't know if we will make it. We have been talking to these companies for a year. Only one company has signed up. We think we will get three or four more, but we need ten. So, the investment to make the ceramic industry competitive against Germany and Japan may not be possible.

Goodwin: Is the model for this the Microelectronics and Computer Technology Consortium—MCC?

Zucker: There are lots of models.

Goodwin: Are you suggesting the model is SEMATECH, the new government–industrial partnership in semiconductor processing R&D, which also requires its member firms to make heavy contributions?

Zucker: SEMATECH is much more ambitious and much more expensive. The ceramic concept at Oak Ridge is relatively cheap.

Cannon: We could spend all day on the relative merits of those models. They all work, more or less.

Now I want to pick up on Frosch's remark about our investment policy as a national financial lottery. In fact, each person who has spoken so far has commented on money as a factor in our industrial–scientific problems. Well, you can't do physics without money. In fact, you can do precious little even with money these days, because physics has become very expensive. We, as practicing managers of physics, have caused it to become very expensive. I think it is probably worthwhile for us to say what we really mean when we criticize the financial structure as not good. We mean that we have to ask someone else for the cash. Let me illustrate: A firm with gross sales of $100 million a year is a small company these days. There used to be a rough rule of thumb—and I believe Dr. Aigrain once mentioned this to me in Paris in the company of George Szasz of General Electric—that with $100 of sales, one has $10 of development expense and perhaps $1 of research—what we describe as three- to eight-year research. So a $100 million corporation has discretion in spending possibly $1 million for research. Consequently, the decision to spend a quarter of that amount in a consortium that is geographically separated and where the results are yet to be seen is in fact a major decision that is likely to be made by the CEO.

Lubkin: Would you explain the logic of that?

Cannon: The early costs of inventing a new product are modest compared with the production costs and expected returns. A rough rule of thumb might be that if one spends $1 on research, one has to be able to see $100 a year in revenue. You have to see this in terms of the corporation that is more or less in equilibrium. The company is growing in accordance with the growth of its market rather than exploiting totally new markets. It is only when the company is new and far from equilibrium that you can expect much larger expenditures for research relative to sales. Perhaps that should be the justification for expecting larger sums to be spent on ceramics.

In our own case, we are a $12 billion corporation. Principally we serve other corporations like General Motors and Ford as well as the Federal government—customers larger than we are. The rate of expenditure on research in our organization is dictated by the rate at which our customers will accept innovation. Our ratios are a little higher in terms of research to sales than the numbers I quoted, but they couldn't be ten times as big. Our customers wouldn't pay for that.

Aigrain: I think that the disagreement between Peter Cannon and Bob Frosch may have to do with the definition of what is research and what is development. The distinction in most industrial companies is fuzzy. If we speak about long-term R&D investments, I think the numbers that Cannon cites are of the right magnitude, especially if your customers are technologically minded.

Pierre R. Aigrain

If your only criterion is what is going to be the cash result each quarter and you find it is not as good as you want, then the best solution to this problem is cut R&D

Then you can afford to be innovative because otherwise you will not get the orders.

But I think one has to be careful about two things: When you speak about the decline of technology in the US, you have to remember first that it was understandable that its market share for products involving high technology increased immediately after World War II. The United States had virtually a monopoly on high tech. It is also understandable that this situation did not endure and that Western Europe and Japan and now some emerging countries like Korea and Taiwan are competitors. The US could not expect the *status quo post bellum* to remain forever. The second thing is that a decreased market share of some high-tech products is not necessarily a serious problem. The right index to use is total trade in high-tech items. Clearly, the situation is more rosy when one looks at the total.

The same holds true when one looks at patent applications. What has happened is that the world economy has become much more multinational and now individuals and companies are applying for patents everywhere. It is perfectly normal. So the percentage of domestic patents is going down for everybody, including the Japanese. Why? Simply because European and American applicants, who had rarely applied before, are now doing so. That reduces the percentage held by Japanese.

Let me discuss the electronics industry, which I know best. In the West, companies and governments are worried about Japanese competition. Japanese competition is mainly in mass-produced products, which are not necessarily the most advanced. These require good production technology in order to achieve high quality and low costs. But if you want to buy advanced microprocessors, you would not turn to Japan or to Europe. So you are not in a bad situation.

Still, as I see it from the outside, from Europe, I am troubled by some financial practices in the US, as exemplified in the most extreme cases by hostile company takeovers, corporate mergers and acquisitions paid for by junk bonds—developments that appear to me to be shocking practices. A lot of American companies have been too sensitive to bottom-line figures in the next three months. That obviously is not the right way to plan long-term research. Indeed, if your only criterion is what is going to be the cash result each quarter and you find it is not as good as you want, then the best solution to this problem is cut R&D. Such an action is not going to affect your market share three months hence and it is going to save money.

Stratton: I want to get back to a point I think is important—the question of being able to afford to join the Oak Ridge national initiative in ceramics and the difficulty each company had in making the investment. First of all, let's put it on the table: There are lots of opportunities in this country for companies to join all kinds of consortiums. I have had three or four offers within the last week.

Frosch: Consider yourself a wallflower.

Stratton: The issue is not the quarter of a million bucks. The issue is, as Peter Cannon said, the implications. Is this a useful way of initiating a much larger effort? There is no point in joining a consortium if you don't have an effort to match it in-house. There is no point in doing the whole thing in the first place if you are not prepared, if successful, to then invest ten times as much to turn out products. That figure is about right. So I think these are not quarter-million-dollar decisions. They are much larger decisions about people, resources and priorities.

