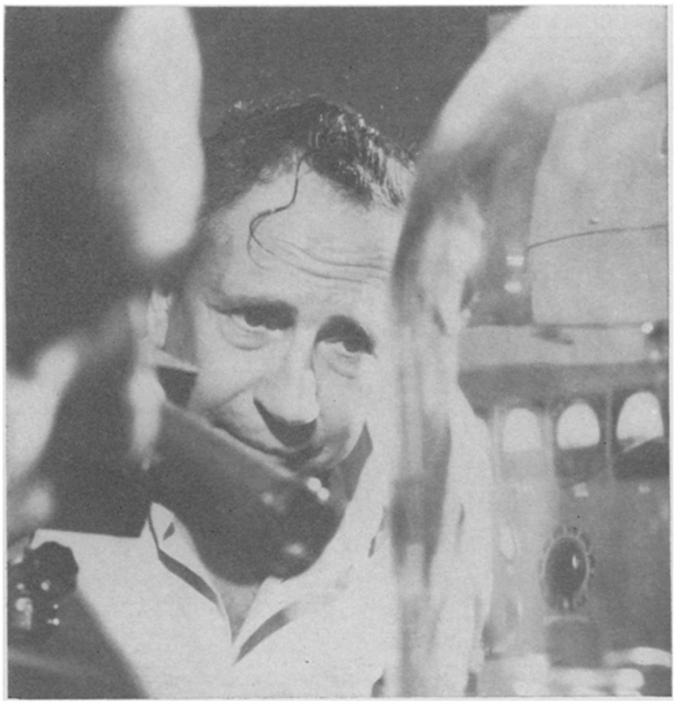
Superconductivity in two dimensions



Bell Labs

Matthias: The patent medicine of superconductivity.

Scientists think superconductivity can be induced at higher temperatures in sandwiches of organic compounds and metals

by Dietrick E. Thomsen

Superconductivity, the ability of certain substances to pass electric currents without resistance, has up to now been confined to certain metals, both pure and alloyed. The phenomenon occurs only at extremely low temperatures. The highest temperature at which it has been seen is not much more than 20 degrees above absolute zero (SN: 9/20, p. 251).

Superconductivity is already of some technical use in magnets and some other electrical components, but it could be of a great deal more use if it could be found at temperatures where complex and expensive refrigeration techniques were not necessary.

Theory has given some physicists the hope that the way to superconductivity at high temperatures, that is, at something like room temperatures, is to be found through attempts to discover it in organic compounds or in sandwiches of organic compounds and metals.

For superconductivity to happen the conduction electrons of the substance must form pairs. Electrons are all negatively charged and normally repel each other, but in some cases interposition of a mediating element between two electrons can change the balance of forces so that there is a net attraction between the electrons.

The first widely accepted theoretical explanation of superconductivity proposed that the mediators are vibrations of the crystal lattice of the metal, the so-called phonons. Some theorists are now saying that the theory must go beyond phonons and include other types of undulatory disturbances, especially various waves that can involve the electrons as well as the lattice. The general name for all these disturbances is excitons.

The processes that lead to superconductivity in the materials where it is now seen work best at low temperatures. Binding together two materials of different structure, some say, may make it easier for the excitons to operate, either by moving along the interface or back and forth from one substance to the other. This difference in structure might lead to superconductivity at higher temperatures.

A group of physicists working in Palo Alto, Calif., Drs. F. R. Gamble of Synvar Research Institute, F. J. DiSalvo of Stanford University, R. A. Klemm of Synvar and T. H. Geballe of Stanford, report finding superconductivity in such sandwiches. They have used the metallic compounds tantalum disulfide, niobium disulfide, tantalum selenide and palladium telluride layered with the organic compound pyridine.

A major theoretical question to be answered in evaluating the experiment is whether superconductivity can exist in substances where the free electrons that form the current can move in only one or two dimensions rather than the three dimensions available to them in crystalline metals. According to the mathematical theory, for superconductivity to happen the conduction electrons have to be more or less evenly distributed through the material. In substances where three-dimensional motion is possible, the electrons have enough possible paths available to maintain an even distribution. Where they are constrained to one or two dimensions, calculation shows that clumps or density fluctuations should appear, and they should destroy superconductivity.

