Is physics too ingrown?

If physicists don't break away from their presently self-imposed restraints, someone else will take over as scientific generalist.

Philip M. Morse

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The state of physics—or of physicists—has deteriorated in the past several years. Support for physics has not increased, as it had been doing in the previous decades. Indeed, in some important areas it has decreased. Such a sudden change in rate of growth is ominous in itself to heads of projects and to physicists in more or less permanent positions. To our younger colleagues, who have not yet found a permanent job or who have not yet completed their graduate work, it has been catastrophic. How can we improve the situation?

The present employment crunch is, of course, greatly enhanced by the positive feedback between the demand for physicists and the output of the educational "pipeline" producing physicists. Reduction in demand eventually reduces supply and, if an important part of the demand is for teachers to train students in the pipeline—as it has been for the past ten years—then the demand is still further diminished. In addition, of course, the time lag of more than five years between the beginning and end of the pipeline is producing an overflow into a "holding pattern" consisting of qualified physicists with continually decreasing chances of finding permanent employment in positions they had expected to find open for them.

The statistics—briefly

Quite a number of articles have appeared, here and elsewhere, giving details of our present dilemma. I cannot give more than a few order-of-magnitude figures as illustration. For example, our present output of PhD physicists is roughly 1400 a year, having dropped from a high of 1600 a year in 1970–1971. It is still dropping, and may drop below 1200 a year in a few years. About a quarter of these are from outside the US, but many would prefer to stay in this country if they could find a job. It looks as though, on the average, over the next four or five years about 1000 PhD's per year will be looking for some reasonably secure position, in the US, that will utilize at least a portion of the knowledge that these people have spent so much of their time and of their energy to learn.

Where will they go? What chance do they have of achieving the tenure appointment in the prestigious physics department that their mentors and their peers have told them is the ultimate reward for all good physicists?

There are about 3000 physics faculty with tenure in PhD-granting institutions in this country. Very few of these departments are growing; some are shrinking in size. Examination of the age distribution in these departments indicates that less than 250 additions per year will suffice to keep the group at its present size. Even if we add the four-year colleges, it is unlikely that there will be as many as 400 new, permanent, academic positions a year open in physics in the near future. These of course are but estimates. Nevertheless, all the data I have seen indicate to me that the new PhD has less than one chance in five of eventually landing a tenure position in a PhD-granting physics department and less than one chance in two of becoming a permanent member of an academic physics department. We can smooth out transient effects by adding instructors and post-doctoral fellows to the holding pattern, but these measures cannot change the long-run facts of life.

What happens to the other 500 or more per year right now? Some of them take jobs in industrial or governmental laboratories or with nonprofit research organizations; some find positions as high-school teachers or in other jobs where they use few of the skills they worked to get. And the others find temporary jobs as post-docs, interns or instructors, increasing the number in the holding pattern. Clearly there is no balance between supply and demand just now, and the longer the unbalance continues, the worse fix we will be in.

What do we do? Do we resign our position in the scientific pecking order and cut back on the number of PhD's we turn out each year? Because of the positive feedback I mentioned and because there is a holding pattern to absorb, the reduction in output would have to be drastic. It might take five years simply to absorb the present holding pattern. I feel sure such a cutback would be the wrong thing to do. Of course it sounds like special pleading for an ex-president of The

American Physical Society to argue against a reduction in the output of trained physicists. But perhaps I can put on the hat of an ex-president of two other scientific societies (the Acoustical Society of America and the Operations Research Society of America) and say that, in my opinion as a nonphysicist, if we cut back on the production of physicists, then someone else would have to produce, under a different name, an equivalent number of graduates, with equivalent training.

Don't get me wrong. I am not advocating that we continue as we have for the past ten years, turning out physicists mainly to train more physicists, to continue doing the research we have been doing during the past ten years. If we are that ingrown we should be superseded. Physicists can do more than just perpetuate themselves, because the well trained physicist is a scientific generalist. I believe the US will need more than 1000 new physicists a year if we return to doing what we have done so well in the past hundred years: leading the way in breaking open new fields of science and, occasionally, in showing how the new fields can be applied.

