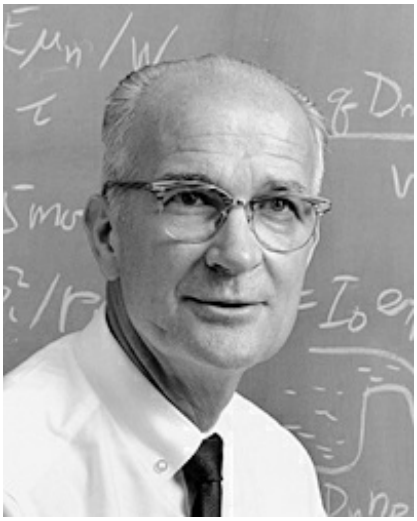
William Shockley

For other uses, see William Shockley (disambiguation).

William Shockley	
	
Born	William Bradford Shockley Jr. (Junior) (1910-02-13)February 13, 1910 Greater London, England, United Kingdom
Died	August 12, 1989(1989-08-12) (aged 79) Stanford, California, United States
Nationality	American
Alma mater	• MIT • Caltech
Known for	
Awards	
Scientific career	
Institutions	
Doctoral advisor	John C. Slater

William Bradford Shockley Jr. (; February 13, 1910 – August 12, 1989) was an American physicist and inventor. Shockley was the manager of a research group at Bell Labs that included John Bardeen and Walter Brattain. The three scientists were jointly awarded the 1956

Nobel Prize in Physics for "their researches on semiconductors and their discovery of the transistor effect."

Shockley's attempts to commercialize a new transistor design in the 1950s and 1960s led to California's "Silicon Valley" becoming a hotbed of electronics innovation. In his later life, Shockley was a professor of electrical engineering at Stanford University and became a proponent of eugenics.[1][2]

Early life and education

Shockley was born in London, to American parents, and raised in his family's hometown of Palo Alto, California from the age of three.[3] His father, William Hillman Shockley, was a mining engineer who speculated in mines for a living and spoke eight languages. His mother, Mary (née Bradford), grew up in the American West, graduated from Stanford University and became the first female US Deputy mining surveyor.[4]

Shockley earned his Bachelor of Science degree from Caltech in 1932 and a PhD from MIT in 1936. The title of his doctoral thesis was *Electronic Bands in Sodium Chloride*, a topic suggested by his thesis advisor, John C. Slater.[5] After receiving his doctorate, Shockley joined a research group headed by Clinton Davisson at Bell Labs in New Jersey. The next few years were productive for Shockley. He published a number of fundamental papers on solid state physics in Physical Review. In 1938, he got his first patent, "Electron Discharge Device", on electron multipliers.[6]

Career

When World War II broke out, Shockley became involved in radar research at Bell Labs in Manhattan (New York City). In May 1942, he took leave from Bell Labs to become a research director at Columbia University's Anti-Submarine Warfare Operations Group.[7] This involved devising methods for countering the tactics of submarines with improved convoying techniques, optimizing depth charge patterns, and so on. This project required frequent trips to the Pentagon and Washington, where Shockley met many high-ranking officers and government officials. In 1944, he organized a training program for B-29 bomber pilots to use new radar bomb sights. In late 1944 he took a three-month tour to bases around the world to assess the results. For this project, Secretary of War Robert Patterson awarded Shockley the Medal for Merit on October 17, 1946.[8]

In July 1945, the War Department asked Shockley to prepare a report on the question of probable casualties from an invasion of the Japanese mainland. Shockley concluded:

> If the study shows that the behavior of nations in all historical cases comparable to Japan's has in fact been invariably consistent with the behavior of the troops in battle, then it means that the Japanese dead and ineffectives at the time of the defeat will exceed the corresponding number for the Germans. In other words, we shall probably have to kill at least 5 to 10 million Japanese. This might cost us between 1.7 and 4 million casualties including 400,000 to 800,000 killed.[9]

This report influenced the decision of the United States to drop atomic bombs on Hiroshima and Nagasaki, which precipitated the unconditional surrender of Japan.[10]

Shockley was the first physicist to propose a lognormal distribution to model the creation process for scientific research papers.[11]

Development of the transistor

Shortly after the war ended in 1945, Bell Labs formed a solid-state physics group, led by Shockley and chemist Stanley Morgan, which included John Bardeen, Walter Brattain, physicist Gerald Pearson, chemist Robert Gibney, electronics expert Hilbert Moore, and several technicians. Their assignment was to seek a solid-state alternative to fragile glass vacuum tube amplifiers. Its first attempts were based on Shockley's ideas about using an external electrical field on a semiconductor to affect its conductivity. These experiments failed every time in all sorts of configurations and materials. The group was at a standstill until Bardeen suggested a theory that invoked surface states that prevented the field from penetrating the semiconductor. The group changed its focus to study these surface states and they met almost daily to discuss the work. The rapport of the group was excellent, and ideas were freely exchanged.[12]

