Aspen Conference on Quantum Crystals

During the week 1–5 September 1969, approximately 100 participants gathered in Aspen, Colorado, for a Conference on Quantum Crystals. The outstanding facilities of the Aspen Institute for Humanistic Studies were made available, and support was provided by the National Science Foundation for the attendance of a significant number of foreign scientists. The organizing committee, consisting of H. R. Glyde, J. A. Krumhansl, H. Meyer, L. H. Nosanow, J. C. Raich, M. G. Richards, and C. A. Swenson, selected a conference format similar to that of the Gordon Conferences, which gave attendees the opportunity during the afternoons to sample the recreational endowments of the Aspen area.

The subject matter comprising the conference was the solid phases of helium and molecular hydrogen in their various isotopic forms. Properties associated with the lattice vibrational degrees of freedom of these crystals were considered, as well as those arising from the nuclear and (for molecular hydrogen) orbital angular momentum degrees of freedom. In addition, attention was given to isotopically and rotationally mixed crystals.

One of the most perplexing situations to emerge from the conference was the decided differences found between the hexagonal close-packed (hcp) and body-centered cubic (bcc) phases of He^3. It was reported several years ago from two different laboratories that the specific heat of bcc He^3 was larger at temperatures below 1°K than expected on the basis of normal lattice vibration theory.

Only recently, however, has this observation been recognized as a real effect, not due to quirks of experimental technique. Work reported by E. D. Adams (Florida) has confirmed the observations using sensitive strain gauge measurements. In addition, low-temperature thermal conductivity measurements by W. C. Thomlinson (Yale), in the region where the phonon mean free path is limited by sample boundaries so that the temperature dependence of the thermal conductivity is given by the specific heat, also indicate an anomaly for the bcc phase but not for the hcp phase. Effects of He^4 impurities can be ruled out. It is hard to escape the suspicion that this is somehow connected with the nuclear spin system of He^3, and the suspicion was enhanced by a reemphasis by M. G. Richards (Sussex) that the spectral density for spin fluctuations [by nuclear magnetic resonance) (NMR)] in the bcc phase was much more nearly of exponential form rather than the Gaussian found in the hcp phase.

Progress reported in techniques for orienting crystals of helium was quite encouraging. The birefringence of the hcp phase of He^4 was used by groups associated with J. P. Franck (Alberta) and with D. Lee (Cornell) to help obtain the ultrasonic elastic constants. The feasibility of orientation by x-ray diffraction in hcp He^4 was demonstrated by S. Fain and D. Lazarus (Illinois) in conjunction with the observation of anisotropy in thermal conductivity. Inelastic coherent neutron scattering has been used successfully by groups at Brookhaven and at Iowa State to obtain phonon dispersion curves, again for hcp He^4. Many of these techniques should also be applicable to hydrogen, particularly in its hcp phase. Similarly, observation of a long wavelength optical phonon in Raman scattering from hcp hydrogen, by W. Hardy *et al.* (North American Rockwell), should also be possible in helium. Neutron scattering experiments in hydrogen were reported by W. Schott (Karlsruhe), in fair agreement with lattice dynamical calculations of W. Biem (Oak Ridge) and F. G. Mertens (Jülich) using the Nosanow treatment of zero-point motion.

Considerable light was shed on the nuclear spin ordering transition expected in He^3. The fact that this would be an antiferromagnetic state, with Néel temperature at about 2×10^{-3} °K, was confirmed in several ways. No less than three groups (Cornell, Brookhaven, Stanford) reported nuclear susceptibility measurements fitted to a Curie-Weiss form. In good agreement was a determination inferred from strain gauge measurements, again by the Florida group. The most recent theoretical computations of the associated exchange splitting by R. Guyer (Harvard) agree with experiment to within a factor of 2, and with density dependence much improved over earlier calculations. The spin disorder of the solid above 2×10^{-3} °K can be used to cool by adiabatically compressing spin-ordered liquid into solid, a technique conclusively demonstrated by groups associated with J. Wheatley (La Jolla) and with Lee (Cornell). It would appear that this refrigeration de-

vice will be of great practical importance for carrying out a wide variety of other experiments in the few millidegree temperature range.

In hydrogen, where the molecule can have a metastable $J = 1$ excitation, an orientation ordering is known to take place due primarily to electric quadrupole interactions. Phonon zero-point vibrations modify the quadrupolar coupling constant, as calculated by A. B. Harris (Pennsylvania), with experiment and theory gradually converging. The orientational transition is closely accompanied by, but now found (groups at Duke and at Los Alamos) not to be simultaneous with, a lattice structural transformation. In the ordered state, rotational wave excitations ("librons") are expected; their observation in the Raman scattering spectrum reported by Hardy *et al.* suggests an inconsistency with the previously accepted orientational arrangement. Further doubts were cast on the accepted arrangement by H. James (Purdue) on the basis of computer simulations of the most stable orientational structure. Studies of these effects by NMR relaxation, as well as of the effects of isotopic and molecular spin mixing, were discussed by J. R. Gaines (Ohio State University) and by H. Meyer. T. Nakamura (Osaka) presented calaculations of the energy of pairs of $J = 0$ molecules in an otherwise ordered $J = 1$ crystal.

Experimental emphasis in the area of helium isotopic mixtures was on spin-lattice relaxation of He^3 with dilute He^4, as reported by M. Bernier (Saclay) and by H. Reich (IBM), and thermal conductivity of He^4 with dilute He^3, carried out by groups at Oxford and at Duke. Theoretical investigation by C. M. Varma (Bell Telephone Laboratories) indicated that effective force constant changes and strain fields are induced around an isotopic defect, due to the large zero-point lattice motion in helium, with sizable effect on phonon transport scattering rates but little effect because of cancellations on the local exchange splitting. This is confirmed in experiments discussed by R. C. Richardson (Cornell). Observed changes in spin-lattice relaxation times with impurity content, as observed at Saclay and IBM, may be connected with defect migration, which drives the known low-temperature phase separation of solid mixtures.

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