

rent through the barriers. Then Giaever, who had been taking a course in superconductivity at Rensselaer Polytechnic Institute, decided to cool the junctions to superconducting temperatures. He speculated that the change in the density of states associated with the onset of superconductivity should cause a change in the I - V characteristic of a tunneling sandwich as one or both of its metal films become superconducting. He decided to switch to lead because he realized it would have a bigger gap and a higher transition temperature than aluminum. Early in 1960, he did the experiment to measure the current in the insulating layer with a sandwich of aluminum-aluminum-oxide-lead, using only a vacuum system for evaporating the metal films, an ammeter, voltmeter, simple cryogenic equipment and liquid helium. He was soon able to show that the linear I - V characteristic of a normal sandwich became highly nonlinear when one of the metals became superconducting and then found that when both metals became superconducting a negative-resistance region appeared. He was thus able to observe the energy gap and the density of states peak that had the form predicted by BCS theory.

The tunneling experiment was soon repeated and extended by workers elsewhere, and Giaever tunneling proved to be a powerful tool for studying the energy gap and neighboring density of states of superconductors; it opened up a new field of phonon spectroscopy.

Josephson, 22 years old in 1962, was a graduate student of Brian Pippard at Cambridge. He was working on boundary effects of superconductivity and had read a recent paper by Morrel Cohen, Leo Falicov and James Phillips (then at the University of Chicago), which explained why the superconducting density of states should be observable in Giaever tunneling. Josephson believed there would be important coherence and phase effects across boundaries and found in the Chicago work terms that did not vanish when the voltage across the barrier was set equal to zero. He showed his calculations to Philip Anderson (who was then on a sabbatical at Cambridge and was teaching Josephson solid-state and many-body theory) and to Pippard and discussed his ideas with them. It was decided to publish a paper in *Physics Letters*.

In the 1962 paper Josephson predicted that a supercurrent could tunnel through a thin insulating barrier separating two superconductors. With no applied voltage, he said that the supercurrent would be proportional to the sine of the difference in phases of the superconducting wave functions in the metals on either side of the barrier. This is known as the "dc Josephson effect." Furthermore, he predicted that

if a voltage V is applied across the barrier, an alternating current would flow with a frequency given by $2eV/h$, and that there would also be harmonics. When V is in millivolts, the frequency is in the high microwave range. Further calculations appeared in the thesis Josephson wrote to become a fellow of Trinity College.

Anderson became an enthusiastic proponent for Josephson's ideas, especially their illumination of fundamental problems of symmetry in quantum mechanics. On returning to Bell Labs in August he decided with John Rowell to attempt to verify the dc Josephson effect. After struggling for several months to make suitable junctions with metals other than aluminum, they eventually made one of tin-tin oxide-lead, saw the dc Josephson effect once the oxide was made thin enough, and observed, as expected, that the current was very sensitive to applied magnetic field.

The following year Sidney Shapiro (Arthur D. Little) observed the ac Josephson effect, showing that applied microwaves could mix with the Josephson oscillation and give steps in the I - V characteristic. To detect the radiation being emitted by the Josephson junction, Giaever in 1965 reported using a second junction to pick up the radiation that leaked from the first to the second junction. Meanwhile, two groups directly observed the radiation—I. K. Yanson, V. M. Svistunov and I. M. Dmitrenko of the Ukrainian Academy of Sciences and later B. N. Taylor, D. N. Langenberg, D. J. Scalapino and R. E. Eck of the University of Pennsylvania.

In retrospect, it appears that Josephson currents in different structures (crossed wires and point contacts) may have been observed by R. Holm and W. Meissner in 1932 and by I. Dietrich in 1952, and in the oxide junction by Giaever and perhaps by others. But as Anderson has pointed out (*PHYSICS TODAY*, November 1970, page 23), the observation could be interpreted as a short across the layer separating the two metals.

As Josephson's predictions were verified, enthusiasm for his ideas grew and led to a great deal of experimental effort. For example the Josephson effect has been used to make a precision determination of the fundamental constant, h/e , and could also be used to measure h/m_e and h/m_{He} . The effect has been used for ultrasensitive electromagnetic measurements, for the detection and demodulation of high-frequency radiation and has the possibility of being used as a high-frequency generator in the region between microwave and infrared frequencies. Some groups are considering using Josephson tunnel junctions to replace transistors in high-performance computers.

Esaki took a diploma in physics from

the University of Tokyo in 1947 and then joined the Kobe Kogyo Corporation. In 1956 he went to Sony, meanwhile working toward his PhD, which he received from the University of Tokyo in 1959. The following year he joined IBM, where he is at present an IBM fellow at the Thomas J. Watson Research Center in Yorktown Heights, New York.

Giaever received a degree in mechanical engineering in 1952 from the Norwegian Institute of Technology, served in the army and worked as a patent examiner in Norway before he joined General Electric's Advanced Engineering Program at the Peterborough Works in Canada in 1955. The following year he transferred to GE in Schenectady, where he worked first as an applied mathematician. In 1964, he received his PhD from Rensselaer. Since 1958 he has been at the GE Research and Development Center, where he is a Coolidge Fellow.

Josephson earned his BA in 1960 from Cambridge and four years later received his PhD. In 1967 he became assistant director of research and in 1972 a reader in the physics department at Cambridge. —GBL

Staff changes at the NSF physics section

Marcel Bardon, NSF physics section head, has announced staff changes in his section. Albert L. Bridgewater, formerly a research associate at the University of California Berkeley, will work with Bardon as staff assistant. David A. Jenkins will serve as associate program director for intermediate-energy physics; he is on leave from Virginia Polytechnic Institute and State University. Richard A. Isaacson, from the Illinois Institute of Technology, is the new associate program director for theoretical physics. He replaces Harold Zapolsky who has become chairman of the Rutgers University physics department.

There are two staff changes in the nuclear-physics program. Gerald T. Garvey, on leave from Princeton University, will direct the program while William S. Rodney is on sabbatical leave at Cal Tech and Los Alamos. Morton K. Brussel, after a year as its associate program director, will return to the University of Illinois.

in brief

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