# Low Temperature Physics and Superconductivity

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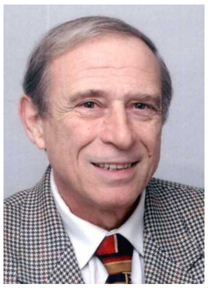

**Abstract.** An attempt is made to trace the development of the studies in the field of low temperature physics and superconductivity in Bulgaria. Centennial anniversary of the superconductivity is an occasion to discuss the achievements of Bulgarian researchers in this field and the future development. The first part traces the way of the experimental and theoretical science after discovering the phenomenon of superconductivity with the aim to emphasize the greatness of its essence and to stress the difficulties of its interpretation. The second part aims to tell when, how, where and why this field of physics has been developed in Bulgaria and where it has arrived to. As a conclusion, the necessity of low temperature investigations in Bulgaria and investments of funds for maintenance of equipment and qualified specialists in this area is justified.

**Keywords**: Bulgaria, Superconductivity, Low temperature physics

## Part One

While the philosophical question "*What is primary, the chicken or the egg?*" has no response yet such question does not exist for the phenomenon of superconductivity! This strange phenomenon of the disappearance of the resistance of some materials would not be found if low temperatures did not exist. To say it more precisely, if the helium gas, which has the lowest boiling temperature of all gases, i.e. 4.20°K was not liquefied there would be no superconductivity. Quite naturally, the man who has liquefied helium for the first time became the inventor of strange superconductivity phenomenon. This man is Heike Kamerlingh Onnes. He liquefied for the first time one of the isotopes of helium – $He^4$ in the Leyden laboratory of Denmark on 10 July 1908. In addition, he immediately began to explore the properties of various pure metals at this low temperature.

Two theories of electrical resistance as a fundamental characteristic of metals have existed at that time. Paul Drude predicted a linear decrease of resistance with temperature, while Lord Kelvin said that at helium temperatures the conductive electrons in the metal will "*freeze*" and at absolute zero electrical resistance will become infinite. Attempts by Kamerlingh Onnes proved crucial to solving this scientific dispute. Onnes began to measure the electrical resistance of some pure metals – mercury, lead, tin etc. He started with mercury the metal that could easily be made very pure by distillation. The experiment was simple, consisting of interconnected capillary tubes filled with mercury, a tube parallel and two perpendicular to it. Electric current was flown along the right tube measured by ampermeter. Voltmeter was connected between the perpendicular tubes to measure the voltage drop created by this current. With the diminution of the temperature the resistance of mercury decreased linear as Drude predicted. However, upon reaching a temperature of 4.1°K the voltage drop jumped down to zero while the current continued to flow. Camerlingh Onnes named this strange phenomenon superconductivity, the name which has not changed up to now. The event occurred in 8 April 1911, which day is considered the birthday of superconductivity. The temperature at which the resistance disappeared (called critical $T_c$) is a characteristic of the material. Kamerlingh Onnes received the Nobel Prize for his discovery in 1913.

The new discovery excited the scientific community. Experiments began in all laboratories that could afford to produce liquid helium. Many new superconducting materials were found. Other physical properties of these materials were also studied. It turned out that superconductors showed abnormalities not only in their electric properties but also in the thermal, magnetic, optical properties, etc. Thus, for example, a new discovery related to the superconductors was made in 1933. Meissner and Ochsenfeld found that within a massive superconductor at a temperature below the critical $T_к$, the magnetic induction B was equal to zero i.e. the magnetic field was pushed out of the volume of superconductor. Subsequently, it appeared that induction did not penetrate the entire volume, but just a thin surface layer with thickness $\delta \sim 10^{-5} – 10^{-6}$ cm, the depth of penetration of the magnetic flux.

First attempts for theoretical explanation of the strange phenomenon started. Such coryphaei in physics as Einstein, Bohr, Heisenberg, joined their attempts, expressing the supposition for the quantum nature of the phenomenon. A number of models and theories were appeared to explain the different experimental characteristics of superconductors. These are two-liquid model of Gorter-Casimir, the theory of London brothers, the theory of Ginzburg-Landau, the theory of Abrikosov-Gorkov, and so on. However, a unified theory explaining all peculiarities in the behavior of the measuring characteristics of superconductors was lacking. If a certain theory explained the electrical properties well it could not explain magnetic peculiarities. If the theory explained the electric and magnetic properties it could not explain the heat. For example, if the heat capacity jumps at the transition in the superconducting state without releasing or absorbing heat then the phase transition is of second type. A unified theory missed. It had to connect the three main parameters of superconductivity – critical temperature $T_c$, critical magnetic field $H_c$ and critical current density $J_c$. Temperature, magnetic field and current determined the domain of the superconducting state.

