75 YEARS OF THE DISCOVERY OF TYPE-II SUPERCONDUCTIVITY (SHUBNIKOV PHASE)

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The paper gives a brief description of the complicated way passed by the experimentalists of 4 countries prior to the discovery of type-II superconductivity at the Ukrainian Physico–Technical Institute in 1936. Basic results and appraisals of the discovery by the foremost experts of the world are presented. The role of the phenomenon in the present-day science and technology is indicated.

As known, Nobel Prize winner H. Kamerlingh–Onnes proposed to use pure superconductors for the production of magnets that can operate without Joule's losses as early as 1913. But then he and his colleagues established in 1914–1926 that the superconductivity of **pure superconductors** is broken by a magnetic field at its certain critical value $H_c < 1$ kOe.

In 1929–1935, it was observed by works performed at four from five cryogenic laboratories over the world (Leiden, Toronto, Oxford, Kharkiv), where the studies were carried on at the liquid-helium temperature, that, in **alloys**, such a transition occurs in a broad interval of field strengths. Since polycrystals of multiphase alloys were mainly investigated, all researchers considered that this effect is caused by the inhomogeneity of specimens. These ideas were formulated as a "Mendelssohn's sponge" hypothesis [1] which assumed the presence of inhomogeneities of the composition and the structure, as well as internal stresses, in alloys, which would lead to the formation of a fine multiconnected structure with high-strength magnetic fields. The inhomogeneities supposedly serve as current ways. This hypothesis was discussed in the literature for 25 years and then was rejected as a wrong one. The theories by C. Gorter and H. London [2] published at the same 1935 assumed the partition of homogeneous alloys in a magnetic field into thin (with thicknesses of at most the penetration depth λ of a magnetic field) superconducting and normal layers and did not become popular among scientists.

In 1936, L.W. Schubnikow, W.I. Chotkewitsch, J.D. Schepelew, and J.N. Rjabinin published their results [3] of studies of properties of **monocrystals of one-phase alloys** Pb–Tl and Pb–In placed in a magnetic field which were thoroughly annealed at premelting temperatures. These authors revealed that a change of the impurity concentration in the alloys causes the appearance of a new type of the superconductivity. Below, we give the main results of those investigations:

1. The critical concentration of an admixture such that the alloys under study behave themselves as pure superconductors at lower concentrations in low magnetic fields (the full Meissner effect) with the subsequent sharp breaking of superconductivity at H_c (see Fig. 1,*a*) was determined;

2. As the concentration of an admixture approaches the critical value (in the frame of modern ideas, with increase in the Ginzburg–Landau parameter $æ > æ_c = 1/\sqrt{2}$), a sharp change of properties of the alloys placed in a magnetic field, as compared with those of pure superconductors, is observed: the Meissner effect exists only prior to the penetration of the magnetic flow into an alloy (when $H_{k1} < H_c$); then, as the field grows, the alloy remains a superconducting one with a gradual penetration of the magnetic flow into an alloy up to the critical field, $H_{k2} > H_c$, where the superconductivity is completely broken (see Fig. 1,*b*).

