Bardeen, Cooper and Schrieffer share Nobel physics prize

The originators of the BCS theory have received the 1972 Nobel Prize in physics for their development of this theory, which explains superconductivity on a microscopic basis. The award of approximately $100 000 is to be shared by John Bardeen (University of Illinois), Leon N. Cooper (Brown University) and J. Robert Schrieffer (University of Pennsylvania). Bardeen, who earlier shared the 1956 Nobel Prize in physics for semiconductor research and for his part in the discovery of the transistor effect, is the first person to win two Nobel Prizes in the same field.

The theory, developed in the period 1955-1957 while all three men were at Illinois, was reported in a Letter to the Editor (*Phys. Rev.* **106**, 162, 1957) and then in a longer paper the same year (*Phys. Rev.* **108**, 1175, 1957). At the time of the work Cooper was a postdoctoral research associate and Schrieffer a graduate student, while Bardeen was just winning his first Nobel Prize.

The work of Fritz London, beginning in the mid-1930's and culminating in his

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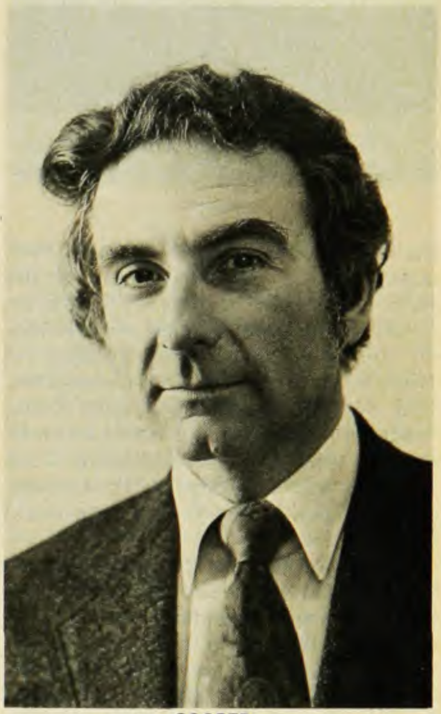
BARDEEN



COOPER

TV satellite worries astronomers

Radio astronomers are concerned about a television broadcasting satellite that may knock out radioastronomy observations in one commonly used band. The satellite, Applications Technology Satellite-F, is scheduled for launch in April 1974 and will spend one year in geosynchronous orbit over the western hemisphere, later moving to a position over India. The experiment that may cause the trouble is funded by the Department of Health, Education and Welfare and will study the feasibility of a permanent broadcasting satellite that may be sent up in the 1980's.

The conflict problem with radioastronomy stems from the fact that the radiofrequency band for the broadcasting satellite—2500 to 2690 MHz—is adjacent to a radioastronomy band at 2690 to 2700 MHz. The satellite will not be broadcasting in the radioastronomy band, but its signal may spill over into the band with enough intensity to prohibit observations in that band.

The 11-cm band that may be affected by the satellite is one of about ten commonly used radioastronomy frequencies. According to Philipp Kronberg of the University of Toronto, most radioastronomy observatories, including the National Radio Astronomy Observatory, can tune to it. Kronberg said that the 2690 to 2700 MHz band is one of the frequency bands open to radioastronomers that can be used to look into our galaxy and other galaxies, because the longer wavelengths available to radioastronomers—21 cm—are absorbed by ionized hydrogen in the galaxies and some shorter wavelengths—below 3.7 cm—are subject to interference in the earth's atmosphere.

Radioastronomers have been alerted to the possible effects of ATS-F, and

SCHRIEFFER

ATS-F may interfere with radioastronomy observations in the 2690–2700-MHz band.

the National Academy of Sciences Subcommittee on Radioastronomy of the NAS Committee on Radio Frequencies (CORF) has been working with NASA on the problem. John Findlay of NRAO, chairman of the Committee, told us that measurements are being made on the ground and would be made later in space to try to determine if the broadcasting interferes with radioastronomy and if the interference could be minimized.

There are no legal grounds on which the radioastronomers can stop the satellite from broadcasting, because it will be broadcasting in its own frequency band and because the spillover, while liable to interfere with radio listening, is of comparatively low intensity.

While most of the radio astronomers we spoke with agreed that if the 11-cm band became unusable by radioastronomers because of ATF-S it would be very serious, not all agreed that the situation could not be remedied for future broadcast satellites. William Howard of NRAO, the chairman of the NAS subcommittee, told PHYSICS TODAY that NASA is equally interested in the needs of the radioastronomers and the telecommunications scientists, and that there is very good cooperation between the parties concerned.