Nearly 50 years after discovering superconductivity such unified theory has still not been developed. United States physicists Bardeen, Cooper and Schrieffer finally developed a microscopic theory of superconductors known as BCS theory in 1957. Two fundamental ideas formed the basis of BCS theory: the idea of electron pairs and the idea of energetic gap between the ground and the excited state of paired electrons. The idea of coupling electrons in electron pairs is based on Cooper's theorem in which under certain conditions in electronic system attraction forces between electrons arise despite Coloumb repulsion force between them. This happens only if the electrons interact with the quanta of crystal lattice vibrations, phonons, in such way that the Coloumb force of repulsion to be shielded, and they prove to be paired. All paired electrons form a lower energy condensate that is separated from other excited electrons by energetic gap. If we want to excite the paired electrons in superconductors in order to overcome this energetic threshold between basic and excited state of electrons we need energy able to excite all the population of electrons. The mechanism of appearance of paired electrons named after Cooper is a quantum one: the electrons exchange phonons between each other and as a result an attraction between them appears. So we believe that superconductivity is a new state of matter in which quantum regularities operate in one macrosystem. BCS theory does not deny but explains the previous phenomenological theories. Moreover, it finds a relation between the basic parameters of superconductors – critical temperature $T_c$, critical magnetic field $H_c$ and critical current density $J_c$.

Moreover, the BCS theory allowed several new effects in superconductors to be predicted the most notable of which are the effects of Josefson. A major shortcoming of the theory is a threshold temperature of about 35-36°K above which paired electrons cannot be formed. During next 30 years the limit was not overcome. Numerous investigations for new superconducting alloys, intermetallic compounds, ceramics, and even organic compounds were in support of this limit and none of them had a transition temperature higher than that predicted by the BCS theory. Highest critical temperature was reached for the intermetallic compound $Nb_3Ge$, 23.2°K below the prediction limit for 75 years since the discovery of superconductivity.

Superconductivity wider use in practice began. Wire of the technological metal alloy $Nb-Ti$ with a critical temperature of 9°K was used to construct superconducting magnets. Thus the BCS theory marched solemnly up to 1986! Bardeen, Cooper and Schrieffer received the Nobel Prize in 1963. In 1983, the Swiss researcher Karl Alexander Müller supervised in IBM branch in Zurich former PhD student Georg Bednorz. He investigated the properties of perovskite materials. He searched for such a combination of substances and stoichiometry having high concentration of electrons in the conducting zone. After two unsuccessful years in 1985, Müler read a French publication about perovskite oxide structure with good conductivity in a wide temperature range. It gave hope to Müler and Bednorz that they were on the right way. Just a year later, in 1986, they succeed to synthesize the fragile ceramic compound $La_{1-x}Ba_xCuO_3$ . This compound had superconducting transition for just a narrow range of values of $x$ around 0.65° at 30°K! It was an isolator for the rest values of $x$. It was unseen up to this moment transition temperature in ceramics, while those in principle must be isolators! The both researchers were surprised by the excellent reproducibility of the results as well. Only in a few weeks different thermal treatment of these samples in different countries brought the temperature of transition to rise up to 35°K. The first paper on this subject appeared in 1986 [1]. The article has very carefully chosen title: "*Possible high-$T_C$ superconductivity in the Ba-La-Cu-O system*". Now, 75 years after discovering the superconductivity the scientific community is shocked again by this strange phenomenon. The situation from 1911, when Kamerlingh Onnes announced his discovery, is repeated once again. Day-and-night the laboratories all over the world tried to reproduce the discovery of Müller and Bednorz. Hectic experiments began in search of new combinations of the new class of substances. In the beginning everything was done in strict secrecy. Nobody shared the substances used, how and under what technological conditions are they created. It was important to report anything new and to be the first. The news came from Houston only five months after Müller and Bednorz. The team of Paul Ching Wu Chu replacing the Lanthanum by Yttrium obtained a superconductor with a transition temperature of 90°K. It was a new record! For the first time since the era of helium superconductors a jump was made into the era of nitrogen superconductors. It was not more necessary to use the expensive and rare liquid helium boiling temperature 4.2°K in order to conduct experiments with superconductors. Now it was replaced by cheaper and widely spread liquid nitrogen with boiling temperature of 77°K. This new achievement and easy access to liquid nitrogen, further increased the intensity of scientific research. In the experiments beside physicists, also chemists, metal science people, even biologists and pharmacists were involved. For a short time over 200000 papers were published about new materials of this class showing superconductivity.

