Women in physics: unnecessary, injurious and out of place?

Despite eight years of affirmative action more changes are necessary to create an atmosphere where women are equally accepted in the field of physics.

Vera Kistiakowsky

The subtitle for this article is taken from a Strindberg essay written at the end of the 19th century opposing the appointment of the mathematician, Sonia Kovalevsky, to a professorship at the University of Stockholm, in which he attempts to prove "as decidedly as that two and two make four, what a monstrosity is a woman who is a professor of mathematics, and how unnecessary, injurious and out of place she is".[1] It is certainly a much more extreme statement than anything likely to be voiced publicly today but it does vividly and tersely encapsulate many of the opinions that have been expressed to me in much more veiled and discursive form over the last ten years. Largely because of these continuing though muted attitudes I have accepted an invitation to write this article for PHYSICS TODAY. I will very briefly sketch the history of women's participation in physics as a background to the current situation and then discuss some statistical information about women physicists in the recent past and present in the United States. It will come as no surprise that the percentage of physicists who are women is small and that their employment patterns are different from those of men. I will discuss the possible reasons for this situation. Finally, I will comment briefly on recent changes and what expectations one may have for the future.

History from Arate to Whiting

Since physics as we know it today only emerged at the beginning of the seventeenth century, I should perhaps start my mention of women's participation with this period. However, having grown up with a pre-history of science, that of the Greek natural philosophers, in which women were conspicuous by their absence, I can not resist remarking that there is evidence that women natural philosophers did exist. Arate of Cyrene was supposedly a contemporary of Socrates (5th century BC) who taught and wrote on natural philosophy in Attica.[1] She was, however, not the first; women were equal members of the Pythagorean school in the 6th century BC[2] and Theano, the wife of Pythagoras, assumed the leadership of the school after his death.[3] Moving forward a millennium we find Hypatia, a neo-Platonic philosopher and mathematician who spent the last part of her brief life teaching at the university in Alexandria at the beginning of the 5th century AD.[3] In the middle ages the physical sciences languished; and, although the convents produced a number of notable women scholars, their writings were mainly in the areas of the biological sciences and medicine. However, one of these women, St Hildegard, the Benedictine Abbess of Bingen-on-the-Rhine in the 12th century AD, wrote on a heliocentric universe in which "the sun attracts the heavenly bodies as the earth attracts its inhabitants," an early intimation of gravitation.[1]

Unfortunately, the beginning of the scientific age coincided with a wave of opposition to the education of women in Europe and Great Britain. The few women who contributed to physics were either of high enough social status that they could follow their inclinations despite the general prejudices of the times, like Emilie de Breteuil, Marquise du Chatelet and Laura Bassi, of the early 18th century[1,3], or like Mary Somerville (early 19th century), who was known principally as a mathematical astronomer, self-educated over the opposition of their families. This situation remained about the same until the end of the 19th century.

In the US the situation of women improved somewhat more rapidly than it did elsewhere. The Boston public schools were started in 1642, and although they did not admit girls until 1789, this occurred considerably earlier than was the case in Europe and Great Britain. Many secondary schools in the US were opened to women at the beginning of the 19th century, apparently because more school teachers were needed. Finally, in 1837, two hundred and one years after the founding of Harvard College, Oberlin College admitted the first three women to the bachelor's degree program.[5] Due to both the economic and feminist pressures for women's education, a few more male institutions became coeducational, and several women's colleges were established. However, the number of these institutions remained small until after the Civil War, and many of the women's colleges were of inferior quality. The lack of greater change in opportunities for women could be considered part of a general pattern where educational reforms which included the establishment of scientific, technical and graduate education remained blocked until after the war ended in 1865. Then both academic science and women's education blossomed and the numbers of women scientists increased. We know of no woman recognized as a physicist prior to this period; the earliest woman scientists in the US of whom there is a record were a botanist, Jane Colden (1724–66), and an astronomer, Maria Mitchell (1818–89). Two of the first women to achieve recognition as physicists were Margaret E. Maltby (1845–1926) and Sarah F. Whiting (1847–1927),

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"I want you to know, gentlemen, that at this moment I feel I have realized my full potential as a woman."

Drawing by Frantscino; © 1973 The New Yorker Magazine, Inc.

who taught at Barnard and Wellesley College respectively.[4]