I would like to return to what I meant by financial problems. Roughly, without going into economic definitions, which I probably couldn't handle anyway, the cost of capital for American companies like ours compared to Japanese companies is about 2 to 1. Since the new tax act [of 1986], it is more like 2.6 to 1. Japanese companies, for reasons that are complex, are able to satisfy their investors with a profit after tax of about 1%. US companies need 5% or 6%. In addition, Japanese companies seem to manage to work with a much higher debt to equity ratio.

If you put all of these things together, it says that Japanese companies have a lot more discretionary money available to do R&D. US companies comparable to mine spend about 6% of their sales on R&D. In Japan such companies spend about 10% or 12%. I think that that is not unique to the semiconductor industry, which I am talking about. I think this is true for a wide range of industries.

I would like to talk about market share. I fully understand that wanting to maintain 100% of the integrated circuit market, for instance, is indecent, to put it mildly, but wanting to retain more than 40% is not. And wanting to stay number 1 or number 2 is not. Now there are many areas of basic technology—and ceramics packaging is one—where as much as 90% of the activity is now in Japan. That has implications not only for our industrial well-being, but for our defense industry as well. We want to be in a competitive world, and we want to see Europe, Japan and the Pacific Basin countries contribute, but we have got to work at techniques for reversing what I think is a continuing downward trend in the United States. Business as usual in the US is not good enough. Bottom-line management of business, the way the universities are run, the way the national labs consider discharging their duties, and the way the government views industry, I think all these are things that contribute to our present troubles. We need to change the way we are doing things. I consider our R&D situation to be serious.

Frosch: Let me return to my imagery of doing research in a financial lottery. I used financial markets as an example not because I think money is the intrinsic problem, but because I think the pressure of the system has led to what I'll call a problem in business technology. The technology of costing, the technology of estimating the result of investment and so on has led inevitably to a terrible condition of business short-term-itis. The instant that management decides to look at research in terms of discounting the future, it immediately concludes it cannot afford the future. There is no possible, reasonable investment to come to fruition in 20 years that can be discounted so it makes economic sense. What we do is fiddle the analyses so the economics look right. If a normal business case is made, it comes out as nonsense. So you don't do it.

Increasingly we are drawn by the assumption that long-term things that we do for good and sufficient reason have to be justified exactly the same way as three-month things. That makes no sense at all. The problem is that the pressures on the people who say they are taking risks are, increasingly, to not take anything that looks like a risk at all. What we are seeing is the gradual erosion of corporate management's ability to do enough research and, what's worse, to proceed into development, because the obstacles that stand in the way of research going into product development are becoming formidable.

I feel a little lonely because I am running an honest-to-God research laboratory in an oldish industry, but as I look about me I am beginning to feel like the tree in the thunderstorm. There is a whole forest around me, but as I look around, I figure I am the only tree that is about to be hit by lightning.

Lubkin: Are you saying that no company is doing research anymore?

Frosch: No. What I am saying is that if you look back 5 or 10 years, I think you would have found a large number of US companies that had a fairly reasonable R&D attitude. It is my distinct impression that that is not the situation today—in some companies because of mergers and acquisitions resulting in two plus two frequently equaling zero, or one and one equaling one,

Daniel Berg

In talking to industrial people, I conclude that physicists don't come out with high marks—not because of any lack of talent but because industry doesn't know how to make the most effective use of them

never two, and occasionally only four-fifths. I think this happened because people with no idea of the technological relationship of R&D to business have taken control of businesses and then more or less, willy-nilly, dismantled the research program. That's not universal, of course. But that is the trend.

The pressure of business does do what Aigrain says. One of the easiest things to not need, say, nine months hence, if you are under pressure, is anything that has to do with what could happen ten years from now. Lots of people in corporate leadership positions succumb to that.

Now, there is a countertrend. People are building small businesses and many are producing new products. But I don't see very many of those businesses growing into medium-size and large ones.

Goodwin: In that kind of atmosphere, how does a research director deal with a profit-minded front office?

Frosch: Lie, cheat, steal, propagandize, yell, politic, be reasonable—all the usual ways.

Goodwin: Can a research director move up the corporate ladder?

Frosch: Well, he's already at the bottom.

Goodwin: Aigrain and Frosch have made the point of mergers, acquisitions and reorganizations affecting research adversely. During the oil glut of the mid-1980s, Exxon and Schlumberger cut back on their research enterprise. GE purchased RCA and immediately dismantled the RCA laboratory. Such actions are not painless. Is this a harbinger of things to come?

Frosch: Yes, I think it probably is.

Stratton: It is not all bad either.

Frosch: I am more worried about whether the rate of conversion of knowledge and fundamental technology into industrial products and processes is what it ought to be. I don't think the reasons why there is difficulty have to do with the competence or incompetence of the technological community and technology transfer. I think it has much more to do with the current business atmosphere for taking any kind of a technological chance. And frequently we do it badly.

Berg: I want to endorse Frosch's recent comments and to make two related points. I also want to get back to the original question that was asked at the start. My perception is that in basic science we are still very competitive, if not leading in many areas—maybe not all the areas in which we used to lead. I think the issue we have been discussing really relates to our lack of international competitiveness in manufacturing, in our ability to deliver products. It used to be that 26% of our work force was engaged in manufacturing. It is down to 22%. There is no question that the US trade balance is disturbing—much more imports than exports, despite the decline in value of the dollar, which makes our exports cheaper for many foreign buyers. We simply are not as competitive as we used to be. This is true for a variety of reasons, including the quality of our products and the absence of product development. It is distressing that our balance of trade in high-tech products turned negative for the first time in 1986.