By the winter of 1946 they had enough results that Bardeen submitted a paper on the surface states to *Physical Review*. Brattain started experiments to study the surface states through observations made while shining a bright light on the semiconductor's surface. This led to several more papers (one of them co-authored with Shockley), which estimated the density of the surface states to be more than enough to account for their failed experiments. The pace of the work picked up significantly when they started to surround point contacts between the semiconductor and the conducting wires with electrolytes. Moore built a circuit that allowed them to vary the frequency of the input signal easily. Finally they began to get some evidence of power amplification when Pearson, acting on a suggestion by Shockley, put a voltage on a droplet of glycol borate (a viscous chemical that did not evaporate, commonly used in electrolytic capacitors, and obtained by puncturing an example capacitor with a nail, using a hammer) placed across a P-N junction.[13]

Bell Labs' attorneys soon discovered Shockley's field effect principle had been anticipated and devices based on it patented in 1930 by Julius Lilienfeld, who filed his MESFET-like patent in Canada on October 22, 1925.[14][15] Although the patent appeared "breakable" (it could not work) the patent attorneys based one of its four patent applications only on the Bardeen-Brattain point contact design. Three others (submitted first) covered the electrolyte-based transistors with Bardeen, Gibney and

John Bardeen, William Shockley and Walter Brattain at Bell Labs, 1948.

Brattain as the inventors. Shockley's name was not on any of these patent applications. This angered Shockley, who thought his name should also be on the patents because the work was based on his field effect idea. He even made efforts to have the patent written only in his name, and told Bardeen and Brattain of his intentions.[16]

Shockley, angered by not being included on the patent applications, secretly continued his own work to build a different sort of transistor based on junctions instead of point contacts; he expected this kind of design would be more likely to be commercially viable. The point contact transistor, he believed, would prove to be fragile and difficult to manufacture. Shockley was also dissatisfied with certain parts of the explanation for how the point contact transistor worked and conceived of the possibility of minority carrier injection. On February 13, 1948 another team member, John N. Shive, built a point contact transistor with bronze contacts on the front and back of thin wedge of germanium, proving that holes could diffuse through bulk germanium and not just along the surface as previously thought.[17]:153[18]:145 Shive's invention sparked[19] Shockley's invention of the junction transistor.[17]:143 A few months later he invented an entirely new, considerably more robust, type of transistor with a layer or 'sandwich' structure. This structure went on to be used for the vast majority of all transistors into the 1960s, and evolved into the bipolar junction transistor. Shockley later admitted that the workings of the team were "mixture of cooperation and competition." He also admitted that he kept some of his own work secret until his "hand was forced" by Shive's 1948 advance.[20] Shockley worked out a rather complete description of what he called the "sandwich" transistor, and a first proof of principle was obtained on April 7, 1949.

Meanwhile, Shockley worked on his magnum opus, *Electrons and Holes in Semiconductors* which was published as a 558-page treatise in 1950. The tome included Shockley's critical ideas of drift and diffusion and the differential equations that govern the flow of electrons in solid state crystals. Shockley's diode equation is also described. This seminal work became the reference text for other scientists working to develop and improve new variants of the transistor and other devices based on semiconductors.[21]

This resulted in his invention of the bipolar "junction transistor", which was announced at a press conference on July 4, 1951.[22]

In 1951, he was elected to the National Academy of Sciences (NAS). He was forty-one years old; this was rather young for such an election. Two years later, he was chosen as the recipient of the prestigious Comstock Prize[23] for Physics by the NAS, and was the recipient of many other awards and honors.

The ensuing publicity generated by the "invention of the transistor" often thrust Shockley to the fore, much to the chagrin of Bardeen and Brattain. Bell Labs management, however, consistently presented all three inventors as a team. Though Shockley would correct the record where reporters gave him sole credit for the invention,[24] he eventually infuriated and alienated Bardeen and Brattain, and he essentially blocked the two from working on the junction transistor. Bardeen began pursuing a theory for superconductivity and left Bell Labs in

1951. Brattain refused to work with Shockley further and was assigned to another group. Neither Bardeen nor Brattain had much to do with the development of the transistor beyond the first year after its invention.[25]

Shockley Semiconductor

Main article: Shockley Semiconductor Laboratory
In 1956 Shockley moved from New Jersey to Mountain View, California to start Shockley Semiconductor Laboratory to live closer to his ailing mother in Palo Alto, California.[26][27] The company, a division of Beckman Instruments, Inc., was the first establishment working on silicon semiconductor devices in what came to be known as Silicon Valley.

