Becoming a professional physicist: A statistical overview

Fewer Americans are pursuing graduate studies in physics—despite increasing employment opportunities—but the number of foreign graduate students in American universities has increased dramatically.

Beverly Fearn Porter and Roman Czujko

In the past decade and a half, major changes have taken place in patterns of physics-degree production and employment of physicists, and new changes are on the horizon. Industrial opportunities continue to expand and positions in academe are on the verge of reopening as the bulk of physics professors hired in the early 1960s move toward retirement. The number of US citizens completing degrees with the aim of pursuing a professional career in physics, however, remains limited. Our major focus in this article will be on graduate training, a requisite for most professional work in physics, but we will also pay attention to the important role that undergraduate and secondary-school preparation plays and to the varied career options available to individuals with a solid physics background.

Currently there are approximately 30 000 physics PhDs working in the United States. Sixty percent of them are employed directly in physics, and most of the remainder work in related areas of science and engineering. While a significant number of physics baccalaureates and master's-degree holders are produced each year, only a minority of them are employed as professional physicists; most use their physics training as background for a wide variety of technical occupations. The total number of professional physicists is thus estimated to be between 50 000 and 60 000.

Beverly Fearn Porter is manager and Roman Czujko is assistant manager of the Manpower Statistics Division of the American Institute of Physics.

The flow diagram in figure 1 presents an overview of the educational process in physics, following a group of physics students from the freshman year in college to graduation with the baccalaureate, into graduate school and, for a small minority, on to receipt of a PhD. (Continued formal training in the form of postdoctoral positions also plays an important role.) The data that appear in the flow diagram and that are cited in other sections of this article are derived primarily from the annual surveys of physics-department chairs, graduate students and degree recipients that the American Institute of Physics has conducted for more than two decades.

Whether the current level of flow can be maintained during the coming decade is a matter of some concern to the physics community. Between 1980 and 1996 the number of 18–24 year olds—the group from which most college entrants come—will decline by 25%. This decline in the number of young people will have major effects throughout society. Competition among disciplines for the bright young minds of tomorrow is likely to intensify. As the pool of students from which physics students have traditionally been drawn shrinks, the physics community will have to make strong recruiting efforts to maintain even its current pattern of enrollments. The fall in physics enrollments that typified the 1970s has been stemmed primarily by the influx of foreign students at the graduate level and the overflow from engineering and computer science at the undergraduate level. Supply and demand in physics have been in precarious balance during the first part of the 1980s; continuing this balance through the 1990s, when human resources will be diminishing, may prove problematic.

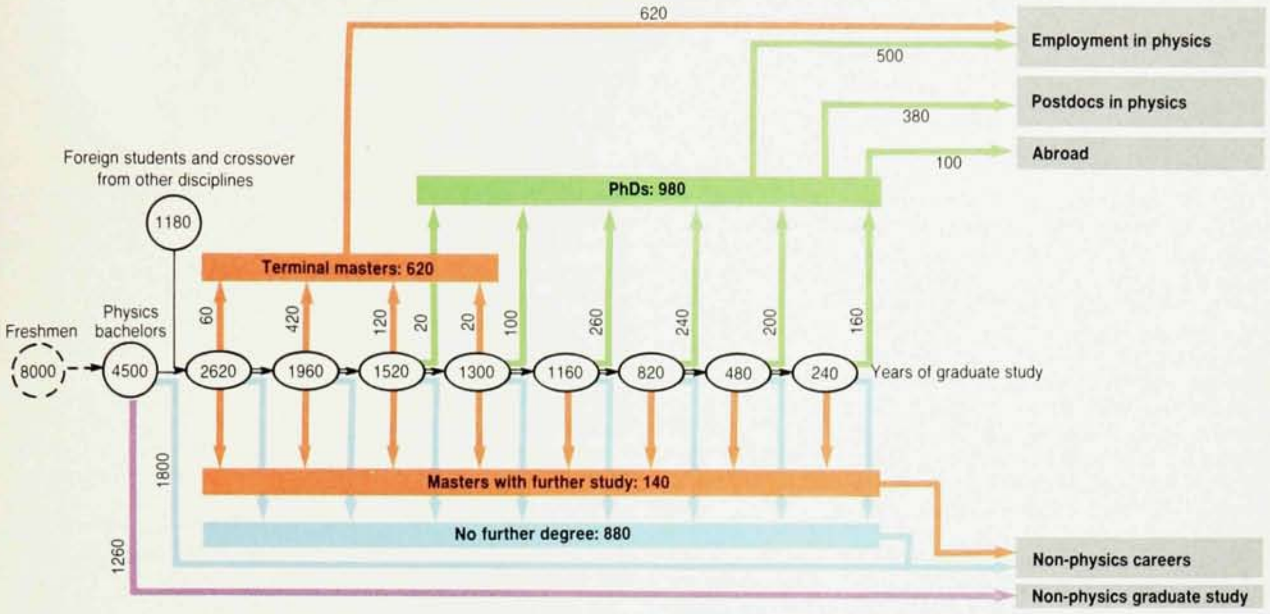
Pre-college physics

The process of selecting a career actually starts before our flow diagram begins—back in secondary school and earlier. For most children, the natural world loses its fascination when studied formally. Only a minority of high-school students ever take physics and only a small proportion of those who do intend to make it a career. In fact only about 5% of high-school physics students plan to major in any of the physical sciences in college.

Physics is considered an advanced course and comes last in the typical high-school science sequence, which usually begins with general science or biology, followed by a year of chemistry. With each additional science course, attrition increases. Thus about three-quarters of all seniors graduating in 1980 had taken at least one year of general science or biology, over one-third had taken chemistry as well, but only about one-fifth had taken[1] physics. In all, nearly half of those who graduated high school in 1980 took no physics and less than two years of science.