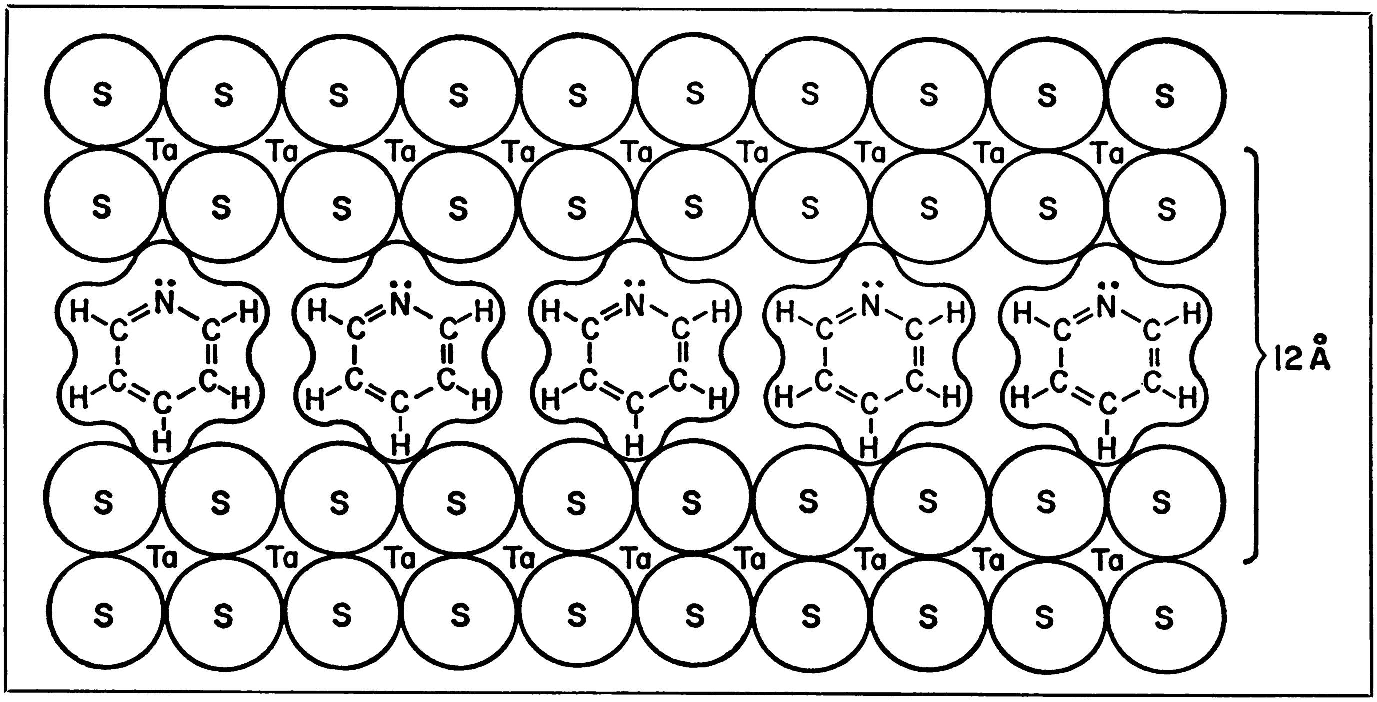
Many organic molecules form chains or layers, which allow only one- or two-dimensional motion to the conduction electrons.

What the Palo Alto researchers believe they have found is either three-dimensional superconductivity in which the organic molecules play a part, or two-dimensional superconductivity in the metal layers, which are only about two atoms thick. Either would alter the theory and lay the mathematical base, at least, for two-dimensional or organic superconductors.

The weight of their opinion inclines toward two-dimensional inorganic superconductivity. "The evidence is pretty good," says Dr. Geballe. He explains that the temperature at which the samples became superconducting did not vary as the thickness of the organic layer was changed. If the organic layer had a part in the superconductivity, he says, the transition temperature should have varied with its thickness. Therefore he is fairly sure that he and his associates have seen two-dimensional superconductivity.

