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ABSTRACT

Those holding the Ph.D. in physics, just as those holding advanced degrees in many other fields, are graduating out of the academic world and finding themselves jobless when they do so. The decrease in federal funding has been directly responsible for the standstill in net employment in government and national laboratories and in nonfaculty research positions. The recession-inflation must be held accountable for the reduction in growth of physics faculties well below the needs to meet increased enrollment. The 2 factors together are probably responsible for the reduction in industrial employment. Some short-range actions may help to alleviate these unemployment problems: (1) new opportunities must be found for physicists; (2) programs to increase the involvement of the physics community in industry must be stimulated; (3) the physics community should be informed of the present situation as quickly as possible; (4) a placement service should be created to advertise job openings; (5) physics departments should tighten their standards for the Ph.D.; (6) physics departments must reexamine their training programs, especially for careers for which few employment opportunities exist; and (7) those financial inducements should be reduced that channel students into fields of little employment potential. (HS)

The American Physical Society

Special Report of the Economic Concerns Committee

April 1971

The Manpower Crisis in Physics

Economic Concerns Committee

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"On many occasions in the future there will be an imbalance between the number of men trained for a given line of work and the number of jobs available. Attempts will be made to minimize this through accurate forecasts of manpower needs, but experience with such forecasts has been discouraging. The alternative—and the wiser course—is to educate men and women who are capable of applying excellent fundamental training to a wide range of specific jobs."

"Nothing contributes more damagingly to the unemployment of educated talent than rigid specialization and rigid attitudes supporting this specialization. The future is necessarily hazardous for the individual who trains himself to do a specific job, receives an advanced degree for that line of work, and believes that society owes him a living doing it." . . .

"Talented young people should not be misled in these matters. They must not be led to assume that there is always a market for talent. But while the individual must be realistic, all who care about excellence in a society must be vigilant concerning the waste of talent."

John W. Gardner
in *Excellence*
(Harper and Row, New York, 1960)
pp. 42—45.

The Manpower Crisis in Physics

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Introduction

The Economic Concerns Committee, appointed in June 1970, was asked to examine what the American Physical Society can and should be doing to assist its members in the present situation and what implications this all has for long range policy on our profession.

This article describing the current manpower crisis is the first report on that commission. In the near future we will report on a study of the migration of physics faculties and on the complete results of surveys which provide some of the data for the present paper. We will also bring to the attention of the physics community the various actions now under study by the ECC.

The principal focus of this paper is on the present situation. A name-by-name census of physicists who left or who entered the various segments of the community between October 1969 and October 1970 is about 50% complete. That is, we have essentially 100% information from about 50% of the institutions polled. These results, together with the results from other national studies, are the foundation of this report. Most of the numbers still have uncertainties of 25%. The Committee doubts that harder information will lead either to significantly greater insights or firmer bases for action.

This article necessarily concentrates on the 15% of our profession who are in the flux of employment, for that is the proper measure of the employment problem in these abnormal times. Such a special view, however, gives a highly distorted picture of the vitality of our profession which, as we will point out, though probably not often enough, has been and will continue to be strong.

This material must also be viewed within the context of the general economy and the current difficult times for highly trained people. The job crisis is not unique to physics; almost every segment of the science and engineering community (not to mention humanities and social sciences) is suffering from a severe shortage of jobs. During the current economic recession, the industrial and governmental hiring of scientists has slowed dramatically. Layoffs have affected scientists of all disciplines. The economic pinch has been felt in the universities where expansion of faculty has not kept pace with the expansion of student enrollment.

The community of physicists in the United States grew little if at all in 1970. Instead, in the flux of employment, including the entrance into the profession of new PhD's, more than 30% of those seeking positions in traditional sectors of physics in this country failed to find such positions. An increasing number of physicists are going abroad. The percentage of unemployed, now about 4% for the new PhD's and from 1.5 to 2.5% for all of physics, is growing. So, too, is the percentage leaving physics. The fraction of new PhD's who went into industry in 1970 was but half that of a few years ago.

The main burden of this crisis is being borne by the more experienced physicists. The new PhD's, for whom many temporary postdoctoral-type positions are available, as well as acceptable, are more and more visible and are generally making it into the system, though with increasing difficulty.

The employment situation in the past will be described in order to contrast the manpower problems of 1970 with the good-old-days of 1967. Those good-old-days from 1960 to 1968 were neither as expansive nor as bountiful for physics as most writers would have us believe. Even so, we will stress that until 1968 there was a chronic shortage in the production of physicists.

The crisis, which followed the economic downturn, will likely worsen in 1971. Universities and research groups have stretched their budgets for the past two years in order to retain those who could not find suitable jobs. This holding pattern did not expand in 1970 and probably contracted.

The prognosis for the next four to five years is for a continuing surplus of PhD production over demand. The number of physics students in the pipeline—at junior and senior levels in college and at each level of graduate school—is known approximately. From this information Grodzins and Viola estimate that the yearly output of PhD physicists will remain close to 1400 to 1500 for the next three years dropping to about 1200 in the academic year 1974—5. During those years the demand for physicists for college teaching and for research is not expected to increase enough over present depressed levels to absorb the outflow. Thus the PhD surplus will grow during the next few years unless immediate incremental funds are provided for physics-related opportunities.

The physicists being forced out of their profession are not part of the losers of society but are among the most talented of their generation. If basic re-

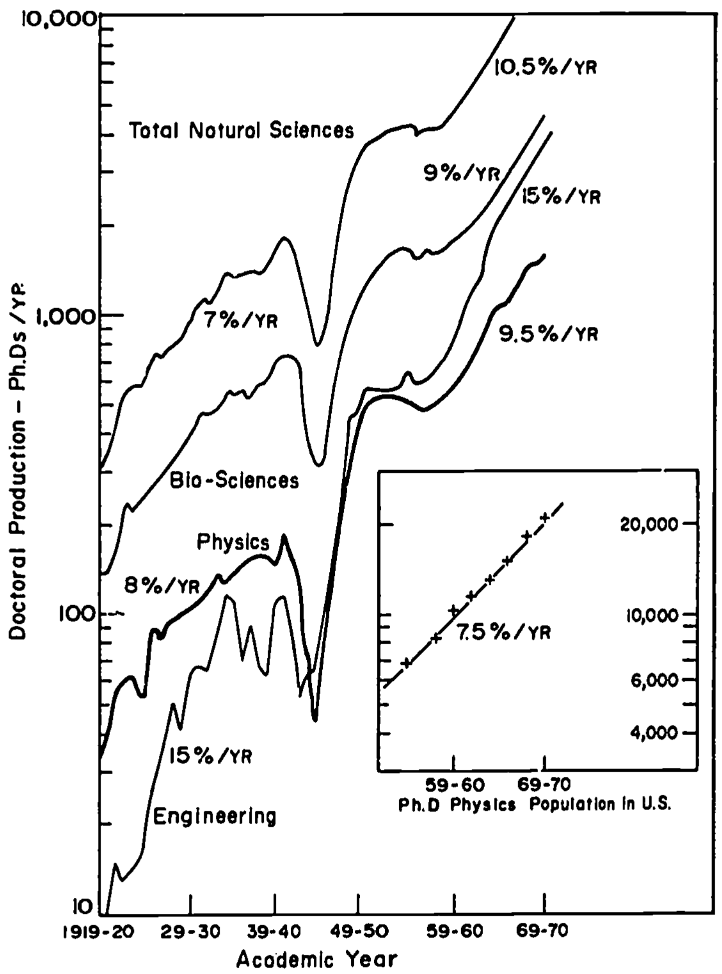

FIG. 1. Doctoral production in the U.S. for selected fields. The approximate percentage growth per year during certain rising times is indicated beside the curves. The inset shows the growth of the PhD physics population as determined from the American Scientific Manpower series. The PhD personnel in those series have been multiplied by a factor of 1.25 to account for incomplete returns of the National Register.

search does not return to a reasonable growth pattern soon we will have to contend with a wreckage of careers which took a decade and hundreds of thousands of dollars to build, in whole laboratories which took years to assemble, and in physics programs vital to our future.

