

**True Genius.** Lillian Hoddeson and Vicki Daitch. Joseph Henry Press, Washington DC, USA. 2002.

Double winners of the Nobel Prize are rare – Madame Curie won the Prize for Physics and Chemistry, Linus Pauling for Chemistry and Peace, Frederick Sanger for Chemistry and Medicine. John Bardeen has the unique honour of winning two Prizes in Physics, in 1956 with Walter Brattain and William Shockley for the invention of the transistor, and again in 1972 with Leon Cooper and Robert Schrieffer for the BCS theory of superconductivity. With two such laurels under his belt, it is surprising that Bardeen never became a household name in USA nor a cult figure in science. When I looked for the new biography, *True Genius: The Life and Science of John Bardeen* by Lillian Hoddeson and Vicki Daitch, at the MIT Coop in Cambridge, nobody in the shop had heard of the man. Eleven years after his death, the authors attempt to explain the psyche and the science of this unobtrusive genius.

Hoddeson had earlier co-authored *Crystal Fire*, an authoritative and entertaining history of the Bell Telephone Laboratories where the transistor was discovered by Bardeen, Brattain and Shockley in December 1947. She explained how no one, not even the inventors, could gauge the impact the transistor would have. After all it was designed to be merely a cheaper and more reliable replacement for the vacuum tube!

The discovery of superconductivity in 1911 by Kamerlingh Onnes was truly pathbreaking as the first evidence of a macroscopic quantum phenomenon, i.e. it could not be explained invoking classical theories of Maxwell and Drude. Onnes, found quite by chance, that below a certain temperature the element mercury lost all its electrical resistance. Despite many attempts by stalwarts such as Heisenberg, Landau and Feynman, the phenomenon remained unexplained for four and a half decades. The problem was finally cracked in 1957 by a team of three scientists from the University of Illinois, led by a soft-spoken mid-Westerner, a co-discoverer of the transistor, John Bardeen. Superconductor technology, though not as immediately successful as transistors, holds the promise to revolutionize 21st Century technology with ‘Maglev’ trains, lossless power

transmission and ultra-high sensitivity MRI devices.

Bardeen was born in Madison, Wisconsin and though his high school records were not exceptional, he showed great skill in mathematics. His undergraduate training was in Electrical Engineering at the University of Wisconsin where he had the opportunity to attend lecture courses by Debye and Dirac. He had a spell as an engineer working in geophysics with Gulf Oil at Pittsburgh but his interest in mathematics and physics prompted him to seek a change in career and take up graduate studies in Princeton where he found Eugene Wigner as adviser. His thesis topic was calculation of the work function of metals, starting with the Hartree-Fock technique and getting into a many-body approach. This foray into the study of surfaces was to stand him in good stead when he and Brattain came to study field-effect in semiconductors and resulted in Bardeen’s classic paper on surface states.

Bardeen then went to Harvard as a postdoc and made his first attempts at understanding superconductivity. One of the problems he worked on was trying to explain the results of O’Byrne and Skinner at MIT, on the sharpness of the Fermi surface of metals. In this he was unsuccessful – nor did he succeed in his attempts to explain ‘exchange forces’. In spite of this, he said that the time he spent at Harvard were ‘the most influential years of my life’. He was probably recognizing the training he got in tackling difficult problems and honing his skills as a theoretical physicist. Bridgman, the pioneer in high-pressure physics, was perhaps his greatest influence in Harvard. Bardeen devised a semi-empirical theory to predict the pressure for the phase transition from bcc to fcc in cesium, the first such calculation. Bridgman was extremely pleased when his experimental results agreed with Bardeen’s prediction.

His first teaching assignment was at the University of Minnesota from where he was reluctantly dragged out during the Second World War to the Naval Ordnance Laboratory in Washington. Here he worked on problems related to the design of mines and torpedoes. This work, strangely enough, brought him into contact with Einstein who had an idea ‘for an induction coil placed inside a torpedo’. Unfortunately, Einstein’s idea of having a plastic warhead or window to avoid attenuation due to steel, could not be

realized for wartime use. In 1945 Bardeen moved to Bell Telephone Laboratories as a Member of the Technical Staff and the rest, as they say, is history.

By 1950 Bardeen was seeking to move out of Bell Labs for a number of reasons. He was not interested in the improvement, design or manufacture of transistors nor was he happy working under the domineering personality of William Shockley, who went so far as to ban both Bardeen and Brattain from working on ‘his baby’ the junction transistor! So, after some soul-searching, Bardeen moved to the University of Illinois in 1951, where he was to remain for the rest of his life.

Bardeen consulted for companies notably Xerox and travelled the world attending conferences receiving many honours but Champaign – Urbana remained his intellectual home. This was an astute choice, since it allowed him to form a research group and concentrate on The Holy Grail of Physics – explaining superconductivity. There was for him no resting with the laurel of one Nobel Prize. With his graduate student John Schrieffer and postdoc Leon Cooper he finally cracked the problem in 1957 – at the age of 49! The BCS theory has become the ‘standard model’ of superconductivity. It was indeed novel in that it proposed that two negatively charged electrons which would normally repel each other, could ‘attract’ and form a pair through the mediation of lattice vibrations, phonons. This theory explained both the Meissner and isotope effects in conventional superconductors. An important by-product of the BCS theory was the notion of ‘broken symmetry’ which was later introduced by Yoichiro Nambu into the theoretical framework of particle physics. At Illinois, Slichter and his student Hebel were among the first to experimentally confirm the BCS theory through NMR measurements on aluminium.