High-school students who have taken physics are, as a group, intellectually exceptional. They tend to have high grade-point averages, to perform well on standardized tests and to rank extremely high in mathematical ability. However, not all bright and capable students take physics: Institutional, social and cultural factors affect a student's decision to take physics in secondary school. Physics enrollments vary markedly depending on where the

0031-9228 / 86 / 0600 70–09 / $01.00



Physics education pipeline entering the 1980s. The first year of graduate school for this group of individuals was 1976. These data come from a survey conducted by the AIP Manpower Statistics Division. Figure 1

student goes to school, whether the school is public or private, and whether the student has enrolled in a college preparatory, general or vocational program. Thus over half of all high-school graduates in 1980 in New England and the Middle Atlantic states were in academic programs and about 30% took physics; by sharp contrast, barely one-quarter of the graduates in the East South Central states (Alabama, Kentucky, Mississippi and Tennessee) were enrolled in such programs, and only 12% took physics.

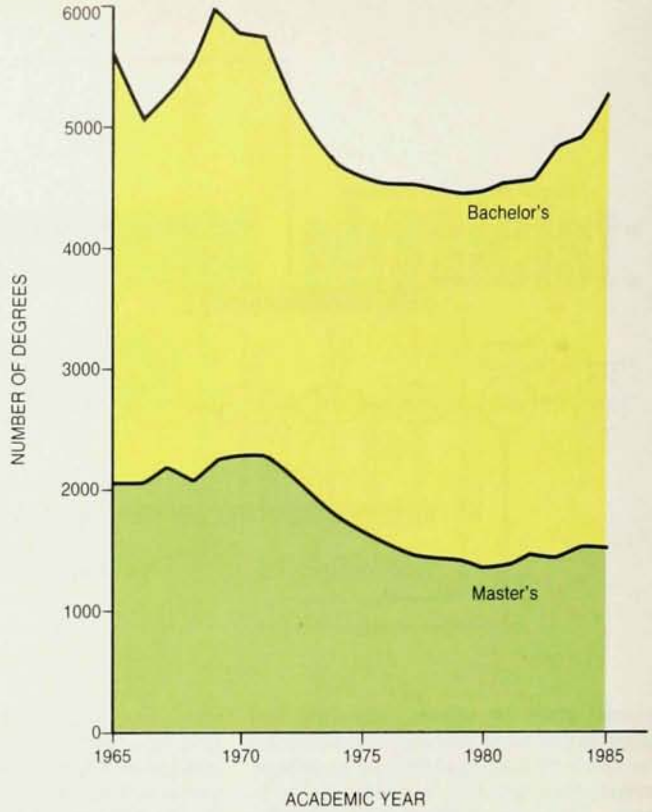
Plans for college study can and do change. Although the majority of college-bound students are not planning careers in physics, it is important to remember that a solid mathematics background and exposure to high-school physics enhance students' chances for success should they change their career goals toward physics: Over the last decade, only 10–12% of the first-year graduate class in physics stated that they had not taken high-school physics.

Undergraduate physics

Over one-quarter of a million college students are enrolled in introductory physics. For most of these students physics is a basic science requirement, one of particular importance for potential engineering, mathematical science and physical science majors, and also for many in pre-med programs and in the biomedical sciences. Physics provides these students with a fundamental analytic framework for understanding and pursuing problems in a wide variety of areas. Fewer than 10 000 of the entering freshmen, however, have any intention of becoming physics majors. The introductory physics course presents these students with a general picture of what a major in physics may involve; it also functions as a screening device, sifting out those students with incompatible interests or abilities. As the college years progress and decisions become more firm, the number of committed physics majors dwindles. In part this is due to the normal attrition process, but primarily it reflects movement to related areas of scientific and engineering study. Although late entry into the physics track is possible, students who first become interested in physics toward the end of their college years are the exception, not the rule: Few first-year students (15%) cross disciplines into physics after receiving bachelor's degrees in other fields, the majority of these students coming from engineering or mathematics.

Regular studies by the American Council on Education indicate[2] that freshman college students in the 1980s are more likely than their counterparts of a decade ago to opt for majors in business, engineering and computer science and less likely to choose majors in the liberal arts and education. The proportion of students choosing to major in the physical sciences has been more stable, but it too has seen a decline since the early 1970s. Study findings indicate that students have become increasingly concerned with their economic well-being. This is reflected not only in the huge growth in business majors, but also in the shift toward engineering and computer science.

For physics, the greatest competition for majors has been with these latter fields. By the time the junior and senior years are reached, potential majors in engineering, computer science and physics frequently have satisfied many of the same basic prerequisites. Which major is chosen at this point may be affected by openings in major programs and upper-level courses, perceived employment opportunities and potential for graduate study. Economic realities make those majors that provide immediately usable technical skills particularly attractive to many able students. The most dramatic increase in majors recently has been in computer science; during the past five years the number of bachelor's degrees awarded annually in this area has more than tripled, going from 7000 to over 24 000. The rapid increase in majors has taxed the resources of many college and university computer-science and engineering departments. Teaching staffs, space and instrumentation have been inadequate to deal with the burgeoning number of students. Caps on engineering and computer-science enrollments have increasingly been imposed; to some extent physics appears to have temporarily been a benificiary of such limitations as some of the students who make up the overflow from these areas opt for a major in physics. Although most of these students have as their goal immediate employment, typically in engineering areas, some will no doubt continue their involvement with physics.