An announcement for superconductivity in a compound without rare-earth element came in 1988 [2]. The authors H. Maeda, Y. Tanaka, M. Fukutumi, T. Asano discovered compound Bi-Sr-Ca-Cu-O (BSCCO) with a critical temperature of 108°K. The same year Z. Z. Sheng, A. M. Hermann published about a thallium compound with a critical transition temperature at 120°K [3]. The team of C. W. Chu in 1993 reported a mercury system with a critical transition temperature at 150°K, but under pressure [4]. Again under pressure this temperature was risen up to 164°K by Gao and collaborators [5]. This is considered the highest critical temperature of transition into superconductive state by now. We should mention the discovery of superconductivity in the compound $MgB_2$ in 2000 with critical temperature 39°K and the discovery in 2008 of full class of iron-based layered superconductors of the kind $La[O1-_x F_x]FeAs$ with critical temperature around 56°K [6-7]. These compounds are less important for the practical use of superconductors but contribute to understanding the nature of high-temperature superconductivity. Here, history repeated events developed for conventional superconductors. During the last 25 years, there is no unified theory that explains consistently all high-temperature superconductors. As in the time of classical superconductivity there are many theories and models for high-temperature superconductivity, but no one single theory to explain the rich variety of high-temperature superconducting materials and their characteristics.

Classical superconductors waited nearly 50 years their BCS theory. Since the discovery of high-temperature superconductivity 25 years have passed. Enormous challenge to contemporary theorists, is not to wait another 25 years to develop a new theory of high-temperature superconductivity. In the next few years they could develop such a theory that explains the existing experimental evidence and how superconductivity arises in high-temperature superconductors, to predict new effects and eventually provide new ideas to search room temperature superconductors. The dominating now two models of spin waves, as an auxiliary mechanism for the electron coupling (instead of phonons in conventional superconductors) give only a qualitative explanation of certain phenomena. Superconductivity is a challenge to experimentalists as well. They are searching for new combinations of substances, alloys and intermetallic compounds even without reliable theoretical background. This could lead to discovery of the dreamed room temperature superconductors. The pledge is large! This will be the next Nobel Prize in the field of low temperatures and superconductivity. There is no other field of physics with so many given Nobel prizes. For low temperature physics and superconductivity these are seven!

**Part Two**

We have seen that low temperature physics and superconductivity are closely related because there are no superconductivity without low temperatures. Furthermore, we learned about the great challenges that this strange phenomenon affixed to our days to both the theoreticians and experimentalists. Let us now follow the road of low temperatures and superconductivity in Bulgaria.

Physicists in Bulgaria started to speak seriously about low temperatures in the time of construction and operation of the scientific experimental reactor at the Institute of Physics with Atomic Research Experimental Base at the Bulgarian Academy of Sciences in 1959. The Academy decided to create a low temperature group. The reason was that some radioactive isotopes from the reactor stored in low temperature. Experiments using the Moessbauer effect required lower temperatures as much as possible. In addition, many groups in the Academy like biologists, zoologists, medical researches and others needed of low temperature for their research purposes.

Thus, after a competition the Academy assigned to a young enthusiastic chemical engineer Eugene Iliev Leyarovski to establish a low temperature group for liquefaction of oxygen and nitrogen from the air. Low temperature equipment was not known in Bulgaria so far. This ambitious engineer, although only 26 years old, was already demonstrated his leadership talent in the Chemical plant in Dimitrovgrad and Metallurgical plant in Pernik. He created a team (engineer Lozko Tsekov, Ferdinand Jerry, Dimitar Stoyanov-Muzi, Simeon Petrov, Todor Tsanov, Hristo Medarov) and together they build a special workshop to install the modern for its time rectification column for liquid oxygen and nitrogen JAK-80. The supply came from the Soviet Union along with the installation and training team for work with the apparatuses. The first drops of liquid nitrogen flowed in 10 October 1960. This can be considered as a birth day of low temperature physics in Bulgaria. An appetite for liquid gases appeared all over the country. Exploitation of the installation began in several day-and-night shifts.

