Meetings and Conferences

VIII ALL-UNION CONFERENCE ON LOW TEMPERATURE PHYSICS

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THESE conferences on low temperature physics have acquired the status of a unique tradition. Physicists (both experimentalists and theoreticians) working in the realm of low temperature physics congregate annually at one of the centers of development in this field of knowledge and discuss the work of the preceding year.

It is noteworthy that with each year the number of participants increases, and the number of papers submitted grows; it has become necessary to divide the conference into sections. The cryogenics meetings have gradually evolved into comprehensive conferences on the physics of the condensed state.

The Eighth Conference, which took place in Kiev in October, 1961, attracted more than 500 participants. Approximately 200 papers were presented. Delegates came from 15 cities of the Soviet Union. Low temperature physics is currently developing, not only at the "classical" centers—Moscow and Khar'kov—but also in Kiev, Tbilisi, Leningrad, Sverdlovsk, and Sukhumi. The number of cryogenic laboratories grows with every year. It is not only the geography of cryogenic physics, however, which is being extended; its scope is also broadening. Optics and the nucleus, semiconductors and isotopes—these are comparatively new fields in low temperature physics—were very widely represented at this latest conference.

The conference was opened on October 13th by the Chairman of the Scientific Soviet for low temperature physics, Academician P. L. Kapitza, who presented the introductory speech for the first plenary session.

In all, two plenary sessions were held, and eight sections met to deal with the following topics:

1. Crystal optics.
2. Properties of helium.
3. Superconductivity.
4. Electronic spectra of crystals (metals and semiconductors).
5. Magnetic properties of condensed systems.
6. Low temperature thermodynamics. Mechanical properties of solids.
7. Nuclear studies.
8. Low temperature technology.

1. CRYSTAL OPTICS

The holding of the conference in Kiev, naturally, influenced its theme. This was especially evident in the attention given to low temperature spectroscopy—an important field of solid-state physics, which has for a number of years been successfully developed by the experimentalists and theoreticians of Kiev. The plenary session with which the conference opened,* as well as one section meeting, were devoted to the problems treated by this group.

As the studies of recent years have shown, the most interesting, and often the most completely unexpected, properties of non-metallic crystals are observed near the region of exciton absorption. For this reason, the majority of the papers were devoted to the study of specific phenomena occurring in this spectral region, and to the development of methods for analyzing the structure of the exciton zones.

S. I. Pekar showed that in the region of strong exciton dispersion the dominant role is played by the spatial dispersion of the dielectric constant ϵ; i.e., by its dependence upon the electromagnetic wave momentum $\mathbf{k}$. In the vicinity of the exciton bands, spatial dispersion gives rise, not, as is usually the case, to the appearance of small corrections, but to a qualitatively new effect in crystal optics—the generation of supplementary light waves. Study of these supplementary waves makes possible, for example, the investigation of the exciton dispersion law $E(\mathbf{k})$ for small $\mathbf{k}$ (the sign and magnitude of the effective mass, etc.).†

During the discussion, **P. L. Kapitza** emphasized the significance of low temperature techniques, without the application of which the experimental investigation of the interesting new phenomena described in the paper would have been impossible.

In order to study the special effects arising in the neighborhood of the exciton bands, a broad program of quantitative experimental studies of a large number of crystals has been undertaken (**M. S. Brodin, A. F. Prikhot'ko,** and **M. S. Soskin**). In accordance with the above-mentioned theory of supplementary waves, oscillations of the optical transmission coefficient as a function of crystal thickness are observed in the mono-

*The second plenary session was the final one. In it, the results of the work of the sections were reported by A. S. Borovik-Romanov, A. G. Zel'dovich, B. G. Lazarev, E. M. Lifshitz, and S. S. Shalyt.

†The texts of the papers by E. V. Shpol'skii and S. I. Pekar', presented at the plenary session, are published in the present issue.

clinic crystal of anthracene, as well as in the cubic crystals of CuCl and sodium uranyl acetate; these are accompanied by oscillations in reflectivity and in the phase of the transmitted light. Inasmuch as the experiment was performed under conditions for which multiple passage of the light through the plate could be discounted, these results represent direct evidence for the existence of supplementary waves. The prominent role played by spatial dispersion is also indicated by the sudden departure from the Kramers-Kronig relation, especially as this departure increases with decreasing temperature (anthracene, benzanthracene). It is necessary also to mention the study made of the form of the exciton absorption band in naphthalene, from which various conclusions may be drawn regarding the exciton interaction force and the nature of the excited states.

Speaking during the discussion, **V. M. Agranovich** reported that according to the results of his calculations, one of the waves in anthracene should be so strongly absorbed as not to arise at all. However, in the opinion of **I. V. Obreimov**, who has acquainted himself in detail with the design of these crucial and extremely complex experiments, the latter were performed with great care, and, although they are not as yet one hundred percent reliable, it may with a high degree of assurance be assumed that the observed oscillations are not associated with side-effects; it will be necessary, of course, to perfect further the techniques and to secure new experimental data.

Optimum conditions for the study of the spectra of complex molecules are achieved when the latter are introduced into appropriate crystalline solvents, since in this case the bands in their low temperature spectra are limitingly narrow. Excellent solvents (matrices) for a broad class of organic materials are provided by the normal paraffins, which insure that narrow-band impurity spectra will be produced, when the lengths of the activator and paraffin-solvent molecules are comparable (**É. V. Shpol'skii**). The experimentally-observed multiplet structure of emission spectra can be described in terms of discrete, spatially separated radiating centers, differing from one another in the distribution of rotational isomers in the vicinity of the activator molecules. Thus, by "inverting" these experiments one can draw certain conclusions regarding the molecules of the matrix.

During the discussion, **N. E. Alekseevskii** and **M. T. Shpak** noted that investigation of the changes in the spectra with pressure, temperature, and concentration should aid in explaining the nature of the multiplets; in this connection, M. T. Shpak referred to his results on the interaction of impurities in solutions of aromatic compounds. **V. N. Vatulev** reported that from changes in the spectrum of anthracene dissolved in dihydroanthracene, a phase transition in the solvent material can readily be detected. Summarizing the discussion, **P. L. Kapitza** emphasized the necessity for extending these studies and developing their systematic interpretation; he noted that the correctness of the hypotheses concerning the role of rotational isomers remains as yet problematical.

This new approach to the investigation of the genesis and structure of exciton zones in molecular crystals makes it possible to study the spectra of materials differing in isotopic composition (**V. L. Broude, É. I. Rashba, E. F. Sheka**). Under these conditions it is possible, as the impurity concentration increases, to follow the transformation of an impurity absorption band into a crystalline (Davidov) doublet. "Impurity exciton" spectra are observed in concentrated solutions. The polarization and intensity of the impurity absorption bands in dilute solutions, it follows from theory, must depend sharply upon the distance of the impurity level from the exciton zone, as well as upon the structure of the latter. This effect must appear for all cases in which the distance between the regions of impurity and exciton absorption is less than, or of the same order as, the width of the exciton zone. In studying mixtures of components having differing isotopic composition, one can displace the impurity band relative to the exciton zone, and thus determine the locations of the zone boundaries, as well as, in perspective, the structure of the zone near its boundaries. In studying mixtures of deuteronaphthalenes, a variation of three orders of magnitude was observed in the polarization ratio, and of two orders of magnitude in the intensity of polarization; it was also shown that the A-band of naphthalene corresponds to the bottom of the exciton zone.

The interpretation of the exciton spectra of CdS proposed by Thomas and Hopfield finds confirmation in recent absorption spectrum studies, in which new bands have been found (**B. S. Razbirin**). This interpretation is also in accordance with data on luminescence spectra, in which radiation is observed which coincides resonantly with exciton absorption bands; from analysis of these results, the conclusion is reached that the quasi-equilibrium between various exciton states is severely disrupted (**V. V. Sobolev**).

The finite velocity of motion of the excitons generated by light has an interesting consequence in the magneto-optics of excitons; specifically, it permits the determination of their effective mass. The absence of an inversion center in CdS leads to additional characteristic phenomena, such as, for example, a change in the spectrum upon inversion of the magnetic field (**E. F. Gross, B. P. Zakharchenya**). To this interesting approach developed by Thomas and Hopfield and by these speakers, objections were voiced by **V. M. Agranovich**, in whose opinion this group of phenomena cannot, in principle, yield the effective mass.