Lastly, the percentage of our nation's gross national product devoted to civilian R&D is approximately half that of two of our main competitors, Japan and West Germany. This needs to be considered in our discussion.

Cannon: Berg just referred to, among other things, the deterioration in our trade balance, specifically in the technological sense. By way of bringing us back a little bit more to physics, I would like to raise the question of whether that problem in particular can be laid at the door of basic physics research in this country.

Yesterday I read an article in which the author made the observation that at the end of World War II, because of radar and the atomic bomb, people in this country were in awe of physicists, who were really working as engineers. I want to ask Berg in light of that what he thinks is the reputation of physicists *cum* engineers in American industry today. Do physicists still have a reputation for being able to do work that translates effectively into competitive products?

Berg: From my perspective, both at the university and in talking to industrial people, I conclude that physicists don't come out with high marks—not because of any lack of talent but because industry doesn't know how to make the most effective use of them. They are very versatile. They are usually well grounded, some of them even intelligent. I don't think the fundamental issue that we are discussing here really relates to the change in the quality or the ability of physicists. I still think they are as capable as they were 20 years ago.

Alexander Zucker

You wouldn't believe how difficult it is for a company director of R&D to come up with $250 000 to join a research corsortium

Lubkin: Does anybody else want to answer Peter Cannon's question?

Frosch: Berg's answer is right, as I see it. I would add one more characteristic of physicists that may be important in how they are viewed in industry or at least how they are perceived. That is arrogance—sometimes justified, but frequently irritating.

Zucker: There is some justification for that arrogance. In the Department of Energy, for instance, the projects that come in on time and within budget are the big accelerators that are built and managed by physicists. Projects that don't are, by and large, managed by engineers.

Frosch: I would like to make an important educational footnote, though. That is, when one thinks of physicists, we think of a profession that is dominated by the PhD. Sure, there are physicists who stop at the bachelor's and the master's degree, but most of the physicists around industry who are perceived as such have the doctor's degree. By contrast, the majority of engineers do not have advanced degrees. They have a bachelor's degree plus on-the-job experience and training. And so industrial physicists, who are in with a large number of engineers with bachelor's degrees, are very likely to shine. But whether this happens because of the difference between physics and engineering or the difference between a lot of education and some education isn't clear to me.

Stratton: Let me comment on the place of physics research in industry as I perceive it. I made a crack before about the decline of the Exxon lab not being all bad. That sounds inhumane at a minimum. My concern is that there are too many companies that had the idea that if you set up a group of 100 brilliant PhDs and leave them alone for ten years, they will at least win a Nobel Prize and also come out with a wonderful revolutionary product. The probability of all that happening is extremely low.

I think there has been a change in American industry that really doesn't have much to do with economic pressures. It has to do with a better understanding of the long life cycle from basic research, truly basic research, to applications. Having said that, I believe there is a fundamental problem in industry, and that is we don't do enough relevant research. By research I mean here work that predates invention. It is work in areas that can be identified as probably being useful.

Physicists in industry are extremely useful, in my opinion. Most R&D managers believe that and want to employ physicists, provided that the physicists do not expect to come into industry and carry on their PhD theses. I have to admit before this group that when I first took a job in industry that was my full expectation. And that was the fashion among physicists for quite some time. The physics community, the physics establishment, certainly plays a role in our economic competitiveness. And I think that they should consider that they play a role.

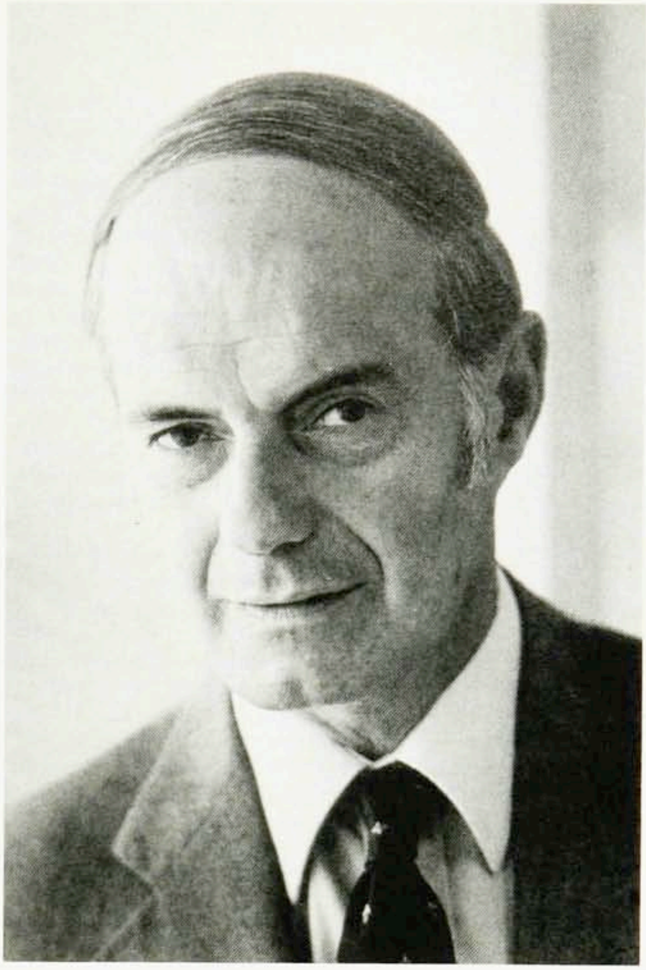
This may not be the time or place to say this, but I think the question of setting priorities among the various branches of basic physics at the universities and the national labs should be considered not purely from the point of view of maximizing our ability to win Nobel Prizes and to enrich the cultural quality of life in the country. I think the issue of economic competitiveness should be considered even in those areas.