Backlash against physics

Science is under a cloud at present, physics more than many others. The reaction is muted just now, but the longer US militaristic actions continue, throughout the world, the stronger will be the eventual revulsion against anything connected with the military. Let me be clear about this. I am completely convinced of the importance and the purity of research in nuclear and particle physics, for example. Nevertheless, research in these fields cannot help getting caught in the revulsion, when the average person relates this research with the atomic bomb and with the well advertised perils of fission power. Anyone who lived through the similar revulsion between the two World Wars will know what I mean. As Robert Oppenheimer has said, we physicists have known sin and, as the Bible has said, the consequences shall be visited unto the third and fourth generation.

This part of our difficulty is not entirely of our own making, of course, although we have not always taken care to dissociate ourselves from the militaristic attitude. For example, I have heard colleagues argue for more sup-

Jobs in applied physics

For the past year I have been anticipating an expansion of opportunities for physicists in applied work and development. Some progress is being made in this direction and is expected to continue as our economy continues to strengthen. This bright spot does not mean that unemployment in physics has vanished and that all physicists have good jobs, but it does point up an important direction for further employment gains in our profession. Here are some brief comments on a few employment indicators.

News from the traditional employers of physicists is in general not good. Universities, anticipating a decrease in enrollments in the 1980's, are not likely to increase their staffs to any great extent during the 1970's. In 1972 we saw, for the first time, a decrease of about one percent in the number of professorial-level faculty, including associate and assistant professors. A small expansion of teaching opportunities for PhD physicists in junior and community colleges, enabling such institutions to upgrade their faculties, is expected to continue for a few more years.

Manpower limitations and freezes on governmental positions have in the main limited the growth of jobs for physicists in government. The Presidential Internships Program, which provided about 500 one-year appointments for scientists and engineers in federally funded laboratories, was the most significant governmental contribution to the technical unemployment problem, but is not likely to continue. The development of jobs for scientists in housing, urban affairs, transportation and other socioeconomic areas has been disappointing and not very fruitful, but potentialities are still being pursued.

There was a substantial increase in the number of PhD physicists employed by industry and government during the 1960's. This increase was mostly in applied and development work. Basic research now occupies a smaller portion of the total work of physicists in government, and the trend toward a smaller apportionment of resources to basic research is even more apparent for physicists in industry.

Rather than bemoan the proportional reduction in basic research, we should note the positive aspects and possibilities concerning employment of physicists in applied areas. Although this expansion flattened out or even reversed in the "depression of 1971," it is now on the upturn according to these indications:

The American Institute of Physics Placement Service expanded its operations last year by installing equipment to store information on candidates, including data on their specialities and technical experience. Employers give us their specialization, educational and experience criteria. We then search our data file for the appropriate parameters and then supply the employer with resumes of candidates meeting his requirements. The employer then negotiates directly with candidates of interest. We currently average almost one search per working day, which is an order of magnitude greater than a year ago. Part of this increase is due to the new service, but the increased number of industrial inquires appears to be a real sign of a pickup. Industrial employers are seeking talents and experience that are directly related to their work in applied physics and development.

The Deutsch, Shea and Evans Engineering/Scientists Demand Index, based on the amount of space in newspapers and technical periodicals devoted to employers' advertisements, is a good gauge of industrial opportunities. This index reached a bottom plateau in 1971 and rose steadily in 1972. The Demand Index correlates well with the data on engineering employment from the US Bureau of Labor Statistics: Engineering unemployment dropped steadily last year. Thus our own placement activity, the Engineer/Scientist Demand Index and Labor Department statistics all point toward an employment recovery in applied technology.

Concern from several sources in engineering, including the Engineering Manpower Commission, was noted in *The Wall Street Journal*, 13 November 1972: "There is almost universal agreement that engineer *shortages* will worsen and become chronic in the years ahead . . . Engineers are becoming scarce in many design areas." This is another indicator that opportunities will continue to develop for physicists to apply their broad talents toward the solution of applied problems. Physicists in increasing numbers should find the same keen intellectual and financial rewards in work on today's technological problems as many of their predecessors have in the past.

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port for their project by saying otherwise Russia would get ahead of us.

