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First International Conference "Fundamental Problems of High-Temperature Superconductivity"

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The *First International Conference on Fundamental Problems of High-Temperature Superconductivity* (*FPS*-04) was held in Moscow on October 18 – 22, 2004. More than 250 participants gave 82 talks reflecting the broad spectrum of theoretical, experimental, and applied studies in the field of superconductor physics. The Russian language, as an official language of the conference, united the physicists who continue working in Russia and those of our compatriots who left their historical fatherland in different periods and for distinct reasons.

Holding a representative conference on fundamental problems of high-temperature superconductivity (HTSC) in Russia can be regarded as tribute paid to the outstanding achievements of our fellow countrymen in precisely this area of physics. Suffice it to recall the pioneering experimental studies of superconducting alloys conducted by L V Shubnikov, and the creation of the phenomenological theory by V L Ginzburg and L D Landau, which outlined many promising trends in the physics of condensed state. The Landau theory of a normal Fermi liquid, the formalism of the microscopic theory of superconductivity constructed by N N Bogolyubov, the equations due to G M Eliashberg that allow examination of superconductivity in the conditions of a realistic electron – phonon interaction (EPI), the theory of type II superconductivity formulated by A A Abrikosov on the basis of Ginzburg – Landau equations, L P Gorkov's equations in the theory of superconductivity which allowed, in particular, the derivation of Ginzburg – Landau equations from the microscopic theory, the pioneering works of A F Andreev and A I Larkin, and many other contributions of our compatriots have become the common property of the world science.

Ideas concerning the possibility of raising the superconducting transition temperature in systems with a lowered dimension [2, 3] and with a mechanism of electron pairing presumably other than EPI had been suggested long before the discovery of HTSC in cuprates [1]. At the same time, a group of theoreticians at P N Lebedev Physics Institute of the USSR Academy of Sciences pioneered a purposeful investigation of the problem of raising the critical temperature in spite of the manifest pessimism expressed at that time by several leading specialists in this field [4].

The main results of the studies performed by this group are published in the well-known book [5], and after a few decades many of them appeared to be in great demand in connection with the problem of superconductivity of cuprates and other recently discovered superconductors. It was established that for the values of crystal parameters necessary to attain a high critical temperature, the crystal lattice stability, which was subjected to question, proved to remain unbroken. Specific features of EPI were considered in both quasi-isotropic and strongly anisotropic systems. The competition and coexistence of insulating and superconducting (SC) phases were thoroughly studied; this question has become particularly topical in recent years because the SC state in cuprates appears to be close in energy to the insulating antiferromagnetic (AF) state and the system, when doped, readily changes from one state to the other.

Spin antiferromagnetism inherent in quasi-two-dimensional (2D) layered systems, comprising cuprate compounds, can, upon doping, alternate with orbital antiferromagnetism (the '*toroidal*' state of matter [6]) and give rise, instead of a spin density wave (SDW), to a density wave of orbital currents possessing, in particular, the d-wave symmetry (DDW), which may result in a special SC state that preserves the memory of its AF origin.

As distinct from conventional superconductors in which the SC state occurs as a result of instability of a normal Fermi liquid under formation of Cooper pairs, the phase diagram of cuprates (in doping – temperature coordinates) turns out to be rather complicated: along with AF and SC ordered states it allows the coexistence of other phases close in energy. The choice between these phases can be made on the basis of the analysis of the microscopic models reflecting the basic properties of cuprate compounds as correlated 2D systems in which the singlet SC state originates from doping of the parent AF insulator. The Hubbard model and related models (for instance, $t-J$) are well suited to describe strong one-site electron correlations. However, the one-site correlation energy in cuprates appears to be of the same order as the bandwidth, and therefore the band description can be used for a qualitative study of moderate electron correlations. So that the Hubbard model and the band model can be regarded as complementary approaches to the description of electron states in cuprates from the side of extremely strong and weak correlations, respectively.

