LT 10: Low-Temperature Conference in Moscow

Superconductivity, properties of helium, electronic properties of metals and antiferromagnetism were the subject matter for the Tenth International Conference on Low Temperature Physics held last August and September in Moscow. The large number of contributed papers, 445, made four simultaneous sessions necessary.

Ceremonial sessions included two addresses by Peter Kapitza, one to welcome delegates and one to summarize the conference, and presentation of the Fritz London award to C. J. Gorter (PHYSICS TODAY, Jan., page 76).

Vortex motion. In a paper on macroscopic quantum effects and vortices, John Bardeen (Illinois) discussed the theory of dc, or "flux-flow," resistance of type II superconductors that he has worked out with Michael J. Stephen (Yale). According to this theory, mixed-state resistance comes from motion of quantized fluxoids induced to move by the Lorentz forces of transport currents. Fluxoid motion produces an electric field that drives the currents through vortex cores. Dissipation is presumed to occur in the normal-like core. Young B. Kim (Bell Labs) discussed the experimental situation. The theory agrees qualitatively with experiment but does not account for the observed Hall angles. It also appears to fail in very-high-critical-field superconductors where Pauli paramagnetism is important in limiting the upper critical field.

Further evidence that dissipation results from vortex motion came from F. A. Otter Jr and P. R. Solomon (United Aircraft), who reported their observation of thermomagnetic effects in the mixed state. They have measured temperature gradients induced by vortex motion and potential differences induced by temperature gradients while the superconductor is in the flux-flow regime. They conclude that temperature gradients can also act as driving forces on vortices and that the resulting vortex motion is accompanied by entropy transport.

I. Giaver discussed an experiment in which a voltage drop across a type-II superconducting "primary" induced a voltage in a nearby superconducting "secondary." The result can be explained by assuming that vortices moving in the primary produce flux motion in the nearby secondary. Solomon reported on a similar experiment in which a type-I superconductor in the intermediate state was used as the primary. It appears that the intermediate state is also characterized by a vortex-like structure, at least over a certain range of magnetic fields.

Despite recent progress, a general understanding of transport processes in the mixed state is still lacking. The main gap is absence of any simple theory of time-varying phenomena. The difficulties involved were brought to light by E. Abrahams (Rutgers) and T. Tsuneto (Osaka) and by M. P. Kemoklidze and L. P. Pitaevski (Institute for Physical Problems, Moscow); time-dependent generalizations of the Ginzburg-Landau equations were derived under the assumption of a sufficiently slow space and time variation of the order parameter. These equations appear hopelessly complicated; moreover, it is not clear that the assumptions correspond to the physical situation for moving vortices.

On the other hand, the thermodynamic properties are well understood, and the theory based essentially on the Ginzburg-Landau equations and Abrikosov's vortex solution is in good shape. According to recent theory the vortex structure should be triangular.

This fact has been beautifully confirmed by W. Fite II (Columbia) and Alfred G. Redfield (IBM Watson Labs). They studied nuclear resonance in the mixed state of vanadium, and demonstrated convincingly that the observed line shape implies a triangular lattice.

One of the remaining mysteries unexplained by BCS theory is the "precursor" absorption of electromagnetic radiation below the energy gap in superconducting lead. In measurements of far-infrared transmission and reflection of dirty lead films Michael Tinkham (Harvard) finds a clean onset of absorption at the superconducting energy gap with no apparent precursor edge.

One-d superconductors. A most interesting controversy concerned one-dimensional superconductivity. The controversy centered about the speculations made several years ago by W. A. Little (Stanford) regarding room-temperature superconductivity in very long organic molecules. Richard A. Ferrell (Maryland) reviewed his objections to this idea. He pointed out that collective fluctuations in electron density are so large in one-dimensional systems that they prevent superconductivity. Little, on the other hand, suggested that although superconductivity in the strict sense may be impossible, a state with an unobservably small resistance could be formed. The picture was further complicated by L. P. Gorkov who, with Yu. A. Bychkov and I. E. Dzyaloshinski (Institute of Theoretical Physics), found a new kind of superconducting state. In this state, which can exist in one dimension, correlations between four particles—two electrons and two holes—are important. Gorkov contends that this state is immune to the criticism offered by Ferrell. On the other hand, recent work by P. C. Hohenberg (Bell Labs) supports Ferrell's position. It appears that the last word on this subject is yet to be said, but no experimental tests are imminent.

