Appendix B: Scientific Contributions of Thirteen Outstanding Female Scientists

Scientific Contributions of Thirteen Outstanding Female Scientists

Gerty Radnitz Cori
(1896–1954)

Gerty Cori, with her husband, received international recognition for discovering how glucose converts to glycogen (Cori cycle). This husband and wife team won the 1947 Nobel Prize in physiology or medicine for "discovering the course of the catalytic conversion of glycogen" (mechanism for blood glucose regulation). Cori's later studies on enzymes and hormones advanced research in diabetes treatment, contributing new understandings that missing enzymes resulted from defective genes. This laid the foundation for future studies of genetic defects in humans. Her research profoundly affected diabetes treatment, allowing physicians to understand how the body stores glucose by converting it predominantly into glycogen, which the body then uses for energy.

Despite her significant research, she fought discrimination and nepotism within the scientific community. In 1947, the same year she became the first American woman and the third worldwide to receive a Nobel Prize in the sciences, she achieved full professor status in biochemistry at Washington University, St. Louis. In 1950, President Harry Truman appointed her to the Board of Directors of the National Science Foundation.

Marie Sklodowska Curie
(1867–1934)

Considered the most famous of all women scientists, this Polish researcher "extraordinarie" was the first person (male or female) to win two Nobel Prizes. At age 16, she had already won a gold medal at the Russian lycée in Poland upon completion of her secondary education. In 1891, almost penniless, she began her education at the Sorbonne in Paris and later became the first woman professor to teach there. Marie Curie (with her husband Pierre) discovered that the source of natural radioactivity did not result from a chemical reaction but rather from a property of the element's specific atoms. This led to the discovery, in 1898, of two highly radioactive elements, radium and polonium, for which they were awarded the 1903 Nobel Prize in physics.

Madame Curie continued her work on radioactive elements and again won the Nobel Prize in chemistry in 1911 for isolating radium and studying its chemical properties. In 1914, she helped found the Radium Institute in Paris and was the Institute's first director.

When World War I broke out, Madame Curie believed that x-rays would help to locate metal fragments and bullets and facilitate surgery. It was also important not to move the wounded, so she invented mobile x-ray vans and trained female attendants.

Curie died of leukemia, presumably from extensive exposure to high radiation levels in her research. After her death, the Radium Institute was renamed the Curie Institute in her honor.

Irene Joliot-Curie
(1897–1956)

Daughter of Marie Curie, Irene continued her mother's work in radioactivity with her husband Frédéric (1900–1958). In 1933, they made the important discovery that radioactive elements can be artificially prepared from stable elements. Their experiments bombarded boron with alpha particles, creating an "artificially" radioactive element, an isotope of nitrogen. The Joliot-Curies were awarded the 1935 Nobel Prize in chemistry "for their synthesis of new radioactive elements." In later years, they extended their work to identifying products of nuclear fission.

Although Joliot-Curie won many awards for contributions to science, the French Academy of Science never admitted her to membership. In 1911, the Institute de France voted to maintain its all-male status, a policy maintained for the next 40 years, even denying Curie membership after she died in 1956. A social activist who lobbied hard for gender equality, Joliot-Curie planned a fund-raising tour of the United States. Even with a valid visa, she was denied entry and kept in a detention center until the French Embassy in Washington intervened.

(*Continued*)

Scientific Contributions of Thirteen Outstanding Female Scientists (*Continued*)

Barbara McClintock
(1902–1992)

America's most distinguished cytogeneticist, McClintock studied genetic mutations by examining changes in the color and texture of kernels and leaf pigments of growing plants. In 1951, McClintock first reported that genetic information could transpose from one chromosome to another. Other scientists didn't believe this unorthodox view of genes, assuming instead that genes remained in place in the chromosome like a necklace of beads. By the early 1970s, scientists finally acknowledged McClintock's view of gene transpositions. Her prodigious research accomplishments clarified our understanding of human disease. The concept of "jumping genes" helped to explain how bacteria develop antibiotic resistance and provided insight as to how these genes play a role in transforming normal cells to cancerous ones. By the late 1970s, her work with transposable elements (i.e., mobile genetic elements that play important roles in inherited birth defects, resistance to antibiotics, and incidence of cancer) became recognized by the scientific–medical community.

During 1980 and 1981, McClintock received eight major awards including the Albert Lasker Basic Medical Research Award, Israel's Wolf Prize in Medicine, and McArthur Foundation Fellowship. In 1983, she was the sole recipient of the Nobel Prize in medicine or physiology. The Nobel Committee called her work "one of the two great discoveries of our times in genetics," the other being the structure of DNA.