Master's and bachelor's degrees awarded in physics, 1965–85. These data were taken from a survey conducted by the AIP Manpower Statistics Division. Figure 2

Whether the quality of students majoring in physics has changed is a frequently asked question, but few meaningful data exist. According to a survey of physics-department chairmen carried out by the APS Education Committee, physics majors of today are perceived to be of higher quality than computer-science or engineering majors, but not quite as capable as physics majors of a decade earlier. SAT and physics achievement test scores, however, show little variation over the past ten years.

Figure 2 indicates that the number of physics bachelor's degrees awarded annually has, after a long period of decline, increased steadily in the 1980s, from 4500 to over 5100. About 750 college and university departments throughout the country offer physics baccalaureate programs—10% fewer than a decade ago. Nearly 60% of the physics bachelors come from departments that also offer graduate programs. The University of California at Berkeley, the Massachusetts Institute of Technology, Harvard University, Cornell University, Rensselaer Polytechnic Institute and the University of California at Los Angeles were the leading producers in 1984, each turning out 50 or more physics bachelors.

Four-year colleges, however, also played a major role. These range from schools such as Reed College (Oregon) and Carleton College (Minnesota), both of which graduate over 20 physics bachelors annually, to many smaller colleges that award a few physics bachelor's degrees each year. Past trends indicate that degree recipients from the four-year colleges are somewhat less likely than those from universities with graduate programs to continue on to graduate study. They are more likely to seek immediate employment: Over the four-year period 1980–83, 22% of students receiving a bachelor's degree in physics from a four-year college said they planned to pursue graduate studies in physics. By contrast, 38% of those graduating with bachelor's degrees from PhD-granting departments, and 31% of those graduating from master's departments, said they planned to continue their studies in physics at the graduate-school level.

In the 1980s about 45% of graduating physics bachelors planned to enter employment directly after receiving their degrees, a considerably higher proportion than was observed during the previous decade. The availability of both civilian and military positions increased during this time. While some of this employment was directly in physics, in such areas as optics and acoustics, much of it was in engineering-related spheres. The students who take these jobs have been able to apply the skills and approaches developed during their undergraduate physics programs to a broad variety of industrial, military and governmental needs. Describing their current jobs in a recent survey, recipients of physics bachelor's degrees noted involvement in some of the following: research assistance, design, data analysis, technical writing, programming, computer-aided design and manufacturing, technical support and quality control. In addition, a small percentage (3–4%) of employment-oriented bachelors chose to teach in secondary schools.

By 1985 the average starting salary of a new physics bachelor had climbed to nearly $24 000, a doubling since the mid-1970s. Between 1976 and 1984 increases in starting salaries averaged 3% per year above the rate of inflation in effect during that period. Increases would have been higher except that a substantial proportion of physics bachelors in the 1980s—up to 8%—chose military service, where the salaries were somewhat depressed. The small proportion of physics bachelors who entered secondary-school teaching drew much lower salaries, $12 000 and less; increases in teaching salaries have been minimal, not keeping pace with inflation.

Graduate physics

In general, students choosing a physics major are more likely than their engineering and computer-science colleagues to intend to pursue graduate study. In the 1980s over half of the physics bachelors chose this direction, 30% continuing in physics and over 20% entering graduate study in related disciplines. The most popular related fields were engineering, mathematics, earth science and computer science. In addition, a substantial number of physics bachelors have used their background as a first step into such professional areas as medicine and law. Most physics graduate students are US citizens who have come through the traditional route of a strong secondary-school background in both science and mathematics followed by a bachelor's in physics.

Total graduate-student enrollment in physics declined through the 1970s, hitting its nadir in 1980 at under 9650, down nearly 40% from its peak in 1969. The decline in physics graduate-student enrollment during the late 1970s and early 1980s continued despite an improved job market for physicists in particular, and scientists and engineers in general. It would appear that physics-degree recipients and potential physics students were no longer being pushed out of physics so much as being drawn into other stimulating or more lucrative fields.

First-year graduate-student enrollment in physics hit its low in 1979. Although it has increased 3–4% a year since then, and the job market has improved considerably since the early 1970s—albeit in non-traditional areas—the number of first-year physics students who were US citizens continued to decrease until 1983. While there was a big jump in the 1983–84 academic year, the size of the US component of the entering class has not increased in the last two years. The reduced ability of physics to draw US students into graduate school has been a major concern within the community.

The increase in total enrollment during the early 1980s has been due to a sharp increase in foreign-student enrollment. During the 1970s foreign nationals formed about 20% of the graduate student body in physics, or about 600 new foreign students a year. However, in 1985–86 they made up 42% of the first-year graduate class, or about 1250 students. This dramatic change in the graduate-student population has raised a number of serious concerns, which Mark McDermott and Edward Thomas cover in depth in their article on page 48.

Departments that grant PhDs play a critical role in basic research and in graduate-level training. The majority of physics graduate students (about 86%) are receiving their training in one of the 172 PhD-granting departments, each of which has 60 graduate students on the average. Despite the shifts in total graduate physics enrollment, the number of departments awarding PhDs has remained stable. In addition, a higher proportion of new physics PhDs came from the highest-ranked departments in the early 1980s than a dozen years earlier. For example, the seven departments that were rated[3] as the best in training graduate physics students by the 1970 Roose–Anderson study accounted for 13% of the new PhDs awarded in that year. Those departments were still rated[4] the best in the 1982 National Research Council assessment of graduate physics departments and accounted for almost 17% of the PhDs awarded in that year. The departments are those at the California Institute of Technology, Cornell University, Harvard University, the Massachusetts Institute of Technology, Princeton University, Stanford University and the University of California at Berkeley. Similarly, the 20 top-rated departments awarded less than a third of all physics doctorates in 1970, but 38% of those awarded in 1982.