The student's dream of engineer Leyarovski, however, was not only liquefaction and distribution of liquid gases for the academic groups. He dreamed to work in a scientific laboratory, to explore properties of materials at low temperature and particularly to separate gases remaining after the liquefaction of the oxygen and nitrogen – the rare and expensive argon, neon, xenon, hydrogen and helium from the air at low temperatures. And because there was not such a laboratory in Bulgaria up to this moment, he struggled to create it. The fight was very difficult because opponent of this idea was Georgi Nadjakov himself, the Director of the Institute of Physics and member of the Bulgarian Academy of Sciences. He said, "*Science is for physicists, engineers must take care for their Dewar flask*"! Engineer Leyarovski, however, showed serious intentions and love in physics. He attended a specialized course for graduate students in condensed matter physics, which at that time Prof. Milko Borissov lectured in the Faculty of Physics at the Sofia University. Perhaps, his successful graduation softened the position of Georgi Nadjakov. He agreed to appoint the physicist, Ljubcho Kaloferov and the electronic engineer, Magdalena Zaharieva. A part-time student in electronics at the Polytechnical University, Constantin Nenkov joined this group too.

Another step towards a dream laboratory was made when two members of the team, engineer Lozko Tsekov and Dimitar Stoyanov, went to specialize in the cryogenic laboratory of Fradkov at the Institute of Physics, Russian Academy of Sciences in Moscow in 1964. The aim of this specialization was Bulgarian specialists to be trained to liquefy hydrogen and helium and to work with the Russian liquefiers. After their return in Bulgaria necessary equipment was imported and installed, allowing to liquefy hydrogen, argon and neon in the special-purpose building with adjustable roof.

Engineer Leyarovski began to think new students to be attracted in his group for gas liquification. The only physicist L. Kaloferov already left. The engineers – Tsekov, Zaharieva and Nenkov had a heavy administrative and organizational work on the supplying and construction of the laboratory. In addition, they participated in experiments of engineer Leyarovski for separation of the mixture of gases after the liquefaction of nitrogen and oxygen from the air.

Two young engineers, Borislav Nikolov and Maria Zhegneva prepared their theses under the tutorship of engineer Leyarovski and successfully defended them in the Polytechnical University in 1964. After that Borislav Nikolov went to military service, and in 1965 was appointed by Tzvetan Bonchev in the Faculty of Physics at the Sofia University with task to equip workshop for liquefaction of gases. Thus, a second center for low temperature physics was been formed in Bulgaria since 1965.

In the same year (1965), the graduate student Bonka Ivanova from the Technical University came in the laboratory of engineer Leyarovski. The first young physicist was Vasil Lovchinov, a graduate student from Sofia University. Low temperature physics ideas and new perspectives attracted Vasil Lovchinov and his colleague Petko Vasilev to study low temperature physics under the tutorship of engineer Leyarovski. This incredible progress in the gas liquefaction unit the enthusiasm of Leyarovski and his ability for young people attraction was noticed by the experienced scientific administrator and director of the Institute of Physics, BAS. Georgi Nadjakov realized the potential of this unit and its leader. Despite his former opposition, he proposed to transform the group in a research laboratory and to promote engineer Leyarovski as a research fellow.

The birthday of the scientific laboratory on "*low temperatures physics*" is 5 July 1965 when the Council of the Institute of Physics decided to transform the unit for gas liquefaction in research laboratory. First head of the laboratory became Sazdo Ivanov, deputy director of the Institute and a leader of the Bulgarian group of experts in low temperatures at the Council for Mutual Economic Assistance then. However, Eugene Leyarovski remained the real leader of the Laboratory. Scientific validation of the newly established laboratory happened in the same year. A research communication was submitted by the laboratory to be reported at *the Forth International conference on physics and technique of the low temperatures* in Dresden, East Germany in September 1965. The experiments were not finished yet! The Laboratory boiled – experiment after experiment were carried out, figure after figure were drawn. The scientific communications was shaping. We worked uninterrupted, sleeping in the laboratory! The report was made and all members of the laboratory including students Vasil Lovchinov and Petko Vassilev became co-authors. Moreover, at the urging and with the assistance of Leyarovski all co-authors traveled to Dresden to contact for the first time with the achievements of renowned scientists, to meet them, to talk. The conference proved a powerful catalyst for the establishment of friendly and creative spirit among members of the laboratory, a family spirit in fact! This spirit was especially strong at the next International Conference on Physics and technology of low temperatures in Wroclaw, Poland in 1967, where the Bulgarian delegation presented seven reports. Two of them the students Petko Vasilev and Vasil Lovchinov presented as plenary lectures, based upon their research for graduation thesis. They graduated in December 1967, 6 months before other students. Immediately after that, they were elected for research fellows in the "*low temperatures physics*" laboratory.