"His way" could generally be summed up as domineering and increasingly paranoid. In one well-known incident, he claimed that a secretary's cut thumb was the result of a malicious act and he demanded lie detector tests to find the culprit, when in reality, the secretary had simply grabbed at a door handle that happened to have an exposed tack on it for the purpose of hanging paper notes on.[28] After he received the Nobel Prize in 1956 his demeanor changed, as evidenced in his increasingly autocratic, erratic and hard-to-please management style.[29] In late 1957, eight of Shockley's researchers, who would come to be known as the "traitorous eight", resigned after Shockley decided not to continue research into silicon-based semiconductors.[30] They went on to form Fairchild Semiconductor, a loss from which Shockley Semiconductor never recovered. Over the course of the next 20 years, more than 65 new enterprises would end up having employee connections back to Fairchild.[31]

A group of about thirty colleagues who had met on and off since 1956 met again at Stanford in 2002 to reminisce about their time with Shockley and his central role in sparking the information technology revolution. The group's organizer said, "Shockley is the man who brought silicon to Silicon Valley."[32]

Political views

See also: Flynn effect and History of the race and intelligence controversy
Late in his life, Shockley became intensely interested in questions of race, human intelligence, and eugenics. He thought this work was important to the genetic future of the human species and he came to describe it as the most important work of his career, even though expressing his views damaged his reputation. Shockley argued that a higher rate of reproduction among the less intelligent was having a dysgenic effect, and that a drop in average intelligence would ultimately lead to a decline in civilization. With regard to racial differences he used the following standard phrase, e.g., on a debate with Afro-centrist Frances Welsing and on Firing Line with William F. Buckley Jr.:

> My research leads me inescapably to the opinion that the major cause of the American Negro's intellectual and social deficits is hereditary and racially genetic in origin and, thus, not remediable to a major degree by practical improvements in the environment.[33]

Shockley's published writings and lectures to scientific organizations on this topic were partly based on the writings of psychologist Cyril Burt and were funded by the Pioneer Fund. Shockley also proposed that individuals with IQs below 100 be paid to undergo voluntary sterilization.[34]

Anthropologist Roger Pearson, whose writings are based on an evolutionary and racialist[35] approach, has defended Shockley in a self-published book co-authored with Shockley.[36] University of Wisconsin–Milwaukee professor Edgar G. Epps[37] argued that "William Shockley's position lends itself to racist interpretations".[38]

In 1981 he filed a libel suit against the *Atlanta Constitution* after a science writer, Roger Witherspoon, compared Shockley's advocacy of a voluntary sterilization program to Nazi experiments on Jews. The suit took three years to go to trial. Shockley won the suit but received only one dollar in actual damages[39] and no punitive damages. Shockley's biographer Joel Shurkin, a science writer on the staff of Stanford University during those years, sums this up as saying that the statement was defamatory, but Shockley's reputation was not worth much by the time the trial reached a verdict.[40] Shockley taped his telephone conversations with reporters, and then sent the transcript to them by registered mail. At one point he toyed with the idea of making them take a simple quiz on his work before discussing the subject with them. His habit of saving all his papers (including laundry lists) provides abundant documentation for researchers on his life.[41]

Personal life

While still a student, Shockley married Jean Bailey at age 23 in August 1933. In March 1934, the couple had a daughter, Alison. Shockley became an accomplished rock climber, going often to the Shawangunks in the Hudson River Valley, where he pioneered a route across an overhang, known to this day as "Shockley's Ceiling."[13] Shockley was popular as a speaker, lecturer, and an amateur magician. He once "magically" produced a bouquet of roses at the end of his address before the American Physical Society. He was also known in his early years for his elaborate practical jokes.[42]

Shockley donated sperm to the Repository for Germinal Choice, a sperm bank founded by Robert Klark Graham in hopes of spreading humanity's best genes. The bank, called by the media the "Nobel Prize sperm bank," claimed to have three Nobel Prize-winning donors, though Shockley was the only one to publicly acknowledge his donation to the sperm bank. However, Shockley's controversial views brought the Repository for Germinal Choice a degree of notoriety and may have discouraged other Nobel Prize winners from donating sperm.[43]

When Shockley was eased out of the directorship of Shockley Semiconductor, he joined Stanford University, where in 1963 he was appointed the Alexander M. Poniatoff Professor of Engineering and Applied Science, in which position he remained until his retirement as professor emeritus in 1975.[44]

Death

Shockley died of prostate cancer in 1989 at the age of 79.[45] At the time of his death, he was almost completely estranged from most of his friends and family, except his second wife, the former Emmy Lanning (1913–2007). His children reportedly learned of his death by reading newspapers.[46] Shockley is interred at Alta Mesa Memorial Park in Palo Alto, California.