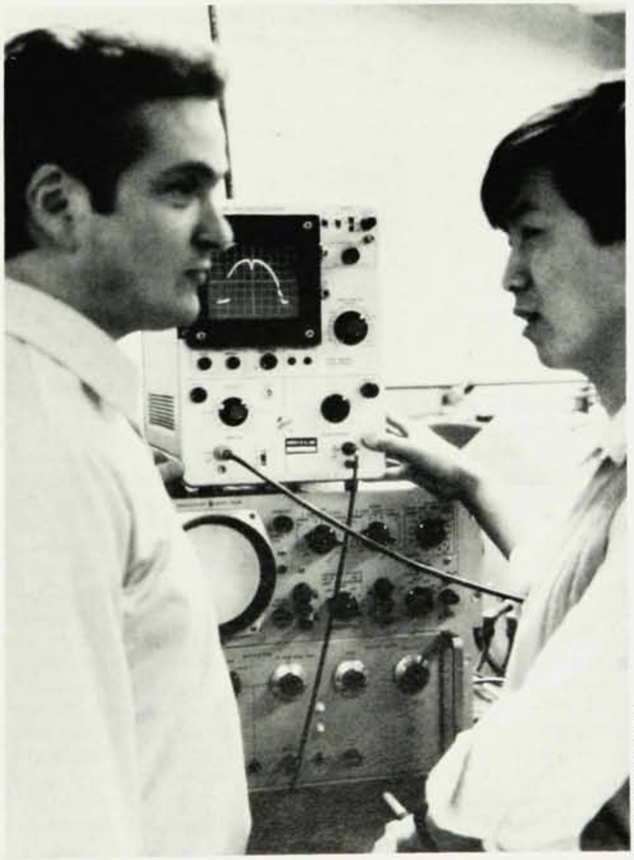
The decline in graduate-student enrollments has hit particularly hard those departments that offer a master's as the highest degree. A dozen years ago there were 129 master's departments; now there are only 90, and they average only ten graduate students each.

Despite the intensive selection process, acceptance into a graduate physics program is not synonymous with success. The attrition rate during the first two years is especially high. Approximately one-fifth of the graduate students drop out during or after the first year; nearly another fifth leave by the end of the second year. In the case of the latter, many terminate their physics education after receiving a master's degree. Typically, less than half of the first-year graduate students in PhD-granting departments go on to achieve doctorates. On the average, completion of a physics PhD requires five or more years of full-time study, often spread over seven calendar years.

The principal exception to these trends are the physics graduate students who arrived from mainland China in the early 1980s. Many of these students were older, already had considerable advanced training in physics and were coming here to complete an education that had been disrupted by political upheavals. Based on preliminary results, it appears that these early students from China complete their doctorates at a very high rate and are getting through in 3–4 years. We believe that the speed with which these students are going through graduate physics training is more a transitional phenomenon than indicative of a long-term trend.

Women are only half as likely as men to take physics in secondary school. Not only is the number of women who enter the physics pipeline at the secondary-school level comparatively small,

continued on page 76


ANDREW GREENBERG

Professor John Sculli and graduate student Jin Wei Zhou (People's Republic of China) discuss a microwave experiment in New York University's graduate laboratory class. Figure 3

Women graduate students

When I started teaching solid-state-physics courses at MIT, nearly 20 years ago, there were very few women at MIT and very few women students in my classes. It was unusual for women students to ask questions in class or to participate in class discussions. As the number of women students increased, they participated more and more, and in very recent years their class participation has become essentially indistinguishable from that of the men. A turning point appeared to occur when the number of women reached a "critical mass" of about 10–15% of the students in a class. But in some other physics courses at MIT the critical mass hasn't been reached.

Although in 1983 only 2.7% of the PhDs working in physics and astronomy were women, many more women are now majoring in physics, both as undergraduates and as graduate students. As recently as five years ago, the AIP Manpower Statistics Division surveys showed only 10% of those earning bachelor's degrees to be women, whereas the class of 1985 had 14% women. Five years ago 6% of the PhD recipients were women; in the class of 1985, 8% were women.

The upward trend for women physicists is even more favorable in universities with a strong science and engineering focus. For example, in 1984 women undergraduates at MIT were 72% as likely as men to be majoring in physics, compared with 44% just five years before. Though this value has fluctuated from year to year by as much as 20%, the long-term increase is statistically unmistakable, and clearly visible in the classrooms.

At MIT we have an especially encouraging milieu for women students. Vera Kistiakowsky, June Matthews and I are all full professors in the physics department, and Margaret MacVicar, also a physicist, is dean of undergraduate education. George Koster, who is the executive officer of the graduate program, is highly supportive of women physicists. In my opinion, the department practices and believes in affirmative action; that is, if we have two applicants of equal ability, we give the benefit of the doubt to a woman. Over the years I have supervised only a few women doctoral students, but nevertheless the percentage of women among my total doctoral students (about 20%) is much higher than the national average.

Though women students today appear to handle the classroom environment on an equal basis with the men, the same may not be true in the lab, based on my own experience supervising graduate thesis research. To obtain some meaningful data on the academic environment for MIT graduate students, the MIT Committee on Women Students' Interests conducted a survey in 20 academic departments. Last year the data were thoroughly analyzed[1] for students in the department of electrical engineering and computer science, where in 1984 there were 642 students, of whom 15.7% were women. This year we analyzed data for graduate students in physics and other departments.