Analysis of the low temperature infrared spectra of crystalline solutions makes it possible to study the rotational freedom of the impurity molecules (**M. O.

Bulatov). Specifically, it has been shown that, while in an Xe matrix rotation of the ammonia molecule about the C_3 axis is almost unhindered, in an N_2 matrix it is completely prevented.

In a paper by **O. N. Trapeznikova, E. I. Feofanova,** and **L. B. Shigaeva,** an analysis of the temperature dependence of birefringence in a series of oriented polymers was used to study their possible configurations and the thermal motion of the radicals.

A communication by **V. V. Eremenko** described a method for measuring the Zeeman effect in pulsed fields.

D. T. Sviridov presented a brief report on the work of the crystal optics laboratory of the Institute of Crystallography of the U.S.S.R. Academy of Sciences, conducted under the direction of S. V. Grum–Grzhimaĭlo and N. A. Brilliantov.

2. PROPERTIES OF HELIUM

The study of the properties of liquid helium represents the classic investigative field in low temperature physics.

In recent years new directions have opened up in the study of liquid helium. In the first place, with the relatively large quantities of He^3 which are now available, studies of both He^3 itself and of He^3—He^4 mixtures have been initiated and carried forth with great success. In the second place, a direct determination of the phonon-roton spectrum of He^4 has been made, based on the inelastic scattering of neutrons. And, finally, the discovery of vortex motion in the superfluid component has given new life to studies of the mechanism by which superfluidity is destroyed. This latter problem formed the subject of papers by **V. P. Peshkov** and **V. K. Tkachenko, V. P. Peshkov** and **V. B. Stryukov,** and **Yu. G. Mamaladze.** In the first paper (V. P. Peshkov and V. K. Tkachenko) a study is made of the processes of formation and propagation of turbulence fronts in a capillary filled with superfluid helium, under a slightly supercritical heat flux. The authors have discovered a complex system of fronts, advancing from the ends of the capillary. Generation of vortices within the capillary was not observed for velocities up to 1.7 times the critical value. In the second paper (V. P. Peshkov and V. B. Stryukov) second sound was used to detect the destruction of superfluidity during the flow through a capillary, either of the superfluid component alone, or of the superfluid and normal components moving in opposition. The authors have shown that the governing factor in the destruction of superfluidity within a capillary is the motion of the superfluid component relative to the walls.

The theoretical paper by **Yu. G. Mamaladze** was devoted to a calculation of the dependence of the critical velocity in superfluid He upon the separation of the bounding surfaces, as well as upon the roughness characteristics of these surfaces (the degree of roughness is especially important in narrow channels). A paper whose theme was close to those of the preceding reports was that by **É. L. Andronikashvili, G. A. Gamtsemlidze,** and **Sh. A. Dzhaparidze**: "Measurement of the Penetration Depth for Motion of a Torsional Pendulum in He II at Supercritical Velocities," in which an investigation was made of the velocity distribution over a disk undergoing forced oscillations. The authors determined the penetration depth of the viscous wave, and derived a relation between the kinematic velocity and the amplitude of the oscillations.

B. G. Lazarev, B. N. Esel'son, N. E. Alekseevskii, and others spoke during the discussion following these papers.

Two papers were devoted to the thermodynamics of He^3—He^4 solutions: "The Problem of Superfluidity in Separated He^3—He^4 Solutions," by **B. N. Esel'son, V. G. Evantsov,** and **A. D. Shvets,** and "Singularities in the Equilibrium Diagrams for He^3—He^4 Solutions at the λ-point," by **D. G. Sanikidze.**

In the first of these papers, experimental means were used to determine (from the break in slope of the heating curve) the λ-points of solutions near their respective phase separation temperatures. The authors came to the conclusion that the λ-point curve meets the phase separation curve at its maximum, which indicates that the lighter phase (in a separated mixture) is in the non-superfluid state.

Speaking during the discussion, **V. P. Peshkov** called attention to the fact that experimental data obtained in his laboratory contradict these results. He expressed doubts as to their correctness, suggesting that the source of error might be a non-adiabatic regime in the apparatus. **B. N. Esel'son,** in answering, noted that the present data agree well with the majority of the published results. Moreover, as N. E. Alekseevskii pointed out, adiabatic conditions in the experimental apparatus are not required for the detection of the λ-transition.

D. G. Sanikidze has investigated theoretically the diagram of state for a He^3—He^4 solution near the point of intersection of the λ-transition line with the first-order phase transition curve. He has shown that the character of the singularity at this point is determined by the singularity in the thermodynamic potential at the He I—He II transition. Thus, if the specific heat possesses a logarithmic singularity to the left and right of the λ-point (as in indicated by the experimental data), then the intersection point is a point of tangency between two curves, and no break in slope should be observed in the first-order phase transition curve.

V. P. Peshkov remarked that at present insufficient accuracy is attainable to permit clarification of the character of the singularity at the intersection point.

The paper "γ-Ray Scattering in Liquid He^3," by **A. A. Abrikosov** and **I. M. Khalatnikov** was devoted to an investigation of pure He^3. In this paper the frequency and angular dependence of the scattered radiation in He^3 are calculated. Numerical estimates indicate a substantial magnitude for the effect, which (if Mössbauer γ quanta are used) provides a possibility for measuring the velocity of "zero sound."

The discussion, in which **Yu. M. Kagan** took part, was devoted to an explanation of the role of multiple-frequency scattering of γ quanta in the phenomenon under study.

Closing the session, Chairman **V. P. Peshkov** remarked that, in his opinion, the most interesting problems in the study of liquid helium consist of its formation of vortices and the mechanism by which superfluidity is destroyed, the investigation of the properties of He^3 at ultra-low temperatures (in particular, the question of whether or not He^3 undergoes a transition to a superfluid state near absolute zero, as predicted by the theory of **L. P. Pitaevskii**), the further study of the properties of He^3—He^4 mixtures, the derivation of a more accurate diagram of state for these mixtures, and, finally, the investigation (both experimental and theoretical) of the magnetic relaxation time of He^3, both in the pure form and in He^3—He^4 mixtures.

3. SUPERCONDUCTIVITY

As is well known, the fundamentals of the microscopic theory of superconductivity were formulated as long ago as 1957. This interesting phenomenon has, however, continued to be studied (both experimentally and theoretically) up to the present time. On the basis of new hypotheses, various phenomena in superconductors are currently under consideration: absorption of electromagnetic waves, ultrasonics, thermal conduction, etc.

One of the most effective experimental results in this area, without doubt, is the measurement of the energy gap in the voltage-current characteristic of a tunnel diode consisting of two superconductors separated by a thin dielectric layer. This result was achieved almost simultaneously by a number of American authors. In the Soviet Union, the tunnel effect in superconductors (Al, In, Sn, Pb) was first studied by **N. V. Zavaritskii**, whose measurements extended over the temperature range down to 0.1°K. This led to improvements in technique, and made it possible to determine a number of important characteristics of superconductors (normal electron density, gap width, gap variation with temperature).

During the discussion, the details of the experiment and its results were first specified in greater detail (**L. P. Gor'kov**), and second, attention was drawn to the falling branch of the voltage-current characteristic, which should lead to a negative resistance at high frequencies.

B. K. Sevast'yanov and **G. F. Zharkov** reported the results of experiments to measure the transverse component of the magnetic moment in thin superconducting films. The measurements agree well with theoretical calculations performed by authors on the basis of the phenomenological Ginzburg-Landau theory of superconductors, which is applicable near the transition temperature.

In the paper by **N. B. Brandt** and **N. I. Ginzburg** results were presented of an experimental investigation of the superconducting modifications of Bi. The authors have observed superconductivity in a modification (Bi II) of bismuth which is unstable at helium temperatures. A careful study was made of the effects of Sb and Pb impurities upon the superconducting properties of bismuth under pressure.

B. T. Geĭlikman and **V. Z. Kresin** presented two papers devoted to the development of a microscopic theory of superconductivity. In the first paper, an attempt is made to generalize the theory to the case of an anisotropic superconductor. To be sure, the authors make use of highly specialized assumptions regarding the form of the Fermi surface (ellipsoid, cylinder). In the second paper, the results obtained from the construction of a theory of thermal conduction in superconductors were presented. In addition to the results previously published, the authors have considered scattering of electrons by phonons. The theoretical results show good agreement with experiments on In and Sn.

