Physics and the Polity

Are physics and society on divergent courses?

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According to my unabridged dictionary, the polity is "the form, constitution, or method of government of a nation or state, or of any other institution in which men are organized and governed." The term *polity* as I use it here is much broader than government; it is intended to include all the institutions and relationships that govern a society, implement its purposes, and reach workable compromises between the divergent interests and values of its parts.

The period from the beginning of World War II to the early part of the 1960's saw a unique marriage between physics and the polity, the ardor of which is now beginning to cool, although it is not yet clear that it will end in divorce. To some extent, of course, the marriage was between society and science as a whole, not just physics. But I think it fair to say that the role of physics has been central in its development. Physicists were prominent in the formation and staffing of the various institutions that have characterized the relations between government and science, and the applications of physics in the creation of the new technologies that have characterized the development of our increasingly science-based society.

Today physics is experiencing the effects of the new disenchantment with science and technology earlier than most of the other basic sciences are. The reasons, perhaps, are not too far to seek. Physics is the science most closely associated with those aspects of technology that have become suspect in the public mind, especially among some of our brightest young people—military weapons, automation, the invasion of privacy through computers and electronic eavesdropping, radioactive fallout, the sonic boom.

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What are some of the current symptoms of the disenchantment with physics? In the first place, graduate enrollments in physics during the period 1960–65 grew to a lesser extent than did those in any other major academic discipline except classical geology. In a period when total graduate enrollment grew by 70 percent, graduate enrollment in physics grew by only 41 percent, and this conceals the fact that most of the slackening of growth occurred in the later years of this period. By contrast, graduate enrollments in mathematics increased by 72 percent; in engineering, 57 percent; in earth sciences (apart from classical geology), 180 percent; in astronomy, 132 percent; in biology, 65 percent, and in the humanities and social sciences together, nearly 90 percent. High school enrollment in physics has been declining both absolutely and relatively, and the number of college physics majors is also declining. Physics no longer appears to be attracting as large a share of the highest talent, although perhaps one may grant that it attracted more than its proportionate share in the past.

The drive to maintain American leadership in world physics has slackened in recent years, while the challenge to our leadership from both Western Europe and the Soviet Union is increasingly impressive. Since science—and especially physics and astronomy—is inherently international, this challenge is not all on the debit side. Yet I think most of us still feel that our leadership in physics is an important barometer of the dynamism and cultural drive of our society, and not merely a concession to our *esprit de corps* as physicists.

In both astronomy and physics, Europe and the U.S.S.R. show signs of forging ahead of us in available instrumentation and support. The U.S.S.R. now has a 76-Gev accelerator operating, more energetic than anything we shall have for at least 7 years. In intermediate- and low-energy nuclear physics, European machines are the equal of anything available in the United States. The Soviet Union has the largest optical telescope, and the Europeans will have the first large optical telescope in the Southern Hemisphere. Both Britain and Australia are going ahead with radio-astronomy "big dishes," while the United States has deferred for another year the financing of any large instrument for radio astronomy. On balance, the United States is still contributing the major share of important discoveries in astronomy and nuclear physics, but this is more a reflection of the momentum of the recent past than a result of our current planning. This year, in the face of general budget cuts, West Germany is increasing its support of academic science by 25 percent, giving special attention to physics, while the United States is cutting its overall support of the physical sciences by about 10 percent—and by more than that in terms of scientific buying power.

It is the budgets of those federal agencies that provide most of the government support for physics that have been most severely limited. At the same time, European and Soviet support for physics still appears to be forging ahead.

This greater rate of growth, if it continues, may begin to produce the more important discoveries, even though it starts from a smaller base. For it is growth rather than absolute volume of support that often supplies the margin and incentive for exploring and exploiting new ideas. When support is stagnating or shrinking, even at the present high absolute levels, everybody tends to make do with what he has, to explore the ramifications of last year's bright idea rather than embark on a wholly new idea that would require new equipment or instrumentation and might promise less immediately visible results to ensure renewal of the next grant after ever-shortening time intervals. It is unfortunate that this is so, but no scientific community has yet learned how to use its resources very effectively in times of declining budgets.

