search & discovery

Neutrons and x rays probe TTF–TCNQ structure

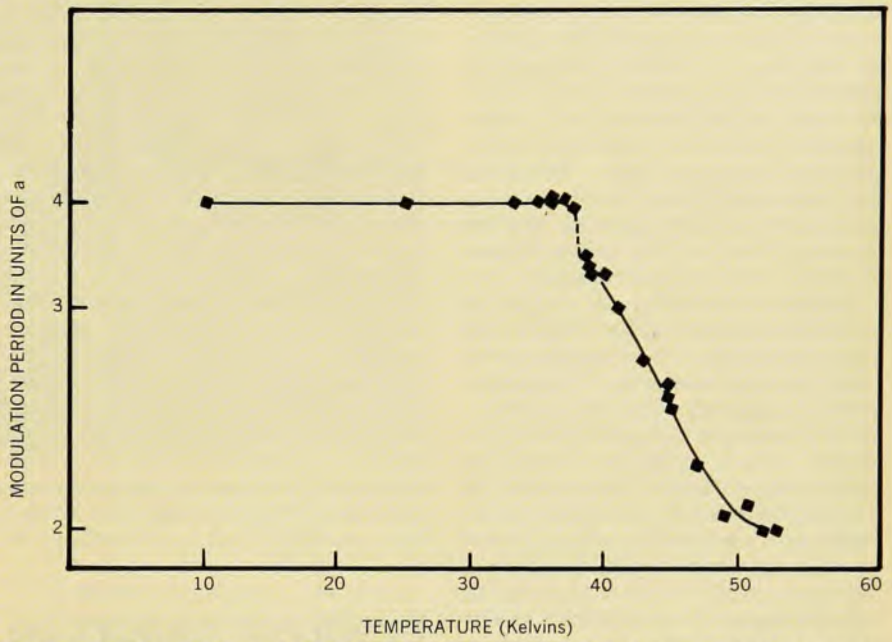
Interest in the organic conductor, TTF–TCNQ, has remained high since the report three years ago by some Penn experimenters that they had observed superconducting fluctuations in the material around 60 K. By now it is generally believed that TTF–TCNQ is not showing superconducting behavior. Nevertheless TTF–TCNQ and related substances continue to be enthusiastically studied because of their essentially one-dimensional behavior and because of strong evidence for charge-density waves.

At the Conference on Low-Lying Lattice Vibrational Modes in San Juan, Puerto Rico, held early in December, four groups reported on x-ray and neutron-scattering studies in TTF–TCNQ that show the existence of phase transitions in the vicinity of 60 K and below.

In the original Penn work by Anthony Garito, Alan Heeger and their collaborators (PHYSICS TODAY, May 1973, page 17), the experimenters reported seeing in three crystals a conductivity up to 500 times the room-temperature value just above a transition from a metallic to a semiconducting or insulating phase.

Subsequent extensive measurements using dc and microwave techniques led the Penn workers to conclude that peak normalized values of approximately 100 were more nearly correct; the typically observed lower values were limited by impurities and crystalline imperfections.

To explain their results the Penn group suggested they were observing superconducting fluctuations above a Peierls instability. In this phenomenon, below the critical temperature, T_p, the crystal becomes a semiconductor because of the formation of charge-density waves, whose wave vector is equal to twice the Fermi wave vector of the metal.



Neutron elastic scattering in TTF–TCNQ. The modulation period of the superlattice structure is 2a near 54 K and gradually increases with lower temperature. At 38 K an abrupt change occurs, and at low temperature the modulation period is 4a. Brookhaven–Orsay–Penn figure.

A year earlier I. F. Shchegolev (Institute of Chemical Physics, Chernergolovka, USSR) reported in a review paper[1] that thermally activated conductivity (as in a semiconductor) had been found at low temperatures in more than 12 different TCNQ salts; however, TTF–TCNQ was not among them.

In mid-1973 Hans Rudy Zeller and his collaborators at Brown Boveri Re-

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Experiments at Stanford approach a free-electron laser

Great expectations for a powerful, high-resolution laser, completely tunable from the infrared through the vacuum ultraviolet region, have been raised by some recent work at Stanford University. Experiments there show that a "free-electron laser"—one in which free electrons stimulate the emission of magnetic bremsstrahlung in a spatially periodic transverse magnetic field—could be a practical device.

So far the test studies, done by Luis Elias, William Fairbank, John Madey, H. Alan Schwettman and Todd Smith, in a collaborative effort of the physics department and the high-energy physics laboratory, have not included the operation of a laser oscillator: Instead, an electron beam has been used to amplify the 10.6-micron radiation from a carbon-dioxide laser. The gain (7% per pass) and lack of saturation strongly corroborate the theory that predicts such lasers are possible. Madey and his colleagues are therefore optimistic about the likelihood of crossing the laser threshold with more powerful electron beams, from existing higher-current accelerators and particularly from electron storage rings.

The idea of using high-energy electrons to amplify optical radiation is not new, as Madey pointed out to us. In 1951 Henry Motz (Stanford high-energy physics lab) analyzed and built[1] a device to produce optical radiation from an electron beam accelerated by a periodic transverse magnetic field. The emission in this earlier case, however, was spontaneous rather than stimulated. Motz derived an equation for the gain, basing his calculations on the traveling-wave formalism developed by Pierce, but did not consider the available gain to be of any practical significance.