In the discussion (**L. P. Gor'kov** and **I. M. Khalatnikov**) the relation was explained between the present work and that of earlier investigators, in particular Pokrovskii, who constructed a phenomenological theory for anisotropic superconductors. The authors remarked that their results do not contradict those of Pokrovskii.

Measurement of the Knight shift in the nuclear resonance frequency provides an extremely sensitive tool for determining the state of the conduction electrons. Experiments in recent years have shown that in the superconducting state the shift is smaller by approximately 30% than in the normal state. A theory for this phenomenon has been developed by **A. A. Abrikosov** and **L. P. Gor'kov**. It turns out that the reason for the shift lies in the spin-orbital scattering of electrons by lattice defects. The theory explains, not only the magnitude of the effect, but also its temperature dependence. **B. T. Geĭlikman** spoke during the discussion following this paper.

4. ELECTRONIC SPECTRA OF CRYSTALS

a) Metals. In recent years a large number of studies have been devoted to the determination of the structure of the energy spectrum of the conduction electrons. Theoretical work in this field (leading up to the paper by **I. M. Lifshitz** and **A. V. Pogorelov**, in which, for the first time, the problem of establishing the form of the Fermi surface from the dependence of the period of the magnetic moment oscillations upon the direction of the magnetic field has been posed and resolved) has revealed a large number of structure-sensitive effects (galvanomagnetic characteristics, cyclotron resonance, ultrasonic absorption, anomalous spin effect, etc.). Not only have most of these effects already been found, they are also currently serving as reliable methods for determining the energy spectra.

Most of the papers presented to the "Electronic Spectra of Crystals" section dealt with this group of problems.

The ordinary methods of studying the forms of Fermi surfaces permit determination of their topology (galvanomagnetic properties), extremal cross-sections (de Haas–van Alphen and related effects), and extremal masses (cyclotron resonance). In the paper by **I. M. Lifshitz, M. Ya. Azbel'**, and **A. A. Slutskin** new, more delicate methods were described which offer the possibility of a complete reconstruction of the Fermi surface, as well as the isolation and investigation of specific sections. Quantization of the areas S in a magnetic field leads to a quantization of the mass m and to the appearance of fine structure in the cyclotron resonance curve, i.e., to quantized cyclotron resonance. The structure may most readily be resolved for small zones and special sections of large zones for which $\partial S/\partial m = 0$. Under the simultaneous imposition upon a crystal of constant and weakly-varying magnetic fields, quantum resonance absorption in the high-frequency region will depend upon those electrons whose frequency is stationary with time. By altering the relative orientation of the constant and weakly-varying fields, it is possible to distinguish various sections of the Fermi surface and to obtain complete information regarding its form.

New data on the Fermi surface make it possible to produce another new resonance effect—giant oscillations in ultrasonic absorption (**V. L. Gurevich, V. G. Skobov, Yu. A. Firsov**). The amplitude of these oscillations in a strongly degenerate electron gas with a sufficiently great electron mean free path is extremely large, to the extent that the maximum absorption may be many times the minimum value. The physical basis of the oscillations lies in the fact that when ultrasound is propagated along **H**, the conservation laws require that it be absorbed only by electrons with momentum components along **H** of $p_0 = mw$, where w is the velocity of the ultrasound. An absorption peak will therefore be observed upon the emergence of electrons of momentum p_0 at the Fermi surface. The oscillations are periodic in H^{-1}, and the height of the peaks is proportional to T^{-1}; they should be observed when the angle between **H** and the direction of propagation of the sound is other than a right angle. For a non-quadratic dispersion law, observation of the peaks permits determination of the effective mass in a section displaced from the center by p_0, which may be important for the study of small zones.

The theoretically predicted giant oscillations have now been experimentally observed in zinc for an electron group with a concentration $\sim 10^{-4}$ electron/atom, at an ultrasonic frequency of 220 Mcs (**A. P. Korolyuk, T. A. Prushchak**).

During the discussion these papers were highly praised as showing great elegance and perspective.

As a result of the drift of electrons in the $(\mathbf{E}\times\mathbf{H})$ direction in crossed electric and magnetic fields, the ultrasonic absorption varies in periodic fashion with E, while the amplitude of the oscillations falls rapidly as E increases. From the period of the oscillations it is possible to determine the extremal effective masses and extremal periods for motion along open, periodic trajectories. (**V. G. Peschanskiĭ, I. A. Privorotskiĭ, Yu. A. Freĭman**).

A powerful method for the investigation of the topology of Fermi surfaces is provided by the study of the galvanomagnetic properties of metals. By investigating angular diagrams and comparing the experimental data with the theory of I. M. Lifshitz and V. G. Peschanskiĭ, **N. E. Alekseevskiĭ** and **Yu. P. Gaĭdukov** have shown that the Fermi surface of lead possesses open trajectories, and has the form of a three-dimensional lattice composed of corrugated cylinders, oriented along the directions of the body diagonals of a cube. At the same time, the Fermi surface for the holes is closed. This form for the Fermi surfaces also agrees with the experimental data of Gold on the oscillations of the magnetic susceptibility.

E. S. Borovik and **V. G. Volotskaya** have observed a marked anisotropy in resistance for ultra-pure Al in a magnetic field.

During the discussion, **V. G. Peschanskiĭ, I. M. Lifshitz** and **N. E. Alekseevskiĭ** made the suggestion that the data presented may be explained if the Fermi surface of Al has the form of "pillows" joined by narrow extensions oriented along (111). A slight bending of the crystal might lead to the apparent destruction of symmetry observed in the experiment. A careful study of the rotational diagrams would be necessary for confirmation of this hypothesis.

V. N. Kachinskiĭ has observed in Sn the narrow minima of the Hall "constant" predicted by I. M. Lifshitz and V. G. Peschanskiĭ. These singularities are associated with the presence in Sn of open trajectories. Observation of effects which are transverse with respect to current (both even and odd) yields a large amount of information on the topology of the Fermi surface. **I. K. Kikoin, E. S. Borovik**, and **V. G. Peschanskiĭ** took part in the discussion following this paper.

Great interest was attracted by a report by **M. S. Khaĭkin** concerning the detection and investigation of cyclotron resonance in Sn and Pb. Increased sensitivity in the apparatus employed, the use of samples of a unique degree of purity, and observation of the effect in a plane-polarized wave, all made it possible to study the energy spectrum of Sn in extreme detail. The author has, moreover, proposed a most original means for the direct determination of the diameter of the section corresponding to extremal mass, based upon the disappearance of the high-order resonance peaks observed in monocrystalline slabs of the metal when the orbital dimensions become greater than the thickness of the slab.

Those persons who spoke during the discussion following this paper drew attention to the need for a detailed comparison of the results concerning the structure of the spectrum obtained in various experiments (**I. M. Lifshitz**, **N. E. Alekseevskii**, **M. I. Kaganov**). **M. Ya. Azbel'** remarked that the careful fulfillment by the author of all of the conditions dictated by theory made it possible (evidently for the first time) to pass from the mere observation of cyclotron resonance to its use as an extremely important and reliable method of studying the electron spectrum.

The observation of cyclotron resonance likewise formed the subject of a paper by **A. A. Galkin** and **V. P. Naberezhnykh**, who observed this phenomenon in a monocrystal of Al. The results which they obtained agree qualitatively with those found ultrasonically.

A further development of the theory of cyclotron resonance was embodied in the paper by **M. Ya. Azbel'** and **G. A. Begiashvili**, which was devoted to the consideration of the Fermi-fluid interaction.

One of the methods by which the electron spectrum of a metal may be affected is the addition of impurities to a metal having a small number of electrons. **N. B. Brandt** and **V. V. Shchekochikhina** have studied the effect of an Sb impurity upon the de Haas–van Alphen effect in Bi. They have shown that the effective mass tensor is unaltered, while the Fermi surface contracts, remaining similar to itself.