This paper may be viewed as a sequel to the article by Wayne Gruner which appeared a year ago.[1] His prognosis of a PhD surplus at least until 1973 was deliberately conservative. It is not surprising that the situation is already far worse than his estimates. His general conclusions—apart from those in the last paragraph of his paper—are echoed in this report.

Economics, Trends, Background

The crisis described in the next sections struck so suddenly, with such widespread disruption in careers and programs, that perspectives are easily blurred. While it is not the primary purpose of this paper either to analyze the past or to project the future, we will need some common denominators.

Figures 1 and 2 show that the growth and funding of physics has been similar to other sciences. Figure 1 shows the doctoral production[2] since 1920 for physics, bio-sciences (which includes agriculture), engineering, and for the sum of the natural sciences. The growth of the doctoral production in physics over the past dozen years has been 9.5% per year, somewhat less than the 10.5% per year growth rate for the PhD production for all natural sciences in this country during that time and not much greater than the 8% per year growth rate in the production of physicists from 1920 to 1942. The production of PhD engineers over the past 15 years has risen at 15% per year, about the same rate as its growth from 1920 through 1935. The forces which expand the population of scientists are long range in time and discipline.

The inset in Fig. 1 shows the growth rate of the PhD physics population in this country as determined from the American Scientific Manpower Series,[3] hereafter abbreviated as ASM. During the 1960's, the growth rate for the field was only 7.5% per year, substantially less than the PhD production rate. Moreover, at least 20% of the PhD physicists got their degrees from other disciplines or from abroad.[4] The growth rate of U.S. physicists due to the output of PhD physicists has averaged less than 6% per year during the past ten years.

Figure 2 shows four curves relating to federal funding of physics and science.[5] Actual dollars have been corrected for inflation and are represented in terms of constant 1958 dollars.[6]

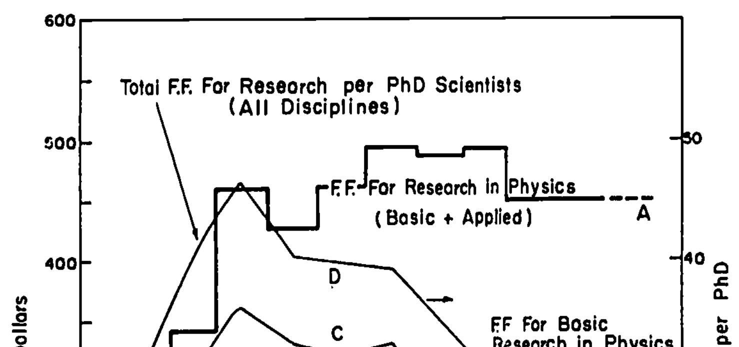

FIG. 2. Federal funds for research in physics in 1958 dollars for the fiscal years from 1960 through 1970.

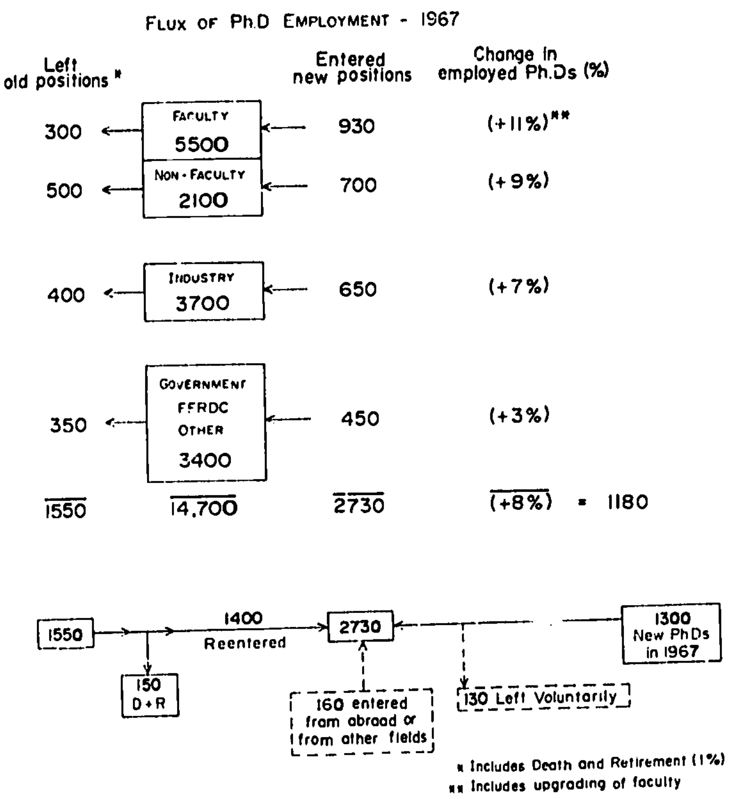

FIG. 3. The flux of PhD employment in 1967. The values in the faculty sector were obtained from direct counts of physics faculty directories together with the following assumption regarding PhD's in the various types of faculty. (See Fig. 5) All faculty who entered or left PhD granting schools were assumed to have a PhD. In the B.S. and M.S. granting schools, ranks below Assistant Professor were ignored; all who entered or left with the rank above Assistant Professor were assumed to have a PhD; only 25% of those who left with the rank of Assistant Professor but all who entered with that rank were assumed to have PhD's. The changes in employment for the other sectors were determined as the averages from 1964 to 1968 according to the ASM series. Other figures are explained in the text.

Curve A of Fig. 2 shows the constant dollar funding for all research in physics from all federal sources. From FY 1963 through FY 1970 the constant dollar funding has been constant at about 460 million. A closer measure of federal funding for PhD's is curve B, since only 15% of the PhD physicists are doing applied research.[7] Federal funds for basic research in physics (again all agencies) reached a peak in 1967 and has declined steadily since.

It is commonly accepted that about 50% of the funds for science, and for physics, comes from federal sources; in some sub-fields, e.g., elementary particle physics, it is close to 100%. This being so, a better indicator of federal support is the funds per scientist. Curve C shows the federal funds for research per PhD physicist. By this measure the effective federal funding in 1958 dollars has been decreasing from a high of $36 000 per PhD since 1963 and is now 30% below that level.

To understand the significance of the parallel behavior between curves C and D, consider the points on these curves representing FY 1966. The number on curve C is the quotient of 488 million dollars divided by 14 800 physicists, the number on curve D is the quotient of 4430 million dollars divided by 112 thousand PhD's. Physics funding is but 10% of the funding for research in science and its rise and fall reflect what happened in the aggregate of science.

Curves C and D tell but part of the story and do not tell that too well. For example, curve C contains large fractions allocated to space and elementary particle physics, which together contain a disproportionately small fraction of the physics population. Then, too, this representation ignores the funding for science from industry and universities, both of which took up much of the decline in the years until 1968.

Several other points should be kept in mind; the growth rate of physics faculties has closely paralleled the growth rate of college enrollments and does not appear to be well-coupled to the growth of federal funding. (The growth of nonfaculty physicists, mainly postdoctorals, in eduction institutions has, to be sure, been directly coupled to federal funding.)

Federal funds for research in physics is roughly 2.5% of the total federal funds for all research and development. Changes in the total federal funding may have little significance for physics.

PhD physicists are not heavily employed either in aerospace or in explicit defense work. For example, less than 200 of the 30 000 employees of NASA are PhD physicists.

The Flux of Employment: Year 1967 Versus 1970

1967 was the last of the "good" years. The approximate input-output figures for employment of PhD's in that year are shown in Fig. 3. In that figure the employment population as well as the percent of changes in employment are derived either from the Directory of Physics Faculties[8] or from the ASM series[3] and are quite reliable. The number of physicists in the columns labeled "left" and "entered" are reasonable but arbitrary (apart from those involved in faculty positions where a close estimate was possible). The values are not, however, critical. The columns do point up, though, the often overlooked fact that the net change in employment is the difference between two larger numbers.

