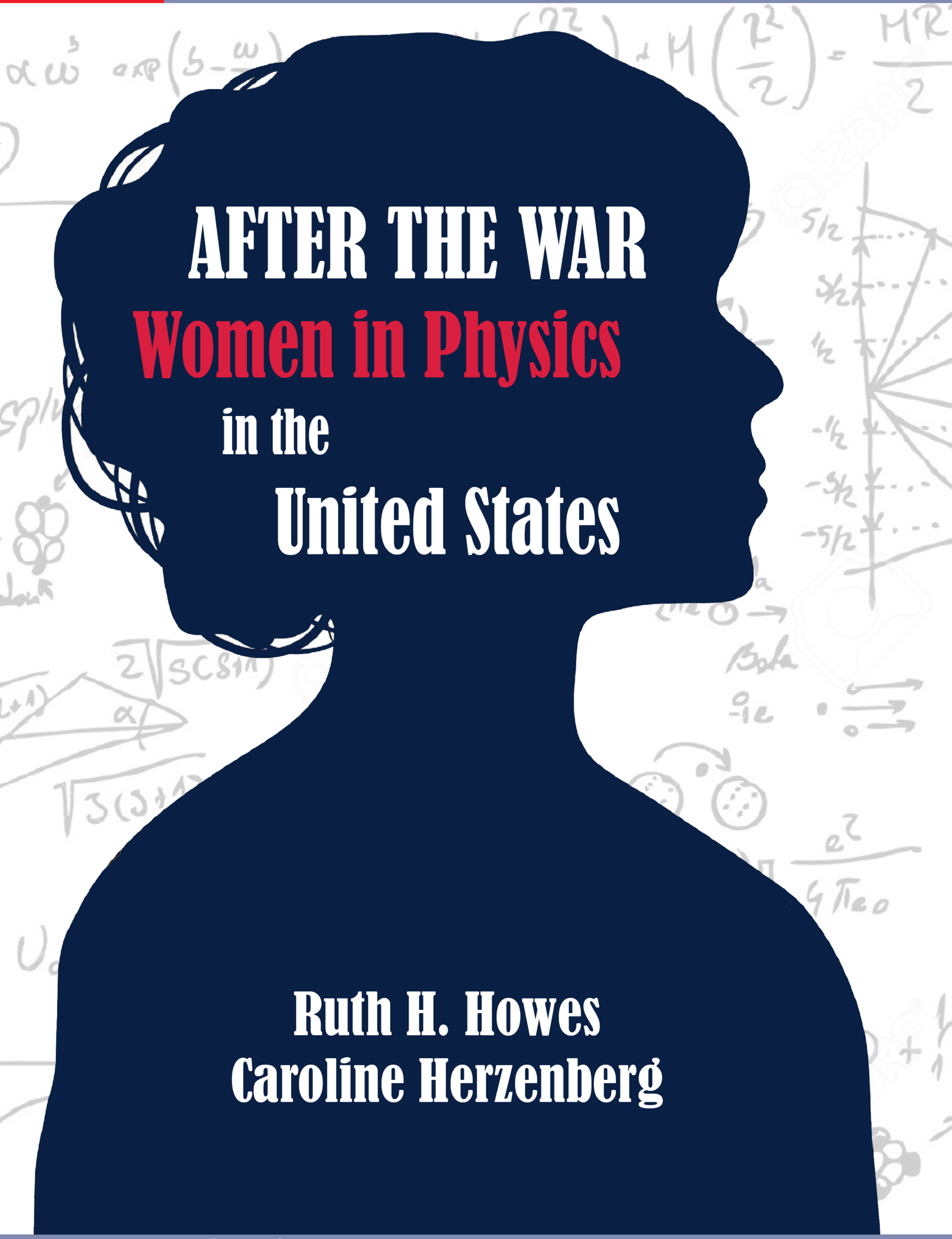
IOP Concise Physics | A Morgan & Claypool Publication



AFTER THE WAR
Women in Physics in the United States

Ruth H. Howes
Caroline Herzenberg

IOP | ebooks

After the War: Women in Physics in the United States

After the War: Women in Physics in the United States

Ruth H Howes
Professor Emerita of Physics and Astronomy, Ball State University

Caroline L Herzenberg
Scientist (retired), Argonne National Laboratory

Morgan & Claypool Publishers

ISBN 978-1-6817-4094-2 (ebook)
ISBN 978-1-6817-4030-0 (print)
ISBN 978-1-6817-4222-9 (mobi)

DOI 10.1088/978-1-6817-4094-2

Version: 20151201

IOP Concise Physics
ISSN 2053-2571 (online)
ISSN 2054-7307 (print)

A Morgan & Claypool publication as part of IOP Concise Physics
Published by Morgan & Claypool Publishers, 40 Oak Drive, San Rafael, CA, 94903, USA

IOP Publishing, Temple Circus, Temple Way, Bristol BS1 6HG, UK

To Robert Howes and Leonardo Herzenberg: models for the supportive husband every married woman physicist needs.

Contents

Preface

A casual reader of the history of physics might easily conclude that there were only a handful of active women physicists in the United States until well into the 1970s. Even the authors, in their earlier work, were surprised when they found more than 300 women who had done technical work on the development of the first atomic bomb*. The current volume focuses on our study of quite a number of women physicists who were professionally active from the end of World War II until the early to mid 1960s. We limited our study to this time period because it was 1963 which saw the publication of *The Feminine Mystique* which marked the reactivation of the women's movement in the United States, which in turn led to many changes in the status of women. Career and educational opportunities opened for women in many areas including physics. Affirmative action became a mandate for federal agencies and a priority for industries seeking government contracts.

In the process of preparing this manuscript, we have identified many fascinating women physicists who were working in the years after World War II and greatly enjoyed their stories. We learned how they managed to overcome the many obstacles to careers in physics posed by the society of the time. We hope that the reader will find them as interesting as we did.

* This work was published by Temple University Press as *Their Day in the Sun: Women of the Manhattan Project* in 1999.

Acknowledgements

We owe thanks to many people, especially the women who allowed us to interview them about their work in physics and their daughters and sons who told us about their mothers and helped us find pictures. We have had input from some of our colleagues in physics, for which we are grateful. We could not have managed without the help of librarians and archivists who helped us with both information and photographs of women physicists. In particular, we thank Wes Agresta, Argonne National Laboratory; Savannah Gignac, Emilio Segrè Visual Archives, American Institute of Physics; Hillary Kativa, Chemical Heritage Foundation; Maryellen Rogusky and Frank Sculli, Columbia University; Derek Potts, DePaul University; Ian Janssen, University of Delaware; Joanna Behrman, Johns Hopkins University; Erin Dix, Lawrence University; Rebecca Collingsworth, Los Alamos Historical Society; Alan Carr and Larry Gibbons, Los Alamos National Laboratory; Leslie Fields, Mt Holyoke College; Ellen Bouton, National Radio Astronomy Observatory; Timothy Gawne, Oak Ridge National Laboratory; Iris Rubenstein, Princeton University; Ellen Alers, Smithsonian Institution; Mary Yearl and Ian Graham, Wellesley College; and Amy Ensley, Wilson College; Lynda McGarry and Donna Dolan, the University of Rochester; and we are grateful to many of their colleagues in addition. Our thanks go out to Jacky Mucklow of IOP who has served as our guide to both the publication process and British English.

Author biographies

Ruth H Howes*

Ruth H Howes is Professor Emerita of Physics and Astronomy at Ball State University. She holds a PhD from Columbia University where she did her dissertation work under the direction of C S Wu. She retired from Ball State as the George and Frances Ball Distinguished Professor of Physics and Astronomy in 2003 and served as Professor of Physics and Chair of the Physics Department at Marquette University until 2008 when she moved to Santa Fe, New Mexico. She has held a Foster Fellowship at the US Arms Control and Disarmament Agency where she worked on verification and intelligence and a AAAS Congressional Fellowship during which she worked on the staff of the Senate Labor and Human Resources Committee then chaired by Senator Edward Kennedy. She has served as president of the American Association of Physics Teachers and the Indiana Academy of Science and as a program officer at the National Science Foundation. Her primary research has been in nuclear physics, lately the structure of very neutron-rich isotopes of light elements. She also worked as deputy chair of the National Task Force on Undergraduate Physics and as one of two project directors of the Strategic Programs for Innovation in Undergraduate Physics and the workshops that followed beginning after her retirement. She is a fellow of the American Association of Physics Teachers, the American Physical Society and the American Association for the Advancement of Science.

Caroline L Herzenberg

Caroline Herzenberg is a physicist who has achieved recognition for her activities relating to women in science as well as for her scientific work.

Born in New Jersey in 1932, she grew up in Oklahoma. As a high school senior in Oklahoma City, she became a winner of the Westinghouse Science Talent Search. She graduated from Massachusetts Institute of Technology with an SB in physics. For graduate study she attended the University of Chicago, where she worked in experimental physics under the guidance of her thesis advisor, Dr Samuel K Allison, and was awarded a PhD in 1958.

She has conducted both basic and applied research and worked in diverse areas including low-energy nuclear physics, Mössbauer spectrometry, instrumentation development, arms control, and technological emergency preparedness; and she was a principal investigator for returned lunar sample analysis for the Apollo 11 and Apollo 12 missions.

* Photograph by Anton Brkić

She has taught on the faculties of several universities, including Illinois Institute of Technology, the University of Illinois at the Medical Center, and California State University, Fresno. She was a senior scientist on the staff of IIT Research Institute, and worked as a physicist on the staff of Argonne National Laboratory until her retirement.

Dr Herzenberg is the author or coauthor of over 100 scientific and technical papers and chapters and articles in books, and is coauthor with Ruth Howes of the book *Their Day in the Sun: Women of the Manhattan Project* and author of the book *Women Scientists from Antiquity to the Present*. She is a past president of the Association for Women in Science, and a fellow of the American Physical Society and of the American Association for the Advancement of Science.

After the War: Women in Physics in the United States

Ruth H Howes and Caroline L Herzenberg

Chapter 1

Introduction. The setting for women in physics after World War II

Prior to World War II, some significant advances in physics took place in the United States, but the number of physicists was small, and the number of women physicists was extremely small. Hiring practices and anti-nepotism rules generally barred married women physicists from university, industrial and even high-school jobs. During and after World War II, both the practice of physics and the situation of American women underwent enormous changes. Throughout this period, the number of women in physics grew, but it has remained low to the present day.

During World War II, the work of most of the physicists in the United States was focused on defeating the Axis powers through work on wartime military projects, three of the most important being the development of radar, sonar and nuclear weapons. World War II was even referred to as 'the physicists' war'. In general, women were encouraged by the government to work in support of the war effort, and the military quickly hired female college graduates with some scientific knowledge. Rosie the Riveter was the poster girl for the effort to get American women into the work force.

At the end of World War II, the US government feared that the flood of returning soldiers seeking jobs would throw the country back into a financial depression. Consequently, the government launched two efforts that significantly affected women: (1) a publicity campaign to encourage women to leave the workforce and care for their families, thereby providing job openings for the returning men; and (2) the GI Bill, a law that provided a range of benefits for returning World War II veterans, encouraging returning soldiers to further their education and thus delay their entry into the work force. The GI Bill attracted large numbers of men to college, helped build the US system of research universities as well as its industrial workforce, and opened up opportunities for educated women and men to teach at college level.

doi:10.1088/978-1-6817-4094-2ch1

Women also took advantage of educational opportunities available through the GI Bill. For example, Marjorie Peason enlisted as a WAVE (Women Accepted for Voluntary Emergency Service—a corps of women who enlisted in the US Navy and served in shore jobs freeing men for sea duty) specifically to get a college education. She worked in Washington on predicting the weather for the Pacific battlefields and Japan. On being discharged in 1946, she spent one week at home and then enrolled in the University of Minnesota to study electrical engineering [1]. The publicity campaign to direct women into homemaking instead of paid employment was more harmful to women in physics because women physicists were generally professionally oriented and uninterested in wearing high heels while vacuuming, and they were unwilling to forsake their interest and professional activities in science.

The end of World War II was soon followed by the beginning of the Cold War, a state of elevated military tension between the powers of the Western and Eastern Blocs, which ramped up in 1947 and continued for over 40 years, until about 1991. As a result, military research and development continued, initially somewhat downscaled from the level during World War II, but soon exhibiting appreciable growth. Research began in additional areas of physics, notably condensed matter physics.

By the late 1940s, the number of students majoring in physics had more than doubled from prewar levels. Demand for physicists continued to outstrip supply well into the 1960s. In a poll conducted in the early 1960s, Americans ranked 'nuclear physicist' as the third most prestigious occupation. However, the situation for women was somewhat different. While many women, almost 90, were awarded doctorates in physics over the postwar decade, the fraction of female PhDs in physics declined to one in 40, and the fraction of women in the profession of physics generally, to one in 25 [2, p 371]. The proportion of women receiving advanced degrees in physics fell by a factor of two between the prewar and postwar decades [3].

Thus, the climate for all physicists, and particularly for women physicists, changed rather abruptly at the end of World War II. Physics grew very quickly, but it branched in many directions, so telling the stories of women who worked in physics after the war is more complex than telling the stories of women who worked on the three great projects of World War II [4].

In the early aftermath of World War II, there were at least three major arenas that impacted heavily on the work of all physicists: the politics of science, military developments usually tied to the Cold War and its arms race, and technical developments that changed the ways physics was done. The story of American women in physics is set against the background of these changes and was strongly influenced by them. Table 1.1 presents the major political events that affected women in physics after the war.

At the end of World War II, the military managed and funded the government's wartime research establishment, notably the group of military research laboratories that included Los Alamos, Oak Ridge, Hanford and other sites used for the design and production of nuclear weapons. On 1 January 1947, the McMahon Act transferred the control of this system of laboratories and associated sites to a civilian agency, the Atomic Energy Commission (AEC). When the McMahon Act

Table 1.1. Politics of science after World War II.

Timeline for the politics of science after World War II	
Servicemen's Readjustment Act (GI Bill)	22 June 1944
Establishment of first National Lab—Argonne	1 July 1946
McMahon Act (Atomic Energy Act)	1 August 1946
The transfer of control of nuclear production to AEC	1 January 1947
McCarthyism	1948–56
The Korean War	25 June 1950–27 July 1953
Establishment of National Science Foundation	10 May 1950
Oppenheimer hearing	12 April 1954
Brown vs Board of Education	17 May 1954
Establishment of NASA	1 October 1958
Publication of *The Feminine Mystique*	1963

separated the development, production and control of nuclear weapons from the military, military aspects were taken over by the Armed Forces Special Weapons Project. The AEC was charged with setting the direction of the research done in the facilities it controlled, on weapons as well as on civilian uses of nuclear technology, and also for any other research programs established. The AEC was additionally responsible for stocking the US arsenal with nuclear weapons. The new agency had to develop a management strategy for individual sites, as well as an overall strategy for its programs. It is no wonder that this was a turbulent time at the Manhattan Project sites, which would later evolve into the National Laboratory System, a system of centralized national laboratories funded by the public and charged with research and development to benefit both the military and the public welfare. Argonne National Laboratory, which had initially been formed to carry out Enrico Fermi's work on nuclear reactors as part of the Manhattan Project, was designated as the first national laboratory in the US on 1 July 1946 [5].

Research developed rapidly at universities around the country, where the military funded new buildings with laboratories staffed, in many cases, by scientists who had worked on the Manhattan Project. The returning GIs flooded classrooms and left the colleges and universities very short of teaching staff. The National Science Foundation (NSF) was created on 10 May 1950 to support research based on scientific merit rather than potential civilian or military applications, and the NSF supported a great deal of academic research.

The Cold War brought what seemed like almost unlimited funding for research in several areas of physics, including nuclear and particle physics. Corporations as well as governments also began to realize how important materials science could be to them. Physics research, no matter how basic, seemed to be a magic bullet for the development of new technologies. However, at the same time the Cold War brought on a wave of fear of aggression from the communist bloc of nations led by the Soviet Union. As a consequence, security measures in science became more stringent, resulting in barbed wire and guarded gates at some research sites, and more security restrictions on information release for topics such as research on fissionable elements, with further restrictions on publication [6]. Suspicion and security regulations drove many scientists to quit government laboratories. The Red Scare, which promoted fear of left-leaning politics and questioned the loyalty of individual scientists, was led by Representative Joseph McCarthy of the House Un-American Activities Committee (HUAC). This changed the demographics of science in the US as various universities fired faculty members who refused to sign loyalty oaths or discuss the politics of their colleagues and friends with HUAC. On 12 April 1954, the scientific leader of the Manhattan Project, J Robert Oppenheimer, was deemed a security risk after a hearing before the AEC and was refused a security clearance, an action that divided the physics community.

This time period also marked the Soviet Union's launch of Sputnik, the beginning of the space race and the establishment of the National Aeronautics and Space Administration (NASA) on 1 October 1958. NASA would employ many physicists, including some notable women, in subsequent years.

World War II also radically changed the way that physics was conducted. During and after the war, the government acquired an unprecedented role in the funding of research. The resources available became enormously larger. Furthermore, the separation between pure research and applied research and technology became blurred. Before World War II, almost all advances were due to one scientist working on her (or his) own or with a very few colleagues. It was often funded by the researchers themselves or interested wealthy individuals. After World War II, this approach became the exception rather than the rule, and physics entered the era of Big Science, which continues to the present day, with concomitant bureaucratization [6]. In 1950, the American Institute of Physics publication *Physics Today* noted that 'The springtime of Big Physics has arrived' [2, p 378].

At the end of World War II, the US had no assembled nuclear weapons. That changed rapidly, as shown in table 1.2. Los Alamos, Hanford and Oak Ridge set to work to remedy this situation by producing a number of weapons based on early nuclear fission designs and beginning design work on more efficient nuclear fission weapons for special purposes. Laboratory directors at Argonne and Oak Ridge also

Table 1.2. Nuclear weapons after World War II.

Timeline for nuclear weapon developments after World War II	
US arsenal: no implosion bomb assembled	1 September 1945
Soviets test of a fission weapon	29 August 1949
Program to develop hydrogen bomb started	30 January 1950
US test of thermonuclear device at Enewetak	November 1952
US arsenal of 841 nuclear weapons, total yield 50 megatons	End of 1952
First Soviet test of a thermonuclear device, Joe 4	12 August 1953
US test of first hydrogen bomb at Bikini Atoll	1 March 1954
US arsenal 5 543 nuclear weapons, yield 17 546 megatons	End of 1957

began to develop nuclear reactors for use in the production of civilian electric power. Laboratory directors at the weapons laboratories argued forcefully for the support of general nuclear research at their facilities because (1) research results might be critical for future weapons development and (2) unless scientific staff had the opportunity to conduct basic research, the most capable scientists would migrate to the developing research universities. The AEC continued these policies immediately after its creation in 1947.

On 29 August 1946, the Soviets tested a nuclear fission weapon well before the US had anticipated it could. (It turned out that the Soviet spy system had provided its nuclear scientists with information on the Manhattan Project, greatly shortening the development time for Soviet nuclear weapons.) The discussion of what to do about the Soviet success involved many physicists, with some, notably Oppenheimer and Fermi, advocating the development of more powerful and sophisticated fission weapons and others, led by Edward Teller, advocating a crash program to develop a weapon based on nuclear fusion which, it was anticipated, could have almost unlimited power. In early 1950, President Truman announced a crash program to develop a thermonuclear (fusion) weapon, the hydrogen bomb. Both the US and the USSR successfully developed and tested such weapons. By the end of the decade, US and Soviet arsenals held thousands of nuclear weapons.

It was also well-established that atmospheric testing of nuclear weapons released radioactive isotopes into the atmosphere. Public fear of nuclear radiation drove support for stopping nuclear testing and by 1963 both governments had agreed on the Limited Nuclear Test Ban Treaty which forbade atmospheric testing. After this, the weapons laboratories developed methods for underground nuclear testing and began to diversify their research portfolios beyond the production and development of nuclear weapons.

Among the new technical developments, there was no device that had a greater impact on physics or was more closely associated with physicists than the computer. Many women were active in computer development, but the story of the computer is a saga in its own right and will not be treated here.

A major contributor to the development of computers was the advent of solid-state electronic devices, specifically the coming of the transistor, which was announced by Bell Telephone Laboratories in late 1947. This led to the replacement of vacuum tubes, which were relatively large and operated at higher voltages, by transistors, which operated at lower voltages, emitting much less heat. The use of transistors also made circuitry much more reliable. The development of the transistor caused a boom in solid-state electronics and spawned the growth of an industry in which many of the major companies supported active research laboratories. Integrated circuits followed in the late 1950s and then microprocessors in the late 1960s and 1970s. The large industrial research laboratories competed with the National Laboratories and the research universities. They provided employment for many physicists and also created a demand for students with technical training. The miniaturization of circuit components enabled by the transistor also made it more feasible to launch spacecraft and contributed to the acceleration of the space race.

Studies in condensed matter physics continued, with some successes and hopes for additional advances in areas such as high-temperature superconductivity, which seemed to promise new and very useful technological applications. The discovery of the Lamb shift in 1947 led to increased interest in quantum electrodynamics.

Additional developments in physics included the invention of the laser in 1958, and further progress took place in many other areas, notably in understanding the nucleus, the fundamental forces and elementary particle physics. Women physicists worked in all these areas. Women were especially active in astronomy and astrophysics as they had traditionally been.

Obviously we have omitted any number of technical developments, but this limited list concentrates on those developments that most affected women physicists.

We will discuss two major classes of women physicists in subsequent chapters. First, a number of women physicists worked on military projects, while others worked in the universities or industrial laboratories while the war was in progress. After the war, some of these women continued in research in areas such as nuclear weapons and nuclear reactor development, some switched into new fields such as health physics and played key roles in their development, and a few dropped out of physics. The second set of women consisted of members of a generation of women who finished their degrees during the war years. They entered the workforce in the late 1940s and early 1950s. They played significant roles in the new large industrial laboratories and in the growing field of condensed matter physics. They also did significant work at NASA and contributed to the educational reforms in science that followed the launch of Sputnik. Like their male colleagues, some of these women suffered for protecting their colleagues and friends from the harsh investigations of the HUAC.

We have organized the stories of these women according to the institutions that employed them. This grouping is necessarily arbitrary, particularly since many of the women we discuss changed jobs and worked in more than one research field during this period. We choose it because it highlights the types of work and the importance of the work that women physicists conducted during the late 1940s and 1950s, and assists us in telling their stories.

We limit our discussion largely to the late 1940s and 1950s, as is evident from the time lines above, although tracing individual careers requires going outside this time limit. During the 1960s, the civil rights and women's movements began to affect all workplaces. Moreover, the physics conducted in the National Laboratories changed with the signing of the Limited Test Ban Treaty in August 1963, and physicists there began to focus on issues of safety and the verification of arms control agreements, as well as new ways of producing energy. The development of the personal computer, which also dates from the early 1960s, vastly changed the way in which physics was done, as did the construction of very large accelerators in dedicated facilities. All these developments affected the work that women physicists did and the character of the physics workforce. While we include some minimal discussion of physics and physicists in the 1960s and later, this book focuses on the challenges and successes of women physicists in the years immediately following World War II, before the eras of affirmative action and the personal computer.

References

[1] Peason M 2006 *Interview with R Howes* (3 November 2006, Menomenee Falls, WI)
[2] Kevles D J 1995 *The Physicists: The History of a Scientific Community in Modern America* (Cambridge, MA: Harvard University Press)
[3] Kaiser D 2004 *Am. Quarterly* **56** 877
[4] Howes R and Herzenberg C 1999 *Their Day in the Sun: Women of the Manhattan Project* (Philadelphia, PA: Temple University Press)
[5] Holl J M 1997 *Argonne National Laboratory: 1946–96* (Chicago, IL: University of Illinois)
[6] Seidel R W 1986 *Historical Studies in the Physical and Biological Sciences* **16** 135

Chapter 2

Women physicists in the National Laboratories

During World War II, almost all physicists were involved in some sort of war-related research or in teaching military officers. Some worked in small groups at universities around the country. The radar project was headquartered at Massachusetts Institute of Technology (MIT) and the sonar project at Johns Hopkins University, while the Manhattan Engineer District oversaw work at the Manhattan Project sites; the large production facilities, however, were managed by industrial contractors (Monsanto at Clinton, TN and DuPont at Hanford, WA). With the end of World War II, leaders in the scientific community turned their attention to the question of what should be done with this enormous research infrastructure. Certainly it should not be dismantled. They also confronted the fact that many physicists engaged in military research were eager to resume their civilian careers. For example, personnel at the Metallurgical Laboratory (Met Lab) at the University of Chicago had been largely moved to positions at Clinton Laboratory or Hanford Laboratory to help with the reactor work there long before the war ended.

The individual laboratories evolved from sites of the Manhattan Project, and were managed in a variety of ways under the direction of the AEC. The model varied. For example, Brookhaven was not an original research site of the Manhattan Project, but it was established by a group of physicists who had worked on the Manhattan Project as a center for the construction of accelerators and reactors for fundamental research. Argonne consolidated the research established in the Chicago area by the Met Lab and was managed by the University of Chicago; Oak Ridge, managed by a consortium of universities, focused on the development of reactors; and Los Alamos, managed by the University of California, focused on weapons development. Lawrence Berkeley Laboratory, managed by the University of California, grew to provide users from industry and academia access to Lawrence's cyclotrons. It was agreed that the labs should compete with one another to ensure that their research programs were efficient economically and of high scientific quality, particularly since classified research could not be published

doi:10.1088/978-1-6817-4094-2ch2

or subjected to peer review. Edward Teller lobbied for the establishment of Livermore as a center of research on nuclear weapons to provide a check on Los Alamos's work [1].

The evolution of the National Laboratories offered a variety of opportunities for women physicists to do exciting physics and avoid the anti-nepotism rules at universities. Edith Truslow and Ralph Smith [2] grouped Manhattan Project scientists at Los Alamos into five categories, which were found at all the Manhattan Project sites:

1. academic personnel on leave from universities and colleges;
2. young PhDs recently arrived from graduate school;
3. graduate students with varying experience;
4. technicians, administrative and clerical personnel; and
5. officers and enlisted personnel.

Most of the established scientists were eager to return to their civilian jobs, and graduate students wanted to finish their degrees. Military personnel were ordered to report to their induction points and muster out. Laboratory directors returned to their civilian positions. Although General Leslie Groves (US Army commander of the Manhattan Project during the war) remained in overall charge, the individual project sites suffered a sudden shake-up in leadership. Many laboratory staff struggled to decide whether to accept jobs offered by the Manhattan Project labs or to accept civilian positions in academia or industry. For women, the situation was often complicated by having young children and, at least in Oak Ridge, Los Alamos and Hanford, the rough housing built cheaply to accommodate wartime staff.

New PhDs were a different kettle of fish. Many of them had joined the Manhattan Project straight out of graduate school and did not have established careers to pursue. Several young married women PhDs who worked on the Manhattan Project remained in the lab system after the war along with their husbands and went on to distinguished careers.

Jane Hamilton (figure 2.1) grew up in Denver and studied at the University of Chicago, where she was awarded her PhD in physics in 1942 [3]. There she met and married David Hall, a fellow physics student. She taught for a year as an instructor at the University of Denver and in 1943 both Halls joined the Met Lab, the Manhattan Project site at the University of Chicago. In 1944, they moved to the Hanford site, where Jane was a senior supervisor for DuPont [3], assigned to work on health physics instrumentation since anti-nepotism rules did not allow her to work with her husband on reactors [4]. In 1945, Enrico Fermi, then the director of the Argonne site of the Met Lab in Chicago, brought Jane to Argonne as an associate physicist and assistant to the director [5]. That lasted only two months because David Hall had accepted a position at Los Alamos. Jane became a staff member at Los Alamos in late 1945 [3].

At Los Alamos, she was a member of the group that designed and built the Clementine reactor, the first plutonium-fueled reactor with liquid metal coolant. It went critical in 1946 and operated until Christmas Eve 1952. Reactor operator Jane Heydorn—who arrived at Los Alamos as a member of the Women's Army Corps (WAC) and worked as a telephone operator before transferring to the electronics

Figure 2.1. Jane and David Hall at the controls of a cyclotron at Los Alamos Scientific Laboratory, 10 September 1947. Photograph courtesy of Los Alamos Historical Society Photo Archives.

construction group, where she returned after her discharge—remembers that Jane Hall trained her to operate Clementine in 1949, when she became probably the first and only woman to operate a fast neutron reactor. She remembers that after training, Jane Hall handed her the key to the reactor console and said, 'Now it's all yours. Take good care of it.' When Clementine shut down, Heydorn moved to the midnight shift on the Water Boiler, another reactor fueled with weapons grade uranium [6].

Jane Hall moved up the ladder of Los Alamos administration to become Assistant Director, while conducting research on reactors, x-ray crystallography, neutron physics and cosmic radiation. In 1967, she was named a member of the AEC Committee on Nuclear Materials and Safeguards. She retired from Los Alamos in 1970, but continued to serve as a consultant [7]. She served as secretary of the General Advisory Committee (GAC) of the AEC from 1956–59 and was named to the GAC itself as its first woman member in 1966 for a term to expire in 1972. On 6 October 1970, she was awarded the AEC Citation and a gold medal as the first woman to receive this award [3].

Another example of a woman who stayed in the lab system, Elizabeth (Diz) Riddle Graves, grew up in Oklahoma City and received her PhD in physics from the University of Chicago, where she married fellow graduate student Al Graves. The Graves moved to Austin, Texas but left in 1943 for Los Alamos. Although Diz Graves had studied neutron scattering for her dissertation, she could not work at the University of Texas because of anti-nepotism rules, and thus the young couple became separated, since Diz stayed in Chicago. Al Graves made it a condition of his coming to Los Alamos that his wife should also be offered employment.

After the war, the Graves family remained at Los Alamos to raise their three children. Al worked in the nuclear testing division and at the time of his death in July 1965 was division leader [8]. Diz worked in the physics division with fast neutron experiments and at the time of her death in 1972 was a group leader there [9]. She was known for her sense of humor and her indomitable devotion to her experiments. She actually went into labor while working on an experiment and continued work while timing her contractions with a stopwatch [10].

On 21 May 1946, Al Graves was in a group of seven men watching as Louis Slotin demonstrated how to push two pieces of enriched uranium or plutonium towards each other to measure the neutrons emitted as fissions were triggered by the neutrons they exchanged. By measuring the distance and heat generated in the samples, he could determine their content of fissile material. The experiment was done by pushing slugs toward one another with a screwdriver and was known to be dangerous (it was called 'tickling the dragon's tail'!).

Slotin was training the men in his techniques when his hand slipped and the room filled with a blue glow of ionization that meant a chain reaction had started. Slotin flung himself over the experiment to push the pieces of fissile material apart. He knew immediately that he had received a lethal dose of radiation. Al Graves had been at Slotin's shoulder when the accident started, and Slotin asked Diz to calculate the dose the person at his shoulder had received without telling her that it was her husband. Graves lived to die of a heart attack, but developed some symptoms of radiation poisoning, including cataracts and temporary baldness [11]. Diz also turned down an appointment to the AEC because she did not want to leave her husband and family soon after the accident [12].

Yet another well-known woman physicist, Leona Woods (figure 2.2), received her PhD in molecular spectroscopy from the University of Chicago in 1943 [13]. In 1942, Met Lab moved into the basement lab where she was working on molecular spectroscopy, and Leona was eager to join the group of intelligent young men who played as hard as they worked [14]. The group built the first nuclear reactor, a 'pile' of graphite bricks with uranium spheres embedded in them, under the football stadium of the University of Chicago. The group made history when this nuclear reactor went critical on 2 December 1942 and produced the world's first self-sustaining, controlled nuclear chain reaction. Woods was included because her skill as a glassblower enabled her to construct the neutron detectors that determined when the pile went critical.

In July 1943, Woods married John Marshall, a physicist who had come to Chicago from Columbia, and the couple helped rebuild the pile outside Chicago in the Red Gate Woods, codenamed Argonne Woods, one of the temporary sites used by the Met Lab prior to the establishment of Argonne National Laboratory. Leona became pregnant and worked on the pile while hiding her pregnancy under overalls and a denim jacket until the baby's birth in 1944, when the Marshalls headed for the Hanford site to help with the construction and operation of the plutonium

Figure 2.2. Leona Woods Marshall at the University of Chicago in 1946. Photo courtesy of Argonne National Laboratory.

production reactors. Leona's mother moved, too, and with the help of Fermi's bodyguard, the baby was raised well [15]. At the end of the war, Leona received a 1946 Mademoiselle Merit Award along with Captain Arlene Schiedenhein, commander of the WACs on the Manhattan Project, and the USS Missouri, glamour girl of the fleet [16].

After the war, the Marshall's returned to Chicago, where she became a research associate at the Institute for Nuclear Studies of the University of Chicago in 1947. Her work with Enrico Fermi supported a gradual transition from nuclear to particle physics. Her second son was born in Chicago in 1949. When Fermi died in 1954, Leona moved to the Institute for Advanced Study in Princeton, while John Marshall moved to Los Alamos. Leona then worked as a visiting scientist from 1958–60 at Brookhaven National Laboratory, before moving to New York University as an associate professor. Although she had then been promoted to full professor, she accepted an appointment as an associate professor of physics at the University of Colorado at Boulder in 1963. She served as a consultant to Los Alamos, TRW Space Systems Group and the Rand Corporation, which named her a staff member from 1966–70. Her interests evolved from nuclear physics to problems in fundamental particles and cosmology.

John Marshall had remained at Los Alamos during this time and in 1966 the Marshalls divorced, with Leona then marrying Willard Libby, who was on the staff at UCLA and had won a Nobel Prize in 1960 for the development of radiocarbon dating. After four years of commuting, Leona accepted positions as a visiting professor of engineering at UCLA and as a staff member at R&D Associates. In 1972, she dropped her affiliation with UCLA and worked full time with R&D Associates. Her interests shifted to problems in cosmology and climate change. She also wrote a book about her experiences in physics, *The Uranium People.* The quality of her work is attested by the fact that she was a fellow of the American Physical Society and the Royal Geographical Society, however, her peripatetic career kept her from leadership positions, although she played important roles in many projects [14, 15, 17].