B. E. Verkin, **I. V. Svechkarev**, and **S. N. Kabakova** have studied the temperature dependence of the magnetic susceptibility χ in weakly-magnetic metals (Tl, Mg, Ca, Zn). In Tl the temperature anisotropy previously discovered in other metals (Sb, Cd, Cr, Zn), and characteristic of metals having small zones, was observed: in going from helium to room temperature, the magnetic susceptibility along the binary axis falls, while that along the principal axis remains constant. The susceptibility is weakly temperature dependent in Ca and Mg.

In addition, the effect of impurities upon the magnetic susceptibility of In was investigated.

During the discussion, emphasis was placed on the novelty of the conclusions regarding the appreciable anisotropy of small groups. At the same time, it was remarked that the interpretation of the temperature dependence of χ in terms of a temperature dependence of the lattice parameter must be verified by direct experiments on the effect of pressure.

The study of the dependence of the resistance of fine wires upon their diameter d, under conditions for which the mean free path is comparable to or even greater than the diameter, has made it possible to determine the mean free path in a number of metals (In, Pb, Al, Sn, Zn, Cd, Bi) purified by zone refining. The mean free path in these metals falls within the range 0.1–0.2 mm (**B. N. Aleksandrov** and **I. G. D'yakov**). The observed temperature dependence of the resistance for $d \ll l$ is treated by the authors as a change in the character of electron scattering at the boundaries of the metal with changing temperature.

Anisotropy in the resistance of fine wires grown in various crystalline orientations is associated with anisotropy of the Fermi surface. (**B. N. Aleksandrov** and **M. I. Kaganov**).

In the discussion following these two papers, **M. Ya. Azbel'** remarked that the temperature dependence of the resistance of fine wires is evidently to be explained, not by scattering of electrons at the boundaries of the metal, but by the specific role of the electrons moving along the axis of the wire, in particular by the role of their collisions with phonons.

V. V. Andreev and **A. M. Kosevich** have constructed a theory of the normal skin effect in a strong magnetic field, when the thickness of the skin-layer is appreciably greater than the radius of the Larmor orbit; the quantized oscillations of the complex electrical conductivity tensor have been computed. Both the case of an arbitrary dispersion law for weak interaction of the electrons with impurities, and that of a quadratic, isotropic dispersion law for an arbitrary interaction with point impurities have been considered.

b) Semiconductors. Among the effective methods for the study of the parameters of zone current carriers in semiconductors, the most prominent are cyclotron and paramagnetic resonance. Spin-orbit coupling, leading to "entanglement" of motions in configurational and spin space, makes possible a new, combined resonance, excited by the electric vector of a high-frequency field and accompanied by a change in the effective spin moment (**É. I. Rashba**, **I. I. Boĭko**, and **V. I. Sheka**). The combined resonance may considerably exceed the paramagnetic resonance in intensity, and is especially strong in crystals without inversion centers; its frequency is equal to a linear combination of the cyclotron and paramagnetic resonance frequencies. The combined resonance has a strong angular dependence, as well as a characteristic dependence upon temperature, magnetic field, and electron concentration. The spin-orbit coupling also leads to the appearance of a special zone structure, for which the extremal energy is reached at the periphery—an extremal loop—while the isoenergetic surfaces for small values of the energy form tori. The electronic properties of such semiconductors are most unusual; for example, up to 50% of the carriers have negative mass.

In the opinion of **S. I. Pekar**, the new resonance predicted in this paper is of interest from a theoretical viewpoint, and, in time, may also assume a practical value.

During the discussion, **M. Ya. Azbel'** reported the results of his work, in which it was shown that in metals, due to the small depth of the skin-layer as compared with the radius of the cyclotron orbit, transitions with a simultaneous change in the orbital and spin quantum numbers are possible even in the absence of spin-orbital interaction; in contradistinction to semiconductors, however, they are excited by the magnetic vector of the rf field and are of lesser intensity.

Interesting possibilities for the study of the resonance properties of semiconductors are offered by the imposition of oriented deformations, lessening the degree of degeneracy and simplifying the spectrum (**G. E. Pikus** and **G. L. Bir**). In undeformed Ge and Si the g-factor for the holes depends upon the quasi-momentum **k**, and there exists therefore a broad band of "spin" resonance frequencies excited by both the electric and the magnetic vectors of the rf field. In deformed crystals, however, when the zone splitting exceeds the characteristic energy of the electrons, the g-factor is determined solely by the orientation of the deformation, and is independent of **k**. The spin resonance frequency for the holes associated with the acceptors is extremely sensitive to the magnitude of the deformation. Their g-factor is determined from equations having the same structure as for the zone holes, but with different values for the constants. The limiting value for the g-factor, which agrees with the g-factor for the holes in the upper zone, is reached only when the deformational splitting of the zones becomes greater than the ionization potential of the acceptor.

An important means for studying the zone structure, and the basic method for analysis of the current carrier scattering mechanisms, is provided by the investigation of transport phenomena.

In addition to the ordinary Shubnikov–de Haas oscillations in the electrical conductivity, a new type of oscillation is found to be possible, associated with singularities in the inelastic scattering of electrons by optical phonons, and occurring even in the case of Boltzmann statistics (**V. L. Gurevich, Yu. A. Firsov**, and **A. L. Éfros**). The location of the oscillation peaks is determined by the resonance condition $\omega = n\Omega$, where ω is the limiting frequency of the phonons, Ω is the Larmor frequency, and n is a whole number. Since $\hbar\omega \gg kT$ appears as a condition for the occurrence of the oscillations, while the heights of the oscillation maxima are proportional to $\exp(-\hbar\omega/kT)$, the oscillations should be observed over an intermediate range of temperatures (~ 100–150°K).

In the discussion, **I. K. Kikoin** raised the question of why the predicted oscillations had not as yet been detected experimentally. In answer, **Yu. A. Firsov** said that the electrical conductivity peaks are logarithmic and are readily "washed out." It is important that the departure from a quadratic dispersion law be small, the coupling with the optical phonons sufficiently strong, and the experiments carried out in the optimal temperature range; a suitable subject for study, evidently, would be InAs.

In recent years it has been found that a major part is played in thermogalvanomagnetic phenomena by the effect discovered by L. Gurevich, especially at low temperatures. The transverse electrical conductivity $\sigma_\perp$ in a strong magnetic field ($\Omega\tau \gg 1$) is limited by the rate of relaxation at structural defects of the electron-phonon system momentum components normal to both fields. Under conditions, therefore, for which momentum loss occurs chiefly by collisions of phonons with defects, with a characteristic time for this process which exceeds the electron-phonon relaxation time, the entrainment processes exert the dominating influence upon the transverse electrical conductivity. In a theory proposed for this phenomenon (**L. É. Gurevich** and **A. L. Éfros**), the dependence of $\sigma_\perp$ upon temperature and magnetic field has been derived for semiconductors and semimetals.

The entrainment effect has a determining influence upon the thermal e.m.f. α in pure specimens of tellurium below 70°K (**I. N. Timchenko** and **S. S. Shalyt**). The phonon component of α is almost isotropic; this is in accordance both with the hypothesis that the hole zone is weakly anisotropic, and with the conclusion of the theory of V. L. Gurevich and Yu. A. Firsov that strong anisotropy in the phonon relaxation time is not accompanied by any significant anisotropy in α. The conclusion that the anisotropy of the hole zone in tellurium is weak is borne out by a study of the galvanomagnetic properties (**R. V. Parfent'ev, A. M. Pogarskii, I. I. Farbshteĭn**, and **S. S. Shalyt**). The appreciable anisotropy of the galvanomagnetic coefficients observed in unannealed specimens is associated with anisotropic scattering by structural defects, and disappears upon annealing, after which there remains only scattering by acoustical phonons and ionized impurities.

The influence of entrainment upon the Nernst-Ettinghausen effect, under conditions in which the picture of the phenomenon is considerably complicated by the presence of two types of holes, is observed in p-InSb and p-GaAs (**Kh. I. Amirkhanov, D. Kh. Amirkhanova**, and **R. I. Bashirov**).

The transition to the region of large magnetic fields provides the possibility of detecting quantum effects. In n-InSb and n-InAs the influence of quantum phenomena upon the Nernst-Ettinghausen effects is observed for $H \gtrsim 10$ kOe, and is accompanied by a sharp increase in the magnitudes of the effects, the longitudinal effect changing sign (**Kh. I. Amirkhanov, R. I. Bashirov**, and **M. M. Gadzhaliev**).