The unprecedented activity in the experimental and theoretical investigations of high-temperature superconductivity, observed in the past two decades, has made it possible

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to receive answers to many questions concerning this phenomenon. One can hardly expect that the theory describing the whole complex of rather unusual properties of cuprates in both the normal and SC states will be as universal and elegant as the Bardeen – Cooper – Schrieffer theory, but even now one can say with sufficient certainty that the key points of cuprate physics have been realized and generalized in a number of recent review articles [7 – 11]. The results of research work in all the main areas on which the attention of the scientific community has lately been focused were presented at the conference being considered. The topical survey of the recent major international symposium — *The Seventh International Conference on Materials and Mechanisms of Superconductivity and High Temperature Superconductors* (M2S-HTSC-VII), Rio de Janerio, Brazil, May 25 – 30, 2003 — is presented in paper [10].

A specific property of underdoped cuprates is the *pseudogap state* observed in a sufficiently wide temperature range above the SC transition point T_C and characterized by a small value of superfluid density and by developed thermal and quantum fluctuations in the order parameter phase in the form of excitations of vortex – antivortex pairs. For this reason, a large number of talks have been devoted to a study of the properties of both individual vortex excitations and their ensembles.

The possibility of applying the new technique to obtain magneto-optical images, based on the Faraday effect and developed earlier at the RAS Institute of Solid State Physics (Chernogolovka), was discussed in detail in the talk by V K Vlasko-Vlasov (Argonne National Laboratory, USA). It appears possible to employ this technique for observing and registering the spatial distribution of a magnetic field, the flow of a magnetic flux in the critical state, the vortex lattice and its melting, as well as the motion of individual Abrikosov vortices. Macroturbulence of vortex matter in HTSC single crystals was discovered and investigated using the method of magneto-optical images (L M Fisher, All-Russia Electrotechnical Institute, Moscow).

Neutron diffraction analysis of vortex structures in thin HTSC films in sliding geometry, when investigating the reflection and scattering of neutrons near the critical angle, has led to the discovery of a new type of transition in the form of a discrete rearrangement of vortex rows in a magnetic field (V L Aksenov, Joint Institute for Nuclear Research, Dubna, Moscow region). The dynamics and interaction of different types of vortices has been investigated by measurements of rf absorption at frequencies of 500 – 1000 MHz (V A Tulin, RAS Institute for the Problems of Microelectronics Technology and Extra-Pure Materials, Chernogolovka, Moscow region).

L N Bulaevskiĭ (Los Alamos National Laboratory, USA) showed in his talk that the solution to the problem of vortex motion in layered systems with transport current perpendicular to the layers suggests a conclusion about the occurrence of an irregular vortex structure in the direction of a (strong) current. Studies of the mechanism of formation of dense vortex chains due to attraction between them were presented at the conference and the intersection of Abrikosov and Josephson vortex lattices was considered (A I Buzdin, Université Bordeaux, France). In addition, a study of quantum transport in Andreev wires, in particular, coherent transport of quasi-particles along vortex lines in type II superconductors (V M Vinokur, Argonne National Laboratory, USA), was presented.

V F Gantmakher (RAS Institute of Solid State Physics, Chernogolovka, Moscow region) showed in his talk that a detailed analysis of pair electron correlations in the insulating phase at an insulator – superconductor transition and an investigation of magnetotransport in amorphous InO films pointed to the violation of such correlations by a magnetic field.

The microscopic approach to cuprate superconductivity as a problem of many strongly interacting particles, which does not allow a solution based on the methods of perturbation theory, is somehow or other associated with the necessity to correctly guess the wave function of the ground state that would describe the fundamental properties of the system in the best possible way. Several different approaches [10, 11] to the construction of the ground state are known, which are based on assumptions about the specific, sometimes rather exotic, properties of the ground state of the nonsuperconducting phase and about the separation of charge and spin degrees of freedom, i.e., the existence of particular elementary excitations — spinless *holons* carrying charge, and electrically neutral *spinons* carrying spin. A number of important results have been obtained on this way, but a gradual return to the orthodox principles of the mean-field theory has recently been observed in the theory of cuprate superconductivity.