Honors

Patents

Shockley was granted over ninety US patents. Some notable ones are:

- US 2502488 *Semiconductor Amplifier*. Apr. 4, 1950; his first granted patent involving transistors.
- US 2569347 *Circuit element utilizing semiconductive material*. Sept. 25, 1951; His earliest applied for (June 26, 1948) patent involving transistors.
- US 2655609 *Bistable Circuits*. Oct. 13, 1953; Used in computers.
- US 2787564 *Forming Semiconductive Devices by Ionic Bombardment*. Apr. 2, 1957; The diffusion process for implantation of impurities.
- US 3031275 *Process for Growing Single Crystals*. Apr. 24, 1962; Improvements on process for production of basic materials.
- US 3053635 *Method of Growing Silicon Carbide Crystals*. Sept. 11, 1962; Exploring other semiconductors.

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Notes

1. ^ Saxon 1989
2. ^ Sparks, Hogan & Linville 1991, pp. 130–132
3. ^ *"IEEE Xplore Full-Text PDF:". ieeexplore.ieee.org.*
4. ^ Shurkin 2006, p. 5
5. ^ Shurkin 2006, pp. 38–39
6. ^ Shurkin 2006, p. 48
7. ^ *Broken Genius* p. 65–67
8. ^ **a** **b** Shurkin 2006, p. 85
9. ^ Giangreco 1997, p. 568
10. ^ *Newman, Robert P. (1998). "Hiroshima and the Trashing of Henry Stimson". The New England Quarterly. **71** (1): 27. doi:10.2307/366722.*
11. ^ The Artful Universe by John D. Barrow, Clarendon Press, Oxford, 1995, p. 239
12. ^ Brattain quoted in *Crystal Fire* p. 127
13. ^ **a** **b** *Crystal Fire* p.132
14. ^ CA 272437 "Electric current control mechanism", first filed in Canada on 22 October 1925
15. ^ Lilienfeld Archived October 2, 2006, at the Wayback Machine.
16. ^ *"William Shockley". IEEE Global History Network. IEEE. Retrieved 18 July 2011.*
17. ^ **a** **b** *Michael Riordan & Lillian Hoddeson. Crystal fire: the invention of the transistor and the birth of the information age. ISBN 978-0-393-31851-7.*
18. ^ *Hoddeson, Lillian; Daitch, Vicki (2002). True genius: the life and science of John Bardeen : the only winner of two Nobel prizes in physics. Joseph Henry Press. ISBN 0-309-08408-3. Retrieved 30 December 2014. Lay summary – American Scientist (30 December 2014).*
19. ^ Brittain 1984, p. 1695 "an observation that William Shockley interpreted as confirmation of his concept of that junction transistor"
20. ^ *"Inventors of the transistor followed diverse paths after 1947 discovery". Associated press - Bangor Daily news. December 25, 1987. Retrieved May 6, 2012. '"mixture of cooperation and competition' and 'Shockley, eager to make his own contribution, said he kept some of his own work secret until "my hand was forced" in early 1948 by an advance reported by John Shive, another Bell Laboratories researcher'"*
21. ^ *Broken Genius*, p 121-122
22. ^ *"1951 - First grown-junction transistors fabricated". Computer History Museum. 2007. Retrieved 3 July 2013.*