However, another part of the difficulty *is* entirely our own doing. An indication of the difficulty is that, in the 1930's, more than half our PhD's went into positions other than academic physics—and liked it—whereas now less than a quarter of them are willing to do so. Thus, in the 1930's, the chances that a fresh PhD would find a permanent job in academic physics were no better than those that exist at present. Is the difference between then and now simply one of attitude? Too many of us talk as though the currently fashionable fields of physics constitute the only true physics and that anyone who stoops to work in an unfashionable field has sold his birthright.

I shall quote, as illustration, from a letter I received last year from a friend. He received a PhD for a thesis in nuclear physics and took a job with a geophysics research company. He enjoyed his work, found it used a great deal of his graduate education, and he ended up directing the work of the company. He wrote, in part: "I still remember with a great deal of pain the greeting I received from the head of my old physics department, when I visited it a year or so after I had taken the industrial job. I was greeted by, 'Well, here is the young man who has sold his soul to the devil.' I am sure that the professor did not mean the statement to sound as ominous as it did to a 26-year-old youngster, but I cite this only as an example of some of the subtle ways we have used to condition the attitudes of PhD's".

Nonacademic but not nonphysics

This comment was part of an answer to a questionnaire I sent out last year. It was sent to those who had received doctorates in physics from Harvard, Cal Tech, MIT and Columbia between 1936 and 1960, who were known to be *not* faculty members of some physics department in 1969–1970. The list comprised roughly a third of the total doctoral output in physics for the 25 years 1936–1960, from those schools. The choice of those to be sent questionnaires was conservative; we can be sure that others, not included, are not now in academic physics positions. Of the 400-odd questionnaires sent out, nearly half were returned.

The persons to whom this questionnaire was sent would be considered, by many in the physics fraternity, as having left physics. This is hotly denied by most of the answerers, so I will call them "nonacademic physicists," although this also is not a completely accurate descriptor. For about a quarter of those answering were in nonphysics academic positions, two fifths of these being now in administration, as college or university presidents or provosts or deans. The other three fifths are in nonphysics departments such as engineering, astronomy, biology or operations research—some of them being heads of departments.

The graduate work of those now in nonphysics academic positions was quite varied. About a third of their thesis subjects were in nuclear physics; subjects for the other two thirds included quantum theory, plasmas, solid state, acoustics and biophysics. After getting their doctor's degrees they stayed in physics departments, on the average, only three years. But for about ten years their work was primarily physics, and even now about a quarter of their work, including that of the administrators, depends on their knowledge of physics. Among the aspects of their graduate work that they have found most useful were their courses in classical theoretical physics, their thesis research—though few have continued in that speciality—and the inspiration they absorbed from individual faculty members. All but six percent of them felt that their graduate training in physics had been a good preparation for their present jobs.

Two thirds of those answering my questionnaire now have jobs in industry or government. One third of this group are now in policy-making positions; the other two thirds are still directly involved in research or development. Included in the policy makers who responded are a president and two vice presidents at Bell Labs, seven presidents of other technological firms, a Director of the US National Bureau of Standards, two division directors in the National Science Foundation, one in the National Aeronautics and Space Administration and four high civilian officials in the Department of Defense.

The distribution of thesis subjects for those now in industry and government was roughly similar to that for the group now in nonphysics academe: about a third nuclear physics, with solid state, quantum theory and classical physics, in decreasing order, making up the rest. Many comments indicate that the value of the thesis has been the experience gained in carrying out research, rather than in the particular subject matter of the research. Their thesis work, whether in nuclear or solid-state or classical physics, has been of positive help to them in their later careers.

The responses of the industrial-governmental physicists about their length of stay in academic physics and the usefulness of their graduate work were remarkably similar to those in nonphysics academic positions. The remainder of those answering the questionnaire, about eight percent, are either self-employed or retired.

The whole survey showed clearly the increasingly ingrown tendency of academic physics. As I have already noted, in the 1930's more than half of our doctoral alumni left academic physics, whereas now less than a quarter of them do so. This diminution may reflect the reduced utility, outside academic physics, of the more recent physics graduates, or it may reflect an increase in snobbishness on the part of academic physics, or both. In fact, the first reason could be a result of the second. In any case it is a question calling for considerable soul-searching both by physics faculties and by those in the present holding pattern. If the trend is not reversible then we had better get ready to reduce drastically the output of physics PhD's.