In spite of the multitude of schemes concerning charge and spin separation, the absence of a true separation (a kind of spinon and holon *confinement*) can be regarded as one of the arguments in favor of the usual mean-field scenario for a qualitative explanation of cuprate superconductivity. Holons and spinons can be treated as interacting quasi-particles and can be described using the mean-field approximation. The study of the conditions of origination of composite fermions (fermion + boson) and more complicated complexes (triples and quadruples) in the mixture of attracting bosons and fermions, presented in the talk by M Yu Kagan (P L Kapitza Institute for Physical Problems, RAS, Moscow), shows that it is the strong spinon – holon attraction that leads to confinement of the charge and spin degrees of freedom of a hole which for energies $\lesssim T_C$ seems to be practically a structureless point particle.

The simplest models allowing for strong electron correlations (the Hubbard and $t-J$ models) are obviously insufficient for a detailed description of the band structure of HTSC cuprates, in particular, for calculating their Fermi surface. As was shown by S G Ovchinnikov (L V Kirenskiĭ Institute of Physics of the Siberian Branch of RAS, Krasnoyarsk), the scheme of calculating the band structure of strongly correlated systems, which involves three-center interactions in the effective Hamiltonian obtained from the Hamiltonian of the multiband p – d model, leads to a reasonable agreement between the results of calculations and the data of angle-resolved photoemission spectroscopy (ARPES) [12, 13] for electron-doped cuprates and suggests the necessity of taking into consideration EPI effects in the case of hole doping. This method enables one to go beyond the framework of the single-electron band scheme and is indicative of the existence of an excitation band due to many-particle effects (such a band can also be interpreted as a band comprising coupled states).

The approaches of different authors to the solution of the problem of the SC state within the framework of the Hubbard and $t-J$ models typically yield contradictory results, which raises doubts concerning the applicability of these models to HTSC cuprates. As was shown by V V Val'kov (L V Kirenskiĭ

Institute of Physics of the Siberian Branch of RAS, Krasnoyarsk), one can state that, disregarding three-center interactions, the Hubbard and $t-J$ models are not equivalent. Indeed, the $t-J$ model inevitably leads to a bound state, whereas the Hubbard model shows no tendency towards the appearance of bound states. When three-center interaction (the $t-J^*$ model) is taken into consideration, the bound states disappear if the energy of one-site correlation exceeds the bandwidth, which can be interpreted as a restoration of equivalence between the Hubbard and the $t-J^*$ models. The three-center correlations, including those allowing for magnetic fluctuations, can play an important role in the formation of the SC phase with d-wave symmetry of the order parameter.

The ARPES methods play a unique part in the physics of HTSC compounds because they enable one to obtain detailed information about the size, shape, and evolution of the Fermi surface depending on the doping and temperature, as well as information on the spectra of quasi-particles in both the SC and normal states. The understanding of the nature of high-temperature superconductivity is largely associated with the application and development of ARPES studies whose detailed survey was presented at the conference by A A Kordyuk (Institute for Solid State Research, Dresden, Germany). He showed that in the Bi-2212 compound the well-defined quasi-particles exist in nodal directions even in the pseudogap state (which is thus sufficiently adequate for a normal Fermi liquid).

The methods of X-ray emission and absorption spectroscopy, outlined by É Z Kurmaev (Institute for the Physics of Metals of the Ural Branch of RAS, Ekaterinburg), in a sense solves the same problems as the ARPES methods, but as distinct from ARPES, which fits well to the probing of near-surface layers, the X-ray methods make it possible to investigate the electron states in a bulk of the sample. These methods, however, do not allow an independent determination of the electron momentum and should be closely connected with calculations of the energy bands.