The turnover in PhD employment during FY 1967 was about 10% and there was an 8% growth due to new PhD's entering the profession. About 1400 of those who left old positions reentered new positions. There was a demand that year for at least 1300 more. The universities in the United States did not produce enough PhD physicists to meet that demand. For one thing, about 15% of the 1300 new PhD's were

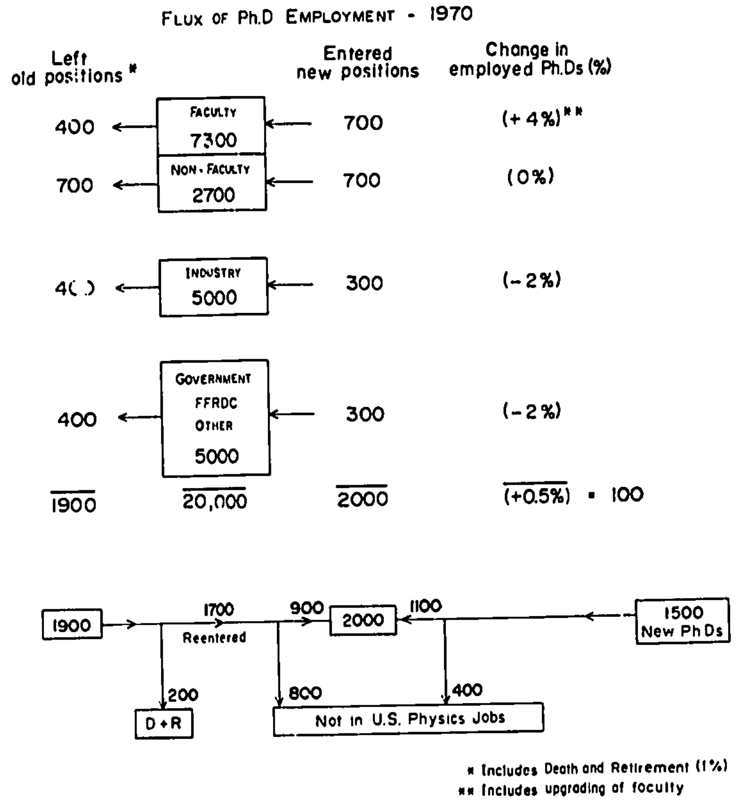

FIG. 4. The flux of PhD employment in 1970. The remarks on faculty figures under Fig. 3 apply here. The changes in employment in the other sectors were estimated from surveys and from information supplied by the funding agencies as described in the text.

foreign nationals and some of them returned home. Moreover, in a normal year about 8% of those who obtain a PhD in physics go directly into another field.[9] We must conclude that there was a net influx of PhD's either from abroad or from other disciplines to satisfy the demand. This very important point has already been made in Ref. 4. To emphasize it further, we note the following fact. From 1930 through 1969, U.S. universities graduated 17 500 PhD's in physics.[2] In 1970, 16 000 reported to the National Register as PhD physicists, and this response was only 80% complete. Thus from 1930 till now more than 5000 PhD's entered physics from other fields and from abroad, taking death, retirement, and attrition into account. Until 1968 the U.S. universities did not produce nearly enough physicists.

The input-output figures for the 1969–70 year are shown in Fig. 4. The numbers here are expected to be more reliable than the comparable numbers in Fig. 3 if only because they were arrived at from more directions. (The figures for faculty migration have an uncertainty of less than 15%. The numbers involving new PhD's also have less than 15% uncertainties, and the column labeled "change in employed PhD's" gives reliable upper bounds.)

As in Fig. 3, the change in physics faculty was determined by a direct count of physics faculty directories together with a reasonable estimate of upgrading of faculty. The 2% decrease in industry is based on a recent survey[10] and on the ECC census. The 2% decrease in PhD employment in government and FFRDC centers is based on figures supplied by NASA and the AEC, as well as by a direct survey of six FFRDC labs. Both the decreases in industry and government are conservative and could on the basis of available data be twice as great. It should also be noted that about 1% of the decrease is accounted for by the nonreplacement of those who died or retired. A major uncertainty is in the change in nonfaculty employment. We have assumed no net growth on the bases that the percentage of new PhD's going into postdoctoral positions seems to be less than in 1969, and that the number of research associates in elementary particle physics declined by 10% during the year.

The only sector to increase its employment of physicists was the faculties of the universities and colleges. Figure 5, which summarizes the migration

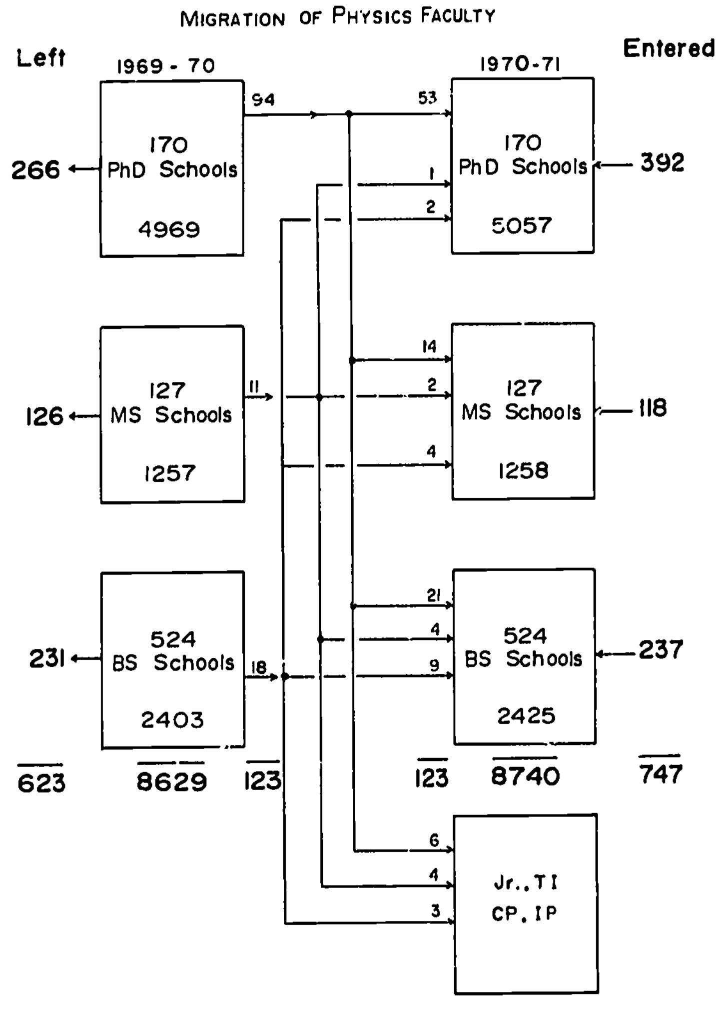

FIG. 5. The migration of physics faculties was determined by a name-by-name matching of all faculties in the 1969–70 and 1970–71 physics faculty directories. All faculty from Instructor and Lecturer and including part-time faculty are counted. Adjunct, visiting, and emeritus professors are not. A separate document, Ref. 19, gives the percentage of PhD's on the faculties in the PhD, M.S., and B.S. granting departments. In 1968–69, these were 97, 76, and 62%, respectively.

between various types of physics departments, shows more clearly what happened in that sector. The detailed analysis from which this summary was taken will be published in the near future.[11] The total faculties in the B.S. and M.S. granting schools of physics did not increase between 1969 and 1970. The 170 PhD granting departments increased their faculties from 4969 to 5059, less than 2%. The actual change in faculties for all schools was thus only 1%. Nevertheless there was a larger change in the PhD employment since many of those who left the B.S. and M.S. schools did not have PhD's while almost all who entered did. We estimate that 200 PhD's may have entered the faculties by this upgrading.

We conclude that in 1970 a total of no more than 300 additional positions opened up in the physics community, 200 of them from death and retirement. Thus there were at least 1000 fewer positions available in 1970 than in 1967 while the graduating class was 20% greater.