Moving out, not growing in

What do we do to reverse the trend? As I see it, no single action will suffice. The effort must be both outward, to persuade others, and also inward, a change of heart on our part.

First, what should APS do? What can it do? The purpose of the society, as stated in its constitution, is the advancement and diffusion of the *knowledge* of physics. Surely this is an important task, one worthy of consuming the major part of the finances and the energies of the society—one that we cannot downgrade and still call ourselves *The* American Physical Society. Surely any other purpose, such as the advancement of the status of physics or the welfare of physicists, must be kept secondary to our proclaimed responsibility. Of course if we don't pay some attention to these other purposes, there might not be further knowledge of

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physics to advance and diffuse; so we cannot be too conservative in our attitude.

In addition, APS operates under a number of legal constraints. It must eschew direct political action, for instance, and it must not benefit its membership financially. If any of these restraints are overstepped, the society will not be able to carry out its primary purpose as effectively as it now can.

These kinds of constraints are not onerous; in fact they are reasonable. There is no advantage in minimizing the number of societies. Quite the contrary: Rather than have one society trying to pursue two disparate tasks, it is better to have two separate societies, each with a clear and consistent purpose. There may well be need for a society—or a union—specifically to advance the welfare of physicists. If so, it should not be APS, which already has a purpose.

Nevertheless, there are many things APS can do, and perhaps should do, to alleviate the plight of physicists and to repair the status of physics, without hindering—perhaps even furthering—its primary duties. A few of these have already been put into effect. There is a group insurance plan; the society supports several activities designed to help members find jobs; some members have conceived, organized and are now conducting, as an integral part of the society, the Forum on Science and Society with its newsletter and general-interest sessions. All of these activities have been judged to be desirable, to have general membership approval and not to interfere with the basic purpose.

There assuredly are other activities the society can initiate, but we have to realize that many of them will cost money, which may mean a corresponding increase in membership dues. For several years now APS Council has been debating the appropriateness, legal implications, cost and feasibility of a number of possible actions. Several committees have been set up to look into details. Two years ago a Committee on Economic Affairs was appointed and last year a Committee on the Future of the Society was formed, with a wider purview. Both of them have turned in reports that have been or will be abstracted in the *Bulletin* of the Society. In addition they are in the process of making specific recommendations to the APS Council.

The task of the Committee on the Future of the APS was to examine the various suggestions for action that have been put forward, to explore the implications of these suggestions in regard to cost and to changes in the structure of the society, and to come up with suggestions for action or for further investigation. The report of this committee has just been presented to the Council and it will be reported soon in one of the issues of the *Bulletin* of The American Physical Society.

It turns out that more than half of the suggestions for additional action on the part of the society involve additional spending, some of it of considerable magnitude. At present APS spends nearly all its income in publishing its journals and holding its meetings—the two basic ways it advances and diffuses the knowledge of physics. What little is left over only just pays for admittedly small efforts in regard to placement and compilation of manpower data. Any appreciable increase in cost would have to be paid for by an increase in dues.

The first step involved in the raising of dues has just been accomplished. The society has just voted overwhelmingly to increase the maximum limit on annual dues for members, from the $20 previously set in the bylaws, to $30, the same as the limit for fellows. Since fellowship is to be simply an honorary label—members as well as fellows can now be elected officers of the society—the Council intends to equalize member and fellow dues, from now on.

The next step, of course, will be for the Council to raise the dues to any appropriate amount up to this upper limit of $30 per year. Before doing this I hope the Council, with its committees, could estimate the cost of the various suggested actions so that when the appropriate time comes, a series of straw ballots could be sent out to the membership. Each ballot could outline a possible additional activity of the Society, plus an estimate of the increase in membership dues it would entail. In this way we could introduce a bit of economic realism into our planning and, at the same time, could be sure of the degree of membership backing for each proposed new service. The APS treasurer is now working out a procedure whereby this sort of membership straw ballot on particular services can be instituted in connection with the bills for 1974 dues.