The other women physicists who worked at Argonne National Laboratory included two women born in Germany, future Nobel laureate Maria Mayer (whose work will be described in a later chapter because her most famous discoveries were made at the University of Chicago) and Luise Meyer-Schutzmeister [18–20]. Meyer-Schutzmeister was awarded a PhD by the Technical University of Berlin in 1943. While in Germany, she taught at the Technical University of Berlin, worked at the University of Gottingen and served as a group leader at the Radioisotope Laboratory of the Max Planck Institute for Medical Research. She married German-born astrophysicist Peter Meyer, who specialized in cosmic rays, and they immigrated to the United States in 1953, going to the University of Chicago, where Peter was appointed to the faculty. Luise became a research associate at the Institute for Nuclear Studies at the University of Chicago in 1953. In 1956 she became an associate scientist in the Physics Division of Argonne National Laboratory, and in 1973, a senior scientist. She conducted resonance absorption and fluorescence measurements of gamma rays in nuclear reactions, was a member of the team that provided the first independent confirmation of the discovery of the Mössbauer effect and was involved in elucidating the structure of nuclear giant resonances [19]. She continued her research studies at Argonne until her death in 1981. Luise and Peter had two sons [21]. Luise was recognized as a Fellow of the American Physical Society. The Luise Meyer-Schutzmeister Award, named in her honor, was created by the Association for Women in Science for graduate students in physics [18, 19].

Physicist Kay Way had been the first PhD advisee of John Wheeler, a brilliant theoretical physicist at the University of North Carolina. She obtained her PhD in 1938, taking the time to co-author three papers because there were no jobs. In 1938, Way obtained a Huff Research Fellowship at Bryn Mawr College, followed by an appointment as an instructor at the University of Tennessee. By 1942, she had been promoted to assistant professor and was working on a project to build a neutron source for the production of an isotope of plutonium from ^{239}Np. She was then recruited to the war effort to study mines and minesweeping. She heard rumors of the Manhattan Project work in Chicago, called Wheeler, and soon found herself helping Alvin Weinberg analyze neutron behavior in Fermi's atomic piles, and studying the systematics of the radioactive decay of fission products, which lead to the well-known Way–Wigner formula. In the early summer of 1945, Way moved to Oak Ridge, Tennessee to work at the Clinton Laboratory of the Manhattan Project, where large experimental reactors were under construction [22]. She had been commuting between Chicago and Oak Ridge in an ancient car that she bought from a friend for 150 US dollars. Her designs supported the plutonium production reactors at Hanford, and she visited there, where she knew Jane Hall. She also visited Los Alamos, since she knew about the 'atomic bomb' project [23].

When the war ended, Way recognized that the vast amount of data on various nuclei collected during the war needed to be organized. So in December 1945, she helped run a conference at Oak Ridge to examine the problem. The conference eventually led to the formation of Oak Ridge Associated Universities, which oversaw the operation of Clinton Laboratory when it became Oak Ridge National Laboratory. In 1946, she also co-edited the book, *One World or None*, an influential discussion of a nuclear world by many distinguished scientists, including several Nobel Laureates, among them Albert Einstein. It was about this time that the McCarthy hearings began affecting several staff members at Oak Ridge. Meanwhile, Way continued to work at Oak Ridge on organizing nuclear data, a vast and essential undertaking. In 1949, she moved to the National Bureau of Standards in Washington to work full time on the data project.

In 1953, Way led the formation of the Nuclear Data Project, for which a group of well-regarded physicists collected and organized data into the Nuclear Data Sheets, which were used by almost all nuclear experimentalists well into the 1970 s. Also in 1953, Way moved to the National Research Council and back to Oak Ridge in 1963. Throughout this period she continued her work on nuclear data. In 1954, she and Marion Wood studied the systematic trends in the half-lives of beta decaying nuclides and published a method for approximating the energy of beta decays in isotopes where it has not been measured, the first example of what became known as a Way–Wood systematic.

Way retired from Oak Ridge in 1968 and became an adjunct professor at Duke University. She was a fellow of both the American Physical Society and the American Association for the Advancement of Science [22].

Mary Langs started her university education at the University of Washington in Seattle and received a fellowship to Mills College, where she earned a master's degree in 1941. She subsequently received another fellowship to George Washington University. In 1942, she married Harold Argo, a fellow graduate student at George Washington. As professors left for war projects, she taught freshman physics. Then the Argos moved to Los Alamos, where they worked in Teller's group doing calculations in support of his project to produce a fusion bomb.

The Argos followed Teller to Chicago when he left Los Alamos in February 1946, and Harold returned to graduate study. Mary worked briefly with future Nobel laureate Maria Mayer and then started a family that would eventually grow to a daughter and three sons. The Argos lived on the top floor of the Mayers' house in Hyde Park in Chicago. In 1948, the Argos moved back to Los Alamos, and Mary Argo returned to work in 1960, doing opacity calculations until her retirement in 1984. She greatly enjoyed her work, never stopped learning and stayed in touch with

Figure 2.3. Judy Gursky in her lab at Los Alamos. Photograph courtesy of Phillip Gursky.

Edward Teller, with whom she collaborated on several projects. Her husband boasted that he never had to explain anything to her [24].

In many ways, Mary Argo's career path was typical of those of younger women who came to Los Alamos to work on the Manhattan Project. For example, Margaret Ramsey came to Los Alamos in the spring of 1945 after completing her bachelor's degree at the University of Rochester, doing calculations in astrophysics under the direction of Robert Marshak. In 1946, she left Los Alamos and studied for a year at Indiana University before getting married in 1947 and moving to Cornell to the complete coursework for her master's degree from Indiana University. For the next few years, she worked as a teaching assistant and a research assistant on the photographic emulsions used to record nuclear events at the Cornell synchrotron and at Caltech. At that point, she decided to drop out of physics [25].

The stories of Margaret Ramsey and Mary Argo illustrate the exodus of scientists, both men and women, from the Manhattan Project labs. The labs in turn recruited new scientists, including several women physicists. The four stories told below illustrate the variety of women who took jobs at the labs after the war, and how they balanced their work and their personal lives.

Judy Gursky (figure 2.3) graduated with a BA in physics from Mt Holyoke College in 1947 and visited the office of the American Physical Society in New York City because she had heard that they kept a card file of open jobs. Judy joined Oak Ridge National Laboratory when she was 20 and worked in the physics division on materials used for shielding, although she was more interested in nuclear level schemes. She then transferred to the electronics group, where she had a phenomenal boss, P R Bell, with whom she spent three years developing and testing materials made for scintillation counters, which also gave her the opportunity to work on nuclear level schemes as a way of testing the detectors. She was of particular value to the group: most male members of the group were color blind and could not read the codes on resistors [26].

Judy then entered graduate school in physics at Vanderbilt University, where she completed the course work for a PhD and met a fellow graduate student, Martin Gursky, who was a theorist and had just finished his qualifying exams. Martin was intrigued by the new female graduate student and introduced himself by sticking his head into her office and asking, 'Do you like chamber music?' Judy and Martin were married in 1953 and soon had their first child. Martin had to get a job while he finished up his PhD. He went to Los Alamos accompanied by Judy and their child. Judy completed her MS in 1954 and Martin completed his PhD in 1958 [26].

By 1955, the couple had a two-year-old son and a baby of eight months, but Judy went back to work at Los Alamos. She was probably the first staff member hired part time. She worked with the electronics group using radioactive lanthanum to look at changes in density during an explosion. After a year, Judy transferred to P (physics) Division, thinking that she would be working on nuclear decay schemes. However, she was put to work making targets for the lab's Van de Graaff accelerator and the cyclotron, a critical skill in accelerator studies of nuclear properties. Judy was good at it! The Gurskys had five children in eight years, and Judy remained half time until all the children were in school, at which juncture she was hired full time and continued making isotopically enriched targets for multiple groups, including a number of visiting faculty members, such as physicist Fay Ajzenberg-Selove. Judy helped form a group of target makers from around the world who met to discuss techniques [26].

At Los Alamos, Judy Gursky worked alone, even declining a technician when she was offered one. She had much useful consultation with the materials division. She made targets from at least two-thirds of the elements, including all of the isotopes of lead and platinum. She remembers carrying finished targets from her lab to the accelerators in a box on her bicycle, since that was the fastest way to get them from one place to another. In 1983, Judy retired although she worked as a consultant until 1993 when the Van de Graaff accelerator was shut down [26].

Like Gursky, Elizabeth ('Beth') Hebb graduated from a women's college, Bryn Mawr, with a BA cum laude and with honors, in 1950. She then moved to Indiana University, where she obtained her master's and PhD degrees in physics. She also met her husband, Eugene Plassman, at Indiana University. He had fought in World War II, then completed his undergraduate work at Hastings College in Nebraska, and was working on his graduate degrees in physics at Indiana University. He had visited Los Alamos as a summer student in 1953 and returned there in 1955 as a staff member after a short stint at the University of Kentucky [27].

Beth moved to Bradley University in Peoria until her marriage to Eugene in 1955, at which time she moved to Los Alamos, where she worked on materials for weapons development. In 1960, she was appointed assistant group leader, in 1970, a group leader, and in 1981, an assistant division leader. In 1982, she was named Associate Division Leader for Weapons Systems and in 1983 she also became the Program Manager for Production and Surveillance. She retired in 1991 as the Design Engineering Leader (also for weapons). At the lab, she was a member and chair of the Staff Review Committee and the Nuclear Criticality Safety Committee. She belonged to the American Physical Society and the American Nuclear Society [28].

Her technical work on weapons development is classified. As an administrator, she was in charge of managing groups of scientists and technicians, most of whom were men. She recalled only one instance in her first year at Los Alamos where being a woman made a difference. When merit raises were to be announced, Eugene's group leader called her group leader to make sure that her raise would not be larger than his and cause bad feelings at home. She also fondly recalled that when she was expecting her first child, the men in her group boiled water every morning without any idea what role it would play in delivering a baby, but knowing that it was traditional and feeling they owed it to her. One of them reports that they drank a lot of instant coffee on those mornings. Beth left work two days before the birth of her son, although she worked until the last minute before the births of her other three children, two daughters and another son. She sometimes worked half or three quarters time if the home situation demanded it, but usually worked full time as a physicist and held another full-time job as a mother. She was well-liked, enjoyed swimming and hiking, and was active in the community [29]. As one woman who worked with her said, she was ahead of her time.

Gertrude ('Trude') Scharff Goldhaber arrived at the newly created Brookhaven National Laboratory in 1950—as the first woman PhD hired by that lab—at an older age and by a more devious path than those followed by Gursky and Plassman. By the time of her death in 1998, she was a senior scientist at Brookhaven, a member of the National Academy of Sciences and a fellow of both the American Physical Society and the American Association for the Advancement of Science. She was also a co-founder of Brookhaven Women in Science [30].

Trude completed her doctoral degree in Munich in 1935 with Walther Gerlach. Her research concerned the way that stress affects magnetization in ferromagnetic materials above the Curie temperature. She realized then that she needed to leave Germany, so she fled to London, where she had difficulty finding a position, in part due to the flood of refugees. After living on the proceeds of the sale of her camera for six months and working as a translator, she finally accepted a postdoctoral position with G P Thompson, working on electron diffraction. It was made very clear that she would not receive a permanent position, so she searched for another job until she married Maurice Goldhaber, a young American physicist whom she had met while he was studying in Berlin. Maurice had a job on the faculty at the University of Illinois, so the couple moved to Urbana, where their two sons, both of whom became theoretical physicists, were born [31–33].

The University of Illinois had strict anti-nepotism rules and refused to hire Trude in spite of her excellent credentials; nor could she be given a laboratory, so she had to either quit physics or join in her husband's research, without a salary.

This she did, and managed to discover that neutrons were emitted in spontaneous fission as well as in neutron-induced fission; however, the paper could not be published until after the war. The Goldhabers would spend 11 years in Urbana, during which time Trude would have no regular job, although after the war, she was appointed a research assistant professor. The Goldhabers observed beta rays impinging on lead atoms and rigorously demonstrated that the beta rays were indistinguishable from electrons [31].

In 1950, the Goldhabers both accepted staff positions at Brookhaven National Laboratory. There Trude worked on the collective excited nuclear states at low energies, verifying the variable moment of inertia model by comparing the energies of the first two excited states in several regions of the nuclear mass spectrum. She is remembered for developing graphs to explain her results. She even managed to publish a paper with her son Alfred, possibly the first paper published in physics by a mother/son team [31, 32]. The importance of her cumulative work is evidenced by the many honors she received, notably her election to the National Academy of Sciences.

Another recruit to the National Laboratories, in this case to Los Alamos, was Alice Hall Armstrong, known widely as Miss A. After Armstrong's graduation from Wellesley College in 1919 with a degree in physics, she took a job with the National Bureau of Standards (NBS) in Washington, D C. The NBS certified the amount of radium in sources used for cancer treatment in the US, and she thought the work would be interesting. She worked as a laboratory assistant for about a year, checking radium dial wristwatches for use by the army, and was then able to transfer to the radium section as an assistant physicist [34]. She said that there were quite a number (half a dozen) of women working at NBS at that time. She often worked late when an unusually large shipment of radium came in. The female technician with whom she worked and who had graduated from Bryn Mawr, Frieda Kenyon, was used to guns, so she brought one in and planned to fire it twice out of the window of the lab to alert the gatekeeper to call the police if needed. They never had to fire the gun, but it made them much happier to have it [35].

The instrumentation they used to measure the radium in samples was a gold-leaf electroscope, which they could charge and then discharge through ionizing the air around it by bringing the radium sample to be tested close. They measured the time it took to discharge the electroscope and compared it to the time it took a standard source, made by Marie Curie, to discharge it. The standard was a small amount of radium barium sulfate in a sealed glass capsule. The German standard had exploded because of the buildup of radon gas, and one night when Armstrong was holding the US standard in forceps, she either dropped it or it exploded. She notified the chief of division immediately, terrified that she had destroyed the national standard. She was given a sheet of brown paper and sent home to shake herself off, undress, wrap all her clothes in the paper and bring them back to the bureau to salvage the precious radium. This happened in 1922 after Curie's visit in 1921, when Armstrong actually met her [35].

Armstrong left NBS in 1922 and enrolled in graduate study at Radcliffe in order to get a master's degree and earn more money. The problem with physics courses was that many of them were offered at Harvard, and at that time women were strictly barred from Harvard undergraduate classrooms, and even at the graduate level some professors banned women from their courses. The department chair at the time did not want women in 'the sacred halls of Harvard' and Armstrong had to sneak past his office to enter the building. She recalls turning 'into a little gray mouse' if he came out of his office [35]. She survived the various hassles, obtained her master's degree in 1923 from Radcliffe and went to work with William Duane and his group [36, 37].

Duane's group bought x-ray tubes unevacuated with the electrodes set in the ends. They put one on a stand and attached it to a vacuum pump by means of a tube that entered the x-ray tube through a hole in one end. The students stood in a lead-lined chamber and looked through lead glass as they gradually raised the voltage until they saw a flash that indicated remaining air. They repeated the procedure until they got the voltage high enough to produce x-rays. The back of the tube was unshielded and held against the wall. When the tube was evacuated enough to produce x-rays, they would call a glass-blower to seal it. After several successful constructions, they had an accident that gave Armstrong half a lethal dose of x-radiation. She stopped menstruating, lost all energy and had to go home for a year and a half. Finally, she began to recover her strength. She said she was the one doing 'menial' work near the tubes and so got the high dose of radiation [35]. Apparently she had stepped outside the lead-lined room to make an adjustment.

For the academic year 1925/6, Armstrong worked as a part-time instructor at Wellesley. She was also awarded a fellowship of $1500 US dollars from Radcliffe. From 1927–29, she worked as a research assistant in biophysics at the Rockefeller Institute for Medical Research in New York. In 1929, she returned to research on x-rays at Harvard while working as a laboratory assistant for the Harvard Cancer Commission at Huntington Hospital in Boston, and received her PhD from Radcliffe in 1930 [34]. Harvard counted the work she had done before the accident towards her degree [35].

In the fall of 1930, Armstrong returned to Wellesley as an assistant professor of physics and was promoted to associate professor in 1936. Her experimental work is documented in a number of publications [34]. In 1939/40, she took a leave from Wellesley to study at the acoustical laboratory at UCLA, and from February 1944 to August 1945 she worked on a war project as a special research associate at the Harvard Underwater Sound Laboratory [38]. She mostly made routine measurements, since women were not allowed on the research boat on Massachusetts Bay because there was no women's lavatory [35]. In 1945, she became the Louise S McDowall Professor at Wellesley and served as department chair from 1945–50.

In 1950, Armstrong was looking for a sabbatical where she could conduct research. Los Alamos was looking for a woman physicist to supervise the work of a group of women who were reading photographic plates covered with a special emulsion that was used as a detector for nuclear reactions. After a year in Los Alamos, she returned to Wellesley in 1952 so that another faculty member could take a sabbatical, even though she had been offered a permanent position at Los Alamos. In June 1953, she resigned from Wellesley to become a permanent staff member at Los Alamos [34, 35]. She was appointed Assistant Group Leader in the Physics Division of Los Alamos in 1957 [39]. She worked on nuclear data analysis until a few years before her retirement in 1964, when she moved to the Vela Satellite Program, studying the distribution of charged particles in the Van Allen belt. Armstrong gave the first paper presented at the American Physical Society on the flux and energy of protons in the lower Van Allen belt [37].

One of the principal developers of the use of layers of emulsions to detect and characterize nuclear particles was the Austrian physicist, Marietta Blau, who studied techniques for the preparation of uniform thick layers of silver bromide that could be used to detect cosmic ray tracks in the 1930s. She also perfected darkroom techniques for the development of the thick emulsions, demonstrated that proton tracks in the emulsions can be distinguished from alpha particle tracks and showed that the proton recoils produced by elastic collisions with neutrons can be detected by the emulsions.

During World War II, emulsions continued to be used primarily in cosmic ray research and were not more widely used because they were not adequately sensitive to the ionization along the tracks of medium energy charged particles produced in accelerators. During the late 1940s and the 1950s, the range of materials used in emulsions increased, and their versatility in the detection of radiation was further extended. In particular, in 1948 H R Berriman announced that he had prepared a photographic emulsion that was more sensitive to ionization, and layered emulsions became the state of the art detection system for nuclear particles at major accelerators, enabling a number of major discoveries to be made in particle physics [40, 41].

Blau's personal life was a story of tragedy. In Vienna, she worked on physics as a volunteer at the Institute for Radium Research and the Physical Institute of the University, having left a paid position in Germany to return to look after her sick mother. Some time around 1931, Blau accepted Hertha Wambacher as a collaborator, even though Wambacher was a member of the Nazi party and had studied law and not physics. They collaborated for nearly a decade, until the Nazi impact on Austria began to be felt. Another member of the Nazi party from the same research group, G Stetter, a married bigwig, was having an affair with Wambacher. Fortunately, when Hitler annexed Austria, Blau, a Jew, was conducting research in Oslo, and was able to escape to Mexico. She worked there during the war, even though her research plans had been stolen during a stop in Hamburg, and the research projects proposed in them were implemented by Stetter and Wambacher.

In 1944, Marietta Blau was able to move to the US, where she joined Brookhaven National Laboratory in 1950. Subsequently, in 1955, she moved to the University of Miami, Coral Gables. Cataracts arising from her work with radiation, nearly blinded her, and she was forced to stop work and return to Austria in 1960 for surgery which she could not afford in the United States. The surgery was eventually successful, but Blau struggled with poverty, living on her American Social Security pension since she was not eligible for Austrian support because she had never had worked there for a salary. She died in Vienna in 1970 [40].

Nuclear emulsions were widely used after the end of World War II. One of the authors (CH) remembers having a summer job during college developing nuclear emulsions at MIT. Phyllis Stcyr Freier used the technique to detect heavy nuclei in cosmic radiation during her graduate studies at the University of Minnesota in April 1948, and her analysis of the emulsions led to her PhD thesis in 1950. Her husband, whom she had met in graduate school, was awarded a faculty position at the University. Anti-nepotism rules prevented Phyllis from any formal position at the university or from teaching at either the graduate or undergraduate level. She could not hold research grants. Nevertheless, she continued her work with cosmic rays, studies of solar flares and gamma ray astronomy mostly, with large, often international collaborations. She was a fellow of the American Physical Society and the American Association for the Advancement of Science, as well as chair of the Cosmic Physics Division, the Nominating Committee and the Council of the APS, while finding time to raise two children [42].

Unlike her older sister-in-law, Gertrude Goldhaber, Sulamith Goldhaber met her husband, Gerson Goldhaber, the younger brother of Maurice Goldhaber (Trude's husband), when they were both working towards their master's degrees at Hebrew University in Jerusalem. Sulamith had been born in Vienna and was brought to Israel, where she grew up as a child. Gerson and Sulamith both received their degrees in 1947, he in physics and she in physical chemistry. The young couple married before moving to the University of Wisconsin. There Gerson received his PhD in physics in 1950, and Sulamith received her PhD in radiochemistry in 1951. Gerson received a junior faculty appointment at Columbia working on the cyclotron and Sulamith joined him there as a research associate in radiochemistry until 1953. At this period of her life, Sulamith changed her field of interest from radiochemistry to particle physics. She and her husband became experts in using nuclear emulsions to identify particles produced in nuclear reactions by both accelerators and cosmic rays [43].

In 1953, Gerson became an assistant professor at the University of California at Berkeley and in 1954, Sulamith became a research physicist at Lawrence Radiation Laboratory (Lawrence Berkeley National Laboratory). In 1958, she received a promotion to become a physicist (a staff member) at the Laboratory [44]. During these years, the Goldhabers established a laboratory and trained teams of scanners and measurers to work on the emulsions. They planned to use the emulsions to collect data from interactions produced on the Bevatron at Lawrence Berkeley National Laboratory, then the world's most powerful accelerator. According to Lawrence Berkeley physicist, Luis Alvarez, one of the Goldhabers always seemed to be in a corner of the Bevatron control room, hoping for a brief exposure for their emulsions. In 1956, Sulamith presented a talk at the Rochester conference, mostly on her own work, which marked an important transition for the discovery of new particles and for those who measured their properties. Previously, such work had been most effectively conducted with cosmic rays. The Goldhabers made use of high-energy accelerators, which were the state of the art. Sulamith published 25 papers, many of them groundbreaking, on her work at the Bevatron, with several collaborators, including but not limited to her husband [43].

By the early 1960s, it became clear that the hydrogen bubble chamber would replace nuclear emulsions as the detector of choice for studies of particles at high-energy accelerators, and Sulamith learned how to use bubble chambers with her usual enthusiasm and energy and quickly became an acknowledged expert. She and Gerson obtained sabbaticals and in the fall of 1965 began a trip around the world to give lectures at various labs and meet the scientists there. In Madras, Sulamith collapsed with an inoperable brain tumor and died suddenly and unexpectedly [43].

The microscopists at the labs and other facilities who analyzed nuclear emulsions were often married to other laboratory employees and were usually women; they were thus similar to the well-known women ‘computers’ of the Manhattan Project, a group of women who worked with Marchant and Friden electromechanical desk calculators to model the shock waves produced by the shaped charges that compressed the core of a plutonium bomb.

The emulsions were mixed in the laboratory, spread uniformly onto glass plates and dried there. They were then stacked, and the stacks were exposed to beams from accelerators or cosmic rays. In the microscopy laboratory the bundles were disassembled and individual plates were developed carefully. The microscopist mounted a plate in her microscope so that its position was reproducible, and she could make measurements in thousandths of an inch using scales built into the scope. She lowered the objective of the microscope into oil and carefully moved the plate so that it could be scanned. Her normal duty was to count the number of tracks that had entered the prescribed area. Occasionally, the job was to identify a track and measure its length and the angle at which it entered the emulsion, which was much more painstaking [45].

In many ways, Dorothy Smith (figure 2.4) was typical of the women microscopists at the labs. She arrived at Los Alamos in 1949 with her husband Milo, a machinist

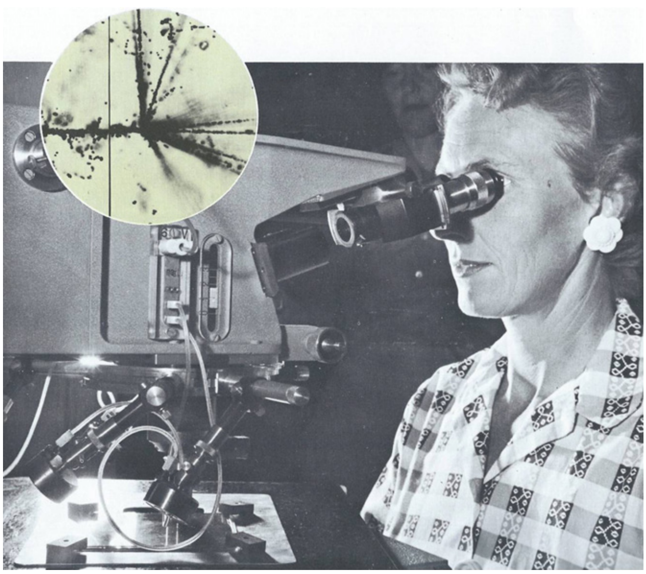


Figure 2.4. Dorothy Smith studying particle tracks in emulsion. Inset: emulsion track (highly magnified) of heavy primary from cosmic radiation colliding with heavy emulsion nucleus at 100,000 foot altitude. Photograph courtesy of Los Alamos National Laboratory and obtained from Dorothy Smith.

who had accepted a one-year assignment there, and her three children. When the youngest entered school in 1953, she was recruited to the emulsions group by a close woman friend, Rexine Booth, whom she had met on her first day in Los Alamos when the three-year-old Smith boy spotted the three-year-old Booth girl watching him from her window. Dorothy Smith was trained in a class of ten women, five in the morning, five in the afternoon. She did well and was assigned a special British microscope whose controls operated essentially backwards from the American models. She was also asked to help with mixing emulsions. Her work was always careful. She remembers noticing that the emulsions were being mixed wrongly. Her tact is evidenced by her question to her supervisor, 'Either I'm not understanding this process, or you're adding ten times too much—'. She was indeed right and they had to throw out 15 gallons that had already been mixed [45].

Thus women physicists arrived in the National Laboratatories by many paths and did a variety of work there. They benefitted from the nearly unlimited funding provided to the labs during the postwar period and the onset of the Cold War. In many cases, the labs provided an environment where married couples could both pursue careers, a stark contrast to the research universities. The next chapter will discuss the careers of women physicists in the research universities, and the role of anti-nepotism rules in their lives will be easily apparent. The National Laboratories frequently benefitted from their ability to recruit and retain married couples.

References

[1] Westwick P J 2003 *The National Labs: Science in an American System 1947–1974* (Cambridge, MA: Harvard University Press)

[2] Truslow E C and Smith R C 1961 *Manhattan District History, Project Y, The Los Alamos Project* (vol 2: August 1945–December 1946) (Los Alamos, NM: Los Alamos Scientific Laboratory)

[3] 1970 *The Atom* **7** 20–1

[4] Parker H 1979 www.ohre.doe.gov (no longer available, but quoted in Howes R H and Herzenberg C L 1999 *Their Day In the Sun: Women of the Manhattan Project* (Philadelphia, PA: Temple University Press) pp 43–4

[5] Kathren R L, Gough J B and Benefiel G Y 1994 *The Plutonium Story: The Journals of Professor Glenn T Seaborg, 1939–1946* (Columbus, OH: Battelle)

[6] Storms B 1966 *The Atom* **3** 27–8

[7] Syles R T 1987 *The Nuclear Oracles: A Political History of the General Advisory Committee of the Atomic Energy Commission, 1947–1977* (Ames, IA: Iowa State University) p 65

[8] 1965 *The Atom* **2** 22

[9] 1972 *The Atom* **9** 22

[10] Barschall H 1991 Telephone interview with R Howes

[11] Rapoport R 1971 *The Great American Bomb Machine* (New York: Ballantine) pp 126–7

[12] Divan R B 1991 Telephone interview with R Howes

[13] 1982 *American Men and Women of Science* 15th edn (New York: RR Bowker)

[14] Howes R 1993 *Women in Chemistry and Physics: A Biobibliographic Sourcebook* ed L Grinstein, R Rose and M Rafailovich (Westport, CT: Greenwood) pp 320–8

[15] Libby L M 1979 *The Uranium People* (New York: Crane Russak)

[16] 1946 *Mademoiselle* magazine (January 1946) 132
[17] Garber E 2004 *Notable American Women: A Biographical Dictionary Completing the Twentieth Century* ed S Ware (Cambridge, MA: Harvard University Press) pp 385–7
[18] Wikipedia http://en.wikipedia.org/wiki/Luise_Meyer-Schutzmeister (accessed 20/2/15)
[19] CWP at UCLA http://cwp.library.ucla.edu/Phase2/Meyer-Schutzmeister,_Luise@841234567.html (accessed 20/2/15)
[20] Schiffer J P 1981 *Phys. Today* **34** 74–5
[21] Herzenberg C 2015 private communication
[22] Martin M J, Gove N B, Gove R M and Artna-Cohen A 1993 *Women in Chemistry and Physics: A Biobibliographic Sourcebook* ed L Grinstein, R Rose and M Rafailovich (Westport, CT: Greenwood) pp 572–80
[23] Way K 1991 Telephone interview with R Howes
[24] Argo H 1991 Telephone interview with R Howes
[25] Keck M R 1991 Letter to R Howes
[26] Gursky J 2013 Interview with R Howes
[27] 2009 Plassmann (obituary) *Los Alamos Monitor* (13 April 2009)
[28] 2011 Elizabeth Plassmann (obituary) *Los Alamos Monitor* (26 May 2011)
[29] Mulkin B 1974 *The Atom* **11** 1–6
[30] Saxon S 1998 Obituary section *New York Times* (6 February 1998)
[31] Bond P and Goldhaber A S 2004 *Notable American Women: A Biographical Dictionary Completing the Twentieth Century* ed Ware S (Cambridge, MA: Belknap of Harvard University) pp 237–9
[32] Bond P D and Henley E 1999 *Biographical Memoirs* vol 77 (Washington, DC: National Academy)
[33] Goldhaber A S 2006 *Out of the Shadows: Contributions of Twentieth Century Women to Physics* ed Byers N and G Williams (Cambridge: Cambridge University Press) pp 262–1
[34] 1949 Faculty questionnaire (Wellesley College)
[35] Armstrong A 1979 Interview with Katherine Sopka *Niels Bohr Archive* (College Park, MD: American Institute of Physics) http://aip.org/history/ohilist/31255.html
[36] Behrman J 2014 private communication
[37] 1964 *The Atom* **1** 18–29
[38] Biographical sketch of Alice Hall Armstrong from the Wellesley archives
[39] Letter in Wellesley College Archives, 7B Alumnae Biographical Files, Class of 1919, Armstrong Alice
[40] Halpern L and Shapiro M M 2006 *Out of the Shadows: Contributions of Twentieth-Century Women to Physics* ed N Byers and G Williams (Cambridge: Cambridge University Press) pp 109–26
[41] Halpern L 1993 *Women in Chemistry and Physics: A Biobibliographic Sourcebook* ed L Grinstein, R Rose and M Rafailovich (Westport, CT: Greenwood) pp 57–64
[42] Waddington C 2006 *Out of the Shadows: Contributions of Twentieth-Century Women to Physics* ed N Byers and G Williams (Cambridge: Cambridge University Press) pp 294–302
[43] Alvarez L 1968 *Advances in Particle Physics* (introduction) http://cwp.library.ucla.edu/articles/goldhaber/tribute.html (accessed 3/16/15)
[44] CWP (UCLA) http://cwp.library.ucla.edu/Phase2/Goldhaber,Sulamith@812345678.html (accessed 24/3/15)
[45] Smith D 2015 Interview with R Howes

Ruth H Howes and Caroline L Herzenberg

Chapter 3

Women physicists in research universities

With the support of the GI Bill, thousands of returning veterans enrolled in colleges and universities. Although faculty members who had been working on military projects such as the Manhattan Project returned to academic jobs, and universities were able to recruit many outstanding refugee scientists, the universities still needed more faculty to teach the sudden flood of new students. The student bodies of major universities grew rapidly and so did the faculties of these schools. In addition, the government under the leadership of Vannevar Bush recognized the importance of basic research to military and economic development and established programs to fund scientific standouts of the war years to continue research in areas such as nuclear physics and the condensed matter physics associated with electronic devices. Women physicists and other women scientists were often able to take advantage of this situation.

On the other hand, many universities refused to hire women for faculty positions, just as they had before the war. Anti-nepotism rules were enforced, forbidding women to work in the same lab, department or even university as their husbands. These rules had been relaxed during the war and were reinstated in full force when it ended. Universities often considered a woman physicist married to a faculty member as free labor for teaching or research. The preceding chapter told the stories of several excellent women physicists and their husbands who accepted positions in the National Laboratories. In these cases, the National Laboratories benefitted from hiring two excellent scientists who were unlikely to leave their jobs for universities (where anti-nepotism prevailed) in spite of attractive financial incentives.

This chapter describes the experiences of several women physicists who built careers in research universities and how they managed to thrive in such environments.

Maria Goeppert-Mayer (figure 3.1) was probably the most distinguished woman physicist who transferred from working on military projects into academic research. She developed the shell model of the nucleus independently and at the same time as

doi:10.1088/978-1-6817-4094-2ch3

Figure 3.1. Maria Goeppert-Mayer (1963). Photograph courtesy of the Nobel Foundation.

Hans Jensen. They shared the Nobel Prize in Physics in 1963. Her story illustrates the challenges that even the most talented woman physicists faced after the war.

