The Story of a University Student and the Discovery of the Josephson Effect

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There is a small pond by the side of the (new) Cavendish Laboratory at the west site of University of Cambridge. Once I had taken a visitor to that favourite spot of mine. A cyclist with a helmet was passing by. The cyclist was moving his head in a slight circulatory motion as he cycled past. The visitor was slightly amused at this sight and made a comment. I told him that he had just seen Prof Brian Josephson – the discoverer of quantum tunnelling effect named after him. The visitor's jaws dropped in awe. Such was the magic of Cambridge.

I took particular pride in Josephson's achievement since he was a Fellow of my first College at Cambridge – the Trinity College. Brian David Josephson was born in1940, and won the Nobel Prize in Physics in 1973.

For me, Prof David Shoenberg – the famous low-temperature physicist (an FRS and a Fellow of Gonville and Caius College, Cambridge) has been a source of several inspiring stories of how science grew at Cambridge. Since my first day of joining Caius as a Fellow, this kind-hearted great man has given me affection, friendship, encouragement and insight. Other than David, I have gathered the following story about the discovery of Josephson Effect by studying directly the writings and interview of the Nobel Laureate Philip Anderson, the famous American physicist working at Bell Telephone Laboratory. Anderson wrote [1] that, other than himself, two other physicists could also give authentic account of Josephson's discovery – they were Prof. Brian Pippard and Prof. David Shoenberg, both of whom were at the Cavendish Laboratory during my time at Cambridge. What fascinates me in the story is the fact that Josephson made his earth-shaking impact in science while he was still a student at the University of Cambridge, just like Frank Whittle inventing the turbojet engine and Francis Crick discovering the double-helix structure of the DNA molecule.

Philip Anderson described Brian Josephson as a prodigy [2]. While still an undergraduate student, Josephson published an important paper on the Mössbauer effect. Josephson was otherwise a very shy student but after attending any lecture he had the habit of coming up to the lecturer pointing out mistakes in the lecture! Philip Anderson offered courses, during his stay at University of Cambridge during 1961-62, on solid-state and many-body theory. Josephson attended these lectures. Anderson recounts [1]: "This was a disconcerting experience for a lecturer, I can assure you, because everything had to be right or he would come up and explain it to me after class". On another occasion [2] Anderson describes: "He was very shy of course in those days, shy even for an undergraduate. But he would come up to me afterwards and discuss what I had said. And usually had some correction or other to make. I had misspoken or something. So it wasn't a matter of his asking for further enlightenment. He was just correcting my caesuras."

One day, after the lectures, Josephson brought to Anderson a handwritten note in which he had the long complicated calculation of the current between two superconductors. Josephson said [2], "This comes out with a very interesting term, which if you're right about this, your concepts of broken symmetry, is a way of measuring the relative phase of two super conductors, and would you check it over." Anderson comments [2]: "And it was god-awful mathematics because he had done it all in the original BCS formalism." This handwritten note contained the work which is now known as the Josephson Effect (and which brought him the Nobel Prize a few years later). Josephson was only 22 at that time, doing his PhD in experimental physics under the guidance of Prof. Brian Pippard at Cavendish Laboratory.

Josephson's theory predicted that a superconducting current can exist at the junction of two superconductors even when there is no voltage drop across it. According to Anderson [1], the remarkable achievement of Josephson was that "from the original idea of a dc supercurrent, he should make the all-important leap not only to the ac supercurrent but also to the mathematics of how to synchronize it with an external ac signal. Furthermore, he explained how to observe the effect in exactly the way that Sidney Shapiro did nearly two years later, and so predicted what is now the standard method for measuring *e/h*."

Anderson and Pippard checked the correctness of Josephson's analysis. Anderson had full confidence, he wrote [1], "by this time I knew Josephson well enough that I would have accepted anything else he said on faith". Nevertheless, probably as a result of an element of "residual uneasiness" [1] about the prediction of the theory, Pippard and Josephson decided to send Josephson's theoretical work to a newly founded journal *Physics Letters* (B.D. Josephson, *Physics Letters*, **1**, 253, 1962). Josephson's work was rejected by John Bardeen in a paper published in *Physical Review Letters* (*PRL)* 1963 (writing, "there can be no such superfluid flow"; John Bardeen is one of the very few scientists who have received twice (1956, 1972) the Nobel Prize in Physics). However, Philip Anderson and John Rowell of Bell Labs in Princeton experimentally proved the existence of zero-voltage supercurrent (the DC Josephson Effect) and published the experimental evidence in a paper in *PRL* (**10**, 230, 1963). S. Shapiro (*PRL*, **11**, 80, 1963) observed the oscillating supercurrent (the AC Josephson effect). At the University of Pennsylvania the AC Josephson effect was used to determine the constant *e/h*.

How honourable science was at the time can be appreciated from the following generous comments written by Anderson [1]: "Earlier in my course I had made some remarks about broken symmetry, and later we discussed how broken symmetry made this peculiar behaviour of the current possible. Josephson has always given me much more credit for these remarks than my understanding at the time deserved. Apart from these ideas about broken symmetry and some very minor points acknowledged explicitly in that Physics Letters paper, I want to emphasize that the whole achievement, from the conception to the explicit calculation to the publication was completely Josephson's. I hope it was no coincidence that these developments occurred in the thoughtful and stimulating atmosphere characteristic of the Cavendish. But the specific achievement was Josephson's own; this young man of 22 conceived the entire thing and carried it through to a successful conclusion."

Anderson [1] has explained the significance and applications of Josephson's discovery. Brian David Josephson received the **Nobel Prize** in **1973**. The citation for the Nobel Prize states: ***"for his theoretical predictions of the properties of a supercurrent through a tunnel barrier, in particular those phenomena which are generally known as the Josephson effects".*** He was only 33 at the time of receiving the prize!

Having reached the pinnacle of traditional science at such a tender age, Josephson devoted his later life to the Mind–Matter Unification Project at the Cavendish Laboratory to explore the idea of intelligence in nature and to establish the relationship between quantum mechanics and consciousness.

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References

1 Philip Anderson, How Josephson discovered his effect, *Physics Today*, November 1970, 23-29

2 Oral History Transcript – Dr. Philip Anderson, American Institute of Physics, http://www.aip.org/history/ohilist/23362_3.html

Link to Web Site for Prof. Abhijit Guha: http://www.facweb.iitkgp.ernet.in/~aguha/