23. ^ *"Comstock Prize"*.
24. ^ *ScienCentral, ScienCentral. "Bill Shockley, Part 3 of 3". www.pbs.org.*
25. ^ *Crystal Fire* p. 278
26. ^ *"Holding On". New York Times. April 6, 2008. Retrieved 2014-12-07. "In 1955, the physicist William Shockley set up a semiconductor laboratory in Mountain View, partly to be near his mother in Palo Alto. ..."*
27. ^ *"Two Views of Innovation, Colliding in Washington". New York Times. January 13, 2008. Retrieved 2014-12-07. "The co-inventor of the transistor and the founder of the valley's first chip company, William Shockley, moved to Palo Alto, Calif., because his mother lived there. ..."*
28. ^ *Crystal Fire* p. 247
29. ^ PBS program - American Experience (2012) 'Silicon Valley'
30. ^ Goodheart, 2006 & "Fed up with their boss, eight lab workers walked off the job on this day in Mountain View, Calif. Their employer, William Shockley, had decided not to continue research into silicon-based semiconductors; frustrated, they decided to undertake the work on their own. The researchers — who would become known as 'the traitorous eight' — went on to invent the microprocessor (and to found Intel, among other companies).
31. ^ *Gregory Gromov. "A legal bridge spanning 100 years: from the gold mines of El Dorado to the "golden" startups of Silicon Valley".*
32. ^ *Dawn Levy (22 October 2002). "William Shockley: still controversial, after all these years" (Press release). Stanford University.*
33. ^ *"Firing Line with William F. Buckley Jr.: Shockley's Thesis (Episode S0145, Recorded on June 10, 1974)". Retrieved 17 September 2017.*
34. ^ *BOYER, EDWARD J. (14 August 1989). "Controversial Nobel Laureate Shockley Dies". Los Angeles Times. Retrieved 11 May 2015.*
35. ^ "Evolution cannot occur unless 'favorable' genes are segregated out from amongst 'unfavorable" genetic formulae' [...] any population that adopts a perverted or dysgenic form of altruism – one which encourages a breeding community to breed disproportionately those of its members who are genetically handicapped rather than from those who are genetically favored, or which aids rival breeding populations to expand while restricting its own birthrate – is unlikely to survive into the definite future." – Pearson, Roger (1995b). "The Concept of Heredity in Western Thought: Part Three, the Revival of Interest in Genetics," *The Mankind Quarterly*, 36, pp. 96, 98."
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38. ^ *Epps, Edgar G (February 1973). "Racism, Science, and the I.Q." Integrated Education. **11** (1): 35–44. doi:10.1080/0020486730110105.*
39. ^ *Kessler, Ronald. "Absent at the Creation; How one scientist made off with the biggest invention since the light bulb". Archived from the original on 2015-02-24.*
40. ^ Shurkin 2006, pp. 259–260 "Essentially, the jury agreed that Witherspoon's column

met the standards of defamation, but that by then, Shockley's reputation wasn't worth very much."

41. ^ Shurkin 2006, p. 286
42. ^ *Crystal Fire* p. 45
43. ^ *Polly Morrice (2005-07-03). "The Genius Factory: Test-Tube Superbabies". The New York Times. Retrieved 2008-02-12.*
44. ^ *Crystal Fire* p.277
45. ^ *"William B. Shockley, 79, Creator of Transistor and Theory on Race". New York Times. 14 August 1989. Retrieved 2007-07-21. "He drew further scorn when he proposed financial rewards for the genetically disadvantaged if they volunteered for sterilization."*
46. ^ *ScienCentral, Inc., and The American Institute of Physics (1999). "William Shockley (Part 3 of 3): Confusion over Credit". Retrieved 1 January 2015.*
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Other notes

- Park, Lubinski & Benbow 2010, "There were two young boys, Luis Alvarez and William Shockley, who were among the many who took Terman's tests but missed the cutoff score. Despite their exclusion from a study of young 'geniuses,' both went on to study physics, earn PhDs, and win the Nobel prize."
- Leslie 2000, "We also know that two children who were tested but *didn't* make the cut -- William Shockley and Luis Alvarez -- went on to win the Nobel Prize in Physics. According to Hastorf, none of the Terman kids ever won a Nobel or Pulitzer."
- Shurkin 2006, p. 13 (See also "The Truth About the 'Termites'" Kaufman, S. B. 2009)
- Simonton 1999, p. 4 "When Terman first used the IQ test to select a sample of child geniuses, he unknowingly excluded a special child whose IQ did not make the grade. Yet a few decades later that talent received the Nobel Prize in physics: William Shockley, the cocreator of the transistor. Ironically, not one of the more than 1,500 children who qualified according to his IQ criterion received so high an honor as adults."
- Eysenck 1998, pp. 127–128 "Terman, who originated those 'Genetic Studies of Genius', as he called them, selected ... children on the basis of their high IQs; the mean was 151 for both sexes. Seventy-seven who were tested with the newly translated and standardized Binet test had IQs of 170 or higher—well at or above the level of Cox's geniuses. What happened to these potential geniuses—did they revolutionize society? ... The answer in brief is that they did very well in terms of achievement, but none reached the Nobel Prize level, let alone that of genius. ... It seems clear that these data powerfully confirm the suspicion that intelligence is not a sufficient trait for truly creative achievement of the highest grade."

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