Maria Goeppert Mayer
(1906–1972)

The first American woman and the second woman ever to win the Nobel Prize in physics, Maria Mayer made extensive contributions to several different technical fields in physics. Mayer calculated the probability that an electron orbiting an atom's nucleus would emit not one but two photons (quantum units of light) as it jumps to an orbit closer to the nucleus.

Because the Johns Hopkins University had strict nepotism rules that forbade her employment (her husband had been hired), she worked without pay or formal academic status. She produced 10 papers in 9 years applying quantum mechanics to chemistry. She and her husband coauthored *Statistical Mechanics,* a textbook in print for over four decades. At the University of Chicago, Mayer worked part time, supported by a federal grant, as senior physicist at the Argonne National Laboratory. There she began her eventual Nobel Prize-winning project elucidating the basic shell model of an atom's nucleus. In 1956, Mayer was elected to the National Academy of Sciences. In 1959, at age 53, after a 30-year career, she was finally appointed full time professor (with pay), at the University of California, San Diego. In 1963, she received the Nobel Prize in physics for her pioneering research.

Rita Levi-Montalcini
(1909–2012)

Rita Levi-Montalcini's first studies between 1938 and 1944 investigated the mechanisms controlling vertebrate nervous system development. In 1952, she showed that when tumors from mice were transplanted to chick embryos, they induced potent growth of the embryo's nervous system, specifically the sensory and sympathetic neurons. Because this outgrowth did not require direct contact between tumor and embryo, Levi-Montalcini concluded that the tumor released a nerve growth-promoting factor (NGF) that selectively acted on specific neurons. Following this discovery, Levi-Montalcini focused on a more sensitive cell culture model to measure NGF activity in various extracts. NGF proved to be an extremely potent biologic substance in that a sensory or sympathetic nerve cell reacted within 30 seconds to minute quantities of NGF. More specifically, one-billionth of a gram of NGF per milliliter of culture medium exerted a powerful effect on growth. The biologic assay to detect NGF paved the way for the next step of discovery—identification of the active nerve growth-promoting substance. The discovery of NGF opened new fields related to pathology such as developmental malformations, degenerative changes in senile dementia, delayed wound healing, and tumor diseases.

Levi-Montalcini received the 1986 Nobel Prize in medicine or physiology (with Stanley Cohen) for their discovery of NGF. From 1993 to 1998, she served as President of the Institute of the Italian Encyclopedia. She is a member of prestigious scientific academies: Accademia Nazionale dei Lincei, Pontifical Academy, Accademia delle Scienze detta dei XL, U.S. National Academy of Sciences, and the Royal Society.

Scientific Contributions of Thirteen Outstanding Female Scientists (*Continued*)

Dorothy Crowfoot Hodgkin
(1910–1994)

Applying her expertise as an x-ray crystallographer, Dorothy Hodgkin developed the analytical methods to identify the structures of penicillin (previously discovered in 1929): cholesteryl iodide (cholesterol), vitamin B_{12} (used to treat pernicious anemia), vitamin B_{12} coenzyme, and the protein hormone insulin. Hodgkin studied more than 100 steroid crystals, reporting on their unit-cell dimensions and refractive indices relative to their crystallographic axes. Her monumental studies of crystalline steroids showed their probable crystal packing and hydrogen-bonding arrangements. Her later studies involved three-dimensional calculations and established the relative stereochemistry at each carbon atom of the steroids.

Hodgkin took the first x-ray diffraction photographs of insulin in 1935 and ultimately resolved this crystal's full structure 34 years later. Hodgkin and colleagues reported the structure of insulin in August 1969. She singly won the 1964 Nobel Prize in chemistry "for her determination by x-ray techniques of the structures of biologically important molecules." In addition to pioneering work in chemistry, she applied computer algorithms to help unravel insulin's complex structure.

Gertrude B. Elion
(1918–1999)

In 1944, Gertrude Elion, with a master's degree in chemistry, was hired by Burroughs-Wellcome (now Glaxo-Wellcome) pharmaceutical company as a $50-a-week research assistant. Prior to that, female scientists had difficulty finding jobs in either academia or the private sector. At Wellcome, however, her strong scientific training paid off. The strategy was to create new medicines by studying the chemical composition of diseased cells. Her research developed acyclovir (Zovirax) for herpes; azathioprine (Imuran) to help prevent rejection of transplanted organs among nonrelated donors and to treat severe rheumatoid arthritis; allopurinol (Zyloprim) for gout; pyriemthamine (Daraprim) for malaria; and trimethoprim (a component of Septra) for bacterial infections.