Chaudhari: I don't think physics as a discipline is any more or any less appreciated than many other disciplines in industry. I believe industry looks at the effectiveness of all of the different disciplines in terms of their overall objectives. Although it is probably appropriate and fashionable to blame the financial institutions we have in the United States for the decline of high-technology industries, I think we have to look inward at ourselves. What have we done to contribute to fixing the problem of competitiveness? Most research labs that I know about and most research managers, including myself, have a fine line to walk. We want to contribute to science; we want to make certain we contribute to the industry we belong to.

It is in the second part of the statement I just made that we have the greatest difficulty, for it involves translating the needs of technology into the parlance of science. It subsequently requires technology transfer or, more commonly, knowledge transfer. This is something we haven't learned to do effectively.

In industrial laboratories, science groups have to learn to manage to do science that is exciting from the standpoint of scientific standards as well as corporate usefulness. It is very difficult for me to imagine that you cannot make a persuasive case to your financial officer that you will bring in money if you have a history of creating products that brought in money.

If history shows that the laboratory has paid off consistently, it is self-sustaining. If you set up a belief amongst top executives that a certain laboratory is going to produce basic knowledge and nothing else, or is going to give you a spectacular product that will make your company unique, then you are probably setting up an environment that will not have a long-term survival.



Robert Stratton

Our ability to translate science and the results of R&D into innovative products is inferior to the capabilities of our rivals, particularly the Japanese

Cannon: I am having real difficulty with the idea that we are in decline in the United States. I don't believe it. We have got the most productive economy in the world. We afford more money for research than just about any other country bar two. Yet our industrial predominance in some products has been affected—drastically. The difficulties seem to come in applying science to products in a timely way.

Physics has a remarkable record of contributions to business and industry. It can do more. Physics can do a lot of things for money management—especially mathematical physics. Frosch has referred to the illusion of simultaneity, and a physicist would recognize immediately the implicit causal paradox. It might be worthwhile to model a study of true yield from junk bonds.

Just think for a moment about "hard" physics. Innovation in metal fabrication is probably the area to which we have been most sensitive in terms of international competitiveness in the last ten years. The whole issue of innovation in texture is metal physics—the study of deformation. These are studies that are immediately applicable on a factory floor and result in drastic savings.

For example, the management of texture in aluminum affords reduction in the weight of parts by 30% to 40% with conservative design practices and consequent cost reductions. Cost reductions far exceed the reductions in weight.

Process management could also be improved through physics. The application of thermodynamics, a traditional field of physics, would be useful in managing steel production. The application of the fourth state of matter, using the principles of plasma physics, is likely to benefit metal fabrication. The application of laser hardening, not just simply laser cutting, can lead to nonequilibrium processing. There are wonderful opportunities for people who want to apply laboratory physics, hard physics, to industry. As Chaudhari points out, it would be hard not to be able to persuade a financial officer of the benefits of such research.

Probably the single most highly leveraged area would be information physics, because in many companies the direct cost of manufacturing today is less than the cost of managing the database of the corporation. Consider the virtues of translating an order from a salesman into something that can be implemented on a factory floor and analyzed for cost. It is essential for physicists who do this kind of work to be very conscious of investment principles. Let me float a disputatious statement: The training of physicists should be liberalized to include consideration of the management of money, just as it occurs in the training of chemists, chemical engineers and metallurgists. After all, if science gets to make money as products through technology, then technology is science that makes money. We have to bring that message home. Physics will make money at the point of application.

Frosch: I am tired of physicists being told they ought to learn about business. Some of us know about it. I am tired of trying to educate businessmen who don't even know about business management, who don't understand the mathematical technology underlying their own subject. A little liberal education in the business schools would go a long way. I agree with Chaudhari and Stratton about the rational case to be made for physics. I frequently have had difficulty having a rational case listened to. That's the only quarrel I have with business school graduates.

You know, I can do an analysis of my own laboratories, and in at least one case I can demonstrate that its minimum rate of return is the highest in the corporation. This does not prevent the financial staff from continuing to view it as a cost center. The perception is ideological.

I want to agree with the comments about the usefulness of physics to note that we ought to distinguish to some degree between the direct usefulness of physics as physics and the usefulness of physicists as research people. Bob Stratton has given some examples. I can give another kind of technological example, of almost straight application. Some of our physicists and mathematicians noted that the logic of attempting to schedule an assembly plant, which has complicated inputs and complicated constraints, was in essence precisely the logic used for simulated annealing. By taking up that idea, they have made a significant improvement in scheduling an assembly plant, as demonstrated by experiment in the assembly plant.

We have got physicists working as engineers, physicists working as physicists, as chemists; chemists working as physicists, and so on. It is a curious combination of doing fairly basic research in materials, in optics, in theoretical physics. Applied research in physics you know, and something that I can only describe as bringing the attitude of a physicist to a problem that may or may not be physics but simply viewing it as a problem one can approach. In fact, I think some of the financial analysis problems we're approaching as physicists and mathematicians have succumbed to some changes.

So, it is the usefulness of the total background training in solving problems that is more the key in my mind to the industrial research situation than whether people are doing physics. As Stratton points out, we occasionally have somebody who wants to redo his doctoral thesis for 20 years. That physicist needs some education.

Stratton: My concern is that we need research, whether it's called basic or applied, in industry in general and in my field in particular. We need it in areas we recognize as being potentially productive. That doesn't mean that the physicist isn't able to carry out good basic research. For example, we have one theoretical physicist in our lab whose work is centered on an esoteric subject—the time dependence of tunneling through thin film barriers formed in semiconductor devices. It's work that leads to calls for invited papers at meetings of The American Physical Society. Still, as far as we are concerned, it is part of a very definite mission-oriented problem—to develop the technology base for what happens beyond today's semiconductor VLSI technology. In that sense, there is room for good physics research in industry.