For fields in this range, however, as **E. A. Zavadskii** and **I. G. Fakidov** have demonstrated for n- and p-Ge in fields up to 200 kOe, there arises a series of secondary phenomena which hinder the interpretation of the experiments. First of all, as H rises, the ionization potentials of the impurities increase and the carrier concentration in the zone decreases, which, for constant current, leads to a rise in the electric field and the ionization, beginning at $E \sim 25$ V/cm. Even earlier, for $E \sim 3$ V/cm, the mobility begins to be dependent upon E. Through analysis of the experimental data, the dependence of the mobility and the carrier concentration upon E and H was derived. For $H < 100$ kOe, agreement is found with the classical theory; quantum effects are observed in larger fields.

Observations made in pulsed fields of up to 450 kOe in n-InSb have revealed oscillations in the longitudinal and transverse magnetoresistance (**Rh. I. Amirkhanov, R. I. Bashirov,** and **Yu. Z. Zakiev**). In the opinion of **É. A. Zavadskii**, et al., however, the method of measurement was insufficiently refined, and the results require further verification.

On the basis of a scheme in which the structure is described by the six-coordinate Drebble-Wolf model, while the relaxation tensor is taken in the form $\tau_{ij} = \varphi(\epsilon) a_{ij}$, a theory has been constructed for the galvanomagnetic phenomena in Bi_2Te_3. For six of the nine galvanomagnetically-measured coefficients two choices were found for the theoretical parameters; the three remaining coefficients were in good agreement with the experiment. In order to choose between the two possibilities, additional experimental data are needed (**B. A. Efimova, I. Ya. Korenblit, V. I. Novikova,** and **A. G. Ostroumov**).

5. MAGNETIC PROPERTIES OF CONDENSED SYSTEMS

a) Ferro- and Antiferromagnetism. Although ferromagnetism and antiferromagnetism are observed in a number of substances at room temperature, which is attributable to a large value for the exchange energy, the study of magnetic properties at low temperatures permits a deeper analysis of the physical nature of magnetic ordering.

As is well known, the application of general symmetry considerations to various magnetic structures allowed I. Dzyaloshinskii, some years ago, to explain the nature of weak ferromagnetism, and to predict a piezomagnetic effect for a number of crystals.

At this conference three papers were devoted to this group of problems.

A. S. Borovik-Romanov, Zh. G. Aleksanyan, and **E. G. Rudashevskii** have studied in detail the piezomagnetic effect discovered by A. S. Borovik-Romanov. The subjects of this investigation consisted of tetragonal ($MnFe_2$, CoF_2) and rhombohedral ($FeCO_3$) antiferromagnetics. The largest effect was observed in CoF_2 (upon application of elastic stresses of ~ 500 kg/cm^2 there appeared a piezomagnetic moment of $\sim 0.1\%$ of the nominal magnetization). For the tetragonal magnets the effect was observed both parallel and perpendicular to the magnetization of the sublattices. In the case of $FeCO_3$ a piezomagnetic moment was observed along the binary axis x, upon application of elastic stresses σ_{yz} (z is the trigonal axis). The observations agree with the theoretical predictions.

During the discussion following this paper, the importance of the results obtained was pointed out (**K. P. Belov, K. B. Vlasov**).

A. S. Borovik-Romanov reported the observation of antiferromagnetic resonance in the carbonates of transition elements ($MnCO_3$, $CoCO_3$) possessing weak ferromagnetism. The use of extremely pure specimens made it possible to observe a very sharp resonance, and to measure directly the "Dzyaloshinskii field" H_D characterizing the relativistic forces leading to weak ferromagnetism. It is of interest to note that the value found for H_D does not agree with the static measurements.

During the discussion, details of the experiment were considered and further possibilities were brought out (**K. P. Belov, V. F. Gantmakher, M. I. Kaganov**).

A theoretical paper by **N. G. Guseĭnov** was devoted to the calculation of the high frequency magnetic susceptibility of tetragonal and rhombohedral weak ferromagnets. For a magnet of the NiF_2 type, the author carried out a computation of the anisotropy in the basal plane. Under the assumption that the relaxation constants and the g-factor are isotropic, a formula was derived which determines the anisotropy in the width of the resonance lines.

Speaking during the discussion, **E. A. Turov** drew attention to the desirability of a careful examination of the dependence of the resonance line width upon the orientation of the magnetic field. This would make it possible to determine the anisotropy of the relaxation constant. Moreover, from the angular dependence of the resonant frequencies, any anisotropy existing in the g-factor may be found. It would be desirable to perform experiments of this type on NiF_2.

The spin wave theory appears at present to be the only theory which permits the determination of specific properties of magnetic substances at low temperatures. The contribution of spin waves to the specific heat is well known. The temperature dependence of the magnetic moment near absolute zero is governed by spin waves.

I. N. Kalinkina and **A. S. Borovik-Romanov** have investigated the specific heats of the carbonates of transition metals ($MnCO_3$ and $FeCO_3$) over the temperature range from 1.5° to 80°K. In the first compound (in accordance with the spin wave theory) the magnetic specific heat is greater by approximately an order of magnitude than that of the lattice, and the transition from the region of excitation of the lower branch of the energy spectrum to the region in which both branches of the spectrum are excited (one of the branches has zero activation energy) is clearly evident. In $FeCO_3$ at helium temperatures, the spin waves are scarcely excited at all, and a pure phonon specific heat is observed. The speakers taking part in the discussion (**B. G. Lazarev, B. N. Samoĭlov**) concerned themselves with the experimental method and also with the difference between calorimetric and magnetic experiments.

G. I. Urushadze has investigated theoretically the effect of spin waves upon the thermal conductivity of antiferromagnetics at low temperatures. The author explained the circumstances under which the heat flux carried by the spin waves governs the thermal transport in an antiferromagnetic.

Proceeding from spin wave theory, **M. I. Kaganov** and **V. M. Tsukernik** have calculated the absorption coefficient for a circularly polarized magnetic field, the polarization being assumed to be such that resonance does not occur. The calculated absorption coefficient depends in a complex manner upon frequency, temperature, and the parameters of the magnet. Experimental studies would permit the determination of the nature of the interaction of the spin waves, both with one another and with phonons.

Yu. M. Kagan and **A. G. Gurevich** spoke during the discussion of the papers by G. I. Urushadze and by M. I. Kaganov and V. M. Tsukernik.

N. V. Volkenshteĭn and **M. I. Turchinskaya** described an investigation of the temperature dependence of the magnetization of a single crystal of the disordered alloy Ni_3Mn. The authors analyze the results obtained in the following way: the alloy is paramagnetic at room temperature and ferromagnetic at nitrogen temperature, while at temperatures of 20.4°K and below the alloy contains regions in both ferromagnetic and antiferromagnetic states. The authors explain this situation in terms of an inhomogeneous distribution of the components of the alloy through the sample.

Speaking during the discussion, **E. S. Borovik** and **P. N. Stetsenko** recommended that independent experiments be performed to verify the inhomogeneous concentration over the sample.

In the paper by **E. E. Semenenko** and **A. I. Sudovtsov** an attempt was made to study the interaction of electrons with spin waves by measuring the resistance of Fe at temperatures below 1°K. A dependence of the linear term in temperature upon the external magnetic field was found. This supports the hypothesis that this term in the resistance results from the scattering of electrons by spin waves. The authors drew attention to the fact that the term proportional to T^2 also depends upon the magnetic field.

E. A. Turov (speaking during the discussion) remarked that the linear law is applicable over an extremely limited temperature range. Therefore the term in T^2 may also be due to interaction with spin waves.

