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PERSONALIA

LEV VASIL'EVICH SHUBNIKOV

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AMONG the scientists who have made important contributions to the development of Soviet physics Professor Lev Vasil'evich Shubnikov of the Kharkov State University should not be forgotten. Shubnikov was born on September 29, 1901 and was graduated in 1926 from the Leningrad Polytechnical Institute with the title engineering physicist. The Narkompros (National Educational Commissariat) then sent him to Holland, where he worked under Professor de Haas in the Kammerlingh-Onnes Cryogenic Laboratory at Leyden. He returned from Leyden in 1930, and, at the suggestion of A. F. Ioffe, proceeded to the Ukrainian Physico-technical Institute, where the director, I. V. Obreimov, had founded a cryogenic laboratory. In 1931 Shubnikov became the scientific director of this laboratory. Under his guidance cryogenic technology was mastered. Hydrogen and helium generators and a Kapitza helium liquefier were constructed. Shubnikov taught, and thereby created, the first cryogenic engineering personnel at the institute and in the U.S.S.R.

Shubnikov was a brilliant organizer of scientific investigations, and a talented scientist. During the period 1934-1937 he did much teaching as a professor at the Kharkov State University, where he headed the department of general physics.

In 1937 Shubnikov was unjustly arrested and sentenced to 10 years imprisonment. He died in 1945. In April, 1957 he was exonerated posthumously by the Military Board of the Supreme Court.

Shubnikov began his scientific activity with work in the field of crystal physics while still a student (1924-1926). His first publication was concerned with one of the techniques for producing single crystals artificially from a molten metal. In this work he was guided and assisted by I. V. Obreimov. The technique, which is known in the literature as the Obreimov-Shubnikov method, can be described briefly as follows. Molten metal poured into a test tube terminating in a fine capillary is placed in a vertical furnace at a temperature somewhat above the melting point of the metal. A "seed" is formed in the capillary when it is cooled by a stream of cold air, and gradually fills the entire test tube as the cooling process continues. Since heat is removed only through the cooled tip, the higher-lying metal always remains above its melting point, so that crystallization centers cannot be formed. A single crystal of metal suitable as an experimental specimen grows from a single center (or seed) appearing at the lower tip of the test tube. This method was used to produce single crystals of Sn, Bi, Cd, Sn, Ho, Mg, and Cu. The Obreimov-Shubnikov method has continued to be successful.

Shubnikov's second publication as a student was his thesis, "An Optical Method for the Study of Elastic and Residual Deformations in Crystals." He collaborated with Obreimov in 1926 to apply this method to an investigation of plastic deformations in rock salt.

Prior to that time A. F. Ioffe, in collaboration with M. V. Kirpicheva (in 1925) and with M. A. Levitskaya (in 1926), had applied x-ray diffraction to the study of crystals; the method had been discovered by von Laue in 1912. Sending a narrow x-ray beam through a rock salt crystal subjected to compression or tension and viewing the Laue diffraction pattern on a fluorescent screen, these three investigators observed that at a certain tension exceeding the elastic limit, and at a given temperature, the pattern changes drastically;

the individual spots become blurred along radial directions from the central spot.

On the basis of the foregoing observation it was established that the mechanism of plastic or residual deformation of rock salt when compressed or stretched consists in different rotations of individual crystalline regions. A residually deformed salt crystal breaks up into mutually bound small crystal blocks. The study of this effect under a constant load showed that the phenomenon occurs abruptly and that the jumps are accompanied by sounds resembling the ticking of a clock (M. V. Klassen-Neklyudova). This led to the important discovery that the internal disorientation of a crystal causes marked strengthening.

Obreimov and Shubnikov applied the optical method to the study of plastic deformations in rock salt crystals, which were placed between crossed Nicol prisms and were observed in polarized light impinging normally to a crystal face. They found that the displacements resulting from deformation (compression- or tension-induced) produce residual strains and become visible in a polarizing microscope by brightening the dark field.