Fond of a Sunday picnic with the family or a round of golf, he did not like big-city life. Proud of his golfing prowess he is reputed to have said, ‘Two Nobels are better than one hole in one’! He married Jane Maxwell, a science teacher, after a long courtship and was a model father, with two of his children following him into science. His life was quiet and devoid of drama. In his physics though, there was excitement enough. One of the most well-known incidents was his encounter with Brian Josephson, then a Cambridge graduate student, at a meet-

ing in London in 1962 just after the latter had proposed the possibility of pair tunnelling in superconductors. Bardeen disagreed but Josephson stuck to his guns. An interesting exchange followed, as narrated in the book. Experiments soon proved that Josephson was right and Bardeen was quick to acknowledge this. The Josephson effect has now become important as a frequency standard and in the detection of very weak magnetic fields. This was recognized by a Nobel Prize in 1973.

Bardeen and his wife visited India in 1977, spending three weeks at the Indian Institute of Science (IISc), Bangalore. At the instance of the then Director of IISc, Satish Dhawan, I was privileged to act as his guide during this visit. He was the antithesis of the common idea of a fast-talking, media-savvy American professor – mild-mannered and soft-spoken to a fault. He thought that science was an area in which there could be international cooperation rather than competition. He was of the opinion that India should not blindly borrow American technology, but develop or adapt technology according to its needs. ‘Science for improving the quality of life’ was a motto that he inherited from his father, a Dean of Medicine at the University of Wisconsin. Thus it was natural for him to be a strong opponent of the Star Wars Initiative (SDI) in the eighties, resigning from US President Reagan’s Science Council on this issue.

He gave two lectures on his discoveries in Bangalore to packed audiences. To the inevitable comparison between his two major achievements, he said that he considered the superconductivity work the greater intellectual challenge while the invention of the transistor was more a collaboration between the experimentalist Walter Brattain and him, with Shockley as the group leader. Nearing seventy, he was actively pursuing the idea of superconductivity at a higher temperature and had proposed an excitonic mechanism (attraction between an electron and a

hole) which however did not quite work out. He also churned up the subject of charge density waves, where he courted more controversy than throughout his entire career.

A word about his style in physics. Unlike his mentor Wigner, Bardeen did not care too much for elegance in problem-solving but preferred to ‘bully through’ to the answer. He learnt to divide a problem into sub-problems, a technique he picked up from Wigner, one that psychologists call ‘problem decomposition’. Perseverance and single-minded concentration on a few important problems were his hallmark. As a group leader, his choice of collaborators with expertise in different areas, e.g. Cooper was a high-energy field-theorist, was another key to his success. Tackling the problem of superconductivity, he asked Schrieffer to look at the thermodynamic properties, Cooper to examine the Meissner effect and other electrodynamic properties while he himself worked on the transport and non-equilibrium properties. Thus it was Cooper who thought up the idea of electron-pairing and Schrieffer who provided the breakthrough in developing the appropriate wave function. His work was heavily grounded in experimentation and he enjoyed collaboration as evident from both his prizes. How to choose a good physics problem? His answer was first, to see whether there was a technological basis; second, whether it was challenging and third, whether it had applications potential.

Hoddeson and Daitch have a final chapter on what constitutes ‘genius’. Invoking the ideas of Kuhn, they propose a criterion in science, as one who creates a change of paradigm. There is no doubt that Bardeen satisfied this criterion through his breakthrough in solving the first many-body problem in condensed matter physics, which had far-ranging implications in branches such as particle physics and astrophysics. A word of caution – the book is not for specialists

in superconductivity as it does not deal with all the nuances of the subject nor does it give a strict chronological history. It accomplishes what it set out to do – explore the thinking of one man. The bibliography does list the important scientific papers of Bardeen and his contemporaries which makes it a useful reference. Also listed are the names of the 31 graduate students he guided between 1952 and 1974, with their thesis titles.

The book discloses the fact Bardeen himself proposed the names of Cooper and Schrieffer several times for the Nobel Prize for their work on superconductivity, but ended up winning it jointly with his colleagues. The award of this year’s Nobel Prize to Abrikosov, Ginzburg and Leggett is further indication of his continuing influence. Abrikosov, a student of Landau, was inspired by Bardeen during his first visit to the USSR in 1960 and considered him a second mentor, visiting Illinois on several occasions. Landau, Ginzburg, Abrikosov and Gorkov developed the theory of type-II superconductors, the ‘dirty’ superconductors with high critical fields necessary for applications. The Englishman Leggett was a postdoctorate fellow with Bardeen in the sixties and later joined as a faculty member. His research was on the nature of superfluid helium, which exists below milli-degrees Kelvin, discovered earlier by Richardson, Lee and Osheroff.

A quiet gentleman of science, Bardeen counted among his graduate students luminaries such as Nick Holonyak, father of the light emitting diode, Dan Mattis and Bill McMillan. A deviant from the common concept of genius – neither an eccentric loner, nor a flamboyant showman – but a true genius nonetheless!

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