Disenchantment with Science

I am afraid that the current problems of physics are much deeper than can be accounted for by budget cuts resulting from Vietnam or by national preoccupation with Great Society programs. The relations between science and the polity seem subject to a deepening malaise, involving a reappraisal of values, whose effects may be very far-reaching. It is to some extent the intellectual public, including some putative spokesmen for science, that is leading the retreat. The rapid growth of science in the United States is not, in fact, so impressive when viewed in relation to other past trends. It is true that the national investment in science and technology has grown rapidly as compared with the gross national product, and that the number of scientists and engineers has grown nearly three times as fast as the labor force. But when these growth rates are related to the number of workers in the "professional and technical" classification, rather than to the total work force, a less striking picture emerges. During the decade of the Depression, the number of scientists and engineers grew at nearly twice the rate of growth of the professional and technical work force, and the number continued to grow more rapidly in the two succeeding decades also, though with a decreasing margin. In the 1960's so far, the relative rates of growth have even been slightly reversed—that is, the number of scientists and engineers has grown more slowly than the professional and technical category of the work force as a whole. These facts, which seem to have been little noted, are contrary to much of the current mythology, which maintains that our culture is being swamped by science and scientists.

Be that as it may, what is more disturbing is an apparent revulsion against science by the whole society, and especially among young people. This is articulated in striking form by a writer popular among the young, Paul Goodman (*1*), in the following rather typical terms: "Given the actual disasters that scientific technology has produced, superstitious respect for the wizards has become tinged with a lust to tear them limb from limb" and is expressed as "murderousness towards scientists as persons, more like anti-Semitism."

According to Goodman the new technologies based on modern science "embody knowledge increasingly far removed from ordinary experience, and therefore they are imposed on society and compel people to move and work in ways increasingly strange to them." This is an expression not of a popular but of an intellectual alienation from science, and it seems directed particularly at physics.

Another example comes from Britain in a story from the *Manchester Guardian Weekly* (*2*), under the headline "Young people appalled by use of science," which states that "in spite of lavish financial prospects, large numbers of exceptionally able young people resolutely declined to pursue an orthodox scientific career. The situation over the natural sciences was quite recent and might not be temporary . . . not peculiar to Britain." The same story goes on to cite "Dr. Kahn's calculation of megadeath" as an example of the misuse of science.

A revealing incident is the recent furor caused in Britain by a British Broadcasting Corporation program entitled "The Assault on Life," which purported to describe recent advances in molecular and cellular biology. This aroused a storm of public protest, partly induced by the misleading and slanted way in which the program was edited. But the protest revealed a deep hostility toward science and scientists, which is a new characteristic of our time, perhaps even more advanced in Britain than in America.

The revulsion against science that I have described is related to the excessive identification of science with technology that has been fostered in the public mind by the press, and to a considerable extent by scientists themselves, in an effort to justify expenditures on basic science in terms of their technological fruits. As a result, the bad effects of technology are often blamed on science, and, in addition, bad effects due to population growth, urbanization, and other largely social trends are attributed to technology. Indeed, it has become a kind of conventional wisdom to blame both the material abundance and the social ills of our society on science and technology. Science—and, above all, physics—has become inseparable in the public mind from the successive revolutionary changes in military technology and from nationalist competition in scientific spectaculars as a surrogate for competition in military power and national influence. This identification, which undoubtedly benefited basic science greatly during the period from Sputnik (1957) to about 1963, has increasingly reacted to its disadvantage, especially among the generation that does not remember World War II.