Ritter: Dan Berg alluded to the overall distribution of resources. He spoke about the research proportion of GNP spent by Japan, Germany and the United States, except that ours has a high percentage of defense R&D. US spending on R&D in 1987 is about $125 billion—roughly 50% civilian, 50% defense, while Japan's defense R&D is minuscule, maybe 1% or 2%.

This implies—and I hear it from people like my colleague Claudine Schneider [Representative from Rhode Island] and others—if more civilian R&D were supported by government, we would somehow have a major impact on this competitiveness issue. I think if you look at the facts, you can't support that claim. Most government expenditures for applied R&D are targeted toward military purposes, space exploration and mission-oriented activities. If you look at the government's civilian R&D, it is very far removed in many of the agencies from any connection with trade competitiveness. As a matter of fact, Washington has spent billions on matters far removed from any science–technology interface with global products in global markets. The SLAC work, the Fermilab facility, and on the horizon the SSC, which by anybody's guesstimate is the most basic of basic research. We will spend $6 billion, probably, on an accelerator that may help us understand the next smallest particles to quarks.

So we need to be careful when we talk about the military–civilian proportions for government-funded R&D. The anti-defense people like to use such arguments as a slap at defense spending. In reality DOD does more than the other agencies on the interface with science and technology closer to products and processes. It is not the civilian part of the Federal budget that is promoting photonics and new concepts in telecommunications. The Federal Communications Commission, for instance, doesn't have much in its budget for R&D, and it has fired most of its good physicists over time.

A secret aside during a break at roundtable engages Berg and Ritter.

Aigrain: I would like to support what Don Ritter just said. One way to learn about what should be done is to learn from other people's mistakes. There are two countries in Europe—France and the United Kingdom—that have applied the rule that government should do more civilian research. Now, I would leave basic research aside. There are other reasons for doing basic research, which have to do with the cultural aspects of basic research. There is a natural need in the human mind to understand the world. Moreover, basic research is directly related to education. I am not sure this means that you should build the SSC. I think a good criterion to know whether you should do basic research is the number of surprises per megabuck. And I am afraid the SSC is going to lead to very few surprises per megabuck.

The idea of government funding of long-term research for civilian applications is something that has been tried for the last 20 years in my country. It has been a dismal failure. Cynics use the phrase "inapplicable applied research" for the kind of things done in France. It doesn't mean that the people in these labs are bad. They are often very good. But what they are doing has nothing to do with the relevance and transfer of technology from these labs to industry.

Chaudhari: I want to endorse Aigrain's point. We have to make a very strong distinction between doing research that we think is basic and research that we think is useful to somebody. In the latter, technology transfer is usually the limiting factor in taking knowledge and making something out of it. That is best done when it is done closely with people who know the marketplace. It doesn't help to set up a national lab that will solve industrial problems when that particular national lab doesn't know anything about the industry whose problems it is trying to solve.

Cannon: I need to address Don Ritter's remark from the standpoint of conscience in the aerospace and defense industry. I think you know exactly where I come from on this. As a matter of conscience in the defense industry, where Federal funds flow through a very convenient mechanism, the Independent Research and Development account, we are increasingly concerned about compartmentalized research and excessive secrecy, and a consequent uncompetitive expenditure of very precious human resources, money notwithstanding. We are inhibited from using that knowledge and those products in international trade because of the requirements to manage the exportation of technology.

Ritter said his colleagues in Congress sometimes take the possibly destructive position that if we did more civilian work via government intervention, we would be better off. Don, your colleague George Brown [Representative from California] has asserted that the National Institutes of Health scheme of doing things is nothing more than a massive subsidy that has resulted in world leadership for the American pharmacological industry. Similarly, the Department of Agriculture extension service appears to us in the defense industry to be an enviable and effective form of subsidized technology transfer.

Lubkin: Well, what would you like from the Federal government?

Cannon: We like the R&D tax credit, which has done so much to favor the growth of the small companies that are so innovative. The R&D tax credit doesn't do a lot of good for large companies. Neither perhaps should it. It's paid for a lot of small companies to get started. Perhaps the assertion of some members of Congress should be tempered and accepted. There *is* an opportunity for further stimulation of commercially oriented research and development and a more liberal application of defense-sponsored science and technology in commercial business.

Ritter: I couldn't agree with you more. And I should add that I was not defending R&D in the defense side of the economy. What I am saying is the idea that somehow if you just pump dollars to the civilian side you are going to make up for the lack of competitiveness would be wrong. People argue for the SSC saying we could build it by not doing the Strategic Defense Initiative or the NASA space station. Well, that argument doesn't get us any closer to support for a competitive America.

I provided the first amendment for SEMATECH in the trade bill out of the House Energy and Commerce Committee. I am a staunch supporter of the SEMATECH partnership concept, in which government will be following the lead of a brains trust from the private sector. The venture may fail, but we have never tried anything like this before. It is the kind of cooperative concept I like.

I am behind the Science and Technology Competitiveness Act of 1987, which puts together a National Institutes of Technology modeled to some extent after the National Institutes of Health and encompasses an advanced-technology foundation that, in essence, is a civilian DARPA. This Federal investment is following some kind of market decision process. It is not simply based on building the next biggest and best megaproject that is politically or scientifically attractive.