Women physicists in the USA

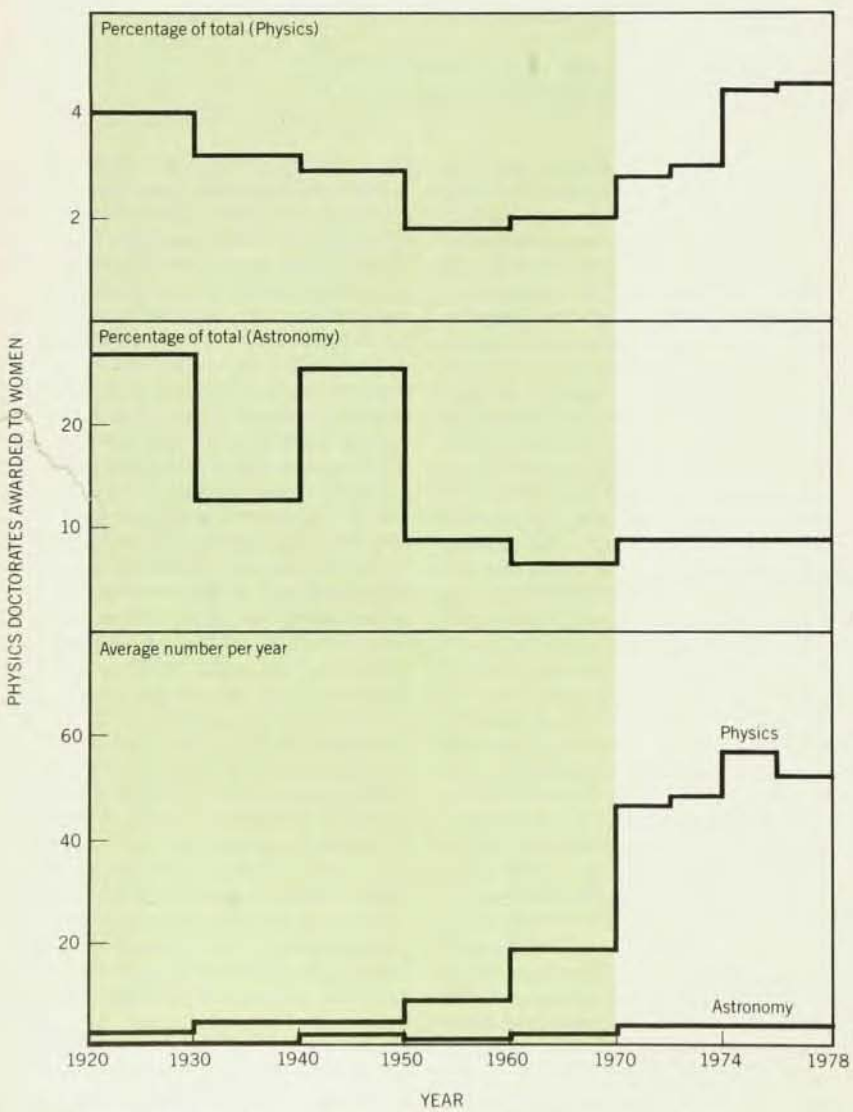
Margaret Rossiter[6] has given us a very detailed picture of the situation of women scientists in the US at the beginning of the 20th century using the information given for individual men and women in the 1906, 1910 and 1921 editions of "American Men of Science." Among the physicists included in her sample are 23 women, a number that corresponds to 2.6% of the total number of physicists listed. It is not surprising that 11 of these women received their undergraduate education at women's colleges and that 21 of them were employed at women's colleges at some point in their career. These colleges were both an important source and the employer of a majority of academic women at the beginning of the century. Three of the women also spent extended periods of time as secondary school teachers, whereas this was true of none of the men, another difference common in fields other than physics. None of the women physicists had married. It was generally accepted before 1920 that the pursuit of a scientific career required a single-minded determination, which was incompatible with marriage for a woman. A wife was expected to be totally dedicated to that role and to subordinate her interests and activities to the aspirations of her husband.

By the end of the 19th century the PhD had become the scientific union card, and one may begin to trace the participation of women in physics through the percentage of doctorates awarded to women. In Rossiter's sample, 65% of the women and 71% of the men physicists had PhD's. The percentage of physics doctorates awarded to women increased until 1920, a year in which four women received physics PhD's, 19% of a total of 21.[7] The figure on page 34 gives the number and percentage of physics doctorates awarded to women from 1920 to 1978. The corresponding numbers and percentages for astronomy doctorates are also shown because some of the statistical information I will discuss later in this paper is available only for physicists and astronomers lumped together. It can be seen in the figure that the percentage dropped steadily to a low of 1.8% in the 1950's. The numbers of women physicsts increased in this period, but less rapidly than was the case for men. The reasons for this pattern, which is also seen in most other fields, include the subsiding of the first wave of feminism, which exhausted itself on the achievement of suffrage and universal education in the early 1920's. The improvement of women's role in marriage, which also occurred, was not far-reaching enough to make marriage and career generally compatible. The depression that followed was a further deterrent to the aspirations of women; any money available in a family was usually dedicated to the education of the men, who were still considered the primary breadwinners. And in World War II, although women went to work by the millions, graduate study did not seem an appropriately patriotic endeavor. After the war the massive return-to-the-home propaganda campaign presented the women of my generation with a clear and explicit message—husband and family came first and this should be the exclusive concern of women. The decline continued, reaching a low point in the 1950's. In the 1960's, when physics was mushrooming in post-Sputnik euphoria, the percentage of doctorates awarded to women began to increase, probably due to the many changes of that decade which affected social attitudes, and marital and economic patterns. These include the resurgence of the feminist movement which became increasingly vigorous in the later 1960's, leading to further changes reflected in the continuing increased percentages for women in the 1970's.

The 1973 New Yorker cartoon in the figure on this page very accurately portrays this change. The phraseology of its caption is that used to describe the womanly woman who was the paragon in the previous three decades, which sounds wildly inappropriate when applied to success in a mostly masculine field.

This renaissance of feminism was felt by professional women and led, among other things, to studies of the situation of women in the various professional societies in the early 1970's. In The American Physical Society, Brian Schwartz started the ball rolling. Through the Forum on Physics and Society, he organized a session on Women in Physics, chaired by Fay Ajzenberg-Selove, at the 1971 Annual Meeting of the APS. This was a most thought-provoking occasion, not only because of the presentations by the speakers but also because of the less than informed comments from some members of the audience. The most memorable was the statement, "If I had been married to Pierre Curie, I would have been Madame Curie," by a well-known male physicist. This session inspired a letter cosigned by 20 women physicists requesting that the APS Council establish a committee on women in physics to study their situation and make recommendations for appropriate actions by the Society. At the 1971 spring meeting in Washington the Council did establish such a committee and with the help of Jerome B. Wiesner, president

of Massachusetts Institute of Technology, it obtained the Sloan Foundation grant that made the study possible. A report and a roster containing the names of women physicists were prepared and submitted to the APS Council at the 1972 annual meeting.[7] Seven years of affirmative action later we are all, perhaps, accustomed to the statistics, but at the time it was novel information. For example, an eminent physicist whom I encountered at an information-gathering session of the Committee on the Future of the APS asked me why the Committee on Women in Physics was wasting its time on a study when there were only two women physicists in the United States and both of them were happy. Obviously, he was aware that there were more than two. However, most physicists would have numbered their women colleagues in the tens and not in the hundreds, which was the outcome of the study. He was also misinformed on the question of happiness. One of the women he had in mind was a member of the Committee, the other was actively supporting it, and neither was happy with the status quo. Only two of the 451 doctoral women physicists who responded to the survey indicated any lack of enthusiasm for the work of the Committee, and a majority of the respondents were strongly supportive. This interest of many women physicists in the issues raised has continued to be active and the Committee has therefore continued with a changing membership carrying out a variety of projects.