The most striking finding of the survey is the essential similarity between women and men graduate students in physics, a department where women represent 14% of the 297 graduate students. Based on the completed questionnaires of 25 women and 86 men physics graduate students, the differences between women and men were smaller in physics than in any other academic department. Essentially all men and women aspire to complete the PhD degree in physics. They were similarly supported during graduate study (by graduate assistantships, teaching assistantships and fellowship support). Neither women nor men experienced significant difficulty in finding research groups, and both men and women were generally satisfied with the types of research they were doing. Interestingly, the ratings women physics students gave their own research performance showed essentially the same distribution as those of the men; for almost all other academic departments, women graduate students perceived their academic performance to be significantly inferior to that of the men, though quantitative measures such as rates of passing qualifying exams and completing degrees indicated more nearly equal performance. Women physics students were as likely as men to present papers at conferences or to be first authors on publications, and women felt that they had no more problems than men in meeting deadlines, in contrast to patterns in many other academic departments. Perhaps the similar career expectations of men and women physics students and a critical mass of women graduate students has helped to create an approximately egalitarian environment.

Some differences between men and women physics graduate students did, however, appear in the survey. Although men and women spent about the same number of hours per week in academic study, women spent significantly more time (about 10 hours per week more) than men doing research work and less time than men in leisure activities; these findings are consistent with those for the electrical engineering and computer science department. Women found the pace and pressure of graduate physics study more severe than did the men. Women students were more likely than men to feel the pressure imposed by their faculty supervisors or by peers. Women students felt that they got somewhat less help with their research work, both quantitatively and qualitatively, than did the men, and women felt they had slightly more trouble than men in developing research skills. Women students valued the help received from faculty and peers more highly than men did, and especially appreciated the opportunity to participate in group discussions. The "atmosphere" in the research group was more important to women than to men, and women were more apt to feel hindered in their productivity by the lack of availability of equipment or lab space.

With regard to courses, men were more critical than women of below-standard classroom teaching. However, women were more apt to feel that exams did not reflect their true ability than men, consistent with findings in almost all of the academic departments.

Although career opportunities for women in physics have become more numerous, many face the problem of dual-career families. Women graduate students in physics at MIT were twice as likely as men to be married and twice as likely to have children. Surprisingly, men complained more of social isolation than did the women, in contrast to my own perception of the situation a decade ago. Women graduate students found social interactions with peers less of a problem than did men. Over the years, I have noted an unusual number of close friendships among the women physics graduate students and a tendency for them to provide support for each other at stressful times. A small but not insignificant number of women (less than 20%) felt that their sex has hindered their achievement as graduate students in physics. I believe that this number would have been higher a decade ago.

Support by male colleagues has been very helpful to women in physics. It is increasingly common for male physicists to have high regard for their female col-

JENS ZORN

Sarah L. Gilbert is adjusting a ring dye laser used in her thesis research at the University of Michigan.

leagues and to recognize their contributions to physics. In fact, women have been more likely than men to win elections of The American Physical Society, both at the society level and within the divisions. Nevertheless many physics departments in universities and industrial and government laboratories still have no women physicists on their staffs.

In fields where research results can be evaluated quantitatively, women students tend to feel more secure about their performance relative to that of men. I think women who choose careers in physics, a field where they can expect to be significantly outnumbered, are generally more confident than those in other fields. But they nevertheless need reassurance. Big discoveries are usually made by taking risks, and women are less apt than men to go off in unknown, risky directions. Women students like to review their work with their supervisors and seek to please them by doing what is expected of them. I believe that on the average they get less feedback from their male peers and supervisors because men hesitate to criticize women. So if a woman doesn't receive a promotion she expected, she's surprised. These problems suggest the urgent need to train our women students to be even more independent than the men.

Affirmative-action programs advocate that with two otherwise equal job candidates, an employer should choose the woman in preference to the man. Such programs at Bell Laboratories and IBM, for example, have created a positive ripple effect. Consequently these two laboratories have attracted very strong groups of women in solid-state physics. Once women are in good jobs and doing well at them, they provide more role models for younger women to emulate.

Sometimes a male thesis supervisor can't visualize a woman as being suited for one of the better jobs and instead recommends her for an inferior one. But if he overcomes this mental block, places a woman in a good job and finds that she does well, he becomes converted to helping more women and may encourage other men to do likewise.

It is clear to me that on the average, women students at both the undergraduate and graduate levels perform better when their numbers reach a critical mass, which operationally means when there is another woman student in the classroom or in the same or a neighboring research group. Their mutual support and shared experiences enhance their confidence and their ability to cope with problems in the academic environment. Faculty and administrators should appreciate this point.

Graduate-student networks are very successful in helping women research students cope with the social and interpersonal problems they commonly face. (Minority students likewise find these student networks essential.) Faculty members should be sensitive to these problems and supportive of student networks.

I have noticed, both with my own students and through the student survey discussed above, that women graduate students, on the average, seek more attention, feedback and help than men, though individual students differ greatly in this regard. Though faculty should be careful not to treat students as stereotypes, sensitivity to this point might be constructive. At MIT, a doctoral student makes a presentation to his or her thesis committee each term. Women students take the event and the feedback more seriously than men students. The average performances of men and women on the various doctoral exams are almost exactly the same. But the women tend to be more anxious about exams than the men and to feel they haven't done as well, even when the results later turn out to be equivalent. I hear from other MIT faculty women that such self-deprecation is typical of women students from department to department.

I have the impression that young women have a greater fear of failure than young men and prefer asking their peers and superiors for help over working on their own to reduce the possibility of failure. I've observed that significant success at an intermediate stage in the thesis work enhances a woman's confidence level and makes her more independent and productive; this is of course also true of men students. Clearly, effective faculty supervision should lead to early student independence.

Women students have a tendency to be more conscientious and to work longer hours. This characteristic should in the long run be an advantage, though in early graduate-school years it may just be a response to insecurity and the need for more help from peers and faculty. Faculty can be especially helpful in channeling this extra effort into productive areas and in helping a student set better priorities for the use of her time.