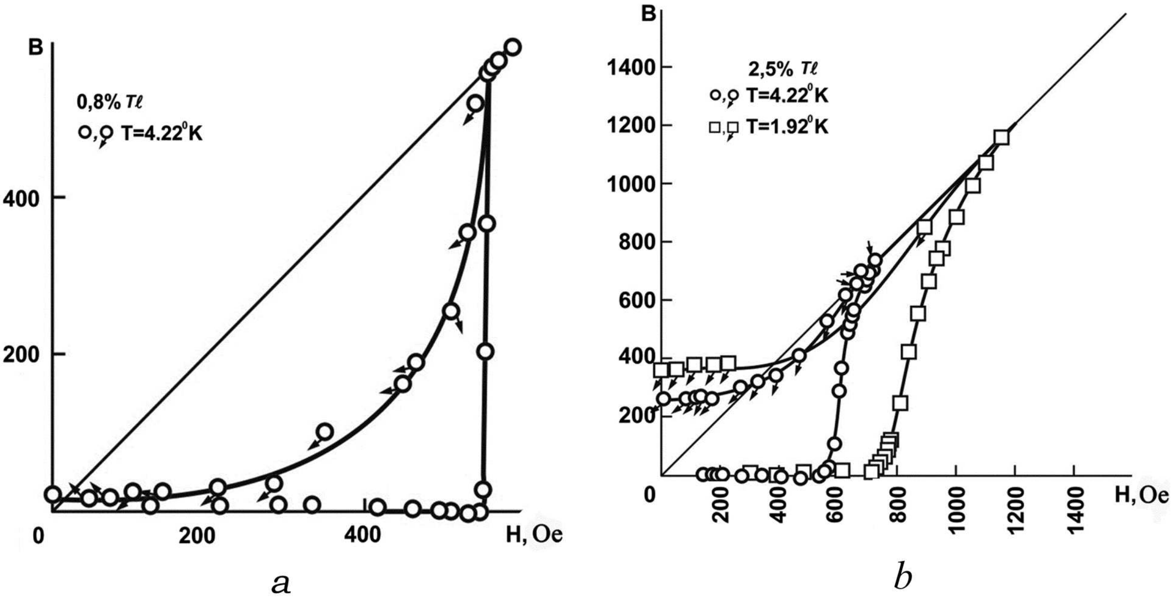

Fig. 1. Induction of long cylinders of monocrystals of the alloys in a longitudinal magnetic field: *a* – Pb+0.8%Tl; *b* – Pb+2.5%Tl

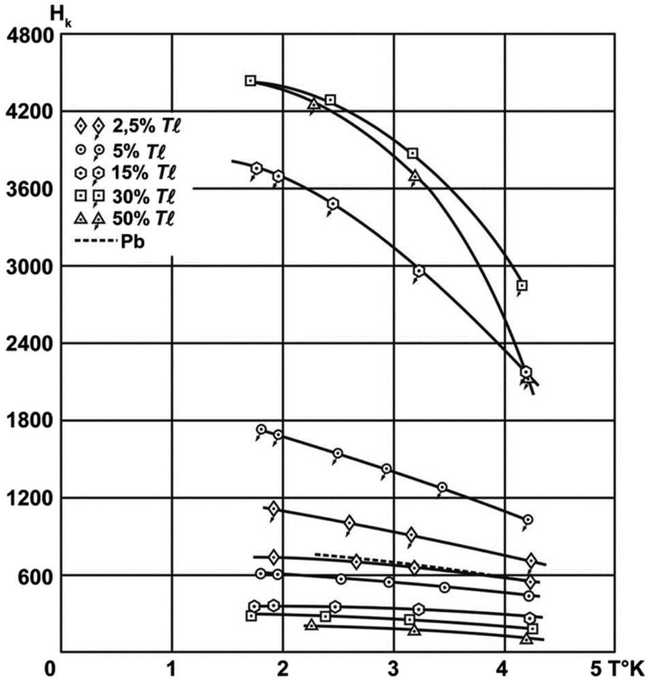

Fig. 2. Temperature dependence of H_{k1} and H_{k2} for monocrystals of alloys Pb–Tl at the indicated concentrations and H_c for pure Pb

3. It was established that, as the concentration of an admixture increases (i.e., the parameter æ grows), the interval between H_{k1} and H_{k2} increases: H_{k1} decreases, whereas H_{k2} increases (see Fig. 2).

