David Pines

(1924–2018)

Physicist who described how electrons interact.

David Pines is best known for his path-forging theory of the collective motion of electrons in metals. He also applied the theory to superconductors, atomic nuclei and neutron stars.

Pines developed this theory with David Bohm at Princeton University in New Jersey in the late 1940s. Their work solved a major puzzle in quantum mechanics, in which electrons are described as waves. Early quantum theory predicted the behaviour of electrons in metals, despite not taking into account the repulsion between electrons.

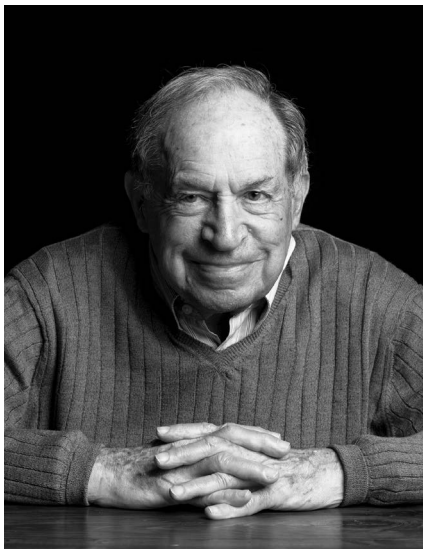
Pines and Bohm looked at electrons differently — as quantum plasma, analogous to a gas consisting of charged particles. They realized that electrons move as a group within a metal. Together, the electrons flow back and forth, alternately attracted to the positive ions that make up the crystal lattice and repelled by each other when they get too close to each other. Pines and Bohm showed that these oscillations in the density of electrons are quantized and exist only with a set of allowable energies; they called the oscillations plasmons. Plasmons soften the repulsive forces between individual electrons, thus explaining why the quantum theory worked.

Pines and Bohm's seminal papers launched the field of quantum materials. Their collective approach is still used to understand all forms of quantum matter.

Pines died on 3 May, aged 93. Born in Kansas City, Missouri, he spent much of his late childhood in Dallas, Texas. After being drafted into the US Navy during the last two years of the Second World War, he returned to his physics studies at the University of California, Berkeley, where he met his wife, Suzy.

Pines hoped to work on his PhD with J. Robert Oppenheimer, wartime leader of the Manhattan Project. When Oppenheimer moved to Princeton to become director of the Institute for Advanced Study (IAS), Pines followed him, to Princeton University. But Oppenheimer could not take him on, so Pines asked one of Oppenheimer's former students, Bohm, to be his adviser.

It was a difficult time for Bohm, who was arrested in 1950 for refusing to testify to a federal committee about his links to communist groups. He was acquitted in 1951 but, at a low point for US academia, lost his job. During this bleak period, Bohm lived as a lodger at Pines's house. Pines often reflected on how things might have turned out had Bohm accepted Pines's recommendation to use a Washington DC lawyer he knew.



MINESH BACRANIA FOR THE SANTA FE INSTITUTE

In 1952, Pines moved to the University of Illinois at Urbana–Champaign (UIUC) to work with physicist John Bardeen. Pines spent most of his remaining career there. In 1954, Pines and Bardeen showed that scattered electrons in a crystal lattice can be attracted to each other (J. Bardeen and D. Pines *Phys. Rev.* **99**, 1140–1150; 1955). This interaction was a key element in the Bardeen–Cooper–Schrieffer (BCS) theory of superconductivity, developed in 1957. That summer, working with Aage Bohr and Ben Mottelson at the Neils Bohr Institute in Copenhagen, Pines extended BCS theory to nuclear physics. This accounted for the difference in the stability of isotopes with even and odd numbers of nucleons, such as uranium-238 and uranium-235.

Pines also worked on quantum liquids and superfluids — liquids that flow without losing energy. He applied superfluid theory to neutron stars, explaining the sudden glitches in the speed at which a pulsar rotates (D. Pines *et al. Prog. Theor. Phys.* **69**, 376–396; 1980). He contributed to 'many-body theory', the study of the collective behaviour of many interacting particles, and to high-temperature superconductivity, after it was discovered in 1987.

Pines was fascinated by 'emergence' — the large-scale behaviour of complex systems that arises from the microscopic properties of system constituents. For example, in superconductors, the pairing of electrons causes electricity to flow without resistance at low temperatures. Pines contributed to many influential articles, including 'The middle way' (R. B. Laughlin *et al. Proc. Natl Acad. Sci USA* **97**, 32–37; 2000), which calls for researchers to seek emergent behaviour across quantum, soft and biological physics.

Indeed, Pines was a master of convening diverse people to pursue new directions. At the UIUC, he set up the Center for Advanced Study, which encompasses science, fine arts and agriculture. He was one of the first condensed-matter physicists active at the Aspen Center for Physics in Colorado, of which he was vice-president from 1968 to 1972. He co-founded the Santa Fe Institute (SFI) in New Mexico, and the Institute for Complex Adaptive Matter (ICAM-I2CAM), an international collective of scientists studying emergent phenomena. Young scientists and education were at the heart of all these endeavours.

Pines excelled at scientific diplomacy. During the cold war, he established the US–USSR Cooperative Program in Physics between 1968 and 1989, which promoted the exchange of ideas between the two communities. David and Suzy visited the USSR regularly and befriended Soviet scientists. In 1978, they travelled on the trans-Siberian railroad to a joint Soviet–American meeting in Moscow, only to discover that other members of the US delegation had cancelled, in protest against the harsh sentence given to a dissident scientist. Pines stayed on, hoping to diffuse the tension; he saved the commission, which operated until the end of the cold war. After the war, Pines organized a visiting programme for former Soviet physicists at the UIUC.

David will be remembered for his boundless energy and enthusiasm. No doubt born a genius, he never stopped growing in his science and life. He was always pushing the boundaries — even publishing several papers this year. He had a zest for life that continued into his 90s. Three years ago, proudly recounting that he had just driven himself from Santa Fe to Aspen — 480 kilometres through mountains — in 6 hours, he joked that the great thing about getting old is that "you get to drive your age". David treated a 90-mile-an-hour drive like a gentle walk in the park. ■

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