I believe it is fair to say that women have come a long way in the last decade in gaining equal access to physics research. It is also fair to say that if the opportunities for further gains in the next decade are taken, we will see better use of talent and more rapid progress in physics.

After carrying out the survey of graduate students at MIT, we became aware of a similar survey that had been conducted[2] at Stanford University. It is impressive that though the questions and approaches of the two surveys were substantially different, they reached similar conclusions with regard to the overall similarities between women and men graduate students, as well as with regard to differences. I hope that the greater anxieties, pressures and insecurities experienced on the average by today's women graduate students will soon vanish as more women enter and contribute importantly to physics. Though much has been gained in the past decade, there is no doubt that much remains to be done.

References

1. M. S. Dresselhaus, IEEE Trans. Educ. **E-28**, 196 (1985).
2. L. Zappert, K. Stansbury, "In the pipeline: A comparative analysis of men and women in graduate programs in science, engineering and medicine at Stanford University," Campus Report (Stanford Univ.), 14 November 1984, p. 11.

MILDRED S. DRESSELHAUS
Massachusetts Institute of Technology

but female students are more likely than their male colleagues to drop out of physics training at different points along the way. Although one-third of all high-school graduates who have taken physics are women, only 14% of the physics bachelor's degrees are awarded to women. Thus it is not surprising that women represent a small percentage of physics graduate students and that fewer than 8% of the new doctorates were earned by them (see box on page 74). In short, physics has had little success in attracting female students early in the education process, and even less success in keeping those exposed to it.

Although physics has a poor track record in attracting female students, its ability to attract and keep indigenous minorities is even worse. While 11% of high-school graduates are black, only 8% of those taking physics in secondary school are black. This small pool is further constricted with advanced training. Only 2.5% of the bachelor's degrees in physics go to blacks and an even smaller percentage of the physics doctorates are earned by blacks. The scenario for Hispanics is no better. One major difference between women and minorities, however, is that women have been making up an increasing fraction of all scientific and engineering fields, while minorities continue to lag behind. It appears, in fact, that many of the gains made in the early 1970s in minority enrollments across the board have been slipping away lately. As the Southern Regional Education Board notes[5] in a recent report, since 1976 there has been a major drop in the rate at which black students enroll in high school and in the rate at which those who graduate go on to college. The board warns that because "the proportion of blacks in the population, particularly the school-age population, is rising, a long-term failure to achieve increased enrollment and completion rates on the part of black students will threaten the well-being of the social, economic and political structures of our society."

Over 9000 physics graduate students receive financial support for their graduate studies. About 40% of them are on research assistantships, more than one-third are on teaching assistantships and another 8% are supported by fellowships. While the fellowship numbers are half what they were in the early 1970s, they have been stable during the 1980s and tend not to change with the number of years of graduate study. Most fellowships are awarded to students in doctoral programs that do not require a formal master's thesis en route. In any given year 150–200 assistantships for first-year students are still unfilled by the beginning of the academic year. These unfilled assistantships occur disproportionately in master's departments and in PhD departments in the Southern and Mountain states.

Trends in assistantships vary substantially with the student's level of training. As illustrated in figure 4, over half of all first-year students are teaching assistants and only one in eight is a research assistant. As the students advance through the system, these sources of support shift. By the time of PhD candidacy, most are research assistants and only one in six is a teaching assistant. Also, as a result of the processes of selection and attrition, approximately 90% of graduate students beyond the second year are on either assistantships or fellowships.

Master's-degree recipients

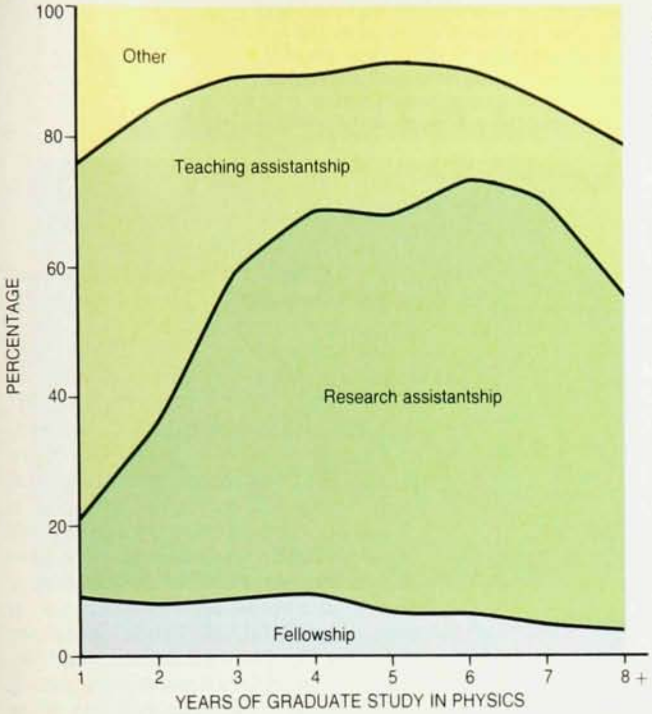
Most physics students who continue on into a second year of graduate study obtain master's degrees. About 1400–1500 master's degrees in physics were awarded yearly in the early 1980s. For many students, a master's is simply a stepping stone en route to a PhD. For about 40% of second-year students, however, it is the final physics degree. While a few of these masters move on to advanced graduate study in related science and engineering areas, the majority use their additional physics training to enter employment, particularly in industry.

Students who terminate their physics training with master's degrees are more likely than those who continue on for PhDs to be women, to have received their bachelor's degrees from departments without doctoral programs and to have done their graduate work on a part-time basis. A large proportion of such "terminal masters" name off-campus employment as their major source of support, and up to one-quarter of them work full time to support their graduate studies. The major subfields of study for these students are solid-state physics, applied physics and optics.