Doctoral degrees awarded to women. From 1920 to 1970 the numbers are averaged over and the percentages are calculated for each decade. From 1970 to 1978 the physics numbers are averaged over and the percentages are calculated for each two year period. The astronomy number is averaged over and the percent is calculated for the eight year period. These data are taken from "Doctorates Awarded from 1920 to 1971 by Subfield of Doctorate, Sex and Decade," National Research Council (1973) and "Summary Report (Year). Doctorate Recipients from United States Universities," National Academy of Sciences, for the Years 1972 through 1977.

Let me briefly summarize the findings of the 1971 study. It described a situation that was little changed from that described by Rossiter for the period before 1920. Women physicists in both studies were employed mainly in academia, were found more frequently in the lower faculty ranks and non-faculty positions, and worked at the less prestigious institutions. In both studies a larger percentage of women than of men were found to suffer from involuntary unemployment and under-employment, and the average salaries of employed women were lower. An interesting difference between the situation in 1971 and that before 1920 is that 60% of women physicists in 1971 were married, compared with none in 1920. The APS study drew the conclusion that overt discrimination, prevalent societal attitudes and the practical problems of combining career and marriage had played important roles in causing the differences observed between the women and men who had chosen physics as a career.

The situation in the 1970's

Let us look briefly at the statistics for the participation of women in physics during the last eight years. The figure on page 34 shows that the number and percentage of doctorates awarded to women have continued to increase since 1971 but the percentage increase is much more dramatic. This has been partly due to the continuing increases in the number of bachelor's degrees in physics awarded to women (see the figure on page 36) and also because the fraction of women students leaving graduate study with only a master's degree has decreased. Thirty-three percent of the women receiving physics baccalaureates in the 1950's went on to a master's degree within an average period of two years and 37% did so in the 1960's. The ratio of the percentages is 1.12, indicating only a small (12%) increase. However, the comparable figures for those completing a doctorate an average of seven years later were 10% for those receiving baccalaureates in the 1950's and 17% for the 1960's, a 70% increase.

The percentage of the doctorates awarded to women in the various subfields of physics in the periods 1960–69 and 1970–76 were not significantly different from those for all subfields combined in those periods, respectively 1.9% and 3.5%. This percentage includes astrophysics in the later period ($4.9 \pm 1.0\%$). The percentage of the doctorates in astronomy awarded to women in 1970–76 was significantly higher ($8.4 \pm 1.4\%$), as was the percentage of doctorates in astronomy and astrophysics combined in 1960–69 ($6.4 \pm 1.2\%$). However, since the astronomy doctorates were only about 5% of the number awarded in astronomy and physics combined in both periods the statistical information for these combined

fields will not be significantly different from that for physics alone.

Some further comments are possible concerning the physics and astronomy doctorates of recent years. For example, 63.3% of the women and 63.5% of the men receiving doctorates in 1974 through 1977 were married, reflecting the very major change in attitudes toward the possibility of combining careers and marriage since the beginning of this century.[8] In the years 1973 through 1975 11% of the black and American Indian doctoral recipients were women, a percentage which is based on very small numbers and is, therefore, not significantly different from the corresponding percentage for whites, of whom 3.4% were women. However, the percentage of foreign citizens awarded doctorates in the years 1974 through 1977 who were women is 7.7%, which is significantly higher than 4.2%, the corresponding percentage for US citizens.[8] In this period both the median age when receiving the doctorate and the median length of time between baccalaureate and doctorate were the same for men and women.[8]

The percentage of doctorates in the physics/astronomy labor force (those employed or seeking employment) who were women rose from 2.0% in 1971[7] to 2.5% in 1975.[9] The percentage of women who were foreign-born US citizens or foreign citizens in the labor force in 1975 was 21.8%, which is not different within the uncertainties from the percentage, 20.6%, for men.[9] The table at the top of this page indicates that the percentage of women employed part time or full time was 89% in 1973, whereas the similar percentage for men was 97%. The percentage of those unemployed and seeking employment was about four times greater for women than for men. Approximately eight times more women worked part time, but in 1973 about half of them were seeking full-time employment. In 1977 the percentage of women doctorates in physics and astronomy in the labor force who were seeking employment was 5.7%, still much higher than that for men.[10] However, between 1973 and 1975 the percentage of women doctorates in physics and astronomy who were working part time and seeking full-time employment dropped from 8.4% to 2.7%, although it was still more than three times greater than the corresponding percentage for men.[11]

The table at the bottom of this page gives the distribution of men and women physicists and astronomers with respect to type of employer. The percentage of women in educational institutions in 1973 was greater than that for men, but decreased from its 1971 value of 77%, with corresponding increases in the percentages in government and nonprofit employment.[7] The percentage of men in industry decreased from 26% in 1971, whereas that of women increased very slightly.[7] It should be noted that the percentages of doctoral women who taught in junior colleges and secondary schools in 1973 are larger than those for men. However, a study of women high-school physics teachers showed that these women are a small minority and, in fact, most women high-school physics teachers do not have any physics degree.[12]

The median salaries for men and women for the various types of employers were consistently lower for women by 5 to 20% in 1971, 1973 and 1977.[7,10] In any number of studies it has been found that further subdivisions of the sample does not remove the differences. For example, in 1977 the median salaries for all age groups of women doctorates including the youngest were significantly less than those for men.[10]

Because the major employer of physicists is the educational institution, it is interesting to examine the situation there more closely. The table on page 37 presents the number and percentage of women in various types of physics departments in 1971–72 and in 1978–79. It is seen that the percentages for the total of all types of departments have decreased except for assistant professors and "other." In the PhD-granting departments the changes are not significant except for assistant professors. The increases in the percentages in the "Top Ten" physics departments are particularly striking but should be interpreted with caution since seven of the eleven women are at MIT. Similarly, although 7.3% (ten women) of all the assistant professors appointed between 1972 and 1979 in these ten departments were women, the figure drops to 4.4% (five women) for the nine departments excluding MIT. It should be noted that except for the "Top Ten" category, the institutions in the various categories are not exactly the same in the two years studied, and thus the changes in percentage and number are a composite of changes in degree-granting type and changes in the employment of women. Eight years of affirmative action can hardly be said to have caused major changes in the presence of women on physics-department faculties. Nonetheless, there has indisputably been an improvement for women at the assistant-professor appointment level.