Maria Goeppert grew up in the university town of Göttingen in Germany, where her father was a professor of pediatrics. She was proud of the fact that on her father's side, she was 'the seventh straight generation of university professors' [1]. The Goepperts were close friends of many outstanding scientists who were also professors at Göttingen; these included Max Born, James Franck and David Hilbert. In addition, Maria would encounter Edward Teller, Victor Weisskopf and Enrico Fermi at the university [2]. She was educated in Germany and managed to pass the *arbitur* examination, the admission examination for German universities. Passing it was an unusual feat for a woman, since women did not receive preparation for it. She entered the university at Göttingen intending to study mathematics, but switched to physics and completed her dissertation as the advisee of Max Born [3].

Maria's father's death led her mother to rent rooms in the family home to students at the university, including a young Rockefeller fellow, chemist Joseph Mayer, who was smitten by the blonde, intelligent daughter of the house, 'the prettiest girl in Göttingen' [3, p 244]. They married and set off for Baltimore, MD, where Joe had a position as an assistant professor of chemistry at Johns Hopkins. Maria had just completed her doctorate and probably knew as much about the new theories of quantum mechanics as anybody in the United States at the time. Nevertheless, Hopkins invoked anti-nepotism rules and only offered her a position as a volunteer associate, which allowed her neither office nor lab space. She joined the physical chemists in her husband's department, learned physical chemistry and was able to apply quantum mechanics to the field, as represented in a number of co-authored papers [4].

When Joe lost his job at Johns Hopkins and moved to a position at Columbia University in 1939, Maria followed him and accepted a half-time teaching position at Sarah Lawrence College in 1941–42, and again in 1945 [5]. Maria Goeppert-Mayer was not an outstanding teacher, giving rather cryptic lectures in a low voice and facing the blackboard while mixing up her cigarette and chalk, which she held one in each hand [6]. A research student described her graduate lectures as 'well organized, very technical and highly condensed', adding that 'Her facility with the methods of theoretical physics was overwhelming to most of the graduate students, in whom she inspired a considerable amount of awe' [7, p 317]. She was not fond of the classroom, although she was widely known for her kindness to individual students. She minded the commute to Sarah Lawrence which took her away from her young family. Thus she was happy to join a war project on the separation of uranium isotopes headed by her friend Harold Urey at Columbia, which paid her a generous part-time salary although she had refused the offer of a full-time position for the sake of her children. She worked on the properties of fission products, which began her interest in nuclear physics [5].

At the end of the war, the Mayers moved to the University of Chicago, where Joe was offered a professorship and Maria was given a half-time appointment as a senior physicist in the Physics Division at Argonne National Laboratory by her former student, Robert Sachs [7]. She was also appointed a voluntary associate professor and a member of the Institute for Nuclear Studies at the University of Chicago. She was not paid, even though she was expected to serve on various committees and assume other faculty responsibilities [3]. Delighted to be in an environment where exciting physics was done, Maria Goeppert-Mayer learned nuclear physics, and Teller interested her in the cosmological origin of the elements. When she began to examine the data, which were by that time extensive, she refined and extended previous observations of 'magic numbers' in nuclei, work that she published in 1948. However, she failed to find a model to explain them until one day Fermi, whose interest in the project increased as Teller's decreased, asked her about the spin–orbit interaction in nuclei. Goeppert-Mayer immediately recognized that a strong spin–orbit interaction gave rise to a nuclear model that predicted the magic numbers and other properties of nuclei [7].

By 1949, she had written up her results and the experimental data supporting them, when she learned that a German group led by J Hans D Jensen had produced identical results. Both published their results in 1949 [8]. Goeppert-Mayer followed up with a much more detailed paper in 1950, which left little doubt that she had pioneered the work. She and Jensen would later become close friends, and they co-authored a book describing their work [9].

In 1954, Enrico Fermi died and the intellectual excitement at the Institute for Nuclear Studies cooled. Thus in 1959, the Mayers accepted two professorships at the new University of California at San Diego (UCSD), in chemistry for him and in physics for her. Although the University of Chicago then offered Maria a full professorship with salary, the Mayers decided to accept the San Diego offer. Shortly after their move, Maria Goeppert-Mayer suffered a stroke that left her much slowed and partly disabled, so that when she became the first woman to receive the Nobel

Prize in theoretical physics in 1963, she worried greatly that her disability might harm the ceremony [3]. She was also elected to the National Academy of Sciences in 1956 and received several honorary doctorates [7]. She is remembered for precision and competitiveness in physics, but she was personally shy and not aggressive. In fact, more than one author remarked that if there was a feminist in the Mayer family, it was Joe, who always encouraged his wife to do physics and not to worry about their two children.

Like Maria Goeppert-Mayer, Hertha Sponer earned her PhD at Göttingen, where she worked under the supervision of Peter Debye. Six years later, in 1926, Sponer joined James Franck's group in the study of molecular spectra [10]. She published several important papers before Hitler came to power. She was dismissed from her position as professor extraordinaria of Physics at Göttingen University because she was a woman and not because she was Jewish or politically active. She accepted a position as a visiting professor at the University of Oslo and published an important book before coming to the United States in 1936 [11]. Franck, who was Jewish, might have managed to retain a professorship at Göttingen, but he had quit his position in protest over Hitler's policies and emigrated to the US a year before Sponer was fired [12]. He was able to persuade Duke University to offer Sponer a professorship in spite of the opposition of the dean of physics research in the US, Robert Millikan, to hiring a woman into a physics department [11].

During World War II, Sponer taught naval officers and assisted as many refugee scientists as she could. She then worked on building up the physics institute at Duke [10]. In 1949, she established a molecular spectroscopy laboratory, which moved to the subbasement of the new physics building, mechanically the quietest place in the building and with a stable temperature. The lab was equipped with special floor mounts for the spectroscopy equipment and she worked there until her retirement in 1968. She published a number of important papers, many in collaboration with noted theorists such as Edward Teller and Lothar Nordheim. She also advised 23 PhD students. Her experimental work confirmed many important theoretical predictions in the quantum mechanics of molecules. In 1946, she married the widowed James Franck. Franck worked at the University of Chicago; Sponer remained at Duke. Thus their marriage was an early example of a commuter marriage. After Frank's death and her retirement, she moved back to Germany to live with the family of a nephew, and died there in 1968 [13].

One of the German refugees helped by Hertha Sponer, Hedwig Kohn (figure 3.2), was two years older than Sponer, and she was the third woman (along with Lise Meitner and Sponer) to obtain the 'habilitation' university teaching degree in Germany before World War II. Kohn received her degree from and worked at the Physics Institute at the University of Breslau, where she was an assistant. She was dismissed in 1933 because she was Jewish and managed to survive on temporary jobs until 1938, when work dried up, and she almost became a victim of the Holocaust. She escaped from Germany through Stockholm and the Soviet Union in 1940 after obtaining three job offers from women's colleges in the US and a visa with the help of her dissertation advisor, Rudolph Ladenburg, Sponer, the American Association of University Women and many others [14].

Figure 3.2. Hedwig Kohn, German physicist, in her laboratory (1912). Photograph courtesy of Brenda Winnewisser.

Kohn's first job in the US was at the Women's College of the University of North Carolina. In 1942, she moved to Wellesley College, from which she retired in 1952 as a full professor. She conducted research with undergraduates in a simple laboratory, but did not publish [15]. Sponer offered her a position at Duke and she worked in Sponer's laboratory until shortly before her death in 1964, publishing seven important papers [14]. Over her career, she wrote many well-cited scientific papers, co-authored a physics text that was popular in Germany in the 1930s and 1940s, received a patent and trained at least two PhDs. She worked out methods for extracting information from the intensity and shape of spectral lines [15].

If Maria Goeppert-Mayer was clearly the outstanding woman theoretical physicist of her day, another immigrant, this time from China, Chien-Shiung Wu (figure 3.3), was the outstanding woman experimentalist in physics. After completing her undergraduate degree in physics at National Central University in Nanjing and working as a teaching assistant at Shejiang University for a year setting up experiments on atomic spectroscopy at low temperatures, she decided to come to America for an advanced degree in physics. Her target was the University of Michigan, but she became excited about the work underway at the University of California/Berkeley and stayed there to pursue graduate work, officially under E O Lawrence's direction, but actually under Emilio Segre's. Her work on the behavior of isotopes produced in fission reactions made her a local expert [16].

Figure 3.3. C S Wu in 1970 at a party in New York with two Chinese graduate students and the child of a female graduate student.

The young, modest and very feminine Wu was known for working very hard until late at night and for her independence. She also found time to fall in love with a Cal Tech graduate student, Luke Yuan. The young couple were actually married in the garden of Robert Millikan, Cal Tech's president, in May 1942. As the war effort expanded, Yuan moved east to Princeton to work for RCA (Radio Corporation of America) on radar, and Wu accepted a teaching position at Smith College, which offered her little opportunity for research. With Lawrence's help, Wu managed to move to Princeton to be near her husband and to teach naval officers at the university [16]. Wu next moved to Columbia University to work on radiation detection for the staff of the Division of War Research in March 1944 [17].

With the end of the war, Wu remained at Columbia as a research associate and was finally able to direct her own research. Throughout her career, she would exhibit a talent for choosing problems in experimental physics where interesting answers would result from her extraordinary attention to detail and continual checking and rechecking of results. Her first experiments focused on careful measurements of the energy spectra of beta particles emitted in radioactive decay. Fermi had used Pauli's prediction that a nearly massless particle, the neutrino, is emitted with the beta particle and carries off some energy in the decay to predict the energy spectra of the beta particles in the decay, but measurements through 1945 disagreed with his theory. Wu recognized that the combination of thick samples that took energy from the emitted particles and the hysteresis effects of the iron cores in the spectrometers of the day were distorting the spectra. She learned to make thin samples and found an old spectrometer without an iron core. By 1950, she had obtained results that confirmed Fermi's predictions [18]. Her work made her an international authority on beta decay and in 1952 she was promoted to assistant professor of physics at

Columbia. In 1954, both the Yuans decided to become American citizens because the unstable political situation in China precluded their return there [16].

In the spring of 1956, two young Chinese professors, T D Lee and C N Yang, called Wu's attention to the fact that symmetry under reflection or parity conservation did not seem to hold in situations controlled by the weak force. This had never been tested in beta decay, the best studied case of an interaction dominated by the weak force. Wu realized that the beta decay of Co^{60} was governed by a very simple matrix element and that radioactive cobalt nuclei could be polarized by a weak magnetic field if they were embedded in crystals of cerium magnesium nitrate at very low temperatures. Of course, Wu had never worked at low temperatures and nor did anyone know how to embed the cobalt nuclei in cerium magnesium nitrate [16].

Wu formed a partnership with the outstanding low temperature group at the National Bureau of Standards, cancelled a long-planned trip with her husband and set to work in the knowledge that several other groups were trying to prove that parity is not conserved in weak interactions [18].

Wu's second woman graduate student, Marion Biavati (PhD 1959), accidentally solved the problem of putting the cobalt nuclei into crystals. One evening, she set some solutions in which she had been trying to grow crystals next to the stove while she cooked supper. The next morning, she found crystals in the beakers [16]. Wu even contributed to the low temperature group's work by suggesting that instead of using just any soap for seals, as they were doing, they employ Ivory because it was (as the advertising slogan claimed) '99 and 44/100% pure'. It may have been a joke, but it worked.

The group with whom Wu collaborated at the National Bureau of Standards resented her insistence on checking every detail of the experiments, particularly because she was teaching and could spend only one day every two weeks in Washington and her checking was delaying publication in a very competitive environment. However, at two in the morning on 9 January 1957, everybody agreed that they had a result ready to be published that showed conclusively that parity was not conserved in beta decay [19].

As a result of intense interest in the parity work, Wu was promoted to full professor of physics at Columbia and elected to the National Academy of Sciences in 1958, although she did not share in the Nobel Prize that was awarded to Lee and Yang in 1957. No less a person than Clare Booth Luce said, 'When Dr Wu knocked out that principle of parity, she established the principle of parity between men and women' [20].

At this stage of her career, Wu was already unusually successful for a woman physicist in a major research university, but she continued to actively conduct experiments in physics, including the use of muons and pions to replace the electrons in atoms. Because the heavier particles spent more time inside the nucleus than the lighter electrons, their spectra, which fell in the x-ray region, provided a more sensitive probe of nuclear structure, particularly for the case of the pion, which interacted with the nucleus through the strong force as well as the electromagnetic and weak forces. She also led a group that searched for neutrinoless double beta decay in the depths of the Morton's salt mine outside of Cleveland. (The idea of double beta decay had first been proposed by Maria Goeppert-Mayer in 1935 [4].) Wu also led a group that used Mössbauer spectroscopy to investigate the structure of the excited states of heavier nuclei and also the hemoglobin in sickle cell anemia.

In doing this work, she mentored many graduate students, particularly women and Chinese students. She also worked to bring Chinese physicists into the international community. Although she passed the years of her youth in China, she is generally acknowledged as one of the outstanding women of US physics. Wu received much recognition for her work, being awarded the first Wolf Prize ever given by Israel and the first Comstock Award from the National Academy of Sciences given to a woman, and she was elected as the first woman president of the American Physical Society, in addition to receiving many honorary doctorates [20].

Wu's first female PhD student, Noémie Benczer Koller, was born in Vienna, escaped occupied France for Mexico, and finally received her PhD in physics in 1958 from Columbia University. She remained at Columbia as a research associate until 1960, when she moved to Rutgers as an assistant professor because her husband, a fellow physicist, found a job at nearby Stevens Institute of Technology [21]. She was the first female assistant professor appointed to the faculty of Rutgers, whose student body was then all male. She continued to advance the careers of other women on the faculty as Director of the Nuclear Physics Laboratory and as Associate Dean for Sciences of the Faculty of Arts and Sciences [22]. She did pioneering work in nuclear structure physics and in the use of Mössbauer spectroscopy in condensed matter physics. Her work was recognized by her peers when she was elected chair of the Division of Nuclear Physics of the American Physical Society, made a fellow of both the American Physical Society and the American Association for the Advancement of Science, and appointed to the Nuclear Physics Advisory Committees of DOE and NSF [23].

Fay Ajzenberg (figure 3.4) was born in Berlin in 1926 and arrived in the United States in December 1940 as a fifteen-year-old Jewish refugee from Europe. Her family had to leave New York briefly for Havana, Cuba to get entry visas for the United States. This was merely the end of a long and winding trip through Europe and she was very glad when the family sailed for New York and a new life in April 1941. She entered the University of Michigan in the fall of 1943, intending to study engineering, the only woman in a class of about 100. The only course where she did really well was in engineering English. She became interested in physics after taking an introductory course from Floyd Firestone. Marie Curie was her idol at the time. She claimed that she did not do well, although she worked very hard. She also had fun and even got to know François Duvalier, then an exchange student at Michigan [24].

After graduation, she returned to New York to live with her parents and in the fall of 1946 she began taking graduate courses in physics at Columbia University, although her academic record forbade her formal entry into the graduate program. The environment in the physics department was very exciting, with lots of older students, many of whom had worked on the Manhattan Project. Fay failed all her first year courses. She got a part-time job teaching physics labs at Hunter College,

Figure 3.4. Fay Ajzenberg-Selove receives the National Medal of Science. Photograph by Sandy Schaeffer and reproduced courtesy of the National Science Foundation.

the woman's college of CCNY, where she was supervised by Rosalyn Yalow, who would later win the Nobel Prize in Medicine for her work in developing radioimmunoassay. Adversity made Ajzenberg even more determined to become a physicist. She was granted US citizenship in December 1946. In the summer of 1947 the Ajzenberg mother and daughter returned to Europe to search for family that might have survived the Holocaust. On her return, she took a job in Chicago at the University of Illinois at Navy Pier teaching veterans [24].

Her father's business was now profitable enough that he could support his daughter in graduate school if she could earn a master's degree in one year. Fay decided to go to the University of Wisconsin, although she had to talk the department chair into admitting her. That year she passed all her courses and even the master's exam at the end of the year. In the summer, she returned to Europe with her mother and took the opportunity to visit cosmic ray observatories in a number of countries. She exposed emulsions, which she carried back to Wisconsin to develop. She also decided that she wanted to be a nuclear physicist because the Wisconsin faculty in that area was the best in the department. She used emulsions to track neutrons emitted in nuclear reactions, and developed a method to make thin lithium 6 targets.

She received her PhD in the spring of 1952 and took a summer job at Caltech to work with Tom Lauritsen on a paper summarizing results on the study of the spectroscopy of light nuclei. For the fall, she took a lecturer's position as a sabbatical replacement at Smith College, although the college had no research facilities. Fortunately, she had graduate school classmates working on nuclear physics at MIT who arranged an appointment as a visiting research fellow, which paid enough so that she could keep an apartment in Northampton near Smith and one in Boston near MIT. The 90 mile commute was exhausting and she did not really connect to the Smith community, so for the following year she took a position as an assistant professor at Boston University, which seemingly had no intention of hiring a woman, but the chair liked her and wanted to start a nuclear physics group. She loved her work, although she became exhausted and had severe allergy problems, and stayed at Boston University until 1957. In the fall of 1954, her friends Aage Bohr and his wife Marietta came to Boston where he was to give a series of lectures at Harvard. Marietta decided that Fay needed to marry and selected Harvard physicist Walter Selove as a perfect mate. Although Fay was very skeptical about meeting him, they fell in love and were married on 18 December 1955. Walter worked at Brookhaven, and Fay brought her students to join him in experimental work [24].

In the fall of 1956, the Seloves both accepted offers in Philadelphia, Walter as an assistant professor at the University of Pennsylvania and Fay as an associate professor at Haverford College, an all-male Quaker college where she was the first woman faculty member hired full time. Fay loved her job at Haverford, which had bright students who were eager to do research with her and were fun to teach and mentor in physics. Here she also became heavily involved with the Federation of American Scientists [24]. By 1960, she had been promoted to full professor and in 1960–61 she served as the acting chair of the physics department [25]. She was able to maintain her research and continued and expanded her work on documenting the properties of nuclei [24], as well as teaching intelligent undergraduates.

As conditions changed at Haverford, Fay moved to the University of Pennsylvania as a research professor of physics without tenure. When she applied for a tenured position there, like those granted to three male faculty members, she was turned down because she was considered insufficiently active in physics. Fay Ajzenberg-Selove appealed these decisions to the State of Pennsylvania and was granted a full professorship, a position that she continued to hold until her death in 2012 [24]. The value of her publications and her remarkable personal journey in science led to her being awarded a National Medal of Science in 2007.

When they immigrated to the United States, the women we have treated so far were either credentialed physicists like Maria Goeppert-Mayer, seeking an education in physics like C S Wu or the children of refugee parents like Fay Ajzenberg-Selove. The influx of talented physicists such as these women and their male counterparts gave physics in the United States a push forward and helped build the US preeminence in science that prevailed until the 1970s. However, another group of women physicists who were born and educated in the United States also helped build the scientific establishment.

Typical of these women was Vivian Johnson (figure 3.5), who was born and educated through high school in Portland, Oregon, where her interests were in math and chemistry. She attended Reed College, where she decided to major in physics, and started graduate studies at Purdue University because they offered her a teaching assistantship and she could afford to study there. She received her master's degree in 1934 and her PhD in 1937.

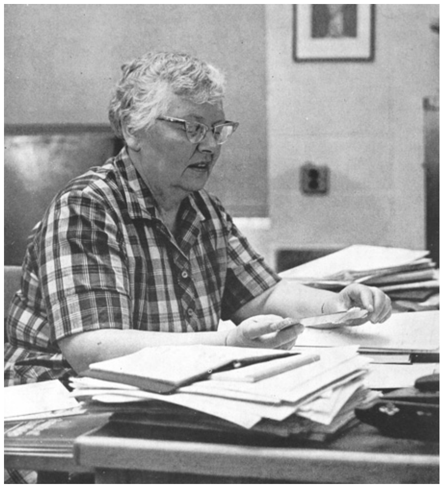


Figure 3.5. Vivian Johnson. Photograph courtesy of Purdue University Libraries, Karnes Archives and Special Collections.

At that time, the Purdue Department of Physics was headed by Karl Lark-Horovitz, who was working hard at changing the department from an intellectual backwater into a world-class research department. One of his strategies was inviting leading physicists to spend time in the department as guest lecturers. As a result, Lothar Nordheim, who would later have a distinguished career in theoretical physics, accepted Purdue's offer as his first position in the United States. Lark-Horovitz and his students had discovered experimentally that the crystal structure of zinc oxide was asymmetric, and Johnson with Nordheim set out to explain this result, which formed her dissertation. She had become a solid-state theorist before the term was invented. She remembers that before World War II, most of the standard graduate texts in physics were translated from German [26].

In 1937, Johnson was named an assistant instructor of physics at Purdue; in 1938, she became an instructor; in 1944, an assistant professor and also a civilian with the US Office of Scientific Research and Development; in 1947, an associate professor; and in 1956, she finally became a professor [27].

World War II had immediate consequences for the physics department at Purdue. Just after Pearl Harbor, Lark-Horovitz contacted MIT and asked the war project there what his department could do and agreed to study the properties of germanium as a semiconductor material at different temperatures with a view to using it as a crystal rectifier, while the University of Pennsylvania would study silicon, which was better understood than germanium. Early work on crystal rectifiers had been dropped when vacuum diodes proved more reliable. With the advent of microwave radar, interest in crystal rectifiers revived because they were small and had low power consumption. Silicon diodes had already been put into use in England, but nobody knew much about germanium. Crystal rectifiers suffered from impure semiconductors and burnt out when power was first applied [28].

The Purdue group located sources of pure germanium and learned to grow large crystals and dope them with various impurities. They studied the electrical properties of germanium and Vivian Johnson was involved with Lark-Horovitz in the theoretical analysis of the properties of germanium [28].

During the war, MIT staff would assemble researchers for secret meetings with colleagues in other institutions or industries such as General Electric (GE) or Bell Laboratories. Lark-Horovitz announced his discovery that both silicon and germanium were intrinsic semiconductors with definite band gaps. Johnson spent her time trying to reconcile experiment with theory, notably the theory of electron scattering by the impurities with which semiconductors were doped, where her work overlapped that of Esther Conwell (who will be discussed in the chapter on women physicists in industry). The experimental group managed to produce point contact crystal rectifiers, which were used by the radar lab in some systems that they developed [28]. The Purdue group finally produced reliable crystal rectifiers that were capable of withstanding back voltages of more than 100 V. By the end of the war, the group had recognized that different dopants produced n-type and p-type materials [28].

At the end of the war, William Shockley and another engineer from Bell Laboratories visited Purdue to investigate the work done there on crystalline devices. GE and RCA also expressed an interest in various aspects of it. By 1948 Johnson and a group in the physics department had moved into the study of semiconductor properties at low temperatures and had developed an early liquefier for helium. Germanium at that time was available only in polycrystalline form and had to be carefully purified or at least checked for purity. In 1948, after the invention of the transistor at Bell Labs, the group turned to the study of the effects of radiation on semiconductors. By 1950, physicists had figured out how to grow single crystals of silicon and germanium, which led to much better transistors. The field of condensed matter physics grew with every new discovery, and Purdue trained many students who went into industrial labs where solid-state technologies were commercialized and their applications expanded [28].

Vivian Johnson continued her theoretical work on the properties of semiconductors at Purdue. She was named a fellow of the American Physical Society and won a teaching award from Standard Oil and a Helen B Schleman Gold Medallion Award from Purdue. She also served a term as assistant physics department head just before her retirement as a professor emerita in 1979 [27].

Another American-educated physicist, Vera Kistiakowsky, is professor emerita of physics at Massachusetts Institute of Technology, and a senior research scientist at the Laboratory for Nuclear Science. She has worked as a research physicist and as an educator, and has also been active in advancing the interests of women in the sciences and in advancing arms control [29, 30]. When she entered Mount Holyoke College she had intended to pursue a career in medicine, but was inspired by Mt Holyoke's well- established and -staffed chemistry department, and she stayed with chemistry, graduating with a bachelor's degree in 1948 [30–32].

She attended graduate school at the University of California, Berkeley, where her mentor as a graduate student in nuclear chemistry was Glenn Seaborg [29]. After completing a research project on the isotopes of promethium, she was awarded a PhD in nuclear chemistry in 1952 [29, 32]. While she was in graduate school, she met and in 1951 married Gerhard Emil ('Jerry') Fischer, who was a physicist [29, 30]. They had two children, Marc and Karen; both became scientists [31, 33].

After receiving her PhD in chemistry in 1952, she found that her career options were limited by the fact that her husband had not yet finished his PhD [30, 32]. Like so many women before and since, she had to make tradeoffs between her career and her marriage. For half a year she had a postdoctoral research fellowship with Seaborg [29]. Then, because of nepotism conflicts at Berkeley, she took a job as a staff scientist at the US Naval Radiological Defense Laboratory in San Francisco, where she set up a nuclear spectroscopy laboratory but was burdened with routine work. She then obtained an American Association of University Women (AAUW) Sarah Berliner Fellowship that enabled her to spend a year as a postdoc with Luis Alvarez in the physics department at the University of California's Radiation Laboratory [29, 32].

When her husband completed his PhD, Kistiakowsky sent out 100 letters to universities and colleges and received only one answer—a polite rejection from an all-male college in Boston [30, 32]. Her husband, however, was immediately offered a job as an instructor in the physics department at Columbia University. Since they were hiring her husband, Columbia University hired Vera Kistiakowsky as a research associate in the chemistry department [29, 30]. After a year, she switched fields to physics and worked as a research associate under Chien-Shiung Wu [29, 31]. Kistiakowsky became a physics instructor at Columbia in 1957 [30].

Her husband Jerry did not get tenure and found a new job at the Cambridge Electron Accelerator. Vera was expecting their first child and wanted to stay at Columbia. She recalled: 'very grumpily, I applied for an assistant professorship at Brandeis. In spite of the unenthusiastic way that I viewed the opportunity, it was offered to me, and I became an assistant professor at Brandeis—not immediately. Mark was born July 3rd, and September, I assumed my assistant professorship at Brandeis' [29].

Vera worked at Brandeis University as an assistant professor from 1959 to 1962, and continued as an adjunct associate professor until 1963 [29, 32]. She had a second child [32]. After her divorce in 1970 from Jerry, she continued to work in Cambridge in a high-energy physics laboratory affiliated with MIT [29, 31]. In 1963, she had joined MIT as a staff member of the Laboratory for Nuclear Science, where she worked until 1969. She was senior research scientist in the Department of Physics from 1969 to 1972 [32]. Although she had outstanding credentials, she was not appointed to a professorship until 1972, when, after some issues about affirmative action, she became a professor of physics (and the first woman appointed MIT professor of physics) [29, 31].

She became a Fellow of the American Physical Society and of the American Association for the Advancement of Science and was awarded an honorary doctorate by Mt Holyoke, among other honors [31]. She retired from MIT as professor emerita in 1994. Dr Kistiakowsky's scientific work in physics has been largely in nuclear physics, experimental particle physics and in observational astrophysics. She and her colleagues conducted significant backward charge exchange experiments with pions and protons [29, 32, 33]. She has published more than 70 scientific papers and has also published in the arms control literature and about women in science, and in addition has published two books on science for children [34].

Rose C LeDieu Mooney-Slater, an outstanding crystallographer, was born and raised in New Orleans and received her BS (1926) and MS (1929) from Tulane University, and her PhD from the University of Chicago (1932) [35]. She taught physics at Newcomb College, the woman's college of Tulane University as an instructor of physics from 1927 through 1930, as assistant professor from 1932 until 1936, and then as associate professor until 1939 [36], when she was awarded a Guggenheim fellowship in Chemistry [37]. Unfortunately, the outbreak of war in Europe ruined her plans for study abroad. Instead she worked at the new x-ray laboratory at MIT, which had been established by department chair John Slater, who would become Mooney's second husband after his divorce in 1954 [38].

She returned to Tulane, where she was named professor of physics and department chair at Newcomb College in 1941. In 1943–44, she took leave from Tulane and moved to the University of Chicago to work with W H Zachariasen on establishing an x-ray crystallography laboratory in support of the Manhattan Project. On her return to Tulane, she continued as department chair at Newcomb College [36]. When the sciences at Tulane were combined across colleges, she was named chair of the combined department in 1948, possibly the first woman to chair a co-ed physics department [39]. She stayed at Tulane until 1952, spending summers doing research at Johns Hopkins, Cal Tech, University of Michigan, Oak Ridge, Argonne, Polaroid and DuPont [36]. In 1952, she joined the National Bureau of Standards as a senior physicist and in 1956, she moved to MIT to join her new husband as a research physicist. In 1966, both Slaters moved to the University of Florida, where Rose was a research professor of chemistry. She was the author of many distinguished papers and was known as a caring mentor to many students and an excellent teacher. She was also active in the southeastern section of the American Physical Society [35].

One student at Tulane who arrived in September 1945 after discharge from the navy and wished to use the GI Bill to work in crystallography describes Dr Rose Mooney and her lab: 'Rose Mooney's office–laboratory–classroom contained a single x-ray tube and a Laue film holder—period. But she was a fine teacher, and I greatly enjoyed her crystallography class.' He also recalls that she was accepted into Caltech's graduate program as R C L Mooney. Caltech's surprise at the fact that 'R' stood for 'Rose' was equaled by Mooney's on learning that Caltech did not accept women. Linus Pauling came to the rescue with a temporary research assistantship and helped Mooney transfer to Chicago [40].

Lucy Julia Hayner (figure 3.6) received her PhD in physics from Columbia University in 1925 under the direction of Professor Webb. She was the fourth woman to receive her doctoral degree in physics from Columbia, and her dissertation was entitled: 'The persistence of the radiation excited in mercury vapor'. After obtaining her degree she worked as a research physicist at GE, where she studied electron emission in vacuum tubes. In 1929, she returned to Columbia as a member of the physics department. By this time, she had married physicist Bernhard Kurrelmeyer [41], also a professor of physics at Columbia. She continued at Columbia until 1971 when she retired as an Associate Professor. The couple had

Figure 3.6. Bernhard Kurrelmeyer and Lucy Hayner Kurrelmeyer at the home of Esther Mintz in New York. Photograph by Esther Mintz, reproduced courtesy of the AIP Emilio Segrè Visual Archives, Esther Mintz collection.

one son [42]. At GE she served as an assistant to Irving Langmuir, then Assistant Director of GE research [43].

In her years at Columbia, she accepted the challenge of running the advanced laboratory, two semesters of which were required of all graduate students. Not only did Dr Hayner maintain equipment and train students to use it to make measurements, she also insisted on rigorous data analysis as part of all lab reports. She is remembered by graduates of 'Lucy Lab' as a demanding teacher who cared about her students and wanted to help them succeed. She stayed late until experiments worked and expected students to do likewise. She once remarked to a grad student whose experiment was simply not working, 'I don't know what's wrong but I'm going to find out. You can go if you want to, but I'm going to stay.' Even though it was Friday night, the student stood up her fiancé and stayed until she and Dr Hayner got the equipment working properly. After her retirement from Columbia, Dr Hayner took an interest in helping people with poor vision and even made a circular Braille slide rule [44].

As physics departments in large US universities focused on training graduate students and conducting fundamental research, they recruited a few very talented women physicists. However, while the National Laboratories gradually repudiated anti-nepotism rules in hiring, often in order to hire two talented physicists at the same time, university departments refused stubbornly to hire two members of a couple, no matter how talented each member of the couple happened to be. Thus this chapter is essentially the story of the ways in which women physicists overcame the barriers created by anti-nepotism rules to their work in US research physics departments. Some remained unmarried; some worked essentially as volunteers beside their husbands; and some found positions at different universities that were close to those that employed their husbands.

An interesting problem in dealing with physicists employed by major universities is that physics departments take widely differing approaches to documenting their own history, while the National Laboratories record their histories more systematically. Some, like the physics department at Purdue, have taken considerable pains to write up their own history and make it available on the department's website. Others rely strictly on the memory of the longest serving member of the department who is still reachable by e-mail. Of course, some physicists, such as Fay Ajzenberg-Selove or Leona Marshall Libby, wrote their own stories, which help us understand their world, and projects like the UCLA Committee on Women in Physics (CWP) Archive and the American Institute of Physics Oral Histories reveal many women physicists' characters and biographical details.

