3

A TWISTED TALE

Women in the Physical Sciences in the Nineteenth and Twentieth Centuries

Margaret W. Rossiter

Dismissed as inconsequential before the 1970s, the history of the contributions of women to the physical sciences has become a topic of considerable research in the last two decades. Best known of the women physical scientists are the three "great exceptions" from central Europe – Sonya Kovalevsky, Marie Sklodowska Curie, and Lise Meitner – but in recent years, other women and other countries and areas have been receiving attention, and more is to be expected in the future. The overall pattern for most women in these fields, the nonexceptions, has been one of ghettoization and subsequent attempts to overcome barriers.

PRECEDENTS

Before 1800 there were several self-taught and privately-tutored "learned ladies" in the physical sciences. Included were the English self-styled "natural philosopher" Margaret Cavendish (1623–1673), who wrote books and in the 1660s visited the Royal Society of London, which had not elected her to membership; the German astronomer Maria Winkelmann Kirch (1670–1720), who worked for the then-new Berlin Academy of Sciences in the early 1700s; the Frenchwoman Emilie du Chatelet (1706–1749), who translated Newton's *Principia* into French before her premature death in childbirth in 1749; the Italians Laura Bassi (1711–1778), famed professor of physics at the University of Bologna, and Maria Agnesi (1718–1799), a mathematician in Bologna; Ekaterina Romanovna Dashkova (1743–1810), the director of the Imperial Academy of Sciences in Russia; and Marie Anne Lavoisier (1758–1836), who helped her husband Antoine with his work in the Chemical Revolution.[1]

[1] Lisa T. Sarasohn, "A Science Turned Upside Down: Feminism and the Natural Philosophy of Margaret Cavendish," *Huntington Library Quarterly,* 47 (1984), 289–307; Londa Schiebinger, "Maria

Women's scattered contributions to the physical sciences became more numerous and less aristocratic around 1800 in Britain when Jane Marcet (1769–1858) started her series of famous popular textbooks, as *Conversations on Chemistry,* and Caroline Herschel (1750–1848) helped her brother William with his astronomy and, on her own, located eight comets.[2] In France, Sophie Germain (1776–1831) read physics books in her father's library, used the pseudonym "Henri LeBlanc" on bluebooks submitted surreptitiously to the men-only Ecole Polytechnique, and corresponded with Karl Friedrich Gauss. In 1831 Scotswoman Mary Somerville (1780–1872) translated Laplace's *Mécanique céleste* into English, and in the 1840s Nantucket astronomer Maria Mitchell (1818–1889) discovered a comet.[3]

Later in the nineteenth century, when higher education opened to women, many more began to study the physical sciences. But inasmuch as higher education placed certain restrictions on their entrance and participation, full careers in the physical sciences opened to only a few. They generally had a higher threshold of entry than the more accessible field of natural history. By the late nineteenth century, a career in the physical sciences required such credentials as higher degrees, often obtainable only at foreign universities, and scientific publications, usually requiring long stays in distant laboratories. In fact the rise of the laboratory, generally acclaimed in the history of the physical sciences, can be seen as a new level of exclusion, creating new male retreats or preserves to which women gained entry only by special permission.

GREAT EXCEPTIONS

The history of women in the physical sciences in the nineteenth and twentieth centuries is dominated by the careers and legends of the three great exceptions

Winkelman at the Berlin Academy, A Turning Point for Women in Science," *Isis,* 78 (1987), 174–200; Mary Terrall, "Emilie du Chatelet and the Gendering of Science," *History of Science,* 33 (1995), 283–310; Paula Findlen, "Science as a Career in Enlightenment Italy, The Strategies of Laura Bassi," *Isis,* 84 (1993), 441–69; Paula Findlen, "Translating the New Science: Women and the Circulation of Knowledge in Enlightenment Italy," *Configurations,* 2 (1995), 167–206; A. Woronzoff-Dashkoff, "Princess E. R. Dashkova: First Woman Member of the American Philosophical Society," *Proceedings of the American Philosophical Society,* 140 (1996), 406–17. On the others, see Marilyn Bailey Ogilvie, *Women in Science: Antiquity Through the Nineteenth Century: A Biographical Dictionary with Annotated Bibliography* (Cambridge, Mass.: MIT Press, 1986; 1990). Her *Women and Science: An Annotated Bibliography* (New York: Garland, 1996) is also indispensable.

[2] Susan Lindee, "The American Career of Jane Marcet's *Conversations on Chemistry,* 1806–1853," *Isis,* 82 (1991), 8–23; Marilyn Bailey Ogilvie, "Caroline Herschel's Contributions to Astronomy," *Annals of Science,* 32 (1975), 149–61.

[3] Louis L. Bucciarelli and Nancy Dworsky, *Sophie Germain: An Essay in the History of the Theory of Elasticity* (Dordrecht: Reidel, 1980); Elizabeth C. Patterson, *Mary Somerville and the Cultivation of Science, 1815–1840* (The Hague: Nijhoff, 1983); Sally Gregory Kohlstedt, "Maria Mitchell and the Advancement of Women in Science," in *Uneasy Careers and Intimate Lives: Women in Science, 1789–1979*, ed. Pnina G. Abir-Am and Dorinda Outram (New Brunswick, N.J.: Rutgers University Press, 1987), pp. 129–46.

who played prominent roles in mainstream European mathematics and science: Sonya Kovalevsky (1850–1891), the Russian mathematician who was the first woman to earn a PhD (at the University of Göttingen in absentia in 1874) and the first woman in Europe to become a professor (at the University of Stockholm in 1889); Marie Sklodowska Curie (1867–1934), the Polish-French physicist-chemist who discovered radium and won two Nobel Prizes; and Lise Meitner (1878–1968), the Austrian physicist who participated in the discovery of nuclear fission together with Otto Hahn and Fritz Strassmann, but who did not share in Hahn's 1944 Nobel Prize in chemistry and spent her later years in exile in Sweden.[4]

Biographies written on these three figures highlight their subjects' uniqueness and specialness. Each woman seemed, for inexplicable reasons, to rise and achieve at a time when few other women did. Few if any had ties to one another or to any women's movement, or so we are told in these works about them, but they did benefit from openings made by other women and probably others have benefited from their "firsts." Generally they worked to make themselves so outstanding as to be worthy of a personal favor or exemption or exception, rather than to build ties and alliances that would effect permanent institutional change. They squeezed through but left the pattern intact.