In summary, the predominant impression gained from looking at the statistics is that there has not been very much change since the beginning of the century or since the 1971 APS study. The exceptions are the continuing increase in the percentage of PhD's awarded to women and presence of a few more women on the faculties of departments in research universities.

Reasons and remedies

If one wishes to speculate on the future it is important to consider the reasons for the low participation of women in physics and for the differences between the careers of men and women. I will discuss various reasons that have been suggested, grouping them into five categories: innate ability, environment, discrimination, career conflicts, and the Matthew effect. I will also comment on remedies.

The question of an insurmountable difference in innate ability between the sexes has become somewhat of an unmentionable topic these days, thanks to the raised level of public sensitivity. There are few Lionel Tigers who will argue in the public press that since males dominate the baboon society, females must be subordinate in human society.[13] However, there are many studies investigating sex differences in various attributes, and it is necessary to deal with this topic by taking a close look at the situation concerning innate and unalterable sex differences. It has been difficult for a non-specialist to get a clear picture of the cumulative outcome of such studies due to the prolixity of the experimental situation, but there is now an encyclopedic compilation and discussion of this research by Eleanor Maccoby and Carol Jacklin.[14] Although there is not universal agreement with all of the conclusions drawn by the authors, their overall picture is generally accepted and disagreement is focused on interpretation of experiments in certain areas. The tabular arrays of experimental results presented in Mac-

Employment status of Men and Women PhD Physicists and Astronomers in 1973

Employment Status	Men	Women
Full-time	94%	66%
Part-time	1.7%	16%
Part-time seeking full-time	0.8%	7%
Unemployed seeking employment	1.7%	7%
Unemployed not seeking, retired, other	3.0%	11%
Total number in sample	17 481	471

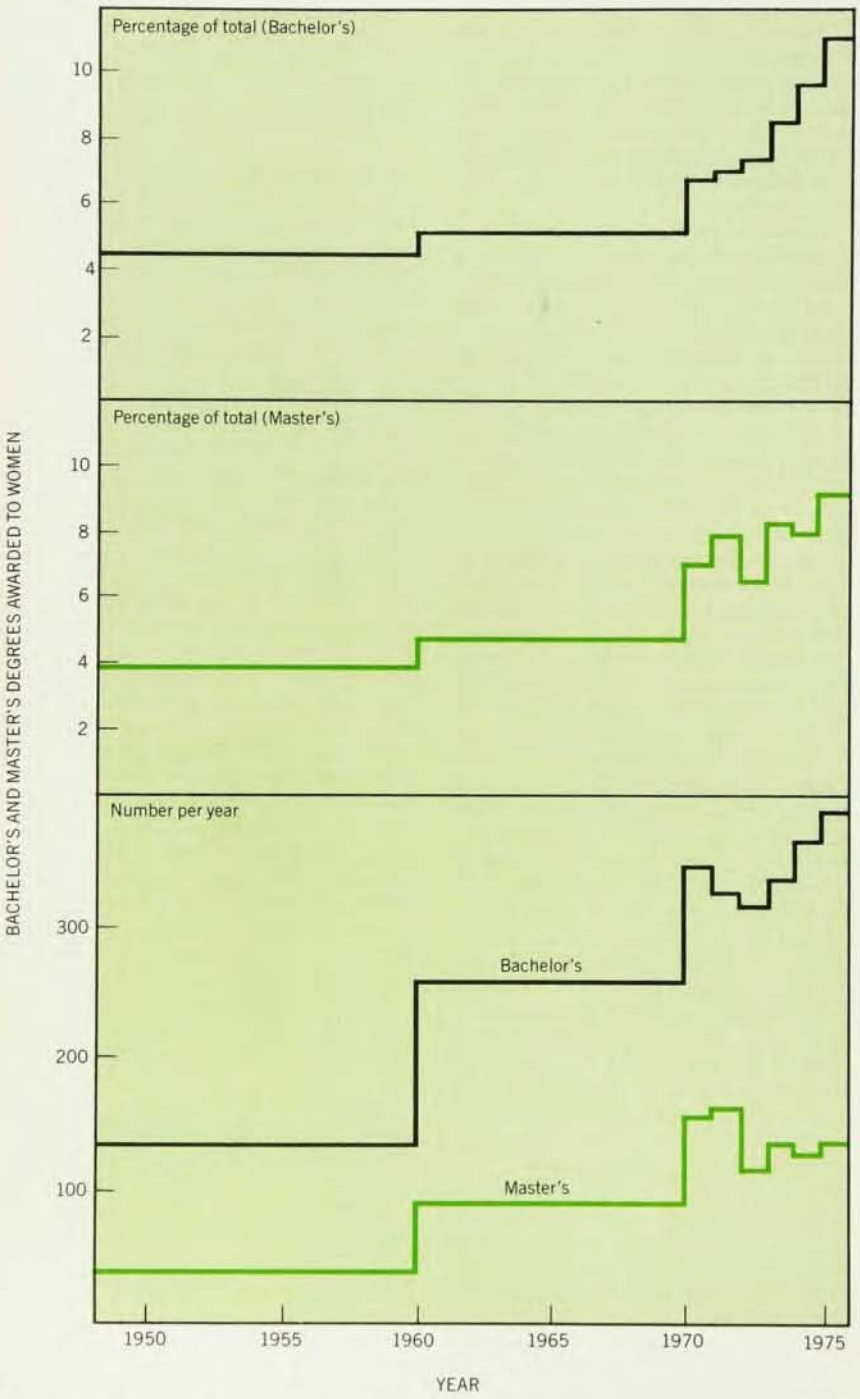
Data from 1973 Survey of Doctoral Scientists and Engineers, National Research Council.

