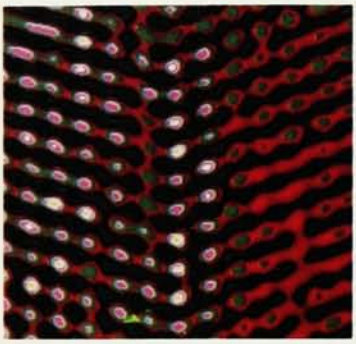
Interface between $NiSi_2/Si$ twin structures, shown in a high-resolution transmission electron micrograph. The sample was prepared by step deposition and annealing to form an epitaxial interface. (Courtesy of W. Krakow and F. K. LeGoues, IBM Watson Research Center.)



Condensed-matter physics

Such extraordinary technological innovations as the transistor, superconducting magnets, solid-state lasers, liquid-crystal displays and highly sensitive detectors of radiant energy come under the umbrella of condensed-matter physics. The basic contributions of condensed-matter physics to the study of critical phenomena, broken symmetry and defects have had a major impact on nuclear physics, elementary-particle physics, astrophysics, molecular physics and chemistry. The panel report on condensed-matter physics is a fascinating tour of this diverse yet unified field. Some of the stops include:

Artificially structured materials. In the past decade remarkable progress has been made in the fabrication and understanding of novel materials that do not occur in nature. Using such techniques as molecular-beam epitaxy, with which materials may be constructed one molecule at a time, and organometallic chemical vapor deposition, investigators have fabricated artificial periodic superlattices consisting of alternating layers of different semiconductors, different metals, or semiconductors and metals. The ability to tailor the structure of materials has led to the discovery and elucidation of many new phenomena, some of which are discussed in what follows.

The quantized Hall effect. Among the more interesting of the new artificially structured materials are purely two-dimensional electron gases. In these materials electron motion is strictly confined to a plane, making them ideal laboratories for the study of the fundamental physics of low-dimensional systems. The most remarkable property of such systems is undoubtedly the quantized Hall effect. At low temperatures and high perpendicular magnetic fields, plateaus are seen in the Hall conductance that are quantized in units of e^2/h, or $^1/_{25\,812.8}\ \Omega^{-1}$. The precision of this result—at least one part in a hundred million—has led to improvement in the measurement of this fundamental constant and to a new portable resistance standard. More recently quantization of the Hall conductance in simple fractions of e^2/h has been seen. The discoverer of the quantum Hall effect was awarded the 1985 Nobel Prize in physics.

Disorder. One of the most striking intrinsic properties of disordered systems is localization, the tendency to form quantum states that cannot move except with the help of thermal energy. Experimentally the study of localization is clarified by resorting to two-dimensional geometry, which makes it possible to observe unique nonclassical behavior of the electronic conductivity, and by technical advances in microfabrication, which allow the study of effectively one-dimensional wires and of tiny loops that show strange conductivity oscillations in a magnetic field.

Mixed-valence atoms and heavy fermions. Some measurements show that a large class of compounds based on the rare-earth atoms cerium, samarium, europium, thulium and ytterbium and the actinide element uranium contain atoms with two simultaneous valences. Other measurements show a fixed valence, sometimes intermediate, sometimes not. It appears that electrons are quantum mechanically tunneling rather slowly in and out of the f shells, with very exotic results. One of the most peculiar is the existence of conduction electrons with effective masses as large as 1000 times the normal electron mass that nevertheless display superconductivity at low temperatures. These superconductors, it has been speculated, are of a totally new type, with the Cooper pairs of electrons in a triplet state, as opposed to the singlet pairing of conventional superconductors. Valence fluctuations in other materials lead to a variety of fascinating effects: metal–insulator transitions, magnetic–nonmagnetic transitions, highly compressible lattices and transitions into exotic magnetic ground states.

Superfluid phases of He^3. A major highlight in condensed-matter physics was the discovery in 1971 that He^3 is a superfluid at temperatures below 3 mK—the only new superfluid to be discovered since 1937, when the superfluidity of He^4 was established. The properties of He^3 differ from those of He^4 because the latter obeys Bose statistics, whereas He^3 obeys Fermi statistics. Superfluid He^3 exhibits a far richer array of physical phenomena than He^4; it is locally anisotropic and exhibits three distinct phases. One possible—and intriguing—explanation for this is that the He^3 atoms form pairs in a triplet state.