Elion never completed her PhD (she took courses at night, commuting 3 hours round-trip). Eventually she had to quit because she was told the PhD program at Brooklyn's Polytechnic Institute required full-time attendance, and she could not afford to give up her job. Nonetheless, Gertrude Elion received 25 honorary degrees from prestigious universities, including Duke, Columbia, Brown, Michigan, and Rochester Institute of Technology. In 1988, she shared the Nobel Prize in physiology or medicine with George Hitchings (coworker at Glaxo-Wellcome) for "important principles of drug development." After retirement in 1983, she helped to oversee development of AZT as the first drug against HIV, the AIDS virus. Elion is the only woman inducted into the Inventors Hall of Fame. Her 45 drug patents have provided wide-ranging benefits in many areas; for example, a drug that helps the body suppress its immune response to foreign tissue—most important, that of transplanted organs. This drug has thus made relatively routine kidney transplants between nonrelated donors and patients.

In addition to the Nobel Prize, Elion received many top awards: 1991 National Medal of Science presented by President George Bush, who said that her work had "transformed the world;" Garvan Medal from the American Chemical Society; President's Medal from Hunter College; Judd Award from Memorial-Sloan Kettering Institute; Cain Award from the American Association for Cancer Research; Ernst W. Bertner Memorial Award from the M. D. Anderson Cancer Center; City of Medicine Award in Durham, NC; Discoverers Award from the Pharmaceutical Manufacturers Association; Medal of Honor from the American Cancer Society; Ronald H. Brown Innovator Award; and the Lemelson/MIT Lifetime Achievement Award. Elion served as past president of the American Association for Cancer Research, and presidential appointee on the National Cancer Advisory Board. She belonged to the National Academy of Sciences, the Royal Society, the Institute of Medicine, the American Academy of Arts and Sciences, the National Women's Hall of Fame, and the Engineering and Science Hall of Fame.

(*Continued*)

Scientific Contributions of Thirteen Outstanding Female Scientists (*Continued*)

Rosalyn Sussman Yalow
(1921–2011)

Rosalyn Sussman Yalow was the first American woman to win the Albert Lasker Prize for Medicine (1976) and Nobel Prize for physiology or medicine (1977) for developing radioimmunoassay (RIA). This procedure uses radioactive isotopes to "tag" previously undetected concentrations of hormones, viruses, vitamins, enzymes, and drugs to study disease and biochemical reactions. In essence, RIA provided the technique that unlocked the field of endocrinology.

On accepting her Nobel Prize, Yalow spoke about women in science careers: "We must believe in ourselves or no one else will believe in us. We must feel a personal responsibility to ease the path for those who come after us. The world cannot afford the loss of the talents of half its people if we are to solve the many problems that beset us."

Yalow holds the title of Distinguished Service Professor from the Mount Sinai School of Medicine. She is a member of the National Academy of Sciences. Honors include Albert Lasker Basic Medical Research Award, A. Cressy Morrison Award in Natural Sciences of the New York Academy of Sciences, Scientific Achievement Award of the American Medical Association, Koch Award of the Endocrine Society, Gairdner Foundation International Award, American College of Physicians Award for distinguished contributions in science related to medicine, Eli Lilly Award of the American Diabetes Association, First William S. Middleton Medical Research Award, and 39 honorary degrees.

Christiane Nüsslein-Volhard
(1942–)

During the 1970s, developmental biologist Christiane Nüsslein-Volhard's research focused on the genetics of mutated fruit-fly embryos. In 1984, she expanded her research by cataloguing 120 well-defined genes that affected the entire embryonic pattern of the fruit fly's development. She received the 1995 Nobel Prize in medicine or physiology (with colleague Eric Wieschaus) for pioneering molecular biology and genetics studies of specific areas of a gene that contributes to mammalian immune system development. Her discoveries had universal application because the same genetic parts that govern gene activity in different cells also similarly operate in plants and many animal organisms, including humans. Defective parts in genes that modulate early growth and development trigger congenital disorders such as spina bifida and cleft palate in humans. Because genes encoding the same protein affect a variety of conditions (e.g., arteriosclerosis, organ rejection, AIDS, and other maladies), the scope of her discoveries had wide-ranging applications. Her awards include membership in the National Academy of Sciences and Royal Society and honorary degrees from Harvard, Yale, and Princeton.