We note that neither the "Mendelssohn's sponge" nor the theories by Gorter and London explained the penetration of a magnetic flow into the superconducting alloys at $H < H_c$. Unfortunately, this discovery was associated with the creative drama and the great human tragedy. L.D. Landau, being a friend of L.W. Schubnikow, supported the "Mendelssohn's sponge" hypothesis and did not recognize the discovery in 1936, as well as in 14 years, when he together with V.L. Ginzburg developed a phenomenological theory of superconductivity [4] which, as it became clear later (see, e.g., [5]), describes well superconductors of the II kind. Though the results by L.W. Schubnikow, W.I. Chotkewitsch, J.D. Schepelew, and J.N. Rjabinin [3] were reported by M. Ruhemann at VI International Congress on Refrigeration, Hague (1936) (because the Soviet authorities did not permit Schubnikow's departure abroad), and the issue of Phys. Z. Sowjet [3] was spread among the participants of the Congress, nobody of the scientists who studied the superconductivity supported or continued these results. We note that the work [3] was cited in a number of publications of famous scientists [6], but the first experimental confirmation of the discovery was published only in 1963 [7].

The tragic events in the USSR in 1937–1938 affected not only the fates of two outstanding scientists L.W. Schubnikow and L.D. Landau, but the development of physics as well. Being falsely accused, L.W. Schubnikow was executed by shooting among hundreds of thousands of other victims of Stalin's repressions. In 1938, L.D. Landau was arrested and was in prison one year.

The results obtained by L.W. Schubnikow and his collaborators [3] were pioneer ones. Only in 20 years, A.A. Abrikosov [8] on the basis of the Ginzburg–Landau thaory [4] and the experimental results [3] developed the theory of superconductors of the II kind. In his Nobel's lecture, A.A. Abrikosov said [9]: "I compared the theoretical predictions of the magnetization curves with the experimental data for alloys Pb–Tl obtained by L.W. Schubnikow and his collaborators in 1937 [3]. The agreement was quite good".

The triumphal recognition of the discovery made by L.W. Schubnikow, W.I. Chotkewitsch, J.D. Schepelew, and J.N. Rjabinin [3] happened at the International Conference on Superconductivity (1963, USA), where the famous experts from various countries C. Gorter, K. Mendelssohn, B. Goodman, T. Berlincourt [10] highly evaluated this discovery in their reports. The Conference Chairman J. Bardeen, the single twice Nobel Prize winner on physics, and the Conference Secretary R. Schmitt [11] recognized officially that the understanding of superconductors of the II kind is mainly related to Landau, Ginzburg, Abrikosov, and Gor'kov, and the first crucial experiments were carried out by Schubnikow as early as 1937. Nobel Prize winner de Gennes [12] introduced the notion "Schubnikow phase" for the region of existence of the superconductivity between H_{k1} and H_{k2} (in the English literature: H_{c1} and H_{c2}).

It is worth noting that all superconductors opened for five last decades (starting from Nb_3Sn and up to cuprates, organic superconductors, fullerenes, MgB_2, and iron-based systems) are superconductors of the II kind. Such superconductors are widely applied: for example, as of 1988, more than 1100 superconducting solenoids 1 m in diameter were used over the world in medicine for NMR studies of a human body [13]. Moreover, none of the great magnetic systems (e.g., Large Hadron Collider (LNC) [14] or International Thermonuclear Experimental Reactor (ITER) ([15]) could be produced without thousands of superconducting solenoids on the basis of superconductors of the II kind.

The information on this theme can be found, e.g., in [16].

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75 РОКІВ ВІДКРИТТЮ ЯВИЩА НАДПРОВІДНОСТІ ІІ-ГО РОДУ (ФАЗИ ШУБНІКОВА)

А.Г. Шепелев

Р е з ю м е

Коротко викладено непростий шлях, який пройшли експериментатори чотирьох країн світу до відкриття в 1936 р. в Українскому фізико-технічному інституті (м. Харків) явища надпровідності ІІ-го роду. Наведено основні результати, оцінку відкриття найбільшими спеціалістами світу, відзначено роль цього явища в сучасній науці і техніці.