Theoretical developments such as renormalization-group techniques have also enriched condensed-matter physics. Originally developed for particle physics, these techniques came into their own in the theory of phase transitions. They have led to a theoretical understanding of empirical relations among different properties near a phase transition or critical point of a given system and have made it possible to predict critical properties very accurately. Studies of turbulence and of systems so far from equilibrium that

Panel on Condensed-Matter Physics

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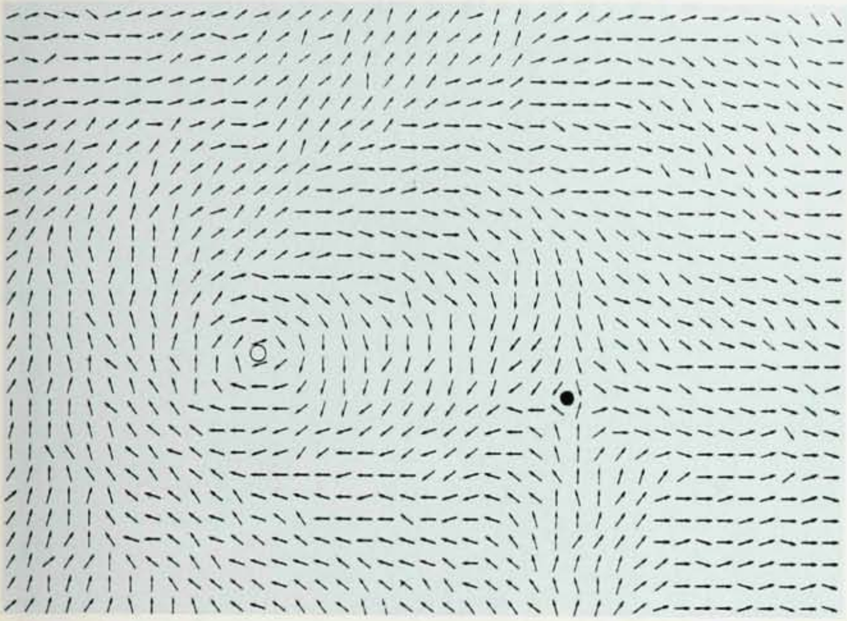

Nonlinear vortex excitation in the two-dimensional x–y model. Dark and open circles denote the centers of spin vortices of opposite circulation.

they must be described by nonlinear equations have also opened up new subfields of condensed-matter physics.

The immense progress in condensed-matter physics in the past decade is largely due to a number of improvements in experimental methods. Bright, tunable, polarized and pulsed sources of synchrotron radiation have made possible a large variety of measurements. Synchrotron radiation is also used in lithography to produce artificial structures with dimensions as small as 70 Å.

Another major advance has been the development of several techniques for "seeing" individual atoms. These include the scanning vacuum-tunneling microscope, which can resolve single atoms; the modern commercial electron microscope, which can resolve structures as small as 1.5 Å; and the scanning transmission electron microscope, whose current resolution is 2 Å.

Even this partial list of outstanding achievements of the past decade demonstrates the vitality of condensed-matter physics. These discoveries have opened entire new fields that will become the research frontiers of the next decade.

What will it take to continue to explore these new frontiers? Most important, of course, to the future of any research is a supply of scientists. Many physics departments are unable to support the full number of graduate students eager to pursue research in condensed-matter physics. This situation, the panel says, represents a loss of opportunity to continue rapid progress in the field as well a threat to the nation's scientific and technological manpower in an area with important implications for the electronics industry and national security.

The national laboratories have traditionally been important in the education and training of postdocs and graduate students, but this function is being threatened by budget cuts. The panel urges that "provision should be made for the continuation of the postdoctoral program" in the nation's laboratories.

Moreover, the panel stresses, it is vital that the most talented young graduates who elect university careers obtain support for their research: "Otherwise science will decline because students will no longer enter the field." Likewise, senior scientists who leave industrial or government laboratories to assume university positions, as well as those who join US universities from abroad, should have opportunities to obtain support for their research: "Otherwise our universities will lose these sources of their enrichment."

The trends in funding, however, run in the opposite direction. The Division of Materials Research of the National Science Foundation, for example, has found it necessary to decrease the number of grants to allow the size of the grants to the best research programs to increase. This, the panel emphasizes, should not be mistaken for quality control, which is provided by the annual turnover of grants. "The increasing competition for a decreasing number of grants," they write, "gives rise to a tendency for investigators to be conservative in the submission of proposals by omitting speculative projects in favor of those that are almost guaranteed to be successful. This is not the way in which major advances in science are made." Consequently the panel recommends that over the next four years sufficient funding should be appropriated to provide for an annual increase of at least 3–4% in the total number of investigators in condensed-matter physics.

Aging, obsolete instrumentation is another problem facing condensed-matter physics. When the Division of Materials Research of NSF announced the establishment of an ongoing instrumentation program that would award \$4 million in fiscal 1983, they received \$27 million in requests; a similar DOD program with \$30 million available was deluged by \$750 million in requests. Even allowing that not all these requests were of equal quality, this discrepancy between supply of and demand for funding indicates a desperate need. The panel therefore recommends that enough money be appropriated to enable Federal agencies supporting condensed-matter research to dedicate 20–25% of their funds to instrumentation. It also recommends that additional new monies be appropriated to allow 10% or more of the total present budget to be spent on computing. All told, the panel estimates that these recommendations will require a steady annual expansion rate of condensed-matter funding of approximately 20% for the next three years.

In addition the panel recommends improvements to the nation's badly underfunded and understaffed neutron-scattering program, the speedy completion of the new generation of synchrotron radiation sources as well as improvements of existing sources, and advanced-instrumentation initiatives in electron microscopy.

—BRUCE SCHECHTER □