Stimulated Compton scattering is similar to stimulated bremsstrahlung, when viewed in the electron rest frame. As early as 1928, Peter Kapitsa and P. A. M. Dirac[2] had considered stimulated Compton scattering. More recently, H. Dreicer (Los Alamos) calculated[3] the gain for thermal electrons, and R. H. Pantell, G. Soncini and H. E. Puthoff (Stanford electrical engineering department) calculated[4] the gain for relativistic electrons. A related group of devices[5] developed mainly at the Naval Research Lab is based on yet another variation, relativistic electrons in a *longitudinal* magnetic field. These devices operate at lower frequencies than the transverse field devices, but are quite promising for high-power millimeter-wave and microwave radiation.

Madey's calculations for stimulated magnetic bremsstrahlung emission are based on the analogy to stimulated inverse Compton scattering.[6] His results show that amplification is possible because stimulated emission occurs at a slightly longer wavelength than does absorption (inverse bremsstrahlung). The wavelength for stimulated emission varies with the electron energy, as well as with the magnet period and field. The tests of this theory at Stanford involved three main components: the superconducting electron accelerator to supply the relativistic electrons; a superconducting right-hand double helix wound around the interaction region to provide the magnetic field and a pulsed carbon-dioxide laser to act as a master oscillator.

The theory for stimulated bremsstrahlung predicts a correlation between the lineshape for spontaneous radiation on the one hand and the gain on the other; both of these were measured. For the spontaneous-emission measurements, the electron beam alone was fed into the magnetic field, bunched at the 1.3-GHz accelerator operating frequency, and the angular distribution, polarization and spectrum were noted. For the gain measurements, 10.6-micron radiation from the carbon-dioxide laser was sent through the interaction region in a beam parallel to the bunched electron beam. The interaction between the bunched electrons and the infrared radiation modulates the infrared radiation at 1.3 GHz: The percentage modulation is equal to the gain per pass. The magnet used during the tests had a 3.2-cm period and was 5.2-meters long; the tube enclosing the interaction region had an inner diameter of 10.2 mm, and the magnetic field was 2.4 kG. The electron energy was varied about 2% in the vicinity of 24 MeV.

The results appear to bear out the theory. For spontaneous emission, the observed linewidth is 0.4%, close to the theoretical homogeneously broadened width of 0.3%. The instantaneous peak gain per pass reached 7% at an instantaneous peak current of 70 milliamps. Correlation between gain and spontaneous-emission lineshape was as predicted, with net gain on the long-wavelength side and net absorption on the short-wavelength side of the lineshape for spontaneous emission. Gain varied linearly with electron current over the 5 mA–70 mA range, and the magnitude of the gain as well as its dependence on electron energy were independent of optical power density in the entire observed range (100 watts/cm^2 through 1.4×10^5 watts/cm^2). The maximum stimulated power was 4×10^3 watts; this power is 10^9 times larger than the spontaneous power with the same electron current.

Madey is particularly pleased about the lack of saturation observed; this factor was the one least amenable to prediction. Now, he explained to us, there is a good likelihood of producing a powerful tunable laser for such large-scale processes as, say, laser-induced isotope separation or industrial photochemical synthesis. The next step is to build a laser oscillator; that is, to enclose the interaction region in an optical resonator and to obtain sufficient electron current so that the gain per pass exceeds the resonator losses. If these tests, scheduled to end this October, are successful, the group would like to rebuild the electron storage ring originally built at Stanford in the 1960's, with a periodic magnet in one arm of the storage ring. As in a conventional storage ring, an rf cavity within the ring would maintain the steady-state energy of the circulating electrons. But in this case high-power coherent radiation would result from stimulated emission within the periodic magnet. —MSR

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Progress report on the VLA

Work goes on at the Very Large Array telescope project's site on the arid Plains of San Augustin, fifty miles west of Socorro, New Mexico. A $2.9-million subcontract for the third phase of construction of the giant radio telescope has been awarded to the Burn Construction Company.

The VLA telescope, which is expected to be fully in operation some time in 1981 (see PHYSICS TODAY, May 1972, page 17), had its origin in studies initiated in the early 1960's to improve the performance of radioastronomy instruments in general. The essential concepts and design of the facility now under construction were developed between 1964 and 1971. Design and construction of the array is the province of Associated Universities Inc., the nonprofit corporation of nine universities that operates the National Radio Astronomy Observatory under contract to the National Science Foundation. AUI also operates Brookhaven National Laboratory.

When it is completed, at an estimated cost of $76 million, the telescope will consist of 27 fully steerable dish-shaped antennas, 82 feet in diameter and 90 feet tall, distributed along three sets of railroad tracks arranged in an equiangular Y configuration. The northward arm will stretch 11.8 miles across the plain, and the others will extend for 13 miles southeast and southwest.

Phase three in the project's construction consists of ten miles of railroad embankment to be prepared, 8.1 miles of double trackage to be laid, 49 radio-telescope antenna foundations to be built, and the installation of railroad switchings and turnouts, as well as an underground electrical system. The Burn company had previously been awarded, in June, 1974, a $605 000 contract for the first phase of the construction. This phase, which involved the setting up of one mile of trackage and six foundations, plus assorted site services, was successfully completed in Spring 1975. Phase two construction consisted of the permanent buildings, site work, and utilities; it has been undertaken by the George A. Rutherford Construction Company for about $2.4 million. Launched in December, 1974, this second stage is about three-quarters finished.

When the Burn company wraps up its work, there will be nine miles of double railroad trackage and 55 antenna bases ready for use. The Very Large Array is scheduled to begin functioning as an instrument for serious scientific work in late 1977, when its first ten antennas