In the 1930's there was great concern among American and British scientists over the nefarious alliance between German science and the all-powerful Nazi state. To some extent this fear of the alliance of science with the state persisted in the American scientific community until the end of the war, and it was expressed in ditties like "Take back your million dollars." But this fear was largely dissolved as a result of the enlightened support of basic research by the Office of Naval Research and the realization that the new scale of physics research in particular made federal support a necessity. In the 1960's we see a revival of this concern with the nefarious alliance, especially among nonscientists. It is an underlying theme of the student protest movement and is lent respectability by the statements of certain prominent public figures.

Furthermore, the reputation of science, and again particularly of physics, has been tarnished by the manner in which the space program has been defended and sold to the American public. The program was, indeed, supported by the public with great enthusiasm at first, but increasingly it is looked upon as a form of vulgar display, a national version of conspicuous consumption in the face of world and domestic poverty, as well as a distortion of sensible scientific priorities. In the early part of the 1960's science seemed to be riding on the popular glamor of the space race. Today, ironically, it appears that the post-Apollo program is trying to ride on the coattails of basic science—not, I hasten to add, entirely illegitimately. At the same time, other forms of expensive science, such as high-energy physics, have tended to share the loss of luster that has overtaken the space program. The disenchantment with expensive science exists not only in the minds of the public and of the political community; it is also widely shared in the scientific community, indeed in some areas of the physics community itself outside of nuclear physics.

A Positive Side

On the other hand, I must also say that there is a positive side to the loss of interest in physics on the part of the younger generation. Some of this effect is due to the very success of physics. The host of new tools that physics has helped provide for other sciences, including the social sciences, in the last 20 years has made these other endeavors intellectually much more attractive to some of the brightest young people. Molecular biology was made possible in part by the application of the tools and experimental techniques of physics and was partly created by converted physicists. The surge of interest in the earth sciences—solid-earth geophysics, atmospheric physics, and physical oceanography—has been partly created by the application of physics techniques and concepts in these fields, which have made it possible to ask and answer types of scientific questions that were completely beyond the scope of observation a few years ago. All these sciences have changed from a purely observational and descriptive mode and style to a mode in which laboratory experiments and testable mathematical models are important techniques. The growing mathematization of the social sciences, especially of economics, has begun to attract some of the most adventurous young minds, who would probably have gone into theoretical physics a generation ago, for it is now possible to get some of the same sorts of intellectual satisfactions in the social sciences that used to be virtually unique to mathematical physics. There are simply many more opportunities in the whole of science for people with a quantitative and abstract turn of mind, and physicists should not too much begrudge the competition thus created. On the other hand, the absolute decline of interest in science makes it clear that the opening up of new opportunities in other sciences cannot be the whole cause of the decline of physics.

Physics and Society on Divergent Paths

I have said that some of the alienation of young people from physics stems from its association with a technology that they find threatening and inhuman. They also see physics increasingly as irrelevant to the dominant human problems facing our society. In this connection, few of them accord a significant place to the problems of military security and national defense. This is, of course, only one aspect of a deeper and more continuing conflict between science and society that has always been with us, and that becomes difficult whenever undirected scientific curiosity makes claims on the general society for financial support. In many ways this conflict is the direct obverse of what I have just been talking about. Whereas one section of the public—especially the intellectual public—sees modern physics in evil alliance with an inhuman technology, another segment, represented by many administrators and politicians and some of their constituents, sees physics as pursuing its own merry and increasingly expensive way with decreasing relation to the needs of technology. This persistent dilemma was beautifully discussed in historical perspective by George H. Daniels in an article in *Science* entitled "The pure science ideal and democratic culture" (*3*). Daniels refers to the "schizophrenia" of basic scientists in their relations with society. According to Daniels:

> As long as a group is dependent upon public support it must seek some means of contact with the values of the enveloping society, and the moment that it does this it departs in some measure from the ideal purity.

A European observer (*4*) of the American scene expressed the same dilemma in a slightly different way:

> . . . in every age scientific research strikes a compromise between the intellectual freedom which gives it its impetus, and the service of ends, which brings it into the mainstream of life.