Employers of Men and Women PhD Physicists and Astronomers in 1973

Employer	Men	Women
Educational Institution	56%	67%
PhD Granting	41%	44%
MA Granting	5%	4%
BA Granting	9%	15%
Jr College	1%	3%
Secondary School	0.3%	1%
Government	15%	16%
Industry	21%	10%
Nonprofit	5%	4%
Other	3%	3%
Total Number	16 689	387

Data from 1973 Survey of Doctoral Scientists and Engineers, National Research Council.

coby and Jacklin's book clearly make the point that the result of a single experiment, or those of a small group of experiments, are never adequate to yield a definitive answer to any general question in this field. The sample choice, the experimental technique and the interpretation of what is measured permit contradictory results for any attribute studied. However, certain patterns do emerge and they are relevant to aptitude for scientific work. First of all, there are eight attributes for which sex differences are commonly believed to exist but for which the evidence is conclusive that this is not the case. These include rote-learning ability, higher-level cognitive processing, analytic ability and achievement motivation. For all of these no sex differences of any origin have been found. For seven other attributes, including competitiveness, dominance and compliance, Maccoby and Jacklin conclude that there is not sufficient evidence to decide the question. They also conclude that there are four areas where sex differences are well established. For two of these, verbal ability and mathematical ability, available evidence does not indicate a sex-linked genetic component, and the sex differences can be attributed completely to environmental effects. The magnitude of the sex differences in mathematical ability varies widely, depending on the age group studied, from none for young children to significant differences for adults. The differences between medians of the relevant test scores for men and women are at most 0.4 of the standard deviations, and the test score distributions extend over the whole range of values for both sexes.



Bachelor's and master's degrees awarded to women. The numbers were averaged over and the percentages calculated for the periods 1948 to 1960 and 1960 to 1970. Annual numbers and percentages are given for the period 1970 to 1976. These data are taken from Table PS-P-2, "Professional Women and Minorities," B. M. Vetter, E. L. Babco and J. E. McIntire, Scientific Manpower Commission, Washington, D.C. (1978).

Finally, there are two attributes for which Maccoby and Jacklin believe evidence exists for a sex-linked genetic component. The first is aggression, which is probably not positively correlated with scientific competence since, as it is defined, it does not include achievement motivation, competitiveness or dominance. Furthermore, since the learned component of this attribute is important and aggression is negatively correlated with intellectual ability in boys, the greater male biological priming for learning aggressive behavior appears to be a negative indicator for a male scientific career. It is interesting to note that the correlation is positive in girls and that aggressiveness could be a positive indicator in their case.

The second attribute for which the authors believe there is evidence for a sex-linked genetic difference is one type of visual-spatial ability. There is some disagreement with this assessment, but, even if it is correct, it only means that one of a number of genes contributing to high spatial ability is sex-linked. Furthermore, there is also an equally important learned component to the exercise of these abilities. The differences observed between the medians of relevant test scores for males and females vary widely between various cultures and are at most 1.4 of the standard deviations. Since there is no information concerning the correlation of spatial ability with scientific achievement it is hard to assess the effect of this attribute. However, it is clear that the one sex-linked genetic component is not a major factor and that the differences could be substantially reduced by an educational process which stresses development of visual-spatial abilities equally for both boys and girls.

Thus, it is extremely unlikely that sex-linked genetic differences are an important factor in the observed differences in scientific participation. There remain, however, the differences that are environmental in origin, and their importance

is evident. It is impossible to establish cause and effect, but I would suggest that the same environmental pressures that have led to the differences on mathematical ability test scores are also responsible for the sharp decrease in the participation of girls in mathematics and physical-science courses in secondary school with the level of the course, rather than mathematical ability itself. The difference in participation is much too great to be plausibly accounted for by the small differences in the medians of the test score distribution. What are these pressures? They start in early childhood when girls are rewarded for "feminine behavior" and given "girl's" toys. They escalate in adolescence when conformity to a particular feminine role is considered necessary to attract boys. To be good at science and math has been considered to be inappropriate for a girl, a threat to her popularity and unnecessary for her future role in society. Alison Kelly has pointed out in a paper describing the substantial differences in participation in secondary school physics in Great Britain, that girls' schools have a significantly better record than coeducatipnal schools, presumably because in that environment there is more faculty encouragement and peer support for achievement in physics.[15]

These effects are also felt at the undergraduate college level, where women's participation in physics continues to be low in spite of the academic selection that has taken place. In general, a lower percentage of women than men prepare themselves for graduate school in any discipline. The seven women's colleges that are linked with the Ivy League men's colleges (The Seven Sisters: Barnard, Bryn Mawr, Mount Holyoke, Radcliffe, Smith, Vassar and Wellesley) have a uniquely excellent record for both the number and percentage of their graduates who have continued to a doctorate and to professional recognition.[16] This record includes the fields of mathematics and the physical sciences, and one can again speculate that a supportive environment is a cause.

That self-selection also plays a role is evident from the excellent record of a few coeducational colleges (Oberlin, Reed and Swarthmore) and from the fact that a greater percentage of women with baccalaureate degrees from MIT later received a doctorate degree than was the case for any other academic institution with a significant number of women (11% versus 9.7% for the next highest).[17] This could hardly be attributed to a reputation for a supportive environment, since, although MIT granted its first degree to a woman in 1867, it was not until nearly one hundred years later that women were recognized as an important part of the undergraduate community. However, my own experience and that of many other women has been that the supportive environment of a woman's college made it much easier to study mathematics and science with the expectation of pursuing careers in these diciplines.