Aigrain: When I said I felt some research was out of joint in France, I meant research done in government labs that would not otherwise be done if left to market considerations and industrial considerations. Let me give an example: We have an atomic energy commission that presently employs about 20 000 people in the civilian sector outside of the weapons program. It has been a very successful organization. When it was started, after the war, French industry was just not able to look into the science and technology of nuclear power. It was so successful that its job is now limited to some specialized areas, such as nuclear safety, and so it now tries to do industrial research in areas where it has no industrial competence.

Zucker: I will defend the civilian sector in the government labs, in part because they pay my salary, and because I believe that there is a vast misconception about what is going on. The national laboratories or the government laboratories in this country were essentially enjoined from working with industry through patent policies. The minute industry touched a government laboratory, its patent position disappeared, and as a consequence, industry stayed away in droves.

That has changed. It has changed in the last three or four years through legislation. And some attitudes have changed. You have to remember that the Federal laboratories get about a third of the R&D funding in this country. They have about a sixth of the scientists and engineers in R&D. So just to write off this resource and to say here's 30% of the money and a sixth of the people and we'll forget about that, that's not very smart. I think the smart thing to do is to see how these people can be used beneficially, how the facilities can be augmented and what they can do to enrich the country, to make it more competitive and to do a number of other, more social things like setting up a Route 128. Lest we forget, in a sense MIT is a national laboratory too. It has more money than Brookhaven gets by a long shot.

The things that national laboratories have—and I am now speaking for DOE laboratories, not for all Federal laboratories—is unique facilities. They are well run. These facilities are currently put at the disposal of industry: Brookhaven's light source, for instance, or the hundreds of industrial people who come to Oak Ridge and Argonne.

We are conscious at the Federal laboratories of the competitive problem, and we work at it. I'll give a couple of examples: The development that we carried out a few years ago in ceramics has blossomed into a $200 million cutting-tool industry, which has wrested the leadership from Japan back to the US. What we developed was a silicon-whisker-toughened ceramic that cuts cast iron.

Another area is in metallurgy. I agree with Peter Cannon that one of the great advances in the last 20 years is to make a science out of metallurgy. It used to be an art. In metallurgy we have developed a high-temperature alloy which is taking the heater element industry back to the US. We had lost that to the Europeans, largely to Sweden.

I have to tell you that it is a very expensive and a very difficult process. It is a process that industry needs to nurture because the technology can be put to profitable use. It's a process that the government needs to nurture

Praveen Chaudhari

In industrial labs we have to learn to do research that is both exciting as science and useful to the corporation. . . . If history shows that the lab has paid off consistently, it is self-sustaining because it is spending a lot of money, and it would be foolish not to try to get some competitive edge out of, say, the $4 billion spent on DOE's national laboratories.

Goodwin: If I understand Praveen Chaudhari correctly, he is saying that the President's initiative for superconductivity, to put $150 million into Federal labs to advance superconductivity, is the wrong thing to do. Is that what you are saying?

Chaudhari: No. What I'm trying to say is that it is very important to keep in mind the distinction between research that provides generic knowledge and research that goes beyond this stage into a competitive environment. Let me take superconductivity as an example. No matter what application you have in mind for superconductivity, you need to make films, you need to make wires, you need to make tapes. The eventual application doesn't matter. So, you need to develop processing techniques. How do you form films? How do you form wires that have the right transition temperature, the right critical currents? These are common problems that require solutions for any application.

It is right and proper for a national lab or an academic center to solve such problems. But to go beyond that, to applications for which the marketplace is not known to them, that is where I begin to question the role they play. If you want to go that far, then I think industry should be involved intimately early on. Industry is most likely to know what is going on in business. My comments are not at all intended to stop a national lab, say, from helping with pre-competitive research. I don't think there is any question that national labs can play a role. The question always is: What is the most effective way of solving the competitiveness problem?

Frosch: I think that is exactly right. The question isn't whether it is defense or space or civil. It is what is done and how is it done. Let me give you an example: When I was in NASA, we were all dragged kicking and screaming into a thing called the Competitive Auto Research Program, which spent an awful lot of money doing a lot of things that on the whole were a total waste of everybody's time and energy. That is what it looked like to me at that point. Then I came into the automobile industry and discovered that I was too calm about it.

On the other hand, one or two very useful things came out of it. It turned out that Sandia and Livermore—I think I have got them right—began to pay attention to what they knew about complicated physical, chemical, thermal processes and began to think about combustion. And out of that has come a couple of informal consortiums. They spend their own money and they talk a lot about combustion. And they are extremely useful, because it took a subject that was, in fact, nuclear bomb design research and moved it into another subject. It probably involved one-hundredth of 1% of all the money that was being pumped into NASA's automobile research, which consisted of trying to invent products that the people inventing them didn't understand.

A more general point, it seems to me, is that without trying to unscrew the inscrutable question of big projects–small projects and so on, I see this as a kind of a continuum from fundamental knowledge to actual product and process. And it tends to be a continuum in time. Very fundamental stuff, say quark physics, will probably turn out to be accompanied 20-odd years later by some very applicable something or other—possibly from quark physics itself or something peculiar that turned up in how you had to do the machinery to do quark physics. But it takes a long time.

Ritter: How do you decide whether you should go for quark physics or photonics? That is what we in the Congress are faced with.

Frosch: Well, I guess my argument is a cop-out in the sense that I think there has to be a mixture of some reasonably small-scale stuff and a few rather large projects. I think it is much easier to decide that you ought to do something like the SSC and photonics on a reasonable scale.

Ritter: But we can't with our current budget constraints.

