ness, of stochastic behavior, and of fluctuation effects. In the electrical context, random motion of electrons can result in *noise*, and as modern electronic devices become smaller and smaller, the consequent noise becomes more and more of a problem. As reported by William Skocpol and his collaborators, it is now possible to measure the "noise" of a single electron as it becomes trapped at the defect in a device, providing, however, the device is small enough. Again a fundamental discovery is made possible by an advance in technology, in this case our ability to fabricate ultrasmall structures.

Finally, although not strictly an advance in condensed matter physics, this seems also to be an appropriate place to remark on the notable advances that were made this year by Charles Brau in the fabrication of the free-electron laser. It seems quite certain that perhaps more than in other areas, the free-electron laser will find enormous potential application in condensed matter physics.

N. W. Ashcroft, Cornell University

Spin Waves in Spin-Polarized Hydrogen Gas

Spin waves are quantum phenomena most commonly found in condensed matter, where the overlap (in terms of quantum mechanics) of adjacent atoms leads to strong correlations between neighboring spins. A spin wave corresponds to a wavelike propagation through a medium of a local tilt of spins from some preferred orientation. Previously spin waves had been observed in a wide variety of systems, including ferromagnetic materials, antiferromagnetic materials, and even in liquid ^{3}He at very low temperatures.

Surprisingly, an experiment recently performed at Cornell University has revealed[1,2] that it is possible to excite spin waves at temperatures of about 0.4 K in a highly rarefied gas of spin-polarized hydrogen (10^{16} atoms per cm^3, corresponding to about one-thousandth the density of air at sea level). In such a dilute gas an atom spends most of its time far away from its neighbors, so that the quantum overlap found in condensed systems occurs only on the very rare occasions when two atoms in the gas collide. It was shown theoretically by physicists in France[3] and the Soviet Union[4] that under special conditions, even the occurrence of these rare collisions in a dilute gas could lead to spin waves. In the case of atomic hydrogen the most important criterion is that two colliding atoms be essentially indistinguishable. Since hydrogen atoms are each composed of one electron and one proton, the indistinguishability requirement is met by arranging for all the electron spins and all the proton spins in a small region of the sample to be lined up in the same direction along an axis usually taken as the z axis.

Suppose an atom from a nearby region of the sample with its proton spin slightly tilted from the z axis enters the region of the cell under consideration and collides with an atom in this region. According to theory, the direction of the proton spins of the two colliding atoms will rotate around one another in the brief interval during which the collision takes place. The cumulative effect of a large number of these so-called identical spin rotations can lead to the establishment of the coherent nuclear spin waves observed in spin-polarized hydrogen gas at Cornell.

Techniques for producing a gas of hydrogen atoms in the laboratory with both the nuclear (proton) and electronic spins polarized along the magnetic field axis have recently been developed.[5] The atomic hydrogen gas, obtained by dissociating H_2 molecules in a high-frequency discharge, traverses a Teflon-lined tube and enters a low-temperature region whose walls are coated with a film of superfluid ^{4}He. The purpose of the Teflon and liquid-helium coatings is to minimize surface recombination of the atoms back into molecules, which would lead to the rapid loss of the sample as well as the release of heat. The atomic hydrogen gas enters a sample region held at a temperature of a few tenths of a degree. The sample cell is in a region of high magnetic field whose purpose is to trap atoms with electron spins antiparallel to the field and to expel atoms with electron spins parallel to the field. The trapped atoms are in quantum states of two possible nuclear spin orientations, either parallel to the electron spin (state "*b*") or antiparallel to the electron spin (state "*a*"). It can be shown from the quantum theory of the hydrogen atom that state *a* will contain a small admixture of a quantum state in which the *electron* spin is turned completely over. In this condition, an atom in state *a* will recombine with any other hydrogen atom in the sample, since the recombination between two atoms with antiparallel electron spins is not suppressed by the Pauli exclusion principle. The *a*-state hydrogen atoms are then consumed by recombination; the remaining atomic hydrogen gas in the *b* state, which has fully polarized nuclear and electronic spins, makes it a good candidate for the identical spin rotational collisions and spin-wave propagation.

Nuclear-magnetic-resonance (NMR) techniques were used by the Cornell group to demonstate the existence of spin waves in spin-polarized hydrogen. The NMR spectrum shows a series of sharp spikes superimposed on the NMR "image" of the sample cell in the field gradient. The sharp spikes were identified with standing spin-wave modes. A theory was developed at Cornell and AT&T Bell Laboratories[6] that reformulated the earlier French theory based on atomic collisions in terms of the many body theories used to describe spin waves in liquid ^{3}He, thus showing the essential unity between spin-wave phenomena in rarefied atomic hydrogen and in condensed systems. The theory for spin waves was utilized to determine the shapes of the NMR spectra in spin-polarized hydrogen for a variety of magnetic field gradients, temperatures, and densities.

D. M. Lee and J. H. Freed, Cornell University

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