Perhaps it is unfair to expect a biographer of one woman in one or several countries and fields to link her subject to other women in other fields in other countries. But this leads to contradictions. Sonya Kovalevsky, we are told, was known throughout Europe in the 1880s, but then there is no evidence in works about Marie Curie that while growing up in Russian-dominated Poland in the 1880s, she ever heard of Kovalevsky, let alone modeled her own career on hers, as she might well have done.[5]

Most of what has been written about these exceptional women has been in a heroic mode or revolves around a central message, such as a love story. Studies of Curie still are based on limited primary materials and are heavily influenced by Eve Curie's sentimental best-selling biography of her mother in the late 1930s, later made into a wartime movie.[6] But other scholars, notably

[4] There are several biographies of Kovalevsky; the most recent is by Ann Hibner Koblitz, *A Convergence of Lives: Sofia Kovalevskaia: Scientist, Writer, Revolutionary* (New Brunswick, N.J.: Rutgers University Press, 1993; rev. ed.). The latest biography on Curie is by Susan Quinn, *Marie Curie* (New York: Simon & Schuster, 1994), reviewed by Lawrence Badash in *Isis* in 1997. See also Ruth Sime, *Lise Meitner: A Life in Physics* (Berkeley: University of California Press, 1996); Elvira Scheich, "Science, Politics, and Morality: The Relationship of Lise Meitner and Elisabeth Schiemann," *Osiris,* 12 (1997), 143–68. For more details on the scientific work of the women physicists mentioned here and of others, see Marilyn Ogilvie and Joy Harvey, eds., *The Biographical Dictionary of Women in Science, Pioneering Lives from Ancient Times to the mid-20th century,* 2 vols. (New York: Routledge, 2000), and the website maintained by Nina Byers, "Contributions of Women to Physics" at <http://www.physics.ucla.edu/~cwp>.

[5] Quinn, *Marie Curie.*

[6] Eve Curie, *Madame Curie,* trans. Vincent Sheean (Garden City, N.Y.: Doubleday, Doran, 1938); and the movie *Madame Curie,* starring Greer Garson and Walter Pidgeon (1943).

Helena Pycior and J. L. Davis, are now studying aspects of Curie's scientific work and research school.[7]

Most satisfactory to date is the biography of Lise Meitner by Ruth Sime, who shows in some detail how much preparation and intelligence (in the espionage sense) it took to be in the right place at the right time.[8] While there are such things as coincidences, a series of them often indicates careful planning. And a successful career in the sciences for a woman required not only luck but a lot of strategic planning to know where to make one's own opportunities and how to avoid dead ends, hopeless battles, and insuperable obstacles.

These women were able to obtain correct information about their best opportunities, and they contrived to come up with the resources (wealthy parents, earnings as a governess, or a "fictitious" marriage to a fellow student) to get there at a time when it was rare even for more mobile male students to do so. As daughters, these women might also have been expected to stay at home and take care of aging parents. Yet the "exceptions" managed to disentangle themselves from this filial obligation and to have innovative family arrangements.

The main reason to leave home and family and to migrate was to find world-class mentors, whom they chose wisely, and who, being insiders, helped them to jump barriers, work on interesting problems, and become exceptions to the many petty rules and exclusions that would have daunted them otherwise. Kovalevsky left Russia with her fictitious husband Vladimir to study mathematics in Germany with Karl Weierstrass, who was devoted to her and assisted her later career, as also did Gösta Mittag-Leffler in Stockholm. Marie Sklodowska traveled to Paris to study physics at a time when various German universities, which did physics better, were still largely closed to women. In Paris she wisely sought out Pierre Curie, married him, and worked with him on her radium research. Lise Meitner studied with Ludwig Boltzmann in Vienna in the first years when women were allowed in Austrian universities and then, encouraged by none other than Max Planck, was allowed by Emil Fischer to work with Otto Hahn at the Kaiser Wilhelm Institute for chemistry outside Berlin – if she used the side door and kept out of sight. Later she became head of the physics section within it. These women all showed extraordinary, even legendary, levels of perseverance and determination.

Though foreign women were often granted educational opportunities denied to local women (who might then expect a job in the same country), their situation could and did become difficult if they stayed on and held

[7] Helena M. Pycior, "Reaping the Benefits of Collaboration While Avoiding Its Pitfalls: Marie Curie's Rise to Scientific Prominence," *Social Studies of Science,* 23 (1993), 301–23; Helena M. Pycior, "Pierre Curie and 'His Eminent Collaborator Mme. Curie,'" in *Creative Couples in the Sciences*, ed. Helena Pycior, Nancy Slack, and Pnina Abir-Am (New Brunswick, N.J.: Rutgers University Press, 1996), pp. 39–56; and J. L. Davis, "The Research School of Marie Curie in the Paris Faculty, 1907–1914," *Annals of Science,* 52 (1995), 321–55.

[8] Sime, *Lise Meitner: A Life in Physics.*

a job in that country. Then sexual indiscretions might be reported in the press, as happened to Marie Curie in Paris in 1911. Worse, if the economy soured and/or right-wing movements arose, as occurred in Germany, Austria, Spain, and elsewhere in the 1930s, those who were Jewish, were particularly vulnerable and could become targets of the press or political regime and even forced to flee at a moment's notice, as many did.

Though they defied all stereotypes and rose to become unique and memorable figures, these "exceptions" did not change the stereotypes and the norms (to which we turn in a moment) that have worked to keep most women out of sight in their own time and throughout history.[9]

LESS-WELL-KNOWN WOMEN

Beyond the exceptions was a host of other female physical scientists of possibly similar caliber who are not as well known. These include the French chemist Irène Joliot-Curie (1897–1956), daughter of Marie and Pierre Curie, who shared the Nobel Prize in chemistry with her husband Frédéric (1900–1958) in 1935 for work on artificial radioactivity; the German-American physicist Maria Goeppert-Mayer (1906–1972), who shared the 1963 Nobel Prize in physics with two others for her work on magic numbers in spin ratios in atoms; and Dorothy Crowfoot Hodgkin (1910–1994), an English crystallographer and biochemist who won the Nobel Prize alone in 1964 for determining the structure of a series of complex biological molecules.[10] Still others who should have won it include Rosalind Franklin (1920–1958), the English crystallographer of nucleic acids; crystallographer Kathleen Lonsdale (1903–1971), who discovered that the benzene ring was flat; and C. S. Wu (1912–1997), the Chinese-American physicist who showed in 1957 that parity was not conserved.[11] Also notable were the astronomers Annie Jump Cannon (1863–1941), Henrietta Leavitt (1868–1921), and the British-born Cecilia Payne-Gaposchkin (1900–1979), all of the Harvard College Observatory.[12] Beyond these would be Agnes Pockels (1862–1935),

[9] Margaret Rossiter, "The ~~Matthew~~ Matilda Effect in Science," *Social Studies of Science,* 23 (1993), 325–41.