References

[1] Goeppert-Mayer M 1964 *Les Prix Nobel en 1963* (Stockholm: Norstedt and Söner) pp 98–9
[2] Rempel T D 1993 *Women in Chemistry and Physics: A Biobibliographic Sourcebook* ed L Grinstein, R Rose and M Rafailovich (Westport, CT: Greenwood) pp 375–81
[3] Dash J 1973 *A Life of One's Own: Three Gifted Women and the Men They Married* (New York: Harper and Rowe) pp 229–346
[4] McGrayne S B 1993 *Nobel Prize Women in Science: Their Lives, Struggles and Momentous Discoveries* (New York: Birch Lane) pp 175–200
[5] Moszkowski S A 2006 *Out of the Shadows: Contributions of Twentieth-Century Women to Physics* ed N Byers and G Williams (Cambridge: Cambridge University Press) pp 202–12
[6] Schiffer J 2015 E-mail to C Herzenberg
[7] Sachs R G 1979 *Biographical Memoirs* (Washington, DC: National Academy) pp 310–24
[8] Dash J 1991 *The Triumph of Discovery: Women Scientists Who Won the Nobel Prize* (Englewood Cliffs, NJ: Julian Messner) pp 1–33
[9] Goeppert-Mayer M and Jensen J H D 1955 *Elementary Theory of Nuclear Shell Structure* (New York: Wiley)
[10] Rechenberg H 2006 *Out of the Shadows: Contributions of Twentieth-Century Women to Physics* ed N Byers and G Williams (Cambridge: Cambridge University Press) pp 127–36
[11] CWP (UCLA) www.physics.ucla.edu/~cwp (accessed 19/2/15)
[12] Wikipedia http://en.wikipedia.org/wiki/Hertha_Sponer (accessed 3/3/15)
[13] Duke University Department of Physics www.phy.duke.edu/history/DistinguishedFaculty/HerthaSponer/ (accessed 3/3/15)
[14] Wikipedia http://en.wikipedia.org/wiki/Hedwig_Kohn (accessed 3/3/15)
[15] Winnewisser B P 2000 *Jewish Women: A Comprehensive Historical Jewish Women's Archive* http://jwa.org/encyclopedia/article/kohn-hedwig (accessed 3/3/15)
[16] Chiang T-C 2013 (transl. Wong T F) *Madame Wu Chien-Shiung: The First Lady of Physics Research* (River Edge, NJ: World Scientific)
[17] Howes R H 1993 *Women in Chemistry and Physics: A Biobibliographic Sourcebook* ed L Grinstein, R Rose and M Rafailovich (Westport, CT: Greenwood) pp 613–25
[18] Benczer-Koller N 2009 *Biographical Memoir* (Washington, DC: National Academy of Science)
[19] McGrayne S B 1993 *Nobel Prize Women in Science* (New York: Birch Lane) pp 255–99
[20] Dicke W 1997 Obituary *The New York Times* (18 February 1997) **C12**
[21] Wikipedia http://en.wikipedia.org/wiki/Noemie_Benczer_Koller (accessed 3/3/15)

[22] Leath P www.physics.rutgers.edu/ugrad/awards/koller.html (accessed 2/3/15)
[23] CWP (UCLA) www.physics.ucla.edu/~cwp (accessed 19/2/15)
[24] Ajzenberg-Selove F 1994 *A Matter of Choices: Memoirs of a Female Physicist* (New Brunswick, NJ: Rutgers University Press)
[25] CWP (UCLA) http://www.physics.ucla.edu/~cwp (accessed 19/2/15)
[26] Henricksen P 1981 Interview with Dr Vivian Johnson *Niels Bohr Library and Archives* (College Park, MD: American Institute of Physics) www.aip.org/history/ohilist/4694.html (accessed 28/12/14)
[27] CWP (UCLA) www.physics.ucla.edu/~cwp/internal/Condensed_Matter_Physics/Johnson,_Vivian_A.@881707512.htm (accessed 21/2/15)
[28] Bray R www.physics.purdue.edu/about_us/history/semi_conductor_research.shtml (accessed 21/2/15)
[29] Kistiakowsky V (interview 2014) *Voices of the Manhattan Project* http://manhattanproject-voices.org/oral-histories/vera-kistiakowskys-interview (accessed 10/3/15)
[30] Harding L R 1999 *Notable Women Scientists* ed P Proffitt (Detroit, MI: Gale)
[31] Cambridge Women's Heritage Project www2.cambridgema.gov/historic/cwhp/bios_k.html—KistiakowskyV (accessed 3/3/15)
[32] Thomas V L 1997 *Notable Women in the Physical Sciences: A Biographical Dictionary* ed B F Shearer and B S Shearer (Westport, CT: Greenwood) pp 228–33
[33] Oakes E H 2007 *Encyclopedia of World Scientists* (revised edn) (New York: Infobase Publishing) p 403 ISBN 978-1-4381-1882-6
[34] Mt Holyoke College www.mtholyoke.edu/175/gallery/verakistiakowsky (accessed 10/3/15)
[35] Crystallographers 1983 *J. Appl. Cryst.* **16** 659
[36] Moulton G 1982 *Phys. Today* **35** 72
[37] John Simon Guggenheim Fellowships *The Foundation's Report for* 1939–40 www.gf.org/fellows/10238-rose-c-l-mooney (accessed 13/3/2015)
[38] Wikipedia http://en.m.wikipedia.org/wiki/John_C._Slater (accessed 13/3/2015)
[39] Rossiter M 1995 *Women Scientists in America: Before Affirmative Action 1940–1972* (Baltimore, MD: Johns Hopkins University Press) p 202
[40] Marsh R E www.amercrystalassn.org/h-Marsh (accessed 21/2/2015)
[41] Hayner L J *Lucy Julia Hayner Papers 1922–1937* (Columbia Rare Book and Manuscript Library) www.columbia.edu/cu/lweb/archival/collections/ldpd_4078876/ (accessed 20/2/15)
[42] Rogusky M 2015 Private communication
[43] CWP (UCLA) www.physics.ucla.edu/~cwp/internal/Atomic_Molecular_and_Optical_Physics/Hayner,_Lucy@872627688.html (accessed 21/2/2015)
[44] Hayner L J 1972 *Physics Today* **25** 97

Ruth H Howes and Caroline L Herzenberg

Chapter 4

Women physicists in industry

During World War II, the military recruited industry to support the war effort in general, and the Manhattan Project and the radar and sonar projects in particular. For example, DuPont administered the Hanford Site and built the plutonium production reactors for the Manhattan Project. After the war, many large industries maintained their own research laboratories funded to conduct long-term, basic research. Many of the industries with central research and development laboratories were essentially monopolies, and the labs were funded directly from corporate headquarters and had little to do with the business divisions. Companies competed with one another to hire the most talented scientists, funded them generously and asked them to design their own research projects. The classic example was Bell Laboratories, established in 1925 by AT&T and tasked with the production of knowledge. This lab developed the transistor in late 1947. In the absence of competition, corporations maintained a commitment to very long-term fundamental research, which they expected would generate new knowledge that could eventually develop new technologies and new very profitable products that could not be imagined by the scientists who developed them [1].

In spite of generous funding and a climate that encouraged staff to pursue research that interested them, industrial labs often found it difficult to recruit young and talented physicists. Many of the physicists who were hired by the industrial labs took jobs because of family connections to the industry or the region where a company was located. This clearly applied to women married to other physicists and barred from jobs at universities where their husbands worked. The administrative structures of the industrial labs changed frequently, and the climate within them depended on the administrative structure. As competition increased, the labs gradually began to obtain their funding directly from the business divisions and had to tie research efforts more and more tightly to product development. However, in the decade after World War II, the industrial labs still followed the model of pursuing fundamental research with long timelines. Unlike many of the scientists in

doi:10.1088/978-1-6817-4094-2ch4

the National Laboratories, industrial physicists were encouraged to publish their research [1]. As at the universities, record keeping varied widely from lab to lab and administration to administration.

In the industrial labs, women tended to occupy lower level technician positions. They faced discrimination, but in these years before equal opportunity legislation nobody could punish bosses for simply refusing to allow a woman in their groups. Thus little was said about the problems, in contrast to the open questioning of anti-nepotism in departments at research universities. The quotation below comes from an IBM internal memo of 10 January 1951 [2] and illustrates attitudes towards women at IBM.

Effective immediately and until further notice:

1. *A female employee will not be required to resign from the Company upon marriage.*
2. *The Company will consider for employment a married female.*

The memo went on to explain that this was a temporary modification of a company policy not to employ any married woman who was not the supporter of a family. Remember that IBM really needed women coders and consider what the environment for women physicists must have been in industries that were not as desperate to employ their talents. Nevertheless, a number of women physicists were able to make real contributions to the growth of the industries in which they worked, as well as to our understanding of physics. This chapter tells some of their stories.

Katharine Burr Blodgett (figure 4.1) was born in 1898 in Schenectady, NY, where her father was a valued patent attorney for the GE research center. Her father died before she was born, and she grew up in New York City and France until she was eight years old, when she enrolled in school at Saranac Lake and then studied at Ryerson School for well-bred young ladies until she was 15 (1913), after which she enrolled at Bryn Mawr College with a scholarship based on examination scores. She was challenged by mathematics and physics, so on Christmas vacation (1917) she welcomed the opportunity to tour the GE research center. She could not have done this had she not been her father's daughter. Her tour guide was future Nobel Laureate Irving Langmuir, who hinted that if she obtained further education she might be employed in the research center [3].

Blodgett decided to attend the University of Chicago, where she received her master's degree in 1918, and after graduation she immediately started work at GE as Langmuir's assistant. Langmuir recognized her talent and helped her enter a PhD program at Cambridge University in the UK. When she received her PhD in physics in 1926, she was the first woman ever to receive a PhD in physics from that university [4]. She immediately returned to GE, where she was the first woman hired as a scientist to work in a GE laboratory [5]. At first, she worked with Langmuir, but she gradually established a reputation in her own right. In World War I, she worked on gas absorption, which was important because of the use of poison gas on the battlefield, and in World War II, she worked on ways to de-ice planes. Although the work was never published, her contributions are cited by other authors. She remained at GE until her retirement in 1963. Her work on the use of thin films to

Figure 4.1. Katherine Burr Blodgett. Photograph courtesy of the Smithsonian archives.

prevent reflection from glass continues to be used today in a variety of applications, including computer screens and eyeglasses. She held six US patents on methods for applying thin films to solids [3].

Blodgett won the respect of the people with whom she worked and became a leading expert on thin films, including their use in modifying the reflection of light from glass and measurements of their thickness. Nevertheless, her name was left completely out of a 1953 *Science* article on the history of research at the GE laboratory, which mentioned men with far less distinguished records [3]. Her major work on films was done in the 1930s and 1940s, but it was recognized somewhat later. Her honors include the American Association of University Women's Annual Achievement Award in 1945, the Francis P Garvan Medal of the American Chemical Society for work on monomolecular films in 1951, fellowship in the American Physical Society and selection by the US Chamber of Commerce as one of the 15 'women of achievement' for 1951, in addition to a number of honorary doctorates [5]. Perhaps the most lasting tribute to her work is the recognition of a field of physics and engineering known as Langmuir–Blodgett film technology [3].

Burr Blodgett had both close family connections with an industrial research laboratory and terrific luck in finding a mentor who was not only an excellent physicist, but also treated her as a colleague and encouraged her to develop her skills as a physicist. Esther Marly Conwell (figure 4.2) had neither family connections nor one excellent mentor, but she had a long and successful career as an industrial physicist. She was a native of New York City and the child of immigrant parents. Her father reminded Esther and her two younger sisters that they must be prepared to support a husband before they got married. Naturally, education was a priority for the family [6]. She received her BA from Brooklyn College in 1948 [7].

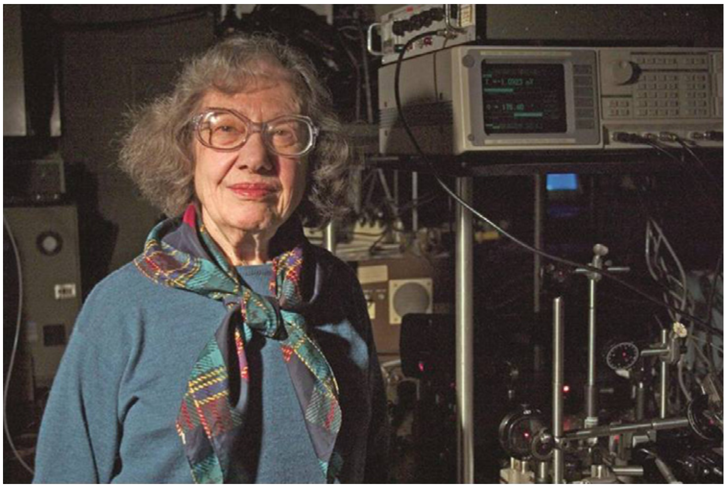


Figure 4.2. Esther Conwell in her laboratory. Photograph courtesy of the University of Rochester.

She entered college in her middle teens and stood out because of her youth and because she was the only woman in her physics classes. Two professors of physics at Brooklyn College, Bernhard Kurrelmeyer, the husband of Columbia physicist Lucy Hayner, and Walter Mais decided to help her prepare for graduate school, although she had entered college planning to be a high-school teacher [8]. Kurrelmeyer in particular seems to have been a strong influence on her, for example taking her to an American Physical Society meeting in Princeton. She also remembers Melba Phillips (treated in chapter 7) as an outstanding teacher, as well as the only woman faculty member in the department [6]. At Brooklyn College, she met her future husband, Abraham Alan Rothberg, the son of two immigrants who married in the US. Rothberg graduated from Brooklyn College in 1942, and served in the Army Signal Corps during World War II. In 1944, he and Esther were married. Rothberg received a master's degree in creative writing from the University of Iowa in 1947 and a PhD from Columbia in 1952 in English literature. He then served as editor of Free Europe Press, a part of Radio Free Europe, as a European Correspondent for the *National Observer* and as a faculty member at Hofstra, Columbia and St John Fisher College in Rochester. He wrote 22 fiction and non-fiction books that were largely based on his Jewish and anti-Soviet background, and which received favorable critical reviews [9].

Meanwhile, Conwell pursued her education in physics and received her MS from the University of Rochester in 1945 [7]. She selected Rochester over Minnesota, since she was only 19 and wished to stay near her family (and maybe Abraham). She chose to work with the refugee physicist Victor Weisskopf. She taught courses for military personnel, and she remembered them as generally unenthusiastic students. Weisskopf visited Purdue, learned of the work there in condensed matter physics, and suggested that Conwell try to model impurity scattering in semiconductors, a topic already under study by Lark-Horovitz and

Vivian Johnson in 1943 (see chapter 3). He proposed that Conwell fit data taken at Purdue. Weisskopf was slated to go to Los Alamos later in 1943, and he left carrying her thesis but never contacted her again. Purdue also asked for her thesis and wrote to say 'good job'. Later her work would be known as the Conwell–Weisskopf formula, and Weisskopf was happy to claim credit for her as his student thirty years later [6].

In 1943, Conwell left for a summer stay in New York City, during which she completed a bit more work on impurity scattering at the Purdue group's request and submitted the thesis, although the work was classified by that time. It would not be published until 1946, at which time she received her master's degree. She took a summer job at Western Electric, the manufacturing arm of Bell Telephone. After a couple of weeks, she was informed that there was no job classification as assistant engineer for a woman, so she would have to be an engineer's assistant with a huge reduction in salary. On her return to Rochester in the fall of 1943, she tried cyclotron research, where she was told (perhaps in jest) that because she was a woman, she should clean the cyclotron. She did not like the work since the cyclotron seemed to be constantly breaking down. So she accepted a war job at Columbia rather than going to Los Alamos, where she felt she did not know enough physics to be useful. She worked on the separation of uranium isotopes and described the job as staring at a galvanometer all day [6].

To escape the boredom, in early 1944 she decided to do graduate work at the University of Chicago, where she also taught introductory physics. In 1945, she was surprised to find that Lark-Horovitz and Johnson had submitted an abstract on the theory of impurity scattering in semiconductors to the American Physical Society in her and Weisskopf's names, but she decided to give the paper anyway. Two representatives from Bell Laboratories, Shockley and Bardeen, came to hear the paper. At Chicago, she graded the papers of any number of future Nobel laureates, working as a grader for Fermi's electromagnetism course. She knew Leona Marshall slightly. Because a member of the faculty did not want to take on a woman student, he arranged that she move off campus to Yerkes Observatory to work with Subramanyan Chandrasekhar, the distinguished astrophysicist, on problems in atomic spectra [6].

Conwell received her PhD in 1948. In 1946, she had accepted a position as an instructor at Brooklyn College while completing her dissertation. She stayed at Brooklyn College until 1951 [7]. At that juncture, she was awarded tenure just as her position was abolished. Fortunately, she was awarded a leave of absence for the year 1951–52, and Kurrelmeyer arranged for her to spend her year of leave at Bell Laboratories working with Shockley. While there she sat in Bardeen's old office, since he was in the process of leaving and not around much. According to Conwell, Bardeen's genius did not rub off on her, although she did manage a few papers. Despite early signs of later strange social views, Shockley was an excellent physicist who introduced her to the study of hot electrons and was kind to her personally. However, she did not enjoy the atmosphere at Bell Laboratories, where she was the only woman on the technical staff, and she felt separated from most of the other women, who were on the support staff. At the end of her year's leave, Shockley helped her find a job at Sylvania (which later became GTE), where there was great excitement spawned by the invention of the transistor [6].

Sylvania was willing to support fundamental research on semiconductors, in which Conwell was interested, although the labs were stronger in chemistry than physics. The company probably expected that hiring some physicists and letting them do what they wanted to do would put the company lab at the forefront of semiconductor development. However, to have a chance of that, they would have needed to hire a top-quality team of physicists to match the chemists already working in the lab. The company thought seriously about manufacturing transistors and opened an establishment in Boston (whose staff met with the laboratory staff), but was focused more on product development. Conwell was pleased that publication was encouraged, happy to be in Queens and very interested in work on semiconductor physics. She was made an area manager and later offered further management responsibility, which she declined, although she enjoyed working with some experimentalists in the company and the younger folk who were working on calculations for her research. She also felt more comfortable at Sylvania because there were a couple of other women around [6].

In 1956, she became pregnant with her son and continued to work after company policy said she should quit. One day, she was sitting in the lunch room when her boss asked her when her due date was. She replied, 'Yesterday!' He panicked and sent her home immediately. Her son was born the following weekend. She took a three-month maternity leave and then worked part time for three months. Formally, the company fired her and then rehired her, which decreased her pension in the long run [8].

In 1962–63, she took a leave as a visiting professor at the École Normale Supérieure in Paris. Her son was six and her husband was a writer, so they could also go along. On her return, she became manager of the physics department, that is people studying electronic materials, at Sylvania, which had been bought by GTE, where she worked on hot electrons and then ultrasonic waves and acoustics. She remained at the company until 1972, when GTE began shutting down the lab. She then spent a year as Abby Rockefeller Mauze Professor at MIT, a position arranged by Millie Dressehaus, a younger physicist who would later be secretary of the National Academy of Sciences. After a year, she moved to Xerox Laboratories as Principal Scientist to do research on glassy one-dimensional organic metals [6], before becoming the manager of the electro-optics program. In 1981, she was named a research fellow [7] and became interested in the conducting properties of DNA [6]. In 1990, she moved to the University of Rochester as Associate Director of the Center for Photoinduced Charge Transfer because a friendly supervisor warned her that it was time to make a move [7]. At Rochester her son was in the chemistry department and associated with the center, and her husband was teaching locally [9].

Conwell's long record of research in semiconducting materials was recognized by many top honors, including becoming the second woman elected to both the National Academy of Engineering and the National Academy of Sciences. She was the first woman in the 93 years of its existence to receive the Thomas Alva Edison Medal of the IEEE [8]. In 2010, she was awarded the National Medal of

Figure 4.3. Betsy Ancker-Johnson Assistant secretary for Science and Technology. Photograph courtesy of Wellesly College Archives.

Science. Conwell remained at Rochester until her death in November 2014 as a result of a car crash [10].

Like Conwell, Betsy Ancker-Johnson (figure 4.3) had a long and successful career in industrial research after receiving her BA in physics from Wellesley College in 1949 [11]. She is the poster woman for using a sense of humor as a survival strategy when working in a male-dominated environment.

At Wellesley, Ancker had the good fortune as a freshman to be placed in a dorm where the faculty apartment was occupied by physicist Hedwig Kohn, who had fled Nazi Germany (chapter 3). Kohn took a lively interest in the bright young freshman and encouraged her to come to her for help in physics. Ancker remembers her great kindness as well as her thick German accent and high, squeaky voice. The chair of the physics department at that time was Alice Armstrong, later at Los Alamos (chapter 2), who also worked hard to encourage the few physics majors who attended Wellesley. Ancker further remembers Lise Meitner's visit to campus, when Meitner and Kohn spent hours gossiping in German [12]. More discouraging were the views of dates from Harvard and MIT, who told her that she would never marry [11].

With Kohn's encouragement, Ancker decided to enter graduate school at Tuebingen University in Germany [11]. She had taken German in college, but was not prepared for difficulties with actual use of the language nor for the culture shock that she encountered. For example, she wore jeans and sweatshirts as she had at Wellesley and considered skilled machinists and technicians as friends and worthy colleagues, whereas German students were far more formal in dress and manners, and the German class system caused graduate students to treat machinists as inferiors. Ancker quickly became known as a character as well as an attractive female, although her fellow graduate students played jokes on her because of her ignorance of the language. She was also not used to having professors assign students a problem and then not expect to see them until they had results to present. The department was not hostile and even established a woman's room for her use, which quickly became known as 'the Betsy' [12]. The mostly male faculty members casually assumed that she was not really interested in physics and must be looking for a husband [11].

With considerable help with the language from her professor and colleagues and from the shop on equipment, Ancker eventually managed to publish two papers in *Annalen der Physik,* one on the measurement of lattice constants of zinc and the second on imperfections, including twinning, in zinc crystals. She took her difficult final oral exam on Thanksgiving day, the papers were accepted as a dissertation, and she managed to convince the examiners that her third subject in addition to physics and mathematics should be American language [12]. She received her PhD in 1953 [11].

Ancker returned to the United States and joined her parents, who had moved to be near her older brother who was in the mechanical engineering department at UC/Berkeley. Of course, she needed a job. The physics department at Berkeley was friendly, but had no openings and so she applied for jobs around the country, but got only offers to be someone's assistant. Her interview with the physics department at the University of Iowa went badly, but she got an offer from the metallurgy department and started thinking about work in environments other than university physics departments. At Berkeley, solid-state physicist Charles Kittel, who appreciated her German credentials, suggested she apply at the Minerals Research Laboratory of the University of California, where she was hired on the spot to do research on crystals. It was not quite what she had had in mind since research focused on applied problems, but she felt it was considerably better than unemployment and managed to publish three papers in a year. She also established a reputation as a good colleague by such stunts as asking for a cigar when one of her colleagues became a father, and then borrowing a smoked cigar stub from another colleague so it appeared that she had smoked it [12]. She found job hunting very discouraging, since she was not given an opportunity to show her ability as a physicist [11].

Ancker was also very active in the InterVarsity Christian Fellowship, as she had been since her Wellesley days. There she met Harold Johnson, a graduate student in mathematics at Berkeley. In 1954, Ancker became a staff member for the InterVarsity Christian Fellowship, working first in California and then in Austria. At the end of two years, she decided that she wanted to go back into physics and found a job as a senior research physicist at the Sylvania Microwave Laboratory in Palo Alto, across the street from Stanford University. She had to work hard, both to get back into thinking physics and to learn something about microwave technology. She managed to audit a course on microwaves at Stanford and worked on the transmission of microwaves through garnets with very low attenuation. In spite of being essentially self-taught, she managed to publish three practical papers in the field [12].

Ancker was again active in the InterVarsity Christian Fellowship and took her vacation to help out at a camp in Los Angeles. On the way home she caught a ride with Hal Johnson, who was still in graduate school because although he was born in 1929 like Ancker he had served in the Air Force and had retired as a captain [13]. Johnson asked Betsy to help him find an apartment in Palo Alto, since he was to spend a year teaching there [12, 13]. She complied since she owed him a favor for the ride home, and a romance blossomed. They decided to marry, much to the shock of their colleagues in the InterVarsity Christian Fellowship, who thought they must be joking since they were both nearly thirty years old and most people at that time married in their teens or early twenties. Johnson received his PhD in 1957 and accepted a three-year appointment at Princeton after his stint at Stanford. The couple were married on 15 March 1958 and Betsy again went job-hunting. This time, she felt she did not have credentials to find a job in academia. Fortunately, there were two industrial labs, Bell Laboratories and RCA's David Sarnoff research center, that needed physicists and were willing to accept Betsy's plan to hire a German girl to be a big sister for any children that might come along, thus solving the child-care problem. Because RCA was closer to her husband's job, she accepted a position on their technical staff [12].

As she started her position at RCA, she learned that the last woman on the staff during WWII had asked the shop to machine a piece of brass, two inches long and a quarter of an inch wide, an eighth of an inch thick, plane and parallel to a thousandth of an inch tolerance. The shop struggled with the demanding job and finally got it perfect. They even kept it in a vacuum. When they called the woman to come for it, she arrived in the shop and blithely asked them to cut it in half. Betsy's first act on arriving at the lab was to tromp down to the shop and ask for a similar piece in a friendly way that was obviously a joke. The machinist laughed heartily with her, and she was accepted and soon became widely known as a friendly character thanks to judicious use of humor. She was asked to work on zeolites and again had to teach herself a new field [12].

Betsy became pregnant after a bit more than a year of marriage and continued working with the blessing of her immediate supervisor, whom she had told as soon as she knew. When she was about six months along, she burned herself badly with a soldering iron and went to the company nurse for salve and a bandage. The nurse was amazed to discover that she was pregnant and reported it to corporate management. The company laid her off and told her that they did not expect her back for a long time [12]. She was not allowed into the lab building for three months before the birth without management permission, even to get a book from her office [11]. Fortunately, her immediate boss and his superior hired her as a consultant so she could work on writing a chapter for a book. After the baby, a healthy girl, was born, Hal encouraged her to get back to work since her restlessness was driving him crazy, and the baby was sleeping through the night. She went back to work, this time very productively, on hot electrons and plasmas in solids, managing to publish a fundamental paper in the field [12].

In 1961, Hal's three-year appointment at Princeton was over and he accepted a tenure line position as an assistant professor of mathematics at the University of Washington in Seattle, although he continued active in the Air Force Reserve [13]. Betsy turned down an appointment in the electrical engineering department at the university because they were not allowed to offer her an associate professorship for fear that she would outrank her husband. She accepted an appointment as a research specialist in the Plasma Physics Laboratory of the Boeing Science Research Laboratories and also worked as an affiliate professor of electrical engineering at the University of Washington. At this point in 1961, the Johnsons had a year-and-a-half-old girl and wanted to complete their family. She was given an excellent technician and worked on problems that interested her with a strong staff and not much guidance from higher management, who assumed that an investment in basic research would benefit the company's bottom line. Her only problem was a rumor that arose because she and a male colleague worked closely together on physics in his office with the door closed [12].

Ancker-Johnson gained professional prominence during the nine years she remained at the Boeing Laboratory, where she was encouraged to do such things as present lectures abroad, including at laboratories in the Soviet Union, where she solved the problem of many vodka toasts by pretending a fondness for Georgian wine. She also participated prominently in international conferences. Her second baby was born while she was at Boeing. This time, in 1964, the company stopped her paycheck eight weeks before her due date, and state law required it be restarted six weeks after delivery, but nobody minded if she worked without being paid [11]. In 1970, Boeing abruptly closed its research lab because of an economic downturn in the aerospace industry; by then the urgency caused by the launch of Sputnik in 1957 had also declined [12].

Ancker-Johnson moved to the business divisions of the company, first as Supervisor, Solid State and Plasma Electronics in 1970–71 and then as Manager, Advanced Energy System until 1973, when she was recruited as the first female presidential appointee in the US Department of Commerce by the Nixon administration. She eventually became Assistant Secretary for Science and Technology, US Department of Commerce, before leaving in 1977 to become Associate Laboratory Director for Physics Research at Argonne Laboratory. In 1979, she moved to General Motors as the first woman vice president in the automobile industry. She was in charge of the environmental activities of the company, a high-profile job involving testifying before congress. She retired in 1992 [11]. She and Hal moved to Austin, Texas in 1997, where they remained active in the church [13].

Blodgett, Conwell and Ancker-Johnson began research in industrial labs immediately after completing their PhD studies. A number of women followed more complex paths into industrial work. For example, Maria Telkes (figure 4.4) completed her PhD studies at the University of Budapest in physical chemistry in 1924. In 1925, when she was 24 years old, she moved to the US to take a job at the Cleveland Clinic Foundation, where she worked on the energy of living systems [14]. She became a US citizen in 1937 and moved to Westinghouse Electric as a research engineer. In 1939, she joined MIT as a research associate in metallurgy. She became interested in using the melting and solidification of salts as a means to store energy. She supported the war effort by designing a solar still to provide drinking water for men trapped on rafts at sea. After the war, she continued her research on storing solar energy using salts [15].

Figure 4.4. Maria Telkes. Photograph courtesy of the University of Delaware.

In 1948, Telkes designed the heating system for one of the first experimental solar-heated homes, constructed with funding from and on the property of Amanda Peabody in Dover, Massachusetts. The system is still in use today and Telkes became famous as the 'Sun Queen' for her work on solar energy. In 1952, she received the first Woman of Achievement Award from the Society of Women Engineers and in 1953, while still at MIT, she received money from the Ford Foundation to design a solar oven. She completed the design before moving to New York University, where she established a laboratory for solar energy research. She moved back to industry as Director of Solar Energy Research at the Curtiss-Wright Company and then in 1961 moved to Cryo-Therm to study space- and sea-proof materials. In 1963, she moved to Melpar, Inc. to direct the company's effort in solar energy, and then, in 1969, to the University of Delaware [14].

At Delaware, she developed salt-based systems that cooled as well as heated solar-powered homes that the university designed. In 1977, she was honored by the National Academy of Sciences Building Research Advisory Board with an award previously given to such luminaries as Buckminster Fuller and Frank Lloyd Wright. She retired in 1978, but remained an active consultant until her death in Hungary in 1995. She was inducted posthumously into the National Inventors Hall of Fame in 2012 [16].

Maria Telkes's creativity was outstanding; however, her career path was anything but traditional since she, like many other early condensed matter physicists, worked on the narrow border between chemistry and physics. Another woman who was educated as a chemist but whose work spanned the boundary between fields so that she became a fellow of the American Physical Society, was Gertrude Fanny Neumark. Coming to the US in 1935 when she was eight as a refugee from Nazi Germany [17], she received her BA in 1948 from Columbia, her MA in 1949 from Radcliffe and her PhD in 1951 from Columbia, all in chemistry. She remained at Columbia for a year as a postdoc supported by an Andersen Fellowship from the American Association of University Women. She then took a job as Senior Physicist at Sylvania Research Laboratories until she moved to Phillips Laboratories in 1960. In 1985, she came to Columbia as Professor of Materials Science, having been a visiting professor and an adjunct professor in the five preceding years. Her field of study was the properties of semiconductors and phosphors, and she developed several important techniques for measuring and analyzing these important materials. She held five important patents for assorted devices [18]. In 1950, she married Henry Rothschild, a commodities trader at Philipp Brothers who had worked on mining in Bolivia [19]. He followed her in death in 2012 [20, 21].

Neumark's excellent work earned her fellowships in the American Physical Society and the New York Academy of Science [18]. A tiny woman standing just about five feet tall, she is remembered for her forceful pursuit of conversations and ideas in science. Her gender and diminutive stature may have led administrators to think that she would not fight for the rights to her intellectual property. Her work at Columbia led to the development of a doping process for semiconductors that formed the basis for the development of short wavelength lasers and LEDs. The process was used by major electronic firms around the world [20]. In 2005, she filed patent infringement suits against several large lighting firms, a David up against several Goliaths. The companies all settled out of court and the money they paid Neumark enabled her in 2008 to file complaints with the US International Trade Commission against such international giants as Sony and Nokia, a complaint that the Commission agreed to hear. By the end of 2009, she had secured about $27 million US dollars in settlements and licensing agreements from more than 40 companies, although she claimed that all she was seeking was what she was owed and the credit she felt she deserved [17]. It is significant that in 2008, Phillips Electronics, one of whose divisions she had sued, endowed a professorship in Electronics at Columbia's Department of Applied Physics and Applied Mathematics in her honor. The Phillips professorship was to be awarded to a newly or recently tenured faculty member and was to be used to increase the diversity of the department [22, 23].

Like Gertrude Neumark, Jenny Rosenthal arrived in the US as a child with her immigrant parents. She would also have a winding career path. Rosenthal was born in Moscow to parents who were Lithuanian and left the Soviet Union as part of a hostage exchange. She attended high school in Berlin and earned her bachelor's degree from the University of Paris in 1926 aged 16 in spite of her wandering childhood [24]. She received her master's in 1926 and her PhD in physics in 1929, both from New York University. It is claimed that she was the first woman to receive a doctorate in physics in the US; however, Lucy Hayner (see chapter 3) received her PhD in 1925 [25].

After graduation, Rosenthal took a position as a National Research Council Fellow at Johns Hopkins. In 1931, she returned to the physics department at New York University and in 1933 moved to the Harvard Observatory as a staff member; in 1935, she took an AAUW Research Fellowship at Columbia University. The research fellowship led to a position as an instructor at the Graduate Division of Brooklyn College. In 1942, she joined the US Army Signal Corps Laboratories, where she met her husband Arthur Bramley. He was a theoretical physicist who had been born in the UK, but had received his PhD at the University of Oregon. He had worked on pure research until World War II [26, 27]. The couple had three children, two sons and a daughter, which probably explains a gap in Rosenthal's work record from 1944–48. In 1948, she returned to the Signal Corps Laboratory and remained there until 1950, continuing as a consultant until 1953. Until 1958, she worked as a Project Engineer at Du Mont Labs, Inc., after which she joined her husband in the firm Bramley Consultants in Falls Church, Virginia [24, 27], leaving in 1962 to become a section head at Melpar, Inc. until 1967, when she became a supervisory physicist at the US Army Night Vision Lab at Ft Belvoir [24]. In 1985, after her husband's death in 1971 [27], she became a professor of physics at the University of Oregon until her retirement in 1988 [24].

Although she changed jobs fairly frequently, seemingly following her husband and presumably moving her family, Rosenthal Bramley had an outstanding record as a researcher in several areas of physics. At New York University for her PhD research, she investigated magnetic dipole hyperfine splitting and published her results with her PhD advisor, Gregory Breit, in 1932. The magnetic dipole correction is known as the Breit–Rosenthal correction. Today the laser laboratory at New York University is named in her honor [28]. In her later positions, she was awarded a total of 16 patents in areas ranging from secondary electron emission through color television to a microwave pumped gas laser [29]. These patents were licensed to IBM by the Bramley consulting firm [30]. She was the second woman elected to fellowship in IEEE. She was fluent in Russian, French, German and English and often served as a scientific translator [29]. She was also a fellow of the American Physical Society and the Washington Academy of Science and in 1985 she received the Women in Science and Engineering Life Achievement Award. She was also cited as the most outstanding woman scientist in federal government [24].