Experimental studies of HTSC cuprates utilizing the Josephson, tunnel, and Andreev spectroscopy methods were reviewed at length by Ya G Ponomarev (M V Lomonosov Moscow State University, Moscow). In his talk he showed that the measurement data can in some cases be explained employing the EPI mechanism supplemented with an allowance for strong Coulomb repulsion [8, 14], while some features of pairing by spin fluctuations manifest themselves in a number of experiments.

The topic covering the mechanism of SC pairing, i.e., the identification of the interaction in an electron system responsible in the end for the occurrence of bound states (electron pairs), is one of the crucial points in the theory of superconductivity, although there are obviously no direct experiments definitely indicative of a concrete interaction resulting in pair formation. Hence, the question is what consequences follow from the assumption about a concrete mechanism of pairing and, therefore, what experiments can be consistently described by this mechanism. Of considerable importance is also a reasonable choice of parameters describing the pairing interaction. Thus, it has already been noted that an extremely high Hubbard one-site energy (the case which can well be described by both the Hubbard and the $t-J$ models) corresponds to the tendency to system dielectrization, i.e., a transition to the Mott insulating state, and so the simplest assumption of an absolute prohibition of a double site occupation proves to be too stringent. The same problem connected, for example, with crystal lattice stability is encountered in attempts to consider extremely high values of the effective coupling constant in the EPI mechanism.

In a real system, one observes, of course, both a screened Coulomb repulsion (with strong enough one-site correlations in such systems as cuprates) and an EPI which can cause an effective electron attraction in a narrow layer (with the energy bandwidth on the order of the Debye energy) enveloping the Fermi surface. For this reason, one should take into account both these interactions, as well as the interaction through spin fluctuations (which results from AF magnon exchange and undoubtedly takes place in cuprates). In the $t-t'-J$ scheme allowing for particle jumps in two neighboring coordinate spheres, this latter inevitably leads to d-wave superconducting pairing (N M Plakida, Joint Institute for Nuclear Research, Dubna, Moscow region).

Many theoretical studies are, in fact, based on the *postulate* that the energy gap in cuprates exhibits d-wave symmetry. This statement follows from the consideration of pairing interaction through spin fluctuations and is indirectly confirmed by experimental data. However, the problem of the symmetry of the SC order parameter cannot obviously be thought of as unambiguously and finally solved. The analysis of a variety of experiments displaying energy gap symmetry undoubtedly testifies to the presence of zeroes of the order parameter on a Fermi surface, which may correspond to either an 'extended' s- [or (s + g)-] wave or d-wave symmetry. Such a conclusion can in particular be regarded as evidence of the important role of Coulomb and electron–phonon interactions in the formation of an ordered SC state.

In spite of the fact that without considering, for instance, Coulomb interaction [8], EPI itself is unable to explain the observed symmetry of the energy gap, the important role of EPI in cuprate superconductors, demonstrated in the report by E G Maksimov (P N Lebedev Physics Institute, RAS, Moscow), necessitates joint examination (within the framework of the Fröhlich–Coulomb model) of strong one-site correlations and long-range Coulomb repulsion and EPI (A S Aleksandrov, Loughborough University, UK). The bipolaron version of the general scheme of the mean-field theory in the regime of strong coupling with a long-range unscreened EPI explains qualitatively the unusual manifestation of the isotope effect and the appearance of the pseudogap state in cuprates, as well as the peculiarities of thermomagnetic transport phenomena. Furthermore, it is demonstrated that the tunnel density of states in cuprates is not a constant (which is inevitable if particles with zero total momentum are paired), but is modulated as on a *chessboard* because the minimum of the band corresponding to the center-of-mass motion of the pair (bipolaron) falls on a nonzero total momentum.