The magnetic structure of Cr has attracted investigators for several years. **R. A. Alikhanov** reported the results of neutron-diffraction studies of Cr of varying degrees of purity, showing that the structure of Cr is highly sensitive to impurities. For example, the helicoidal magnetic structure evidently occurs only in impure Cr. On the other hand, the occurrence of two transition points in Cr is not related to its purity. The results of T. I. Kostina from magnetic susceptibility measurements confirm the existence of two transition points. **A. S. Borovik-Romanov, I. Ya. Dekhtyar**, and **M. I. Kaganov** spoke during the discussion.

b) Nuclear and electron paramagnetic resonance. An interesting example of the effect of the indirect exchange interaction via the conduction electrons upon nuclear paramagnetic resonance has been observed in mixtures of the isotopes Tl^{203} and Tl^{205} (**Yu. S. Karimov** and **I. F. Shchegolev**). In weak magnetic fields the indirect exchange leads to the formation of a single spin system, and in the spectrum of the isotope mixture, one absorption peak is observed. As the external magnetic field is increased, the exchange interaction vanishes and two peaks are observed, corresponding to absorption by the different isotope nuclei. The experimental data are in good agreement with the Kubo-Tomita theory.

Paramagnetic resonance with $g = 2.06$ has been observed in monocrystalline aluminum (**A. A. Galkin** and **V. P. Naberezhnykh**). From the temperature independence of the relaxation time over the range 4—20°K, the conclusion is reached that the scattering is due to impurities with strong spin-orbital coupling. The asymmetry of the resonance curve is of opposite sign to that in the alkali metals.

Analysis of the interaction of hypersound with a non-equilibrium spin system shows that favorable conditions exist for the amplification and generation of hypersound by the maser principle (**U. Kh. Kopvillem** and **V. D. Korepanov**). Generally speaking, the conditions for generation of phonons are more favorable than for photons. A suitable medium should be provided by the rare-earth ions, since in these the spin-lattice interaction is especially large.

U. Kh. Kopvillem and **R. M. Mineev** have proposed a new method for the polarization of nuclei in diamagnetic and paramagnetic crystals, based upon the application of pulsed magnetic and ultrasonic techniques. This method should lead to a high degree of polarization, independent of relaxation processes and retained through the period of spin-lattice relaxation.

S. A. Al'tshuler, Sh. Sh. Bashkirov, and **M. M. Zaripov** have analyzed the nature of the splitting of the d-terms of titanium in corundum, and have studied the special characteristics of paramagnetic resonance and paramagnetic relaxation in this system. The relaxation should be of the single-phonon type only for $T \lesssim 1°K$; at higher temperatures two-phonon processes predominate. The temperature dependence found for the relaxation time agrees satisfactorily with experiment.

The spin-lattice and spin-spin relaxation times for methane, determined by the "spin-echo" method, are found to be similar in magnitude. Over the range $77° \leq T \leq 100°K$ they vary by approximately an order of magnitude. Evaluation of the self-diffusion coefficient for liquid methane yields $D \sim 10^{-7}$ cm²/sec (**E. E. Bogatyrev, A. A. Galkin, I. V. Matyash,** and **L. M. Tarasenko**).

6. LOW TEMPERATURE THERMODYNAMICS MECHANICAL PROPERTIES OF SOLIDS

Differences in the physical properties of the isotopes of a single element are manifested chiefly at low temperatures. It is not surprising, therefore, that each year the study of isotopes occupies a large place at these conferences. This year, three papers were devoted to this problem. In the first (**V. S. Kogan, B. G. Lazarev, V. I. Khotkevich, R. F. Bulatova,** and **A. S. Bulatov**) a description was given of an x-ray structural investigation of the isotopes of a series of elements having molecular (H_2, HD, D_2, Ne^{20}, Ne^{22}) and metallic (Li^6, Li^7, Ni^{58}, Sn^{116}, Sn^{124}) binding forces in the solid state. These studies have shown that the isotopic effect depends fundamentally upon the binding forces: it is considerably greater in the molecular crystals. The dependence upon temperature was also investigated: at some specific temperature the effect changes sign. In the second paper (**R. F. Bulatova, V. S. Kogan,** and **B. G. Lazarev**) measurements were reported of the mutual solubility of deuterium and deutero-hydrogen in the solid phase at $T = 1.5°$ and 4.2°K. Although HD and D_2 are structurally isomorphous, the solubility is found to be limited.

E. S. Borovik, speaking during the discussion, remarked that in comparing different structures it is necessary to refer the results to a single reduced temperature. **B. G. Lazarev** noted that the difference in the magnitudes of the isotope effect for lattices with differing forces is so great that it cannot be eliminated by reduction to a common temperature. Within the limits of a group of substances possessing forces of a given type it is necessary, of course, to consider such a reduction of the temperature.

The third paper (**V. N. Grigor'ev**) was devoted to the measurement of the differences in the saturated vapor pressures of krypton and xenon isotopes, separated in an open rectification column working at low vapor velocities. It was found that $(\Delta p/p)_{Kr} \approx 1.2 \times 10^{-4}$ and $(\Delta p/p)_{Xe} \approx 2 \times 10^{-5}$ (per unit mass number). To a question by **E. S. Borovik** regarding the method used to determine the theoretical number of disks in the column, without which it is impossible to measure $\Delta p/p$, the author answered that the number was determined both from computational formulas and directly from the dependence of enrichment upon the separation rate.

R. F. Bulatova and **V. N. Grigor'ev** described the use of a miniature open column (2 mm in diameter and 300 mm high) to obtain practically pure orthohydrogen from the natural mixture (75% o-H_2 and 25% p-H_2).

During the discussion following this paper, **B. G. Lazarev** pointed out that the method used by the authors to determine the ortho- and parahydrogen concentrations is simpler than those previously used. The accuracy of the method (~ 2–3%) is, however, completely satisfactory.

Yu. A. Gotlib and **I. V. Sochava** reported the results of a theoretical computation of the specific heats of linear polymer chains of the ($-CH_2-$) type at low temperatures. The calculation was carried out by the Born-Karman method. Comparison of the results obtained with experimental data shows that the linear temperature dependence observed experimentally is a consequence of the superposition of two branches, widely separated in temperature, of the vibrational spectrum of the polymer chain. As was made clear by the answers to questions by **E. S. Borovik** and **B. G. Lazarev**, the elastic constant for the chains is obtained from optical experiments; there are no measurements available for these substances at helium temperatures. It is not known, for example, to what temperatures the $C \propto T^3$ law extends.

S. I. Novikova has investigated the temperature dependence of the thermal broadening coefficient α for elements of group IV, and the compounds $A_{III}B_V$ which are isoelectronic with respect to them, in the vicinity of the low temperature anomaly $\alpha < 0$. In all cases the polar band is anomalously strengthened. This observation agrees with the theory of Barron and Blakeman, who predicted such an anomaly in the Grüneisen constant (to which α is directly related) for ionic crystals.

V. A. Pervakov and **V. I. Khotkevich**, in their paper "The Influence of Defects in the Crystal Lattice upon the Specific Heats of Metals at Low Temperatures," described measurements of the difference in the specific heats of Au, Ag, and Cu in the plastically-deformed (or vacancy-saturated) and annealed states, over the temperature range from 4.2° to 300°K. In all cases an increase in the specific heat was observed, which can be described in terms of a reduction in the Debye temperature.

During the discussion, experimental details were considered, and the nature of the lattice dislocations and deformations was clarified (**I. Ya. Dekhtyar, B. G. Lazarev, E. S. Borovik, E. Itskevich**).

Two papers were devoted to the investigation of the mechanical properties of solids at low temperatures.

It should be noted that this problem is attracting more and more attention, especially in view of the discovery in a number of metals of polymorphism, appearing both on reduction of temperature and during the process of plastic deformation. In the latter case, the deformation proceeds in a substance with continuously varying parameters, giving rise to special mechanical properties for the metal: a large increase in plasticity, homogeneous deformation, hardening.

I. A. Gindin, B. G. Lazarev, Ya. D. Starodubov, and **M. B. Lazareva** reported on a study of Na under tension over the temperature range from 1.6° to 300°K, covering the region of its polymorphic transformation. For Na, analogously to Li, previously studied, singularities were found in the behavior of the mechanical properties which confirm the existence of "mechanical" criteria for low temperature polymorphism (a minimum in the relative elongation, a non-monotonic increase in the elastic and yield limits, microhardness).

O. V. Klyavin and **I. B. Borovskii** spoke during the discussion of this paper.

The effect of the state of the surface upon the tensile diagrams of Al at helium temperatures was investigated in the paper by **O. V. Klyavin** and **A. V. Stepanov.** The treatment of the surface (electrolytic polishing, etching) as well as the rate of deformation, were found to affect the number and character of the discontinuities in the tensile diagrams of Al (99.3%) at T = 1.3°K.

