state & society

Nobel Prize shared by Esaki, Giaever and Josephson

For their discoveries regarding tunneling phenomena in solids, three physicists have been awarded the 1973 Nobel Prize in physics. Half of the $120 000 prize will be shared by Leo Esaki (IBM Thomas J. Watson Research Center), who is honored for his experimental discovery of tunneling in semiconductors, and Ivar Giaever (General Electric Research and Development Center), who is honored for his experimental discovery of tunneling in superconductors. The other half of the prize goes to Brian D. Josephson (Cavendish Laboratory, Cambridge University), "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." Each of the three winners did the work for which they are being honored before they received their PhD's.


JOSEPHSON


ESAKI


GIAEVER

In 1958 Esaki, while working at the Sony Corporation in Tokyo, was able to demonstrate the existence of Zener tunneling or interband tunneling and at the same time he found a wholly unexpected behavior of the *I–V* characteristic. Tunneling between bands had been proposed by Clarence Zener in 1934 as a possible mechanism for breakdown in insulators subjected to high fields. Subsequent experiments with insulators did not clearly confirm Zener's prediction. When interest in semiconductors became strong, some experimenters reported seeing tunneling currents in low-breakdown semiconductor p–n diodes. Because relatively wide junctions had been used, the tunneling current was not pronounced.

Esaki realized that by making the junction much narrower he would increase the probability of a tunneling current. He had to grow extremely heavily doped crystals of germanium and then form alloy junctions. By this technique, he was able to reduce the junction width to about 150 Å. These narrow junctions gave a clear demonstration of Zener tunneling in the backward direction.

By reducing the junction width still further, to about 100 Å, Esaki was able to see tunneling in the forward direction, that is, he saw negative resistance behavior. In the *I–V* diagram the curve rises at low voltage, then there is a peak, the current drops down almost to zero, there is a flat region and then the curve rises again. The unusual thing

continued on page 74

Industrial-academic interactions is topic of AIP meeting

Many of the problems of interactions between the academic and industrial parts of the physics community were brought to light during the 1973 AIP Meeting of the Corporate Associates (2-3 October). Invited to the meeting for the first time in large numbers were chairmen of PhD-granting departments, in addition to corporate-associate representatives from industry. At issue during much of the conference was communication and coordination between the universities that turn out physicists, and industry, a major consumer of trained physics personnel. The dimensions of the problem were measured by two of the keynote speakers: J. Ross Macdonald (Texas Instruments) who had conducted a comprehensive 99-company survey (80% responded) of needs for and use of physics personnel, and Ralph O. Simmons (University of Illinois) who polled some of his fellow department chairmen on a number of related issues. Discussion groups during the second day spoke to many of the points that Macdonald and Simmons raised.

The results of Macdonald's survey, which covered companies employing a total of about 10 000 physicists, were weighted for the number of physicists that each respondent was speaking for. The survey revealed that industry wants physicists with more experience in problem solving, more inclination toward applied research and with more training in business, economics and patent law. Industry representatives who responded were also asked to make a hypothetical choice between a PhD engineer or physicist in the same

MACDONALD

SIMMONS

thesis area for a job opening. 60% answered that the engineer would be more desirable and 18% the physicist (the remainder were neutral). Engineers were cited as being more application oriented, having more problem-solving training, more flexibility, and more inclination toward getting useful results. Industry respondents felt that engineers were involved in creating, accomplishing and doing, whereas physicists tended to investigate, measure and understand.

In general, Macdonald's survey revealed that general capability rather than experience or thesis topic was rated more important as a physicist's asset by 63% of those responding (9% answered that experience was more important). In actual hiring practice, experience is weighted more heavily than capability about 30% of the time. A greater demand for more specialized physicists appeared for the companies employing many physicists, although in all companies surveyed, fewer than half of the PhD physicists were likely to remain in their specialized field until retirement. Among physicists at work in industry, the survey indicated that 77% carry on technical work oriented toward specific business goals and 16% toward knowledge-oriented goals. Respondents also indicated that the time from BS to PhD should be about four years rather than the 5–6 years which is the present average.