[10] Margaret Rossiter, "'But She's an Avowed Communist!' *L'Affaire Curie* at the American Chemical Society, 1953–55," *Bulletin for the History of Chemistry,* no. 20 (1997), 33–41; Bernadette Bensaude-Vincent, "Star Scientists in a Nobelist Family: Irène and Frédéric Joliot-Curie," in *Creative Couples* ed. Helena Pycior, Nancy Slack, and Pnina Abir-Am, chap. 2. See also Karen E. Johnson, "Maria Goeppert Mayer: Atoms, Molecules and Nuclear Shells," *Physics Today,* 39, no. 9 (September 1986), 44–9; Joan Dash, *A Life of One's Own* (New York: Harper and Row, 1973), and Peter Farago, "Interview with Dorothy Crowfoot Hodgkin," *Journal of Chemical Education,* 54 (1977), 214–16.

[11] Anne Sayre, *Rosalind Franklin & DNA* (New York: W. W. Norton, 1975); Maureen M. Julian, "Dame Kathleen Lonsdale," *Physics Teacher,* 19 (1981), 159–65; N. Benczer-Koller, "Personal Memories of Chien-Shiung Wu," *Physics and Society,* 26, no. 3 (July 1997), 1–3.

[12] John Lankford, *American Astronomy, Community, Careers, and Power, 1859–1940* (Chicago: University of Chicago Press, 1997), p. 53; *Cecilia Payne-Gaposchkin: An Autobiography* (Cambridge: Cambridge University Press, 1984).

the German housewife whose letter to Lord Kelvin about soap bubbles helped to launch the study of thin films; Julia Lermontova (1846–1919), the first Russian woman to earn a doctorate in chemistry; physicists German Ida Noddack (1896–1978) and Canadian Harriet Brooks (1876–1933); and Swiss chemists Gertrud Woker (1878–1968) and Erika Cremer (b. 1900).[13]

These less-well-known women merit study because their careers should show us more about everyday science and the opportunities open and closed to most women. In addition, their presence, usually controversial, so strained the levels of tolerance of the time that by the 1920s, when faculty positions had opened to more than a trickle of women, the increase in numbers provoked strong opposition and produced a reaction or backlash, which was especially pronounced in Germany but also of note in Spain and Austria. There, fascist groups, fueled by widespread fears and resentments of many kinds, rose up, seized power, and drove out many of these women, often Jewish, who were just getting a foothold in university faculties in the physical sciences. Mathematicians Emmy Noether and Hilda Geiringer von Mises fled into exile, and French historian of chemistry Hélène Metzger disappeared forever on the way to Auschwitz. The Nazis were relentless and, unlike others, made no exceptions, especially not for these otherwise nearly exceptional women.[14]

RANK AND FILE – FIGHTING FOR ACCESS

The history of women in science, particularly in the physical sciences, is unbalanced in that it centers largely on a few famous women who were pretty much exceptions to the prevailing norms in their society at the time. (This is also true of the history of men in science, which emphasizes the work of the Nobelists, even though it is logically and pedagogically incorrect to discuss the exceptions to a rule before stating what that rule or norm is.) This focus or emphasis on the exceptions and near exceptions is particularly unfortunate in the history of women in science, for it overlooks and so minimizes or dismisses the far more common patterns of exclusion, marginalization,

[13] M. Elizabeth Derrick, "Agnes Pockels, 1862–1935," *Journal of Chemical Education,* 59 (1982), 1030–1 Charlene Steinberg, "Yulya Vsevolodovna Lermontova (1846–1919)," *Journal of Chemical Education,* 60 (1983), 757–8; Fathi Habashi, "Ida Noddack (1896–1978)," *C[anadian] I[nstitute] of M[etals] Bulletin* 78, no. 877 (May 1985), 90–3; Ralph E. Oesper, "Gertrud Woker," *Journal of Chemical Education,* 30 (1953), 435–7; Marelene F. Rayner-Canham and Geoffrey W. Rayner-Canham, *Harriet Brooks: Pioneer Nuclear Scientist* (Montreal: McGill-Queen's University Press, 1992); Jane A. Miller "Erika Cremer (1900–)," in *Women in Chemistry and Physics: A Biobibliographic Sourcebook* ed. Louise S. Grinstein, Rose K. Rose, and Miriam H. Rafailovich (Westport, Conn.: Greenwood Press, 1993), pp. 128–35. This biobibliography is one of a new genre of useful reference works.

[14] Noether and Joan L. Richards, "Hilda Geiringer," in *Notable American Women: The Modern Period, A Biographical Dictionary*, ed. Barbara Sicherman and Carol Hurd Green (Cambridge, Mass.: Harvard University Press, 1980), pp. 267–8; Suzanne Delorme, "Metzger, Hélène," in *Dictionary of Scientific Biography*, IX, 340.

underemployment and unemployment, underrecognition, demoralization, and suicide. But it is hard to correct this imbalance, for little is known about these generally obscure women. Thus, in a further twist – that might please the whimsical British mathematician Lewis Carroll, who wrote about Alice in Wonderland – the exceptions have in a sense become the norm, since we seldom hear of the rank and file, who have been largely obliterated from history.[15] This distortion has led to an imbalance in current knowledge about women's place in the physical sciences.

The focus on the exceptions, who experienced few problems, particularly omits the long struggle for higher degrees faced by women aspiring to be scientists or even just wanting to study science. Universities were founded beginning in the mid-twelfth century in Europe, but women were not admitted to any institutions for higher education until 1865 when Vassar College opened in the United States. Thus, women were not allowed to study at the university level for nearly seven centuries, despite Laura Bassi's presence on the Bologna faculty in the mid-eighteenth century.

It was only with the opening of higher education to women – first at mid-nineteenth century in the United States, but in the 1880s in Britain, in France in the 1890s, and finally in Austria in 1897 and Germany in 1908 – that there were to be more than a few women in science. For several decades, there was such an uneven level of educational and occupational opportunity in Western countries that women in search of greater opportunities often had to leave home and travel abroad. Some stayed only a few years; others spent their entire careers abroad. Much progress had been made by the 1930s, so much, in fact, that the women's more visible presence provoked the backlash mentioned earlier, especially against Jewish women. Some were expelled, but, unable to return home, they were then forced to seek refuge in another foreign country. Others faced worse. Much more progress was made after World War II, when many ex-colonial and newly socialist nations, such as China and those in Eastern Europe, made female literacy and education a priority.