Speaking during the discussion, **I. A. Gindin** noted that discontinuities are observed under these conditions for a number of metals, and expressed doubts concerning the validity of the analysis of the results obtained.

7. NUCLEAR STUDIES

Following Mössbauer's discovery, the relation between the physics of the condensed state and nuclear studies has become greatly strengthened, inasmuch as the resonance absorption of γ quanta offers great new possibilities for the study of the energy spectrum of solid bodies, especially the splitting of nuclear levels in external and internal fields. It is therefore not surprising that the greater portion of the papers read at the sessions of the "Nuclear Studies" section were devoted to the Mössbauer effect.

V. V. Sklyarevskii, V. V. Samoĭlov, and **B. I. Stepanov** have studied the hyperfine splitting of the nuclear levels of Dy^{161} and Ir^{193} with the aid of the Mössbauer effect. It is interesting to note that splitting occurs in the paramagnetic region; this permits certain conclusions to be drawn concerning spin relaxation. In addition, the authors drew attention to the weak temperature dependence of the effect; it was observed even at temperatures on the order of 10^3 °K. This latter circumstance is (as was pointed out by Yu. M. Kagan) associated with the great difference in the masses of the atoms in the lattice (in the experiments on Dy^{161}, $Gd_2^{160}O_3$ was used as the source, and $Dy_2^{161}O_3$ was the absorber). **M. Ya. Azbel', N. E. Alekseevskii, Yu. M. Kagan,** and **U. Kh. Kopvillem** participated in the discussion of this paper.

V. A. Bryukhanov, N. N. Delyagin, and **V. S. Shpinel'** reported on a study of the resonance absorption of γ-quanta of energy 23.8 keV by Sn^{119} nuclei in various crystals. Sn^{119m} was used as the source, in the form of the compound SnO_2, and SnO_2, SnO, β-Sn, and Nb_3Sn as absorbers. The experiment was conducted at several temperatures.

Two papers devoted to the development of a theory of the Mössbauer effect were presented by **Yu. M. Kagan.** In the first, the influence of the optical branches of the lattice vibrations upon the effect was considered, and it was shown that in many cases the inclusion of these vibrations provides an explanation of the observed weak temperature dependence. In the second communication (given jointly with **Ya. A. Iosilevskii**), a theory of the Mössbauer effect for an impurity nucleus in a crystal was constructed.

Both of these papers aroused great interest. **M. A. Krivoglaz** (who pointed out the reason for the broadening of the lines due to the impurity vibrations), **V. S. Shpinel', N. E. Alekseevskii,** and others participated in the discussion.

Two papers by **A. F. Lubchenko** and **I. P. Dzyub** were also concerned with the theory of the Mössbauer effect.

In recent years, a great deal of work has been devoted to the study of the interaction of electrons with nuclei in solids. An important parameter in the description of this interaction is provided by the magnetic field governing the polarization of the nucleus.

B. N. Samoĭlov, V. V. Sklyarevskii, and **E. P. Stepanov** described an investigation of anisotropy in the γ and β radiation from Sb nuclei imbedded in ferromagnetic metals. These studies permitted determination, not only of the magnitude of the magnetic field at the nucleus ($\sim 10^5$–10^6 Oe), but also of its sign.

As was pointed out by **Yu. M. Kagan,** the analysis of these experiments shows that the field at the nucleus is evidently due, not to the conduction electrons, but to those at lower levels. This, according to **E. A. Turov,** is confirmed by nuclear resonance experiments on ferromagnetic dielectrics. In addition to Yu. M. Kagan and E. A. Turov, **N. E. Alekseevskii, I. F. Shchegolev, V. S. Shpinel', A. S. Borovik-Romanov,** and others participated in this discussion.

8. LOW TEMPERATURE TECHNOLOGY

The majority of the papers presented before this section described the work of the cryogenics division of the Joint Institute for Nuclear Research. A basic survey of the organization of its work and the equipment of its laboratory was given by **A. G. Zel'dovich.**

The liquefiers installed at Joint Institute are designed for delivery of hydrogen and helium into Dewars and for the filling and thermostatting of liquid chambers. A compressor room having a total capacity of approximately 1000 m^3 of hydrogen per hour permits operation of a hydrogen liquefier producing 250 liters of liquid per hr. This liquefier serves to supply the hydrogen bubble chambers, and is installed at the site of the proton synchrotron, at a distance of 1100 m from the compressor room, to which it is connected by high- and low-pressure piping.

The hydrogen is generated in an electrolyzer of 24 m^3/hr capacity, and is stored in reservoirs under pressure.

The combined hydrogen-helium liquefier VGO-1, is currently operating at a capacity of 40 l/hr for hydrogen and 30 l/hr for helium, and the capacity of the VOC-3 machines has been increased to 20 l/hr for liquid hydrogen. Two helium compressors are operating at 240 m^3/hr each.

Gaseous hydrogen and helium are cleansed of air impurities by activated charcoal, cooled to a temperature of 78°K.

The compressed gas is freed of oil in settling tanks filled with Raschig rings, and is filtered through fibrous material. The hydrogen is additionally passed through a chrome-nickel catalyzer, to eliminate traces of oxygen.

All rooms are equipped with gas analyzers which automatically turn on a ventilation system in the event of a dangerous hydrogen concentration in the air.

The laboratories have a centralized system for pumping and collection of helium in gasholders. The latter are situated at some distance from the building, and are equipped with telemetry to indicate the positions of their bells.

The paper by **A. G. Zel'dovich** and **Yu. K. Pilipenko** described the construction of, and the results of tests on, the VGO-1 combination liquefier. This hydrogen-helium liquefier is constructed in the form of two separate units, each of which can operate independently. Liquefaction occurs as a result of the Joule-Thomson effect, with preliminary cooling of the hydrogen by nitrogen, and the helium by hydrogen, boiling at a reduced pressure. The capacity of the hydrogen unit of the liquefier is 40 l/hr, and that of the helium section, 30 l/hr.

Each of the units is 500 mm in diameter and 2200 mm high. Thermal isolation of the helium unit is provided by a high-vacuum space and a nitrogen shield, and for the hydrogen unit by microporous material and forepump vacuum. The heat exchanges consist of a bundle of tubes of the same diameter, soldered into thermal contact with tin. The liquefier is supplied by hydrogen and helium compressors having capacities of 180 and 240 m^3/hr, respectively.

Speaking during the discussion, **E. S. Borovik** gave an analysis of the operation of the heat exchangers, showing that those used in the VOS-3 and VGO-1 liquefiers, consisting of a large number of fine tubes soldered together, are inefficient, since the breaking up of the flow of low pressure gas into a number of parallel channels lowers the Reynolds number which, in turn, degrades the conditions for thermal exchange. E. S. Borovik noted that the use of heat exchangers consisting of soldered tubes of differing diameters, in which each stream of gas passes through its own size of tubing, would permit the weight and volume of the liquefier to be reduced by a factor of 3–6, and would considerably simplify its construction for a given liquefaction capacity.

A. I. Sudovtsov compared the hydrogen section of the VGO-1 liquefier with the hydrogen liquefier having cross-flow heat exchangers, which is in operation at Khar'kov. He noted the advantages of the latter: small mass and size, as well as low hydraulic resistance to the flow of the low pressure gas.

The paper by **Yu. K. Pilipenko** was devoted to an analysis of the operation of and test results for a finned, counterflow heat exchanger of the "tube within a tube" type. On a 7 × 1.5 mm inner tube, external fins are milled to a depth of 1 mm, with a thickness of 0.3 mm and a spacing of 1 mm; this should improve the heat transfer conditions for the low pressure gas flowing through the space between the tubes. In the conclusion to the paper it was noted that one of the VGO-1 heat exchangers, weighing 40 kg and having a hydraulic resistance of 700 mm Hg, could be replaced by a finned-tube heat exchanger whose weight would not exceed 20 kg, with a resistance of 200 mm Hg.

I. F. Mikhaĭlov remarked during the discussion that comparable heat exchangers, made up of tubes differing in diameter, would weigh 6–8 kg. Moreover, in the finned heat exchanger effective transfer of heat can occur only between two streams of gas, which is unsatisfactory for the upper heat exchangers in liquefiers.