A dramatic shift in the sites of basic research since the early 1950's has created some problems for the graduate schools and industry. The NSF publication *National Patterns of R&D Resources 1953–1973* shows that the proportion of all basic research done by industry has dropped from 31% to 16% in the last 20 years, while university basic research has risen from 35% to 58%. Simmons noted these figures and said, "It is no wonder that, on the one hand, science departments have felt that industry has a decreasing interest in graduates oriented toward basic research, and, on the other hand, that industry has felt that university science departments have a decreasing effectiveness in producing graduates suited to industry needs."

Although the pattern of applied and basic research has been greatly altered in the last 20 years, only a few physics departments have programs to train physicists for industrial or interdisciplinary work. Some effort has been made to coordinate physics programs with engineering schools and to encourage students to have a broader background by taking courses in other departments. A large majority of graduate programs, though, fall into the traditional mold of two years for course work and three or more years of specialized research that, in contrast to industry, does not have to adhere to a strict time schedule and is terminated for technical rather than business reasons. Discussion groups that discussed this problem during the meeting noted that in industry, high-caliber work by researchers is often not reason enough to continue a project if economic considerations militate against it.

The changing research picture appears to call out for a new accommodation between universities and industry. Macdonald's survey reveals a strong increase in industrial applied R&D in the last two years, and an even stronger increase is anticipated over the next five years. What can be done to meet this challenge? Simmons suggested some possible ways to bridge the gap between industry and the universities. Thesis programs could be developed in cooperation with industry, including summer programs for students to sample industrial physics before their selection of a thesis topic. University seminars featuring industrial physicists could be held with the speaker explaining why the company is interested in the seminar topic. Perhaps there could be exchanges of personnel for six months to a year to help increase understanding between academic and industrial communities. Simmons closed by commenting, "Let us hope that both university physics departments and industrial companies can benefit from an increased willingness of physics graduates to see challenges and rewards in careers in industry." —RAS

Nobel Prize

continued from page 73

about the Esaki diode (also known as a tunnel diode) is the current hump. Between the peak and the valley is the negative-resistance region, which Esaki interpreted in terms of tunneling.

The Nobel committee remarked on the usefulness of Esaki's observations for applications, particularly the tunnel diode, which can be used for an oscillator, an amplifier and as a switch. Because it is a very fast device, many thought it might prove a successor to the transistor, for example in computers. Besides its device applications, Esaki's work gave solid-state physicists a tool for studying phonons in a very simple way as a function of applied pressure, temperature and different shear stresses, and as a tool for studying band structure in general, particularly in heavily-doped materials, previously only amenable to optical spectroscopy.

Giaever, who originally studied mechanical engineering, started doing solid-state physics research at General Electric in 1958. Two years later, he had demonstrated the tunneling of electrons through a sandwich containing a thin oxide layer surrounded with a superconductor on both sides or with metal on one side and a superconductor on the other side. This experiment provided simple, direct evidence for the existence of the energy gap in superconductors.

The BCS theory, for which John Bardeen, Leon Cooper and J. Robert Schrieffer received the Nobel Prize last year (PHYSICS TODAY, December 1972, page 73), showed the origin of the small energy difference (the gap) that for many years had been believed to separate the first excited state of a superconductor from the ground state; in a superconductor no electrons can have energies in this forbidden range. In 1957 Rolfe E. Glover III and Michael Tinkham at Berkeley presented evidence for the gap from studies of the way infrared radiation passed through or was absorbed by very thin films of superconductors.

Giaever and John Fisher, using evaporated-film junctions of aluminum–aluminum oxide–aluminum, showed that electron tunneling caused the current 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 juction, 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

Copies of the brochure "Fellowship and Research Opportunities in the Mathematical Sciences" covering pre- and post-doctoral awards for 1973–74 are available free of charge from Division