Elizabeth Armstrong Wood was born in New York City and had a much less turbulent childhood than Rosenthal Bramley. However, her path into industrial research was also no straight line. She received a BA in Geology from Barnard College in 1933 [31], where she was inspired by the outstanding female geologist Ida Ogilvie [32], who was her instructor. She pursued graduate study in geology at Bryn Mawr College and received her MA in 1934 and her PhD in 1939. At Bryn Mawr, physicist Lindo Patterson encouraged her interest in crystallography, a field that clearly crosses the lines of traditional academic disciplines [31]. She worked as an instructor in geology at Bryn Mawr in 1934–35, and as an instructor of geology and mineralogy at Barnard College from 1935–37. In 1937–38, she spent a year as an instructor at Bryn Mawr before receiving her PhD and moving back to Barnard and becoming a research assistant at Columbia University until 1941. In 1942, she joined the staff of the Bell Telephone Laboratories Physical Research Department as the first woman scientist hired there. She remained at Bell Labs for 24 years, pursuing an active research program in crystallography [33].

Wood's research interests included growing single crystals of materials with useful properties, including semiconductors, laser materials, ferromagnetic materials and superconductors. She became a widely respected expert on the magnetic and piezoelectric properties of these materials and was frequently consulted by many of the expert researchers on the staff at Bell Labs. She was also active in forming the American Crystallographic Association and became its first woman president in 1957. It is noteworthy that the second woman president, chemist Isabella Karle, was not elected until 1976 [33]. According to a history of Bell Labs, Elizabeth Armstrong Wood's work was important for understanding the relationship between the structure of materials and their physical properties [31].

In addition to her outstanding research in crystallography, Armstrong Wood served Bell Labs in a series of ceremonial roles. In addition, she became heavily involved in education in the physical sciences when interest in it suddenly peaked after the launch of Sputnik in 1957. She was a member of the Governing Board of the American Institute of Physics and served for nine years as a member of the Commission on College Physics, for four years as Associate Director of the NSF project Physical Science for Nonscience Students and for five years on the School Mathematics Study Group. She was also a gifted writer of books for both students and the general public, including the popular *Science for the Airline Passenger*, published in 1968 [31, 33]. She was named a fellow of the American Physical Society [32] and presented with a Distinguished Service Citation in 1970 by the American Association of Physics Teachers (AAPT) [34]. The American Crystallographic Association established the Elizabeth A Wood Science Writing Award to honor excellent science writing for the public in recognition of Wood's excellence in this arena. She also received honorary doctorates from three institutions [33].

Elizabeth was married to Sandy Wood and enjoyed gardening and sailing. She recorded many books for the blind, and found time to be active in several societies dedicated to the cultivation of iris [33].

During the years immediately following World War II and in the 1950s, a number of women physicists conducted important research in the industrial research laboratories funded by the central management of major US corporations, which often held monopolies on products and services. They participated actively in the exciting development of condensed matter physics that formed the basis of the electronic gadgets that were revolutionizing society. Despite their important science, many of these women's careers were less continuous than those of women physicists in academia. This occurred because the industrial labs themselves were changing and becoming more focused on product development at the expense of long-term physics research. Women physicists in industry often played a variety of roles as the research emphasis in the labs changed along with their management. Furthermore, tracking their careers is made more difficult because of gaps in lab records and the difficulty of obtaining them. Nevertheless, it is clear that women physicists were conducting significant research in the important industrial labs of the era.

References

[1] Anderson R J, Butler O R and Juris M 2008 *History of Physicists in Industry: Final Report* (College Park, MD: American Institute of Physics)

[2] Rosen R 2013 www.theatlantic.com/technology/archive/2013/02/the-internal-memo-that-allowed-ibms-female-employees-to-get-married/272832/

[3] Thomas F K and Siegl P J 1993 *Women in Chemistry and Physics: A Biobibliographic Sourcebook* ed L Grinstein, R Rose and M Rafailovich (Westport, CT: Greenwood) pp 65–71

[4] Williams G A 2006 *Out of the Shadows: Contributions of Twentieth-Century Women to Physics* ed N Byers and G Williams (Cambridge: Cambridge University Press) pp 149–57

[5] CWP (UCLA) http://www.physics.ucla.edu/~cwp (accessed 19/2/2015)

[6] Ashrafi B 2007 Interview with Dr Esther Conwell *Niels Bohr Library and Archives* (College Park, MD: American Institute of Physics) www.aip.org/history/ohilist/29913.html (accessed 28/12/2014)

[7] CWP (UCLA) http://cwp.library.ucla.edu/Phase2/Conwell,_Esther_Marly@841873837.html (accessed 19/2/2015)

[8] Rothberg L 2006 *Out of the Shadows: Contributions of Twentieth-Century Women to Physics* ed N Byers and G Williams (Cambridge: Cambridge University Press) pp 315–23

[9] Hevles D 2011 *New York Times Books* (13 April 2011) www.nytimes.com/2011/04/14/books/abraham-rothberg-who-wrote-of-golem-and-stalin-dies-at-89.html

[10] University of Rochester 2014 http://www.newswise.com/articles/esther-conwell-pioneering-professor-of-chemistry-dead-at-92 (accessed 3/4/15)

[11] CWP UCLA www.physics.ucla.edu/~cwp/Phase2/Ancker-Johnson,_Betsy@841234567.html (accessed 5/4/2015)

[12] Butler O 2008 Interview with Dr Betsy Ancker-Johnson *Niels Bohr Library and Archives* (College Park, MD: American Institute of Physics) http://www.aip.org/history/ohilist/33363.html (accessed 4/4/2015)

[13] 2009 *Austin American-Statesman* (28 September 2009) www.legacy.com/obituaries/statesman/obituary.aspx?pid=133607240

[14] Kubiszewski I 2006 *The Encyclopedia of Earth* www.eoearth.org/view/article/156459

[15] Casey 2006 http://mariatelkes.blogspot.com/ (accessed 9/4/15)

[16] Bryant T 2012 UDel—University of Delaware, Communications and Public Affairs www.udel.edu/udaily/2012/mar/telkes-solar-energy-032712.htmlCall

[17] Kiley K 2011 *The Chronicle of Higher Education* (9 January 2011) http://chronicle.com/article/Gertrude-Neumark-Rothschild/125879/

[18] CWP (UCLA) http://cwp.library.ucla.edu/Phase2/Neumark,Gertrude_Fanny@900123456.html, (accessed 31/3/15)

[19] Rothschild, 1913-2011: a finding aid Arthur and Elizabeth Schlesinger Library on *the History of Women in America (Harvard University)* http://oasis.lib.harvard.edu/oasis/deliver/~sch01488 (accessed 21/4/15)

[20] The Fu Foundation School of Engineering and Applied Science (Columbia University) 2010 http://engineering.columbia.edu/eminent-columbia-materials-scientist-dies (downloaded 11/4/15)

[21] 2012 Henry Rothschild *New York Times* (4 June 2012) (paid obituary notice) www.legacy.com/obituaries/nytimes/obituary.aspx?pid=157928976

[22] Grimes W 2010 Business day *New York Times* (17 November 2010) www.nytimes.com/2010/11/18/business/18rothschild.html?_r=0

[23] The Fu Foundation School of Engineering and Applied Science (Columbia University) 2008 http://engineering.columbia.edu/new-philips-electronics-professorship (accessed 11/4/15)
[24] CWP (UCLA) www.physics.ucla.edu/~cwp/Phase2/Bramley,_Jenny_Rosenthal@901234567.html (accessed 15/4/15)
[25] IEEE biography http://ethw.org/Jenny_Rosenthal_Bramley (accessed 17/3/15)
[26] 1997 Obituary *New York Times* (2 June 1997) www.nytimes.com/1997/06/02/us/jenny-bramley-87-physicist-and-inventor.html (accessed 16/3/2015)
[27] Barton H A 1971 *Physics Today* **24** 73
[28] Stroke H H 2002 http://physics.nyu.edu/alumni/Doctoral/bramley.jenny.html (accessed 16/ 4/15)
[29] CECOM Historical Office 2011 http://cecomhistorian.armylive.dodlive.mil/2011/01/05/Dr-jenny-rosenthal-bramley/ (accessed 16/3/15)
[30] FIAP 1998 Newsletter (February 1998) www.zoominfo.com/p/Jenny-Bramley/77054706
[31] Abrahams S C and Glusker J P 2006 *Physics Today* **59** 75
[32] Rossiter M 1995 *Women Scientists in America Before Affirmative Action 1940–1972* (Baltimore, MD: Johns Hopkins University Press) p 243
[33] International Union of Crystallography 2007 Obituary www.iucr.org/news/newsletter/volume-14/number-4/elizabeth-armstrong-wood-1912-2007
[34] American Association of Physics Teachers Awards Programs *Awards Search table* www.aapt.org/Programs/awards/awardstable.cfm

Chapter 5

Women physicists in the women's colleges

Colleges that admitted only women ranged from Catholic colleges for women to parts of private universities like Radcliffe College of Harvard and Barnard College of Columbia University; from private colleges supported by generous patrons like Wellesley College or Smith College to special institutions established by states, such as the Women's College of the University of North Carolina and Douglass College in New Jersey. Their importance both in training women in physics and in providing jobs for the few women who obtained PhDs in physics is evident from the biographies of women physicists presented in previous chapters. The majority of these women had an association with one of the women's colleges as either students or members of the faculty or staff. This chapter will deal with women whose primary careers were spent as faculty members in the women's colleges.

The tradition of women physicists working in women's colleges is an old one. For example, the two women present at the founding of the American Physical Society in 1899 were both on the faculties of women's colleges. Isabelle Stone received her PhD in physics from the University of Chicago in 1897 and was employed as an instructor at Vassar College in 1899 [1], and Marcia Anna Keith, the first full-time instructor of physics at Mt Holyoke College and later the department head, held a BA from the college and pursued further study at Worcester Polytechnic Institute and in Berlin before 1899, moving to the University of Chicago in 1900. She was unable to finish her degree in physics, but she was evidently a gifted teacher and she is believed to be the first instructor to offer individual laboratory work for her students [2].

Before World War II, most of the women's colleges refused to hire married women and even fired female faculty members who dared to get married. Many women faculty members lived in apartments within student dorms and took their meals with students. The prohibition on marriage was relaxed when there was a shortage of scientists during World War II, with many of the faculty members having taken long-term leave to work on war projects, but in many instances it was suddenly reinstated at the war's end and then gradually relaxed again during the 1950 s. At the same time, many of the women's colleges began to preferentially hire

doi:10.1088/978-1-6817-4094-2ch5

and support the research of male physicists (preferably married) until, in some cases, faculties that had been majority female became majority male. Although this hiring practice reduced employment opportunities for women at the women's colleges, they remained focused on providing excellent training in physics for women students, and departments encouraged their students to pursue careers in physics. The women's colleges benefitted from federal research grants and generous donations from foundations and individuals, and actually grew in both numbers and enrollments immediately after the war [3]. Since women were denied admission to many of the leading undergraduate institutions, many of the most talented female scientists of the postwar years studied at the women's colleges.

This chapter focuses on those women whose careers were heavily influenced by the women's colleges. They were a remarkable group of talented physicists and physics teachers who received very little recognition from the physics professional societies for their efforts. There is little information in the literature on many of them. The major source of information on faculty members in the women's colleges is the excellent series of interviews conducted by physicist and historian Katherine Sopka (see chapter 7) in the late 1970s, many of which focused on these women faculty members. The Niels Bohr Library and the Archives of the American Institute of Physics digitized these interviews so that they are available on the web. Because the Sopka interviews focused on women's colleges in the northeast, this chapter also focuses on these schools, although there were excellent women's colleges throughout the country, for example, Mills College in Oakland, California, and women's colleges associated with other universities. Several liberal arts colleges, such as Brooklyn College and DePaul University, employed excellent women physicists. The professional issues faced by women faculty members in the liberal arts colleges were similar to those faced in the women's colleges, including an emphasis on excellent teaching and limited facilities for conducting research.

Lucy Wilson (figure 5.1), a long-time faculty member at Wellesley College, a private college for women outside Boston, provides a model for the way women physicists in the women's colleges worked to find other colleagues and build up their departments. It is very clear that these colleges sought women who were excellent physicists, who cared about their students and who were gifted teachers. No woman who had not done some research was hired. No woman who could not teach was retained.

Lucy Wilson was born in 1888 near Chicago [4]. Her father worked in the business department of AT&T, as his father had. When she was just two years old, her father died. Lucy's mother then moved the family to Bloomington, Illinois to live with her father, mother and sister. Lucy's grandfather was a well-respected physician and Lucy remembered going on house calls in the country with him in his horse-drawn buggy. Her grandfather had gone to Harvard and the family assumed that the children would go east to college. Lucy attended Wellesley College and her brother went to MIT. After her brother graduated, he went to work for the Aluminum Corporation of America, eventually becoming president and chairman of the board there, as well as a member of the MIT Corporation [5].

Lucy Wilson entered Wellesley with an interest in mathematics and did not take her first college course in physics until her sophomore year. She was very interested

Figure 5.1. Lucy Wilson with a faithful friend. Photograph courtesy of Wellesley College Archives.

in psychology, but decided to major in physics and mathematics because she enjoyed the subjects and the women who taught them. She graduated in 1909 [4] and obtained a position as an instructor at Mt Holyoke College because a member of the Wellesley faculty who lived in her dorm recommended her to a friend who was in the physics department there. She worked very hard at Mt Holyoke over the next three years, realized that she was more interested in physics than psychology, and decided to get a PhD in physics. Her mother insisted that she first take some time off for her health. After this she worked part time at Mt Holyoke for another year. She decided to go to Johns Hopkins for her PhD because a friend on the Mt Holyoke faculty told her about the interesting work being done there. She skipped a master's degree because she knew she wanted a PhD and finished the degree in three years, receiving it in 1917 [5]. She returned to Wellesley, where she was interested in both optics and human perception [4]. She eagerly accepted an opportunity to visit and work in the laboratory of Lawrence Bragg at the University of Manchester in the UK [5]. While in Manchester, she met Dorothy Heyworth, then an undergraduate physics honors student at Manchester, and talked with her about taking a teaching job in the US. This resulted in Heyworth coming to Mt Holyoke after she finished her master's degree at Manchester [6].

Just after World War I, Lucy Wilson enrolled in a course at the YMCA and then offered a one-credit course at Wellesley in auto mechanics, during which the students actually worked on the chassis of a car. She said that Wellesley faculty members often used their connections with the faculty members at other women's colleges to recruit new young women as instructors and assistants for the physics department [5].

In 1935, Wilson became a professor of both physics and psychology at Wellesley. In 1938, she was named acting dean of the college, and then in 1939, dean of students. In 1945, she was named Sarah Frances Whiting Professor. She retired in 1954 and senior students established a scholarship in her name at Wellesley. She died in 1980 [4].

Dorothy Weeks (figure 5.2) founded and chaired the physics department at Wilson College, a private Presbyterian-related college for women in Chambersburg, PA. Her activities were recognized by an Achievement Award and a fellowship named in her honor from the American Association of University Women. Weeks was born in 1893 [7] in Philadelphia, but the family moved to Washington, DC when she was seven years old so that her father could take a job as an engraver at the Bureau of Engraving and Printing. Weeks had a younger sister who was primarily interested in music, but her brother, one year older, built various gadgets from materials he purchased second-hand or borrowed from various sources. Weeks remembers his trying to keep her out of his attic workspace, where she loved to play. She was educated entirely in Washington public schools, where she had two years of

Figure 5.2. Dorothy Weeks. Taken in 1955 on a physics class field trip to the Chambersburg Engineering Corporation. Photograph courtesy of the Hankey Center and C Elizabeth Boyd '33 Archives, Wilson College.

high-school chemistry and two years of physics taught by a teacher, Roberta Wallace, whom Weeks remembers as being excellent. Weeks also developed her interest in mathematics [8].

Weeks decided to attend Wellesley College, since her parents remembered it as a beautiful place. She took her first physics course from Louise McDowell in her sophomore year and was so impressed by McDowell's teaching that she decided to major in physics. She already had an interest in topics like electricity from collaborating with her brother and moved quickly through introductory labs. The Wellesley College physics department had four women instructors and two women astronomers at that time [8].

Weeks received her bachelor's degree in 1916 [7] and went job hunting. The National Bureau of Standards did not hire women as secretaries, let alone as scientists, but Weeks learned that the Patent Office would hire women as patent examiners and she managed to pass the six three-hour exams that were required (as did her Wellesley classmate Jessica Dee) [2], and landed a job as an assistant patent examiner in 1917. She stayed at the Patent Office until 1920, when she left for the National Bureau of Standards, where she worked as an assistant [7].

During World War I, MIT had difficulty in recruiting young male college graduates as scientific assistants, so the department chair contacted the chairs of the physics departments at Wellesley, Barnard and Mt Holyoke to see if he could locate some talented women graduates in physics who might be interested in becoming assistants in physics at MIT. He managed to recruit four women, including Weeks [8], who became a research assistant at MIT in 1921, then a research associate, and finally an instructor in physics from 1922–24 [7]. At MIT she worked as a laboratory instructor in the required electronics course taken by 600 MIT sophomores. The only woman student in the course, Excellenza Morse, eventually became the first female Principal Patent Examiner [8].

Dorothy Weeks received her master's degree in physics at MIT in 1923 with a thesis on powder diffraction by x-rays. The door to the laboratory where she worked was labeled 'Miss Weeks, danger 50,000 V', which became a standing joke. In the electronics lab, she learned how to organize and run a large operation in physics instruction [8].

With her physics master's degree in hand, Weeks took a part-time job at the Buckingham School in addition to her instructor's position at MIT. She decided that as she was interested in administration, she would enroll in graduate business courses at Simmons College [8]. She received a master's degree in business in 1925 and from 1925–27, she was employed as employment supervisor at the Jordan Marsh Company [7]. Eventually, she decided that although the job at Jordan Marsh had greatly expanded her experience as an administrator, she could not support some of the company's policies, so she left. She found a part-time position analyzing data for a professor at the Harvard Medical School and then decided that she wanted to go back to get a PhD at MIT. At that time, the physics department at MIT had become interested in industrial physics, which did not interest Weeks, so she decided to get her degree in mathematics, where theoretical physics was then being taught [8]. Norbert Weiner became her thesis advisor and she completed a

PhD thesis on a matrix method for analyzing polarized light. To support herself during this time, she took a position as a three-quarters-time physics instructor at Wellesley from 1928–29, managing the commute from MIT to Wellesley with the help of a model A Ford [8].

Dorothy Weeks received her PhD from MIT in 1930. She was convinced that she could only find a physics job in a women's college, since universities did not offer faculty positions to women, no matter how well qualified they might be. In 1930, she was the only member of the Wilson College physics department, acting as both the professor and the janitor. After working at MIT in the summer of 1935, she began to study spectroscopy because she felt it was a suitable research area for the environment at an undergraduate institution. She also arranged for students from women's colleges to work without pay and without paying on a summer program at MIT to learn spectroscopy and what research was all about. The program was nicknamed 'the Charm School' by the MIT faculty member in charge [8].

In 1949–50, Weeks held a Guggenheim Fellowship, which she spent analyzing spectra at MIT before taking the opportunity to visit spectroscopy labs in Europe. By the time she left Wilson, she had built the physics department to resemble the department at Wellesley. She said that she always felt that women's colleges were uniquely suited to interest young women in physics careers, to educate them well to pursue these careers, and to give these young women the confidence to function effectively in what is still a male-dominated profession [8].

From July 1943 to the summer of 1945, Weeks took a position at the Office of Scientific Research and Development (OSRD) as a technical aide in charge of British reports. She did not know about the Manhattan Project, but remembered being asked to send certain reports to a post office box [8]. She returned to Wilson College until 1956 and worked part time at the National Science Foundation from 1953–56. She then held an appointment as a physicist at the US Army Ordnance Material Research Office at the Watertown Arsenal until 1962 [7] where she worked on materials for shielding against radiation from nuclear weapons [9]. In 1964, she took a part-time position as a spectroscopist at the Harvard College Observatory, that she held until 1976 [8]. While at Harvard she studied solar satellites [9]. During her time there, she lectured at Newton College of the Sacred Heart, a Catholic college for women that later merged with Boston College. She set up that college's physics program. Her only expressed regret was that so many of her opportunities came as a result of the shortage of manpower during wars [7].

Weeks never married. She retired in 1976, but worked past her retirement, dying in 1990 at the age of 97 [9].

In her interview with Katherine Sopka, Weeks mentioned several former students who had successful careers, including Pauline Morrow Austin, a Wilson graduate who headed the MIT program on weather radar [8].

Pauline Morrow (shown with her husband James Austin in figure 5.3) was born in Kingsville, TX in 1916, but was raised in Mexico, where she was home schooled by her parents who were educational missionaries. Later, she attended the North Avenue Presbyterian School in Atlanta for her sophomore and senior years of high school [10]. She graduated from Wilson in 1938 with a degree in mathematics,

Figure 5.3. Pauline Morrow Austin with husband James in the MIT Weather Lab; the Austins share a common interest. Photograph courtesy of the Hankey Center and C Elizabeth Boyd '33 Archives, Wilson College.

because Wilson offered only a few physics courses at that time. She received her master's in physics from Smith College in 1939 and her PhD from MIT in 1942 [11].

In 1941, Morrow met a fellow graduate student in physics, James Murdoch Austin, a New Zealander who received his PhD in physics from MIT in 1941 [12]. According to the Austins' daughter, her father's New Zealand accent was so thick that Pauline could not understand the help he tried to give her with the only homework problem she ever flunked at MIT [10]. According to Dr Weeks, Pauline passed every graduate course at MIT with honors, a superb and rarely equaled record [8].

The two graduate students were married in 1941 and remained at MIT, where James was a professor of meteorology from 1941–83. During World War II, he served as a consultant to the US Army Air Force Weather Service in Europe and used his skills as a forecaster to assist in major military maneuvers, including the D-Day landing. In 1946, President Truman awarded him the Medal of Freedom for his service. In June 1948, he produced a live nightly weather forecast on Boston television, the first live television program broadcast from Boston. This made him a pioneer in presenting science to the public and a well-known figure in Boston in addition to being a distinguished scientist elected to the American Academy of Arts and Sciences for his groundbreaking work on air pollution. He died in 2000 [12]. The couple had two daughters.

In January 1942, Pauline Morrow Austin was named by the *New York Times* as one of the top female scientists aiding the war effort, an accomplishment achieved even though she had not completed her PhD. She never discussed her war work since it was classified, indicating only that it dealt with electromagnetic waves in the ionosphere [11].

In 1946, MIT launched a program to explore the use of radar in predicting the weather and asked Pauline Austin to join the Weather Radar Research Project as the only woman working on it. In this work, she compared radar echoes, particularly in the ‘bright band’, to the amount of rain that actually fell during a storm; this work led to the ability to use radar data to predict weather patterns. From 1953–55, Austin was a lecturer at Wellesley. In 1956, she was appointed Director of the Weather Radar Research Project and remained its leader until her retirement in 1980 [11].

Beginning in the late 1940 s, Pauline Austin appeared on her husband’s television show and introduced viewers to the use of radar to predict the weather. She was very active in the American Meteorological Society, chairing its Committee on Radar Meteorology and becoming the first woman elected a Councilor of the Society, in 1974. In 1962, she received a Woman of Achievement Award from the Massachusetts Federation of Business and Professional Women’s Clubs [11]. After her husband’s death, she moved to Gainesville, FL to be near her daughter. She died in 2011 from the complications of a stroke [10]. She is remembered by colleagues as very modest about her own significant achievements and always eager to give the credit to others. One person described her as ‘just a dedicated scientist’ [10].

When Alice Armstrong (see chapter 2) resigned as the chair of the physics department at Wellesley College to move to Los Alamos, Dr Dorothy Heyworth (figure 5.4) became chair. Heyworth had been born in a small town about 20 miles from Manchester, in the UK. She won a scholarship to the University of Manchester. There, she talked W L Bragg (who won the Nobel Prize in physics in 1915) into letting her into the honors program in physics. In the first year, there were 26 men and four women in the honors program. By the second year, there were 13 men and the very determined Dorothy Heyworth [6]. She was in Owens College and graduated with first class honors in 1924 [13]. Although she had the offer of a teaching position in the US thanks to her meeting with Dr Lucy Wilson of Wellesley College, she decided to remain at Manchester to obtain her master’s degree, which she did in 1925. She then left to come to the US and accept a position at Mt Holyoke College. In 1929, she left Mt Holyoke to do graduate work at the University of Chicago, where she pursued her interest in experimental crystallography. In the spring of 1931, she ran out of money and asked if she could return to Mt Holyoke as an instructor for the spring semester of 1932. They made room for her and she managed to finish her dissertation[6].

In the fall of 1932, Heyworth moved to Wellesley because she knew Lucy Wilson there and wanted to be near a big city, Boston. She travelled back to Chicago to take her PhD orals between semesters and received her PhD at the end of 1932. She was gradually promoted to assistant professor and then associate professor. While at Wellesley, she even managed to do some research at MIT on cosmic rays in collaboration with a male friend there who was on the physics faculty. She had arrived at Wellesley with 35 cents in her pocket, so she accepted the department’s strong suggestion that she become one of the faculty members who lived in an

Figure 5.4. Dr Dorothy Heyworth, Physics. Photograph courtesy of Wellesley College Archives.

apartment in one of the dorms, which was economical if not very private. After she became chair of the department, she was re-elected for 12 years until her retirement. She claimed that hers was the only no vote in the election for chair [6].

Dr Heyworth's greatest pride was in how well she was able to prepare Wellesley students for graduate work in physics, and she noted proudly that they were recruited by graduate programs. She devoted herself to teaching and later also to her duties as chair and found little time for research. She attended meetings of the American Physical Society and kept herself current in physics. She stayed in touch with Alice Armstrong and they remained good friends [6]. She died in 1989 and will be remembered for teaching at Wellesley College for 36 years [14].

Another outstanding member of the physics faculty at a women's college, Mildred Allen (figure 5.5), was born in Sharon, Massachusetts, outside of Boston. Her father, who had graduated from MIT, travelled west to work on the railroad in New Mexico. There he met her mother, a Chicago high-school teacher, who had come west to keep house for her brother who had tuberculosis. At the time of Mildred's birth, her father was teaching civil engineering at MIT and had been admitted to the Boston bar. Mildred and her sister, who was a year younger, were home schooled by an aunt until Mildred was 9½ years old, at which time she entered public school in Boston after the family moved to Roxbury [15].

Mildred Allen was awarded obtained a BA in physics by Vassar College in 1916 and she started graduate work at Clark University while still serving as a visiting lecturer at Vassar until 1918, when she moved to Mt Holyoke College. She obtained

Figure 5.5. Mildred Allen with students in 1942. Photograph courtesy of the Mt Holyoke College Archives and Special Collections.

her MS in 1917 and her PhD in 1922, both in physics and both from Clark [15], although she actually conducted her thesis research at MIT, helped by her father's influence. She also had small graduate fellowships from Vassar for two years, which covered her living expenses [15]. In 1921, she became an instructor in physics at Wellesley College and in 1923, she moved to Mt Holyoke. From 1927–30, Allen was a Research Fellow at the Bartol Research Foundation of the Franklin Institute [16], where she worked on electron energy loss in gold foils but did not obtain significant results [15]. She studied summers and vacations at Harvard in 1931–33 and visited both Yale and the University of Chicago as a student [16].

She spent the academic year 1930–31 as a research instructor at Oberlin College and then returned to Mt Holyoke as a professor of physics. From 1940 to 1958 she served as chair of the physics department, retiring in 1959 [16].

Allen continued to teach after her retirement and was also active in research concerned with the measurement of gravitational anomalies using a massive torsion pendulum, notably during solar eclipses [15]. She published in well-respected journals such as *Physical Review* and was elected to a fellowship in the American Physical Society and the American Association for the Advancement of Science. She continued to be an active researcher for many years after her retirement. She was also active in several professional organizations, including the American Association of Physics Teachers and Sigma Xi [16].

Dr Allen's most important legacies may well have been the inspiration she provided to generations of women physics students and her love of teaching physics to liberal arts students. She never married and devoted herself to providing both high-quality physics instruction and emotional support to her students. Students remember her climbing the stairs to the student study room during the push to final comprehensive examinations in physics, which all seniors had to take, in order to make sure that the students were comfortable and to answer any questions they might have. This is well documented by the following excerpt from her obituary in the *Mt Holyoke Alumnae Quarterly*, written by Eleanor Chaffee, a student in the class of 1956 [16]:

Miss Allen represents one of a still too few distinguished women physicists and educators; she truly serves as an inspiration to the young woman of science who meet old-fashioned criticism upon entering this 'man's field'.

As a professor emerita, she continued to serve as a role model for women physics students at Mt Holyoke until well into her 90s.

In addition to the all-women's colleges, some of the liberal arts colleges welcomed women physicists to their faculties, using the same criteria of intense interest in students, teaching ability and documented excellence in physics that the women's colleges used. Mary Elizabeth Layne Boas (figure 5.6) is a good example of such a woman. She was born in 1917 and grew up on a poultry and fruit farm in eastern Washington state. She earned her bachelor's degree in 1938 and her master's degree in 1940, both from the University of Washington. She then moved to Durham, North Carolina to pursue graduate study at Duke University. She also worked briefly as an instructor at Duke. There she met Ralph Phillip Boas Jr, a mathematics instructor who had also been born in Washington state and had received his PhD from Harvard in 1937. They married on 12 June 1941 in Massachusetts [19]. Ralph had moved to Duke in 1939 and on to the US Navy Preflight School in Chapel Hill, NC in 1942. After a year, he moved to Harvard to teach from 1945–47, and to MIT from 1948-49, and finally to Northwestern University near Chicago in 1950, where

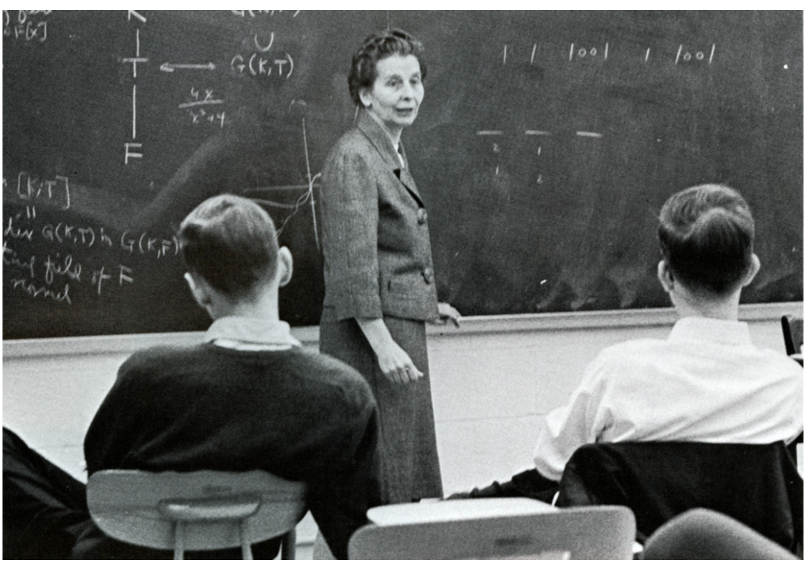


Figure 5.6. Mary Boas teaching; *DePaulian* 1967, Special Collections and Archives, DePaul University, Chicago, Illinois.

he would spend the rest of his career, including serving as department chair from 1957–72 [18].

Mary Boas followed his moves and earned her PhD in physics in 1948 from MIT. She then found a job at DePaul University, a Catholic University in Chicago with a focus on the liberal arts. She taught physics until she retired in 1987 and while teaching wrote a leading textbook, *Mathematical Methods in the Physical Sciences*. Mary and Ralph Boas also raised three children, one of whom became a distinguished mathematician in his own right [17]. In retirement, the Boases moved to Seattle, where Mary Boas established an endowed scholarship in 2008 at the University of Washington to recognize outstanding achievements in physics by female students. She died in 2010 [19].

The women physicists treated so far in this chapter primarily served as faculty members in women's or liberal arts colleges. Dr Dorothy Davis Locanthi is included here as an example of a woman who found her profession as a physicist during her education at one of the women's colleges and then took her first jobs teaching at two of them, but later went on to a distinguished career as an astronomer.

Dorothy N Davis was born in 1913 in East St Louis and left home at fifteen to attend Vassar College. She earned her BA in physics in 1933 with minors in astronomy and mathematics [20]. She knew then that she wanted to pursue a career in astronomy, but Vassar did not offer a major in it. Consequently, she went to Mills College, a women's college in Oakland that had offered her a teaching assistantship [21]. While commuting to Berkeley to take basic graduate courses in astronomy, she completed her master's degree research with a thesis on S-type stars that were long period variables [22]. She continued her studies at Berkeley, earning her PhD in 1937 with a dissertation on the spectrum of the star Antares.

After completing her PhD, she needed a job and (as frequently happened to women physicists then) she was hired by not one but two women's colleges. In 1937–38, she taught at Smith College and in 1938–39 she moved to Vassar for a year [21]. The following year she received an AAUW Fellowship, which allowed her to conduct research at the Mt Wilson Observatory in Pasadena, collecting data on stellar spectra [23]. From 1940 until 1942, she worked at Princeton with Henry Norris Russell on the spectrum of ionized europium [20].

Dorothy Davis remembered how Russell cared very deeply about the people who worked with him, and that when her mother broke an ankle during her second year at Princeton, he let her take time off to return to East St Louis to look after her. In the spring of 1942, Davis got a job as a replacement physics teacher in an East St Louis high school and enjoyed the job so much that Russell was afraid that she would leave research. He detoured to St Louis on a trip to Chicago to meet her mother and instruct her to persuade Dorothy to come back to research. Dorothy eventually went back to Princeton, but her mother did not move there because Dorothy's job was not a permanent position. After two years, she returned to Mt Wilson [22].