As was shown by Aleksandrov, the effective bipolaron mass in the Fröhlich–Coulomb model is relatively small because of the long-range Fröhlich interaction and because the motion of a strongly localized bipolaron across the square lattice in the cuprate plane can induce a change in its spatial orientation owing to a hopping by one of the particles from the pair along the diagonal of the square. The probability of such a hopping is determined by the first (rather than second, as in a simultaneous hopping by both particles of the pair) power of the tunnel integral t. Such an idea of the motion of pairs of particles in the cuprate plane makes it possible to consider pairs of holes in a strongly overdoped region of a phase diagram as already prepared pairs in a real space for a superconducting state (A F Andreev, P L Kapitza Institute for Physical Problems, RAS, Moscow). For decreased doping, Bose condensation of such pairs begins when the Fermi level reaches the bottom of the *band of pair states*. The Bose condensation temperature of pairs in a 2D electron system of a cuprate compound is determined by a certain cutoff energy associated with the pair hopping into a neighboring cuprate plane and being proportional to t^2.

É A Pashitskiĭ (Institute of Physics of the National Academy of Sciences of Ukraine, Kiev) showed that the retarded screened Coulomb interaction promotes a rise in the SC transition temperature and permits the appearance of a pseudogap above T_C owing to nesting of almost flat regions of the Fermi surface, when it mostly lies in extended neighborhoods of saddle points. The 'extended' saddle points correspond to a strong anisotropy of the longitudinal and transverse (with respect to the isoenergetic surface) effective-mass components and in a 2D system lead to a logarithmic van Hove singularity in the density of states with a large amplitude dependent on the effective-mass component ratio. In the case of an extremely high anisotropy, such a singularity in fact degenerates into an inverse root singularity typical of one-dimensional systems [15]. The manifestations of the isotope effect observed in cuprates are fairly diverse, up to sign reversal, and can hardly be explained in the framework of the EPI mechanism of pairing only.

The talk by O V Dolgov (Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany) was devoted to an analysis of EPI singularities in MgB_2 crystals within the framework of the two-band model and to a comparison of the calculated results with the data of tunnel experiments, which allowed establishment of the branches of the phonon spectrum that make the basic contribution to SC pairing.

Coulomb repulsion is customarily considered to hamper the appearance of the SC state. Within the exciton mechanism of superconductivity, the increase in the pre-exponential factor is suppressed to a large extent by a strong competition between the Coulomb repulsion and the attraction 'induced' by excitons. In cuprate compounds, along with Cooper pairing with zero pair momentum, an important part can be played by the channel of SC pairing with large momentum. In this case, the smallness of the region of momentum-space kinematic restriction enables a description of screened Coulomb interaction with a degenerate kernel determined by the effective coupling constant and by the screening radius. Such a kernel allows for both moderate one-site correlations and interaction of electrons at different crystal lattice sites. The spectrum of this kernel contains one negative eigenvalue, which is one of the necessary conditions of SC pairing upon repulsion, analogous to the condition of pairing with a nonzero orbital momentum. Within the region of kinematic restriction, a two-component order parameter possesses a line of zeroes intersecting the Fermi contour (the cross section of a Fermi surface by a CuO_2 plane) and can correspond to both the s + g-wave symmetry and d-wave symmetry with additional zeroes caused by the repulsive interaction (V I Belyavskiĭ, State Pedagogical University, Voronezh). Thus, the number of pairs of order-parameter zeroes can be regarded in the case of repulsion as a sufficiently large quantity; moreover, the line of order-parameter zeroes is mainly located near the Fermi contour. The large-momentum pairing in cuprates is associated with the channels of an insulating AF (spin triplet or orbital singlet) pairing. EPI, the same as doping, promotes suppression of spin antiferromagnetism and the development of orbital antiferromagnetism. The mirror nesting of a Fermi contour [10] provides an asymptotically exact (in the limit of small effective coupling constant) solution in the case of Coulomb repulsion, which leads to SC ordering irrespective of the interaction mechanisms through boson fields (phonons, AF magnons, excitons). Pairs possessing large momentum under repulsion, as distinct from pairing attraction, are found in the pseudogap state above T_C in the form of incoherent long-lived quasi-stationary states of relative motion.