A lot of what is written about women "in science" is really about gaining access to its institutions, because while individuals might have a variety of attitudes toward women in science, most institutions were exclusionary, either deliberately – in written policies or in unwritten traditions – or inadvertently, as when there was simply no precedent, for no women had applied before or been present at its creation. This institutional barrier was a big hurdle for the first women who later sought entrance; in some cases, this was a very long struggle that dissipated energies that in a more egalitarian society could have been spent on other ventures. England and Germany, where so much of the world's science was done and taught in the nineteenth and twentieth

[15] In addition to exclusionary barriers, women scientists were also held to a higher level of expectations. (See Margaret W. Rossiter, *Women Scientists in America: Struggles and Strategies to 1940* [Baltimore: Johns Hopkins University Press, 1982], p. 64.)

centuries, were (and still are) particularly restrictive about admitting women to educational and scientific institutions.

Women's entrance into the older British universities was glacially slow and proceeded incrementally, with admission to examinations (including the natural sciences Tripos at Cambridge), the creation of separate women's colleges, the awarding of certificates and then actual degrees, and finally admission to the traditional colleges.[16] In the United States, the movement started in the 1830s with the establishment of many women's seminaries, some of which later became colleges.

WOMEN'S COLLEGES – A WORLD OF THEIR OWN

Separate, independent colleges for women, as well as coordinate colleges for women affiliated with men's universities, have played a large role in the training and especially the employment of female physical scientists, primarily in the United States and England. Astronomer Maria Mitchell, for example, became the first woman science professor in the United States when she was hired at Vassar College in the 1860s. Among her students were chemist Ellen Richards (1842–1911), one of the founders of the field of home economics; Mary Whitney (1847–1921), her successor in astronomy at Vassar; and Christine Ladd-Franklin (1847–1930), a physicist-turned-psychologist of note. Several of these colleges had science departments that were (and still are) quite strong in chemistry, such as Mount Holyoke, which remains into the new millennium the largest producer of female PhDs in chemistry in the United States. Sophie Newcomb College in New Orleans was also strong in chemistry, while Bryn Mawr College, the only separate women's college with a graduate school that awarded doctorates in the physical sciences, also trained a string of notable women geologists. Wellesley College was important in several fields, including astronomy, mathematics, and physics. Notable among the faculty with long careers at American colleges for women were physicists Frances Wick at Vassar; Sarah Whiting (1847–1927) and Hedwig Kohn (1887–1965) at Wellesley; Rose Mooney at Newcomb and Hertha Sponer-Franck (1895–1968) at Duke University's women's college; and chemists Emma Perry Carr (1880–1972), Mary Sherrill (1888–1968), Lucy Pickett (b. 1904), and most recently Anna Jane Harrison (1912–1998) at Mt. Holyoke College.[17]

[16] Roy MacLeod and Russell Moseley, "Fathers and Daughters: Reflections of Women, Science, and Victorian Cambridge," *History of Education,* 8 (1979), 321–33; Carol Dyhouse, *No Distinction of Sex? Women in British Universities 1870–1939* (London: UCL Press, 1995).

[17] Marie-Ann Maushart, *"Um mich nicht zu vergessen:" Hertha Sponer – Ein Frauenleben für die Physik im 20. Jahrhundert* (Bassum: Verlag für Geschichte der Naturwissenschaften und der Technik, 1997); Carol Shmurak, "Emma Perry Carr: The Spectrum of a Life," *Ambix,* 41 (1994), 75–86; Carol Shmurak, " 'Castle of Science': Mount Holyoke College and the Preparation of Women in Chemistry, 1837–1941," *History of Education Quarterly,* 32 (1992), 315–42.

There were also a few important colleges for women in England. Dorothy Hodgkin spent her long career in crystallography at Somerville College, Oxford, where one of her chemistry students was Margaret Thatcher, whose subsequent career took a different turn. Rosalind Franklin was a graduate of Newnham College, Cambridge, in chemistry.

Elsewhere, American missionaries established colleges for women in Istanbul, Beirut, and India, but such colleges never caught on in Germany, where separate institutions for women were considered inferior. Nevertheless, in France Marie Curie taught for a time at the normal school for female teachers at Sèvres.[18]

To a certain extent these colleges trained women for burgeoning areas of "women's work" (as we shall see), but their alumnae include a relatively large proportion of the pioneers and subsequent, even current, participants in most of the physical sciences, often as many as from the far larger "coeducational" universities that in reality had very few women majors in the physical sciences. Agnes Scott College in Georgia, for example, had by 1980 graduated fifteen women who later earned PhDs in chemistry – the same number as the far larger Massachusetts Institute of Technology, where relatively few women completed majors in chemistry.[19]

The role of the women's colleges in the United States has diminished in recent decades, because around 1970 the trustees at some colleges voted to admit men. At about the same time, their counterparts at many previously all-male institutions (Caltech, Princeton, Amherst, the Jesuit institutions, the military and naval academies, and others) admitted women for the first time. Yet single-sex education is hardly dead, as currently there is in the United States a resurgence in all-girl schools at the primary and secondary school level, and it is widely known that they prepare women better in nontraditional areas, including the physical sciences.

GRADUATE WORK, (MALE) MENTORS, AND LABORATORY ACCESS

Switzerland was unusually important for women in science and medicine because its educational institutions, especially the University of Zurich, were staffed largely by liberal faculty members ousted from Germany after the 1848 revolution. They admitted large numbers of female students starting in the

[18] James C. Albisetti, "American Women's Colleges Through European Eyes, 1865–1914," *History of Education Quarterly,* 32 (Winter 1992), 439–58; Jo Burr Margadant, *Madame le Professeur: Women Educators in the Third Republic* (Princeton, N.J.: Princeton University Press, 1990). Nuclear physicist Salwa Nassar (Berkeley PhD, 1944) chaired the physics department at the American University of Beirut and in 1966 became head of the Beirut College for Women ("We See by the Papers," *Smith College Alumnae Quarterly,* 57 [1965–6], 163).

[19] Alfred E. Hall, "Baccalaureate Origins of Doctorate Recipients in Chemistry: 1920–1980," *Journal of Chemical Education,* 62 (1985), 406–8.