By rotating crystals they also discovered that when the principal cross sections of the Nicols are parallel to (100) cubic faces a plastically deformed crystal is crossed by bright and dark bands in the (110) direction, but that when the axes of the Nicols coincide with the direction of glide planes the bands disappear. This indicates that the principal stresses in a crystal are parallel to (110). A quartz wedge was used to measure these stresses; the magnitude 230 kg/cm^2 was obtained. This large value shows that a crystal can be greatly strengthened by plastic deformation. The breaking point of rock salt at room temperature is ordinarily 45 kg/cm^2, while A. F. Ioffe gives its elastic limit as 90 kg/cm^2. Obreimov and Shubnikov succeeded in observing a maximum internal stress of 1000 kg/cm^2. Their investigations demonstrated the jerky breakup of a single crystal into blocks. In a polarizing microscope they observed the sudden appearance of bands, following each other at different time intervals, when a crystal was subjected continuously to a tension of 78 g/mm^2. The sharp separation of bright and dark regions was characteristic of all the bands, which did not disappear when the load was removed but were oriented parallel to the edges of the cube.

The experiments also revealed another characteristic of plastically deformed crystals. Under a constant load the time interval between two successive slips increases gradually until they no longer occur. (This indicates that crystals harden gradually.) Additional slips occur when the load is increased.

The next stage in Shubnikov's scientific career came during the years that he spent abroad (1926-1930). At the Kamerlingh-Onnes Cryogenic Laboratory in Leyden Professor de Haas suggested a basic problem—the production of perfect single crystals of bismuth for use in precise investigations of electrical conductivity at low temperatures in external magnetic fields. At that time all investigations of this nature employed bismuth crystal samples prepared from large crystals by a mechanical treatment. These samples all yielded different and nonreproducible results because the crystals were usually damaged by the mechanical processes. It was suggested that artificially grown crystals might yield reproducible results.

By greatly modifying and improving Kapitza's method for growing bismuth single crystals from a melt, Shubnikov and de Haas produced bismuth crystals at Leyden which were extraordinarily pure and perfect for that time. Their technique enabled the growth of crystals with a predetermined shape and predetermined locations of the crystallographic axes.

Having produced perfect bismuth single crystals by their own technique, Shubnikov and de Haas immediately proceeded to investigate the electrical properties of these crystals in a magnetic field at low temperatures. These investigations led to the discovery of a new and previously unknown phenomenon—the periodic change of resistivity in bismuth as a function of the magnetic field; this is called the Shubnikov–de Haas effect.

The third and last period of Shubnikov's scientific career was the period of his work in Kharkov (1930-1937), at the just previously organized cryogenic laboratory of the Ukrainian Physico-technical Institute. He first became interested in the magnetic properties of superconductors. The prevailing view until 1933 was that superconductors possess the magnetic properties of an ideal conductor having the electrical conductivity $\sigma = \infty$. The magnetic induction $B = \text{const}$ is consequently derived from electrodynamical equations. However, some simple considerations show that this hypothesis is incorrect. Thus, when a superconducting cylinder is cooled to $T < T_c$, after which a magnetic field is switched on, then since $B = \text{const}$ is assumed the field within the superconductor should not change; if $B = 0$ before switching on the field, this value should be found afterwards. If the cylinder is placed in an external field H_0 and is again cooled to $T < T_c$, then both in its normal state and after its superconducting transition in the magnetic field we find $B = H_0$, i.e., there is no change of the magnetic induction. Thus different results are obtained depending on the sequence of operations leading to identical final conditions; in one case $B = 0$, while in the other case $B = H_0$.

Two views can be held regarding the foregoing discrepancy: Either the superconducting state is not one of thermodynamic equilibrium (which would be determined uniquely by external conditions without depending on the process whereby a sample reaches the state) or the equation $B = \text{const}$ is false. The first of these two views can be eliminated, since as early as 1932 the Leyden physicists Rutgers, Gorter, and Casimir had shown in developing the thermodynamics of superconductors that the superconducting state is one of equilibrium; this was soon confirmed experimentally. The second view was therefore correct, but required verification, which was provided for the first time in 1933 by the work of Meissner and Ochsenfeld in Berlin, and a little later, independently, by Ryabinin and Shubnikov in Kharkov.

The German physicists measured the distribution of an external magnetic field around a tin or lead superconducting cylinder having its axis perpendicular to the field. They obtained an unexpected result. When the sample became superconducting through cooling in a static magnetic field the magnetic flux was completely expelled from its interior, so that the magnetic induction was zero. This is known as the "Meissner effect."