V F Elesin (Moscow Institute of Engineering Physics, Moscow) considered in his talk the extension of the mirror nesting condition to spin subbands of the electron dispersion law — *magnetic nesting* — and showed that the coexistence of ferromagnetism and an inhomogeneous Cooper SC state (studied by V L Ginzburg [16] before the appearance of the microscopic theory of superconductivity) is possible (in the case of an ideal magnetic nesting) for an arbitrarily high magnetization. This explains the coexistence of ferromagnetism and superconductivity in some of the layered cuprate compounds in which the critical magnetization value is finite but sufficiently large, owing to an approximate fulfillment of the magnetic nesting condition.

SC phases with a spatially inhomogeneous order parameter in a ferromagnetically magnetized electron system with a quadratic dispersion law, predicted in 1964 by P Fulde and R A Ferrel as well as by A I Larkin and Yu N Ovchinnikov, correspond to a condensate of Cooper pairs with a nonzero but comparatively small momentum (FFLO state). A spatially inhomogeneous state with an incommensurate period (on the order of the inverse value of pair momentum), the state analogous to the FFLO state and reflecting the crystal symmetry of the cuprate plane (the chessboard order in the distribution of order-parameter sign), also occurs in cuprates upon pairing with large momentum.

The pseudogap observed in cuprates can be regarded as a true gap existing in the spectrum of one-particle excitations and associated with orbital antiferromagnetism [6]. The corresponding density wave with d-wave symmetry — the d-density wave (DDW) — leads to the chessboard pattern in the distribution of the sign of orbital current circulations in elementary cells. Within the framework of the $t-J$ model, the pseudogap state can be described as fluctuations between d-wave SC and orbital AF states, leading to correlations (slowly decreasing with distance) of currents that have opposite signs of circulation in neighboring elementary cells [10, 11].

In large-momentum pairing, the structure of the order parameter corresponds to the cuprate plane division into cells according to the chessboard pattern (a generalized FFLO state) with opposite signs of the current circulation in neighboring cells. Thus, as a result of long-range fluctuations in the order-parameter phase, a DDW-like incommensurate ordered (on the scale of phase fluctuations) AF structure occurs in the form of circulations of orbital currents.

There are many pieces of evidence that in cuprate compounds, especially in the pseudogap regime, inhomogeneity shows up in either a real or a momentum space [7], for instance, the stripe structure, which can be judged from the diffraction of neutrons and indirectly from the one-dimensional character of conductivity in the Hall effect, or inhomogeneity of the electron scattering ('hot' and 'cold' spots on a Fermi surface). It was demonstrated by G B Teĭtel'baum (E K Zavoĭskiĭ Physical-Technical Institute, Kazan') that the pseudogap behavior of nuclear spin relaxation in cuprates is connected with dynamic phase separation into metallic and AF regions and that the spin relaxation rate of copper nuclei is associated with two mechanisms, namely, the temperature-independent relaxation by incommensurate stripe-excitations and the temperature-dependent chaotic movements of metallic and magnetic inclusions.

Measurements performed by M R Trunin (RAS Institute of Solid State Physics, Chernogolovka, Moscow region) on microwave conductivity and resistivity along and across cuprate planes of an HTSC compound upon variation of doping show that the transition to the pseudogap state leads to a considerable change in conductivity along the CuO_2 layer and has almost no effect on the transverse conductivity.

M V Sadovskiĭ (Institute of Electrophysics, RAS, Ekaterinburg) took the fluctuation parameters of the insulating short-range order as characteristics of the pseudogap state and used the notion of strong electron scattering due to the presence of 'hot' points on the Fermi surface (or, in other words, to a peculiar momentum dependence of the electron interaction energy) to carry out a thorough analysis of the well-known anomalies in an SC state upon both the s- and d-pairing. The microscopic derivation of the Ginzburg–Landau functional within the 'hot' point conception with allowance for the existence of a pseudogap state makes it possible to describe the SC transition upon temperature lowering and also to calculate the transition temperature and the basic superconductor characteristics.