The engineer Bonka Ivanova, the physicists Svetla-Marya Branekova, Nikola Todorov, engineer Jordan Georgiev and engineer Vesselin Kovachev, who graduated in Moscow, have been appointed to the Laboratory meanwhile. Engineer Borislav Nikolov came back in the Laboratory from the Sofia University. It must be noted that so many young people were appointed in the laboratory. It was a result of the meeting between Ivan Popov, Chairman of the State Committee of Science and Technical progress, Sazdo Ivanov and E. Leyarovski from our laboratory. The idea of Leyarovski turbodetander to be used for separation of neon and helium from the air impressed Ivan Popov. Calculations showed that Bulgaria could win annually several millions leva obtaining these rare gases from the residual gas after the liquefaction of the air in large installations of Kremikovtsi metallurgical plant. The idea was patented. It won a gold medal on the exposition of Brussels for innovative technologies. Ivan Popov approved the project and provided financial and human resources for its realization. Days of hard work started for the Laboratory of low temperature physics. All above mentioned researchers and new masters of scientific equipment were employed there. New apparatuses and lines were imported when the project began. Closely associated with the project our research continued at the same time. The material of turbodetander was chosen to work at helium temperature. The physical characteristics of this material at low temperature and enormous speed of the turbine were studied carefully in order to avoid any problems. Thermodynamic structural magnetic and electrical properties of the material were investigated.

New stage in the research of the laboratory and the Bulgarian low temperature physics started when the contract for establishment of the International Laboratory of High Magnetic Fields and Low Temperatures was signed in Wroclaw, Poland (1968). Conversations began on the conference in Wroclaw in 1967 and successfully finished on 25 April 1968 with the agreement between the four countries: Bulgaria, East Germany, Poland and Russia. After that moment, every Bulgarian scientist could work with helium temperatures and strong magnetic fields in Wroclaw. V. Lovchinov was the first Bulgarian scientist who benefited from this opportunity. He worked in Poland for the introduction and utilization of a new technology 10 months during the first year. Two Czech helium liquefiers were delivered in the Institute of Physics – BAS and in the Faculty of Physics at the Sofia University in 1968.

International Laboratory of Strong Magnetic Fields and Low Temperatures in Wroclaw, Poland is the most inexpensive and attractive place for helium temperatures and strong magnetic fields investigations up to now. Bulgarian scientists have there the opportunity to meet and exchange experiences with colleagues from many countries in the world and make contact with eminent scientists in the field of low temperatures and magnetism. Many Bulgarian scientists began their first systematic research on classical superconductors exactly in that laboratory in 1969.

The increased prestige of the Bulgarian low temperature physics and numerous meetings of Bulgarian researchers with their colleagues from foreign countries were sufficient grounds to vote confidence to Bulgaria. Tenth jubilee international conference on physics and technique of the low temperatures at the Council for Mutual Economic Assistance was organized in Varna from 23 September to 3 October 1971. In the area of superconductivity, four reports from the Laboratory of low temperatures physics (BAS) and one report from the Sofia University were presented in the conference. Respect, recognition and trust have attested to Bulgarian scientists many times after the first conference. Responsibility for organization of many international forums in low temperatures and superconductivity was entrusted to us after that. The adoption of two young Bulgarian PhD students in the laboratory of famous coryphaei of low temperatures physics and technology was considered as a recognition for the Bulgarian science. Vesselin Kovachev was a PhD student (1967 – 1971) of Pyotr Leonidovich Kapitza (1978 Nobel Prize winner) in the Institute for Physical Problems, Moscow. Mikhail Bushev was a PhD student (1971 – 1974) of Alexei Alexeyevich Abrikosov (2003 Nobel Prize winner) in the same institute.