Whether job opportunities are better for graduates with physics master's degrees than for physics bachelors is a question frequently posed. The situation has been mixed over the years. In contrast to that for PhDs, the market for lower-degree holders is typically local, and employment opportunities may vary considerably by region and over time. In general, master's-degree recipients take somewhat longer than bachelor's-degree recipients to obtain satisfactory employment offers, perhaps because their expectations are higher. Once employed, however, they consistently receive higher starting salaries than bachelor's-degree recipients, reflecting the more specialized skills

Number of physics PhDs

Year	Condensed matter	Elementary particles	Nuclear	Atomic–molecular	Plasma	Astrophysics	Optics
1969	360	220	188	127	61	55	16
1970	402	258	212	152	85	63	30
1971	442	278	227	124	86	54	25
1972	393	198	234	150	93	66	31
1973	400	222	182	122	74	67	33
1974	351	148	144	120	57	77	26
1975	319	124	130	138	53	71	33
1976	282	128	96	116	75	72	50
1977	257	138	93	105	72	57	31
1978	243	135	77	88	68	74	33
1979	243	119	103	72	62	57	46
1980	202	117	73	69	59	69	43
1981	250	117	62	65	65	59	54
1982	235	118	53	96	69	50	42
1983	221	136	90	71	72	65	50
1984	258	138	72	77	73	56	53



Financial support for physics graduate students by number of years of study: The number of fellows tends to remain constant; most teaching assistants become research assistants as their studies progress. These data were taken from a survey conducted by the AIP Manpower Statistics Division. Figure 4

many of them have developed. In industry, the major employer of both groups, this differential has been running around \$5000 in recent years; by 1984 the starting industrial salary for new holders of physics master's degrees had risen above \$30 000.

PhD candidates

The normal pattern for the graduate-level education of a professional physicist consists of two years of course work followed by three or more years of research and the writing of a doctoral dissertation. After a graduate student has completed the formal course work and advanced to PhD candidacy, specialization in a physics subfield begins. As a rule, twice as many graduate students work in experimental as in theoretical physics. This ratio, however, varies strongly with the research subfield. Thus, PhD candidates whose dissertations are in optics, biomedicine, condensed-matter physics, or atomic and molecular physics are most likely to be working on experimental problems. By contrast, dissertations in elementary particles, plasma physics and astrophysics are more likely to center on theoretical issues.

The table on page 76 indicates that most PhDs are earned in the traditional physics subfields. Thus, about one-quarter of the doctorates are awarded in condensed-matter physics, one-eighth in elementary-particle physics and about 7% each in atomic and molecular physics, nuclear physics, plasma physics and astrophysics.[6] These figures represent a redistribution among the areas of concentration from the high-doctorate-production days of the early 1970s. While production is beginning to climb again, the number of PhDs awarded is still nearly 40% below its peak (figure 5) and this has had various effects on the individual subfields of physics. Plasma physics and astrophysics have suffered only minor declines, while optics—although a comparatively small field—has gained a significant number of PhDs. By marked contrast, nuclear physics is producing only a third as many doctorates as it did in 1972. In part, these shifts in areas of specialization reflect changes in the employment opportunities for entry-level physicists. As we discuss below, traditional academic jobs remain difficult to find, while industrial opportunities continue to abound.

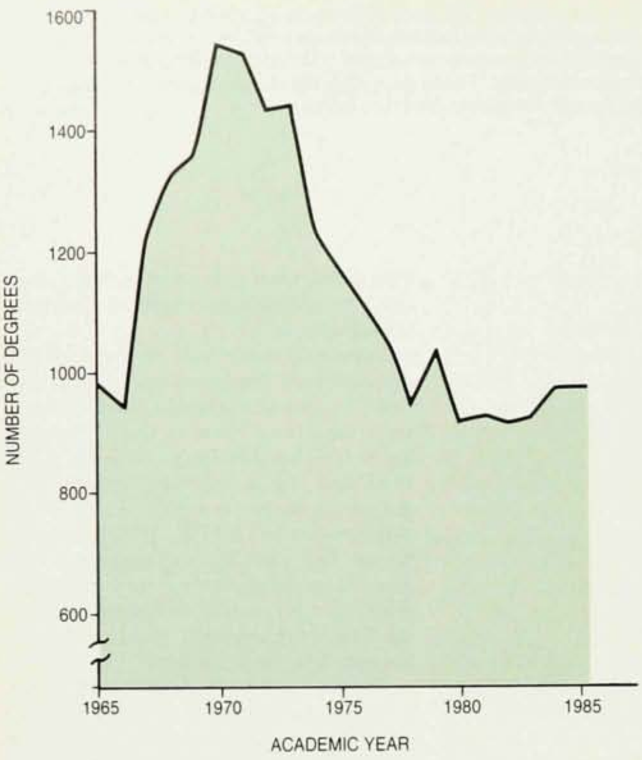
Postdoctoral positions

Formal training does not terminate with the PhD for many physicists, but continues for one or more years in the form of temporary postdoctoral positions. Over 40% of current PhD recipients in physics take such positions. As noted[7] in a report published several years ago by The American Physical Society, postdoctoral positions provide "the new PhD with an opportunity to further his research experience, to delve more deeply into complex problems and frequently to work with leading research figures in his area ... freed from teaching and administrative responsibilities." Although in difficult economic times such as the early 1970s some of these positions were simply low-paid substitutes for research employment, they also continued to serve their traditional function of advanced training.