The question of math and science avoidance has been discussed by many authors, notably Shiela Tobias,[18] and a number of programs to counteract this situation have been established. One of these is an informal network of women scientists and mathematicians working in San Francisco area schools and colleges to encourage girls to take science and math courses and to tell them about career options in the various fields. The program, originated primarily by Lenore Blum and Nancy Kreinberg, presently involves more than 400 women scientists and mathematicians.[19]

Societal views of appropriate roles for women are changing. Admittedly, the progress is uneven, but I do not think that there can be a pre-teenage girl whose family owns a television set who views marriage and motherhood as the only option for a woman, even though this may be the only option of interest to her. She knows that there are women in many "men's" fields, including the physical sciences, and gradually this should result in increases in the numbers of girls who take physical sciences and advanced math in high school and who can therefore consider such majors in college. Again, the changes are slow, but since our society is now one in which the majority of women are employed outside of the home for a major part of their adult lives, they should lead to much more substantial numbers of young women laying the foundation in high school and college for graduate work in physics.

In the past, there has also been substantial attrition in graduate school, with twice as many women graduate students in physics terminating with a master's degree than was the case for men.[7] Again, anecdotal evidence indicates that negative peer attitudes concerning the appropriateness of scientific careers for women were an important factor, together with the perception that job opportunities were limited for doctorate-level women

Women Faculty in Physics Departments

Department Type and Rank	1971–72[a]	1978–79[b]
	Percent (number)	
"Top Ten"[c]		
All Professors	0.8 (4)	2.7 (11)
Full Professor	0.6 (2)	1.0 (3)
Associate Professor	1.1 (1)	5.8 (3)
Assistant Professor	0.9 (1)	7.7 (5)
Other[d]	2.8 (1)	5.0 (1)
PhD Granting		
Number of Departments	(158)	(212)
All Professors	1.5 (74)	1.7 (88)
Full Professor	1.0 (23)	1.2 (38)
Associate Professor	1.8 (24)	1.5 (22)
Assistant Professor	2.0 (27)	4.5 (28)
Other[d]	5.9 (17)	4.5 (15)
MA Granting		
Number of Departments	(133)	(123)
All Professors	2.3 (28)	2.5 (27)
Full Professors	1.9 (7)	1.5 (8)
Associate Professor	2.2 (9)	2.9 (12)
Assistant Professor	2.6 (12)	4.4 (7)
Other[d]	4.6 (6)	16.2 (11)
BA Granting		
Number of Departments	(743)	(606)
All Professors	5.4(144)	3.9 (93)
Full Professor	5.8 (55)	3.2 (29)
Associate Professor	4.9 (33)	3.9 (35)
Assistant Professor	5.2 (56)	6.9 (39)
Other[d]	9.5 (44)	11.4 (27)
All Three Types		
Number of Departments	(1034)	(941)
All Professors	2.8(246)	2.5(218)
Full Professor	2.4 (85)	1.7 (75)
Associate Professor	2.7 (66)	2.5 (69)
Assistant Professor	3.3 (95)	5.5 (74)
Other[d]	7.6 (67)	8.3 (53)

a. 1971–72 data from "Women in Physics", report of the Committee on Women in Physics of the American Physical Society, *Bull. Am. Phys. Soc.* **17**, 740 (1972).

b. 1978–79 data compiled from the "1978–79 Directory of Physics and Astronomy Faculties," American Institute of Physics (1978). Astronomy Faculty are not included.

c. The top ten in 1970 according to the American Council on Education: Berkeley, Caltech, Chicago, Columbia, Cornell, Harvard, Illinois, MIT, Princeton and Stanford. The same institutions were included for 1978–79 sample. There were two additional women in the Division of Physics and Astronomy at Caltech who were designated astronomy faculty.

d. Lecturer, instructor, research professor, etc.

physicists. Bluntly, why get a PhD in physics when you can't get an interesting job and it makes it harder to be married? Other contributing factors that have been mentioned are isolation, not being included in the collegial interactions of the peer group, and "invisibility"—not being perceived as a serious student by professors. Here again, changing attitudes concerning appropriate roles for women and the changing views of marriage must also have improved the general situation in the last ten years. Furthermore, affirmative action, ineffective as it has been on the whole, has created the impression that doctoral women scientists can get jobs. It comes then as no surprise that more women now continue to a doctorate.

The third category of reasons for the difference between the statistical patterns for women and those for men listed at the beginning of this section is discrimination. Although it is generally hard to document, there is considerable direct evidence that discrimination has been an important factor. Universities have had overt policies of not accepting women graduate students, of not hiring women faculty even though they educated women students, and of favoring men for promotions and pay increases because they "needed it more, they had a family to support." There is also considerable anecdotal evidence of discriminatory attitudes. For example, there is the thesis supervisor who advised a woman student to look for a job as a scientific editor, since such a job would be more compatible with marriage and a family than a position requiring her to do research. Or the numerous professors who said that they did not want women graduate students because they once had a very good one who quit to raise a family as soon as she got her degree. It is interesting that, although I have heard this from so many individuals that it should be a significant statistical effect, the evidence is quite to the contrary. Approximately 95% of the women who received a PhD have remained professionally active, although a substantial number took time off or worked part time when their children were small.[7]

There have also been regulations that were *de facto* discriminatory, such as nepotism rules invoked mainly against wives. The classic example is Maria Goeppert Mayer, who was denied a paid scientific position for a major part of her scientific career and did not receive a full-time professorship until after the publication of her Nobel prize–winning work on the nuclear shell model.[20]