Changes in attitude needed

Not all the suggested actions, of course, will cost money; some will require personal action on the part of some or all APS members. For example, any suggested changes in graduate curricula would require action by the academic members of the society to implement. I, for one, do not believe the curriculum needs major revision in regard to required subjects; I think the major needed change is in attitude. There is a very large difference between teaching a subject as a self-contained speciality and teaching it as an example of a way of studying nature. None of us learned in graduate school all the physics we now know. What we learned there or should have learned, was *how* to learn, how to apply the experimental and theoretical techniques, developed for one brand of physics, to learn about another.

I do not believe the subject matter of our PhD thesis fixes the speciality we must follow for life. If that were the case, then we were trained as engineers, not as physicists. As I have already mentioned, more than half of those who responded to my questionnaire were working in fields differing from the field of their thesis, yet a large number of them believe that their thesis research was one of the most valuable parts of their graduate education. An important question, in any study of graduate curricula, will be the relative importance of research work, pre-thesis and thesis, versus course studies.

The problem of public education is a vast one. Some of this education, to be done well, must be done by experts, and the cost may be too great for APS on its own to underwrite. But I am sure we can do more, individually, than we have been doing. Each one of us occasionally has the opportunity to get across to a lay audience that a physicist is not always concerned with dangerous or unproductive mysteries. More of us should be explaining the potentialities—and the limitations—of physics: that it can bring not just more gadgets but also more understanding, and thus a greater ability to plan for a more equitable use of this world's riches.

It would be useful, I believe, for us to demonstrate, to ourselves and others,

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our versatility, our ability to reach this deeper understanding in a variety of fields of pure and applied science. For those of you not yet in permanent positions, I suggest greater interest in opportunities outside your present speciality. I assure you there are many fields of science with opportunities as great and problems as exciting as the one you now work in, and that your present education will enable you to contribute to these fields, if you are willing to take an interest. There are a number of plans, some of them under consideration by APS and the American Institute of Physics, some I hope in process of implementation by governmental agencies, for providing internships and fellowships, to introduce young physicists to industrial and governmental laboratories and to Congressional staff work. Much work still needs to be done, to persuade industry and government of the value of such transitional support, but this work will be useless unless many of you are willing to take the plunge.

All of us must join in this rebroadening of interest. Those of us who teach should keep it in mind as we form our student's attitudes. And, of course, the most convincing demonstration would be for more of us to start some research in a field different from our present specialities. I don't mean we should necessarily look for immediate practical applications to work on. Some of us may find them rewarding, but many of us will be excited only if we are digging out new understanding. This too is important—as Michael Faraday once said of electromagnetic theory when it was a babe: "Someday it will pay taxes." The important thing is to pick a "relevant" field that may respond to the methods of physics and to the cooperative talents of physicists. The fields may not be fashionable now, but fashions change.

The scientific generalist

Invading new fields is a regular habit of ours. In the 1920's and 1930's we investigated atoms and molecules, and gained deeper understanding of their nature than the chemist had achieved. Twenty-five years ago our work in solid-state physics culminated in the transistor, which has revolutionized communications and data processing. Since then we have invaded the realm of the metallurgist, in addition to pursuing our quest for the nature of particulate matter. Our most recent incursion in force has been in astrophysics. An early encroachment occurred just before World War II, with Hans Bethe's carbon cycle and the early work on stellar interiors, the application of quantum and statistical mechanics to the calculation of opacities and equations of state at extreme temperatures and pressures, for example. Recently, with our increased knowledge of plasma physics, with techniques borrowed from many other areas of physics and with vastly more observational data to work on, astrophysics, or cosmic physics, has turned into one of the more fashionable areas of physics, indeed, it has become a division of APS.

But other areas, once active physics but now relegated to specialists, need fresh examination, with new tools and insights. Acoustics, for example, is beginning to have relevance and could bear further study. In the 1930's the new instrumentalities of electronics and the theoretical techniques developed for wave mechanics served to rejuvenate acoustics. Now may be the time for a fresh injection. The whole subject of the scattering and radiation of sound from turbulence could stand much more study. There are opportunities here for basic experimental and theoretical research, as well as for practical applications in connection with jet noise.