At the time of her return to Mt Wilson, World War II was in full swing so Dorothy worked on secret projects at the observatory for a while and then moved to Caltech, where she worked on their rocket project. While she was at Caltech, she met and married Bart N Locanthi, a student at Caltech who was six years her junior. She worked on rocket projects with Caltech scientists until 1946, when she took a job at the Beckman Lab to support her husband while he finished his undergraduate degree, which he did in 1947 [22]. Their first daughter was born in 1948 and Dorothy had to take two years off work. Then she took a half-time job with the Naval Ordnance Test Station at Inyokern, California, which had an office in Pasadena. In 1952, the Locanthis had a second daughter and subsequently Dorothy took ten years off research to raise the couple's (eventually three) children. Fortunately, Bart Locanthi had become a creative and productive audio engineer who worked on analog computers as well as acoustical transducers and digital techniques. He was very successful and undoubtedly earned a comfortable income so that Dorothy did not have to work for financial reasons. Bart was active in a variety of professional organizations until his death in 1994 [23].

In 1962, Dorothy took a part-time position at Caltech, measuring and analyzing spectra for Jesse Greenstein. When that job ended in 1969 because of budget cuts [22], she found another at the Jet Propulsion Laboratory with the planetary atmospheres group, where she worked through to her retirement in 1985.

In addition to her love for astronomical spectroscopy, Dorothy was an unusual woman in other ways. She stood 6′ 4″ tall and broke the world record for women in the standing broad jump as a teenager. She was also a skilled photographer and her work (including a portrait of Albert Einstein) was exhibited at the American Institute of Physics. Dorothy loved to sing and participated in a number of choral groups. She died in 1999 and was remembered as one of the early American women who had a career as a PhD in astronomy [20].

Several of the women's colleges also had a proud tradition of educating women in astronomy. For example, Dorothy Hodson attended Goucher College, then a women's college, in Towson, MD, where she discovered astronomy. She earned a PhD from the University of Michigan in 1933, after which she taught at Wellesley (spending summers at the Meudon Observatory outside Paris) until 1943, when she moved to the MIT Radiation Laboratory, where she spent the three final years of World War II, before returning to Goucher while continuing her research on solar flares at Michigan. In 1947, she moved to Michigan as a professor of astronomy on the staff of the McMath-Hulbert Observatory, where she would later serve as associate director. She published over 130 articles and received the Annie Jump Cannon Prize in 1954 from the AAS and the Faculty Distinguished Achievement Award from the University of Michigan in 1974. She was married to Edward L Prince, and used to sail across Lake Angelus to work at the observatory. She was a gifted teacher, bringing Goucher graduate, Emma Ruth Hedeman, to the McMath-Hubert Observatory as a long-time colleague [24].

Emma Hedeman graduated from Goucher in 1931, earned a master's degree in mathematics from Duke in 1936 and taught high-school math in Baltimore before serving in the WAVES as a meteorologist in World War II. After the war, she went to Michigan to pursue advanced studies and earned her master's in astronomy in 1948. She loved to travel and after her retirement from the McMath-Hulbert Observatory, she returned to Annapolis, MD to be near her family. She was a strong advocate of higher education for women and active as a Goucher alumna [25].

In addition to hiring new women PhDs in physics, the women's colleges also hired women who had left universities in Germany and elsewhere in Europe, taking advantage of their excellent training. For example, Hedwig Kohn (chapter 3) found her first job in the US at the Women's College of the University of North Carolina. Another refugee woman physicist helped in this way was Hildegard Stücklen, who held a PhD from the University of Göttingen and worked in spectroscopy. Stücklen first taught in the US in 1931 at Mt Holyoke College. She had previously taught at the University in Zurich and the Institute of Technology in Delft. In 1943, she became chair of the physics department at Sweetbriar College, a private college for women, and in 1956, she retired to move to Wilson College to replace Dorothy Weeks as chair of the physics department. She returned to Germany in 1961 and stayed there until her death in 1964 [26].

Janet Brown Guernsey's (figure 5.7) career at Wellesley, where she taught physics and served as chair of the physics department, extended from 1942 for 36 years almost into the 1980s. Unlike her predecessors whose lives are described above, she was married and the mother of five children. Her story indicates the changes in the hiring practices of the women's colleges after World War II.

Janet Brown was born in Germantown, Pennsylvania and was educated at a private day school, Germantown Friends, until she left to attend Wellesley College in 1931 when she was 18. She managed to be the first girl in Germantown Friends to take calculus, over the objections of the headmaster, thanks to her mother's willingness to battle the bureaucracy on her behalf. When Brown arrived at Wellesley, she introduced herself to the chair of the physics department, the redoubtable Louise McDowell, who thought Brown was probably too sociable to be a physics major. The department at that time consisted of Louise McDowell, Alice Armstrong, Lucy Wilson and Dorothy Heyworth, who had just arrived, along

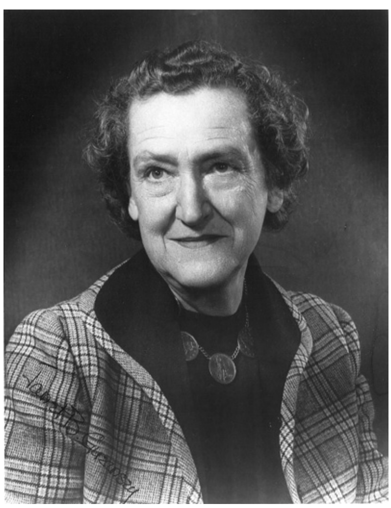


Figure 5.7. Janet Guernsey Brown. Presidential photograph courtesy of the American Association of Physics Teachers.

with a few teaching assistants. It was a very strong department that was dedicated to its students and Brown arrived determined to major in physics. Then as now, physics was a small department and there were only three majors in the class of 1935 [27].

Brown had a blind date for her senior prom, William Guernsey, who was at that time working at a law firm in Boston. Guernsey, later to be Brown's husband, had been born in Wellesley and had graduated from Wesleyan College and Harvard Law School [28]. The date was a success, but marriage was not immediate. After graduation, Brown worked as apprentice teacher at the Baldwin School in Bryn Mawr, Pennsylvania, which involved teaching labs and working on special projects with students who wanted to do them. She learned a good bit about teaching but had taken the job on a temporary basis because she was engaged to be married in June 1936 to William Guernsey and thought that she would not work after marriage. She actually started a family, had three children and stayed home until she started to get bored [27].

In the second semester of 1942, Wellesley was looking for people to take a refresher course in radio, which meant electronics in those days. Janet decided to take it since she was living in the town of Wellesley and it might allow her to get a part-time war job. While Janet was taking the refresher course, Dorothy Heyworth broke her leg and Janet was hired as a temporary replacement to teach the sophomore course in electricity and magnetism, the course in circuit theory and the beginning course in physics during the fall semester [27].

In the spring of 1943, Janet decided against moving to MIT for a war-related job because she enjoyed teaching undergraduate physics. Louise McDowell found a position for her at Wellesley, but told her she would need at least one more degree to stay on the faculty. So Guernsey enrolled at Radcliffe in 1945 to take one Harvard physics course at a time and earned her master's degree in 1948 in engineering and applied physics while she continued teaching at Wellesley. Having finished her master's, she wished to continue for the PhD, but the physics department at Harvard let her know that they did not welcome part-time students, which she would have to be because of her responsibilities to her growing family and also to Wellesley, where she had been made an assistant professor when she obtained her second degree. MIT assured her of their appreciation for part-time students, so she began work on the PhD there. She finished her course work in 1953, but struggled with the preliminary exam and in finding a sponsor for her dissertation [27].

Finally, Al Wattenberg accepted her and she worked on the Van de Graaff accelerator with a group of 'boys' who were probably under 21. They had to operate and maintain the accelerator and collect and plot by hand the data from a 10-channel multichannel analyzer built in the lab. Guernsey studied nuclear energy levels excited by neutrons in deformed nuclei described by the collective model. It was a difficult experiment since the nuclei were hard to excite with neutrons and emitted soft gammas that were tricky to detect. In 1955, she finished her PhD just as she came up for promotion to tenure at Wellesley. She wrote a dissertation in three weeks, but attended her son's graduation at Roxbury Latin School rather than her own, which fell on the same day [27].

Family issues were important in Janet Guernsey's life. Her husband went into the navy during the war and left Massachusetts just as she started work at Harvard.

When he returned to Wellesley and Janet in 1946, he was very supportive of her studies. In 1942, she was fortunate in hiring a live-in housekeeper who had one son who was three years older than the Guernsey's eldest [29]. The son and the housekeeper essentially became part of the family and the housekeeper worked side-by-side with Guernsey on domestic activities such as making jelly and freezing summer vegetables.

Life was not always easy. Janet remembered being very pregnant while at Harvard so that when she had her fourth baby, she got a night of sleep after a physics exam before going to the hospital to deliver the baby, which arrived in half an hour [27]. When she had her fifth child, she again took an exam, ran home, packed a suitcase, made a list for her husband, went to the hospital and had her last child and only daughter after ten minutes [29]. William decided to return to Boston University for a PhD in history and he taught English constitutional history and Roman history as an instructor and then an assistant professor at Boston University from 1965 until he retired in 1975 [30].

Janet Guernsey cared deeply about her students and worked with her department on strategies to encourage young women to pursue careers in physics and how to provide them with state-of-the-art training. She regretted not being able to be more active in nuclear physics research, although she visited MIT and Los Alamos during the summers to work at the Van de Graaff accelerators there and even went to Livermore for one summer to work on laser fusion [29].

Guernsey joined the American Association of Physics Teachers in her early days at Wellesley and was active in restarting the New England section [28]. In 1978, she was elected as the second woman president of the AAPT. She was also a fellow of the American Physical Society. After her retirement, she was active in the Wellesley community until her death in 2001 [31].

Clearly the women's colleges treated women physicists as first-class members of their professions, which was unusual at the time. These women took the study of physics seriously and worked to prepare undergraduate women for careers in physics. For any teenager lacking the determination of a Dorothy Weeks, these colleges provided a sheltered environment for women interested in physics to develop both their skills as physicists and the social skills they would need to function in a competitive male-dominated environment. They also sheltered a very large number of women physicists who earned the PhDs in the early stages of their careers, including C S Wu and Maria Mayer, who both taught at women's colleges before moving to more research-oriented institutions.

The stories of the women presented in this chapter clearly illustrate the great changes in physics brought on by World War II. Society demanded research, which it considered to be a panacea for economic ills and the way to grow an industrial base and a strong military through new technologies. This brought physics into the age of big science, where large groups worked at remote user facilities such as accelerators with funding from federal agencies, rather than there being one professor and a couple of students conducting an experiment funded by themselves or a private foundation. Faculty members in the physics departments at the women's colleges began to travel to larger institutions to conduct research as members of groups rather than establishing labs on the college campuses. The careers of the women described above clearly reflect this trend.

Finally, social perceptions of women who worked outside the home changed, so that married women physicists were allowed to work and teach, although anti-nepotism rules remained in effect, at least at the departmental level in research universities. Married women were increasingly welcomed in physics departments at the women's and liberal arts colleges, but were considered a bargain if their husbands were employed in the geographical area or another department at the school, since they could be paid less and were unlikely to leave since two jobs were hard to find. This trend is demonstrated by Janet Guernsey and also by other women physicists like her who have not been included here.

References

[1] CWP (UCLA) http://cwp.library.ucla.edu/Phase2/Stone,Isabelle@941234567.html (accessed 23/4/15)

[2] CWP (UCLA) http://cwp.library.ucla.edu/Phase2/Keith,_Marcia_Anna@941234567.html (accessed 23/4/15)

[3] Rossiter M 1995 *Women Scientists in America: Before Affirmative Action 1940–1972* (Baltimore, MD: Johns Hopkins University Press) chapter 10

[4] Wikipedia http://en.wikipedia.org/wiki/Lucy_Wilson (accessed 19/4/15)

[5] Sopka K 1978 Interview with Dr Lucy Wilson *Niels Bohr Library and Archives* (College Park, MD: American Institute of Physics) www.aip.org/history/ohilist/4971_1.html (accessed 28/4/15)

[6] Sopka K 1979 (College Park, MD: American Institute of Physics) http://www.aip.org/history/ohilist/4671.html (accessed 27/4/15)

[7] CWP (UCLA) www.physics.ucla.edu/~cwp/internal/Atomic_Molecular_and_Optical_Physics/Weeks,_Dorothy_Walcott@863653425.html (accessed 19/4/15)

[8] Sopka K 1978 Interview with Dr Dorothy Weeks *Niels Bohr Library and Archives* (College Park, MD: American Institute of Physics) www.aip.org/history/ohilist/4943.html (accessed 7/4/15)

[9] 1990 Dorothy Weeks Obituary *New York Times* (8 June 1990) www.nytimes.com/1990/06/08/obituaries/dorothy-weeks-97-a-physicist-who-led-in-variety-of-careers.html

[10] 2011 Pauline Austin Obituary *Gainesville Sun* (4–5 September 2011) www.legacy.com/obituaries/gainesville/obituary.aspx?pid=153470676

[11] Landergan K 2011 *The Boston Globe* (12 October 2011) www.boston.com/bostonglobe/obituaries/articles/2011/10/12/pauline_austin_developed_weather_radar_after_wwii/

[12] Wikipedia http://en.wikipedia.org/wiki/James_Murdoch_Austin (accessed 19/4/15)

[13] Marshall R 2015 www.robinMarshall.eu/papers/staffngraduatesb.pdf

[14] Obituary Dorothy Heyworth 1990 *The Boston Globe* www.highbeam.com/doc/1P2-8133796.html

[15] Sopka K 1979 Interview with Dr Mildred Allen *Niels Bohr Library and Archives* (College Park, MD: American Institute of Physics) www.aip.org/history/ohilist/4480.html (accessed 28/12/15)

[16] CWP (UCLA) www.physics.ucla.edu/~cwp/internal/Education_and_the_Profession/Allen,_Mildred@872811949.html (accessed 19/4/15)

[17] 2010 Mary Elizabeth Layne Boas Obituary *Seattle Times* (20–1 February 2010) www.legacy.com/obituaries/seattletimes/obituary.aspx?n=mary-elizabeth-layne-boas&pid=139866372

[18] 1992 Ralph Philip Boas Obituary *Mathematics Association of America* (25 July 1992) www.maa.org/about-maa/governance/maa-presidents/ralph-philip-boas-Jr-1973-1974-maa-president
[19] Wikipedia http://en.wikipedia.org/wiki/Mary_L._Boas (accessed 16/3/15)
[20] Adelman S J and Dworetsky M M *Physics Today* **53** 88
[21] Osterbrock D E 2000 *Bull. Am. Astron. Soc.* **32** 1677
[22] DeVorkin D 1977 Interview with Dr Dorothy Locanthi *Niels Bohr Library and Archives* (College Park, MD: American Institute of Physics) www.aip.org/history/ohilist/4747.html (accessed 30/4/15)
[23] Eargle J 1994 *J. Audio Eng. Soc.* **42** 208–9
[24] Lindner R P 2002 *Bull. of the Amer. Astronomical Soc* **41** 575
[25] Couser J H 2006 *The University of Michigan Record* (6 February 2006) www.ur.umich.edu/0506/Feb06_06/obits.shtml (accessed 25/7/15)
[26] 1964 Hildegard Stücklen Obituary *Lynchberg News* (24 January 1964)
[27] Sopka K 1977 Interview with Dr Janet Guernsey *Niels Bohr Library and Archives* (College Park, MD: American Institute of Physics) www.aip.org/history/ohilist/4648.html (accessed 28/2/15)
[28] 1996 Obituary *The Boston Globe* (3 January 1996) www.highbeam.com/doc/1P2-8364579.html (accessed 2/5/15)
[29] Guernsey J 1951 *Wellesley Alumnae Magazine* **35** 137–38
[30] History at Boston University www.bu.edu/history/about/history-of-the-department/the-keylor-years-iii-1995-2000/ (accessed 2/5/15)
[31] 2001 Janet Guernsey Obituary *The Boston Globe* (6 September 2001) www.highbeam.com/doc/1P2-8670540.html (accessed 4/5/15)

Ruth H Howes and Caroline L Herzenberg

Chapter 6

Women in astrophysics and early NASA space science

Astronomy and astrophysics have a long history of involving women in physics, although women were often given little credit. For example, in the early nineteenth century the gifted English astronomer, Carol Herschel, operated in the shadow of her astronomer brother, Sir William Herschel, who received the bulk of the recognition for their joint discoveries. He was appointed Court Astronomer, while she became one of the first two female honorary members of the Royal Astronomical Society (Mary Somerville was the other). In the aftermath of World War II, there were a number of examples of women working in areas involving physics in the space sciences. They worked notably in astrophysics, but also on other physics-related problems, especially at NASA. They are essential to rounding out our understanding of American women working in physics in the decade or so following the end of the Second World War.

In the late 1800s, Harvard College Observatory had opened its doors to women when the director of the observatory needed a work force to examine thousands of photographs in order to calculate the positions of the stars and to examine and analyze the spectra of stars. Although these new employees were needed to carry out involved calculations and measurements, they, as women, were hired into positions of relatively low status and low pay. All the same, this gave American women an early foothold in astronomy and related fields. Some of these women, for example Annie Jump Cannon and Henrietta Leavitt, managed to make significant contributions to the field.

Because work in astronomy had to some extent been opened to American women before many other areas of physical science, there were already an appreciable number of women in astronomy and a few in astrophysics by the end of World War II. We will look at examples of women who worked in physics-related areas in the space sciences, and who were active in the decade or so following World War II.

doi:10.1088/978-1-6817-4094-2ch6

Figure 6.1. Cecilia Payne-Gaposchkin at work. Photograph courtesy of the Smithsonian Archives.

The British–American astronomer and astrophysicist, Cecilia Payne-Gaposchkin (figure 6.1), brought us a new understanding of the composition of the stars. She discovered that hydrogen and helium are the most abundant elements in stars and, therefore, in the Universe [1, 2]. She became one of the first important astrophysicists in the United States [3, 4].

Cecilia Payne was born in the UK in 1900. At the age of 19, she was in the audience when the famous astronomer Sir Arthur Stanley Eddington lectured about his observations during the recent solar eclipse validating Einstein's general theory of relativity. After the lecture, she told him that she wanted to become an astronomer and Eddington suggested some reading and invited her to use the Cambridge Observatory's library [3, 5].

She studied at Cambridge as an undergraduate, but did not receive a degree because the university did not award degrees to women at that time [1]. After meeting a visiting American astronomer, Harlow Shapley, the newly appointed Director of the Harvard College Observatory, who had just established a graduate program in astronomy there, she applied for and received a fellowship to conduct research and study at the obervatory. Faced with limited educational opportunities in the UK and pleased with the prospect of studying and working at Harvard, she left for the United States in 1923.

Shapley became a mentor, persuading her to write a doctoral dissertation, and in 1925 she became the first person to earn a PhD in astronomy from Radcliffe College (now the women's college of Harvard). Her PhD dissertation was described by the distinguished astronomer Otto Struve and his colleague Velta Zebergs as 'undoubtedly the most brilliant PhD thesis ever written in astronomy' [3].

Her work was of fundamental importance in the development of the field of stellar atmospheres. At that time it was thought that the stars had approximately the same chemical composition as the Earth. From the spectra of stars, using calculations of ionization as a function of temperature, she determined stellar temperatures and chemical abundances based on the thermal ionization equations recently discovered by the Indian astrophysicist Saha [2]. In particular, she discovered that all stars have very similar relative chemical compositions, with hydrogen and helium vastly more abundant than any heavier elements. This showed that hydrogen is the overwhelming constituent of the stars and accordingly is by far the most abundant element in the Universe. She thus set the stage for our modern understanding of stellar structure and of the elemental composition of the Universe.

Upon receiving her PhD in 1925, Payne continued work at Harvard Observatory. She made significant contributions to additional fields of astronomy, notably galactic structure and variable stars. Observations and analyses of variable stars were conducted in collaboration with her husband Sergei Gaposchkin a Russian-born astrophysicist whom she married in 1934 after meeting him in 1933 during a trip to Europe and helping him get a visa to the US [1, 3]. These studies laid the basis for all subsequent work on variable stars and their use as indicators of galactic structure [2]. Sergei and Cecilia subsequently had three children [1]. She became an American citizen in 1931 [4].

Cecilia Payne-Gaposchkin entered Harvard's academic community at a time when opportunities for women in astronomy were limited. She did not receive adequate recognition for her accomplishments and was paid a smaller salary than her male counterparts [1]. She continued working at Harvard College Observatory and taught at Harvard, assuming all of the responsibilities of a member of the faculty; however, because she was a woman, her only title was 'technical assistant' and none of the courses that she taught at Harvard were recorded in the catalog until 1945 [3, 6].

During the 1950s, Payne-Gaposchkin published four books on the subject of stars and stellar evolution, *Stars in the Making* (1952), *Variable Stars and Galactic Structure* (1954), *Introduction to Astronomy* (1956) and *Galactic Novae* (1957). In 1979, she published the book *Stars and Clusters* [1]. In 1956, she became the first woman promoted to a full professorship from within the faculty of Harvard's Faculty of Arts and Sciences [1, 3]. In that year, she also was appointed chair of the Department of Astronomy and thus became the first woman to chair a department at Harvard [1]. One of the coauthors (CH) recalls seeing Cecilia Payne-Gaposchkin assertively participating in discussions at Harvard seminars on a number of occasions during the early 1950s.

In 1967, Payne-Gaposchkin became an emeritus professor of Harvard University [6]. She continued her research as a member of the staff at the Smithsonian Astrophysical Observatory [6]. She received considerable recognition, including the Henry Norris Russell Prize of the American Astronomical Society, and a number of honorary doctorates, among them an honorary doctorate from Cambridge University. In 1977, the minor planet 1974 CA was named Payne-Gaposchkin in her honor [1, 3, 4].

Another British-born American astrophysicist, Margaret Burbidge, helped to bring us an understanding the process of nucleosynthesis, the way chemical elements are formed in the depths of stars through nuclear fusion. She is regarded as one of the foremost women astronomers in the world.

Margaret Burbidge was born Margaret Peachey in 1919 in Great Britain. As a child, she was encouraged in her interest in science by her parents, who were both chemists [7–9]. In 1948, Margaret Peachey married Geoffrey Burbidge, a theoretical astrophysicist who was then a fellow graduate student at University College London. The Burbidge's daughter Sarah was born in 1956 [10].

Margaret was awarded a PhD in astrophysics by University College London in 1943 [11, 12]. The wartime reassignment of many faculty and staff of University College gave her an earlier and wider range of responsibility and independence than would otherwise have been the case for a young scientist [7]. But in 1945, despite her qualifications, she was turned down for a Carnegie Fellowship to Mt Wilson Observatory because appointments to the obervatory were reserved for men and the administrators did not permit women to use the telescope [7].

From 1948 to 1950, Margaret Burbidge served as assistant director and from 1950 to 1951 as the acting director of the Observatory of the University of London [8, 12]. In 1950, she applied successfully for a grant at the Yerkes Observatory in Wisconsin and in 1951 the Burbidges came to the United States, where they both had research fellowships. They had to work around the anti-nepotism rules of the University of Chicago, which operated Yerkes [7, 11]. Her research interests focused on chemical abundances in stars. In 1953, she and her husband returned to the UK and started research in collaboration with American nuclear physicist William A Fowler and British astronomer Fred Hoyle. They studied element formation in nuclear fusion reactions inside stars and the associated evolution of the stars, research that culminated in the landmark paper 'Synthesis of the elements in stars' [7, 11].

Based on the results of experiments and observational data examined by Margaret and Geoffrey Burbidge, the research team introduced a working hypothesis that all chemical elements are synthesized in stars by nuclear reactions [11]. The resulting astrophysical theory of stellar nucleosynthesis, the production of heavier elements from lighter elements by nuclear fusion in stars, was published in 1957 and was called the B2FH theory after the participants who collaborated in the research (Burbidge, Burbidge, Fowler and Hoyle). According to B2FH theory, as stars age, they engage in a series of nuclear reactions that make heavier and heavier elements by fusing the nuclei of the elements made in the preceding reactions. When stars become visible, they are converting hydrogen into helium, while at a later stage of stellar history, stars might be building carbon out of helium [11]. Their theory originated the contemporary theory of stellar nucleosynthesis, and was regarded as being worthy of consideration for a Nobel prize. While no Nobel prize was awarded for this work (possibly because four scientists were involved in the collaboration and the Nobel prize is usually awarded to one or two individuals), Fowler subsequently shared a Nobel prize for this and other work in astrophysics.

In order to gather additional data to provide further support for the B2FH theory, the Burbidges returned to Mt Wilson Observatory in 1955 after Geoffrey obtained a Carnegie Fellowship for research [11]. Because women were still ineligible for such an appointment at Mt Wilson, Margaret accepted an appointment as a research fellow in astrophysics at Cal Tech from 1954 to 1957 [8, 11, 12]. Despite her expertise, Margaret was not officially allowed to use the telescopes at Mt Wilson, so Geoffrey applied for telescope time and Margaret accompanied him for the observing sessions by posing as his assistant, so that in 1955 she finally gained access [11]. (When the subterfuge was found out, the observatory management eventually agreed that she could stay, if she and her husband went to live in a separate cottage on the grounds, rather than staying in the dormitory that had been intended for male occupancy only, thus preserving propriety.)

In 1957, Margaret became a Shirley Farr fellow and, two years later, an associate professor of astronomy at Yerkes Observatory of the University of Chicago [11]. In 1962 the Burbidges settled into permanent positions at the University of California, San Diego [7]. She joined the university as an associate research professor and in 1964 became a full professor of astronomy in the Department of Physics [8].

When the Burbidges visited the UK in 1971, Margaret was asked to head the Royal Greenwich Observatory, a post that no woman had ever held before. She took a leave of absence from UCSD to serve as director of the Royal Greenwich Observatory from 1972 to 1973 [7, 8, 11]. However, her job as director did not come with the customary honorary title of Astronomer Royal, which instead was given to a male astronomer [7, 8]. Burbidge reportedly regarded this as an example of discrimination against women, as did many other members of the scientific community [7, 8].

Her experiences turned Burbidge into one of the most influential personalities in the effort to end discrimination against women in astronomy. She turned down the Annie J Cannon Award of the American Astronomical Society because it was awarded to women only, stating 'It is high time that discrimination in favor of, as well as against, women in professional life be removed' [8, 11]. Twelve years later the society awarded her its highest gender-neutral honor, the Henry Norris Russell Lectureship.

From 1979 to 1988, Margaret served as the first director of the Center for Astronomy and Space Sciences at the University of California at San Diego, where she helped to develop some of the Hubble space telescope's original instruments, and where she has worked since 1962 [8, 11]. She has served as research professor in the Department of Physics at the University of California, San Diego since 1990.

In addition to her work in proposing and explaining stellar nucleosynthesis, she made notable contributions to the theory of quasars and conducted pioneering work on measurements of the rotations and masses of galaxies (she provided some of the first accurate estimates of the masses of other galaxies), and headed a team that designed a faint object spectrograph, one of the instruments used on the Hubble space telescope [8, 11]. She also worked to increase opportunities for women in science [8, 11].

She received much recognition for her work, including many honorary degrees, sharing the Helen B Warner Prize for Astronomy in 1959 with her husband, the

National Medal of Science in 1983, the Albert Einstein World Award of Science in 1988 and the Gold Medal of the Royal Astronomical Society, with her husband, in 2005 [11]. She served as president of both the American Association for the Advancement of Science and the American Astronomical Society, and she was elected a Fellow of the Royal Society [8, 11].

The American astrophysicist, Charlotte Moore Sitterly, became a recognized authority in both solar astronomy and the use of spectra to determine atomic energy levels. She was widely known for her compilations of atomic spectroscopic data obtained from laboratory observations, which became a classic reference entitled *Atomic Energy Levels*.

Charlotte Moore was born in Pennsylvania in 1898 to a family of educators. In 1937, she married astronomer Bancroft Sitterly, then a member of the faculty of Wesleyan College and later chairman of the physics department at American University in Washington, DC. She studied at Swarthmore College, supporting herself by tutoring and teaching, and graduated in 1920 with a BA degree in mathematics. From 1920 to 1925, she worked in the Princeton Observatory. Initially she was engaged in the tedious measuring and calculating that were the 'women's work' in astronomy at that time, but she also had the opportunity to work as an assistant to a well-known astronomer and spectroscopist, Henry Norris Russell (like Dorothy Locanthi, see chapter 5) [13–16].

In 1925, she went to the Mt Wilson Observatory to work on the preparation and publication of a new analysis of the solar spectrum. After preparing a thesis on the spectra of sunspots, she was awarded a doctorate in 1931 by the University of California at Berkeley. She was then appointed to the staff of the Princeton University Observatory, where she remained, first as a research assistant and then as a research associate, until 1945 [13–16].

In 1937, some of the artificial radioactivity produced by a particle accelerator in Berkeley was attributed to a new element that seemed to fill a gap in the periodic table. One of Charlotte Sitterly's most noted contributions to physics and astronomy was her demonstration soon afterwards that this new element, technetium, was actually present in the Sun on the basis of measurements and analysis of the solar spectrum. This provided the first evidence that the highly unstable element technetium occurs in nature [14].

In 1945, Sitterly switched from working mainly in astronomy to working mainly in physics when she joined the then National Bureau of Standards as a physicist in the Spectroscopy section of the Atomic Physics Division. She managed the atomic spectroscopy program and worked at the bureau until 1968 [16]. She started work almost immediately on atomic energy levels. As her assistants, she hired a number of retired scientists and arranged to have her former supervisor, Henry Norris Russell, appointed as a consultant. (The idea of having her former boss working for her apparently amused her [13].) Subsequently, she worked as a consultant to the Office of Standard Reference Data and as a consultant to the Naval Research Laboratory (NRL) [13, 16].

Thus, her work in the postwar years was largely in physics rather than in astronomy or astrophysics [13–15]. Although she published more than 100 papers after 1945, she was best known for the three volumes of *Atomic Energy Levels*, published from 1949 through 1958, and her earlier multiplet tables [13, 17]. Her tables of atomic spectra and energy levels, published by NBS, became and remained essential references in spectroscopy for decades [18]. After the war, it became possible to launch instruments on rockets so as to obtain spectra in the ultraviolet, and she extended her work to analyzing ultraviolet solar spectral lines [18].

Charlotte Sitterly received a number of honors, including many awards and several honorary degrees [13, 15, 16]. These included the Annie J Cannon Prize, awarded in 1937, while she also became the first women elected as a foreign associate by the Royal Astronomical Society of London [13, 16]. She died in 1990, in Washington, DC, at the age of 91 [13, 15]. The asteroid 2110 Moore-Sitterly was named in her honor.

During the 1950s few women in the United States worked outside of the home, and even fewer earned doctorates or went on to have professional careers. In astronomy and the space sciences, most women were restricted to low-level positions in which much of the work that they did was the kind of drudgery that has more recently been relegated to computers. Even during the 1950s, when there were more women working in the space sciences, few of them were in positions of authority. However, Nancy Grace Roman (figure 6.2) is a notable exception. She was one of very few women in NASA in the mid-twentieth century, and the only one with an executive position [19]. She became the first chief of astronomy at NASA.

Nancy Roman was born in Tennessee in 1925. Her father, a US Geological Survey geophysicist, encouraged her interest in science. While growing up in Reno, Nevada, she started an astronomy club at the age of eleven. By the time she was a freshman in high school, she knew that she wanted to be an astronomer [19–22].

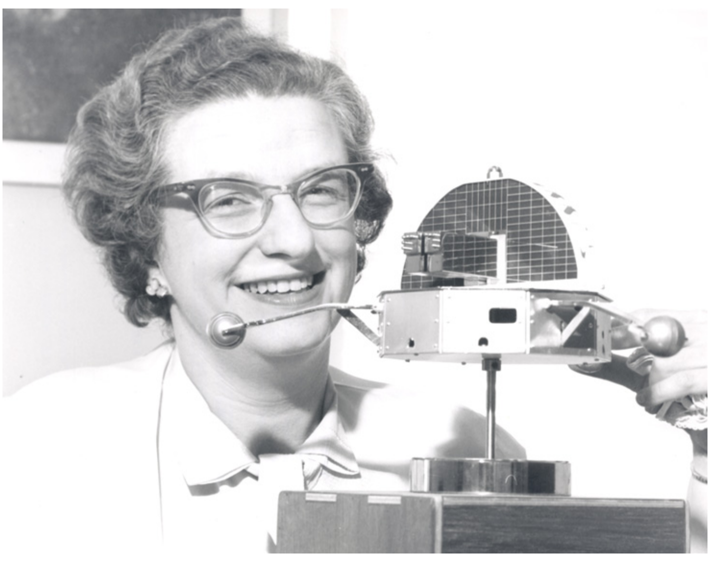


Figure 6.2. Nancy Grace Roman. Photograph courtesy of NASA.

Pursuing her interest in astronomy was not easy. Girls and women of her generation were systematically discouraged from going into science. 'I still remember asking my high school guidance teacher for permission to take a second year of algebra instead of a fifth year of Latin,' she said. 'She looked down her nose at me and sneered, "What lady would take mathematics instead of Latin?" That was the sort of reception that I got most of the way' [23].

While studying astronomy at Swarthmore College, she worked at the Sproul Observatory [19, 20]. She graduated from Swarthmore with a BA degree in astronomy in 1946 [21]. Thus, she was a college student during World War II and she seems to have felt that at that time higher education suffered because of war-related understaffing of the faculty and student morale problems [24].

She received a PhD in astronomy from the University of Chicago in 1949. She stayed on for six years working at the University of Chicago's Yerkes Observatory, first as a research associate and then as an assistant professor, and made several visits to other observatories. However, she did not anticipate getting tenure at the University of Chicago, as no women had tenure in a major astronomy department at that time, and very few women even had faculty positions [19–21].