And finally there has been an inability to recognize women as plausible scientists, which certainly must have colored the reactions of those men so affected toward the hiring or promotion of a woman scientist. An experimentalist recently commented to me that physics departments were obviously "leaning over backward to appoint women as assistant professors" because in the last five years the percentage of these appointments that have gone to women has been about the same as the percentage of recent physics doctorates earned by women. The phase "leaning over backward" clearly reflects an attitude about the qualifications of women in general which can not help but influence decisions on individuals. This perception of women physicists is still quite widespread and is not only held by older scientists. The person who made this remark is a generation younger than I. Discriminatory attitudes also frequently manifest themselves in an unwillingness to admit that a woman could succeed. I have heard a number of people say that Enrico Fermi "gave" Maria Mayer the nuclear shell model, or that Pierre Curie was mainly responsible for the Nobel prize shared with Marie Curie. The evidence supports neither assertion. It is, of course, difficult to assign credit when work is done jointly by husband and wife. However, in numerous articles mentioning Marie Curie as a scientist who won a Nobel prize in 1903 jointly with her husband and Antoine Becquerel, there is no mention that she received a second unshared Nobel prize in 1911 for the discovery of radium and polonium after her husband's death and no mention of the fact that she was the only person to receive two Nobel prizes until 1962. These stories are not as trivial as they may seem, because they translate to "Oh, her husband (professor, coworker, and so on) did the important part of the work" when such attitudes are encountered by less famous women scientists. Only time can cure such attitudes, as the men who hold them retire and are replaced by others who have had women physicists as professors and peers, and are at ease with them.

The fourth category of reasons for the differences between the participation of men and women in physics stems from conflicts between the demands of a career and those of personal life, particularly if these involve marriage and children, because these conflicts have in the past generally been seen as a problem that the wife must resolve. An interesting consequence of this was observed by Lindsey Harmon in a study of early performance indicators, such as high-school grade point averages and college entrance tests, of individuals who subsequently received doctorates. Almost without exception in all fields the married women ranked highest on all indicators, with single women ranking next, followed by single men and finally by married men. This was a totally unexpected result for which Harmon suggested the following explanation: "When the superiority of women over men doctorate-holders was noted in

Women Nobelists. Opposite page, Maria Goeppert Mayer, her husband Joseph E. Mayer, Robert d'Escourt Atkinson, Paul Ehrenfest and Lars Onsager lounging on the lawn of the University of Michigan summer school in 1930. Left, Marie Curie. Rarely is it mentioned that she received a second Nobel Prize in 1911 for the discovery of radium and polonium after the death of her husband. She remained the only person to receive two Nobel Prizes until 1962. (Photos courtesy of APS Niels Bohr Library.)

the study of 1958 graduates, the hypothesis was advanced that this was due primarily to the greater hurdles the women had to overcome to attain the doctorate degree . . . It is assumed . . . that marriage and its attendant responsibilities is a handicap rather than a help in further academic attainment for the women".[21]

This is true not only in the US. In the USSR women participate in substantial percentages in all branches of science and technology through the first level of the universities, but there is a steady decrease in the percentages for higher levels of achievement. For example, in 1970, 50% of the junior scientific assistants, 24% of the senior scientific assistants, 21% of the docents (roughly postdoctoral level) and 10% of the professors were women. Twenty-seven percent of the candidate degrees in science (roughly PhD level), but only 13% of the doctorate degrees in science (a higher level) were awarded to women.[22] A number of sociologists, both Soviet and non-Soviet, have suggested that this is due to the fact that Soviet women are mainly responsible for the care of the household and children.[23] Although it is obvious to even the occasional visitor that other factors such as discrimination also contribute to the differences in the Soviet Union, it is clear that the much greater difficulty of maintaining a family in the USSR would be a crushing burden to a research career.

In theory, evidence that marriage adversely affects women's careers could be observed in terms of differences in rates of publication. Experimentally, different studies give different answers to this question.[24,25] I am personally aware of a substantial number of women scientists who have combined an active research career with raising a family. However, in numerous surveys it has been found that in the past women scientists have frequently accepted less demanding careers because of their roles in their marriages. They have been willing to put their husband's career first, to move to areas where there were no or inferior job opportunities for the wife, to assume the major share of household labor and the responsibility for children, and to choose teaching over research because it meshed better with their family duties. In recent years, however, there has been a change in the attitudes toward marriage and roles in marriage. Many young couples are considering having no children or, at most, one, and many marry with an explicit understanding that their careers have equal priority and that they share equal responsibility for all facets of their married lives. It will be interesting to see the effects of these changes in the next decade.

Returning to my list of possible causes for the differences between men and women physicists there remains the Matthew effect, first so identified by Robert Merton. In the words of the apostle:

"For unto everyone that hath shall be given and he shall have abundance; but from him that hath not shall be taken away even what he hath" [Matthew 13: 12].

In Merton's words, the Matthew effect in science "consists in the accruing of greater increments of recognition for particular scientific contributions to scientists of considerable repute and the withholding of such recognition from scientists who have not yet made their mark".[26] The existence of a scientific elite has been discussed by sociologists, notably Johnathan and Stephen Cole, Merton, and Harriet Zuckerman, and the pattern is clear.[25-27] Those scientists who work in leadership positions at the research universities accrue grants and students that result in publications which are in turn rewarded by more grants, students, and prizes in a spiral of success. On the other hand, those who are in secondary positions or at less prestigious institutions (categories in which women have been heavily represented) do not receive this type of support and are unlikely to join the elite. Even women with tenure at major research universities may be outside this circle, whose members are known to each other and who are proposed by one another for leadership or advisory positions, prizes and other forms of recognition. If the women scientists are perceived as outsiders, it is unlikely that they will develop the contacts to become members of the scientific old boys' club. I was quite distressed when an eminent theoretical physicist said to me about five years ago that it would take two generations before there were good women theorists. I was unhappy at the possible impact of this point of view, and appalled at the apparent callous disregard of existing women theorists. But in terms of the Matthew effect, he was correct. These women were not part of the inner circle, and given the small numbers at the top universities and the slow change in the attitudes toward woman physicists held by people like himself it will take time for women theorists to attain significant representation among the elite, but hopefully not two generations.