Another wide-open field is the physics of the Earth. John von Neumann spent some time studying the immensely complex problem of the Earth's atmosphere and came to the conclusion that the data-gathering techniques and the computer capacities available at that time were not adequate for a fundamental attack. Perhaps it's worth a reappraisal now. There are, of course, many competent meteorologists working on the problem, but an injection of physicists with a fresh point of view just might crack it open.

A less populated field, but one crying for attention, is the study of ground water. Some water came into the ground from last week's rain; some has been there since the last Ice Age. Before we can fully understand the effects of our remodelling of the Earth's surface, we must know what it does to the water under the surface. Here everything is needed: adequate measurement techniques, masses of new data and new theories of percolation, flow and transpiration.

The study of the Earth's interior has already had a rejuvenation, with the new discoveries in plate tectonics and the new measurements of the ocean bottom. But many more top-notch workers are needed to extend and solidify the breakthroughs. The study of the source and nature of the motion of the core, for example, and its effects on Earth's magnetism and on continental drift, invite the concentrated efforts of a number of high-quality minds, well versed in all aspects of modern physics.

One could go farther afield, to cases where the contribution is not the carrying over of new facts from physics, but just in applying the methodology of physics. Operations research or systems analysis is a case in point. An operation is a pattern of activity of men and machines carrying out a repetitive task, subject to rules and with desired goals. Transport is an operation; so is the collection, storing, and distribution of whole blood. Operations can be measured and experimented with. Mathematical theories for them can be devised, tested and then used to predict their behavior in the face of changes in rules of operation or in external conditions. These predictions can then be used by the manager of the operation to plan so the operation can more effectively comply with the ends decided on.

Admittedly this sort of research has little relation to the great body of physics. Nevertheless its approach and its methods are closely allied to those of physics and a number of its theories have interesting parallels with physical theories. The equations describing the flow of automobile traffic, for example, have analogues in the equations describing the flow of a compressible fluid, and the equations describing the arrival in time of aircraft at an airport are closely related to those used by Eugene Wigner to describe the distribution of energy levels in complex nuclei.

It has turned out that many of the leaders in operations research were trained as physicists, and many graduate students in physics take naturally to the work. Over the past fifteen years at MIT, an average of one physics PhD a year has gone directly into a career in operations research. Even now, more could be placed. The possibilities for relevant work are large and are growing, as more Federal, state, and municipal agencies begin to understand the usefulness of the work. Research in public health and in public safety has already led to practical applications, improvements in procedures that have been adopted and have demonstrated their superiority. Moreover, the operations research workers participated in setting the criteria for improvement.

The potentialities in the study of various ecological systems are tempting. For example an authoritative study of the energy needs, resources and cost-benefit equilibria for the US would need people with the theoretical scope and technical background of good physicists, together with experts in other fields. There are many similar problems facing this country today.

This list of research opportunities for the physicist are but a small sample of those available; they were chosen in part by my own personal interests. Many others could be mentioned, but perhaps I have already made my point. We need to show we can act as physicists, as scientific generalists, willing to tackle new problems and interested in any branch of science where our quantitative methods are applicable. Those of you in the holding pattern: Don't hold back because you fear your training was too specialized. Are you physicist or engineer? You'll be pleasantly surprised to find how much of your education turns out to be relevant.

How do we get started? We'll have to take the initiative—we can't expect much support until we show what we can do. But this has always been the case, and the preliminaries shouldn't take long. We'll have to learn what we can about the new field of our choice, and then try our hand at doing some minor research, in our spare time. Those of us in academic positions might teach an introductory course in the new field, or help a colleague teach the course—or at least mention its possibilities to our graduate students. Unless more of us do something of this sort, to break out of our presently self-imposed restraints, we had better resign ourselves to a drastic reduction in numbers, status, and scope. Someone else will take over as scientific generalist. To reverse this trend will require a little effort on the part of all of us and a lot of effort on the part of some. It can be done if we will just look up from what we are doing, look around us and see where we can help in returning physics to its pristine universality.

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This article is adapted from the Address of the Retiring President of APS, given 30 January in New York. □