In the model of SC paring with large momentum in the conditions of repulsion, a two-component order parameter is described by a *system* of Ginzburg–Landau equations which may have more than one nontrivial solution (more than one phase in the SC region). The system of Ginzburg–Landau equations for components of the order parameter, as in the case of two oppositely charged condensates connected with each other through an electromagnetic field, can generate various excitations (differing from the Abrikosov vortex) of the order-parameter phase. The two-component gauge-invariant model leads to a spatially inhomogeneous (toroidal) current state and a nontrivial topological classification of solutions to the corresponding system of Ginzburg–Landau equations in the case of a doped AF insulator (A P Protogenov, Institute of Applied Physics, RAS, Nizhniĭ Novgorod).

The progress in experimental and theoretical investigations into the physics of superconductivity is closely related to the achievements of the last two decades in chemistry and technology that have allowed us to fabricate perfect crystals and unique solid-state structures for physical studies and to create new SC materials, including those with high values of critical parameters.

The talk by E V Antipov (M V Lomonosov Moscow State University, Moscow) was devoted to a precision structural analysis, using high-resolution neutron diffractometry, of mercury-containing cuprate compounds under normal conditions and at a high pressure. The structural parameters that have a dominating effect on the SC transition temperature have been found. The established relationship between T_C and structural parameters allows the prediction of possible ways of modifying layered cuprate structures for reaching high transition temperatures to the SC state. In particular, in the synthesis of layered oxyfluorides, conditions were established under which fluoride atoms can be incorporated into layered cuprate structures. This incorporation is accompanied by structure transformations with the creation of new phases and allows a variation in hole concentration with a corresponding change in T_C.

V V Moshchalkov (Katholieke Universiteit Leuven, Belgium) spoke about detailed studies on nanostructured superconductors that revealed the influence of periodically located pinning centers upon the critical currents and interpreted this influence as one of the possible reasons for their significant heightening.

The numerous experimental and theoretical investigations into the physics of SC cuprates, including the studies presented at the FPS-04 conference, suggest some conclusions concerning the nature of the superconductivity in 2D systems possessing complex chemical composition and structure and showing strong electron correlations (Yu V Kopaev, P N Lebedev Physics Institute, RAS, Moscow). The unusual behaviors of such systems in both low-temperature (SC) and high-temperature (pseudogap) states have a common origin conditioned by the mutual influence of SC and insulating correlations. In the description of these correlations, one should take into account both the screened Coulomb repulsion (not only one-site, but also intersite) and interactions due to the exchange of phonons (EPI in cuprates cannot be thought of as point or weak) and AF magnons. The absence of a real small parameter necessitates the consideration of interaction in an electron system of cuprates utilizing two complementary approaches developed for describing the extremely strong and extremely weak electron correlations. The results obtained using these two approaches can hardly be compared, but they nevertheless have much in common, which reproduces a rather complete and consistent idea of the character of SC and pseudogap states in cuprates. The SC state can be represented as a Bose-condensate of localized bosons (in the Hubbard limit) or as a coherent state of singlet pairs with large momentum (in the band scheme). The pseudogap state corresponds to the loss of coherence in the system of localized bosons (decoupling of vortex–antivortex coupled pairs) or the appearance of quasi-stationary states of pairs with large momenta. The insulating and SC pairings have a common structure (two types of bosons in the charge and spin separation scheme or two components of the order parameter in the scheme of pairing with large momentum under repulsion) corresponding to the chessboard pattern in the distribution of the sign (AF ordering) of current circulations in the pseudogap and SC states.

The discovery of high-temperature superconducting cuprate (and then other) compounds became a powerful stimulus for the development of fundamental studies in condensed state physics. These studies not only provide new knowledge, but also promote the creation of new technologies for producing SC compounds with high critical parameters, which can find, and have already found, application as subjects of physical studies and as unique materials to be employed in energetics and low-temperature technology. The growth in the field of high-temperature superconductivity gives an example of the influence of fundamental studies on applications and new technologies.

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