To an extent modern physics has "lost contact with the values of the enveloping society" and is no longer regarded as in "the mainstream of life." At this point it is futile to debate whether the fault lies with physics or with society. In fact, for the past 5 years physics and society have been on increasingly divergent paths.

In the early postwar period the frontiers of existing physics were in happy coincidence with the values and goals of society. In retrospect it seems that this may have been a unique moment in the evolution of physics. Prior to that moment physics was cheap enough, and the community small enough, so that physics could advance largely in response to its own conceptual necessities, independent of the values of the enveloping society. Then, for a time, as physics became more expensive, physics and society traveled the same road, thanks, alas, largely to the cold war. But in the last 15 years the principal frontiers of physics have advanced well beyond the requirements even of the cold war as they have penetrated more deeply into the very small or the very large. At the same time, the costs of physics have continued to rise exponentially. Simultaneously the threats and rivalries of the cold war and the stark technological confrontation that was its essence have receded into the background, to be replaced by the problems of the Great Society and of limited forms of conflict in the military sphere.

A Logical Plateau

We may also have to admit to ourselves that the total volume of activity in physics has reached a logical plateau, or a point of diminishing returns. Except in elementary-particle physics and in cosmology, a large proportion of our activity is devoted to the elaboration of the consequences of theories and principles that are already well understood in principle—what Weisskopf (*5*) has called extensive science. This sort of elaboration of the applicability of known principles is well justified, in large volume, if the results *also* have some bearing on the solution of practical problems or perhaps of problems in other sciences more obviously related to human needs. Intensive science—elementary-particle physics, molecular biology, cosmology, pure mathematics—can be justifiably pursued for its own intrinsic intellectual values, but the intellectual structure of science by itself may be an insufficient guide for the pursuit of "extensive science."

How far, for example, is it justifiable to go in the elaboration of the energy-level structures of intermediate-mass nuclei or the calculation and verification of more and more solid-state band structures? Is there a point at which we should say the problem has been solved in principle, and therefore little further work is desirable unless a specific application for further elaboration of detail arises from technology? These may be questions that physicists will increasingly have to ask themselves in the next few years. If we look objectively at the recent history of physics, we may have to admit that we have been exploring a number of areas that received their initial impetus from technology but that have gradually diverged from the technological stream of which they were originally a part. Nuclear-structure physics and nuclear engineering may now be in this state of diverging interest. Some areas of solid-state physics may be approaching a similar situation.

The questions I have raised here cannot be answered dogmatically, and I hesitate to single out examples because I am not wise enough—nor is any single individual—to pronounce on the work of a whole field of science. The development of a field of physics is like the growth of the branch of a tree. As the branch thrusts out, more and more foliage luxuriates around it, but at the very moment that the foliage seems most luxuriant, the branch may be dying at the trunk that originally thrust it forth. Physicists must be increasingly alert to such situations.

It may well be that, if we are to have the resources to pursue the most important areas of intensive physics, we shall have to be more selective in the pursuit of all the many possible avenues of extensive physics. What I am saying, in a sense, is that we should be giving the highest priority *either* to the most fundamental in a largely philosophical sense or to the most significant in a largely technological sense (including the technology of other sciences), and that that big gray area in between may be less important.

Physics since World War II

As we look back over the history of physics since the war, we see that it has been propelled forward by a series of technological thrusts. First came the bomb, which gave a tremendous boost to nuclear physics in all its aspects. Next came the transistor, which created the basis for both governmental and industrial large-scale support of solid-state physics. The momentum of this effort was periodically renewed as various descendants of the transistor were born: tunnel diodes, parametric amplifiers, solid-state rectifiers, solar cells, integrated circuits, the Gunn oscillator, the laser diode, the semiconductor particle detector, doped semiconductor infrared detectors, solid-state plasma effects. Another major impetus both in support and in scientific opportunity was generated by the realization of the first practical laser. While the solid-state laser gave a new lease on life to the study of insulators and of the optical properties of solids, the gas laser resuscitated the moribund subject of atomic spectroscopy and gas-discharge physics. The superconducting magnet came along to attract support into superconductivity and low-temperature physics in general.