The accumulated knowledge, skills, capabilities and human resources gave possibility to start practical application of classical superconductors in Bulgaria at that time. After his return from Moscow in 1977, Vesselin Kovachev as a deputy director of the Institute of Solid State Physics made an important contribution. He divided the *Laboratory of low temperatures* into three new laboratories: *Superconductivity and superconducting materials*, *Low temperatures and magnetism* and *Cryogenic Engineering* and became head of the first one. He informed Ministry of energetics for perspectives of the laboratory in the area of superconductivity. After that, the laboratory *superconductivity and superconducting materials* started to work jointly with the biggest scientific association Energoproject. So, the Institute of Solid State Physics was included in the project of the Council for Mutual Economic Assistance "*Development and creation of the experimental sections of superconducting and cryogenic resistive lines for transfer of energy and equipment for them*". Scientists from the Institute of Solid State Physics participated in the international meeting "*Structural and dielectric materials for cryogenic energy transfer lines*" in 1979. ISSP jointly with the Ministry of Energy and *Energoproject* organized the International School "*Superconductivity in energy and electrical engineering*" in Varna (1982). The *laboratory superconductivity and superconductive materials* presented many reports in this school. Our results for dissipative processes in superconductors made a strong impression because Bulgaria was one of the very few countries in the world that possessed apparatuses for their investigation.

Bulgaria was organizer and host of an international forum again in 1983. The Twenty-First International Conference on physics and technology of low temperatures of the Council for Mutual Economic Assistance was held in Varna from 11 to 14 October 1983. Such coryphaei of the theory and experiment of low temperatures and superconductivity as A. A. Abrikosov (2003 Nobel Prize winner), Borovik-Romanov, A. F. Andreev, A. D. Alexeevski, N. B. Brandt, R. S. Shepherd and many others presented plenary lectures in the conference.

Thus, Bulgarian physics of low temperatures and superconductivity arrived at the cherished year 1986, having by then most of the necessary working facilities and a well-trained, ambitious scientists with largely extensive international experience and recognition. The news that the system $La_{1-x}Ba_xCuO_3$ has "probable" superconductivity at 35 K surprise not only physicists from around the world, but our own. However, the news came from Houston in February 1987 that the group of Paul C. W. Chu, Li Vu and collaborators, changing lanthanum by yttrium and obtaining a superconductor with temperature of the transition $90^oK$ was even more amazing!

The main competition in Bulgaria was between the research group from the Faculty of Physics at the Sofia University and the two laboratories *Superconductivity and superconducting materials* and *Low temperature and magnetism* from the Institute of Solid State Physics. Colleagues from the Institute of Electronics, Institute of General and Inorganic Chemistry, Chemical Technology University and many, many others were curious to watch the new miracle, high-temperature superconductivity. The colleagues from the Faculty of Physics at the Sofia University and laboratory *Low temperatures and magnetism* tried to obtain the lanthanum system of Müller and Bednorts. Vesselin Kovachev, head of the *Superconductivity and Superconducting Materials Laboratory*, and Deputy Director of ISSP negotiated the head of the *Crystal Growth Laboratory* at ISSP Dr. Marin Gospodinov, whose enormous experience with complex compounds permitted him to obtain immediately the system of Paul C. W. Chu (*Y-Ba-Cu-O*). V. Lovchinov recorded in his laboratory diary on 20 April 1987 at 16:18 pm. "*Today is a great day. I observed the transition in the superconducting state at nitrogen temperatures for the first time. The temperature of the transition was 86.5*$^o$*K. How simple is it*?". It was the first day of Easter**.** The records of Lovchinov were repeated many times, clear and without residual resistance at liquid nitrogen temperature. Therefore, they were demonstrate to all the visitors of the laboratory. Meanwhile, colleagues from the Faculty of Physics at the Sofia University were produced a high-temperature superconductor with residual resistance at nitrogen temperature and transition in $48.5^oK$.

The enthusiasm was common. The interest was huge! State, political, academic, institutional and many other leaders poured praises and promises to buy modern equipment and materials for the new superconductors. Then, some high level discussions took place about creation of Bulgarian inter-technology center for superconductivity. Many business organizations interested in practical application of high-temperature superconductors and expressed willingness to participate in a future center. The Council of Ministers even took a Decision № 46 for this center and published it on 10 August 1987. Unfortunately, funding and management issues could not be solved and the Center was not realized.