Unnecessary, injurious, out of place?

It must be fairly clear by now that the adjectives in the subtitle of this article are not as extreme as they may have seemed initially. They have all been used many times with respect to women physicists. Therefore let me use them as a framework for some comments on what the future may hold.

Is it unnecessary that women have equal opportunity and encouragement to become physicists? It is both as necessary and as unnecessary as is the case for men. Depending on how you look at it, the job outlook for the future is bleak (prestige academic positions), or better than most fields (physics-related positions). I think that it is safe to say that a reasonable employment situation would continue if the number of doctorates remains approximately constant; and because the percentage of physicists who are women is so small their participation could increase by a factor of five to six without increasing the number of doctorates if there is a corresponding con-

tinuation in the decrease in the number of men receiving doctorates in physics. But why encourage this to occur? The answer is simple. Women in this country face a future in which most of them will work during most of their adult lives. They therefore deserve a society in which they can choose employment according to their interests and abilities, and for which they will receive the same rewards as men. And it can only benefit the profession to move closer to a situation where rewards are based on a perception of scientific merit that concerns itself with the substance of performance, not with the externals of sex or race.

The question of whether increased participation by women in physics would be injurious has two aspects. One is the indubitable fact that, if a field or job category has become identified as a woman's field, it has in the past been accorded lower prestige and a lower salary. Since women are reaching out into almost all careers these days their entry into various fields is unlikely to continue to have this effect. The other aspect of the question is that it has required and will continue to require external pressures such as affirmative action to effect equality of opportunity; this is viewed by some as an infringement of personal or institutional prerogatives by the government and a dilution of quality. In view of the small increases that have been achieved by eight years of affirmative action it is not possible to tell what the effect on quality has been. As for the question of infringement of prerogative, I would argue that no one should enjoy the prerogative to choose faculty in a manner biased by preconceptions and misconceptions of women. Affirmative action is still necessary to prime the pump, to increase the visibility of successful women physicists in order to create an atmosphere where women are accepted and rewarded for their contributions in all aspects of the profession. If some appointments are made which are not successful, it will not be a new phenomenon. Many men hired by academic institutions have been denied promotion and tenure in the past without any discussion of injury to the profession.

Finally, there is the question of whether women are out of place in physics. There is no compelling evidence that girls are not equally endowed with the abilities necessary to become successful physicists. There is overwhelming evidence that the attitudes of society and the pressures of marriage and family have made this much more improbable for women than for men. A prominent physicist once remarked to me, "It is too bad that you were not born a man." And indeed, there are very few women physicists for whom there has not arisen some career obstacle, whether internal or external, directly attributable to their sex. But, if we are indeed to take seriously the ideal that participation in physics should be based on interest, aspiration and ability, then certainly no individual should be discouraged on any grounds other than these.

References

1. H. J. Mozans, *Women in Science*, Appleton (1913); reissued by MIT, Cambridge, Mass. (1974).
2. G. Sarton, *A History of Science*, Harvard U. Cambridge, Mass. (1952).
3. L. M. Osen, *Women in Mathematics*, MIT, Cambridge, Mass. (1974).
4. E. T. James, *Notable American Women 1607–1950*, Harvard U., Cambridge, Mass. (1974).
5. F. Rudolph, *The American College and University*, Knopf, New York (1962).
6. M. W. Rossiter, *American Scientist* **62**, 312 (1974).
7. APS Comm. Women in Physics, Bull. Am. Phys. Soc. II, **17**, 740 (1972).
8. D. M. Gilford, P. D. Syverson, "Summary Report [*Year*] Doctorate Recipients from US Universities," Nat. Acad. of Sci. (1972 through 1978).
9. D. M. Gilford, J. Snyder, *Women and Minority PhD's in the late 1970's: A Data Book*, Nat. Acad. of Sci. (1977).
10. B. D. Maxfield, N. C. Ahern, A. W. Spisak, *Science, Engineering, and Humanities Doctorates in the United States. 1977 profile*, Nat. Acad. of Sci. (1978).
11. B. D. Maxfield, N. C. Ahern, A. W. Spisak, *Employment Status of PhD Scientists and Engineers. 1973 and 1975*, Nat. Acad. of Sci. (1976).
12. M. E. Law, J. Wittels, R. Clark, P. Jorgenson, Bull. Am. Phys. Soc. **21**, 888 (1976).
13. L. Tiger, *New York Times Magazine*, 25 October 1970, page 35.
14. E. E. Maccoby, C. N. Jacklin, *The Psychology of Sex Differences*, Stanford U., Stanford, Cal. (1974).
15. A. Kelly, *Phys. Bull.* **30**, 108 (1979).
16. M. J. Oates, S. Williamson, *Signs*, 795 (Summer, 1978).
17. M. E. Tidball, V. Kistiakowsky, *Science* **193**, 646 (1976).
18. S. Tobias, *Overcoming Math Anxiety*, Norton, New York (1978).
19. C. E. Max, "Opportunities for Women in Physics," U. California Rad. Lab. Report UCRL-80943 (1978).
20. J. Dash, *A Life of One's Own*, Harper and Row, New York (1973).
21. L. R. Harmon, *High School Ability Patterns*, Nat. Acad. of Sci. (1965).
22. G. F. Schilling, M. K. Hunt, "Women in Science and Technology: US/USSR Comparisons," Rand Paper Series P-239, Santa Monica, Cal. (1974).
23. W. M. Mandel, *Soviet Women*, Doubleday, Garden City, N.Y. (1975).
24. J. A. Centra, *Women, Men and the Doctorate*, Educ. Testing Serv., Princeton, N.J. (1974).
25. J. R. Cole, S. Cole, *Social Stratification in Science*, U. Chicago, Chicago, Ill. (1973).
26. R. K. Merton, *Science* **159**, 56 (1968).
27. H. Zuckerman, *Scientific Elite*, Free Press, New York (1978). □