It seems to me noteworthy, in this history, that, contrary to some of the mythology concerning the relationship between basic and applied science, the big stimulus to research in an area followed rather than preceded an invention. The basic science was motivated by the necessity to generate ancillary technology to feed the development and exploitation of an initial invention, rather than vice versa. Of course, this search for ancillary technology often generated new inventions in unexpected directions, and the fact that it was conducted in a relatively free and inner-directed environment helped increase the number of unforeseen by-products. Nevertheless, we must note that in almost every case a technological invention preceded much of the explosive growth in many subfields of physics.

Needed Efforts

What, then, do we do, as physicists or as a physics community?

First, I think more of us need to be more active in explaining ourselves to the public, and especially the scientifically educated public. In particular, we should make an effort to explain to our colleagues in other fields of science and in engineering the significance of what we are doing. For this scientifically literate public is increasingly large and influential and affects the views and attitudes, toward our science, of a much larger public, with which it communicates more easily and directly than physicists do.

Second, I think that as a profession we need to acquire a more sophisticated and explicit understanding of the processes by which the concepts and techniques of physics find their way into application. The relations between physics and applications are much less direct than those between, say, chemistry or biology and applications. Often physics reaches application only through its use as a tool in other fundamental sciences that are subsequently applied.

Furthermore, this more sophisticated understanding of the social consequences of physics, if you will, must be communicated to our graduate students. We should recognize more frankly that a majority of physics Ph.D.'s do not go into fundamental physics research, and that, while this fact may not demand different content in their education, it may demand somewhat altered attitudes and expectations. We should take more seriously our own contention that physics is education rather than training, and that the special talent of a well-educated physics Ph.D. is his ability to transfer his skills and way of looking at things to a wide range of scientific problems. Physics, more than any other branch of basic science, has maintained the tradition of the talented (and sometimes irritating) amateur who can turn his hand to anything in a pinch. We should do more to maintain that tradition.

Perhaps one way of doing this would be to try more consciously to increase the general scientific literacy of physicists; for example, we might give each graduate one course in which he is exposed to as wide as possible a variety of problems to which the methods and concepts of physics can be potentially applied. Or perhaps we might substitute some general sort of test of scientific literacy at, say, the *Scientific American* level, for the now somewhat controversial, if not obsolete, language examination.

Third, more physicists should worry about the problem of making nonscientists scientifically literate. How can we teach "science appreciation" as well as literature or art appreciation? Perhaps we shall have to approach the teaching of physics to laymen to a larger extent through the impact of physics on technology and on society, rather than through the beauty and intellectual austerity of its basic ideas, which is what appeals most to us as physicists. I. I. Rabi (*6*) has referred to this as teaching humanistic science. At the very least, we must recognize that there are more routes to the appreciation of physics than those we have, for the most part, pursued.

Fourth, physicists as a community may have to become more explicitly concerned about priorities in their own field. I know *priorities* is a horrid word, and I have been the loudest in my protestations that scientists cannot be asked to set priorities within a broad field. Nevertheless, I think we may be forced to do so to survive. Perhaps also we need to be more active in searching out new basic research areas emanating from technology as a way both of enriching the field of physics and of convincing our patrons and our public of what we can do. I am *not* suggesting that we do more applied research but suggesting, rather, that we try to distill a wider range of new basic questions out of the applied research of others.