A breakthrough has been made in understanding correlations between superconductivity and ferromagnetism in the periodic table. It is well known

that exchange interactions in metals enhance the static spin susceptibility. Norman F. Berk and J. Robert Schrieffer (Pennsylvania) described an additional repulsion between electrons having opposite spin that is due to critical spin fluctuations. This repulsion tends to suppress superconductivity, and accounts, at least qualitatively, for the empirical rules found by Bernd T. Matthias concerning superconductivity and ferromagnetism. It was also shown that these fluctuations could account for the large specific-heat-effective mass of palladium.

Another aspect of this problem was discussed by S. Doniach and M. J. Rice, who find that the same interactions are responsible for an anomalous electronic specific heat having the form $T^3 \log T$. They suggest that such an effect may be responsible for the low-temperature anomaly observed in the specific heat of He^3.

Tunneling. Barry N. Taylor, W. H. Parker and Donald N. Langenberg (Pennsylvania) described their recent measurement of the Josephson radiation frequency $\nu = 2eV/h$. By measuring ν and fixing the voltage V very accurately, they were able to determine the fundamental constant e/h with an improved accuracy of six parts per million.

Another interesting paper on tunneling was that of W. J. Tomasch who has observed size-dependent resonances in the second derivative of the voltage-current characteristic of Al-AlO_x-Sn tunnel junctions. These resonances are thought to result from a perturbation in the order parameter at the free surface of tin that couples the reflected quasi-particles and holes and modifies the state density at the junction. Since resonance spacing depends on Fermi velocity, the technique may be useful in measurement of this important quantity.

Sound in helium. Some of the most interesting sounds at LT 10 were in the session on helium, where the first observation of zero sound in He^3 and second sound in solid He^4 were reported.

Zero sound is a collective mode of a neutral fermion system somewhat analogous to the well known plasma mode of a charged fermion system. Landau predicted it in 1957 in his now classic work on Fermi liquids, but until recently it has eluded direct observation. W. R. Abel, Ansel C. Anderson and John C. Wheatley (Illinois) have measured sound velocity and attenuation and find a maximum in the attenuation of a 15.4-MHz sound wave at about 0.01°K, accompanied by a 3% change in velocity. These results are characteristic of the transition from zero sound to first sound, and appear to agree qualitatively with the Abrikosov-Khalatnikov theory.

H. A. Fairbank (Duke) and his group reviewed their recent observation of second sound in solid He^4. A temperature pulse was propagated through a very carefully grown single crystal. At high temperatures the received pulse exhibited dispersion and its arrival time was temperature dependent as expected for heat propagation by diffusion. Below 0.7°K, however, they observed a dispersion-free pulse with a temperature-independent velocity approximately equal to that expected theoretically.

A new theory of absorption and dispersion of first and second sound in superfluid helium was the subject of an invited paper delivered by I. M. Khalatnikov. Experimental corroboration of predictions of first sound was reported by W. M. Whitney (Cal Tech), C. E. Chase (MIT) and a group from Argonne; in general, it appears that experiment and theory on first sound are in satisfactory agreement. As yet, the theoretical prediction that the high-frequency second-sound velocity should approach zero at very low temperatures has not been experimentally confirmed.

Third and fourth sound are excitations of He II in which the normal fluid is effectively clamped and only the superfluid oscillates. Rounding off the Moscow sessions on sound propagation was an invited paper on third sound by Kenneth R. Atkins (Pennsylvania) and several contributed papers from the Kharkov group on fourth sound.