1860s when no other European universities would do so. Hardly any of these early students were Swiss; most were from Russia, France, Germany, England, and the United States.[20] Also in Zurich around 1900 was the Serbian Mileva Marić (1875–1948), who has since gained fame as Albert Einstein's fellow student at the Eidgenössische Technische Hochschule (ETH) and as his first wife.[21]

Starting in the late nineteenth century, work at certain laboratories in physical sciences became important, though at first these were male spaces. Yet some professors heading these world-famous laboratories accepted women, and a trickle of female students and researchers began to work with them. Starting in the 1880s, for example, a series of female physicists worked at the famous Cavendish Laboratory at Cambridge University. Among these were Rose Paget, who later married its director J. J. Thomson; the Canadian Harriet Brooks, whom Ernest Rutherford invited to follow him when he became the laboratory's director; the American Katharine Blodgett (1898–1979), the first woman to earn a doctorate at Cambridge University and later the collaborator of Irving Langmuir at General Electric, in the 1920s; and Joan Freeman of Australia in the late 1940s.[22]

Some mentors welcomed female students, worked with them, and supported their subsequent careers. Madame Curie welcomed students from Eastern Europe at her Radium Institute, and physiological chemist Lafayette B. Mendel (1872–1937) trained forty-eight women PhDs at Yale University in the 1920s and 1930s.[23]

"MEN'S" AND "WOMEN'S" WORK IN PEACE AND WAR

Women are generally quite rare in what can be considered "men's work" – mainstream university departments and large industrial laboratories, often supported by defense budgets and infused with a military ethos – and very

[20] Ann Hibner Koblitz, "Science, Women, and the Russian Intelligentsia: The Generation of the 1860s," *Isis,* 79 (1988), 208–26. See also Thomas N. Bonner, *To the Ends of the Earth: Women's Search for Education in Medicine* (Cambridge, Mass.: Harvard University Press, 1993).

[21] Gerald Holton, "Of Love, Physics and Other Passions: The Letters of Albert [Einstein] and Mileva [Marić]," *Physics Today,* 47 (August 1994), 23–9, and (September 1994), 37–43; *Albert Einstein/Mileva Marić: The Love Letters,* ed. J. Renn and R. Schulman (Princeton, N.J.: Princeton University Press, 1992).

[22] Paula Gould, "Women and the Culture of University Physics in Late Nineteenth-Century Cambridge," *British Journal for the History of Science,* 30 (1997), 127–49; Marelene F. Rayner-Canham and Geoffrey W. Rayner-Canham, *Harriet Brooks;* Kathleen A. Davis, "Katharine Blodgett and Thin Films," *Journal of Chemical Education,* 61 (1984), 437–9; Joan Freeman, *A Passion for Physics: The Story of a Woman Physicist* (Bristol, England: Adam Hilger, 1991).

[23] Marelene F. Rayner-Canham and Geoffrey W. Rayer-Canham, sr. authors and eds., *A Devotion to Their Science: Pioneer Women of Radioactivity* (Philadelphia: Chemical Heritage Foundation; and Montreal: McGill-Queen's University Press, 1997); Margaret Rossiter, "Mendel the Mentor: Yale Women Doctorates in Biochemistry, 1898–1937," *Journal of Chemical Education,* 71 (1994), 215–19.

predominant in the two kinds of "women's work."[24] Jobs deemed suitable for women have often been low-level, subordinate, dead-end, invisible, and monotonous staff and service positions, such as technical assistants of various sorts, chemical librarians, chemical secretaries, calculators or computers, computer programmers, and astronomical counters. Among the more famous women in these positions were Annie Jump Cannon of the Harvard College Observatory and Jocelyn Bell Burnell (b. 1943) of the United Kingdom, who participated in the discovery of pulsars that won Anthony Hewish and Martin Ryle the Nobel Prize for physics in 1974.[25]

The somewhat different jobs deemed suitable for women are often situated away from the men, usually in a slightly removed location or discipline, such as teaching a science at a women's college, serving as a dean of women, or working in the field of "home economics," a branch of nutrition and domestic science developed for female chemists in the United States in the late nineteenth century.[26] Unlike the assistants mentioned previously, some women have held high rank in these womanly jobs. This pattern of sex-typing has spread to some other countries as well, and female physical scientists, such as Rachel Makinson of Australia, have been employed in the area of "textile physics."[27]

Some female physical scientists have held government jobs, as with the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia; various agencies of the American government, such as the U.S. Geological Survey and the National Bureau of Standards; and the Geological Survey and the Dominion Observatory in Canada.[28] Historically, these organizations have paid lower salaries to women than to men, refused to hire married women, and offered little advancement, but there have been some reforms in recent decades. In the early 1970s Anglo-American astronomer E. Margaret Burbidge (b. 1919) even served briefly as Astronomer Royal of the Royal Greenwich Observatory in the United Kingdom.

[24] Ellen Gleditsch (1879–1968) became in 1929 the first female professor at the University of Oslo. See Anne-Marie Weidler Kubanek, "Ellen Gleditsch (1879–1968), Nuclear Chemist," in *Notable Women in the Physical Sciences*, ed. Benjamin F. Shearer and Barbara S. Shearer (Westport, Conn.: Greenwood Press, 1997), pp. 127–31. This very useful biobibliographical work has information on 96 women. For data on the proportion of women employed in particular subfields of the physical sciences in the United States in 1956–8, see Margaret Rossiter, "Which Science? Which Women?" *Osiris,* 12 (1998), 169–85.

[25] Margaret Rossiter, "Women's Work in Science, 1880–1910," *Isis,* 71 (1980), 381–98. See also Margaret Rossiter, "Chemical Librarianship: A Kind of 'Women's Work' in America," *Ambix,* 43 (March 1996), 46–58. On Jocelyn Bell, see Sharon Bertsch McGrayne, *Nobel Prize Women in Science: Their Lives, Struggles, and Momentous Discoveries* (Secaucus, N.J.: Carol Publishing, 1993), which includes several other near-Nobelists.

[26] See Sarah Stage and Virginia Vincenti, eds., *Rethinking Women and Home Economics in the Twentieth Century* (Ithaca, N.Y.: Cornell University Press, 1997).

[27] Nessy Allen, "Textile Physics and the Wool Industry: An Australian Woman Scientist's Contribution," *Agricultural History,* 67 (1993), 67–77.

[28] See, for example, Nessy Allen, "Achievement in Science: The Careers of Two Australian Women Chemists," *Historical Records of Australian Science,* 10 (December 1994), 129–41.