Frosch: It is easy to decide whether you are going to do the SSC or the space station. Politically you can't. Economically I think there is validly almost no problem for the US. We have a terrible problem of saying the SSC costs us $6 billion or $7 billion while we are idly noticing that the cost of Congress only goes up $150 million a year, which in fact is $1.5 billion in a decade. When we don't like something, we calculate it as the total integrated cost over the next 15 years and say it is impossible. When we do like it, we give you the annual cost.

Ritter: I am asking you where do we get this. What do we give up? And if you have got a space station, which already has a head of steam behind it, if you've got the shuttle program, which you want to continue, if SDI seems to have across the spectrum some support because the Soviets are doing it, where do we go?

Frosch: You can easily discount the cost of the Defense Department by at least 10% to 20% without cutting our defenses, and I don't mean the R&D part.

Ritter: Who can? Who will? You're the guy from industry, and I'm a guy from politics. We should be able to agree at a more pragmatic level.

Frosch: We are starting from two different points. I am, in fact, talking about a little more than theory, and you are, in fact, talking about practical politics. If you do not have a fighting chance of touching the problem, then I think we are going to be in deep trouble.

Ritter: The Defense budget over the last three years has been essentially flat. In real terms it may have even gone down. There are commitments out there.

Frosch: Well, I lived in the Pentagon for a long time, so I have some idea of where the looseness is in the system. A reasonably rational set of improvements to the procurement system would probably save between $10 billion and $15 billion a year, but we are going hysterically in the wrong direction.

Ritter: Absolutely. I agree with you. There are a lot of growth areas—Federal-supported science and things like the Advanced Technology Foundation, which is an attempt at a civilian DARPA, outside the confines of the DOD. The foundation has $10 million for its first-year funding, and next year it could get $435 million. In photonics, the Japanese are installing three or four national facilities. Photonics is likely to be the next wave from Japan and the Pacific Basin countries leaving us gasping for breath. We have only one research center for that technology and it happens to be in my district.

Frosch: Why is Congress unwilling to turn around and look at questions like the inefficiency of the procurement system, which has been driven by the way Congress has set up the rules?

Ritter: In fact, it is looking at it.

Frosch: You can squeeze that sponge not very hard and there is water all over the floor.

Ritter: The opposite is happening. Despite its desire to have oversight and accountability, Congress still wants to avoid having every bureaucrat look over every other bureaucrat's shoulder.

Goodwin: Isn't the procurement problem also present in NASA?

Frosch: Yes, because it has to live by the same rules.

Stratton: I made what I considered a very provocative comment earlier in our conversation. I spoke about the application of physics in industry. People in industrial physics, even people responsible for the allocation of resources to basic physics, need to set priorities . . .

Ritter: Absolutely. Sure.

Stratton: . . . on issues other than the beauty of research.

Ritter: What a revolutionary comment!

Stratton: So I will deal with one of Congressman Ritter's questions. If we have a choice between the SSC and photonics—and I think the SSC is grand—I would vote for photonics research.

Ritter: What about SEMATECH versus the SSC?

Stratton: SEMATECH. SEMATECH versus photonics?

Frosch: Gentlemen, we are falling into the lawyer's trap.

Ritter: This is the reality that every single member of the Congress faces.

Frosch: But you have built the trap for yourself. You insist upon saying either/or.

Ritter: Congress's inability to say either/or is a source of our major national problem, believe me.

Frosch: You are saying either an SSC or photonics, this or that. In fact, the real question is given a certain amount of money, how do you go about spending it? And that may or may not be either/or. It may be scale and timing. It may be another set of solutions and so on. But instead of confronting the issue courageously, we get into situations where someone says, well, either it's this or that. We never seem to get out of that trap. I would like to see a blue-ribbon committee address how to spend *N* billion dollars in basic research and in improving the nation's technological state.

Aigrain: Just to try to clarify things, I would think we have to distinguish between what you do in basic research, to understand the nature of things for cultural reasons. And I think that one has to decide how much money can be put on these things. To do that one has to establish priorities.

If there is one area of physics that doesn't claim to have any practical application, it is certainly astrophysics. Nonetheless it is a booming field. We are not expecting any practical applications from it, even though there have been some indirect applications. Astrophysicists in fact have been first to actually use Josephson junction mixers for low-noise millimeter-wave applications. This may turn out to be useful in other areas. I certainly would support a number of similar not-so-cheap research projects—but not as costly as the SSC, by the way—because they have led to remarkable results.

Within basic research, you have to make choices. I think the basic criterion is to lead to the unexpected—surprises about the universe and ourselves. If you try to imagine what is the probability of basic surprises per megabucks spent, I'm afraid you would probably put astrophysics ahead of the SSC.

The other thing is that governments provide some facilities that are just too large for any single company. I have just spent one agonizing year solving the problem of the European Synchroton Radiation Facility. I have concluded that the money that is going to be put into it, approximately $600 million over the next ten years, is a good investment in basic research. It will also be useful for industry. In another field, I think that it is clear that wind tunnels need to be built by government and used collectively by people in government, industry and universities.

The other remark I want to make comes back to Peter Cannon's remark that on the whole the management of research programs within the Defense Department has not been perfect, but still remarkably good compared with other agencies. That problem has been possibly a little different in the United States from those European countries that have large defense research projects, as in the UK and France. You can find whole industries in the defense area that cannot survive in their own market. Many are basically in the export trade. The defense part of Thomson SA, which I know well, exports 65% of its production, some to the United States.

I think that defense research money has a great impact, and the fact that you have a tendency toward increased secrecy, trade restrictions and exchange limitations, even with friendly countries, may turn out to reduce the effectiveness of your defense program. I will be extremely sorry for you if this occurs.