Helium mixtures. Recently it was observed that solutions containing less than 6 mole percent He^3 in He^4 are stable, apparently even at zero de-

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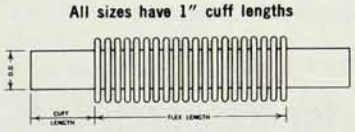

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grees. This implies that the attractive potential between He^3 atoms in solution is greater than that between He^3 atoms in pure liquid. In an invited paper, David Pines (Illinois) and Wheatley discussed how experimental data can be used to predict magnitude and momentum dependence of the additional attraction. It turns out that the attraction is very weak so that such solutions exhibit properties that are easily predictable theoretically for a weakly interacting Fermi fluid. The effective attraction could lead to a superconducting state having a transition temperature of about 2 microdegrees, a prediction that appears to be safely insulated from experimental onslaught, at least for the time being.

In addition to their intrinsic interest, He^3-He^4 mixtures are used to attain ultra-low temperatures. The He^3-He^4 mixture refrigerator uses the cooling effect of continuous dissolution of He^3 in He^4. One of the more successful of these refrigerators has been constructed at the Joint Institute for Nuclear Research at Dubna where temperatures as low as 0.025°K have been attained. Some of the relevant theory was described by V. P. Peshkov.

A method of cooling that we hope will yield temperatures below the millidegree range is adiabatic demagnetization of nuclei, described by John M. Goodkind and E. B. Osgood (U. of California, La Jolla). So far they have been able to go as low as 3 millidegrees.

Rotation. One of the more exciting helium sessions was on rotating helium. Keynote speaker was E. L. Andronikashvili who reviewed work carried out over the past few years at Tbilisi. The most important conclusion was that the rotating superfluid undergoes a first-order transition to the normal state. This result is quite surprising since it is thought that rotating He II is analogous to a type-II superconductor in a magnetic field, in which case the transition to the normal state is second order. The main evidence presented by Andronikashvili was observation of a 9% discontinuity in liquid density across the transition point. In addition, he observed interesting hysteretic effects typical of a first-order transition.

Several new results were reported during a session on critical phenomena. Leo P. Kadanoff (Illinois) spoke about a new theory of phase transitions that enables him to predict relations between the functional forms of singularities in various thermodynamic properties near a critical point. By studying the temperature dependence of the angular momentum of a persistent current, John Reppy and J. R. Clow (Yale) conclude that the superfluid density ρ_s varies as $(T_\lambda - T)^{2/3}$, in agreement with Kadanoff's prediction from the logarithmic specific-heat singularity.

M. I. Barmatz and Isadore Rudnick (UCLA) reported on their measurements of sound velocity near the lambda transition. They find the velocity continuous across the transition, in contradiction to earlier measurements.

Another interesting critical-point paper given by Peshkov and A. P. Borovikov dealt with an experimental study of the interface between He I and He II established by a heat current that enables them to determine the λ point with four-place accuracy.

Critical velocities. Liquid-helium flow in both wide and narrow channels is a subject of considerable interest. It is now well established that not one but several critical velocities exist in He II. Their existence is related to different dissipative processes that can become operative. In an invited paper E. F. Hammel (Los Alamos) discussed these processes and showed how they can be separately identified from experimental flow measurements. He pointed out four independent dissipative mechanisms: viscous dissipation by the normal fluid, mutual friction between normal fluid and superfluid, dissipation due to turbulent normal flow and dissipation due solely to superfluid flow in narrow channels or films. Associated with these are four independent critical velocities so that measured values of v_c must depend on which mechanism is operative.

An experiment that elucidates some of the difficulties in identifying these critical velocities was discussed by W. M. van Alphen, J. F. Olijhoek, R. de Bruyn Ouboter and K. W. Taconis

(Kamerlingh Onnes Laboratorium). They find that the superfluid critical velocity varies as $d^{-1/4}$ over eight decades, even for channels larger than 10^{-3} centimeters. It had previously been observed that the critical velocity was proportional to d^{-1} in wide channels, but the authors suggest that the earlier measurements reflect onset of normal turbulent flow rather than superfluid dissipation. Origin of this rather strange thickness dependence is not yet understood.

He II flow in very small geometries is exemplified by superfluid transfer through the film ($d \backsimeq 3 \times 10^{-6}$ cm). Although many measurements of film-transfer rates have been made in the past, these display a notable lack of reproducibility. W. E. Keller (Los Alamos) and Hammel described a simple method for investigating how superfluid dissipation in the flowing film is distributed along the flow path. Their results demonstrate that under varying conditions the dissipation can be either highly localized or spread out over the path and that changes in this distribution are responsible for variations in the observed transport rates.