It was the pressing manpower needs of World War I that opened jobs for women in chemistry and engineering in Canada, Australia, England, Germany, and elsewhere. Marie Curie, Lise Meitner, and other physical scientists made themselves useful as x-ray technicians – a new job at the time – during the war. At the other extreme, German chemist Clara Immerwahr (1870–1915), Fritz Haber's wife at the time, committed suicide, perhaps in protest of his development of poison gases.[29]

In World War II, several immigrant female physicists (such as Maria Goeppert Mayer and Leona Woods Marshall Libby (1919–1986) worked on the atomic bomb project in the United States, while others filled in for male professors at the universities and otherwise "kept the seat warm" for the men's eventual return. Lise Meitner, one of the discoverers of nuclear fission, was one of the very few physicists who refused an invitation to Los Alamos to work on the atomic bomb. Other scientists with antiwar political views were the English crystallographers Dorothy Crowfoot Hodgkin and Kathleen Lonsdale. The latter, a Quaker, developed a reputation as a pacifist and protester of nuclear testing in the 1950s and 1960s. By contrast, Frenchwoman Irène Joliot-Curie was pro-Communist in the 1940s and 1950s and helped to train some of the Chinese physicists who would later build China's hydrogen bomb. As such, she was unwelcome in the United States and not even acceptable as a member of the American Chemical Society despite her Nobel Prize in chemistry.[30]

SCIENTIFIC MARRIAGES AND FAMILIES

Because female scientists have often married male scientists, there is a phenomenon of "endogamy," or marrying within the tribe. Most famous are the two Curie couples – Marie and Pierre and then Irène and Frédéric Joliot. Others of note were the American chemists Ellen and Robert Richards, Irish and English astronomers Margaret (1848–1915) and William Huggins, British mathematicians Grace Chisholm (1868–1944) and Will Young, Czech-American biochemists Gerty (1896–1957) and Carl Cori, German-American physicist Maria and American chemist Joseph Mayer, and Chinese-American physicists C. S. Wu and Yuan (Luke) Wu, to name just a few.[31]

[29] Gerit von Leitner, *Der Fall Clara Immerwahr: Leben für eine humane Wissenschaft* (Munich: Beck, 1993); Haber's second wife Charlotte published an autobiography, *My Life with Fritz Haber* (1970).

[30] Gill Hudson, "Unfathering the Thinkable: Gender, Science and Pacificism in the 1930s," in *Science and Sensibility: Gender and Scientific Enquiry, 1780–1945*, ed. Marina Benjamin (Oxford: Blackwell, 1991). See n. 10.

[31] Several are in Helena Pycior et al., *Creative Couples*. There are lists of American couples in Margaret W. Rossiter, *Women Scientists in America*, p. 143, and Margaret W. Rossiter, *Women Scientists in America: Before Affirmative Action, 1940–1972* (Baltimore: Johns Hopkins University Press, 1995), pp. 115–20. All the couples listed were heterosexual.

Beyond the mother–daughter relationship of Marie and Irène Curie have been father–daughter combinations, as the chemists Edward and Virginia Bartow; mother–son sets, as among astronomers Maria Winkelmann Kirch (1670–1720) and Christoph Kirch; and brother–sister combinations, as astronomers William and Caroline Herschel and chemists Chaim and Anna Weizmann (?–1963) in England and Israel; and sister–sister dyads, such as the Anglo-Irish popularizers of astronomy Ellen (1840–1906) and Agnes Clerke (1842–1907), the Americans astronomer Antonia (1866–1952) and paleontologist Carlotta Maury (1874–1938), and the American-French neuroanatomist Augusta Déjerine-Klumpke (1859–1927) and astronomer Dorothea Klumpke Roberts (1861–1942).[32]

UNDERRECOGNITION

Many scientific societies, starting with the very first, the Royal Society of London in 1662, long refused to admit women as members. The Royal Society relented in the late 1940s after decades of struggle and admitted three outstanding women, including crystallographer Kathleen Lonsdale.[33] Practices at other younger and more specialized societies varied. Ellen Richards and a few others were present at the founding of the American Chemical Society in 1876; Charlotte Angas Scott (1858–1931) was elected a member of the council at the first meeting of the American Mathematical Society in 1894; and Sarah Whiting (1847–1927) was a charter member of the American Physical Society in 1899. But even when women became members, it was often a long time – a century with the chemists and longer with the mathematicians – before any woman became president. In this there were wide national differences. In Britain, the Chemical Society of London was among the laggards.[34] The American and French national academies were also very slow. The first female physical scientists elected to the U.S. National Academy of Sciences, which was established in 1863, were physicists Maria Goeppert Mayer in 1956 and C. S. Wu in 1958. The Académie des Sciences did not elect its first woman until physicist Yvonne Choquet-Bruhat in 1979.[35]

Female physical scientists have probably been more active over the years in local and regional groups than in national or international ones, but

[32] Meyer W. Weisgal, "Prof. Anna Weizmann," *Nature,* 198 (1963), 737; for the others, see Ogilvie and Harvey, eds., *The Biographical Dictionary of Women in Science.*

[33] Joan Mason, "The Admission of the First Women to the Royal Society of London," *Notes and Records of the Royal Society of London,* 46 (1992), 279–300. On Lonsdale, see n. 11; on Stephenson, see Rober E. Kohler, "Innovation in Normal Science: Bacterial Physiology," *Isis,* 76 (1985), 162–81.

[34] Joan Mason, "A Forty Years' War," *Chemistry in Britain,* 27 (1991), 233–8, is on women's admission to the Chemical Society of London.

[35] Jim Ritter, "French Academy Elects First Woman to Full Membership," *Nature,* 282 (January 1980), 238.

the former groups are less often studied.[36] In the eighteenth century, social settings like salons or coffee houses were conducive to women's participation, but more recently, even local organizations, such as campus clubs, were for a long time staunchly male-only. This had adverse consequences for female students or professionals, for a lot of "informal communication" took place at rathskellers, men's clubs, other smoke-filled rooms, and sacrosanct places, such as the bar at the Chemists' Club in New York City.[37]

Two American organizations have responded to the general underrecognition of women by scientific societies by establishing separate women's prizes, for example, the Annie Jump Cannon Prize of the American Astronomical Society (AAS) and the Garvan Medal of the American Chemical Society (ACS). The Cannon Prize was started in the early 1930s when Annie Jump Cannon received an award from the Association to Aid Women in Science shortly before it went out of existence. Not agreeing with the association's leaders that women's problems in science had then been solved, Cannon donated the $1,000 to the AAS that set up a woman's prize. It was offered at three-to-five-year intervals until the early 1970s when Anglo-American astronomer E. Margaret Burbidge caused a bit of a stir by refusing to accept it on the grounds that a separate prize for women was discriminatory. A committee was set up to investigate this problem, and it recommended using the funds for a fellowship for a young female astronomer, to be administered by the American Association of University Women.[38]

Similarly, the Garvan Medal was started in the late 1930s when foundation official Francis P. Garvan was overheard in an elevator saying that there had never been any female chemists. When corrected by an indignant woman, he agreed to underwrite a special ACS prize for a distinguished female chemist. It has since been supported by the W. R. Grace Company and is awarded annually by the ACS.[39]

POST–WORLD WAR II AND "WOMEN'S LIBERATION"

After World War II, two developments affected opportunities for female scientists. In many countries, including India, Vietnam, and Israel, as they became independent nations, the literacy rate and educational level of women

[36] Icie Macy Hoobler was in 1930 the first woman to head a section of the American Chemical Society. See Icie Gertrude Macy Hoobler, *Boundless Horizons: Portrait of a Pioneer Woman Scientist* (Smithtown, N.Y.: Exposition Press, 1982).