The flux of employment in Fig. 4 gives a reasonable representation of what happened. From October 1969 until October 1970, about 1900 PhD's left old positions and of these about 1700 sought new positions in the physics profession. During that time about 1500 new PhD's graduated and perhaps 1350 of them sought positions in the physics community. There were about 2000 positions to accommodate the 3000 or so who sought them. The result is shown graphically in the lower part of Fig. 4. The branching ratios for the percentage who did not find physics jobs in the U.S. are discussed in the next sections. About 1100 of the new PhD's found acceptable positions; about 400 did not. (Presumably many of the latter would have gone abroad or left the field even in a normal year.) Only about 900 of the experienced PhD's found acceptable positions; the rest did not. Thus, instead of an undersupply of doctorates as in 1967 we had an oversupply in 1970 almost equal to the production rate. About as many experienced physicists left the profession of physics in the United States as new graduates entered that profession.

In the next two sections, we consider in some detail what happened to those who sought positions in 1970.

The New PhD's

In the fall of 1970, the ECC carried out a survey of a number of physics graduate schools asking the departments for the names, citizenship, date of PhD, sub-field of thesis, and the professional address and type of employment of their recent graduates. The returns from 38 schools were essentially complete and the data on the 750 graduates of these schools were used for Fig. 6. Ten of the top 21 so-called Cartter schools are represented. Seven of the 38 schools are not listed among the 59 schools of the Cartter study.[12] We hope that in the final report on this survey we will have results from more schools and more complete information from others not yet included. We do not expect, however, that the percentages will change beyond that expected from statistical variations.

We asked for and obtained information on fall 1970 graduates. The situation for them was similar to that for June 1970 graduates and all groups are included in Fig. 6. The 750 PhD's represent 40% of all the U.S. production from September 1969 through September 1970 inclusive.

The following points annotate and amplify Fig. 6:

1. The percentages of graduates according to subfield of thesis are, for a few fields, as follows: atoms and molecules, 8%; elementary particles, 23%; nuclear physics, 20%; condensed matter, 26%; plasmas and fluids, 4%. The fraction in elementary particles who did theoretical theses was 45%; in nuclear physics, 42%; in condensed matter, 26%.
2. Foreign nationals made up 15.2% of the graduates. They concentrated on selected areas; 26% of the theorists but only 11% of the experimentalists were foreign nationals.
3. 14% of the graduates, half of them U.S. citizens, left the country. It is perhaps significant that 55% of those who left the U.S. went to Europe and two-thirds of the latter were Americans. (That is, 6% of the U.S. citizens who got their degrees in physics last year went to Europe for employment.)

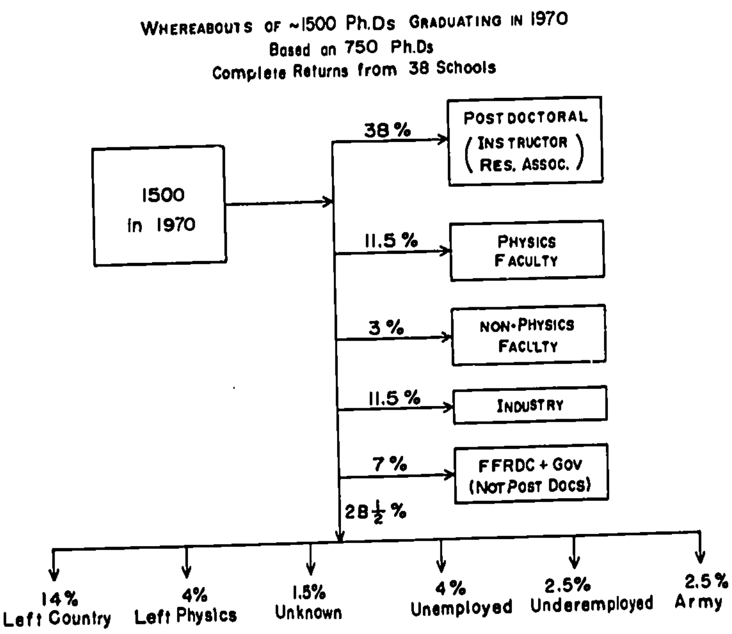

FIG. 6. The employment status of the PhD's in physics who were awarded degrees from September 1969 through September 1970. FFRDC stands for Federally Funded Research and Development Centers. The category, Faculty, does not include instructors or lecturers; these are included under postdoctoral. The postdoctoral category includes only those who took postdoctorals in the United States.

4. 4% were listed as unemployed; two-thirds were U.S. citizens. This may appear to some to be a normal number for these difficult times but 4% is really a figure of disaster. Remember that the ECC survey was conducted several months to a year after graduation. A PhD unemployed in May is not likely to be unemployed in September, and if he isn't, then his department is unlikely to report that he was ever unemployed. Remember, too, that the new PhD looked for a position for six months and more prior to taking his thesis examination (unlike the usual unemployed worker who starts looking after he has been laid off). Finally, we recall that for decades and until 1969, U.S. universities did not graduate enough PhD's to fill the nation's demands.

5. The category of underemployed in Fig. 6 contains mainly graduates who took high school and junior or community college positions; some are teaching mathematics as well as physics.

6. Summing the percentages in the unknown, unemployed, underemployed, and left-physics categories, we find 14% of the graduates, most of them American citizens. We note here that none of these groups include the 2% (15 graduates) who took positions in hospitals, in science writing, and in science education. All of the latter were assumed to have stayed in physics, albeit peripheral areas.

7. The percentage that entered industry was down by a factor of 2 from 1968. This significant drop is another piece of evidence that fewer were hired by industry than left. Only 18% of those who got their degrees in solid state physics (condensed matter) entered industry.

8. 38% of the new PhD's took postdoctoral type positions in the U.S., and 85% of this group went into educational institutions. Most of the rest went into federally funded research centers.

   The percentage taking postdoctoral positions may be decreasing from previous years. If so, we may be observing the breaking up of the holding pattern which rescued the new PhD's in 1969 and which may now be turned to rescue those already in postdoctoral positions. There is, however, a severe problem with the definitions of a postdoctoral. We used the definition in *The Invisible University*[15] and made category decisions on the basis of the type of position reported on the returned forms. (We asked the respondents to indicate whether positions were of the postdoctoral type, but many did not answer or used a different definition.)

9. 11% of the doctorates took positions in their own university, independent of department or type of position. About one-third of this group were in a holding pattern having been kept on because suitable employment could not be found.

To summarize some of the salient points on new PhD's, the graduating class in 1970 was the largest so far, 1500 physicists. From a census of about half of this group, we conclude that about 350, 300, and 400 graduates did their thesis in elementary particles, nuclear physics, and condensed matter, respectively. The first two groups represent increases over previous years. About 550 physicists took postdoctoral type positions and about 400 others did not take positions in this country in traditional sectors of physics. The postdoctoral percentage seems to be less than in 1969, while the percentage not going into U.S. physics may be greater by a factor of 2 from a normal year.

A significant number of Americans are going abroad for employment. Most are taking temporary positions but we may be seeing the beginnings of an inverse brain drain.

For all of the hardship, however, the new PhD fared better than the experienced PhD.

The Experienced PhD

The new PhD has many advantages over the experienced PhD in the job market. He is more mobile, he will work for less, he comes as the youngest member of the team, and needs less ancillary support. Moreover, getting a position is a *de facto* part of getting a degree. In most cases the major professor and, in these times, the department as well as the professional societies work to find him a proper position.[16] Thus the new PhD is visible and many are helping him. The older PhD is far less visible and he has far less help in finding a position.

The experienced PhD's on the job market divide into several groups. There are the postdoctorals. The physics community has some 2000 transient positions in which the young PhD is expected to make the transition from being supervised to being the prime mover. These positions are sometimes named postdoctoral positions, sometimes research associateships, sometimes instructorships. (Now they may even be assistant professorships.) The important point is that the great majority who take these positions expect to find a new position in a few years. The turnover rate is very high, perhaps 25 to 30% per year. This group has been aptly named the Invisible University.[15] The average age of this group is about 30.