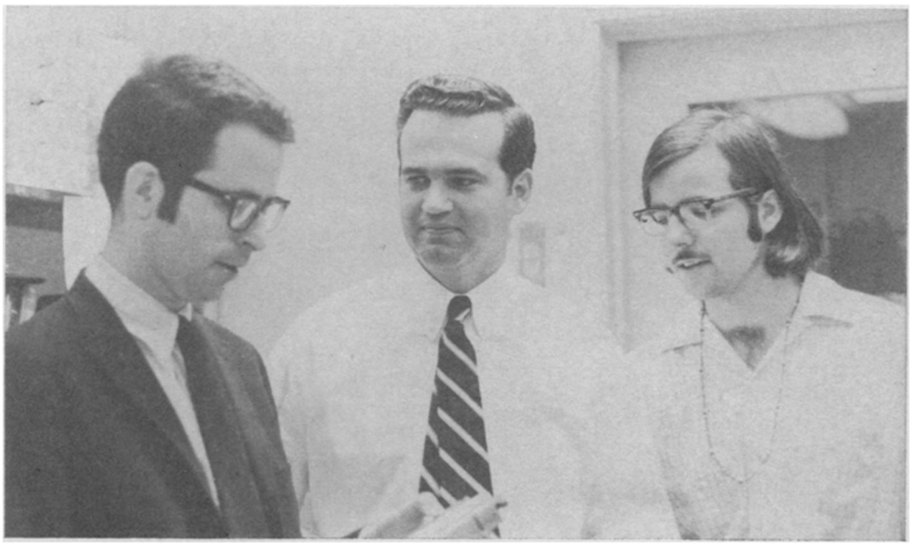
"My feeling is he hasn't (seen two-dimensional superconductivity)," says Dr. Bernd T. Matthias of the University of California, San Diego, at La Jolla. Dr. Matthias's objection arises because the experimental samples do not show characteristic magnetic behavior, the so-called Meissner effect.

The Meissner effect is the name for a kind of tension between superconductivity and magnetism; a superconductor tends to act like a perfect magnetic insulator. If a sample is in a magnetic field as it is cooled to its



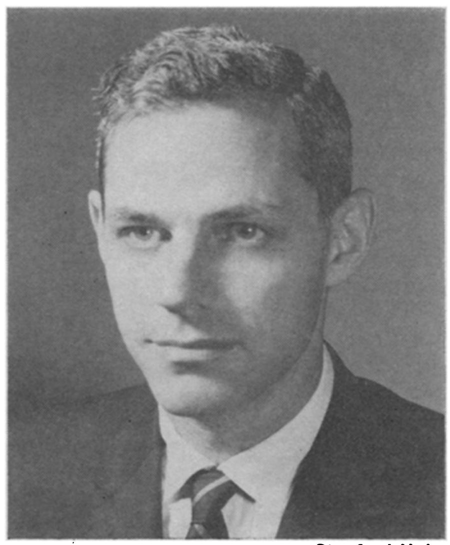
Gamble/Science

Tantalum disulfide and pyridine sandwich: Either two-dimensional or organic superconductivity is reported.



Synvar

DiSalvo, Gamble and Klemm: It could be two-dimensional superconductivity.



Stanford Univ.

Geballe: Meissner effect no criterion.

superconducting temperature, it will expel the magnetic field from within itself when it becomes superconducting. Conversely, if the field surpasses a certain critical strength, which varies according to the material, the field will force its way into the sample and in doing so destroy the superconductivity.

The Palo Alto researchers report that their samples showed no Meissner effect. In light of this Dr. Matthias says they should ask themselves: "Have we discovered a new kind of superconductivity?"

"There are lots of things that don't show a Meissner effect," Dr. Geballe replies. And he cites superconducting materials of which magnets are made, such as alloys of tin and niobium.

Dr. Matthias concedes that there are substances that can maintain both superconductivity and a partial penetration of a magnetic field over certain ranges of field strength, but he insists that at low fields all superconductors show a Meissner effect.

If the superconductivity comes from trace impurities, rather than from the whole sample, Dr. Matthias suggests, then no Meissner effect would appear, since the magnetic field would penetrate all of the sample except those impurities. He sums up by saying: "The whole thing seems rather murky."

Dr. Matthias is even less tolerant of the possibility of organic superconductors, and has been for some time (SN: 2/15/69, p. 169). "Organic superconductors," he says, "are the snake oil of superconductivity. It's the same old jazz, and nothing ever comes of it."

Something should come of it, Dr. W. A. Little of Stanford believes. For years he has been trying to put together an organic molecule that would be superconducting (SN: 9/20, p. 251). In the system he envisions, the motion of the electrons would be one-dimensional, and he is much encouraged by the experiment of Dr. Geballe and his associates, which he takes as a demonstration of two-dimensional superconductivity. Since the theoretical difficulties facing one-dimensional superconductivity are qualitatively the same as those facing two-dimensional superconductivity, he says, "It is strong support for the idea that even in one dimension fluctuations will not affect superconductivity." □