Nevertheless, Bulgaria can be proud being one of the first countries in the world succeeded to reproduce the effect only three months after the discovery of high-temperature superconductors, before Russia, before England and before many other developed economics. It was an excellent attestation for the Bulgarian scientists, dealing with low temperatures and superconductivity and an honor for all Bulgarian science. The struggle of implementation in practice began after the discovery of high-temperature superconductivity. It turned out that nature was put many obstacles here also. The newly discovered high-temperature superconductors are complex ceramic compounds with fragile structure, brittle and it was difficult for treatment. It was almost impossible to make a wire for energy transfer or any other superconductivity device from such a nontechnological material. Newly discovered ceramic compounds based on bismuth, thallium and mercury had the same defect: they were not technologically applicable. Scientists looked again how to circumvent the barriers of the Nature.

A modern technology (OPIT) for production of superconducting tapes for energy transfer was mastered under the leadership of Dr. Vassil Lovchinov in the Superconductivity and superconducting materials laboratory in the framework of two projects funded by the National fund for scientific studies. Joint action with the Factory of Non-ferrous metals in Plovdiv for the production of these tapes was achieved. On the basis of this work, NATO project was granted to our laboratory for training Greek colleagues from the center "*Democritus*" in Athens. Common investigations in the refinements of this technology and the obtained tapes were carried out. The project lasted four years from 1996 to 2000 and Bulgarian scientists shared their experience and knowledge to Greek scientists.

Dr. Nikolay Balchev mastered and examined the mercury system together with Belgian scientists. He is perhaps the only Bulgarian scientist who still continues to explore new combinations of compounds to obtain new superconductors with unique properties. Dr. Emil Vlakhov in collaboration with colleagues from Dresden, Rossendorf and Poland participated in several research and development optimization of thin film manganate structures, some of which had practical purposes. Based on these studies several patents were received in Bulgaria and Germany.

Investigations on the classical yttrium system with substitution of calcium for enhancing the critical current density of these perspective superconducting materials are carried out now. The purpose is to implement high-temperature superconductors in the framework of the "*Euroatom*" international project under the leadership of Vesselin

Kovachev and Associate professor Dr. Elena Nazarova, head of *Low temperature physics laboratory* of ISSP-BAS. Only a few activities related to international superconductivity projects are listed there to emphasize the prestige of Bulgarian scientists in this field.

What was the reason, superconductors attract researchers already 100 years by now? Before all, it is expected to appear the changes of their widespread use in life. It is considered that the technical transformations that will occur after the discovery the room temperature superconductivity will be larger than those that occurred after discovering the transistor. Let us recall some possible applications of superconductors in our life:

1. Trains with superconducting magnet with speed up to 500-600 km/h and losses only by the friction to surrounding air and minimum cost of energy using the Meissner effect to push magnetic field out of the volume of superconductor and to provide levitation.

2. Superconducting batteries with minimum size will use the ability of superconductors to carry and accumulate huge current densities of $10^6 - 10^8\ A/cm^2$ without any losses. All vehicles will be able to move with such miniature batteries.

3. Superconducting transmission lines for transfer of energy. The present current transmission systems have 10-20 % energy losses. The losses in the superconducting lines will be 0 % due to their zero resistance.

4. Superconducting quantum interference devices (SQUID), ultra-sensitive to magnetic field due to the Josephson effect. The magnetic signal from the heart is $10^{-10}$ *Tesla*, and the signal from the brain is $10^{-13}$ *Tesla*. These biosignals could be detected and examined only by superconducting quantum interference devices with sensitivity of $10^{-16}\ Tesla$.

5. Superconducting magnets for tomography, colliders, magnetic guns, even spacecraft launchers. These magnets are produced and used largely now, but they need expensive rare liquid helium with temperature of boiling 4.2°K. Using high-temperature superconductors the expenditures will be reduced many times. Revolution of room temperature superconductors will be enormous.

Bulgaria was among the first counties confirmed the high-temperature superconductivity and demonstrated the large possibilities of new phenomenon. Our scientists in the field of low temperatures physics and superconductivity took part in projects funded by the National Science Fund, NATO, Rossendorf, EURATOM, etc. Superconductivity at room temperature will be finally discovered in a future. If there are qualify specialists to meet this new discovery and to train people for production of a new room temperature superconductors, then Bulgaria certainly will be among developed countries!

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