Following the postdoctoral, and sometimes directly after graduation, there are those who sign three to six year contracts, especially in universities, with the understanding by both parties that these positions could lead to actual or effective tenure. Unfortunately, with the economic and funding downturns many of these positions could not be renewed and an increasing number of assistant professors and

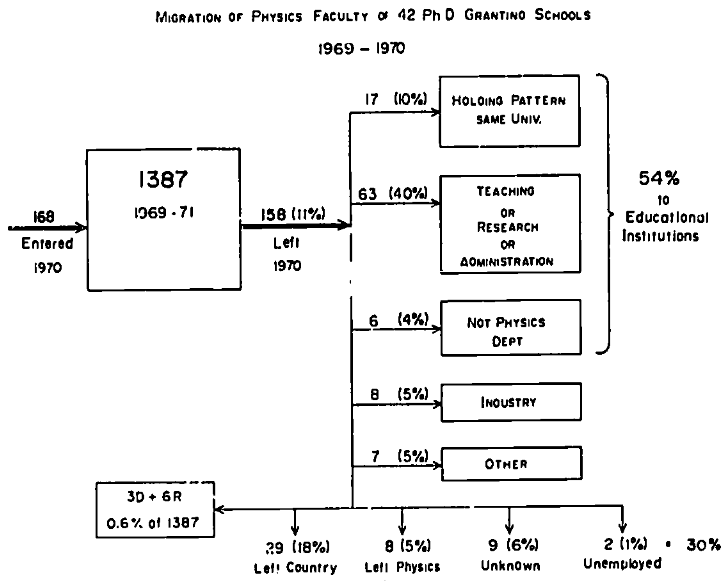

FIG. 7. Migration of physics faculties from 42 PhD granting schools. These schools include most of those that provide the data for Fig. 6.

associate professors without tenure as well as physicists in national labs have found themselves needing new positions.

Most scientists who took staff positions in industry or government during the past 20 years tacitly assumed, as did their employers, that their jobs were secure. The crisis in the last two years, however, forced many companies and government centers to reduce their staffs. In some cases they have been forced to close entire laboratories.

Massive layoffs such as occurred from the closure of the NASA Electronics Research Center in Cambridge, Mass., present qualitatively different employment problems from normal attrition or the forced layoffs of small groups. Massive reductions mean that everyone is looking for a job, the recommendors as well. Many have similar backgrounds, related skills, and search in the same geographic area. It seems reasonable to describe the reemployment following such catastrophes in terms of a diffusion process. How else can one account for the fact that when the NASA center closed down in July of 1970, the 48 PhD's in physics already had six months notice, yet in November there were 19 still unemployed despite a vigorous placement effort by NASA.

To understand what happened to the experienced PhD's who had to find positions in 1970, the ECC carried out two surveys, each asking for the names and the data on all individuals who entered or left institutions from October 1969 through October 1970. We thus obtained complete information on a sample of universities and national laboratories. These surveys are continuing and full reports will be published. A third survey, on industrial labs, was not representative enough to be included here though the results have been factored into the input-output information of Fig. 4.

Figure 7 shows what happened to 158 physicists who were in faculty positions in 42 PhD granting schools in 1969—70 but were not in the same faculty according to the 1970—71 Directory of Physics Faculties.[8] Again we stress that the 158 comprise every faculty member that left.

The 42 schools had a total faculty of 1387 in 1969, increasing to 1397 in 1970. Nine faculty left for the natural reasons of death and retirement. (The percentage, 0.6%, agrees well with the actuarial calculation of Wayne Gruner[1] based on the age distribution of all PhD physicists.) Forty-eight more left traditional physics in this country.

We find it surprising that departments would not know the whereabouts of faculty who left in June, 1970, but such was the case for nine physicists, most of whom were assistant professors.

Fifteen of the 158 took faculty positions in other PhD universities and 15 of the 168 that entered in September 1970 came from other universities. (See Fig. 5.)

The 17 faculty listed as being in a holding pattern were young faculty members who were not listed in the 1970—71 Physics Faculty Directory but nevertheless were still at the university.

Only six of the 158 left the faculties to take administrative positions. The outflow of senior physicists to administrative posts does not appear to be a significant source of new positions.

Figure 8 summarizes the input-output information from five National Laboratories: Argonne, Brookhaven, Livermore, Los Alamos, and Oak Ridge. One hundred PhD physicists left; their average age was 38. Seventy-nine PhD's were hired; their average age was 30. Lest there be a misinterpretation on this point, we emphasize that except in the postdoctoral type positions, the younger physicist did not displace an older physicist in any direct fashion.

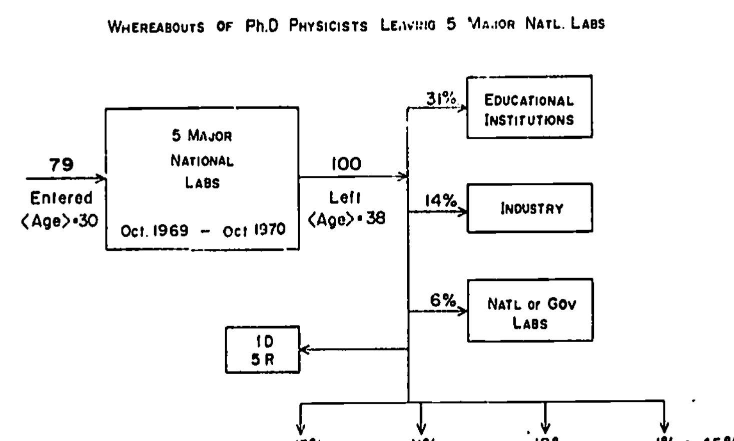

FIG. 8. The employment status of PhD physicists who left Argonne, Brookhaven, Livermore, Los Alamos, and Oak Ridge National Laboratories between October 1969 and October 1970.

As we can document, those who left involuntarily were working in a different area from those that were hired. A striking example was evident in one laboratory where a long-term commitment to a large project required that new physicists be hired. To do this on a decreased over-all budget forced the laboratory to effectively shut down an entire program in a quite unrelated sub-field of physics.

This seems to be an appropriate place to stress that there is a great deal of internal mobility during these difficult times which remains largely invisible to the surveyors of the scene. Whenever possible, universities, industry, and government have held onto their most valued members. They do this by offering the physicist employment in another research group or in another function of the organization. The saving of the key man, however, still leaves unrescued the research groups which took years to assemble and work smoothly.

The 100 who left the national labs did not do as well as those who left the PhD universities. Three of those who retired were in their fifties. Most of the 18 who are listed as unknown were not working when last heard from. Two-thirds of those who left the country were foreign nationals, but almost all of those who left physics or are unknown were American citizens.

The final figure on experienced PhD's, Fig. 9, derives from a survey in November 1970 by Suzanne Ellis of the AIP, of those physicists who applied to the AIP Placement Service in 1970, mainly in the spring. Figure 9 shows what happened to those 202 of the registrants who had obtained their PhD prior to 1966 and who answered the survey. It is not then a census study like those summarized in Figs. 6, 7, and 8. Like other sample surveys, it may be biased in some directions. For example, fewer of those who went abroad may have received the questionnaire. And there may well be overlap between the group represented in Fig. 9 and those represented in previous figures. Nevertheless, it is a valuable survey presenting as it does the first large-scale study of how the experienced physicists in the job market view their own employment.

Only 60% of the group are using their physics extensively, 32% are definitely not, and 7% are in situations which we would classify as underemployed. The time scale tells much of the story. 17% of an older group of physicists who were looking for a position in the spring of 1970 write more than six months later that they are unemployed. That this survey represents a lower bound on the crisis is indicated by the lack of foreign nationals in the unemployed group.

The three figures surely speak for themselves. Close to 40% of the experienced PhD's seeking new jobs left the physics community in this country; in normal years essentially none did so. And we cannot refrain from noting that the survey on the major national labs and the PhD schools looked at the most prestigious hirers. Surveys of other segments (e.g., the colleges and small industries) have not yet been made.