In 1955, Roman was offered a position in the then new field of radio astronomy, and she accepted an appointment as a physicist in the Radio Astronomy Branch of the Naval Research Laboratory. There she worked on various projects, including measuring the distance from the Earth to the Moon using radar, and mapping the sky at a wavelength of 67 centimeters, while she continued her earlier research on stellar motions. She became head of the microwave spectroscopy section in 1956, and continued in this capacity to 1958. Again, she concluded that, as a woman, her prospects for advancement were limited. So, in 1959, she accepted a position at NASA to set up a program in space astronomy [19, 21, 23].

She seemed to have had ambivalent feelings about giving up research for administration, but then found that she enjoyed management. She became the first Chief of Astronomy in the Office of Space of Science at NASA, and thus became the first woman to hold an executive position there. She was the highest-ranking woman in NASA for many years, serving as chief of astronomy and solar physics from 1960 to 1963, and then as chief of astronomy and relativity programs from 1964 to 1979 [19–21].

While chief of astronomy she managed nearly all of NASA's astronomical projects during the 1960s and also many in the 1970s, apart from those dealing with the Earth or planets [22]. Also at NASA, she developed an ambitious plan to study objects in space using rocket and satellite observations. Throughout the 1960s, she was involved in the design of instrumentation and the conduct of measurements ranging between gamma and radio frequencies. She worked on improving orbiting observatories during the 1970s and 1980s [20]. She was instrumental in establishing the new era of space-based astronomical instrumentation.

Nancy Grace Roman planned and oversaw missions as diverse as three orbiting solar observatories (which she was involved in launching), three small astronomical satellites, and four geodetic satellites, along with astronomical observations with balloons and rockets. She worked as program scientist for the Hubble Space Telescope

Figure 6.3. Katherine Johnson's work at NASA's Langley Research Center spanned 1953 to 1986 and included calculating the trajectory of the early space launches. Photograph by Sean Smith for NASA.

and because of her contributions she was referred to as 'the Mother of Hubble' [19, 22]. She worked for NASA for 21 years and after officially retiring in 1980, she worked part time on various NASA programs from 1981 and into the 1990s. She was a senior scientist at NASA's astronomical data center, which she headed from 1994. There, she supervised work to prepare and edit computer-readable versions of astronomical catalogs and databases [20–22]. During the 1950s, she authored several publications, including a catalog of approximately 600 high-velocity stars published in 1955, and a paper on the detection of extraterrestrial planets in 1959 [19]. Her achievements were recognized by a number of awards and she was the recipient of four honorary doctorates. The asteroid 2516 Roman was named in her honor [19, 21, 24].

Among the early women working in the space sciences at NASA was Katherine Coleman Goble Johnson (figure 6.3), a well-known and very capable African-American woman, who contributed to US aeronautical and space programs. Her work successfully guided American astronauts throughout the historic early era of manned space flight [25, 26].

Katherine Coleman was born in West Virginia in 1918 into a family where the children's education was a primary focus. In childhood she already showed an early affinity for mathematics. She was a talented student and her unusual abilities were recognized by faculty mentors throughout her education. She entered college (West Virginia State University) when only 15 years old and earned a bachelor's degree in 1937 [26, 27]. She later went on to pursue graduate studies in mathematics and physics at West Virginia State. In the years following her graduation, she taught mathematics, but during the aftermath of the Depression, permanent positions were difficult to come by. She married James Gobie and after his death in 1956, she married James Johnson in 1959. Her life is cheered by her children, grandchildren and great-grandchildren [26–28].

Johnson worked at NASA during most of the 1950s. In 1953, she took a job as a mathematician at Langley research center with the National Advisory Committee in

Aeronautics, the precursor of NASA. Initially she worked in a group of women assigned to performing calculations, and then she was assigned to assist the all-male flight research team. The flight research division became the nucleus of the American space project [27, 28].

Her specialty was calculating the trajectories for space shots [28]. When she started, women were not allowed to attend briefings or be included as the authors of reports that they had worked on, but these restrictions were changed through her efforts. Her groundbreaking report, 'Determination of azimuth angle at burnout for placing a satellite over a selected Earth position', provided a theoretical basis for launching, tracking and returning vehicles in space [27]. She was involved in the computations for many space trajectories; worked on challenging problems of interplanetary trajectories, space navigation and the orbits of spacecraft; and worked with the tracking teams of manned and unmanned orbital missions, analyzing data gathered by tracking stations around the world during the lunar orbital missions.

Among other projects, she worked on the trajectories for the space flight of Alan Shepard, the first American in space; John Glenn, the first American to orbit Earth; and Apollo 11, the first American manned mission to the Moon. She developed emergency navigational methods that astronauts could use if their spacecraft lost contact with ground control. In preparation for the Apollo lunar landing project, she calculated the trajectories for putting a spacecraft into lunar orbit, sending its lunar lander to the Moon's surface, returning the lunar lander to the spacecraft and returning the mission to Earth [26–28].

For her pioneering work in the field of space navigation problems, she was the recipient of the Group Achievement Award presented to NASA's Lunar Spacecraft and Operations team, the Maria Mitchell Living Legacy Award and a number of other awards and honorary degrees [29, 30]. On November 24, 2015, President Obama presented Katherine Johnson with the Presidential Medal of Freedom in recognition of her work for NASA.

The group of women working on analyzing plates at Harvard mentored other women and probably led to the presence of outstanding researchers there. In a similar way, a group of women studying solar phenomena developed at the University of Michigan so that the department actually had two women professors, Helen Dodson Prince (see chapter 3) and Hazel M Losh, who earned her PhD in astronomy from the University of Michigan in 1924. She served as an instructor at Smith College for a year before moving to the Solar Department at Mt Wilson Observatory. She returned to the University of Michigan in 1927 and remained there until her retirement 41 years later. She is remembered for her skill in teaching astronomy to non-majors [31].

Nannilou Dieter Conklin (figure 6.4) earned her PhD at Harvard and went on to become a pioneer in radio astronomy. She attended Goucher College, majoring in mathematics, and graduated in 1948. She took a course from Helen Dodson (see chapter 5) in 1946. Dodson encouraged her enthusiastic student to work at the Maria Mitchell Observatory on Nantucket Island during the summers of 1947 and 1948 under the direction of Margaret Harwood [32]. Nannilou enjoyed research, but decided to get married in 1950 and had to find a job because her new husband was

Figure 6.4. Nan Conklin (then Nan Hepburn) at Harvard in the late 1950s. Photograph from 1950s and 1960s slides, H I (Doc) Ewen Collection, Archives, National Radio Astronomy Observatory/Associated Universities, Inc./National Science Foundation.

attending theological seminary in Alexandria, Virginia. She obtained a job with the US Coast and Geodetic Survey, working alone in an underground room monitoring an experiment designed to detect tides in the solid earth. It was not challenging and, of course, did not pay well. In March 1951, she was happy to move to the Naval Research Lab, where she could travel by boat across the Potomac to work. Her first child was born in December 1951 and she was lucky enough to find excellent childcare from a woman who came to her home [33].

At NRL, she was introduced to radio astronomy because the lab had just acquired a large radio antenna instrumented using experience in radar during World War II, and they proposed to study radio waves from the Sun with it. Nobody at NRL had experience in observational astronomy, so Nan was an ideal hire since her summer experience on Nantucket gave her a good background in visible astronomical observation, and she was eager to find a challenging job [33]. In 1952, she published a paper on solar outbursts in the radio region of the spectrum and this was the first paper published in radio astronomy by an American woman [32].

Although her work was going well, her husband seems to have had a psychological breakdown. He was expelled from the seminary and became increasingly erratic. At the end of 1953, Nan and the baby moved to a small apartment in DC and her husband disappeared from their lives. She claimed that she worked both because she needed the money and to retain her sanity [33]. At this time she met Carl Dieter, who worked in the Sound Lab at NRL. He was passionate about music and, as they became friends, he introduced her to classical music. She met Bart Bok and Richard Thomas at a meeting of the American Astronomical Society and both of them encouraged her to apply to Harvard for graduate work. Even with a scholarship, she could not support herself and the baby, so she decided not to apply until Carl proposed that they marry and that he get a job at the Air Force Cambridge Research Laboratory to support the family. They married in August 1955 and Nan now Dieter started graduate work that fall along with four other (male) students, who were easily five years younger than she [33].

Dieter took a course on variable stars from Cecelia Payne-Gaposhkin, who she remembers once took her to lunch at the Harvard Faculty Club, mostly to demonstrate that women had to use the side door. She began her observations at Harvard's Agassiz Station Observatory using the 60 foot radio antenna there. In April 1958, she was five months pregnant when she took her final oral for the PhD, which was signed by the presidents of both Harvard and Radcliffe. Her dissertation on the radio emissions of the Galaxy M33 was the first by a woman using her own radio astronomy data [33].

She received a one-year fellowship from the National Science Foundation to study the Andromeda Galaxy at radio wavelengths using Harvard's new maser-based receiver. Unfortunately, the new receiver was still under construction, so she had to give up the fellowship and find a job. She was again lucky in obtaining good childcare for the new baby and took not one but two jobs at the Air Force Cambridge Research Lab. She worked on Space Track, a program to watch the growing number of satellites, and at a program to fund research at observatories around the world, which gave her the opportunity to visit Europe in 1960. In 1963, the Air Force completed an 85 foot radio antenna and Dieter turned happily to her own research studying the behavior of radio emissions from OH [33].

Although Carl had adopted Nan's older daughter, the marriage was in trouble and the situation was not improved by the fatigue and lack of co-ordination that were troubling Nan [33]. She was diagnosed with multiple sclerosis in 1960 and began a terrific struggle to continue both research and single parenting despite the disease. In 1965, she moved to the Radio Astronomy Laboratory of the University of California at Berkeley [32]. There she found a stimulating atmosphere, including graduate students. She loved the fact that from the Hat Creek Radio Observatory she could see both Mt Lassen and Mt Shasta [33]. Her personal life also became much happier when she married the owner of her rental house, Garret Conklin, in 1968 [32]. He had retired as assistant dean of the Episcopal theological seminary in Berkeley and was some 20 years older than she. He found time to teach the entire family to sail, although he was still doing volunteer work for the seminary on its suicide hotline. They each had children and embarked on a mostly happy marital odyssey that would take them from a pied-a-terre in Paris to homes in Berkeley, Menorca (Spain), Vermont and finally Seattle. Garret developed Alzheimer's disease and died there in 2002 [33].

Meanwhile, Nannilou's work in radio astronomy continued to focus on the very rapid changes in the OH radio emissions from galactic nebulae and she began a radio study of the structure of the Milky Way [33]. Throughout her life, she would continue to love radio astronomy, but as her disease worsened, travel became harder and she took early retirement in 1977, although her last paper was published in April 2014. After Garret's death, her health declined and she was forced to enter a retirement home in Seattle. She died on 16 November 2014.

We have only briefly examined a limited sampling of American women who worked after World War II in astrophysics and space sciences, and who clearly model the determination and ability needed for women physicists in the 1950s. They are a remarkable group and represent many other women working in these or related fields. Their research clearly illustrates the impact of physics developments in areas such as nuclear physics, spectroscopy and rocketry during World War II on astronomy and space science.

References

[1] Payne-Gaposchkin C H Papers of Cecilia Helena Payne-Gaposchkin: an inventory (Cambridge, MA: Harvard University) http://oasis.lib.harvard.edu/oasis/deliver/~hua03004 (accessed 25/4/15)

[2] Payne-Gaposchkin C H *CWP* Contributins of 20th Century Women to Physics, University of California at Los Angeles (UCLA) http://cwp.library.ucla.edu/Phase2/Payne-Gaposchkin,_Cecilia_Helena@861234567.html (accessed 15/4/15)

[3] Fidushin D 1997 *Notable Women in the Physical Sciences* (Westport, C T: Greenwood) ed B F Shearer and B S Shearer pp 286–91

[4] Soter S and Tyson N 2000 *Cosmic Horizons: Astronomy at the Cutting Edge* (New York: New Press)

[5] Wayman P A 2002 *Astronomy and Geophysics* **43** 1.27–9

[6] Wikipedia http://en.wikipedia.org/wiki/Cecilia_Payne-Gaposchkin (accessed 16/4/15)

[7] Trimble V 2006 *Out of the Shadows: Contributions of Twentieth-Century Women to Physics* ed N Byers and G Williams (Cambridge: Cambridge University Press) pp 282–93

[8] Encyclopedia Britannica www.britannica.com/EBchecked/topic/84933/Margaret-Burbidge (accessed 20/3/15)

[9] Oleck J 1999 *Notable Women Scientists* ed P Profitt (Detroit, MI: Gale) pp 69–71

[10] Bailey J 1998 *American Women in Science—1950 to the Present* (Santa Barbara, CA: ABC-CLIO)

[11] Warren R L 1997 *Notable Women in the Physical Sciences* ed B F Shearer and B S Shearer (Westport, CT: Greenwood) pp 27–31

[12] CWP (UCLA) http://cwp.library.ucla.edu/Phase2/Burbidge,_E._Margaret@932123456.html (accessed 23/4/15)

[13] Roman N G 1991 *Bulletin of the Am. Astronomical Soc.* **23** https://aas.org/obituaries/charlotte-moore-sitterly-1898-1990 (accessed 18/4/15)

[14] Sullivan W 1990 Obituary *The New York Times* (8 March 1990) www.nytimes.com/1990/03/08/obituaries/charlotte-sitterly-91-devoted-career-to-sunlight-studies.html

[15] Kiser H B 1999 *Notable Women Scientists* ed P Profitt (Detroit, MI: Gale) pp 540–1

[16] Slight-Gibney N 1997 *Notable Women in the Physical Sciences* (Westport, C T: Greenwood) ed B F Shearer and B S Shearer pp 375–81

[17] DeVorkin D 1978 Interview with Dr Charlotte Moore Sitterly *Niels Bohr Library and Archives* (College Park, MD: American Institute of Physics) www.aip.org/history/ohilist/4784.html (accessed 25/4/15)
[18] Martin W C 1991 *Phys. Today* **44** 128–30
[19] Wikipedia http://en.wikipedia.org/wiki/Nancy_Roman (accessed 29/4/15)
[20] Smith J A 1999 *Notable Women Scientists* ed P Profitt (Detroit, MI: Gale) pp 496–8
[21] Roman N G 1997 *Notable Women in the Physical Sciences* ed B F Shearer and B S Shearer (Westport, CT: Greenwood) pp 345–9
[22] Stephens S in Marcy G http://w.astro.berkeley.edu/~gmarcy/women/roman.html (accessed 18/4/2015)
[23] Wright R 2000 Interview with Nancy Grace Roman NASA *Headquarters Oral History Project* www.jsc.nasa.gov/history/oral_histories/NASA_HQ/Herstory/RomanNG/RomanNG_9-15-00.htm (accessed 25/4/15)
[24] DeVorkin D 1980 Interview with Nancy G Roman *Niels Bohr Library and Archives* (College Park, MD: American Institute of Physics) www.aip.org/history/ohilist/4846.html (accessed 23/4/15)
[25] Wikipedia http://en.wikipedia.org/wiki/Katherine_Johnson (accessed 29/4/15)
[26] National Visionary Leadership Project oral history archives www.visionaryproject.org/johnsonkatherine (accessed 28/4/15)
[27] Warren W 1999 *Black Women Scientists in the United States* (Bloomington, IN: Indiana University Press) pp 140–7
[28] Makers: The largest video collection of women's stories www.makers.com/katherine-g-johnson (accessed 28/4/15)
[29] Brown M *The Faces of Science: African-Americans in the Sciences* https://webfiles.uci.edu/mcbrown/display/katherine_johnson.html (accessed 28/4/15)
[30] National Women's History Museum https://www.youtube.com/watch?v=8YqwM1G5piQ (accessed 29/4/15)
[31] Hiltner W L http://um2017.org/faculty-history/faculty/hazel-m-losh/memorial (accessed 24/7/15)
[32] Bouton E, Hooker C and Goss M 2014 Obiuary *The San Francisco Chronicle* (7 December 2014) www.legacy.com/obituaries/sfgate/obituary.aspx?pid=173368278
[33] Conklin N D 2006 *Two Paths to Heaven's Gate* (Charlottesville, VA: National Radio Astronomy Observatory)

Ruth H Howes and Caroline L Herzenberg

Chapter 7

Other women physicists

The women physicists treated in previous chapters generally devoted the majority of their efforts to one arena of work, such as research in the National Labs or research universities, developing space science at NASA or teaching at the women's colleges. Many of them held positions that crossed these boundaries at one time or another. The women treated in this chapter all made important contributions to physics, but they did it in thoroughly unconventional ways or by working in new fields of physics.

One group of women trained in nuclear physics left physics and applied the new knowledge of radioactivity to develop radiation biology and health physics. Women have always been more welcome in developing fields of physics, so it is not surprising to find these well-trained physicists starting a new field of interdisciplinary biology. Katherine Sopka trained as a physicist and then, when faced with the geographic challenges to her own career posed by her husband's career, switched fields to the history of physics, with a particular interest in women physicists. Melba Phillips's story indicates the impact of the Red Scare on the careers of physicists, since it forced her to change fields. Finally, Joan Hinton, a protégé of Fermi who worked at Los Alamos, became so disgusted with what she saw as the militarization of physics that she moved to China and used her skills in dairy farming.

Edith Hinkley Quimby was a pioneer in the use of radionuclides in medicine and the development of standards for radiation protection. Her 75 articles outline major research contributions to biophysics. Her books established the basis for modern health physics. *Physical Foundations of Radiology*, written with Glasser, Taylor and Weatherwax, and first published in 1944, was the 'bible' for thousands of students studying for the American Board of Radiology's physics exam, who called it simply 'Quimby' [1].

Edith Hinkley was born in Rockford, Illinois on 10 July 1891 and attended Boise High School following a family move to Idaho. She received a four-year scholarship to Whitman College, a liberal arts co-ed college in Walla Walla, Washington, where she became the first woman to undertake the mathematics/physics major. She received her

doi:10.1088/978-1-6817-4094-2ch7

BS in 1912 and took a two-year appointment to teach physics and chemistry in a high school in Nyssa, Oregon. In 1914, a fellowship allowed her to pursue a master's degree in physics at the University of California at Berkeley, where she met a fellow graduate student, Shirley Leon Quimby. They married on 9 June 1915 and she received her MA in physics in 1916 [1].

Shirley Quimby taught high school in Antioch, California until 1918, when he enlisted in the navy during World War I. Edith Quimby replaced him as a high-school teacher. In 1919, he accepted a position as an instructor at Columbia University and began work on a doctorate in physics. The instructorship paid $1200 US dollars a year, which was not enough to live on in New York, so Edith Quimby went looking for a job. Through physics department connections she landed an interview with Gioacchino Failla, who was looking for an assistant to work on medical uses of radiation in his laboratory at New York City Memorial Hospital for Cancer and Allied Diseases. Failla interviewed the young, blond, cheerful woman and, according to Quimby, said, 'Well, I never thought of having a woman for an assistant, but I don't mind trying it for six months' [2].

In 1919, radiation, primarily from radium and its radioactive daughter product radon, was being used as a cure for cancer and as a therapy for other diseases (see Alice Armstrong's description of her first job at NBS in chapter 2). However, radiation doses to humans were measured by erythema, the reddening of the skin, which was difficult to standardize because of variations in human reactions. Eventually Edith Quimby thought of using strips of film as radiation detectors and relating the dosage at a given location to the shadowing of the film there. This became the beginning of the standard film badges used to document the radiation exposure of workers during the rest of the twentieth century [3]. Failla and Quimby developed equipment to approximate radiation doses in tissues using techniques such as embedding radon-filled tubes in butter and beeswax in order to relate dosages to workers to the strength of sources, their surroundings and the distance of the workers from the radiation source. Failla and Quimby mapped out techniques for treating human tumors with nuclear radiation and later with x-rays while keeping medical personnel safe from overexposure to radiation [1].

At Memorial Hospital, Edith Quimby served as assistant physicist (1919–32), associate physicist (1932–43) and then as Assistant Professor of Radiology at Cornell Medical School (1941–42). In 1942, she followed Failla to the College of Physicians and Surgeons at Columbia University as Associate Professor of Radiological Physics. In 1954, she was promoted to Professor of Radiological Physics and remained at Columbia until her retirement in 1960 as a professor emerita [4]. In the early days at Columbia, she worked part-time on the Manhattan Project studying the biological effects of radiation exposure [5]. Throughout her career and for several years after retirement, she continued research on the clinical use of radioactive isotopes. Her laboratory provided isotopes to the medical personnel of Columbia and its associated hospitals for clinical use [6].

Since her days at Memorial Hospital, Quimby had been active in training medical personnel in the safe use of radioactive isotopes in medicine. Medical students, interns and residents rotated through her laboratory, where she trained them in handling radioactive materials safely while they acted as her assistants. At Columbia after the war, she became increasingly involved in developing courses for physicians in the physics and biological effects of radiation. This work gave rise to her best-known publications and she continued teaching after retirement [7].

In 1940, Edith Quimby was the first woman and second non-physician to receive the Janeway Medal of the American Radium Society. She also won the Gold Medal of the Radiological Society of North America (1941), a medal of achievement from the International Women's Exhibition (1947), the American Design Award from Lord and Taylor (1949), the Katherine Berkan Judd Award to the scientist making the greatest contribution to finding a cure for cancer (1962), the Gold Medal of the American College of Radiologists (1963) and the William D Coolidge Award for career achievements from the American Association of Physicists in Medicine (1978). She was a fellow of the American Physical Society and the American College of Radiology and held honorary doctorates from Whitman College (1940) and Rutgers University (1956). She served as president of the American Radium Society in 1954, as a member of the Advisory Committee on Isotope Usage of the AEC and as a consultant on radiation therapy for the US Veterans Administration [4].

In addition to her professional success, Quimby had a busy personal life, although she had no children. Her husband, a successful professor of physics with interests ranging from the Mayan calendar to the dimensions of racing yachts, supported and guided her career. She enjoyed reading detective stories, going to the theater, playing bridge and 'domesticity'. She was active in the Episcopalian Church, the Democratic Party and the League of Women Voters. She had a gift for friendship and remained a happy, attractive woman standing 5′ 8″ tall, weighing around 150 lb and sporting gray eyes and gray hair. She died at her home on 11 October 1982, and her husband followed four years later [8].

One of the brightest young people to work in Edith Quimby's laboratory learning nuclear medicine was Rosalyn Sussman Yalow (figure 7.1), who would share the

Figure 7.1. Portrait of Rosalind Sussman Yalow circa 1977. Photograph courtesy of the Williams Haynes Portrait Collection, Chemical Heritage Foundation.

Nobel Prize in Physiology or Medicine in 1977 for 'for the development of radioimmunoassays of peptide hormones' [9].

Rosalyn Sussman was born in New York City in 1921 to parents who had not finished high school but were determined that their children would finish college [10]. She went through public school in New York and then attended Hunter College, the women's college of City University of New York, where tuition was free at the time. Rosalyn intended to be a teacher, but physics faculty at Hunter, notably Herbert Otis, Duane Roller and Jerrold Zacharias, encouraged her to major in physics and pursue graduate study [9]. She had to major in chemistry until her senior year because Hunter College had not established a physics major, but she managed to receive her bachelor's degree in physics in January 1941 [11]. She says that because she wore lipstick and dated, the women in the department did not think she was serious about physics [12].

Sussman worried that her preparation in physics at Hunter was weak because the physics major was so new, and she wanted to be better prepared for graduate study so Zacharias found her a job as secretary to a leading biochemist at Columbia's College of Physicians and Surgeons, which would allow her to take physics courses as a university employee. A condition of employment was that she should learn stenography. Fortunately, she received a teaching assistantship in physics at the University of Illinois in February for the next fall. She celebrated by tearing up her stenography books and taking two tuition-free physics courses at New York University in the summer before reporting to Illinois in September 1941 [10].

The physics department at the University of Illinois was and is part of the College of Engineering. Sussman discovered that she was the only woman teaching among 400 members of the faculty of the College, and the dean congratulated her on her acceptance as the first woman since 1917. She managed all As in her courses, except for an A− in optics lab (the chairman of the physics department remarked that this grade showed that women were not fit for laboratory work). Sussman worked with Dr Maurice Goldhaber and his wife, Gertrude Goldhaber (who had no formal position because of anti-nepotism rules, see chapter 3), and received her PhD in nuclear physics in 1945 [10].

During her first day at Illinois, Rosalyn Sussman met a fellow beginning physics graduate student, Aaron Yalow, who made fun of her Bronx accent [9]. He came from a very conservative, orthodox Jewish family from Syracuse, NY and religion was always an important part of his life and identity [13]. The couple fell in love and married in 1943, which conflicted with the university's anti-nepotism rules since they both held teaching assistantships. Fortunately, Aaron received a research assistantship so he was no longer technically an employee of the university [11].

Rosalyn finished her dissertation in January 1945, while Aaron was still working on his. She returned to New York and could find only a position as the first woman engineer at the Federal Telecommunications Laboratory, a research arm of the International Telephone and Telegraph Corporation. Her research group there folded in 1946, so Yalow took a job at Hunter College, primarily teaching returning male veterans [12].

Meanwhile Aaron had finished his degree and came to New York in September 1945 [12]. He took a position in medical physics working with radioactive isotopes at Montefiore Hospital in the Bronx. Rosalyn became frustrated with Hunter's lack of research facilities. Aaron introduced her to Edith Quimby and Rosalyn became a voluntary assistant in Quimby's lab to learn the medical applications of radioactive isotopes. Quimby recommended Yalow to Dr Gioacchino Failla, who made a call recommending Yalow to the VA Hospital in the Bronx, which was in the process of establishing a radioisotope program to serve returning veterans. The VA made her a part-time consultant in 1947 and gave her a janitor's closet to convert into a radioisotope laboratory. Yalow designed and built much of the equipment in the laboratory and went to work studying the diagnosis of thyroid conditions and the treatment of cancer. In addition, she became interested in using isotopes to trace physical processes in the body. In January 1950, she became a full-time staff member at the VA and in July 1950, she was joined by Dr Solomon Berson, who would be her long-time research collaborator [14].

Berson was an outstanding clinician as well as a talented violinist, chess player and general Renaissance man, who was also a good writer and speaker. Yalow was well versed in chemistry, physics and mathematics and quickly learned more physiology than many of the outstanding physiologists of her day. However, she held a PhD and not an MD, and consequently would never have been able to sell her ideas to the medical establishment. The two quickly formed a tight partnership in which they planned experiments together, although she usually set up the equipment and took care of details like plane reservations and getting manuscripts typed. They developed a house language within the laboratory and bounced ideas off one another at machine-gun pace. Berson never treated Yalow as anything but a full research partner, although the outside world sometimes saw her as a super technician and Berson as the group leader because he used his social skills and status as a physician to present a public face for the research group. Both Yalow and Berson always claimed to be, and apparently were, equal partners [12].

Yalow and Berson pioneered techniques for using insulin labeled with radioactive iodine to determine concentrations of insulin in the human body as a function of time. Their first project showed that type II diabetics treated with insulin actually developed antibodies to the pig and cow insulin used in their treatment. So while insulin concentrations in their blood remained high, the body could not use the insulin to digest sugar. Prestigious scientific journals rejected their paper on the subject, because reviewers seem to have believed that the insulin molecule was present in too small a quantity to trigger the production of antibodies. In the course of this work, Yalow and Berson developed radioimmunoassay, which subsequently revolutionized endocrinology. In this technique, a small amount of a substance labeled with a radioactive isotope is introduced into the body. Then a blood plasma sample is taken to measure the amount of the substance bound to antibodies present in the blood. The more unlabeled substance present in the body, the less radioactively labeled substance will be collected by antibodies. Exact concentrations are obtained by comparison to the activity of solutions of known concentrations. By 1959, the method was widely accepted and used in a variety of applications [14].

Berson and Yalow were considered strong contenders for the Nobel Prize in Physiology or Medicine.

In 1952, Yalow gave birth to a son. At that time, pregnant women were required to stop work at five months, something Yalow was not about to do. She joked that her son was the only eight-pound, two-ounce baby born four months early, since she took only four days off work. Two years later she took another four days to give birth to a daughter. She had good live-in help and managed to have lunch and dinner with her family. Her mother dropped by nearly every day to visit with the children. As her children entered school, she used part-time help but still did mother duty on class trips [12].

In 1968, Berson left the VA to become professor and chair of internal medicine at Mt Sinai School of Medicine of the City of University of New York. He assumed that he could reorient the Mt Sinai department towards research and continue research with Yalow. Yalow felt that he should not take the job, since she thought it was unlikely that he could reorient the department. He quickly experienced frustration with the administration at Mt Sinai, but as his time at the laboratory became more and more limited, he was able to recommend a resident, Dr Eugene Straus, to Yalow as a medical partner in the isotope research. In 1972, during a medical meeting in Atlantic City, Berson died alone in a hotel room from a massive heart attack [11].

Yalow was devastated personally by Berson's death. Initially, following his death, other professionals in the field assumed that Yalow would no longer be able to produce significant research, since they thought that Berson was the leading partner of the team. Yalow was removed from her candidacy for the Nobel because the prize was not awarded to the survivor of a research team. Yalow set to work to demonstrate that she could do cutting-edge research alone, and she expanded her research team with herself as team leader. In 1974, she renamed the VA laboratory The Solomon A Berson Research Laboratory, so that Berson's name would appear on all published papers. She accepted public speaking engagements and took other steps to raise her professional profile. In 1975, she was elected to the National Academy of Sciences. In 1976, she received the Albert Lasker Award for basic medical science, which is generally considered to be the precursor of the Nobel Prize. Rosalyn Yalow shared the 1977 Nobel Prize in Physiology or Medicine. She received the National Medal of Science in 1988 [15]. She continued active research until she had to close her laboratory following a stroke. She had a second stroke in 1995 and a fall in 1997 [11], dying in 2011 [15].

Rosalyn Yalow was undoubtedly one of the best scientists of her day. She was also a very strong woman who was determined to make the world go the way she thought it should. McGrayne illustrates this with a story of Rosalyn Sussman as a child. When a first-grade teacher smacked Rosalyn's older brother's hand with a ruler, he cried and vomited. Five years later, the same teacher hit Rosalyn, who hit her back and explained to the principal that she had been waiting five years to avenge her brother [12].

Rosalyn Yalow's relationships to her husband, her children and colleagues were extremely complex and are explicated in the biography by her long-time friend and

Figure 7.2. Elda Emma Anderson from Oak Ridge Employee News Letter (1950's), provided by Oak Ridge National Laboratory which is managed for the US Department of Energy by UT-Battelle, LLC.

colleague Eugene Straus, which is informative since Straus knew all the players. Yalow could be extremely kind, as she was to Mildred Spiewak Dresselhaus, a very bright student at Hunter College whom Yalow persuaded to switch her major from elementary education to physics. Dresselhaus, who would later become treasurer of the National Academy of Sciences and a winner of the National Medal of Science and of the Presidential Medal of Freedom among many other honors, remembers that although she had gone into a different area of physics, Yalow and her husband would always come to presentations she made in the area and credits Yalow's mentoring and work ethic for helping her succeed [12]. She could also be very stern and even spiteful. Rumor has it that in her office, Yalow kept a standard sign that read 'To be considered as good as a man, a woman must work twice as hard and be twice as smart.' Underneath in pen was written, 'Fortunately that is not difficult.'

Elda Emma Anderson (figure 7.2) entered health physics after a career in nuclear physics and participation in the Manhattan Project. She was born in 1899 in Green Lake, Wisconsin [16]. She received her bachelor's degree from Ripon College in 1922 and her master's degree in physics in 1924 from the University of Wisconsin [17]. To earn money to continue her studies, she served as dean of physics and mathematics at Estherville Community College in Iowa from 1924–27. In 1929, she became professor of physics, and in 1934, head of the physics department at Milwaukee-Downer College (then a women's college). Anderson continued her studies at the University of Wisconsin and received her PhD in atomic physics in 1941. Her thesis was on low energy levels in the atomic spectra of cobalt and nickel [18].

No sooner had Anderson completed her degree than she requested a sabbatical from Downer to join the Office of Scientific Research and Development at Princeton

University in order to conduct war research. In 1943, she was recruited to Los Alamos, where she worked on measurements of basic fission parameters, including the number of neutrons emitted per fission and the time delays associated with neutron absorption and neutron emission. Among other work, she prepared the first sample of U-235 received by Los Alamos for use in experiments [18]. At 50 and with white hair, 'Andy' Anderson was an old-timer on the Hill. Other women remember that she lived in the dormitory, worked mostly at night and wore jeans and a plaid shirt. She was clearly not a conformist [19].

After the war, in 1946, Anderson returned to Milwaukee-Downer College as head of the physics department with a joint appointment at the University of Wisconsin. She was recruited to Oak Ridge National Laboratory in 1949 to be the first director of the Education and Training Division of the Health Physics Division. She started a joint graduate program in health physics with Vanderbilt University and began to establish health physics as a legitimate scientific discipline. She served as secretary–treasurer of the newly created Health Physics Society from 1956 until 1959, when she became the Society's president [17].

In 1960 as president of the Health Physics Society, she played a leading role in establishing the American Board of Health Physics to provide professional certification to health physicists, and served as its chair until her death in 1961 from breast cancer and leukemia. She mentored many graduate students from 1949 on and is remembered by colleagues as the person to whom one could take problems both in physics and in personal issues [17]. To honor her, the Health Physics Society established the Elda E Anderson Award, presented annually for outstanding research by a physicist under 40 [20].

Katherine Russell Sopka studied physics successfully before marriage, children and World War II interrupted her studies. She eventually became a distinguished historian of science and is responsible for much of what we know about women physicists after World War II. Her knowledge of physics enabled her accurate study of the discipline and the probing questions she asked of the women she interviewed. Her story illustrates the difficulties faced by married women with children who wished to pursue careers in physics.