[37] See Margaret W. Rossiter, *Women Scientists in America . . . to 1940,* chaps. 4, 10, and 11, and *Women Scientists in America, . . . 1940–1972,* chap. 14.

[38] Margaret W. Rossiter, *Women Scientists in America . . . to 1940,* pp. 307–8; Rossiter, *Women Scientists in America, . . . 1940–1972*, pp. 352–3; E. Margaret Burbidge, "Watcher of the Skies, "*Annual Reviews of Astronomy and Astrophysics,* 32 (1994), 1–36.

[39] Rossiter, *Women Scientists in America . . . to 1940,* p. 308; Rossiter, *Women Scientists in America, . . . 1940–1972*, pp. 342–5; Molly Gleiser, "The Garvan Women," *Journal of Chemical Education,* 62 (1985), 1065–8.

rose dramatically. Other countries, especially in Eastern Europe, were taken over by Communist governments, which accorded women more education and higher status than had often been true earlier. Other governments have also made literacy and numeracy for women a high priority. Little has yet been written about any of this, but it should have been a golden age for the higher education of women.[40]

Nevertheless, female physical scientists, such as physicists Joan Freeman and Yuasa Toshiko (1909–1980) and astronomer Beatrice Tinsley (1941–1981), have felt it necessary to leave their home countries, Australia, Japan, and New Zealand, for greater educational and employment opportunities in the United Kingdom, the United States, and France, respectively. Because the only job Yuasa, trained in France by the Joliot-Curies, could get in her homeland in the late 1940s was in a women's college, and because the American occupation forces prohibited nuclear research in Japan at the time, she returned to France and spent her whole career at the Centre National de la Recherche Scientifique (CNRS).[41]

As funding for the physical sciences skyrocketed in the post–World War II era, largely as a result of the Cold War between the United States and "the Communist bloc," women in many countries found new opportunities in different kinds of scientific employment.[42]

In the United States between 1969 and 1972, a branch of the "women's liberation" movement was devoted to science. Vera Kistiakowsky (b. 1928) led the move to start a women's committee within the American Physical Society, and Mary Gray (b. 1939) was one of the founders of the independent Association for Women in Mathematics, both of which still exist. In the 1980s various well-publicized Women in Science and Engineering (WISE) and "new blood" schemes made news in England, and in Australia and Germany in the 1990s. Since 1992, the European Union has awarded fellowships named for Marie Sklodowska Curie (who left Poland for France) to scientists who will go to other European countries.[43]

[40] John Turkevich, *Soviet Men [sic] of Science, Academicians and Corresponding Members of the Academy of Sciences of the USSR* (Princeton, N.J.: D. Van Nostrand, 1963), includes meteorologist Ekaterina Blinova, chemists Rakhil Freidlina and Aleksandra Novoselova, and hydrodynamicist (and biographer of Sonya Kovalevsky) Pelageya Kochina. On Soviet women astronomers, see A. G. Masevich and A. K. Terentieva, "Zhenshchiny-astronomy," *Istoriko-Astronomischeskie Issledovaniia,* 23 (1991), 90–111.

[41] Joan Freeman, *A Passion for Physics;* Edward Hill, *My Daughter Beatrice: A Personal Memoir of Dr. Beatrice Tinsley, Astronomer* (New York: American Physical Society, 1986); and Eri Yagi, Hisako Matsuda, and Kyomi Narita, "Toshiko Yuasa (1909–1980), and the Nature of her Archives at Ochanomizu University in Tokyo," *Historia Scientarum,* 7 (1997), 153–63.

[42] On the United States, see Margaret W. Rossiter, *Women Scientists in America, . . . 1940–1972*.

[43] David Dickson, "France Seeking More Female Scientists with Offer of $4,500 Scholarships," *Chronicle of Higher Education,* 25 September, 1985; Allison Abbott, "Europe's Poorer Regions Woo Researchers," *Nature,* 388 (1997), 701. The Marie Curie Fellowship Association of current and former fellows has a website: www.mariecurie.org.

Although as stated at the outset, most of what is written about women in physical sciences centers on the United States and Western Europe (as does most history of science), some data published in 1991 is already helping to broaden scholarly concern to female physical scientists in other places. In 1991 physicist W. John Megaw of York University, Canada, presented data on the worldwide distribution of female physicists in 1988, which have been widely cited since then.[44] His study shows dramatically that women account for the highest proportion of physics faculties in Hungary (47%), followed by Portugal (34%), the Philippines (31%), the USSR (30%), Thailand (24%), Italy (23%), Turkey (23%), France (23%), China (21%), Brazil (18%), Poland (17%), and Spain (16%). East Germany at 8% outranked Japan (6%), the United Kingdom and West Germany (4%), and the United States (3%). Megaw's data may attract more scholarly interest to the history in these countries of female physical scientists about whom little is known, but who are faring and succeeding better institutionally than their counterparts in presumably enlightened Western Europe and the United States.[45] Among the reasons for these wide national differences are historical issues, such as the modernization of Kemal Ataturk in Turkey in the 1930s, the amount of scientific training required of both sexes in secondary schools (as in Italy and Turkey), and the status and monetary compensation of the scientific profession in general.[46] For example, in Latin America and the Philippines, private corporations hire and pay men so well that the universities must hire women.[47]

International comparisons may help to further gender analysis of the physical sciences, for once it is shown that many countries do it all differently, it will be easy to supersede Western-based essentialist arguments of what is "manly" and what women do "differently." Getting beyond the "great exceptions" and into the many other responses to patriarchy provided by

[44] W. John Megaw, "Gender Distribution in the World's Physics Departments," in National Research Council, *Women in Science and Engineering: Increasing Their Numbers in the 1990s* (Washington, D.C., 1991), p. 31; a special issue of *Science,* 263 (11 March, 1994); Mary Fehrs and Roman Czujko, "Women in Physics: Reversing the Exclusion," *Physics Today,* 45 (1992), 33–40; "Global Gaps and Trends," *World Science Report, 1996* (Paris: UNESCO Publications, 1996), p. 312.