Physics Manpower in the 1970's

The crisis of 1970 became visible in 1968. 1969 was already a year of anguish. We estimate that about 1500 PhD physicists have now been displaced out of the physics community in this country. The situation is deteriorating; the percentages going abroad, leaving physics, and of unemployed are all increasing. From an underproduction in 1967 we find overselves with severe overproduction now. The abrupt reversal could not have been reasonably predicted and there are as many pitfalls to prophesying the future. We do not know what breakthroughs in fusion or in laser applications will require massive inputs of physicists. We cannot foretell whether disenchantment with science will grow or lessen. We do not yet know the commitment of the nation to the challenge of societal needs nor do we know the role of physics in meeting that commitment. We can, however, make several predictions which should be the basis for actions and planning.

First, in the next few years we will have a severe oversupply of PhD's. The physicists now in holding patterns in this country and abroad, together with those who have not completely left physics, will continue to compete for physics positions. It will take years to reabsorb this log-jam in the face of a sustained PhD production.

Second, in the next few years there will continue to

PRESENT EMPLOYMENT STATUS "SENIOR" PH.D APPLICANTS AT SPRING 1970 AIP PLACEMENT SERVICE

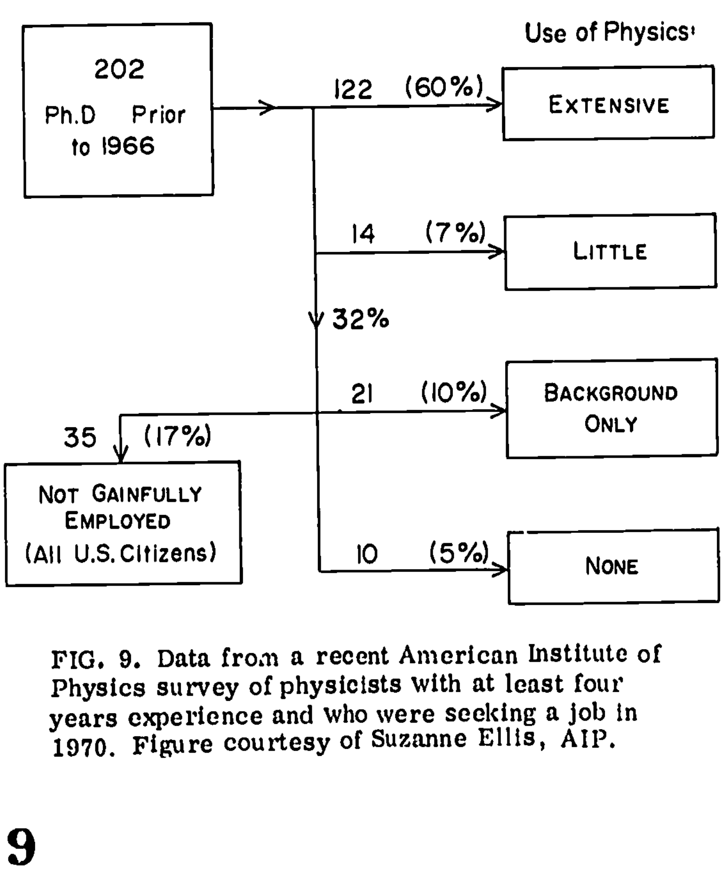

FIG. 9. Data from a recent American Institute of Physics survey of physicists with at least four years experience and who were seeking a job in 1970. Figure courtesy of Suzanne Ellis, AIP.

be a severe imbalance between the training and the aspirations of students and the opportunities which will exist. The imbalance itself and the attendant problems could have been predicted. We should have known that in 1970 about 40% of the PhD graduates would do their theses in either particle or nuclear physics. The sub-field of elementary particle physics now contains about 1500 PhD physicists; nuclear physics houses about 2000. Neither field has grown significantly in the past few years. Nuclear physics with its direct links to solid state physics, to medical physics, and to nuclear power provides greater options for its graduates but surely a 15% growth rate (half in theoretical aspects) is excessive. And we must realize that the many new nuclear accelerators in universities throughout the country will tend to maintain the outflow of students trained in nuclear physics.

Elementary particle physics is a field of zero population growth, at least for the near future. Yet the number of graduate students presently in the pipeline of particle physics (more than 1000 beyond their first year of graduate school) will sustain the output for years. At least 75%, and probably more than 90%, of this group will eventually have to find employment outside of elementary particle physics.

Third, Allan Cartter has made believable predictions[17] of the need for scientists in college faculties on the basis of student population growth based on birth rates, together with reasonable assumptions concerning increased enrollment trends, constant ratios of student to faculty, unchanged retirement and tenure policies, etc. Cartter states that his predictions for individual fields are less certain than for all of science. For physics some of this uncertainty is diminished by the availability of harder information than is known for most fields. We have redone Cartter's projections for physics using more precise numbers for death and retirement (Cartter used 2% per year) and for the percentages of PhD's now in various categories of physics departments (he used 68%). Also, we took into account that in physics there has been a constant upgrading of faculty accompanying the flux of employment. The results, which will be published separately,[18] are in reasonable agreement with Cartter's estimates and show that (1) the growth of physics faculties in the country from 1962 through 1967 tracks the changes in total student enrollment (all disciplines). For example the percent increases in physics faculties in 1963, 1965, and 1967 were 4.0, 10.0, and 7.3%, respectively. The corresponding increases in enrollment[17] were 6.3, 10.0, and 7.1%. (2) The growth of physics faculties in 1968, 1969, and 1970 fell well below the need. (Cartter estimated a need in 1970 for 568 new physics faculty compared to an actual growth of about 125.) (3) Through the 1970's physics faculties will probably need an average of no more than 300 to 600 new PhD's per year.

The last point requires amplification. Predictions of need through the 1970's are but one part of Cartter's message. His principal point is that we now know the college age population through 1990 and from these data we know that the college student population in the 1980's will decrease, as will the need for additional faculty. (If the mid-1980's seem too distant for bother, remember that considerations for tenure then will be made on faculty who are undergraduates now.) A sensible faculty growth pattern will take this decreased need into account by underexpanding in the 1970's. We have assumed just such a growth in the prognosis for 300 to 500 new PhD faculty members per year.

Physics faculties now house 40% of the PhD physicists. If the other sectors grow at the same rate as physics faculties, there will be a need for only 800 to 1200 new PhD's per year into the profession, which, with attrition, translates to a production need no greater than 1400 PhD's per year through the 1970's. Each reader can make his own reasonable estimates of the future needs for physicists.

Various recent projections[17] by the Office of Education, by the National Research Council, and by Allan Cartter are that by 1980 the physics graduating class will be at least 2500 PhD's per year; the average through the 1970's is projected by these groups to be at least 2000 per year. These estimates are far too high. The NSF, which originally made similar projections, is now revising their estimates downward. Their present numbers are not too different from those recently made by Grodzins and Viola[18] which are summarized here.

The NSF,[20] the AIP, and the Office of Education[21] have carried out separate surveys of graduate and undergraduate populations by discipline. The numbers for physics differ depending on the definition of student (the NSF separates full-time from part-time, the AIP does not), the breadth of coverage (the AIP is probably the most complete, especially in recent years), whether astronomy departments are counted in with physics, the time of year when information is gathered, the source of the information, etc. Though the numbers from different surveys may differ by 20%, each seems to be internally consistent from year to year and the over-all conclusions are essentially the same whichever of the surveys one uses.