Metals. In addition to the usual dose of papers on "Fermiology," the session on metals offered several sections on more fundamental matters.

It appears that the de Haas-van Alphen effect, useful in study of Fermi surfaces, will also be helpful in studying a certain class of interactions among electrons in metals. It has been known for several years that the magnetic field "seen" by an electron in a metal is, to a first approximation, induction B rather than H. This difference can lead to drastic modifications of the line shape of the de Haas-van Alphen oscillations. These modifications were first seen in the noble metals, but the phenomenon now seems to be quite general. In an invited paper, David Shoenberg (Cambridge) discussed his analysis of work done on gold and silver, in which magnetic interactions are quite important.

J. H. Condon (Bell Labs) pointed out that magnetic domains are expected to exist whenever differential mag-

netic susceptibility is greater than $\pi/4$. He has performed a calculation of domain size by including surface-energy and field-energy contributions to the free energy. The experiments of George M. Seidel and W. Broshar (Brown) on silver and beryllium agree qualitatively with Condon's prediction, but a direct observation of the domain structure has not yet proved possible.

Edward F. Greene, A. Houghton and J. J. Quinn (Brown) have studied the response to a small spatially varying field of an electron gas in a uniform magnetic field within the framework of the random-phase approximation. For large fields the susceptibility diverges for some wave vector and this fact suggests that the system can spontaneously support a spatially varying magnetization.

When a metal with very small band gaps is placed in a large magnetic field, electrons can tunnel from the Fermi surface in one band to the Fermi surface in another. This is known as magnetic breakdown and was the subject of two invited papers. W. G. Chambers showed how the usual effective-Hamiltonian theory for Bloch electrons must be modified. Leopolde M. Falicov (Chicago) discussed the theory of the galvanomagnetic properties of magnesium and zinc, which both display strong breakdown effects, the most pronounced being the saturation of the high-field magnetoresistance.

Observations of geometric resonances in magnetoacoustic attenuation were the subject of an invited paper by John B. Ketterson (Argonne). This work has brought to light fine points in the already analyzed Fermi surface of magnesium.

The Fermi surface of arsenic has recently been under intensive study and the de Haas-van Alphen work was the subject of an invited paper by M. G. Priestley (Chicago), and A. D. C. Grassie, P. R. Baker and Langenberg discussed the Shubnikov-de Haas cyclotron-resonance measurements. There appears to be good agreement with the pseudopotential calculation of Falicov and P. J. Lin.

Cyclotron-resonance experiments have usually been done with either the Azbel-Kaner or Galt geometries in

which the magnetic field is applied in one case parallel and in the other case perpendicular to the surface. The use of inclined magnetic fields is potentially useful, and was discussed by M. Y. Azbel, P. E. Bloomfield, E. A. Kaner and A. Ya. Blanc. For small inclinations from the surface, a splitting and broadening of the Azbel-Kaner resonance frequency due to a Doppler-like mechanism is predicted. This type of geometry can also be useful in magnetoacoustic work.

Antiferromagnetism. I. E. Dzyaloshinsky outlined his work on antiferromagnetic structures. He pointed out that four types of magnetic structure can exist: "classical" structures in which the magnetic period is commensurate with the lattice period; "beats," which appear as a result of either spin-orbit interaction or a pronounced exchange-force anisotropy; structures possessing periods close to the inverse value of some extremal diameters of the Fermi surface, which arise from the long-range Ruderman-Kittel interaction; "accidental" structures with totally arbitrary periods.

The experimental evidence concerning localized moments in metals was summarized by Alan J. Heeger (Pennsylvania). In most cases the virtual-level widths are small compared to the Coulomb and exchange energies responsible for localized moments. This suggests that the Hartree-Fock treatment of the problem is suspect and that correlations may play a dominant role. Heeger also emphasized the need for studying the single-impurity problem, which is very difficult experimentally because of the long-range Ruderman-Kittel interaction. He suggested that one could isolate the impurities by limiting the conduction-electron mean free path and hence reduce the range of the impurity-impurity interaction.

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Leonard W. Gruenberg
MIT □