Lise Meitner
(1878–1968)

Lise Meitner was the first woman to earn a doctoral degree in physics at the University of Vienna in 1906, which had previously awarded only 14 doctorates to women in the prior 541 years. Meitner worked at the Kaiser-Wilhelm Institute with radiochemist Otto Hahn (eventual Nobel Prize winner). They discovered the 91st element, *protactinium,* and studied neutron bombardment of uranium. Meitner became joint director of the Institute and head of the Physics Department in 1917. After fleeing Nazi Germany in 1938, she worked at the Nobel Physical Institute in Stockholm, continuing her research with nephew Otto Frisch. Meitner predicted that the atom's nucleus captures neutrons, causing enough instability to pinch it in two, much like a water droplet splitting into two parts. According to Einstein's equation $E = mc^2$, an observed loss of mass must unleash energy. Meitner, combining Bohr's liquid-drop model of the nucleus and Einstein's equation, predicted that a proposed experiment by Hahn should yield barium, krypton, and energy. Within days, she and Frisch worked out a theoretical model for nuclear fission. Frisch, hastily working in Bohr's institute in Copenhagen to test Meitner's expectations, quickly verified the theory. The Meitner-Frisch paper introducing nuclear fission appeared in early 1939. Their momentous discovery (they had split the uranium nucleus) was termed "fission" and predicted the existence of the chain reaction that contributed to the development of the atomic bomb.

During World War II, Meitner refused to work on the atomic bomb. In 1947, the Swedish Atomic Energy Commission established a laboratory where she continued to work on an experimental nuclear reactor. She received the Max Planck Medal, the Leibnitz Medal, and in 1966 she shared the Fermi Award. In 1946, Otto Hahn received the Nobel Prize for his work on fission. Interestingly, he failed to acknowledge that Mietner's ideas had stimulated his research—contributions that many in science believed were considerable. Though denied the Nobel Prize, an international commission in 1994 named element 109, artificially created by slamming bismuth with iron ions, meitnerium.

McArdle WD, Katch FI, Katch VL. "Introduction: A View from the Past." In *Exercise Physiology: Nutrition, Energy, and Human Performance*, 8th ed. Baltimore, MD: Wolters Kluwer, 2015.

Scientific Contributions of Thirteen Outstanding Female Scientists (*Continued*)

Rosalind Franklin
(1920–1958)

A graduate of Cambridge University who specialized in chemistry, Franklin's expertise focused on understanding the chemical (atomic) structure of complex organic compounds. She perfected the technique of x-ray crystallography that locates atoms in any crystal by precisely mapping the image of the crystal under an x-ray beam. Using an extremely fine beam of x-rays, Franklin produced high-resolution photographs of single DNA fibers. These fibers, finer than ever seen before, were then arranged in parallel bundles. Her results showed that DNA's sugar-phosphate backbone lies on its outside; in essence, she elucidated the basic helical structure of the molecule. Unfortunately, Franklin's notes and photographs about the discovery were made available (without her permission) to Watson and Crick at Cambridge University, who were rushing to determine DNA's final structure. Within days, Watson and Crick applied Franklin's data to complete their own detailed and ultimately correct description of DNA's structure.

The strained relationship with her immediate supervisor (Maurice Wilkins) and other aspects about King's College where she worked (women scientists were forbidden to eat lunch in the common room with men) led Franklin to seek employment elsewhere. She turned her attention to tobacco mosaic viruses, publishing 17 papers in 5 years—a body of knowledge that formed the basis for structural virology. Franklin began work on the polio virus before succumbing to ovarian cancer in 1958. Ten years after deciphering the double-helix structure (and following Franklin's death), Watson, Crick, and Wilkins received the Nobel Prize in physiology or medicine, thus forever denying Franklin the formal credit she richly deserved for her crucial discovery of DNA's helical structure.

Chien-Shiung Wu
(1912–1997)

A pioneering physicist, Wu radically altered modern physical theory by changing the accepted view of the structure of the universe. Her experiments helped to demolish a proposed "law" of nature concerning the conservation of parity. Wu was the first woman to receive the prestigious Research Corporation Award and the Comstock Prize—given once every 5 years from the National Academy of Sciences—for her contributions to atomic research (understanding of beta decay and the weak interactions) on the Manhattan Project.

Wu became the first woman to receive an honorary Doctorate of Science from Princeton University (and 10 other doctorates, including ones from Harvard and Yale), was elected first woman president of the American Physical Society, received the first Wolf Prize from the State of Israel, was awarded a full-professorship and endowed chair (Pupin Professor of Physics) at Columbia University, became the seventh woman elected to the National Academy of Sciences, and was awarded the National Medal of Science prize, the nation's highest science award. And complementing her accomplishments, she was the first living scientist to have an asteroid named after her.