Howard told us that after the satellite is launched, experiments would be conducted for the year that the satellite is over the western hemisphere, in which different configurations of the satellite transmitter position and radioastronomy telescopes would be tried out. Presumably during the year that the satellite is up any radioastronomy difficulties would show up.

We contacted George Swenson Jr, who is involved in conducting the ground tests on the satellite with the transmitter configuration proposed by NASA. He told us that the present transmitter configuration would be "disastrous" for radio astronomy, and that it would probably put out noise at a level about 30 dB over the guidelines suggested by the Consultative Committee on International Radio, the advisory body to the International Telecommunications Union. He said that it would be possible to reduce the interference with a filter, but this would still result in noise at a level about 6 dB over the guidelines in the lower half of the radioastronomy band in question, although the upper half would be in accord with the guidelines.

Swenson said that he doubted such a filter would be installed because it would limit the broadcasting capabilities of the satellite.

According to one radioastronomer, the fact that the broadcast will be coming from a satellite over the western hemisphere makes it especially bad. "When it was a question of radar you could just set up your antenna in a valley, but with a satellite, there's no way to get away from it." —SMH

Nobel prize

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1950 book, emphasized the essentially quantum-mechanical nature of superconductivity and suggested that superconductivity is "a quantum structure on a macroscopic scale."

In 1950 it had been found that in a number of materials the superconducting transition temperature varies inversely as the square root of the isotopic mass. This isotope effect, found by Bernard Serin and his collaborators at Rutgers University and by Emanuel Maxwell at the National Bureau of Standards, indicated that the lattice plays an important role in determining the critical temperature. Meanwhile Herbert Fröhlich (then at Purdue University), who was unaware of the experiments, and Bardeen independently tried to develop a theory of superconductivity based on the self-energy of the electrons in the phonon field; Bardeen has noted that these attempts were not successful.

In 1956 Cooper showed that in the presence of an attractive interaction a pair of electrons (now called "Cooper pairs") outside the normal Fermi sea will form a bound state regardless of how weak the interaction is. Earlier Fröhlich, and Bardeen and David Pines had shown that an interaction between electrons by exchange of virtual phonons provides just such an attraction. At about the same time, Vitaly Ginzburg and independently M. Roby Schafroth (University of Sydney) had suggested that if electrons are associated in pairs, the pairs would obey Bose–Einstein statistics and that superconductivity would be a consequence of Bose condensation. However the attempt by Schafroth, John M. Blatt and S. T. Butler (University of Sydney) to work out a detailed theory along these lines proved insufficient.

In their 1957 paper Bardeen, Cooper and Schrieffer took as their fundamental postulate that superconductivity occurs when the attractive phonon-induced interaction dominates the repulsive screened Coulomb interaction for electrons near the Fermi surface. The superconducting ground state is made up of configurations in which the states of the individual electrons are occupied in pairs of opposite spin and momentum; if in any configuration one of the states is occupied, so is the other. When there is current flow, the total momentum of each pair is nonzero but it is exactly the same for all pairs. Random scattering of individual electrons does not change the momentum of the pairs; so once a current is started it will persist indefinitely unless acted on by a force, such as an electric field, which acts on all or a large fraction of the pairs at the same time.

The paper was able to explain the following experimental facts: a second-order phase transition at the critical temperature; an electronic specific heat varying as exp $(-T_0/T)$ near $T = 0$ (T_0 is related to the critical temperature) and other evidence for an energy gap for individual particle-like excitations; the Meissner effect; effects associated with infinite conductivity, and the isotope effect.

The BCS theory stimulated great theoretical and experimental activity. In 1959 Lev P. Gor'kov (then at the Institute for Physical Problems) extended BCS theory to derive the Ginzburg–Landau phenomenological theory that had earlier been applied by Alexei Abrikosov (then at the Institute for Physical Problems) to Type-II superconductors. The tunneling experiments of Ivar Giaever (General Electric) in 1960 exhibited the excitation spectrum of the superconductor and showed the presence of the energy gap with great precision; tunneling is now a widely used spectroscopic tool for excitations in solids. In 1962 Brian Josephson (Cambridge University) predicted the existence of phase coherence across a tunneling barrier; this has led to a wide variety of scientific and technological applications.

Beyond the field of superconductivity, following the initial work of Aage Bohr, Ben Mottelson (Bohr Institute) and Pines, BCS theory has been applied to many aspects of the nuclear many-body problem: in astrophysics, some theorists have suggested that the core of a neutron star might be a superfluid. Some of the ideas of the BCS theory, especial-