Figure 10 summarizes from 1953-54 till now, the number of B.S. physics degrees granted during an academic year, t, the number of full-time first year physics graduate students in PhD granting schools in the academic year, $t+1$, and the number of physics PhD's granted in the year, $t+5$. Figure 11 summarizes the ratios of first-year graduate enrollment $(t+1)$ to B.S. degrees (t), the PhD $(t+5)$ to first-year graduate enrollment $(t+1)$, and the PhD $(t+5)$ to B.S. degree (t). The figures in the

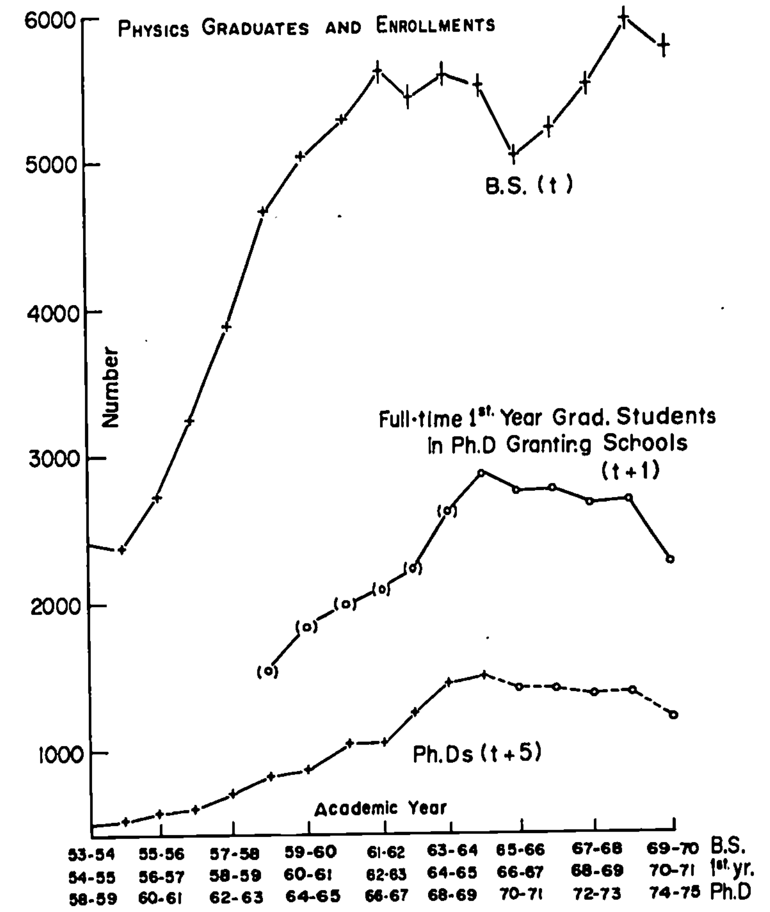

FIG. 10. Yearly rates of physics graduates and first year graduate enrollments. AIP data were used for the upper (B.S.) curve. NRC data, Ref. 2, were used for the lower (PhD) curve. NSF data were used for the later year figures for first year graduate enrollment. The numbers for the earlier years (in parentheses) are based on Office of Education data but corrected for part-time students according to the NSF information of the past six years.

graphs do not distinguish between growth due to the proliferation of physics degree granting departments and the growths in individual departments.

About 35% of the physics baccalaureates continued on as full-time graduate students during the early years. The fraction increased to above 50% in the years from 1965 through 1968 only to fall back to about 40% in 1970. (The increase seems to be partially related to the draft.) The attrition rate in graduate school has been close to 50% for the seven years for which data are available. From the constancy of the latter and the knowledge of the number of first year graduate students who entered during the past five years we can estimate the PhD production during the next five years. The estimate is given as the dashed part of the PhD production curve of Fig. 10. We also know the number of seniors and juniors who are presently physics majors and these data allow us to estimate that the PhD production during 1976 and 1977 will be no greater than for 1975. Since the leakage out of the pipeline is expected to be no less in the coming years than it has been in the past seven we conclude that the prediction in Fig. 10 does not over-estimate the production.

We conjectured above, that the demand for physicists in traditional sectors will be from 800 to 1200 per year from 1972 through 1980. It appears that from 1975 on, the production will not differ much from the conjectured demand. Unfortunately, unless new opportunities are found soon there seems no escaping the conclusion that from 1969 through 1974 we will produce from 3500 to 5000 PhD physicists beyond the demand. Most of this group will want to be absorbed into the system in physics related work. If this does not happen then the log-jam will doubtless continue throughout the 1970's.

In all of the projections of supply and demand one tends to ignore the individual supply-demand problems of the sub-fields, of theorists versus experimentalists, of aspirations for teaching-research versus opportunities. These are thorny problems which must be faced. We cannot sweep the problems under someone else's rug.

For many years, probably throughout this decade, Grodzins and Viola conclude that the physics community will have to contend with an imbalance between training and apsirations, and the availability of matching jobs.

Summary and Conclusions

From three different directions we arrive at similar conclusions regarding the present manpower crisis. The decrease in effective federal funding of research (precipitous cutbacks in some areas) together with the economic downturn are the causes. The decrease in federal funding has been directly responsible for the standstill in net employment in government and national labatories and in nonfaculty research positions. The recession-inflation must be held account-

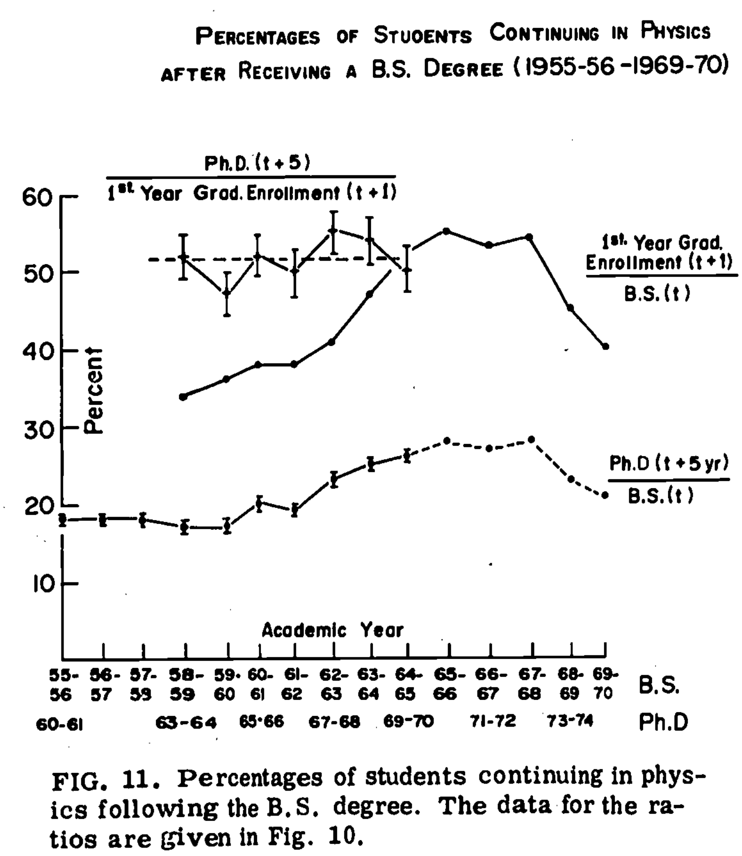

FIG. 11. Percentages of students continuing in physics following the B.S. degree. The data for the ratios are given in Fig. 10.

able for the reduction in growth of physics faculties well below the needs to meet increased enrollment. (For example, the B. S. and M. S. granting schools, Fig. 5, which receive little government support, increased their physics faculties by more than 10% in 1967 but not at all in 1970.) The two factors together are probably responsible for the reduction in industrial employement.

The effect of these downturns, bad as it has been, was less than one might have expected on the basis of Fig. 2 because each sector of the physics community acted to buffer the pressures.

During the first years of the decline in effective federal funding, industry and educational institutions took up much of the difference in their sectors and government laboratories continued to grow somewhat (apparently at the expense of new scientific equipment and support personnel). Since 1968, however, nonfederal funding has been unable to close the widening gap between federal support and need.

The effects of these declines were that in all categories of employers and in all areas of the country, in most fields and in group after group, members were let go. Wherever possible, groups reduced their expenditures, stretched out their research, operated on a lower dollar per man expenditure. Growing groups preferred younger less expensive PhD's over those more experienced. As the downturn continued institutions, which first transferred key members to other parts of the organization, let go manpower critical to the fabric of the group. There have been wholesale layoffs in some industries; entire research laboratories have been shut down. Throughout the physics community the fixed costs, i.e., the untouchables in the system, have resulted in substantial fiscal leverage against the vulnerable.