[45] For starters, see Carmen Magallon, "Mujeres en Las Ciencias Fisico-Quimicas en Espana: El Instituto Nacional de Ciencias y el Instituto Nacional de Fisica y Quimica (1910–1936)," *Llull,* 20 (1997), 529–74; Monique Couture-Cherki, "Women in [French] Physics," in Hilary Rose and Steven Rose, *The Radicalisation of Science: Ideology of the Natural Sciences* (New York: Holmes & Meier, 1976), chap. 3 On East Germany, see H. Tscherisch, E. Malz, and K. Gaede, "Sag mir, wo die Frauen sind!" *Urania,* 28, no. 3 (March 1965), 178–89; on Australia, Ann Moyal, "Invisible Participants: Women Scientists in Australia, 1830–1950," *Prometheus,* 11, no. 2 (December 1993), 175–87.

[46] Chiara Nappi, "On Mathematics and Science Education in the U.S. and Europe," *Physics Today* 43, no. 5 (1990), 77–8; Albert Menard and Ali Uzun, "Educating Women for Success in Physics: Lessons from Turkey," *American Journal of Physics,* 61, no. 7 (July 1993), 611–15.

[47] Marites D. Vitug, "The Philippines: Fighting the Patriarchy in Growing Numbers," *Science,* 263 (1994), 1492.

international comparisons promises to open up fascinating and long-overdue new insights into the worldwide history of women in the physical sciences.

RISE OF GENDER STEREOTYPES AND SEX-TYPED CURRICULA

In the seventeenth and eighteenth centuries, mathematics and physics had not been typed by sex – Bernard de Fontenelle's classic *Conversations on the Plurality of Worlds* (1686) has as its leading figure the Marquise, a bright, witty, and attractive lady, and Francesco Algarotti's *Newtonianism for the Ladies* (1737) was aimed at a similar audience. There was also the curiously titled magazine *The Ladies' Diary* that lasted throughout most of the eighteenth century in England, though only about 10 percent of its contributors were women. All offered entertainment as well as popular education in elementary science and mathematics.[48]

But by the 1820s, sex-typing of the physical sciences was common, and arithmetic, physics, chemistry, and to a lesser extent astronomy were considered masculine.[49] Recent work has shown that nineteenth-century American academies taught mathematics and science to boys and girls, but around 1900, when girls began to outnumber boys in the American public schools, efficiency experts armed with IQ and interest tests were introduced in order to limit the student's training to his or her appropriate future. Since women were deemed unlikely to make much use of advanced high school mathematics, it was dropped from the curricula offered them. Social practices arose (such as asking "What is a nice girl like you doing in physics class?") that deterred many bright women from high school physics and steered them toward Latin, biology, or home economics. Similarly with the college curriculum, women were induced to think that they would be happier or more successful in the humanities or social or biological sciences than in the physical sciences.[50]

Since then, whole areas of educational research have been devoted to why students pick the majors they do or why in the course of their four years at college so many drop their initial intentions to major in physical sciences. Even when the American government was offering fellowships in

[48] Bernard de Fontenelle, *Conversations on the Plurality of Worlds,* introduction by Nina Gelbart (Berkeley: University of California Press, 1990); Teri Perl, "The Ladies' Diary or Woman's Almanack, 1704–1841," *Historia Mathematica,* 6 (1979), 36–53; Ruth and Peter Wallis, "Female Philomaths," *Historia Mathematica*, 7 (1980), 57–64.

[49] Patricia Cline Cohen, *A Calculating People: The Spread of Numeracy in Early America* (Chicago: University of Chicago Press, 1983).

[50] Kim Tolley, "Science for Ladies, Classics for Gentlemen: A Comparative Analysis of Scientific Subjects in the Curricula of Boys' and Girls' Secondary Schools in the United States, 1794–1850," *History of Education Quarterly,* 36 (1996), 129–53.

these very areas because the nation was having scientific manpower shortages, relatively few fellowships went to women. More than stereotyping was at work here; there was active disrecruitment in almost every physical science classroom.

Yet feminist philosophers have had little success in analyzing the gender components in the physical sciences. A few have tried or are trying. Meanwhile, anthropologist Sharon Traweek has published an ethnography of the Stanford Linear Accelerator in California and Ko-Enerugie butsurigaku Kenkyusho (KEK) in Japan in the 1980s, which describes a great deal of gender bias in the workplace and more importantly in the minds of the workers in both countries, though it manifests itself in different ways.[51]

In many ways, women's experience in the physical sciences has been the obverse of the usual history of physical sciences: There have been relatively few female physical scientists (unlike the many in the biological and social sciences), but a few of them, such as Marie Curie, are the best known of *all* scientists. Back in the seventeenth and eighteenth centuries when the sciences, including especially the physical sciences, were struggling to identify themselves, their methods, and their terrain, women were deliberately excluded from participation. They seemed to represent all that "science," whatever it was, was claiming not to be: Science portrayed itself as rational, unemotional, and logical. By the nineteenth century when many institutions had been created to embody these earlier masculine attitudes, women found that they had to fight to participate – in nearly every country and at every university. Even the victors were marginalized or ghettoized in segregated employment. Only the three Great Exceptions reached the highest levels and made important scientific and mathematical discoveries that have withstood subsequent attempts to drop even them from the historical record.

The fight for access was long but successful enough for a new cohort of younger women both to participate in World War I and then afterward to incur the attention, wrath, and brutality of the Nazis in the 1930s and 1940s. Since then, with women's liberation movements in many countries, women have been making progress in the physical sciences. Recently they have been doing best numerically and proportionally in socialist and Latin countries, but there, too, they have encountered a so-called glass ceiling or limitation on their advancement. Their failure during the last twenty-five years to make as much quantitative progress in the United States as have women in the biological, geological, and other sciences is also a cause for concern.[52]

[51] Sharon Traweek, *Beamtimes and Lifetimes: The World of High Energy Physicists* (Cambridge, Mass.: Harvard University Press, 1988). See also Robyn Arianrhod, "Physics and Mathematics, Reality and Language: Dilemmas for Feminists," in *The Knowledge Explosion: Generations of Feminist Scholarship* ed. Cheris Kramarae and Dale Spender (New York: Teachers College Press, 1992), chap. 2.

[52] Mary Fehrs and Roman Czujko, "Women in Physics: Reversing the Exclusion."