Methods of cleansing condensed gases of oil vapors were discussed in the paper by **N. E. Buyanova** and **A. G. Zel'dovich.** For these studies, the authors developed a method of luminescent analysis, capable of detecting the presence of 0.005 mg of oil in 1 m^3 of gas.

As a result of these experiments, the ability of a variety of substances to absorb oil was determined. It was found that fibrous materials, such as medical cotton or glass wool, are the most effective absorbers. Their absorption capacity is approximately 10 times that of activated charcoal, alumina, silica-gel, or other adsorbents. These results make it possible to calculate specifications for compressor filters.

During the discussion, **A. I. Sudovtsov** described an apparatus for gas purification by freezing which is in operation at the Physico-technical Institute of the Ukrainian Academy of Sciences. The advantage of this system lies in the fact that the gas is cleansed, not only of oil and water vapor, but also of most oil decomposition products. In operating this apparatus in conjuction with a 35 m^3/sec helium compressor, not over 1 l/hr of liquid nitrogen is consumed.

Two papers by **A. V. Belonogov** were devoted to an experimental study of the consequences of the loss of vacuum isolation in Dewars.

One paper was concerned with failure of the outer wall of the Dewar, the other with that of the inner wall.

The thermal loads determined by the author make it possible to calculate the safety devices required to prevent rupture of the flasks. A simple safety valve has been designed for rapid release of the vapor generated, and its construction was described.

In view of the wide usage of liquefied gases, the results of this carefully done work are of immediate importance.

L. B. Golovanov presented the results of a study of thermal conduction in multi-layer insulation, and compared it with that for powdered materials and high vacua. The conductivity of the multi-layer insulation was determined from the quantity of hydrogen evaporated from a measuring volume. Insulators consisting of glass cloth with 0.01 mm thick aluminum foil, and of glass wool with the same foil, were studied. The insulation was placed in a hermetically-sealed container in which a pressure of 10^{-2} mm Hg was maintained. The best results were obtained with a glass-cloth insulation 1 cm in thickness, containing five layers of foil. Its thermal conductivity was found to be 5.8×10^{-4} kcal/hr-deg-m. This insulation was superior to powdered material, but for the thicknesses of 60—80 mm commonly used it is inferior to high-vacuum isolation with a cooled shield.

This insulation was employed in the construction of a hydrogen target in the form of a cylindrical hydrogen container 1500 mm long and 200 mm in diameter. The ends of the container were made of stainless steel, 0.14 mm thick. This cylinder was enclosed in a vacuum jacket with ends of the same material. In addition to the multi-layer insulation, provision was made for pumping the jacket to a high vacuum.

The paper by **R. A. Buyanov, A. G. Zel'dovich**, and **Yu. K. Pilipenko** was devoted to a thermodynamic analysis of the catalytic transformation of orthohydrogen into parahydrogen during the liquefaction process. In the paper, a cycle is considered in which the cooling results from throttling, and it is shown that the thermodynamic losses are redistributed as the arrangement of the converters with respect to temperature is changed, which in turn leads to a change in the areas over which heat exchange occurs.

A. B. Fradkov spoke during the discussion, noting that for double conversion of the hydrogen, at the levels of the nitrogen and hydrogen baths, respectively, the loss in refrigerative capacity is reduced by 30%.

In his paper, **A. B. Fradkov** proposed the construction of an apparatus to produce liquid neon by using the low temperature of liquid hydrogen, consisting of a heat exchanger and a collector for the liquid neon. Neon is a good cooling agent; its heat of vaporization is 40 times that of helium and 3.5 times that of hydrogen. **Ben'yaminovich** remarked during the discussion that neon may be used as a cooling agent over the temperature range from 18 to 35°K, and stated that the development of small neon liquefiers for scientific research in institutes and industrial laboratories would be highly desirable.

The paper by **N. N. Mikhaĭlov** and **A. Ya. Govor** of the Institute for Physics Problems, U.S.S.R. Academy of Sciences devoted to resistance thermometers of leaded brass for temperature measurement in the helium region, was heard with great interest. The coil of temperature-sensitive phosphor bronze obtained by the Kamerlingh Onnes Laboratory from the firm of Hartmann and Braun, was used up during the years 1930—32. Since that time, efforts have been made to develop methods for producing temperature-sensitive alloys. The bronzes which have been produced, containing a small lead impurity, have had poor mechanical properties and short temperature measurement ranges.

The authors prepared a number of copper-zinc alloys containing small lead impurities. An alloy containing 62% Cu, 36.2% Zn, 1.7% Pb, and 0.1% W was found to be the most suitable material for thermometers.

Even better thermosensitive properties are possessed by the standard leaded brass for the clock-making industry, specification LS-59-1. The questions which the authors were asked were primarily concerned with comparisons of this type of thermometer with carbon thermometers: the dependence of its readings upon measuring current and magnetic field, residual resistance, etc.

In his conclusion, **N. N. Mikhaĭlov** commented on the accuracy of the metallic thermometer and the stability of its readings.

The effect of the physical properties of the substrate upon the behavior of superconducting memory elements was examined in the paper by **S. Ya. Berkovich, P. P. Golovastikov**, and **R. A. Chentsov**, representing the Institute for Precision Mechanics and Computer Technology, U.S.S.R. Academy of Sciences.

Using the M-20 computer, the authors carried out an analysis of the thermal transfer from a thin film of superconducting material, deposited upon a substrate and placed in liquid helium. Heating of the film by rectangular current pulses was specified, and it was shown that in the operation of such an element, its mean temperature depends upon the specific heat of the substrate in such a way that the principal role in establishing this temperature is played by the heat transfer from the film to the substrate, and not into the helium.

R. I. Isaeva, A. S. Rastorguyev, R. A. Chentsov, and **V. A. Gromakovskii** have made measurements of the current required to destroy superconductivity in films over the range from the critical temperature down to 2°K. Cooling curves were obtained for the films after they were heated by current pulses of 0.02 to 0.5 millisec duration.

The role of the substrate in the process of cooling the film was studied by measuring the cooling rate for a film deposited on substrates of various sizes. From these measurements the coefficients for heat transfer from a tin film into helium, from a quartz substrate into helium, and between film and substrate were determined.

A. E. Dubravskaya, A. I. Zimarev, and **R. A. Chentsov** described a new superconduting memory element, in which two connected superconducting loops consisting of films, are employed. One of these is always superconducting, while the other changes its state according to the information. In constructing this element, account was taken of all necessary conditions for rapid dissipation of heat, which permits up to 2×10^4 operations per second to be obtained; this compares favorably with the Crow superconduting memory element. The magnitude of the signal from the element is 10 mV.

Three types of regulators for parameters of liquid nitrogen and hydrogen were proposed in the paper by **L. B. Golovanov** and **E. M. D'yachkov** (Joint Inst. Nuc. Res). In the first type of liquid level regulator, the sensitive element is a bellows attached to the end of the filling tube, and filled with gas which condenses upon contact of the bellows with the liquid whose level is being maintained. The accuracy to which the level can be held constant is 2—3 mm. The second type of level regulator differs from the first in that it is situated outside the filling vessel, and the controlling pulse is sent by a remote pickup within the working volume.

The authors have developed a bellows regulator which maintains constant pressure in the bath of a hydrogen bubble chamber, to an accuracy of 0.05 atm.

S. F. Grishin, speaking during the discussion, described an electrical level regulator used at the Physico-technical Institute of the Ukrainian Academy of Sciences with a sensing device that consists of a coil of copper wire whose resistance changes as a function of temperature. When the temperature of the sensor rises, a relay turns on a heater in the Dewar, from which the liquid is transferred via a siphon, due to the increased pressure over it.

B. N. Esel'son, B. G. Lazarev, and **A. D. Shvets** reported that a number of simple cryostats for production of temperatures below 1°K were developed at the Physico-technical Institute (Khar'kov). They use charcoal adsorption pumps for extracting the helium vapor. In an apparatus containing 40 g of activated charcoal, the minimal temperature of 0.7°K in liquid He^4 can be maintained for two hours. The use of liquid He^3 makes it possible to obtain temperatures down to 0.35°K.

Translated by S. D. Elliott