Shubnikov and Ryabinin measured $\Delta B/\Delta H$ ballistically. (This is the change of magnetic induction resulting from a sudden small change of the external field.) They obtained a continuous curve for B as a function of H_0 in the entire range from H_c to $-H_c$ (the entire cycle of magnetization). These measurements showed that close to the critical field H_c the magnitude of B changes sharply as the external field is decreased or increased. The discontinuity of B at $H_0 = H_c$ was attributed to the initiation of the new superconducting phase with $B = 0$, thus fully confirming the existence of the Meissner effect. It also followed from their results that there is an additional, more complex, hysteretic effect associated with inhomogeneity or "imperfection" of the superconductor.

Shubnikov and his collaborators also investigated the magnetic properties of superconducting alloys (in 1937) and established the existence of both a lower H_{c_1} and an upper critical field H_{c_2}. For $H < H_{c_1}$ there is no penetration of the field into the superconductor; penetration begins to occur when $H = H_{c_1}$. Therefore in the range $0-H_{c_1}$ we find $B = 0$; a superconducting alloy here behaves like a pure metal. Above the first critical point B increases with H, but the zero resistance of a sample persists up to H_{c_2}, when superconduction is destroyed and the sample returns to its normal state. This field can be much higher than for pure superconducting metals, reaching up to 100 000 Oe. The Meissner effect is not present in the interval $H_{c_1}-H_{c_2}$; an alloy can be superconducting while partially penetrated by a magnetic field. The size of this interval for all alloys increases with the percentage of impurity content. The foregoing experimental results were accounted for theoretically in 1957 by A. A. Abrikosov in his paper entitled "On the Magnetic Properties of Type II Semiconductors."

In 1936 Shubnikov and V. I. Khatkevich studied in detail the destruction of superconductivity in a tin ring that was subjected to a magnetic field while carrying a high current such that the magnetic field at the ring's surface equalled the critical value. This was an exceptionally simple method for determining the critical current, critical field, and critical values for combined field and current effects. These experiments with a superconducting ring have now become of practical importance in connection with the construction of superconducting solenoids.

The scientific program of the Kharkov laboratory was not confined to superconductivity. During the period 1934-1937 Shubnikov and another group of young scientists at the laboratory (O. I. Trapeznikova, G. A. Milyutin, and others) published several papers on the temperature dependence of the specific heats of some transition-element chlorides ($FeCl_2$, $CoCl_2$, $CrCl_3$, and $NiCl_2$) at low temperatures. It was known that the magnetic susceptibility of these anhydrous salts obeys the Curie-Weiss law $\chi(T-\theta) = C$, which is the same law that governs the paramagnetic susceptibility of ferromagnetic substances. Below the Curie point the magnetic susceptibility is strongly dependent on the external field; in this respect the salts resemble ferromagnets without actually becoming ferromagnetic.

To account for these anomalies and their relation to the existence of the molecular field in the salts it was necessary to perform specific heat measurements; these were obtained by the Kharkov physicists for the range 13—130°K. (A vacuum calorimeter had been used for this purpose.) The curve for each salt exhibited a sharp maximum associated only with spontaneous magnetization (a second-order phase transformation).

The results obtained by Shubnikov and his collaborators indicated, at that early date, that a magnetic transformation occurs in paramagnetic salts (the chlorides of transition elements). This is the transformation from the paramagnetic state to another, so-called antiferromagnetic, state that had been predicted by L. D. Landau in 1933. The Soviet scientists had thus initiated an entire branch of physics—antiferromagnetism. Hundreds of antiferromagnets are now known.

From the foregoing account it is seen that during his short career (1924-1937) Shubnikov made a large contribution to science. His name is associated with the founding of the first cryogenic laboratory and with the beginnings of low-temperature investigations in the U.S.S.R., the devising of original methods for growing single crystals of different metals, the Shubnikov–de Haas effect, remarkable studies of the magnetic properties of superconductors and alloys, the experimental discovery of antiferromagnetism, and the organization of a refrigeration laboratory in Kharkov. This incomplete list of his accomplishments attests to the great talent and inexhaustible energy possessed by the scientist Shubnikov, whose life terminated so prematurely.

In conclusion I wish to acknowledge my indebtedness to O. I. Trapeznikova for furnishing valuable material used in this article.

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