Currently, over half of the 1300 US postdoctoral positions in physics are held[8] by foreign citizens. Some of these physicists have come to the US specifically for this advanced training after receiving PhDs abroad; others—the majority—have received PhDs from universities in the US. For this latter group the postdoctoral position also provides continued residency in the US while more permanent decisions regarding employment, either here or abroad, are being made.

Approximately three-quarters of the postdoctoral positions are provided by academic institutions, with most of the remainder being offered by the national and government laboratories. While postdoctoral positions are offered in many subfields of physics, they are perhaps most traditional in elementary-particle physics, astrophysics and biomedical physics. Individuals holding postdoctoral positions in the first two of these areas and such subfields as condensed-matter physics, nuclear physics and plasma physics are frequently continuing or expanding on research begun during their dissertation years. The few entry-level academic staff positions currently available in these traditional physics areas at research-oriented universities frequently require good postdoctoral backgrounds. The same is true of many of the openings at the national laboratories. In contrast, physics PhDs holding postdoctoral positions in such areas as biophysics and chemical physics frequently have moved out of their dissertation subfields and are using the postdoctorals primarily to develop new skills or to use their skills in new areas.

Some physics PhDs moving into industrial employment have spent time in postdoctoral positions; however, this is not the traditional route to industrial employment. When further advanced training or new skills are needed in this sphere, they most frequently come from on-the-job training. In the late 1970s, in fact, there was even some question as to whether advanced postdoctoral training might be a liability for those entering industrial employment. Although the answers were not straightforward, studies conducted during that period indicated that many physics PhDs entering applied indus-



Physics PhDs awarded between 1965 and 1985. The leveling-off indicated for the 1980s is due primarily to the large influx of foreign students into American universities. These data were taken from a survey conducted by the AIP Manpower Statistics Division. Figure 5

trial work following a postdoctoral position felt that they were at somewhat of a career disadvantage.

The majority of physics PhDs emerging from the graduate-school pipeline directly enter employment. Research remains the primary focus, although it is increasingly combined with development activities. About one-quarter of new PhDs and a majority of those who complete postdoctoral training assume academic positions, both at universities and at four-year colleges. Some of these are tenure track, but a number of others are nontenured research-scientist positions heavily dependent on Federal funding. Regular academic staff opportunities were still scarce in the 1980s, a reflection of the large number of physics faculty awarded tenure in the previous decades.

Currently over half of the new physics PhDs who choose immediate employment are engaged in industrial work, a substantially higher proportion than observed in earlier years. The steady growth in industrial employment of physicists reflects both the increasing opportunities in the industrial sphere and the virtual closing of academic doors throughout much of the 1970s. The slowing of academic hiring has produced an aging physics faculty, most of whom are not due to retire for another decade. When retirement does increase and the tight academic market eases in the 1990s, universities may well find themselves in direct competition with industry, which has become the predominant employer of new physics PhDs.

Starting salaries for new physics PhDs average over \$30 000; beginning industrial salaries are nearing the \$40 000 mark. In less than seven years, starting salaries have doubled; regular annual increases averaged more than 6% above the rates of inflation in effect during that period. Unemployment rates for physicists are negligible. Clearly the period of limited employment opportunities for PhD physicists is long past.

Physics, more than any other scientific discipline, has traditionally trained practitioners not only for work within the field but for employment in a multitude of developing science and engineering areas. Currently about 30% of physics PhDs move out of physics within three years of obtaining their degrees—into systems, electronic and computer engineering and interdisciplinary areas such as materials research, geophysics and biophysics. Much of this mobility is related to the increased presence of physicists in industry, where applications of physics research easily move across disciplinary barriers. There appear to be ample opportunities for physicists to work at the cutting edges of interdisciplinary and emerging areas, frequently with superior facilities and major salary differentials. The extent to which this mobility out of the field will dampen when traditional academic positions reopen is unclear. The question may be, will bright young PhDs be available to fill these positions or will the attraction of neighboring fields, which has been strong during the past decade, continue to predominate?

Should shifting employment patterns have an effect on the manner in which PhD physicists are trained? This question has been raised frequently in recent years as more and more physics PhDs have entered industrial employment. Dissertation subfields in physics do not directly track subfields of employment. Some employers have suggested that more hands-on experience and applied-physics preparation would be useful, as Bruce Schechter describes in his article on page 58. Even so, physicists have moved among subfields within physics and into other areas of science and engineering with remarkable ease, an illustration perhaps of the flexibility provided by their basic-research training. The analytic problem-solving perspective that new physics PhDs bring with them has proven particularly useful in industry, with its complex and changing demands.

* * *

Special acknowledgment is given to Susanne Ellis (AIP Manpower Statistics Division), who was responsible for the four surveys from which many of the data in this article are derived.

References

1. *High School and Beyond: A National Longitudinal Study for the 1980s*, Natl. Ctr. for Education Statistics, Dept. of Education (1984).
2. A. W. Astin, K. C. Green, W. S. Korn, M. Schalit, *The American Freshman: National Norms for Fall 1985*, Am. Council on Education, Los Angeles (1984).
3. K. D. Roose, C. J. Anderson, *A Rating of Graduate Programs*, Am. Council on Education, Washington, DC (1970).
4. *An Assessment of Research-Doctorate Programs in the United States: Mathematical and Physical Sciences*, NRC (1982).
5. *The Enrollment of Black Students in Higher Education: Can Its Decline Be Prevented?* Southern Regional Education Board, Atlanta, Ga. (1985), p. 2.
6. *Summary Reports, Doctorate Recipients from United States Universities*, NRC (1969–84).
7. *The Transition in Physics Doctoral Employment 1960–1990*, APS, New York (1979), p. 17.
8. *Academic Science–Engineering: Graduate Enrollment and Support, Fall 1983*, report no. 85-300, NSF (1985). □