Finally, we must recognize that great discoveries in physics can still be made with small means. In times of generous support, there is always the danger that our thinking will be mastered by our equipment, rather than vice versa. But this danger becomes even greater in times of shrinking budgets, when we are tempted to squeeze one more achievement or elaboration out of the equipment or the computer program we have already developed at great expense. The very time when it may be most important to scrap some of our accumulated research technology in favor of thought may be the time when the shortage of funds makes the prospect of getting new equipment dimmest. Yet physics is probably less likely to die of starvation than of slow strangulation.

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NEWS AND COMMENT

Defense Research: Senate Critics Urge Redeployment to Urban Needs

The assignment of a high priority to military-related research has been a standard fixture of American political life since the end of World War II. In recent years, however, as Soviet-American tensions have somewhat eased and domestic problems have become increasingly painful, more and more questions have been raised about the purposes to which the nation is putting its scientific and technological resources, and about the desirability of a large military role in the support of academic research. Last week, in the U.S. Senate and in the presidential campaign, these questions were raised with new vigor. The effect in the Senate was a slight cutback in funds for military research, with a good deal of the debate focused on Defense support of academic science. In the presidential campaign the effect was a strong, though imprecisely defined, indication that, if Robert F. Kennedy makes it to the White House, there is likely to be a significant redeployment of technological resources away from military and space activities and toward the problems of the cities.

In the Senate, the issue was embodied in a military procurement bill that the Armed Services Committee brought to the floor after snipping out 3 percent from the category of research, development, test, and evaluation (RDT & E). This left the total bill at $22 billion, and reduced the RDT & E component from the $8.015 billion requested by the administration to the $7.875 billion approved by the committee. Clearly, even this reduced sum would leave military research comfortably above the poverty line. But when the bill came to the floor, it was assailed from various directions, with, curiously enough, several of the opponents expressing particular distaste for military support of basic research. The rationale for singling out this relatively small proportion of the total—some $450 million in all—was never presented in any systematic fashion. But it may be inferred that, since a lot of people are disturbed by the military's relatively large presence in American life and since basic research is the least comprehensible and, in the short run, least utilitarian of military-supported activities, it stands out as a target for budget chopping. Thus, Senator Philip Hart (D-Mich.), who, on the floor, offered an amendment to reduce the research budget still another 3 percent below the committee's figure, stated that he was reluctant to cut back on Defense spending while Americans were fighting in Vietnam, "but it seemed to me that research was the area least likely to affect a man under fire." He was joined by Senator George McGovern (D-S.D.), who assailed the Defense Department's argument that it is essential to avoid fluctuations in military support of academic science. "Presumably," McGovern said, "the alternative is for these institutions to lose some of their military research orientation. In the light of the premium we are placing on research today, I see little reason to fear that our scientific capabilities will decline if these defense projects are reduced or channeled through other sources. I have yet to be persuaded that the Nation's research manpower and facilities could not be quickly mobilized in case of an emergency requiring them for military purposes." Quoting a remark that Defense Secretary McNamara made in the course of the Armed Services Committee hearings, to the effect that he had doubts about the return on the $1 billion a year that Defense spends in exploratory research, McGovern stated: "Excessive military expenditures that strain our economy and bleed off resources needed for other purposes actually weaken rather than strengthen our Nation's power and influence in the world."

Senator Margaret Chase Smith (R-Me.) defended the budget request, but not too vigorously. In fact, she observed, "I must say that the results of the research and development efforts funded by the Defense Department over the last few years have seemed disproportionately small in relation to the cost. Yet, I continue to believe that our military preparedness depends so heavily on the investment in research and development that I am reluctant to risk the consequences of inadequate funding."

Senator J. William Fulbright (D-Ark.) joined the debate and took up the subject of the Defense Department's increasing interest in social and behavioral science research. Citing such Defense Department support projects as "Politics and Economic Growth in India," Fulbright demanded to know why the military is involved in such subjects, and answered his own question by declaring, "The Defense Department has blanketed the field in any kind of research, primarily because they have the money." Citing DOD's refusal to release a study to him that the Institute for Defense Analyses made of the Gulf of Tonkin incident,