Goodwin: You notice that in this group, Dr. Aigrain aside, four of the seven other participants are foreign-born Americans. That raises the question of the people who are going after the PhD in physics today. Many are foreign nationals. In engineering, the proportion of foreign students is about 50%, and worse yet, interest in learning engineering is on the wane among Americans. What do we need to do to rejuvenate interest among American students in the hard sciences, in physics, mathematics, chemistry?

Aigrain: I would like to answer that question. I think a lot of the problem rests with secondary education, not only in this country, but in many countries. And the problem is not that students should learn a lot more physics in secondary school. This is probably impossible anyway. The problem is that the teaching of physics and other hard sciences in secondary education needs to be attractive. I don't know how many people found physics was fun when they were in secondary education.

The only reason I found physics to be fun was because I had a professor who was hated by everybody, and I was charged by my classmates with making all his classroom experiments fail. So I had to learn a lot of physics to find out what tricks I could use. I was successful for about a year. For example, I remember he was showing us how to measure the density of solid bodies, and I did things to make sure he never got a positive result. All his densities came out negative. Well, I learned a lot of physics and found it was fun, but that is not something which can be generalized. I think a great effort has to be made so that learning hard sciences is attractive.

Frosch: I would like to put the premise that I don't think it's particularly bad or difficult for us that so many non-US-born are in the graduate schools. I have got a laboratory in which we have been hiring whoever comes out of the graduate schools. So it is a little bit like a small United Nations. And on the whole, it turns out to be a very good thing, quite aside from the fact that that is a traditional way of producing Americans. It turns out that a diversity of cultural views, as we have, is a very useful thing in a research institution because people look at the world differently. That is a great thing to have.

I think we are likely to be running into trouble globally in producing people interested in science and technology. The roots are not in the secondary school. It goes even farther back, to the primary schools. And it has been decaying calmly in the US for a long time.

I think one of the reasons it was good when I was in high school—secondary teaching in New York was very good—was because we were emerging from the Depression. And a lot of people who would otherwise have been teaching in colleges and universities had held onto jobs teaching in high schools. At least that was true in New York. And the quality of teaching was very high.

Donald L. Ritter

We need to be careful when we talk about military–civilian proportions for government-funded R&D. . . . DOD does more than the other agencies on the interface of science and technology to products and processes

Now it has gone back to the traditional quality of secondary- and primary-school teaching, which has never been terribly high except spottily.

Zucker: I think we agree on the real problem, and the problem is not colleges, not secondary education. It is illiteracy. Thirty percent of this country is illiterate. That's an enormous problem.

Goodwin: And 99% of the Japanese society is literate.

Zucker: I don't want to talk about the Japanese. I want to talk about the people in this country who can't read functionally. That is at the base of all physics education. That is at the base of understanding in this country, and that is at the base of a lot of things that are happening in this country. If we don't address that effectively, we are going to go down the tubes. It has nothing to do with industrial management. It has nothing to do with a lot of things we have been talking about.

Stratton: I think because of the *status quo*, one of the key things we have to make sure of is that we don't shoot ourselves in the foot and make it impossible or difficult for foreign-born graduate students in our universities to work in American industry. That is the first point.

I agree entirely with Bob Frosch that having these people in industry is a clearly great advantage and adds to the richness of overall scientific resources.

The problem is, it's just like market share. At least 50% of all electrical engineering degrees are being awarded to noncitizens. And it is not that there shouldn't be noncitizens in American universities. The problem is the number is just too large. We need to do more to encourage Americans at the high-school level, *et cetera*, to enter universities. The issue is not to keep out foreign born graduate students or, for heaven's sake, to force them to go back to their country of origin. Allow them to accept a job if they want to work here. I think again it is a question of a balance.

Cannon: I've got a slightly different solution to that. The problem is not that we have foreign-born in American graduate schools. The problem is that we have made it very difficult for them to become Americans so you and I can hire them. And that is a matter that can be solved by the Immigration and Naturalization Service with a change in the visa rules. The challenge is not to restrict the number of foreign nationals in the country. The challenge is to turn them into Americans.

Sweet: Can you give us a sense of how big a problem that is? How often are you unable to hire people?

Cannon: It is not that it is impossible to hire a foreign national. It is that it represents a lot of administrative work for some people who are not particularly interested in doing it. And it takes about a year to two years in any specific instance.

Frosch: And sometimes impossible.

Stratton: It changes with the company and even its location. In my company it is much easier for the central research labs to hire noncitizens and then get their visas converted to residency permits than it is for parts of the company that are primarily in defense work. And there the problem gets so big that they don't try very hard to hire foreign citizens.

Cannon: Because it is administratively extremely difficult.

Lubkin: Well, are you saying that American industry is really suffering because we can't hire foreign-born scientists?

Cannon: No. This is a quite different discussion with different dynamics.

Stratton: No, but I'm concerned that there are moves afoot that could change the situation. There was legislation before Congress requiring all foreign-born graduates to go back to the country of origin for at least two years. If such a bill became law, I think it would be harmful to industry and society.

Aigrain: I agree. Foreign students can be a boon to this country. Please don't make it harder for these people to work here if they so desire.

On the other hand, I think that the number of students doing physics or physics–engineering who are American born is anomalously small. It is not that the number of foreign students is too high. It's the number of American students that is too low. You need to attract bright young Americans to fields like physics rather than law. One of the main problems in this country is that you probably have twice as many lawyers as you require. You could improve the efficiency of this country tremendously by just reducing the number of lawyers.

Chaudhari: If the careless teaching of physics in the early school years is responsible for discouraging students from becoming physicists, we can put that rubric to use in decreasing the number of lawyers in this country. What we need to do is teach law in the elementary schools. ■