Katherine Russell was born and grew up in Boston as the fourth of six children. After attending the Girls' Latin School (now Boston Latin Academy), she obtained her bachelor's degree in physics from Radcliffe [21]. In a physics class, she met John J Sopka, who had received his bachelor's degree in physics from Harvard in 1942 and was working on a doctorate in physics. They married in 1943 and then moved to Dayton, Ohio, where John worked on plutonium–beryllium initiators for the Manhattan Project [22]. Katherine was also considered for a position on the Manhattan Project, but did not receive it because she was pregnant at the time with their first son, who was born in 1944 [23].

At the end of the war, the Sopkas returned to Harvard. Their second son and their daughter were born there. John switched to mathematics and earned his PhD in 1950 [22], while Katherine completed her master's in physics at Harvard [23]. The Sopkas then moved to Silver Spring, Maryland, where John had taken a position as a research mathematician at Johns Hopkins Applied Physics Laboratory. In 1954, IBM recruited John to its New Jersey laboratory and the Sopkas lived in Elizabeth, New Jersey. Katherine taught physics at Newark State Teachers' College.

Subsequently, John became director of computing for the National Bureau of Standards Laboratory in Boulder, Colorado, and the family moved to Boulder. Katherine taught physics and physical science at the University of Colorado, where she worked on curriculum development with Frank Oppenheimer and David Hawkins, including working on the Physical Science Study Committee (PSSC) project, which had been introduced by Francis Friedman and his colleagues at MIT in 1956 with the objective of reviewing introductory physics education and designing and monitoring improvements to it. When their children were out of college and had left home, John became a professor at the University of Texas at Arlington, and John and Katherine moved to Arlington.

John then became a professor at Boston College and John and Katherine lived in Framingham, Massachusetts, with Katherine working with Professor Gerald Holton in the history of science department at Harvard. She received her PhD in 1976 with a dissertation on the development of quantum mechanics, which was later published as a book [23].

In 1980, the Sopkas moved to Ft Lewis College in Durango Colorado. After retiring, they moved back to the Boston area in 1999 and lived in Marblehead, Massachusetts. Katherine worked as an editor for AIP's *History of Modern Physics* series while conducting insightful oral interviews with many women physicists, as well as many distinguished male physicists. Transcripts of the interviews are

Figure 7.3. Melba Phillips, presidential photograph. Photograph courtesy of the American Association of Physics Teachers.

available through AIP's Niels Bohr Archive [23]. The Sopkas' marriage lasted 66 years until Katherine's death in 2009 [22].

Melba Phillips (figure 7.3) seemed set for a career in physics research until she refused to testify before the Senate Judiciary Committee's McCarran internal security subcommittee [24] and was forced into a (very distinguished) career in physics education and non-profits. She was born in 1907 on a farm near Hazelton, Indiana. Her father was primarily a farmer, but also taught school and was an influential member of the rural community. The family was financially close to break-even, but Phillips's parents stressed education for Melba and her three younger brothers. After starting in a one-room school house where her father was the teacher, she finished high school in Union City, Indiana, just before her sixteenth birthday [25]. She would have liked to teach school, but could not until she was eighteen, so she went to the cheapest and nearest college she could find, Oakland City College in Indiana, from which she graduated in 1926. She remembers having a teacher who got her interested in mathematics [26].

After graduation, Melba Phillips taught a year of high school. Then she met the president of Battle Creek College in Michigan, who spoke at a program she was attending. She managed to impress him and he invited her to apply for a teaching fellowship at Battle Creek College, which she did. She taught basic courses and learned advanced calculus and the physics that she had not studied as an undergraduate at Oakland City College [26]. She received a master's degree from Battle Creek College in 1930.

In 1929, Phillips attended one of the famous summer schools at the University of Michigan, where the founders of quantum physics gathered to teach and to learn. She met Edward Condon and impressed him by humbly asking for help with a problem for which she could not get his answer. Although she blamed herself for having difficulty, the error was Condon's, and the two became friends. He recommended her to the physics department at the University of California at Berkeley. For her first two years there, she held a standard teaching assistantship and played catch-up with graduate and undergraduate courses in physics. In her third year, she received a Whiting Fellowship, which paid less than $1000 US dollars a year, but was enough to live on. She began to consider dissertation topics and decided to work with Robert Oppenheimer, then a promising young theoretical physicist [26]. She received her PhD in 1933 [27] with a thesis on the photoionization of potassium vapor and the inversion of doublets in the spectra of alkali atoms. She could not find a job because of the Depression, so she stayed at Berkeley doing research and supporting herself through whatever teaching she could find, a not-uncommon strategy for new physics PhDs. Although she was the only woman in her PhD class, she remembered that there were several women graduate students in the department while she was there.

She was part of the exciting physics world centered at Berkeley and made a number of friends who were or became leaders in physics [25]. She was welcome in Oppenheimer's close-knit group of graduate students and would remain friends with Oppenheimer himself for the rest of his life [26]. A number of graduate students shared a house in Berkeley and would often host distinguished visitors to the physics department there, since Oppenheimer worked to make visitors feel welcome [28].

In 1935, Oppenheimer and Phillips published a paper in *The Physical Review* describing a nuclear reaction in which a moving deuteron passing through matter collides with the nucleus of an atom and transfers a neutron to the target nucleus, thus creating a heavier isotope, a reaction known today as the Oppenheimer–Phillips process [29]. Most likely because of this outstanding work, Phillips received a Helen Huff Research Fellowship from Bryn Mawr College for 1935–36 and an AAUW Margaret Maltby Fellowship at the Institute for Advanced Study at Princeton University for 1936–37. For the academic year 1937–38, she took a position as an instructor at Connecticut College, which was then a college for women. In 1938, she became an instructor of physics at Brooklyn College [27].

Phillips remained at Brooklyn College until 1941, when manpower shortages opened opportunities for her as a lecturer at the University of Minnesota. She taught the introductory theoretical physics course to very talented students at Minnesota [25]. She turned down an offer to go to Los Alamos because she was having so much fun teaching and wanted to continue. In 1944, she left the University of Minnesota and returned to Brooklyn College as an assistant professor. She also spent five months in 1944 at the Harvard Radio Research Laboratory working on war projects.

Immediately after the war, Phillips became a founding member of the Federation of American Scientists (originally founded as the Federation of Atomic Scientists in 1945 and renamed in 1946). She was also a member of the Association of Scientific Workers, a British organization founded at that time. On leave from Brooklyn College, she did part-time office work for the Federation of American Scientists in Washington and played a significant but behind-the-scenes role in making the infant organization effective in its effort to place nuclear weapons under civilian control. Because of this effort, the Federation came under scrutiny from the Federal Government during the Cold War [28].

At Brooklyn College the postwar students were unusually talented and Phillips enjoyed teaching them. She preferred to teach undergraduate students, since it turned out that they were generally more talented than the graduate students. The undergraduates came from all over New York City and survived a stringent admission process, since there was free tuition at the city colleges for a limited number of undergraduates. Several of these Brooklyn College undergraduates later became well-known physicists or outstanding scientists in other disciplines [26]. Phillips also held a part-time position in the Radiation Laboratory at Columbia University [27], where she worked on projects associated with microwaves.

In 1952, Melba Phillips was called before the Senate Judiciary Committee's McCarran internal security subcommittee and refused to testify about her friends. She was summarily fired from both her jobs in October 1952, right in the middle of a semester [28]. Moreover, she was blacklisted and, as a result, unable to find a position in physics. This would continue for four-and-a-half years, until 1957. Phillips pointed out that it took courage to hire any of the people in trouble during that time and that discrimination was not related to gender [26].

Phillips survived unemployment with the help of friends. She stayed busy writing two highly regarded text books: *Principles of Physical Science* (1957), with Francis Bonner, and *Classical Electricity and Magnetism* (1955), with Wolfgang Panofsky [24]. In 1957, Ed Condon, then chair of the physics department at Washington University in St Louis, was assistant director of the Academic Year Institute for secondary school physics teachers, which was funded by the National Science Foundation [25]. He hired Phillips and she enjoyed the next five years, spent running the institute for classes of fifty teachers and learning about how physics was taught at the secondary level. In 1962, she moved to the University of Chicago as a professor of physics, where she took charge of the large course in physics for non-majors. In 1972, she became a professor emerita at Chicago and held a visiting professorship at SUNY/Stony Brook until 1975. In 1980, she became a visiting professor in the graduate school of the University of Science and Technology, Chinese Academy of Science, Beijing.

In 1960, Phillips was named to the Commission on College Physics. She had joined the American Association of Physics Teachers in 1943 and became its first female president in 1966. She also acted as its executive officer from 1975–77 [25] and is credited by members of the organization who were active at the time with almost single-handedly saving AAPT from disappearing. She received AAPT's Oersted Medal in 1973, the Karl Taylor Compton Award from the American Institute of Physics in 1981 and the Joseph Burton Award of the American Physical Society in 2003. At present, the American Association of Physics Teachers' highest honor is called the Melba Newell Phillips Award. She was a fellow of the American Physical Society and the American Association for the Advancement of Science [30].

Despite her outstanding record in physics education and research, Melba Phillips' most important legacy may be her unparalled encouragement of younger women physicists. For example, in 1972 a woman employed as a visiting assistant professor said, 'Please Dr Phillips, how do you go about designing an introductory lab?' Phillips looked a bit startled and then replied, 'My dear, you steal!' Then, within a week she mailed copies of her Chicago labs to the young physicist, who since that time has reportedly only stolen from the best.

Phillips is not the only woman physicist who struggled with her career because she chose to follow her conscience. Sallie Ann Watkins was born in Jacksonville, Florida in 1922. She chose to become a nun because this was one of the few paths open to her that provided an opportunity to use her talents to serve humanity. She graduated from Notre Dame College in 1946, taught chemistry at Notre Dame Academy in Cleveland, Ohio, and finally received her doctorate in physics from Catholic University in 1958. In 1966, she moved to Pueblo, Colorado with a group of 10 nuns from her Cleveland convent and with Phillip and Daniel Berrigan to start the Community of Christian Service. She eventually became a professor of physics and then Dean of the College of Science and Mathematics at the University of Southern Colorado and worked tirelessly as an advocate for minorities and women in the sciences. She is remembered with gratitude and admiration by the many students she mentored over the years. Like Phillips, whose friend she became, Watkins was honored over and over again, receiving the

Figure 7.4. The Engst Family in Beijing, 1967: Fred Engst, Erwin Engst, Karen Engst, Joan Hinton, and Bill Engst. Photograph courtesy of Bill Engst.

Robert A Milliken Award from the American Association of Physics Teachers and serving on numerous state committees and boards in Colorado [31]. Watkins is remembered for her unfailing willingness to help women and minorities, as well as her self-effacing good humor.

Other women physicists switched fields or developed new areas of study. Joan Hinton (figure 7.4) left the country and put her physics training to work designing milking systems for a dairy farm near the Chinese border with Mongolia. Hinton, born in 1921, graduated from Bennington College in three years and moved to the University of Wisconsin for graduate work. Although there was no physics major at Bennington, she built a cloud chamber and was fascinated by it. Her older brother was studying at Cornell and Joan spent a couple of winter field periods there at Bennington's suggestion. She got to know the cyclotron group, since she loved tinkering with equipment. That group went to Los Alamos in early 1944 and invited Joan to join them. She received her master's degree in a hasty exam during which she sat on the floor and showed the committee photographs of another cloud chamber which she had built. They knew she was leaving for war work [32]. One of her professors at Madison describes her as 'a good student, a rather eccentric girl, blonde, sturdy, good looking' [33].

Hinton reached Los Alamos in February or March of 1944 and was assigned to a group lead by Enrico Fermi, which was building a reactor fueled by enriched uranium in a slurry, called the Water Boiler, for its coolant. The purpose of this reactor was to study critical assemblies of uranium and subsequently to study critical assemblies of plutonium. LOPO, the first 'low power' reactor, went critical in May 1944. It was located down in a canyon reached either by climbing down from the mesa where the tech area was located or by driving down a twisting road. The Omega group working on reactors consisted of five professors (all male) and four graduate students (Joan, Harry Daghlian, Bob Carter and Harold Hammel), supported by two uniformed members of the army's special engineering detachment

(Skeets and Bill Starner) and a mechanic. The group literally built the LOPO reactor and then its successor HYPO (for high power) by hand. Cars were kept up on the mesa and there was a small room where workers could leave possessions and pick up keys. The group had several cars, one of which was wrapped around a tree by a visiting European physicist, as well as a most useful four-wheel drive weapons carrier. Conditions were a bit primitive. For example, gases emitted by the reactor were vented through a tube that ran up a tree [34]. The young group worked and played vigorously outdoors. Joan also played the violin with a local combo [32].

After the successful test of LOPO, the canyon group split over two projects (and were joined by Louis Slotin and later Phil Morrison): (1) building the next reactor, the HYPO and (2) testing critical assemblies of fissile materials as plutonium began to arrive from Hanford. At this point the group argued over whether experiments should be conducted behind a safety wall with remote controls or with the experimenter near the equipment and controlling things by hand. Some felt that the surest control was a human being, while the others felt that the possibility of human error was just too great and a tiny slip could be very dangerous. The HYPO was built with its controls on the other side of a safety wall, but the tests of critical assemblies were controlled directly by humans on the same side of the wall as the reactor. As the testing group received macroscopic quantities of plutonium, they tested various tamper configurations and different materials around the samples while measuring neutron counts [34].

The next part of the story has several versions. Here is Joan's [33]. She was driving back to the canyon after lunch on 21 August 1945, after the Japanese had surrendered, when Bill Starner came out of the building to say, 'Harry's had an accident. Could you drive him up to the hospital?'

In the morning the group had been testing different configurations of paraffin blocks. When Harry beat the others back to the lab after lunch, he began to continue the experiments himself. He picked up a piece of paraffin intending to place it on the other side of the plutonium sphere being tested, but he dropped it on top of the sphere, which immediately went critical and glowed blue. He knocked the paraffin block off the sphere with his right hand and then the hand felt funny, and he worried that he might lose it and kept rubbing it on his knee. When they arrived at the hospital, the doctors gave Joan all the metal objects that Harry had on him like keys and a knife and told her to 'count' to estimate radiation dose. The metal objects pegged the counters at the Omega site. Daghlian died on 15 September 1945 as his body's cells disintegrated.

Joan Hinton wanted to continue her graduate work at the University of Illinois, where Carter and Hammel were going, but Illinois did not welcome women in the physics graduate program (see Yalow's experience there), so she was relieved when Fermi and Sam Allison asked her to come to the Institute for Nuclear Studies in Chicago. In the meantime, Hinton became politically active in working for the international control of nuclear weapons, sending US mayors samples of debris from the Trinity site with notes saying, 'Do you want this to happen to your town?' [32].

She joined the group around Fermi at Chicago in the fall of 1946. She claims that once in Teller's quantum theory class, she corrected T D Lee's correction of Teller, so that she got a good grade in the course although she made only 40% on the final exam.

She won a fellowship in her second year and shared an attic office with Harold Agnew, later director of Los Alamos. The other half of the attic was used to store a large quantity of heavy water that belonged to the military and Allison could not get a drop, although he badly needed it for his experiments. Finally, a friend in Norway sent a small flask of heavy water with a note reading, 'I thought you had civilian control' [32].

At that juncture, Joan learned that her fellowship came from the Navy and became troubled by the increasing security that accompanied the ramping up of the Cold War. So, in 1948 she decided to take a year off and travel to China to see her brother Bill, a sociologist who was running a dairy farm up near the Mongolian border with his Cornell roommate Erwin ('Sid') Engst. Her brother put her in touch with the China Welfare Institute through Madame Sun Yat Sen, then a widow. Her Chicago group wished her well and gave her a camera. Fermi gave her a light meter and warned her to watch what she said. After a year in Beijing she was smuggled through Nationalist lines and into Maoist China. In 1949 she married Ernst Engst because she felt she was expected to get married [32].

In 1953, Engst was appointed deputy director and technician at the Xi'an Caotan farm, Joan Hinton was appointed technician, and they set to work designing equipment for the large dairy farm. In 1972 they were transferred to a Beijing commune as consultants in the development agricultural machinery. Their work received many honors from the Chinese government. For example, in January 2003 the Chinese Academy of Agricultural Mechanization Sciences awarded Erwin Engst and Joan Hinton the Golden Cow Award (Personal Contribution Award) [35].

Hinton was a devoted follower of Chairman Mao and never hesitated to express her admiration of the man and his policies. Unsurprisingly, her strong stand against nuclear weapons, which she did not hesitate to express in public, attracted the attention of anti-communists in the United States. In 1952, Hinton was caricatured as a femme fatale in a trench coat, 'the atom spy that got away', in spite of the fact that she was very pregnant at the time. Hinton claims that she was never involved with Chinese nuclear research and lived in primitive conditions with her family and 200 cows [36].

She did not return to the US for 29 years and then claimed that all her old friends had become lab directors [32]. She and her husband had three children who spoke Chinese and learned English as adults. Today her sons live in Beijing and the US, and her daughter lives in France. In a 2002 interview with National Public Radio, she stated: 'I've taken part in two of the greatest things of the 20th century—the development of the atom bomb and the Chinese revolution. Who could ask for anything more than that?' [37]. Obituaries in various newspapers published diverse perspectives on Hinton and her work in China.

The women physicists whose portraits form this chapter illustrate the new ground—both inside and outside of science—that these women broke. They were not alone. For example, the economics Nobel prize winner and gifted mathematician, John F Nash Jr, whose life inspired the film *A Beautiful Mind*, married Alicia Larde (figure 7.5), a MIT physics major born in El Salvador, one of 16 women in the class of 1955 [38]. She was 21 at the time of their wedding, which took place despite the fact that Nash had a son with another woman, whom he refused to acknowledge [39].

Figure 7.5. Nash and his wife, Alicia Larde (right), who died with him May 23, are pictured at a March 25 reception in honor of Nash's receipt of the 2015 Abel Prize from the Norwegian Academy of Science and Letters; Princeton University, Office of Communications, Danielle Alio (2015).

When Alicia Nash became pregnant with her first child, John Nash's behavior became more and more bizarre, and he was diagnosed with schizophrenia. After the baby was born and months of strange behavior, Alicia had John involuntarily committed to a private psychiatric hospital. On his return to society, John Nash resigned from the MIT faculty and went to Europe, where Alicia followed him, had him deported and finally brought him to Princeton. Alicia got a job and supported the family until their divorce in 1962, following his involuntary commitment in 1961 to yet another psychiatric hospital. In 1970, she took John Nash in, as he was then homeless. In the 1980s, he began to recover and shared the Nobel Prize in economics in 1994. Thirty-eight years after their divorce, the Nashes remarried [39]. They died together on 23 May 2015 in the crash of a taxi that they were riding in on the New Jersey Turnpike [38].

No woman physicist seems to have had an easy time in life, whether in physics or another field. While these women physicists were exceptional in many ways, their stories exemplify the climate for women professionals in the decade and a half after World War II.

References

[1] Howes R 2004 *Notable American Women: A Biographical Dictionary Completing the Twentieth Century* ed S Ware (Cambridge, MA: Belknap) pp 532–3

[2] Taylor L S and Sauer K G 1984 Interview with Edith H Quimby *Vignettes of Early Radiation Workers* pp 229–41

[3] The Health Physics Society http://www.orcbs.msu.edu/radiation/resources_links/historical_figures/quimby.htm (accessed 14/5/15)

[4] CWP (UCLA) www.physics.ucla.edu/~cwp/Phase2/Quimby,_Edith_Hinkley@842345678.html (accessed 14/4/15)

[5] Howes R and Herzenberg C 1999 *Their Day in the Sun: Women of the Manhattan Project* (Philadelphia, PA: Temple University Press) pp 115–7

[6] 1965 *Journal of Nuclear Medicine* **6** 383–5 http://jnm.snmjournals.org/content/6/5/383.full.pdf.html

[7] Rossi H H 1982 *Physics Today* **35** 71–2

[8] Rothe A (ed) *Current Biography: Who's News and Why 1949* (New York: H W Wilson) pp 492–3

[9] Opfel O S 1986 *The Lady Laureates: Women Who Have Won the Nobel Prize* (Metuchen, NJ: Scarecrow) pp 254–64

[10] Les Prix Nobel 1977 http://cwp.library.ucla.edu/articles/yalow/yalow-autobio.html (accessed 2/5/15)

[11] Dresselhaus M S and Stahl F A 2006 *Out of the Shadows: Contributions of Twentieth-Century Women to Physics* ed N Byers and G Williams (Cambridge: Cambridge University Press) pp 303–14

[12] McGrayne S B 1993 *Nobel Prize Women in Science: Their Lives, Struggles and Momentous Discoveries* (New York: Birch Lane) pp 333–55

[13] Straus E 1998 *Rosalyn Yalow, Nobel Laureate, Her Life and Work in Medicine* (New York: Plenum)

[14] Biermann C l A and Biermann L 1993 *Women in Chemistry and Physics: A Biobibliographic Sourcebook* ed L Grinstein, R Rose and M Rafailovich (Westport, CT: Greenwood) pp 626–39

[15] Wikipedia http://en.wikipedia.org/wiki/Rosalyn_Sussman_Yalow (accessed 16/5/15)

[16] Anderson G 2010 http://www.findagrave.com/cgibin/fg.cgi?page=gr&GRid=55473916 (accessed 9/5/15)

[17] *Physics Today* **14** 68

[18] Wikipedia http://en.wikipedia.org/wiki/Elda_Emma_Anderson (accessed 13/5/15)

[19] Barschall H 1991 Telephone interview with R Howes

[20] Encyclopaedia Britannica Online www.britannica.com/EBchecked/topic/23599/Elda-Emma-Anderson (accessed 9/5/15)

[21] Wikipedia http://en.wikipedia.org/wiki/Katherine_Sopka (accessed 7/5/15)

[22] 2014 *The Durango Herald* (January 2014) http://www.durangoherald.com/article/20140130/NEWS07/140139966

[23] 2009 Salem News (3 August 2009) http://www.salemnews.com/obituaries/katherine-j-sopka/article_cd996673-cab3-575a-bcdb-5da3ecb6e4e7.html

[24] Wikipedia http://en.wikipedia.org/wiki/Melba_Phillips (accessed 21/5/15)

[25] Bonner F T 1993 *Women in Chemistry and Physics: A Biobibliographic Sourcebook* ed L Grinstein, R Rose and M Rafailovich (Westport, CT: Greenwood) pp 488–93

[26] Sopka K 1977 *Interview with Dr Melba Phillips Niels Bohr Library and Archives* (College Park, MD: American Institute of Physics) www.aip.org/history/ohilist/4821.html (accessed 22/5/15)

[27] CWP (UCLA) http://cwp.library.ucla.edu/Phase2/Phillips,_Melba_Newell@851234567.html (accessed 21/5/15)
[28] Kojevnikov A 1997 Interview with Dr Melba Phillips *Niels Bohr Library and Archives* (College Park, MD: American Institute of Physics) www.aip.org/history/ohilist/32719.html (accessed 22/5/15)
[29] Wikipedia http://en.wikipedia.org/wiki/Oppenheimer%E2%80%93Phillipsprocess (accessed 22/5/15)
[30] The University of Chicago News Office 2004 http://www-news.uchicago.edu/releases/04/041116.phillips.shtml
[31] 2011 Pueblo Chieftain (28 December 2011) http://www.findagrave.com/cgiin/fg.cgi?page=gr&GRid=82503332
[32] Hinton J 1990–1 Telephone interview, letters and conversation with R Howes
[33] Ulam S M 1976 *Adventures of a Mathematician* (New York: Charles Scribner's Sons) p 144
[34] Hinton J 1984 Letter to Joe McGinnis (29 August 1984, sent to R Howes by J Hinton)
[35] Chinese Academy of Agricultural Mechanization 2012 http://en.caams.org.cn/academic/experts/foreignexpert/2012/04/12279.shtml
[36] Rampell C 2004 www.nbcnews.com/id/5653644/ns/world_news/t/atom-spy-got-away/-.VWKAl2eD600
[37] Schudel M 2010 *Washington Post* (11 June 2010) http://www.washingtonpost.com/wp-dyn/content/article/2010/06/10/AR2010061005064_2.html
[38] Goode E 2015 *The Santa Fe New Mexican* A-2 (25 May 2015)
[39] WGBH and PBS http://www.pbs.org/wgbh/amex/nash/peopleevents/pjnash.html

Chapter 8

Epilogue: some final thoughts

In this book, we have examined a particular aspect of the history of science in America: the lives and contributions of American women physicists who were active in the years following World War II, during the middle decades of the 20th century.

As we have seen, the possibilities open to these women were in general largely defined by the culture and politics of the period. The end of World War II was soon followed by the Cold War with the Soviet Union, a period with only a limited amount of actual explicit warfare but greatly heightened threats and rapidly increasing activity in military-related areas, in particular in the design and production of new weapons, including new nuclear weapons. This in turn was followed by the Vietnam War, a Cold War era proxy war that started in 1955 and ended in 1975. The Space Race and the founding of NASA also motivated the funding of intensive research in physics.

The early years of the mid-century period constituted a time of recovery, regrouping and reorganization for our society following World War II. This in turn was followed by an intermediate period in the early 1960s, during which various striking social and cultural and scientific initiatives began. Subsequently, some of these initiatives that started during the 1960s led to important structural changes in society, which became more apparent during the 1970s. For example, we have seen how ad hoc efforts to provide jobs for returning soldiers reversed many of the gains made by working women during the war, as governmental and industry efforts were made to remove women from the workforce in the aftermath of World War II. Then, during the early 1960s, there were several events that prefigured changes in the social structure of science and in the role of women. Journalist Betty Friedan's book *The Feminist Mystique* was published in 1963; it would prefigure the flourishing of feminist theory and the associated efforts and great strides in women's rights in the 1970s. Furthermore, Thomas Kuhn's book *The Structure of Scientific Revolutions* was published in 1962, and introduced the idea of paradigm shifts in scientific fields, and this, together with related work of others, led to a new and expanded conceptualization of science by the intellectual community [1].

doi:10.1088/978-1-6817-4094-2ch8

Women from a range of backgrounds were involved in physics research and teaching physics during the midcentury period. These women generally came from either reasonably well off rather than economically deprived backgrounds or less advantaged backgrounds that stressed education for children, as an adequate education was a necessity to become a practicing physicist. Most of the women had been born and educated in America, however, a number of these women physicists had come from Europe, many of them with Jewish backgrounds. Another postwar effect from World War II had been that because of the destruction and loss of scientific infrastructure, social as well as physical, many of the more developed and successful scientists immigrated to the United States. As a result, some of the foreign-born women scientists who worked in the United States after the war had actually done some of their most productive work prior to that time period.

There were not many women physicists of Asian, Hispanic or African-American origin, as their entry into the ranks of US physicists was limited not only by existing biases against women in the field as documented above, but also by immigration restrictions, quota systems in universities, cultural barriers within their families and economic challenges. Thus women from these ethnicities faced higher barriers to education and employment.

As we have seen, these women worked in a variety of different settings in the years following the war. It is hard to imagine the challenges these women faced. They went from being pariahs in academia, to being heavily recruited, to being pariahs again in a matter of six years. It is a wonder few of them reported whiplash. Those who survived adopted a variety of strategies that women in science have used since.

1. Find a distinguished male scientist who values your work and promotes your career as a mentor. Katharine Burr Blodgett followed this path with the mentorship of Irving Langmuir. In many cases, women followed husbands in the same field into science careers. Diz Graves, Jane Hall and Maria Mayer provide three very talented examples.
2. Work in a niche field or a newly developing area of science. Many of the pioneers in nuclear physics in the early 20th century were women (Meitner and the Curies, for example), when it was a relatively new field. As it matured, women began to work in such new disciplines as health physics, the biological effects of radiation and the instrumentation associated with them. Elda Anderson, Rosalyn Yalow and Vivian Johnson provide examples.
3. Change fields completely to find a job that is needed badly. Melba Phillips, Esther Conwell and Betsy Anker Johnson provide examples of this strategy.
4. Be so darn good and work so darn hard that the science cannot do without you. The best examples are the nuclear physicist C S Wu, who won the Wolfe Prize for her work on parity non-conservation, Esther Conwell, who did outstanding research at Bell Telephone Laboratories, GTE Laboratories and Xerox Corporation, which resulted in her being awarded the National Medal of Science and of course the indomitable winner of the Nobel Prize in Physics, Maria Goeppert-Mayer.

Of course, several of these women used one or more of these strategies, just as many of them worked in more than one arena, crossing the somewhat artificial groupings around which we have organized this manuscript. For example, the astrophysicist Cecilia Payne-Gaposchkin, the first woman professor in astronomy at Harvard, not only had a strong mentor in Harlow Shapley but was also very good at research in her field and worked extremely hard.

At least two other factors played important roles in the careers of these women: networks of women in science and the support of male colleagues in research. This study shows that contrary to the image of the solitary 'queen bee' successful woman in science, these women frequently supported junior colleagues and several of our limited samples reported being more comfortable working in an environment where there were women peers. Many of them worked long and hard to interest young women in physics and help these young women find productive careers.

The support of the women's colleges for women physicists, both in educating young women for physics careers and in hiring young female PhDs, is notable, and these women formed a web of connections that is illustrated over and over again in the stories told here, even for women who did not work in the women's colleges. Many of the women described here served as important role models for the generation of women physicists who became active after 1963 as affirmative action began to open a wider variety of jobs to them and destroy barriers such as anti-nepotism rules. Of course, affirmative action also prompted many single-sex colleges to become co-educational, destroying the unique environments for women's research produced in the women's colleges, but also raising a generation of physics researchers for whom marriage and children were the norm, not the exception.

A second example of a network of women was and is the prevalence of women in astronomy and astrophysics. This is a much older grouping of women researchers, typified by the Harvard astronomers and the solar astronomers at the University of Michigan. Health physicists were also apt to be women who knew one another and were found in a relatively few places, most notably the New York City institutions. Affirmative action greatly strengthened these networks as the federally supported institutions such as NASA and the National Labs were affected by the new laws early in their history. The research prompted by the continuing Cold War and the Space Race opened up jobs for physicists in precisely these areas and women were welcomed by federal mandate.

So far this chapter has concentrated on social factors, both in society at large and in the workplace that supported women physicists. However, it would be intellectually dishonest to ignore at least two critical private factors that made succeeding as a woman physicist difficult. The stories of the women above illustrate the importance of finding solutions to these problems. First, any professional woman who worked full time and was also a mother needed good household assistance to help care for the children and maintain the household. When women like the ones discussed above, most of whom were married and many of whom had children, tell their own stories, many of them spend paragraphs describing the women who helped them balance domestic and professional lives. Janet Guersey is particularly eloquent in her essay, 'The married school marm' [2].

A second significant problem, the so-called two-body problem, occurs when two professional people marry one another. In that case, one must become a trailing spouse. Several of the women described here, for example, Mary Boas and Fay Selove,

Figure 8.1. Vera Kistiakowsky, 1991. Photograph courtesy of Vera Kistiakowsky and Karen Fischer.

significantly affected their own careers by following their husbands. A second solution to the two-body problem is the so-called commuter marriage, where spouses live and work in different towns and maintain two homes. A strong example of this is C S Wu and her husband Luke Yuan, who lived in New York City and on Long Island, maintaining both a strong marriage and strong professional careers. Not all commuter marriages survived the stress of being separated, but many did and do. It is important to note that the National Labs and some industries took advantage of the two body problem to hire talented scientists who were married to other scientists. For example the University of California at San Diego hired both the Mayers and both the Burbidges as couples thereby luring them away from larger research universities where anti-nepotism rules prevailed.

It seemed inevitable that the professional organizations for physicists should eventually show concern for the small numbers of women in the profession. While at MIT during the late 1960s, Vera Kistiakowsky (figure 8.1) became increasingly concerned about the difficulties faced by many women scientists whose careers had stalled. In 1969, she, Elizabeth Baranger and Vera Pless started Women in Science and Engineering (WISE) in Boston. In 1970, she and some women colleagues organized the Committee on the Status of Women in Physics of the American Physical Society to assess the role of women in physics, and she later chaired the committee. She served as president of the Association for Women in Science in 1982/1983. She has also been concerned with weapons policy and international security, and addressed the issues raised by the Strategic Defense Initiative. She has been a member of the board of Center for Arms Control and Non-Proliferation, and became director of the Council for a Liveable World in 1983 [3–5].

During the early 1970s, further organizations such as the Association for Women in Science got going and aided not only women scientists in their careers, but also helped interest young women in science and in becoming scientists.

Today the physics professional societies all encourage women to pursue careers in physics. Formal anti-nepotism rules have disappeared and employers are required to provide maternity leave. The percentage of PhDs in physics awarded to women has risen from six per cent in 1983 to 20% in 2012, an all-time high for women as well as an all-time high for the award of PhDs in physics. About half of these PhDs were awarded to US citizens [6].

Clearly, the situation for women is much better than it was in the decade after World War II. Equally clearly, we are still far from equity and women who study physics can learn much from the women treated in this book.

References

[1] Hollinger D A 1996 *Science, Jews, and Secular Culture: Studies in Mid-Twentieth-Century American Intellectual History* (Princeton, NJ: Princeton University Press)

[2] Guernsey J 1951 *Wellesley Alumnae Magazine* **35** 137–38

[3] Vera Kistiakowsky interview *Voices of the Manhattan Project* http://manhattanprojectvoices.org/oral-histories/vera-kistiakowskys-interview (accessed 10/3/15)

[4] Cambridge Women's Heritage Project http://www2.cambridgema.gov/historic/cwhp/bios_k.html#KistiakowskyV (accessed 3/3/15)

[5] Thomas V L 1997 *Notable Women in the Physical Sciences* ed B F Shearer and B S Shearer (Westport, CT: Greenwood) pp 228–33

[6] Mulvey P J and Nicholson S 2014 *Trends in Physics PhDs* (College Park, MD: American Institute of Physics) www.aip.org/statistics (accessed 5/8/14)