The crisis will likely worsen this year and for many years our profession will contend with an overproduction of PhD's for traditional physics jobs. Unless we take action, our problems will continue to intensify.

The Economic Concerns Committee has not addressed the long-range questions, but for the near future there are actions that we can and should take.

1. We must find new opportunities for physicists. Raymond Sears of the AIP is now working full time on this project. We should give him every possible assistance. Our crisis involves a relatively small number of people so that partial solutions can be effective. For example, if each large hospital in the country were to employ one or two additional physicists (many hospitals already have physicists on their staffs), if each large secondary school system were to employ a physicist as a science advisor (the Texas Project), if junior colleges were to realize the opportunity to obtain top quality science teaching, if the promise of opportunities to work on societal needs becomes even a partial reality, if only some some of each of these avenues are opened, then much of the immediate crisis will dissolve.
2. In the next decade a larger share of the jobs for PhD physicists will have to come from outside the educational institutions. To this end programs to increase the involvement of the physics community in industry must be encouraged and stimulated.
3. In the years preceeding 1968 there were about 3000 openings annually for PhD physicists; even in 1970 there were about 2000. No placement service listed more than a fraction. The result of this dearth of communication has been that most job seekers and most employers have had restricted choices, there has been considerable wasted effort in the writing and answering of broadcasted job applications, and many from both sides of the employment aisle have been ill served. Even in normal years the traditional employment methods, based mainly on personal contacts, worked well only for "standard" types of employment. For example, such methods were not particularly effective when the PhD wished to work in an area far from his thesis field, when the major professor had limited acquaintanceship with the hirers of physicists, when the recommender had neither a strong reputation or useful contacts. Members of the Economic Concerns Committee have advocated the implementation of a National Placement Service based on field representatives working under a central facility. Such a service would deal with both open and closed listings of jobs, though we believe that the placement service should strive towards an eventual system of open information of all positions available to physicists.
4. The physics community, especially the students and faculties should be informed of the present situation as quickly and as thoroughly as possible.
5. Physics departments should tighten their standards for the PhD. Institutions must look beyond the immediate employability of their PhD's and ask whether their students have the talent, the training, and the attitudes for a physics career in a tightening market.
6. Physics departments must reexamine their training programs especially for careers for which few employment opportunities exist. Is it too much to ask that a physicist who gets a PhD in elementary particle physics demonstrate a competence in research in an unrelated physics area?
7. We should reduce those financial inducements which channel students into fields of little employment potential. Students should select and stay in fields such as elementary particle physics

subject to a minimum of direct financial pressure such as research assistantship support. The funds freed by the reduction of graduate assistantship support might appropriately be used to hire postdoctorals to maintain each group's research effectiveness. For the next few years this stratagem appears to have many merits.

8. We will still need to have incentives for the most promising students to continue graduate work for we have always had a need for prime movers in the field and we will continue to have a need in the foreseeable future. The top students are still making it to the top. To attract such students in as balanced a way as possible we should maintain the number of nationally awarded fellowships. The present policy is, however, to sharply reduce the number of nationally awarded fellowships and encourage an increase in graduate assistantships. Such a policy is short-sighted and probably counter productive. We urge that the national fellowship programs for students in science be strongly supported.

9. Finally, in counselling students we gaze into the crystal ball to an uncertain time, years hence. There will be a need for physicists then as there has been in the past, but we cannot predict what fields or sub-fields will be fruitful. We surely cannot base counsel on a predicted 4% per year manpower growth. Apart from telling students the facts of the situation, we should advise them towards a well-grounded preparation in fundamentals, carried through with the broadest of attitudes and the widest of visions. We expect that a physics training based on such a foundation, however narrow may be the thesis topic, will better prepare a man for a future scientific career than would any alternative training We know of no better advice than the wise words of John Gardner quoted in the preface of this paper.

Acknowledgements

The Economic Concerns Committee is but one of several groups surveying the physics manpower scene. Our work would not have been successful without the considerable assistance and the knowledge obtained from all of these groups. In particular we would like to thank the AIP, whose far-ranging Education and Manpower Division, under A. Strassenburg and including Suzanne Ellis, has cooperated fully in providing much needed unpublished information as well as numerous services. The Manpower Divisions of various government agencies, including the AEC, NSF, and NASA have contributed valuable data. Finally, the Physics Survey Committee of the NRC has kept us fully informed of their findings.

The author has benefited from so many sources that it is not practical to acknowledge them all. I would, however, like to take this opportunity, on behalf of the Committee as well as myself, to thank E. Purcell, who has been a constant well-spring of encouragement and guidance. My own debt must also be acknowledged not only to my Committee members but to others whose continued interest and inputs helped formulate the insights in this paper: G. Seidel of Brown University; A. Rosenfeld of the University of California, Berkeley; D. Teaney of the National Academy; and my colleagues at MIT, particularly R. Alberty, M. Deutsch, H. Feshbach, B. Schwartz, and V. Weisskopf. Finally, my special thanks to J. Viola, who has worked with me on the manpower statistics for many months, to T. Woodruff of Michigan State University, who carried out the industrial survey for the ECC, and to my secretary J. Tyzenhouse for constant assistance.

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[1] W. Gruner, Phys. Today, June, 21 (1970).

[2] *NAS-NRC*, *Doctorate Production in United States Universities*, 1920—1962, Publ. 1142, Washington, D.C. 1963; *NAS-NRC*, *Doctorate Recipients from United States Universities*, 1958—1966, Publ. 1489, Washington, D.C., 1967 together with summary reports for 1967, 1968, and 1969; 1970 data from private communications of the American Institute of Physics and the Engineering Manpower Commission.

[3] American Scientific Manpower Series 1954, 56—58, 60, 62, 64, 68, and unpublished data for 1970. National Science Foundation. The figures we have used from the series are taken to be 80% complete for PhD's. An 80% return rate is a proper figure for physics faculty in 1966 and 1968; we assume it holds for all sectors and for all years.

[4] See, for example, A.S.M., 1968 (NSF 69-38), Table A-13; 2356 out of the total of 14 311 PhD physicists received PhD's in fields other than physics or astronomy.

[5] *Federal Funds for Research and Development*, *Vols. I through XIX*, National Science Foundation.

[6] Michael March Economic Report, Center for Political Studies, University of Chicago.

[7] A.S.M., 1968, p. 60.

[8] Directory of Physics Faculties (AIP). These are compiled during the summer of the academic year on the basis of information from the department heads.

[9] See, for example, *Profiles of PhD's in the Sciences*, NRC Publication 1293, or *Doctoral Recipients from U.S. Universities*, 1958—1966, p. 90, and *Doctoral Recipients*, Summary Report, 1969.

[10] Physics Survey Committee, National Research Council, unpublished data.

[11] L. Grodzins and J. Viola, Migration of Physics Faculties, to be published.

[12] *An Assessment of Quality in Graduate Education*, 1966, Allan M. Cartter, published by the American Council on Education.

[13] Physics Manpower, 1969, American Institute of Physics.

[14] American Institute of Physics data.

[15] *The Invisible University*, National Academy of Sciences, 1969.

[16] A recent survey of 200 physics majors who got their PhD's from 1964 through 1969 shows that about 20% felt that their major professors did not help (and in some cases were a hindrance in getting a job). In 1970 such situations must have made it difficult for the student to get a job.

[17] Allan M. Cartter, Scientific Manpower Trends for 1970—1985. Science, to be published.

[18] The Growth of Physics Faculties, L. Grodzins and J. Viola III, to be published.

[19] *Student's Guide to Undergraduate Physics Major Departments*, AIP Publication, June, 1969.

[20] Graduate Student Support and Manpower Resources in Graduate Science Education; Fall 1965—66, NSF 68-13; Fall 1967, NSF 69-34; Fall 1969, NSF 70-40.

[21] Enrollment for Advanced Degrees, series 1959 through 1968, National Center for Educational Statistics, Office of Education, U. S. Department of Health, Education, and Welfare.